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TECHNICAL REPORT 0-6905-R1 TxDOT PROJECT NUMBER 0-6905

Investigation of Performance of Skewed Reinforcing in Inverted-T Bridge Caps

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August 2020; Published November 2020

University of Houston College of Technology Department of Civil & Environmental Engineering

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| 1. Report No. 2. Government Accession No. | 3. Recipient's Catalog No. | | |
| 111WA/1A-21/0-0703-K1 1 1 Title and Subtitle | 5 Papart Data | | |
| 4. The and Subline Investigation of Parformance of Skewed Deinforcing in Invested T Bridge | 5. Report Date August 2020: Published November | | |
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| Caps | 6 Performing Organization Code | | |
| 7 Author(a) | 8. Performing Organization Code | | |
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| 0 Derfemning Operation News and Address | $10 \text{ W}_{\text{cut}} \text{ Lu}(1) \text{ (TDAIC)}$ | | |
| 9. Performing Organization Name and Address | 10. WORK UMI NO. (TRAIS) | | |
| University of Houston | 11. Contract or Grant No. | | |
| 4800 Calnoun Road | 0-0903 | | |
| Houston, 1X //204-4003 | | | |
| 12. Sponsoring Agency Name and Address | 13. Type of Report and Period Covered | | |
| Personal and Technologie | l echnical Report | | |
| Research and Technology | January 2016–August 2020 | | |
| D O Day 5000 | 14 Sponsoring Agency Code | | |
| P. O. BOX 5080 Austin Tayon 78762 5080 | 14. Sponsoring Agency Code | | |
| Austin, Texas / 0/05-3000 | 1 | | |
| 15. Supplementary Notes | and the Endersel III channels A durinistration | | |
| rioject performed in cooperation with the rexas Department of Transportation | and the Federal Highway Administration. | | |
| 16. Abstract | | | |
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TxDOT Project 0-6905

Investigation of Performance of Skewed Reinforcing in Inverted-T Bridge Caps

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Research Report 0-6905-R1

DISCLAIMERS

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ACKNOWLEDGMENTS

The authors would like to express their gratitude to the Texas Department of Transportation (TxDOT) for their financial support and collaborative efforts for this project. This research is supported by TxDOT for Grant 0-6905. The authors would like to specifically thank the contributions of the project supervisory committee, which consists of Jade Adediwura and Chris Glancy, RTI (Research and Technology Implementation Office); Michael Carlson, HOU; Bobby Bari, HOU; Walter "Ray" Fisher, DAL; Courtney Holle, BRG; Aaron Garza, BRG; Hector Garcia, DOT and Andrew Smyth, DOT. Finally, the authors appreciate the rest of the support staff at the Thomas T.C. Hsu Structural Lab at UH (University of Houston) and the many other researchers who helped with instrumentation, testing, and analysis of results.

ABSTRACT

In the past several decades, reinforced concrete inverted-T bridge caps (ITBCs) have been widely used in the bridges in Texas and the United States as they are aesthetically pleasing and offer a practical means to increase vertical clearance. Many of the ITBCs are skew when two roads are not aligned perpendicularly and exceed the angle of 45 degrees based on the construction requirements. The ITBCs in Texas are designed using the traditional empirical procedures outlined in the TxDOT Bridge Design Manual (TxDOT BDM) LRFD that conform to the AASHTO (American Association of State Highway and Transportation Officials) LRFD (2014) Bridge Design Specifications. There are no precise calculation methods or guidelines given in the AASHTO LRFD (2014) or TxDOT BDM-LRFD (2015) to design skew ITBCs. For a skew ITBC, the TxDOT Manual states that hanger and ledge reinforcement should be placed perpendicular to the centerline of the skew bent and the detailing of the skew ends of the bent should be done with a section of skewed stirrups and ledge reinforcements. Typically, the transition of perpendicular bars to the skew bars is carried out over column support, where the transverse reinforcement spacing is less critical. The designer of ITBC flares the bars out to match the skew angle while trying to maintain a minimum and maximum spacing based on the outcome of the design calculations. Such detailing of transverse reinforcements creates unequal spacing on both sides of the web, producing congestion of reinforcements on one side. The traditional method of flaring the transverse reinforcement out in skew ITBCs brings in significant complexity in design and during the construction process. In addition, the detailing of the transverse reinforcement has a profound influence on the overall shear capacity of the bent cap as well as the performance of the support ledge. Therefore, any kind of improper detailing can cause poor placement of concrete and cracks within the concrete structure, which would reduce the load-carrying capacity and increase future maintenance costs. Faster and easier construction can be obtained if the skew transverse reinforcing throughout ITBCs is utilized, and it can provide an alternative approach that will significantly reduce the design complexities and construction period. According to the results of lab tests (TxDOT Project 0-6905), using skewed transverse reinforcement throughout ITBCs will have the same load capacity as the traditional design. In addition, it is found that using skewed transverse reinforcement throughout ITBCs will have less number of cracks and smaller crack widths when compared to the traditional design.

Skewed transverse reinforcement has been applied to the design of ITBCs in TxDOT bridges because of its advantages. The Research Team (RT) selected Bent Cap 2, Bent Cap 6 and Bent Cap 7 of the bridge on Donigan Road over IH 10 to perform the preliminary FE analysis using ABAQUS. Once the overall structural behavior of actual ITBCs with skewed transverse reinforcement is better understood, the critical loading patterns during the load tests and crucial strain gage locations can be determined. Later, the developed numerical models will be calibrated against the field test results for the numerical simulation, considering unexplored parameters. From the preliminary FE analysis, it was observed that the critical locations to paste the strain gauges and attach LVDTs are the cantilever end faces of the bent caps. Moreover, it was also observed that all the bent caps with skewed transverse reinforcing are safe under service and ultimate state loading.

Due to the construction delays, a task (named Task 9a) is added and completed. In Task 9a, three cases of reinforcement design for ITBCs are investigated to cover the majority of the design detailing in Texas bridges. Based on the parametric FE simulation of 96 specimens and the cost-benefit analysis results, the

conclusions are summarized as follows: (1) The skew transverse reinforcement (Case 1) achieves better structural performance compared to traditional transverse reinforcement (Case 2 and Case 3) with notably reduced construction cost. Therefore, the skewed transverse reinforcement can well be used for the design of skewed ITBCs. (2) The increase of the S Bar area notably enhances the stiffness and ultimate strength. In addition, the increase of the S Bar area also reduces the crack width. The increase of the S Bar area will contribute notably to the construction cost. Based on the parametric simulation results, the current design of the S bar area is adequate for structural safety and crack resistance. (3) The increase of the G Bar area notably reduces the maximum crack width with a negligible influence on the stiffness, ultimate strength, and construction cost. The current design of the G Bar (No. 7 Bars) is adequate for crack control. (4) When the concrete strength increases from 5 ksi to 7 ksi, the ultimate strength and the stiffness of ITBCs increase with reduced crack width. In addition, the influence of concrete strength on the construction cost is negligible.

With skewed transverse reinforcement, the RT presents four design examples of ITBCs with skew angles of 0, 30, 45, and 60 degrees by using AASHTO (2017) and TxDOT (2020). The design examples are based on the TxDOT Inverted Tee Bent Cap Design Example (2010), which follows the AASHTO LRFD Bridge Design Specifications, 5th Ed. (2010), as prescribed by TxDOT Bridge Design Manual -LRFD (May 2009). The design steps of skewed ITBCs are also illustrated. In addition, the updates from AASHTO (2010) to AASHTO (2017) are also summarized in Appendix 1 of R1A, including the section number, the equations, and the tables, which are required to design an ITBC.

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CHAPTER 1: INTRODUCTION

1.1 PROJECT OVERVIEW

The Inverted-T Bridge Caps (ITBCs) are widely adopted in many bridges in Texas and all over the United States to reduce the beam height. In addition to the increased vertical clearance of the bridges, the ITBCs minimize the visible size of transverse bent caps and presents an aesthetically pleasing design. Another significant advantage of the ITBC system is its usage of precast beams, which can be quickly assembled on-site without any extra formwork (Synder et al., 2011). The precast components also enable higher quality and reduced construction periods. Figure 1.1 shows the component details and reinforcement details of the ITBCs. Unlike traditional rectangular bridge girders, the cross-section of the ITBC consists of the web and the ledge. The web is the primary section to transfer the shear forces, while the ledge serves as brackets to transfer girder load to the web. In order to transfer the vertical load, two types of reinforcements have been introduced in the ITBC, including the web shear reinforcements and the ledge reinforcements are web vertical stirrups that transfer the ledge load from the bottom of the web to the top of the web, and the ledge reinforcements are horizontal stirrups that help the cantilevered ledge to resist flexural tension forces in the transverse direction.



The skewed ITBCs serve as beam elements with concentrated loads applied to the bottom ledge (Coletti et al., 2011). Unlike traditional top-loaded beam structure, the force transfer mechanism of the skewed ITBC is as follows: (1) the loads are transferred from the ledge to the web in the transverse direction through the vertical hanger reinforcements; (2) the loads are transferred into the web section and reach the supports in the longitudinal direction (Zhou et al., 2020). During this process, the unequal loading position on the cantilevered skewed ledge may induce a three-dimensional flexural-shear-torsional combined load and complex cracking problem. Several experimental studies were conducted on the ITBC. Furlong et al. (1971) first investigated and demonstrated the shear and anchorage behavior of the ITBC reinforcements and provided suggestions for the design procedures of the ITBC specimens. Mirza and Furlong (1983a; 1983b; 1985) first investigated the failure mechanisms and serviceability behavior of the reinforced concrete ITBC by testing 27 simply supported specimens at a scale ratio of 1/3. Six typical failure mechanisms were reported as (1) flexural failure, (2) flexural shear failure, (3) torsional failure, (4) hanger failure of shear reinforcement, (5) flange punching failure, and (6) flange shear friction failure. The first three failures are the main control modes, while the others are premature failures and should be avoided during the design. Zhu and Hsu (2003) investigated the crack control of ITBCs and predicted the diagonal crack widths observed in tests based on a two-dimensional analytical model. Ambare and Peterman (2006) performed a finite element (FE) simulation of inverted T bridge systems to check the effects of live loads distribution on the behavior of the inverted T bridge system. The results were also compared with AASHTO LRFD (2014) and AASHTO Standard Specifications (2002), which indicated that loading distribution patterns have a direct effect on the bridge system, and the code method was more conservative than the FE method.

In design practice, many bridges have to be skewed according to the landscaping or construction requirements. Some of the ITBCs in practice have the skew-angle over 45° based on the angle of the bridges crossing roadways, waterways, and railways. The ITBCs in Texas are widely designed using the traditional empirical procedures outlined in the TxDOT (Texas Department of Transportation) Bridge Design Manual-LRFD that conforms to the AASHTO LRFD 2014 Bridge Design Specifications. There are no precise calculation methods or guidelines given in the AASHTO LRFD or TxDOT Bridge Design Manual-LRFD to design skew ITBCs. The TxDOT Bridge Design Manual states only that hanger and ledge reinforcement should be placed perpendicular to the centerline of the skew bent. The detailing of the skew ends of the bent should be done with a section of skew stirrups and ledge reinforcements. Typically, the transition of straight bars to the skew bars is carried out over the column support, where the transverse reinforcement spacing is less critical. The designer of the ITBC flares the bars out to match the skew angle while trying to maintain a minimum and maximum spacing based on the outcome of the design calculations. Such detailing of transverse reinforcement in skew ITBCs brings complexity to the design and construction process. This transverse reinforcement has a profound influence on the shear capacity of the bent cap and the performance of the support ledge. Therefore, any kind of improper detailing can cause poor placement of concrete and cracks within the concrete structure, which may reduce the load-carrying capacity and increase future maintenance costs. In addition, the provision of end face reinforcement to control the displacement at the free end of the ITBCs is necessary. Faster and easier construction can be obtained if skew transverse reinforcing steel is utilized, and it can provide an alternative approach that will significantly reduce the design complexities and construction period.

To understand the structural behavior of skewed ITBCs, Project 0-6905 started in 2016 with the following eight tasks included:

- Task 1: Literature Review
- Task 2: Parametric Study
- Task 3: Examination of Diverse Design Methodology
- Task 4: Design, Fabrication, and Testing of 1/2-Scale Skewed Inverted-T Bent Caps
- Task 5: Analysis of Task 4 Experimental Results
- Task 6: Advanced Numerical Analysis
- Task 7: Development of Details for Skewed Reinforcing Steel
- Task 8: Preparation of Final Report & Close Out Meeting

According to the results of lab tests (TxDOT Project 0-6905), using skewed transverse reinforcement throughout ITBCs will have the same load capacity as the traditional design. In addition, it is found that using skewed transverse reinforcement throughout ITBCs will have less number of cracks and smaller crack widths when compared to the traditional design. Because of the advantages of skewed transverse reinforcement, skewed transverse reinforcement has been applied to the design of ITBCs in TxDOT

bridges. The Research Team (RT) has selected Bent Cap 2, Bent Cap 6 and Bent Cap 7 of the bridge on Donigan Road over IH 10 to perform the preliminary FE analysis using ABAQUS. After these eight tasks were completed and the final report was submitted, the project was extended in February 2019 with the following tasks:

- Task 9: Development of Preliminary Finite Element (FE) Models of the Significant ITBCs
- Task 10: Instrumentation of the Significant Skewed ITBCs to Conduct the Load Test
- Task 11: Analysis of Experimental Results
- Task 12: Calibration of the FE Models Developed in Task 9 with the Measured Load Test Data
- Task 13: Design Recommendations

Due to the construction delays, after Task 9, a new task was added to improve the knowledge on design methods and reinforcement detailing in the design of the skewed ITBCs:

• Task 9a: Development of Preliminary FE Models of the Significant ITBCs

Because of the environmental issues in the construction site, the project 0-6905 was decided to be on pause by the end of October 2020. Starting from Task 10, the tasks will be completed under a new project when the site becomes available.

From the experimental and analytical studies in Tasks 4 and 6, the following observations were made:

- The peak load-carrying capacity of the ITBC with skew reinforcing is almost equal to the traditional one.
- The number of cracks observed is fewer in the case of the ITBC with skew reinforcing; the observed maximum crack width is smaller in the case of skew reinforcing.
- The design and construction complexities can be significantly reduced, and a faster and easier construction process can be achieved when skew reinforcing is used.

Based on the above observations, implementation of the skew transverse reinforcing in inverted-T bridge caps was suggested; hence the project extension was proposed to implement the research findings to the actual full scale skewed ITBC in the bridge system. For the implementation task (Task 10), a seven-span bridge is proposed, which is under construction on Donigan Road over IH 10 near Brookshire in Waller County. The primary reasons for selecting this bridge for instrumentations and load tests are:

- Proximity to the UH research lab
- In agreement with the TxDOT project team
- Easy accessibility to bent caps and field equipment (lower bent heights)
- Limited traffic control required to instrument the bent caps and perform controlled load tests

A controlled load test will be performed on this bridge to investigate the performance of the skew ITBCs with skew reinforcing. Three bent caps are selected for instrumentation and load tests based on the severity and criticality of the loading condition. The primary features of these three bent caps are provided in Table 1-1. Strain gauges and other necessary sensors will be attached at the critical locations of rebars

during the fabrication stage of the selected bent caps based on the analytical results in Task 9. Once the bridge construction is completed, the controlled load tests will be carried out based on standard procedure. During the load tests, transverse rebar stresses and bent deflections will be measured under known loading conditions. A wireless data acquisition system will be developed and used to monitor and record the data as it requires less on-site setup time than traditional wired systems and significantly minimizes traffic control time and disruptions to traffic. Each load test will continue for 5-20 minutes. In Task 9, the Research Team (RT) performed the preliminary FE analysis of the selected skewed inverted-T bridge caps using ABAQUS to understand the overall structural behavior of skewed reinforcement in actual large-scale ITBCs and to determine critical loading patterns during the load tests and crucial strain gauge locations. Later, the developed numerical models will be calibrated against the field test results for the numerical simulation assigned in Task 12, considering unexplored parameters. Based on the literature review, the FE simulation and the cost-benefit analysis for the ITBCs have not been reported (Bhargava 2009). The parametric FE modeling and cost estimation can be effectively used in the engineering design (Yazdani et al. 2017). The scope of the added Task 9a will significantly leverage the impact of this project and solve the dearth of reliable design methods and reinforcement detailing in the design of the skewed ITBCs.

| Description | Bent 2 | Bent 6 | Bent 7 |
|-----------------------------|--|---|---|
| Skew angle | 43 ⁰ | 330 | 33 ⁰ |
| Loading condition | unsymmetrical dead loading | symmetrical dead loading | unsymmetrical dead loading |
| Elevation from ground level | 18 ft | 19 ft | 19 ft |
| Span length | 100 ft (back station) / 135 ft (forward station) | 125 ft (back station) / 135 ft (forward station) | 135 ft (back station) / 115 ft (forward station) |
| No. of girders | 9 (back station) / 15 (forward station) | 11 (back station) / 15 (forward station) | 15 (back station) / 9 (forward station) |

Table 1.1. Details of the Bent Caps for the Instrumentation

1.2 PROJECT OBJECTIVES

The objectives of this project are summarized as follows:

- 1. To understand the overall structural behavior of skewed reinforcement in actual large-scale ITBCs and to determine critical loading patterns during the load tests and crucial strain gage locations.
- 2. To compare and evaluate the structural performance of skew transverse reinforcement with traditional reinforcement in ITBCs regarding strength criteria.
- 3. To compare and evaluate the structural performance of skew transverse reinforcement with traditional transverse reinforcement in ITBCs in terms of serviceability criteria considering the cracking widths and stiffness.
- 4. To compare and evaluate the structural performance of skewed ITBCs with end bars and skewed ITBCs without end bars.

- 5. To compare and evaluate the cost-benefit analysis of skew transverse reinforcement with traditional reinforcement in ITBCs regarding design and construction cost.
- 6. The ITBC test specimens will be modeled in finite element software ABAQUS.
- 7. The general design recommendations and changes to the TxDOT practice to design skewed reinforcements in ITBCs will be proposed.

1.3 PROJECT SIGNIFICANCE

This project will provide the following benefits to the TxDOT and other stakeholders:

- 1. By replacing a traditional transverse reinforcement with a skewed one, proper placement of concrete and less complex fabrication of reinforcement could be ensured. As a result, the construction costs involved would be reduced.
- 2. Skewed reinforcement would reduce the congestion in the skew region of the bent cap. As a result, proper placement of concrete could be achieved. It would reduce the complexity in detailing the skew region of the bent cap by providing uniform spacing and the same size reinforcing bars. Therefore, lesser working hours and laborers would be required for the fabrication/construction of the ITBC with skewed reinforcement.
- 3. So far, no significant research has been undertaken to study the performance of skew transverse reinforcement in ITBC. A lack of experimental research has thwarted the use of skew reinforcing. Therefore, there are no specific design guidelines for the design of skew reinforcements in inverted-T bent caps, which makes the design unreliable with increased risks of failure. By providing proper design guidelines for different skew angles, high levels of lifetime uncertainties and risks of failure could be prevented. The skew reinforcement approach could reduce the replacement cost and increase the reliability, thereby benefiting the TxDOT and other stakeholders financially.

1.4 ORGANIZATION

This report is divided into five chapters. Chapter 1 introduces an overview and the objectives of the research in addition to an outline of this report. Chapter 2 presents the analytical results of the three skewed ITBCs (Task 9), that are shown in Table 1.1, to understand the overall structural behavior of skew reinforcement in actual ITBCs. Chapter 3 shows the cases of parametric study and finite element analysis results (Task 9a) for different design parameters to compare the cost-benefit analysis results of skew transverse reinforcement with those of traditional transverse reinforcement. Following the finite element analysis results, the design recommendations for skewed ITBCs are presented in Chapter 4. Moreover, to explain the step-by-step design procedures, four skewed ITBCs design examples are presented. All findings and conclusions of the research program are summarized in Chapter 5.

CHAPTER 2: DEVELOPMENT OF PRELIMINARY FINITE ELEMENT MODELS OF THE SIGNIFICANT ITBCs

2.1 INTRODUCTION

In this chapter, the preliminary finite element (FE) analysis of the selected skew inverted-T bridge caps is performed using ABAQUS to understand the overall structural behavior of skew reinforcement in actual large-scale ITBCs and to determine critical loading patterns during the load tests and crucial strain gauge locations. As significant ITBCs, Bent Cap 2, Bent Cap 6, and Bent Cap 7 of a seven-span bridge, which is under construction on Donigan Road over IH 10 near Brookshire in Waller County, are selected. The primary features of these three bent caps are provided in Table 1.1. Figure 2.1 shows the Google Map image of the proposed new bridge location and the existing old bridge.



(a) Proposed new bridge location



(b) Existing old skewed bridge

Figure 2.1 Proposed bridge on Donigan Road over IH 10 near Brookshire in Waller County

2.2 FINITE ELEMENT MODELING OF BENT CAPS IN ABAQUS

The finite element models of the actual ITBCs were developed using ABAQUS (2014). Figure 2.2(a) and Figure 2.2(b) show the typical cross-sectional view with reinforcing details of all the bent caps at the inner and end face locations, respectively. A partial plan view of the bent caps showing the transverse rebar details is shown in Figure 2.2(c). The 3D FE model of the bent caps depicting a cross-section view at the end face is shown in Figure 2.3. The typical FE mesh of a partial bent cap is provided in Figure 2.4. The concrete of the ITBCs is modeled using an eight-node, reduced integration, hourglass control solid element (C3D8R). A two-node linear three-dimensional (3-D) truss element (T3D2) was used to model the reinforcement because it is only subjected to axial force. The fours square rigid supports representing columns under the bridge bent cap 2, Bent Cap 6, and Bent Cap 7, respectively. The superstructure loads from bridge girders are transferred to the bridge bent caps through these loading pads. The analysis was performed with two loading cases. The first one is the service load, which includes dead load and live load with the load combination factor equal to one. The second loading case is the factor load.







(b) Finite Element Model of Bent Cap 6 with Skew Angle 33⁰



(c) Finite Element Model of Bent Cap 7 with Skew Angle 33⁰ Figure 2.3 3D FE Model of Bent Caps in ABAQUS



Figure 2.4 Partial 3D Finite Element Mesh of a Bent Cap (C3D8R Solid Element for Concrete and T3D2 Truss Element for Reinforcements)

2.3 MATERIAL MODELS

The Concrete Damaged Plasticity (CDP) model was used as the constitutive model of concrete in the FEM model (Lee and Fenves, 1998). The CDP model requires the definition of uniaxial behavior in compression and tension. The stress-strain curves of concrete considered in the constitutive model are adopted from the book "Unified Theory of Concrete Structures" by Hsu and Mo (2010).

The uniaxial compression stress-strain behavior of concrete can be defined using the parabolic stressstrain model as shown in Figure 2.5. Equation 2-1 is used to develop the compression stress-strain curve.

$$\sigma_{c} = f_{c}^{t} \left[\frac{2\varepsilon_{c}}{\varepsilon_{0}} - \left(\frac{\varepsilon_{c}}{\varepsilon_{0}} \right)^{2} \right] \text{ (psi)}$$
(Eq. 2-1)

In ABAQUS, the model of concrete (Lubliner et al., 1989) requires the definitions of initial elastic modulus E_c and Poisson ratio v. The initial elastic modulus E_c can be calculated using the AASHTO empirical equation (AASHTO 2014):

$$E_c = 57000 \sqrt{f_c'} \text{ (psi)}$$
 (Eq. 2-2)

The Poisson ratio of concrete under uniaxial compressive stress ranges from about 0.15 to 0.22, with a representative value of 0.19 or 0.2 (AASHTO). In this report, the Poisson ratio of concrete is assumed to be v = 0.2.

The uniaxial tension stress-strain behavior of smeared (average) concrete was proposed by Belarbi and Hsu (1994), as shown in Figure 2.5. Equations 2-3 and 2-4 are used to develop the tensile stress-strain curve.

Ascending branch:

$$\sigma_{\rm c} = E_{\rm c} \varepsilon_{\rm c} \varepsilon_{\rm c} \leq \varepsilon_{\rm cr} \tag{Eq. 2-3}$$

Descending branch:

$$\sigma_{c} = f_{cr} \left(\frac{\varepsilon_{cr}}{\varepsilon_{c}}\right)^{0.4} \varepsilon_{c} > \varepsilon_{cr}$$
(Eq. 2-4)

where E_c = the elastic modulus of concrete, ε_{cr} = the cracking strain of concrete taken as 0.00008, and f_{cr} = the cracking stress of concrete taken as 0.00008E_c.



Figure 2.5 Stress-Strain Curves of Concrete in Tension and Compression

The stress-strain curve of the reinforcing bar is assumed to be elastic and perfectly plastic, as shown in Figure 2.6. In the ABAQUS program, the bond-slip effect between concrete and steel is not considered. In order to properly model the steel bars, the cross-section area, position, and orientation of each steel bar within the concrete element need to be specified.

Elastic branch:

$$f_s = E_s \varepsilon_s \ \varepsilon_s \le \varepsilon_y$$
 (Eq. 2-5)

Plastic branch:

$$f_s = f_y \varepsilon_s > \varepsilon_y$$
 (Eq. 2-6)

where E_s = the elastic modulus of steel taken as 29000 ksi and ε_v =the yielding strain of steel.



Figure 2.6 Stress-Strain Curve of Mild Steel

The details of the material parameters of the concrete damaged plasticity model for full-scale bent caps are listed in Table 2.1.

| Specimen designation | Young's modulus (ksi) | Poisson's ratio | Compressive strength (ksi) | Tensile strength (ksi) | Dilation angle (°) | Flow potential eccentricity | K |
|-------------------------|-----------------------------|--------------------|-------------------------------|------------------------------|-----------------------|-----------------------------------|------|
| Bent 2 | 4031 | 0.2 | 5.0 | 0.325 | 31 | 0.1 | 0.67 |
| Bent 6 | 4031 | 0.2 | 5.0 | 0.325 | 31 | 0.1 | 0.67 |
| Bent 7 | 4031 | 0.2 | 5.0 | 0.325 | 31 | 0.1 | 0.67 |

Table 2.1 Material Parameters for the Concrete Damaged Plasticity Model

2.4 3D FINITE ELEMENT RESULTS OF BENT CAPS

The analysis is performed for service load, which includes dead load and live load with the load combination factor equal to one. The ultimate load (strength limit state 1) is calculated by multiplying a factor of 1.25 with dead load, 1.75 with live load and 1.5 with overlay.

2.4.1 Stresses in Transverse Rebars at Service Load

The service loads for each of the interior girder locations and all the exterior girder locations of each bent cap are described in Table 2.2. Figure 2.7, Figure 2.8, and Figure 2.9 illustrate the contour plot of tensile stresses in the transverse reinforcement of skewed Bent Caps 2, 6, and 7, respectively, corresponding to skew angles of 43°, 33°, and 33°. As shown in Figure 2.7 the maximum tensile stress in the rebars of Bent Cap 2 is 9.08 ksi, which is within the stress limit prescribed by TxDOT and occurs in the transverse rebars at the end face (marked in the circle). Hence, the bent cap is safe in the service load condition. Similarly, as shown in Figure 2.8 and Figure 2.9, the maximum tensile stress in the rebars of Bent Cap 7 is 7.56 ksi and 9.73 ksi, respectively. The rebar stresses in Bent Cap 7 are higher than those in Bent Caps 2 and 6, due to the higher service load. It is evident that the stresses in rebars of all the bent caps under the service load are low and hence safe.

| Bent | Service Load at Interior Bearing Pads (kips) | Service Load at Exterior Bearing Pads (kips) |
|--------|---|---|
| Bent 2 | 222.48 | 240.19 |
| Bent 6 | 226.64 | 238.86 |
| Bent 7 | 244.52 | 258.00 |

Table 2.2 Service Loading for Bent Caps







Figure 2.8 Tensile Stress Contour at Service Load of Bent Cap 6 [S11 = Tensile stresses in ksi in Rebars] [Top (Red in color): Maximum stress, Bottom (Blue in color): Minimum stress]



Figure 2.9 Tensile Stress Contour at Service Load of Bent Cap 7 [S11 = Tensile stresses in ksi in Rebars] [Top (Red in color): Maximum stress, Bottom (Blue in color): Minimum stress]

2.4.2 Stresses in Transverse Rebars at Strength Limit State

The strength limit state loads for each of the interior girder locations and all the exterior girder locations of each bent cap are described in Table 2.3. Ultimate load (strength limit state 1) is calculated by multiplying a factor of 1.25 with dead load, 1.75 with live load and 1.5 with overlay. Figure 2.10, Figure 2.11, and Figure 2.12 illustrate the contour plot of tensile stresses in the transverse reinforcement of the skewed Bent Caps 2, 6, and 7, respectively, corresponding to skew angles of 43°, 33°, and 33°. As shown in Figure 2.10, the maximum tensile stress in the rebars of Bent Cap 2 is 24.20 ksi, which is within the stress limit prescribed by TxDOT. Hence, the bent cap is safe at the ultimate load condition.

Similarly, as shown in Figure 2.11 and Figure 2.12 the maximum tensile stress in the rebars of Bent Caps 6 and 7 is 23.25 ksi and 26.95 ksi, respectively. The rebar stresses in Bent Cap 7 is higher than those of Bent Caps 2 and 6, due to the higher ultimate load demand as shown in Table 2.3. It is evident that the stresses in rebars of all the bent caps under the ultimate load are lower than the yielding stress of steel rebars, which is considered to be 60 ksi and hence safe.

| Bent | Strength Limit State Load at Interior Bearing Pads (kips) | Strength Limit State Load at Exterior Bearing Pads (kips) | | | | |
|--------|--|--|--|--|--|--|
| Bent 2 | 334.84 | 365.82 | | | | |
| Bent 6 | 335.83 | 357.22 | | | | |
| Bent 7 | 365.23 | 388.82 | | | | |

Table 2.3 Strength Limit State Loading for Bent Caps



Figure 2.10 Tensile Stress Contour at Strength Limit State of Bent Cap 2 [S11 = Tensile stresses in ksi in Rebars] [Top (Red in color): Maximum stress, Bottom (Blue in color): Minimum stress]



[S11 = Tensile stresses in ksi in Rebars] [Top (Red in color) : Maximum stress, Bottom (Blue in color): Minimum stress]



Figure 2.12 Tensile Stress Contour at Strength Limit State of Bent Cap 7 [S11 = Tensile stresses in ksi in Rebars] [Top (Red in color) : Maximum stress, Bottom (Blue in color): Minimum stress]

2.4.3 Comparison of Displacements at Service Load

Figure 2.13 shows the magnitude of the deformations of three bent caps at the service loading. As can be seen from the figure, for Bent 2 (43-degree skew case) there is a maximum deformation of 0.05 inch. This deformation is in a downward direction and occurs at the acute angle skew end location (blue color). Similarly, for Bent Caps 6 and 7, the maximum observed deformation is 0.043 inch and 0.05 inch, respectively. The maximum deformation in the bent cap under service loading always occurs at the acute angle skew end, and the net deflection is in the downward direction. Though Bent Caps 6 and 7 have the same skewed angle, the magnitude of deformation is more in Bent Cap 7 because of the higher demand for service load. The maximum displacement is shown in the deep blue color contour, and the negative sign indicates that the displacement is downward. The larger deformation at the end face can be attributed to torsion generated by the unsymmetrical locations of the bearing pads on the ledges of the bridge cap. This deformation pattern will be verified during the load tests.





Figure 2.13 Displacement at Service Load for Bent Caps

2.4.4 Comparison of Principal Tensile Strains

Figure 2.14 shows the FE analysis results which address the comparison of the cracking among all the three bent caps. In the figure, the contour of the principal tensile strain in concrete is illustrated. To show the cracking zone, a lower limit of the principal strain (i.e., 0.00008) was defined so that the regions at which principal strain is less than cracking strain have a different color than the cracked regions. The other regions with different colors, therefore, represent the higher tensile strains. As can be seen from the
figure, the tensile strains in most of the parts of bent caps are much lower than the cracking strain. These regions are represented by deep blue color. Locations near loading pads and the re-entrant corner between ledge and web have higher tensile strain, which is represented by light blue and red colors. Hence, under the application of service load, no cracks should be observed in most of the regions of the bent caps. There may be some microcrack formations in some local regions of the bent caps. The principal tensile strain of Bent Cap 7 is observed to be higher because of higher service load.





Figure 2.14 Comparison of Principal Tensile Strain at Service load

2.5 SUMMARY

Because of the advantages of skewed transverse reinforcement, skewed transverse reinforcement has been applied to the design of ITBCs in TxDOT bridges. The Research Team (RT) has selected Bent Cap 2, Bent Cap 6 and Bent Cap 7 of the bridge on Donigan Road over IH 10 to perform the preliminary FE analysis using ABAQUS. Once the overall structural behavior of actual ITBCs with skewed transverse reinforcement is better understood, the critical loading patterns during the load tests and crucial strain gage locations can be determined. Later, the developed numerical models will be calibrated against the field test results for the numerical simulation, considering unexplored parameters. From the preliminary FE analysis, it was observed that the critical locations to paste the strain gauges and attach LVDTs are the cantilever end faces of the bent caps. Moreover, it was also observed that all the bent caps with skewed transverse reinforcing are safe under service and ultimate state loading.

CHAPTER 3: DEVELOPMENT OF PRELIMINARY FINITE ELEMENT MODELS OF THE SIGNIFICANT ITBCs

3.1 INTRODUCTION

In this chapter, the preliminary finite element (FE) analysis of the selected three bent caps (explained in Chapter 2) are performed using ABAQUS to conduct the cost-benefit analysis of skew ITBCs considering different parameters (Task 9a). Due to the construction delays, a task (named Task 9a) was added. Based on the literature review, the FE simulation and the cost-benefit analysis for the ITBCs have not been reported (Bhargava 2009). The parametric FE modeling and cost estimation can be effectively used in the engineering design (Yazdani et al. 2017). In cost-benefit analysis, stiffness of the bent caps under the service load, maximum crack width under the service load, and the ultimate strength of the bent caps are compared as structural behavior. The design parameters, FE Modeling, and the cost-benefit analysis of the bent caps are explained in the following sections.

3.2 CASES OF PARAMETRIC STUDY

The parametric study on the full-scale was performed on Bent 2, Bent 6, and Bent 7 of the bridge on Donigan Road over IH 10, including Case 1, Case 2, and Case 3 for each bent. For the detailing of transverse reinforcement, the following three cases of reinforcement design for the ITBCs have been investigated to cover the majority of the design detailing in Texas bridges.

(1) Case 1: the skew transverse reinforcement is applied, and the U1 Bars, U2 Bars, U3 Bars, and G Bars are also applied at both ends of the bent cap. This case is the same as that presented in Task 9. However, in Task 9, only critical locations were determined from the analytical results. In this additional task, detailed analyses in Case 1 have been completed, including the investigation of the effect of the G Bars and S Bars on the structural performance of the ITBCs. Figure 3.1, Figure 3.2, and Figure 3.3 show the skew reinforcements (Case 1) for Bent 2, Bent 6, and Bent 7, respectively.



Figure 3.1 Case 1 for Bent 2 (Current Design of Skew Reinforcement, unit: inch)



Figure 3.2 Case 1 for Bent 6 (Current Design of Skew Reinforcement, unit: inch)



Figure 3.3 Case 1 for Bent 7 (Current Design of Skew Reinforcement, unit: inch)

(2) Case 2: the traditional method of flaring the transverse reinforcement out in skew ITBCs is adopted. Figure 3.4, Figure 3.5, and Figure 3.6 show the traditional detailing of reinforcement without end bars (Case 2) for Bent 2, Bent 6, and Bent 7, respectively. Figure 3.7 shows the sectional and elevation end view of Bent 2 without end bars.



Figure 3.4 Case 2 for Bent 2 (Traditional Detailing of Reinforcement without End Bars, unit: inch)



Figure 3.5 Case 2 for Bent 6 (Traditional Detailing of Reinforcement without End Bars, unit: inch)







Figure 3.7 Bent 2-End View of Traditional Design Without End Bars in Case 2 (unit: inch)

(3) Case 3: in addition to the traditional detailing of flaring transverse reinforcement in Case 2, the U1 bars, U2 bars, U3 Bars, and G bars are applied at both ends of the bent cap. Figure 3.8 shows the sectional and elevation end view of Bent 2 with end bars.



Figure 3.8 Bent 2-End View of Traditional Design with End Bars in Case 3 (unit: inch).

Table 3.1 shows the specimens for the parametric FE simulation. The defined nomenclature of the specimens is as follows: For Specimen C3B2C5Smin, the first "C" denotes Case (1, 2, or 3) for the transverse reinforcement detailing; the second character "B" denotes Bent (2, 6, or 7); the third character "C" denotes the concrete strength (5 or 7 ksi); the last character "S" denotes S Bar area [minimum (i.e. 26% less than current design), 0% more (i.e. current design), 20% more or 40% more than current design]. In order to investigate the minimum reinforcement design of the AASHTO (American Association of Highway and Transportation Officials) LRFD (2014) Bridge Design Specifications, the RT calculated the minimum reinforcement area of S Bars for each bent based on the design service load and the AASHTO specifications to serve as the reference group and denote it as "Smin.," which is 26% less than the current design. If "G3" to "G6" are used at the end of the nomenclature, they denote the size of G Bars (No. 3 to No. 6 bars). Specimens C1B2C5S0, C1B6C5S0, and C1B7C5S0 denote the current design of Bent 2, Bent 6, and Bent 7, respectively.

| | | | I | Bent Ca | ıp | Con Stre (k | crete ngth si) | Transv | verse Reinforce | ment Detailing | Amou | nt of Trans | verse Reł | oar | (| GΒ | ar S | Size | |
|-----|------------|------|--------|-----------|-----------|-------------------|----------------------|------------------------|-----------------------------|----------------------------|----------------|-------------------|--|--|----|----|------|------|----|
| No. | Name | Case | Bent 2 | Bent 6 | Bent 7 | 5 | 7 | Skew w/ end bars | Traditional w/o end bars | Traditional w/ end bars | Minimum (M) | Current Design | 20% higher than current design | 40% higher than current design | #3 | #4 | #5 | #6 | #7 |
| 1 | C1B2C5Smin | 1 | Х | | | X | | X | | | Х | | | | | | | | Х |
| 2 | C1B2C5S0 | 1 | Χ | | | X | | X | | | | Χ | | | | | | | Х |
| 3 | C1B2C5S20 | 1 | Х | | | X | | X | | | | | Х | | | | | | Х |
| 4 | C1B2C5S40 | 1 | Х | | | X | | X | | | | | | X | | | | | Х |
| 5 | C1B2C7Smin | 1 | Х | | | | X | X | | | Х | | | | | | | | Х |
| 6 | C1B2C7S0 | 1 | Х | | | | X | X | | | | Х | | | | | | | Х |
| 7 | C1B2C7S20 | 1 | Х | | | | X | X | | | | | Х | | | | | 1 | Х |
| 8 | C1B2C7S40 | 1 | Х | | | | X | X | | | | | | X | | | | 1 | Х |
| 9 | C1B6C5Smin | 1 | | Х | | X | | X | | | Х | | | | | | | | Х |
| 10 | C1B6C5S0 | 1 | | Х | | X | | X | | | | X | | | | | | | Х |
| 11 | C1B6C5S20 | 1 | | Х | | X | | X | | | | | Х | | | | | 1 | Х |
| 12 | C1B6C5S40 | 1 | | Х | | X | | X | | | | | | X | | | | | Х |
| 13 | C1B6C7Smin | 1 | | Х | | | Х | X | | | Х | | | | | | | 1 | Х |
| 14 | C1B6C7S0 | 1 | | Х | | | Х | X | | | | Х | | | | | | | Х |
| 15 | C1B6C7S20 | 1 | | Х | | | Х | X | | | | | X | | | | | | Х |
| 16 | C1B6C7S40 | 1 | | Х | | | Х | X | | | | | | X | | | | 1 | Х |
| 17 | C1B7C5Smin | 1 | | | Х | X | | X | | | Х | | | | | | | | Х |
| 18 | C1B7C5S0 | 1 | | | Х | X | | X | | | | X | | | | | | 1 | Х |
| 19 | C1B7C5S20 | 1 | | | Х | X | | X | | | | | Х | | | | | | Х |
| 20 | C1B7C5S40 | 1 | | | Х | X | | X | | | | | | X | | | | 1 | Х |
| 21 | C1B7C7Smin | 1 | | | Х | | X | X | | | Х | | | | | | | | Х |
| 22 | C1B7C7S0 | 1 | | | Х | | X | X | | | | Х | | | | | | 1 | Х |
| 23 | C1B7C7S20 | 1 | | | Х | | Х | X | | | | | X | | | | | | Х |
| 24 | C1B7C7S40 | 1 | | | Х | | Х | X | | | | | | X | | | | 1 | Х |
| 25 | C1B2C5G3 | 1 | Х | | | X | | X | | | | Х | | | X | | | | |
| 26 | C1B2C5G4 | 1 | Х | | | X | | X | | | | X | | | | Χ | | | |
| 27 | C1B2C5G5 | 1 | Х | | | X | | X | | | | Х | | | | | Χ | | |
| 28 | C1B2C5G6 | 1 | Х | | | X | | X | | | | X | | | | | | Х | |
| 29 | C1B6C5G3 | 1 | | Х | | Х | | Х | | | | Х | | | Χ | | | | |

Table 3.1 Specimens of Parametric Finite Element Simulation

| | | | F | Bent Ca | р | Con Stre (k | crete ngth si) | Transverse Reinforcement Detailing | | Amour | nt of Trans | verse Reł | bar | | G B | ar S | Size | ; | |
|-----|------------|------|--------|-----------|-----------|-------------------|----------------------|------------------------------------|-----------------------------|----------------------------|----------------|-------------------|--|--|-----|------|------|----|----|
| No. | Name | Case | Bent 2 | Bent 6 | Bent 7 | 5 | 7 | Skew w/ end bars | Traditional w/o end bars | Traditional w/ end bars | Minimum (M) | Current Design | 20% higher than current design | 40% higher than current design | #3 | #4 | #5 | #6 | #7 |
| 30 | C1B6C5G4 | 1 | | Х | | X | | X | | | | Х | | | | Х | | | |
| 31 | C1B6C5G5 | 1 | | Х | | X | | X | | | | Х | | | | | Х | | |
| 32 | C1B6C5G6 | 1 | | Х | | X | | X | | | | Х | | | | | | Х | |
| 33 | C1B7C5G3 | 1 | | | Х | X | | X | | | | Х | | | X | | | | |
| 34 | C1B7C5G4 | 1 | | | Х | X | | X | | | | Х | | | | Х | | | |
| 35 | C1B7C5G5 | 1 | | | Х | Х | | Х | | | | Х | | | | | Х | | |
| 36 | C1B7C5G6 | 1 | | | Х | X | | Х | | | | Х | | | | | | Х | |
| 37 | C2B2C5Smin | 2 | Х | | | X | | | Х | | Х | | | | | | | | |
| 38 | C2B2C5S0 | 2 | Х | | | Х | | | Х | | | Х | | | | | | | |
| 39 | C2B2C5S20 | 2 | Х | | | X | | | Х | | | | Х | | | | | | |
| 40 | C2B2C5S40 | 2 | Х | | | Х | | | Х | | | | | Х | | | | | |
| 41 | C2B2C7Smin | 2 | Х | | | | Х | | Х | | Х | | | | | | | | |
| 42 | C2B2C7S0 | 2 | Х | | | | Х | | Х | | | Х | | | | | | | |
| 43 | C2B2C7S20 | 2 | Х | | | | Х | | Х | | | | Х | | | | | | |
| 44 | C2B2C7S40 | 2 | Х | | | | Х | | Х | | | | | Х | | | | | |
| 45 | C2B6C5Smin | 2 | | Х | | Х | | | Х | | Х | | | | | | | | |
| 46 | C2B6C5S0 | 2 | | Х | | Х | | | Х | | | Х | | | | | | | |
| 47 | C2B6C5S20 | 2 | | Х | | Х | | | Х | | | | Х | | | | | | |
| 48 | C2B6C5S40 | 2 | | Х | | Х | | | Х | | | | | Х | | | | | |
| 49 | C2B6C7Smin | 2 | | Х | | | Х | | Х | | Х | | | | | | | | |
| 50 | C2B6C7S0 | 2 | | Х | | | Х | | Х | | | Х | | | | | | | |
| 51 | C2B6C7S20 | 2 | | Х | | | Х | | Х | | | | Х | | | | | | |
| 52 | C2B6C7S40 | 2 | | Х | | | Х | | Х | | | | | Х | | | | | |
| 53 | C2B7C5Smin | 2 | | | Х | X | | | Х | | Х | | | | | | | | |
| 54 | C2B7C5S0 | 2 | | | Х | X | | | Х | | | Х | | | | | | | |
| 55 | C2B7C5S20 | 2 | | | Х | X | | | Х | | | | Х | | | | | | |
| 56 | C2B7C5S40 | 2 | | | Х | Х | | | Х | | | | | Х | | | | | |
| 57 | C2B7C7Smin | 2 | | | Х | | Х | | Х | | Х | | | | | | | | |
| 58 | C2B7C7S0 | 2 | | | Х | | Х | | Х | | | Х | | | | | | | |
| 59 | C2B7C7S20 | 2 | | | Х | | Х | | Х | | | | Х | | | | | | |

| | | | E | Bent Ca | р | Con Stre | crete ngth si) | Transv | Transverse Reinforcement Detailing Amount of Transverse Rebar | | oar | G Bar Size | | | | | | |
|-----|------------|------|--------|-----------|-----------|-------------|----------------------|------------------------|---|----------------------------|----------------|-------------------|--|--|----|----|----|-------|
| No. | Name | Case | Bent 2 | Bent 6 | Bent 7 | 5 | 7 | Skew w/ end bars | Traditional w/o end bars | Traditional w/ end bars | Minimum (M) | Current Design | 20% higher than current design | 40% higher than current design | #3 | #4 | #5 | #6 #7 |
| 60 | C2B7C7S40 | 2 | | | Х | | Х | | Х | | | | | Х | | | | |
| 61 | C3B2C5Smin | 3 | Х | | | Х | | | | Х | Х | | | | | | | X |
| 62 | C3B2C5S0 | 3 | Х | | | Х | | | | Х | | Х | | | | | | X |
| 63 | C3B2C5S20 | 3 | Х | | | Х | | | | Х | | | Х | | | | | X |
| 64 | C3B2C5S40 | 3 | Х | | | Х | | | | Х | | | | Х | | | | X |
| 65 | C3B2C7Smin | 3 | Х | | | | Х | | | Х | Х | | | | | | | X |
| 66 | C3B2C7S0 | 3 | Х | | | | Х | | | Х | | Х | | | | | | X |
| 67 | C3B2C7S20 | 3 | Х | | | | Х | | | Х | | | Х | | | | | X |
| 68 | C3B2C7S40 | 3 | Х | | | | Х | | | Х | | | | Х | | | | X |
| 69 | C3B6C5Smin | 3 | | Х | | Х | | | | Х | Х | | | | | | | X |
| 70 | C3B6C5S0 | 3 | | Х | | Х | | | | Х | | Х | | | | | | X |
| 71 | C3B6C5S20 | 3 | | Х | | Х | | | | Х | | | Х | | | | | X |
| 72 | C3B6C5S40 | 3 | | Х | | X | | | | Х | | | | Х | | | | X |
| 73 | C3B6C7Smin | 3 | | Х | | | Х | | | Х | Х | | | | | | | X |
| 74 | C3B6C7S0 | 3 | | Х | | | Х | | | Х | | Х | | | | | | X |
| 75 | C3B6C7S20 | 3 | | Х | | | Х | | | Х | | | Х | | | | | X |
| 76 | C3B6C7S40 | 3 | | Х | | | Х | | | Х | | | | Х | | | | X |
| 77 | C3B7C5Smin | 3 | | | Х | Х | | | | Х | Х | | | | | | | X |
| 78 | C3B7C5S0 | 3 | | | Х | Х | | | | Х | | Х | | | | | | X |
| 79 | C3B7C5S20 | 3 | | | Х | Х | | | | Х | | | Х | | | | | X |
| 80 | C3B7C5S40 | 3 | | | Х | Х | | | | Х | | | | Х | | | | X |
| 81 | C3B7C7Smin | 3 | | | Х | | Х | | | Х | Х | | | | | | | X |
| 82 | C3B7C7S0 | 3 | | | Х | | Х | | | Х | | Х | | | | | | X |
| 83 | C3B7C7S20 | 3 | | | Х | | Х | | | Х | | | Х | | | | | X |
| 84 | C3B7C7S40 | 3 | | | Х | | Х | | | Х | | | | Х | | | | X |
| 85 | C3B2C5G3 | 3 | Х | | | Х | | | | Х | | Х | | | Х | | | |
| 86 | C3B2C5G4 | 3 | Х | | | Х | | | | Х | | Х | | | | X | | |
| 87 | C3B2C5G5 | 3 | Х | | | Х | | | | Х | | Х | | | | | Χ | |
| 88 | C3B2C5G6 | 3 | Х | | | Х | | | | Х | | Х | | | | | | X |
| 89 | C3B6C5G3 | 3 | | Х | | Х | | | | Х | | Х | | | X | | | |
| 90 | C3B6C5G4 | 3 | | Х | | Х | | | | Х | | Х | | | | Χ | | |

| | | | I | Bent Ca | p | Cone Stree | crete ngth si) | Transv | erse Reinforce | ment Detailing | Amou | nt of Trans | verse Reł | oar | | G B | ar S | ize |
|-----|----------|------|-----------|-----------|-----------|---------------|----------------------|------------------------|-----------------------------|----------------------------|----------------|-------------------|--|--|----|-----|------|-------|
| No. | Name | Case | Bent 2 | Bent 6 | Bent 7 | 5 | 7 | Skew w/ end bars | Traditional w/o end bars | Traditional w/ end bars | Minimum (M) | Current Design | 20% higher than current design | 40% higher than current design | #3 | #4 | #5 | #6 #7 |
| 91 | C3B6C5G5 | 3 | | X | | Х | | | | Х | | X | | | | | Х | |
| 92 | C3B6C5G6 | 3 | | X | | Х | | | | Х | | X | | | | | | X |
| 93 | C3B7C5G3 | 3 | | | Х | Х | | | | Х | | X | | | Х | | | |
| 94 | C3B7C5G4 | 3 | | | Х | Х | | | | Х | | Х | | | | Χ | | |
| 95 | C3B7C5G5 | 3 | | | Х | Х | | | | Х | | Х | | | | | Χ | |
| 96 | C3B7C5G6 | 3 | | | Х | Х | | | | Х | | Х | | | | | | X |

3.3 3D FINITE ELEMENT MODELING OF BENT CAPS IN ABAQUS

The FE models of three different cases (Case 1, Case 2, and Case 3) of ITBCs were developed using ABAQUS (2020). 3D FE modeling of large-scale ITBCs are described in "2.2. FINITE ELEMENT MODELING OF BENT CAPS IN ABAQUS". To model the specimens in this chapter, the same method is followed. The same material model is used for the concrete and the steel in the ABAQUS models as defined in "2.3. MATERIAL MODELS". Table 3.2 shows the details of the material parameters of the concrete damaged plasticity model for full-scale bent caps for 5 ksi and 7 ksi concrete.

| Concrete grade | Young's modulus (ksi) | Poisson's ratio | Tensile strength (ksi) | Density (<u>lb/ft³</u>) | Dilation angle (°) | Flow potential eccentricity | K |
|-------------------|-----------------------------|--------------------|------------------------------|------------------------------|-----------------------|-----------------------------------|------|
| 5 ksi | 4031 | 0.2 | 0.325 | 150 | 31 | 0.1 | 0.67 |
| 7 ksi | 4770 | 0.2 | 0.382 | 150 | 31 | 0.1 | 0.67 |

 Table 3.2 Material Parameters for the Concrete Damaged Plasticity Model

There is a total of 24, 26, and 24 bearing pads tied on top of the ledges of Bent Cap 2, Bent Cap 6, and Bent Cap 7, respectively. The superstructure loads are transferred from the bridge girders to the bridge bent caps through these bearing pads. The analysis was performed with two loading cases. The first loading case is the service load, which includes dead load and live load with the load combination factor equal to one. The second loading case is the ultimate load.

3.3.1 Boundary Conditions at Service Load

The service load for the bent caps is calculated following the AASHTO LRFD Bridge Design Specifications, 8th Ed. (2017) as prescribed by the TxDOT Bridge Design Manual – LRFD (2020). According to this specification, the service load is applied differently on the exterior and interior bearing pads. Figure 3.9 shows the surfaces for exterior and interior bearing pads in ABAQUS models. The calculated service load is applied as a uniform pressure to these surfaces. The service loads for Bent Cap 2, Bent Cap 6, and Bent Cap 7 are shown in Table 3.3.

| Bent | Service Load at Interior Bearing Pads (kips) | Service Load at Exterior Bearing Pads (kips) |
|--------|---|---|
| Bent 2 | 222.48 | 240.19 |
| Bent 6 | 226.64 | 238.86 |
| Bent 7 | 244.52 | 258.00 |

Table 3.3. Service Load for Bent Caps



(b) Interior Bearing Pads Figure 3.9 Loads on the Bearing Pads in ABAQUS Models

3.3.2 Boundary Conditions at Ultimate Load

To calculate the ultimate load capacities of the bent caps, the uniform and equal loads are applied to all bearing pads. This load is provided through a reference point assigned to the top of the bent caps. Figure 3.10 shows the coupling constraint between the reference point and the bearing pads for calculating ultimate capacity. As shown in Figure 3.10, a coupling constraint is defined between the reference point and all bearing pads. Subsequently, a deflection of two inches is applied to the reference point in order to provide the load.



Figure 3.10 Coupling Constraint between the Reference Point and Bearing Pads for Ultimate Loads

3.4 3D FINITE ELEMENT ANALYTICAL RESULTS OF BENT CAPS

The 96 specimens are modeled in ABAQUS in order to investigate structural performances of ITBCs under the service load and ultimate load. Design parameters are skew angle (43° or 33°), detailing of transverse reinforcements (skew transverse reinforcement or traditional transverse reinforcement), end bars (with or without U1 Bars, U2 Bars, U3 Bars, and G Bars), size of S Bars (minimum, current design, 20% more or 40% more than current design), size of G Bars (No. 3 to No. 7 bars), and concrete strength (5 or 7 ksi). Based on these parameters, the displacement and the stiffness at the service load, the principal tensile strain of concrete and crack widths at the service load, and the ultimate capacities of the bent caps are investigated.

3.4.1 Displacement and Stiffness Comparisons at Service Load

The deflections at the midpoints of the two ends of the bent caps, named as D1 and D2 as shown in Figure 3.11, are obtained by the FE simulation results. To calculate the stiffness, the total vertical load is divided by each of both the deflections at these points. Table 3.4 shows the deflection results of each specimen under the service load.



Figure 3.11 Location of Mid-Points of Both Ends D1 and D2

| No. | Name | Deflection @ D1 (in.) | Deflection @ D2 (in.) |
|-----|------------|-----------------------|-----------------------|
| 1 | C1B2C5Smin | -0.0179 | -0.0190 |
| 2 | C1B2C5S0 | -0.0177 | -0.0188 |
| 3 | C1B2C5S20 | -0.0176 | -0.0187 |
| 4 | C1B2C5S40 | -0.0176 | -0.0187 |
| 5 | C1B2C7Smin | -0.0151 | -0.0161 |
| 6 | C1B2C7S0 | -0.0151 | -0.0160 |
| 7 | C1B2C7S20 | -0.0150 | -0.0159 |
| 8 | C1B2C7S40 | -0.0150 | -0.0159 |
| 9 | C1B6C5Smin | -0.0153 | -0.0160 |
| 10 | C1B6C5S0 | -0.0152 | -0.0159 |
| 11 | C1B6C5S20 | -0.0152 | -0.0158 |
| 12 | C1B6C5S40 | -0.0151 | -0.0158 |
| 13 | C1B6C7Smin | -0.0130 | -0.0135 |
| 14 | C1B6C7S0 | -0.0129 | -0.0134 |
| 15 | C1B6C7S20 | -0.0129 | -0.0134 |
| 16 | C1B6C7S40 | -0.0128 | -0.0134 |
| 17 | C1B7C5Smin | -0.0176 | -0.0164 |
| 18 | C1B7C5S0 | -0.0174 | -0.0163 |
| 19 | C1B7C5S20 | -0.0172 | -0.0162 |

| Table 3.4 Deflection | Results at | Points D1 a | and D2 ur | nder the S | ervice Load |
|----------------------|------------|-------------|-----------|------------|-------------|
|----------------------|------------|-------------|-----------|------------|-------------|

| No. | Name | Deflection @ D1 (in.) | Deflection @ D2 (in.) |
|-----|------------|-----------------------|-----------------------|
| 20 | C1B7C5S40 | -0.0172 | -0.0161 |
| 21 | C1B7C7Smin | -0.0147 | -0.0138 |
| 22 | C1B7C7S0 | -0.0146 | -0.0138 |
| 23 | C1B7C7S20 | -0.0145 | -0.0137 |
| 24 | C1B7C7S40 | -0.0145 | -0.0137 |
| 25 | C1B2C5G3 | -0.0179 | -0.0190 |
| 26 | C1B2C5G4 | -0.0178 | -0.0189 |
| 27 | C1B2C5G5 | -0.0178 | -0.0189 |
| 28 | C1B2C5G6 | -0.0178 | -0.0189 |
| 29 | C1B6C5G3 | -0.0154 | -0.0160 |
| 30 | C1B6C5G4 | -0.0153 | -0.0160 |
| 31 | C1B6C5G5 | -0.0153 | -0.0159 |
| 32 | C1B6C5G6 | -0.0152 | -0.0159 |
| 33 | C1B7C5G3 | -0.0176 | -0.0164 |
| 34 | C1B7C5G4 | -0.0175 | -0.0164 |
| 35 | C1B7C5G5 | -0.0175 | -0.0164 |
| 36 | C1B7C5G6 | -0.0174 | -0.0163 |
| 37 | C2B2C5Smin | -0.0182 | -0.0194 |
| 38 | C2B2C5S0 | -0.0180 | -0.0192 |
| 39 | C2B2C5S20 | -0.0179 | -0.0191 |
| 40 | C2B2C5S40 | -0.0177 | -0.0190 |
| 41 | C2B2C7Smin | -0.0154 | -0.0166 |
| 42 | C2B2C7S0 | -0.0153 | -0.0165 |
| 43 | C2B2C7S20 | -0.0152 | -0.0164 |
| 44 | C2B2C7S40 | -0.0151 | -0.0163 |
| 45 | C2B6C5Smin | -0.0150 | -0.0158 |
| 46 | C2B6C5S0 | -0.0148 | -0.0156 |
| 47 | C2B6C5S20 | -0.0148 | -0.0154 |
| 48 | C2B6C5S40 | -0.0147 | -0.0153 |
| 49 | C2B6C7Smin | -0.0125 | -0.0131 |
| 50 | C2B6C7S0 | -0.0125 | -0.0130 |
| 51 | C2B6C7S20 | -0.0125 | -0.0130 |
| 52 | C2B6C7S40 | -0.0125 | -0.0129 |
| 53 | C2B7C5Smin | -0.0170 | -0.0162 |
| 54 | C2B7C5S0 | -0.0166 | -0.0158 |
| 55 | C2B7C5S20 | -0.0165 | -0.0156 |
| 56 | C2B7C5S40 | -0.0164 | -0.0155 |
| 57 | C2B7C7Smin | -0.0140 | -0.0135 |
| 58 | C2B7C7S0 | -0.0139 | -0.0132 |
| 59 | C2B7C7S20 | -0.0138 | -0.0132 |
| 60 | C2B7C7S40 | -0.0138 | -0.0131 |
| 61 | C3B2C5Smin | -0.0180 | -0.0192 |
| 62 | C3B2C5S0 | -0.0178 | -0.0190 |
| 63 | C3B2C5S20 | -0.0177 | -0.0189 |
| 64 | C3B2C5S40 | -0.0176 | -0.0189 |
| 65 | C3B2C7Smin | -0.0152 | -0.0162 |
| 66 | C3B2C7S0 | -0.0151 | -0.0161 |

| No. | Name | Deflection @ D1 (in.) | Deflection @ D2 (in.) |
|-----|------------|-----------------------|-----------------------|
| 67 | C3B2C7S20 | -0.0151 | -0.0161 |
| 68 | C3B2C7S40 | -0.0150 | -0.0160 |
| 69 | C3B6C5Smin | -0.0147 | -0.0155 |
| 70 | C3B6C5S0 | -0.0146 | -0.0153 |
| 71 | C3B6C5S20 | -0.0146 | -0.0152 |
| 72 | C3B6C5S40 | -0.0146 | -0.0152 |
| 73 | C3B6C7Smin | -0.0124 | -0.0130 |
| 74 | C3B6C7S0 | -0.0124 | -0.0129 |
| 75 | C3B6C7S20 | -0.0124 | -0.0129 |
| 76 | C3B6C7S40 | -0.0124 | -0.0129 |
| 77 | C3B7C5Smin | -0.0164 | -0.0157 |
| 78 | C3B7C5S0 | -0.0163 | -0.0155 |
| 79 | C3B7C5S20 | -0.0162 | -0.0154 |
| 80 | C3B7C5S40 | -0.0162 | -0.0154 |
| 81 | C3B7C7Smin | -0.0138 | -0.0132 |
| 82 | C3B7C7S0 | -0.0137 | -0.0131 |
| 83 | C3B7C7S20 | -0.0137 | -0.0131 |
| 84 | C3B7C7S40 | -0.0137 | -0.0131 |
| 85 | C3B2C5G3 | -0.0179 | -0.0191 |
| 86 | C3B2C5G4 | -0.0179 | -0.0191 |
| 87 | C3B2C5G5 | -0.0179 | -0.0191 |
| 88 | C3B2C5G6 | -0.0179 | -0.0190 |
| 89 | C3B6C5G3 | -0.0147 | -0.0155 |
| 90 | C3B6C5G4 | -0.0147 | -0.0154 |
| 91 | C3B6C5G5 | -0.0147 | -0.0154 |
| 92 | C3B6C5G6 | -0.0146 | -0.0154 |
| 93 | C3B7C5G3 | -0.0165 | -0.0157 |
| 94 | C3B7C5G4 | -0.0164 | -0.0157 |
| 95 | C3B7C5G5 | -0.0164 | -0.0156 |
| 96 | C3B7C5G6 | -0.0163 | -0.0156 |

The total vertical load is the summation of the service load on the interior and exterior bearing pads and is calculated as 5413 lb, 5950 lb, and 5920 lb for Bent Cap 2, Bent Cap 6, and Bent Cap 7, respectively. The stiffness is calculated by the following equation.

$$k = \frac{F}{\Delta}$$
(Eq. 3-1)

where *F* is the total vertical load, and Δ is the deflection.

Figure 3.12 shows the comparison of stiffness values of the specimens for each bent cap at points D1 and D2. Based on the FE analysis results, the stiffness slightly increases with increasing the S Bar area because the S Bars reduce the tensile strain of the bent caps. In addition, increasing the concrete compressive strength from 5 ksi to 7 ksi significantly enhances the stiffness, which is attributed to the higher tensile strength and elastic modulus of higher strength concrete. As shown in Figure 3.12, the stiffness values of specimens in Case 2 are lower than that of specimens in Case 3 with end bars. Therefore, the end



bars (U1 Bars, U2 Bars, U3 Bars, and G Bars) have a significant influence on the stiffness since they reduce the deflection at the bent cap ends. Moreover, the stiffness increases with respect to the G Bar area.

(a) Influence of S Bar Area on Bent 2 with 5 ksi Concrete at D1



(c) Influence of S Bar Area on Bent 2 with 7 ksi Concrete at D1



(b) Influence of S Bar Area on Bent 2 with 5 ksi Concrete at D2



(d) Influence of S Bar Area on Bent 2 with 7 ksi Concrete at D2



(e) Influence of G Bar Area on Bent 2 with 5 ksi Concrete at D1



(g) Influence of S Bar Area on Bent 6 with 5 ksi Concrete at D1



(i) Influence of S Bar Area on Bent 6 with 7 ksi Concrete at D1



(f) Influence of G Bar Area on Bent 2 with 5 ksi Concrete at D2



(h) Influence of S Bar Area on Bent 6 with 5 ksi Concrete at D2



(j) Influence of S Bar Area on Bent 6 with 7 ksi Concrete at D2



390 Siffness Defined at D2 (10³ k/in.) 385 380 375 370 365 Case 1 360 Case 3 355 0.1 0.4 0.2 0.3 0.5 0.6 0.7 0 Area of G Bar (in²)

(k) Influence of G Bar Area on Bent 6 with 5 ksi Concrete at D1



(m) Influence of S Bar Area on Bent 7 with 5 ksi Concrete at D1



(o) Influence of S Bar Area on Bent / with ksi Concrete at D1

(l) Influence of G Bar Area on Bent 6 with 5 ksi Concrete at D2



(n) Influence of S Bar Area on Bent 7 with 5 ksi Concrete at D2



(p) Influence of S Bar Area on Bent 7 with 7 ksi Concrete at D2



Figure 3.12 Comparison of Stiffness at the Service Load

3.4.2 Principal Tensile Strain and Crack Width Comparisons at Service Load

Based on the concrete damaged plasticity model in ABAQUS, the cracking behavior of each specimen at the service load is investigated. Cracks are generally observed at the interface between the ledge and the web, and cracking is generally developed in horizontal crack surfaces. The vertical load, applied from the girders to the ledge, is transferred through the S Bars the bent cap. Since no prestress is applied to the S Bars, the bent cap is prone to micro-cracking under the concentrated loads under the service load. Figure 3.13 shows the location of micro-cracks of Specimen C3B2C5S0. As shown in Figure 3.13, most of the microcracks are observed at the interface between the ledge and the web, close to the end of the bent cap.



(a) Sectional View of Principal Tensile Strain



(e) Cutting side view of principal tensile strain

Figure 3.13 Principal Tensile Strains in Current Design of Bent 2 at the Service Load (Specimen C3B2C5S0)

The principal tensile strain is obtained from the FE analyses to calculate the crack width. The maximum principal tensile strain of the concrete section for each specimen is shown in Table 3.5. The maximum cracking strain, ε_{cr} , is calculated by subtracting the maximum tensile strain obtained from ABAQUS simulation results by the crack strain. The average crack spacing, L_m , is calculated as recommended by ACI Committee 224 (ACI, 2001). The crack width is calculated by multiplying the maximum cracking strain, ε_{cr} , with the average crack spacing, L_m . Both traditional and skewed design causes microcracking, which is difficult to see with the naked eye and will generally not affect the structural behavior. Therefore, the structural serviceability of the current design at the service load is verified. Figure 3.14 shows the comparison of the crack width of each specimen for all bent caps. Because the location of the maximum crack width is at the end of the ITBCs, the end bars (U1 Bars, U2 Bars, U3 Bars, and G Bars) have a significant influence on crack width. Besides, maximum crack width significantly decreases with

the increasing G Bar area. Increasing the S Bar area and the compressive strength of concrete notably decreases the crack width.

| No. | Name | Maximum Tensile Strain | Maximum Crack Width (in.) |
|-----|------------|------------------------|---------------------------|
| 1 | C1B2C5Smin | 0.000833 | 0.0082 |
| 2 | C1B2C5S0 | 0.000711 | 0.0069 |
| 3 | C1B2C5S20 | 0.000644 | 0.0062 |
| 4 | C1B2C5S40 | 0.000589 | 0.0057 |
| 5 | C1B2C7Smin | 0.000571 | 0.0054 |
| 6 | C1B2C7S0 | 0.000511 | 0.0047 |
| 7 | C1B2C7S20 | 0.000473 | 0.0043 |
| 8 | C1B2C7S40 | 0.000436 | 0.0040 |
| 9 | C1B6C5Smin | 0.000700 | 0.0068 |
| 10 | C1B6C5S0 | 0.000609 | 0.0058 |
| 11 | C1B6C5S20 | 0.000557 | 0.0053 |
| 12 | C1B6C5S40 | 0.000512 | 0.0048 |
| 13 | C1B6C7Smin | 0.000478 | 0.0043 |
| 14 | C1B6C7S0 | 0.000426 | 0.0038 |
| 15 | C1B6C7S20 | 0.000380 | 0.0033 |
| 16 | C1B6C7S40 | 0.000339 | 0.0029 |
| 17 | C1B7C5Smin | 0.000876 | 0.0087 |
| 18 | C1B7C5S0 | 0.000751 | 0.0074 |
| 19 | C1B7C5S20 | 0.000683 | 0.0067 |
| 20 | C1B7C5S40 | 0.000630 | 0.0061 |
| 21 | C1B7C7Smin | 0.000606 | 0.0057 |
| 22 | C1B7C7S0 | 0.000544 | 0.0051 |
| 23 | C1B7C7S20 | 0.000506 | 0.0047 |
| 24 | C1B7C7S40 | 0.000474 | 0.0044 |
| 25 | C1B2C5G3 | 0.000910 | 0.0091 |
| 26 | C1B2C5G4 | 0.000867 | 0.0087 |
| 27 | C1B2C5G5 | 0.000822 | 0.0082 |
| 28 | C1B2C5G6 | 0.000771 | 0.0076 |
| 29 | C1B6C5G3 | 0.000818 | 0.0081 |
| 30 | C1B6C5G4 | 0.000766 | 0.0076 |
| 31 | C1B6C5G5 | 0.000711 | 0.0069 |
| 32 | C1B6C5G6 | 0.000664 | 0.0064 |
| 33 | C1B7C5G3 | 0.001054 | 0.0107 |
| 34 | C1B7C5G4 | 0.000969 | 0.0098 |
| 35 | C1B7C5G5 | 0.000892 | 0.0089 |
| 36 | C1B7C5G6 | 0.000826 | 0.0082 |

Table 3.5 Principal Tensile Strain and Maximum Crack Width of Concrete at Service Load

| No. | Name | Maximum Tensile Strain | Maximum Crack Width (in.) |
|-----|------------|------------------------|---------------------------|
| 37 | C2B2C5Smin | 0.001042 | 0.0105 |
| 38 | C2B2C5S0 | 0.000859 | 0.0086 |
| 39 | C2B2C5S20 | 0.000724 | 0.0071 |
| 40 | C2B2C5S40 | 0.000633 | 0.0061 |
| 41 | C2B2C7Smin | 0.000682 | 0.0066 |
| 42 | C2B2C7S0 | 0.000590 | 0.0056 |
| 43 | C2B2C7S20 | 0.000541 | 0.0051 |
| 44 | C2B2C7S40 | 0.000495 | 0.0046 |
| 45 | C2B6C5Smin | 0.001058 | 0.0107 |
| 46 | C2B6C5S0 | 0.000878 | 0.0088 |
| 47 | C2B6C5S20 | 0.000724 | 0.0071 |
| 48 | C2B6C5S40 | 0.000641 | 0.0062 |
| 49 | C2B6C7Smin | 0.000662 | 0.0064 |
| 50 | C2B6C7S0 | 0.000527 | 0.0049 |
| 51 | C2B6C7S20 | 0.000475 | 0.0044 |
| 52 | C2B6C7S40 | 0.000450 | 0.0041 |
| 53 | C2B7C5Smin | 0.001239 | 0.0127 |
| 54 | C2B7C5S0 | 0.001025 | 0.0104 |
| 55 | C2B7C5S20 | 0.000885 | 0.0089 |
| 56 | C2B7C5S40 | 0.000800 | 0.0080 |
| 57 | C2B7C7Smin | 0.000813 | 0.0080 |
| 58 | C2B7C7S0 | 0.000665 | 0.0064 |
| 59 | C2B7C7S20 | 0.000599 | 0.0057 |
| 60 | C2B7C7S40 | 0.000571 | 0.0055 |
| 61 | C3B2C5Smin | 0.000863 | 0.0086 |
| 62 | C3B2C5S0 | 0.000729 | 0.0071 |
| 63 | C3B2C5S20 | 0.000613 | 0.0059 |
| 64 | C3B2C5S40 | 0.000569 | 0.0054 |
| 65 | C3B2C7Smin | 0.000565 | 0.0053 |
| 66 | C3B2C7S0 | 0.000488 | 0.0045 |
| 67 | C3B2C7S20 | 0.000416 | 0.0037 |
| 68 | C3B2C7S40 | 0.000402 | 0.0036 |
| 69 | C3B6C5Smin | 0.000785 | 0.0077 |
| 70 | C3B6C5S0 | 0.000636 | 0.0061 |
| 71 | C3B6C5S20 | 0.000565 | 0.0054 |
| 72 | C3B6C5S40 | 0.000556 | 0.0053 |
| 73 | C3B6C7Smin | 0.000501 | 0.0046 |
| 74 | C3B6C7S0 | 0.000418 | 0.0037 |
| 75 | C3B6C7S20 | 0.000416 | 0.0037 |
| 76 | C3B6C7S40 | 0.000412 | 0.0037 |

| No. | Name | Maximum Tensile Strain | Maximum Crack Width (in.) |
|-----|------------|------------------------|---------------------------|
| 77 | C3B7C5Smin | 0.000866 | 0.0086 |
| 78 | C3B7C5S0 | 0.000713 | 0.0070 |
| 79 | C3B7C5S20 | 0.000677 | 0.0066 |
| 80 | C3B7C5S40 | 0.000659 | 0.0064 |
| 81 | C3B7C7Smin | 0.000588 | 0.0055 |
| 82 | C3B7C7S0 | 0.000523 | 0.0049 |
| 83 | C3B7C7S20 | 0.000516 | 0.0048 |
| 84 | C3B7C7S40 | 0.000507 | 0.0047 |
| 85 | C3B2C5G3 | 0.000820 | 0.0081 |
| 86 | C3B2C5G4 | 0.000800 | 0.0079 |
| 87 | C3B2C5G5 | 0.000779 | 0.0077 |
| 88 | C3B2C5G6 | 0.000756 | 0.0074 |
| 89 | C3B6C5G3 | 0.000817 | 0.0081 |
| 90 | C3B6C5G4 | 0.000779 | 0.0077 |
| 91 | C3B6C5G5 | 0.000728 | 0.0071 |
| 92 | C3B6C5G6 | 0.000686 | 0.0067 |
| 93 | C3B7C5G3 | 0.000923 | 0.0093 |
| 94 | C3B7C5G4 | 0.000886 | 0.0089 |
| 95 | C3B7C5G5 | 0.000839 | 0.0084 |
| 96 | C3B7C5G6 | 0.000783 | 0.0077 |









Figure 3.14 Comparison of Crack Width at the Service Load

3.4.3 Comparisons of Ultimate Capacity

To calculate the ultimate capacity of bent caps, the vertical force is uniformly applied at each bearing pad. Based on the FE analyses results, the deflections at point D1 as defined in Figure 3.11 are obtained and the load-displacement curve is defined for each specimen. The principal compressive strain of concrete at the ultimate capacity is obtained from the FE analyses. Figure 3.15 shows the principal compressive strain of concrete for specimen C3B2C5S0. As shown in Figure 3.15(a)–(c), the compressive softening of concrete material is localized around both ends of the specimen. The S Bars yielded at both ends of the specimen at the peak load, as shown in Figure 3.15(d). In addition, Figure 3.15(e) shows that the sectional view of reinforcement stress was not symmetrical, indicating the failure mode of Bent 2 is attributed to the combination of shear force and torsional moment instead of the shear failure.



(a) Sectional View of Principal Compressive Strain of Concrete



(b) Local View of Principal Compressive Strain of Concrete



(c) Plan View of Principal Compressive Strain of Concrete



(d) Reinforcement Stress at the Peak Load



(e) Sectional View of Reinforcement Stress at the Peak Load Figure 3.15 Stress and Strain Contours in Specimen C3B2C5S0 at the Ultimate Load

The ultimate capacity of specimens is compared in Figure 3.16. The ultimate capacity of specimens notably increases with the increase of the S Bar area and concrete compressive strength. In addition, the capacity of Case 2 and Case 3 are notably lower than Case 1, which indicates the rebar detailing has a significant influence on the ultimate capacity. For all bent caps, skew transverse reinforcement is better than the traditional transverse reinforcement. The dramatic difference between the specimens of Case 2 and Case 3 shows that end bars (U1, U2, U3, and G Bars) have a notable effect on the ultimate capacity. Moreover, the ultimate capacity of the ITBCs considerably increases with increasing the G Bar area.







(i) Influence of G Bar area on Bent 7 with 5 ksi Concrete Figure 3.16 Comparison of Ultimate Capacity

3.5 COST-BENEFIT ANALYSIS

A literature review is conducted on the cost analysis of bridges in Texas. The RT consulted many bridge engineers about the design and construction cost in bridge construction in conducting the cost-benefit analysis. In this analysis, only the direct costs of construction and design are considered. In this section, basic assumptions on cost estimation of ITBCs, and comparison of costs and benefits of the specimens are clarified.

3.5.1 Basic Assumptions

In cost estimation, only the direct costs, which are the cost for material and labor, design man-hour, and construction time schedules, of ITBCs are considered. To calculate the direct material cost, the quantity takeoff is performed for the specimens. Table 3.6, Table 3.7, and Table 3.8 show the quantity takeoff and the amount of materials of Bent Cap 2 for Case 1, Case 2, and Case 3, respectively. As a material cost, only reinforcing bars and concrete are included. The formwork, shoring tower placement, and removal are not included because these do not depend on the reinforcement detailing and concrete strength. As can be seen from Table 3.6, Table 3.7, and Table 3.8, the only difference in the material cost between the cases is the amount of M Bars, N Bars, S Bars, and the end bars (U1 Bars, U2 Bars, U3 Bars, and G Bars). The amount of the reinforcement bars for each specimen is estimated following the same steps. The total amount of concrete is calculated as 155 cubic yards for Bent Cap 2 and 135.4 cubic yards for Bent Cap 6 and Bent Cap 7. The influence of concrete strength on the cost is negligible. Therefore, the unit material cost and casting cost of 5 ksi concrete and 7 ksi concrete are assumed to be the same.

| Reinforcement Bars | | | | | | |
|--------------------------|-------|--------|---------------|--------------|--------------|--|
| Bar | No. | Size | Area (in2) | Length (in.) | Weight (lbs) | |
| Α | 20 | # 11 | 1.56 | 1389 | 12329 | |
| В | 16 | # 11 | 1.56 | 1389 | 9863 | |
| Т | 24 | # 7 | 0.6 | 1389 | 5690 | |
| D | 8 | 1 1/4" | 1.23 | 20 | 56 | |
| М | 234 | # 7 | 0.6 | 329 | 13142 | |
| Ν | 234 | # 5 | 0.31 | 127 | 2621 | |
| S | 388 | #6 | 0.44 | 299 | 14522 | |
| G | 15 | # 7 | 0.6 | 150 | 384 | |
| U1 | 12 | # 6 | 0.44 | 157 | 236 | |
| U2 | 21 | # 6 | 0.44 | 134 | 352 | |
| U3 | 12 | # 6 | 0.44 | 171 | 257 | |
| Total | 59453 | | | | | |
| Concrete | | | | | | |
| Item | | : | Strength (psi | | Volume (cy) | |
| Class "F" Concrete (Cap) | | | 5000 | | 155 | |

Table 3.6 Quantity Takeoff for Specimen C1B2C5S0

| Table 3.7 | Quantity | Takeoff for | Specimen | C2B2C5S0 |
|-----------|----------|-------------|----------|----------|
| | | | | |

| Reinforcement Bars | | | | | | |
|--------------------|-----|--------|------------|--------------|--------------|--|
| Bar | No. | Size | Area (in2) | Length (in.) | Weight (lbs) | |
| Α | 20 | # 11 | 1.56 | 1389 | 12329 | |
| В | 16 | # 11 | 1.56 | 1389 | 9863 | |
| Т | 24 | # 7 | 0.6 | 1389 | 5690 | |
| D | 8 | 1 1/4" | 1.23 | 20 | 56 | |
| M1 | 14 | # 7 | 0.6 | 331.5 | 792 | |
| M2 | 2 | # 7 | 0.6 | 323.7 | 111 | |
| M3 | 2 | # 7 | 0.6 | 316.5 | 108 | |
| M4 | 2 | # 7 | 0.6 | 311 | 106 | |
| M5 | 2 | # 7 | 0.6 | 305 | 104 | |
| M6 | 2 | # 7 | 0.6 | 297 | 101 | |
| M7 | 2 | # 7 | 0.6 | 292 | 100 | |
| M8 | 2 | # 7 | 0.6 | 287 | 98 | |
| M9 | 2 | # 7 | 0.6 | 282 | 96 | |
| M10 | 2 | # 7 | 0.6 | 277 | 95 | |
| M11 | 2 | # 7 | 0.6 | 273 | 93 | |
| M12 | 2 | # 7 | 0.6 | 270 | 92 | |
| M13 | 2 | # 7 | 0.6 | 268 | 91 | |
| M14 | 2 | # 7 | 0.6 | 266 | 91 | |
| M15 | 2 | # 7 | 0.6 | 265 | 90 | |

| | R | einforc | ement Bars | | |
|---------|-----|---------|------------|--------------|--------------|
| Bar | No. | Size | Area (in2) | Length (in.) | Weight (lbs) |
| M16 | 192 | # 7 | 0.6 | 262 | 8587 |
| Total M | 234 | # 7 | 0.6 | #varies | 10756 |
| N1 | 14 | # 5 | 0.31 | 127 | 157 |
| N2 | 2 | # 5 | 0.31 | 124 | 22 |
| N3 | 2 | # 5 | 0.31 | 120 | 21 |
| N4 | 2 | # 5 | 0.31 | 117 | 21 |
| N5 | 2 | # 5 | 0.31 | 114 | 20 |
| N6 | 2 | # 5 | 0.31 | 110 | 19 |
| N7 | 2 | # 5 | 0.31 | 107 | 19 |
| N8 | 2 | # 5 | 0.31 | 105 | 19 |
| N9 | 2 | # 5 | 0.31 | 102 | 18 |
| N10 | 2 | # 5 | 0.31 | 100 | 18 |
| N11 | 2 | # 5 | 0.31 | 98 | 17 |
| N12 | 2 | # 5 | 0.31 | 97 | 17 |
| N13 | 2 | # 5 | 0.31 | 96 | 17 |
| N14 | 2 | # 5 | 0.31 | 95 | 17 |
| N15 | 2 | # 5 | 0.31 | 94 | 17 |
| N16 | 192 | # 5 | 0.31 | 93 | 1575 |
| Total N | 234 | # 5 | 0.31 | #varies | 1993 |
| S1 | 28 | # 6 | 0.44 | 299 | 1048 |
| S2 | 4 | # 6 | 0.44 | 296 | 148 |
| S3 | 4 | # 6 | 0.44 | 293 | 147 |
| S4 | 4 | # 6 | 0.44 | 290 | 145 |
| S5 | 4 | # 6 | 0.44 | 287 | 144 |
| S6 | 4 | # 6 | 0.44 | 284 | 142 |
| S7 | 4 | # 6 | 0.44 | 282 | 141 |
| S8 | 4 | # 6 | 0.44 | 280 | 140 |
| S9 | 4 | # 6 | 0.44 | 277 | 139 |
| S10 | 4 | # 6 | 0.44 | 276 | 138 |
| S11 | 4 | #6 | 0.44 | 274 | 137 |
| S12 | 4 | #6 | 0.44 | 273 | 137 |
| S13 | 4 | # 6 | 0.44 | 272 | 136 |
| S14 | 4 | #6 | 0.44 | 271 | 136 |
| S15 | 4 | #6 | 0.44 | 270 | 135 |
| S16 | 304 | #6 | 0.44 | 268 | 10199 |
| Total S | 388 | #6 | 0.44 | #varies | 13212 |
| G | 0 | # 7 | 0.6 | 0 | 0 |
| U1 | 0 | #6 | 0.44 | 0 | 0 |
| U2 | 0 | #6 | 0.44 | 0 | 0 |

| Reinforcement Bars | | | | | | |
|---|------------|-------|---------------|-----|-------------|--|
| Bar No. Size Area (in2) Length (in.) Weight (lb | | | | | | |
| U3 | 0 | #6 | 0.44 | 0 | 0 | |
| Total | | 53900 | | | | |
| | | Cor | ncrete | | | |
| Item Stren | | | Strength (psi | i) | Volume (cy) | |
| Class "F" Concrete (Cap) | (Cap) 5000 | | | 155 | | |

| | Case | 3 / Bent | t Cap 2 Detai | ils | |
|---------|------|----------|---------------|--------------|--------------|
| Bar | No. | Size | Area (in2) | Length (in.) | Weight (lbs) |
| Α | 20 | # 11 | 1.56 | 1389 | 12329 |
| В | 16 | # 11 | 1.56 | 1389 | 9863 |
| Т | 24 | # 7 | 0.6 | 1389 | 5690 |
| D | 8 | 1 1/4" | 1.23 | 20 | 56 |
| M1 | 14 | # 7 | 0.6 | 331.5 | 792 |
| M2 | 2 | # 7 | 0.6 | 323.7 | 111 |
| M3 | 2 | # 7 | 0.6 | 316.5 | 108 |
| M4 | 2 | # 7 | 0.6 | 311 | 106 |
| M5 | 2 | # 7 | 0.6 | 305 | 104 |
| M6 | 2 | # 7 | 0.6 | 297 | 101 |
| M7 | 2 | # 7 | 0.6 | 292 | 100 |
| M8 | 2 | # 7 | 0.6 | 287 | 98 |
| M9 | 2 | # 7 | 0.6 | 282 | 96 |
| M10 | 2 | # 7 | 0.6 | 277 | 95 |
| M11 | 2 | # 7 | 0.6 | 273 | 93 |
| M12 | 2 | # 7 | 0.6 | 270 | 92 |
| M13 | 2 | # 7 | 0.6 | 268 | 91 |
| M14 | 2 | # 7 | 0.6 | 266 | 91 |
| M15 | 2 | # 7 | 0.6 | 265 | 90 |
| M16 | 192 | # 7 | 0.6 | 262 | 8587 |
| Total M | 234 | # 7 | 0.6 | #varies | 10756 |
| N1 | 14 | # 5 | 0.31 | 127 | 157 |
| N2 | 2 | # 5 | 0.31 | 124 | 22 |
| N3 | 2 | # 5 | 0.31 | 120 | 21 |
| N4 | 2 | # 5 | 0.31 | 117 | 21 |
| N5 | 2 | # 5 | 0.31 | 114 | 20 |
| N6 | 2 | # 5 | 0.31 | 110 | 19 |
| N7 | 2 | # 5 | 0.31 | 107 | 19 |
| N8 | 2 | # 5 | 0.31 | 105 | 19 |
| N9 | 2 | # 5 | 0.31 | 102 | 18 |

Table 3.8 Quantity Takeoff for Specimen C3B2C5S0

| | Case 3 / Bent Cap 2 Details | | | | | | |
|--------------------------|-----------------------------|------|---------------|--------------|--------------|--|--|
| Bar | No. | Size | Area (in2) | Length (in.) | Weight (lbs) | | |
| N10 | 2 | # 5 | 0.31 | 100 | 18 | | |
| N11 | 2 | # 5 | 0.31 | 98 | 17 | | |
| N12 | 2 | # 5 | 0.31 | 97 | 17 | | |
| N13 | 2 | # 5 | 0.31 | 96 | 17 | | |
| N14 | 2 | # 5 | 0.31 | 95 | 17 | | |
| N15 | 2 | # 5 | 0.31 | 94 | 17 | | |
| N16 | 192 | # 5 | 0.31 | 93 | 1575 | | |
| Total N | 234 | # 5 | 0.31 | #varies | 1993 | | |
| S1 | 28 | #6 | 0.44 | 299 | 1048 | | |
| S2 | 4 | #6 | 0.44 | 296 | 148 | | |
| S3 | 4 | #6 | 0.44 | 293 | 147 | | |
| S4 | 4 | #6 | 0.44 | 290 | 145 | | |
| S5 | 4 | #6 | 0.44 | 287 | 144 | | |
| S6 | 4 | #6 | 0.44 | 284 | 142 | | |
| S7 | 4 | #6 | 0.44 | 282 | 141 | | |
| S8 | 4 | #6 | 0.44 | 280 | 140 | | |
| S9 | 4 | #6 | 0.44 | 277 | 139 | | |
| S10 | 4 | #6 | 0.44 | 276 | 138 | | |
| S11 | 4 | #6 | 0.44 | 274 | 137 | | |
| S12 | 4 | #6 | 0.44 | 273 | 137 | | |
| S13 | 4 | #6 | 0.44 | 272 | 136 | | |
| S14 | 4 | #6 | 0.44 | 271 | 136 | | |
| S15 | 4 | #6 | 0.44 | 270 | 135 | | |
| S16 | 304 | #6 | 0.44 | 268 | 10199 | | |
| Total S | 388 | #6 | 0.44 | #varies | 13212 | | |
| G | 15 | # 7 | 0.6 | 150 | 384 | | |
| U1 | 12 | # 6 | 0.44 | 157 | 236 | | |
| U2 | 21 | #6 | 0.44 | 134 | 352 | | |
| U3 | 12 | # 6 | 0.44 | 171 | 257 | | |
| Total | | | | | 55129 | | |
| Concrete | | | | | | | |
| Item | | | Strength (psi | | Volume (cy) | | |
| Class "F" Concrete (Cap) | 5000 | | | | 155 | | |

Table 3.9 shows the estimated construction time for skew and traditional reinforcement detailing in hours based on previous experiences. To estimate the values, the RT used a previous lab test where 6 laborers worked for 8 hours to prepare the caging of a skewed reinforcement detailing of a 20 ft bent cap. In addition, 6 laborers worked for 1 hour in pouring and vibrating the concrete of the same bent cap. For the 20 ft bent cap specimen with traditional reinforcement detailing, 4 more hours were spent than skewed

reinforcement to prepare the reinforcement cage, and 1 more hour was spent for casting concrete. The construction time for a 20 ft bent cap is scaled to predict the full-scale specimen with a length of 116 ft, and the total construction time is estimated as 310 hours for skewed reinforcement and 480 hours for traditional reinforcement.

| Itom | | Unit | |
|---------------------------------|--------|-------------|-----|
| Item | Skewed | Traditional | Umt |
| Rebar Preparation and Placement | 280 | 420 | hr |
| Concrete Casting | 30 | 60 | hr |
| Total | 310 | 480 | hr |

Table 3.9 Estimated Construction Time

The annual wage for rebar workers and concrete workers is obtained from the U.S. Bureau of Labor Statistics (Website, 2020) as \$50,960 and \$38,380, respectively. To determine the cost of employees, the payroll taxes, insurance, benefits, and supplies are also added to the annual wage. The hourly wage of rebar labor and concrete labor is calculated to be \$30.81 and \$24.30, respectively. Table 3.10 shows the items and amounts to calculate actual labor costs.

| Itom | Rebar L | abors | Concrete Labors | | |
|--------------------|----------|---------|------------------------|---------|--|
| Item | Quantity | Unit | Quantity | Unit | |
| Working Hour | 2080 | hr/year | 2080 | hr/year | |
| Wage | 24.5 | \$/hr | 18.45 | \$/hr | |
| Payroll Labor Cost | 50960 | \$/yr | 38380 | \$/yr | |
| Payroll Taxes | 4120 | \$/yr | 3165 | \$/yr | |
| Insurance | 2000 | \$/yr | 2000 | \$/yr | |
| Benefits | 2000 | \$/yr | 2000 | \$/yr | |
| Supplies | 5000 | \$/yr | 5000 | \$/yr | |
| Total | 64080 | \$/yr | 50545 | \$/yr | |
| Wage | 30.81 | \$/hr | 24.30 | \$/hr | |

Table 3.10 Estimated Labor Wage

Another item included in the cost analysis is the design procedure of bent caps. In this section, the design time is calculated, including engineering design, technical drawings, and review. It is assumed that a design engineer designs the bent cap, a draftsman does technical drawings, and a senior engineer reviews the project. After consulting with several bridge engineers, the design of traditional reinforcement detailing is estimated to require 40% more time than skew transverse reinforcement detailing. The design time and hourly wages of design are shown in Table 3.11 and Table 3.12, respectively

| 8 | | | | | | |
|--------------------|--------|-------------|-----|--|--|--|
| Itom | | Unit | | | | |
| Item | Skewed | Traditional | Umt | | | |
| Engineering Design | 30 | 42 | hr | | | |
| Drawing | 60 | 84 | hr | | | |
| Review | 4 | 6 | hr | | | |

Table 3.11 Estimated Design Time
| Item | Quantity | Unit |
|-----------------|----------|-------|
| Design Engineer | 150 | \$/hr |
| Draftsman | 120 | \$/hr |
| Senior Engineer | 200 | \$/hr |

 Table 3.12 Estimated Design Wage

3.5.2 Comparison of Costs

The direct cost of ITBCs is calculated as the sum of the material cost, the labor cost, and the design cost. As an example, the estimated cost of Specimen C1B2C5S0 is shown in Table 3.13

Table 3.13. The cost estimation is compared for Case 1, Case 2, and Case 3 in Figure 3.17. The cost analysis indicates that the cost of the specimens of Case 1 is 11% to 16% lower than the cost of the specimens of Case 3. The savings in cost are mainly attributed to the reduced construction hours and lower design costs. Therefore, the skew transverse reinforcement is notably effective in reducing the design and construction cost of skew ITBCs. In addition, the comparison in Figure 3.17 shows that adding G bars has very little influence on the direct cost while adding S bars has a larger influence on the direct cost. This is attributed to the fact that the G bars are only applied to both ends of the ITBCs while the S bars are applied uniformly in the ITBCs. Therefore, Figure 3.17 indicates that adding G bars is a more economical way of reducing the crack width observed at both ends of the ITBCs.

| Item | Quantity | Unit | Unit Price | Total Price |
|-----------------------------|----------|------|-------------------|--------------------|
| Gr60 Reinforcing Bars | 59453 | lb | \$0.46 | \$27,348.38 |
| Class "F" Concrete (Cap) | 155 | cy | \$86.35 | \$13,384.25 |
| Design (Engineering) | 30 | hrs | \$150.00 | \$4,500.00 |
| Design (Technical Drawings) | 60 | hrs | \$120.00 | \$7,200.00 |
| Design (Reviewing) | 4 | hrs | \$200.00 | \$800.00 |
| Labor (Rebar) | 280 | hrs | \$31 | \$8,624.00 |
| Labor (Concrete) | 30 | hrs | \$24 | \$729.00 |
| Total | | | | \$62,585.63 |

Table 3.13 Cost Estimation for Specimen C1B2C5S0





(a) Influence of S Bars on Cost for Bent 2



(c) Influence of S Bars on Cost for Bent 6









(d) Influence of G Bars on Cost for Bent 6





Figure 3.17 Comparison of Estimated Cost for Case 1, Case 2, and Case 3

3.5.3 Comparison of Benefits

Cost-benefit analysis is conducted for the specimens considering the stiffness, the crack widths, and the ultimate capacities. The FE analysis results presented in Section 3.4 "3D FINITE ELEMENT ANALYTICAL RESULTS OF BENT CAPS" are combined with the estimated costs. Table 3.14 shows all the calculated results of the cost-benefit analysis.

| No | No. Name | Cost | Stiffness defined | Stiffness defined | Crack Width (in) | Ultimate |
|------|------------|----------|---------------------------------|---------------------------------|-------------------|-------------|
| 110. | | Cost | at D1 (10 ³ kip/in.) | at D2 (10 ³ kip/in.) | | Load (kips) |
| 1 | C1B2C5Smin | \$60,839 | 302.6 | 284.4 | 0.0082 | 12613 |
| 2 | C1B2C5S0 | \$62,585 | 305.6 | 287.2 | 0.0069 | 12997 |
| 3 | C1B2C5S20 | \$63,921 | 307.1 | 288.8 | 0.0062 | 13293 |
| 4 | C1B2C5S40 | \$65,257 | 308.2 | 289.8 | 0.0057 | 13488 |
| 5 | C1B2C7Smin | \$60,839 | 357.6 | 336.9 | 0.0054 | 14322 |
| 6 | C1B2C7S0 | \$62,585 | 359.3 | 338.4 | 0.0047 | 15002 |
| 7 | C1B2C7S20 | \$63,921 | 360.4 | 339.6 | 0.0043 | 15394 |
| 8 | C1B2C7S40 | \$65,257 | 361.4 | 340.7 | 0.0040 | 15633 |
| 9 | C1B6C5Smin | \$54,954 | 388.3 | 371.8 | 0.0068 | 15812 |
| 10 | C1B6C5S0 | \$56,368 | 390.9 | 374.8 | 0.0058 | 16719 |
| 11 | C1B6C5S20 | \$57,450 | 392.2 | 376.3 | 0.0053 | 17152 |
| 12 | C1B6C5S40 | \$58,532 | 393.4 | 377.5 | 0.0048 | 17480 |
| 13 | C1B6C7Smin | \$54,954 | 458.8 | 441.0 | 0.0043 | 17743 |
| 14 | C1B6C7S0 | \$56,368 | 460.7 | 442.9 | 0.0038 | 18999 |
| 15 | C1B6C7S20 | \$57,450 | 462.3 | 444.6 | 0.0033 | 19450 |
| 16 | C1B6C7S40 | \$58,532 | 463.5 | 445.6 | 0.0029 | 19908 |
| 17 | C1B7C5Smin | \$54,980 | 336.7 | 360.3 | 0.0087 | 13237 |
| 18 | C1B7C5S0 | \$56,394 | 341.1 | 364.2 | 0.0074 | 13816 |
| 19 | C1B7C5S20 | \$57,476 | 343.4 | 365.9 | 0.0067 | 13990 |
| 20 | C1B7C5S40 | \$58,558 | 345.2 | 367.4 | 0.0061 | 14415 |
| 21 | C1B7C7Smin | \$54,980 | 403.7 | 428.0 | 0.0057 | 14843 |
| 22 | C1B7C7S0 | \$56,394 | 405.7 | 430.0 | 0.0051 | 15811 |
| 23 | C1B7C7S20 | \$57,476 | 407.0 | 431.3 | 0.0047 | 16245 |
| 24 | C1B7C7S40 | \$58,558 | 408.1 | 432.4 | 0.0044 | 16338 |
| 25 | C1B2C5G3 | \$62,441 | 303.2 | 285.3 | 0.0091 | 12259 |
| 26 | C1B2C5G4 | \$62,467 | 303.6 | 285.6 | 0.0087 | 12656 |
| 27 | C1B2C5G5 | \$62,500 | 304.1 | 286.0 | 0.0082 | 12870 |
| 28 | C1B2C5G6 | \$62,538 | 304.7 | 286.6 | 0.0076 | 12967 |
| 29 | C1B6C5G3 | \$56,229 | 387.3 | 371.3 | 0.0081 | 15310 |
| 30 | C1B6C5G4 | \$56,255 | 388.1 | 372.0 | 0.0076 | 15833 |
| 31 | C1B6C5G5 | \$56,286 | 389.4 | 373.3 | 0.0069 | 16368 |
| 32 | C1B6C5G6 | \$56,323 | 390.2 | 374.0 | 0.0064 | 16422 |
| 33 | C1B7C5G3 | \$56,255 | 336.4 | 360.4 | 0.0107 | 12509 |
| 34 | C1B7C5G4 | \$56,281 | 337.7 | 361.2 | 0.0098 | 13007 |
| 35 | C1B7C5G5 | \$56,312 | 338.7 | 362.1 | 0.0089 | 13522 |
| 36 | C1B7C5G6 | \$56,348 | 339.7 | 363.0 | 0.0082 | 13681 |
| 37 | C2B2C5Smin | \$68,563 | 297.7 | 278.6 | 0.0105 | 10623 |
| 38 | C2B2C5S0 | \$70,152 | 300.8 | 282.0 | 0.0086 | 10830 |
| 39 | C2B2C5S20 | \$71,367 | 303.1 | 283.7 | 0.0071 | 10978 |
| 40 | C2B2C5S40 | \$72,583 | 305.4 | 285.4 | 0.0061 | 11002 |
| 41 | C2B2C7Smin | \$68,563 | 350.9 | 325.7 | 0.0066 | 11989 |
| 42 | C2B2C7S0 | \$70,152 | 354.5 | 328.2 | 0.0056 | 12490 |

Table 3.14 Cost-Benefit Analysis Results

| No. | Name | Cost | Stiffness defined at D1 (10 ³ kip/in.) | Stiffness defined at D2 (10 ³ kip/in.) | Crack Width (in.) | Ultimate Load (kips) |
|-----|------------|------------------|--|---|-------------------|-------------------------|
| 43 | C2B2C7S20 | \$71,367 | 356.3 | 330.5 | 0.0051 | 12536 |
| 44 | C2B2C7S40 | \$72,583 | 358.5 | 332.6 | 0.0046 | 12673 |
| 45 | C2B6C5Smin | \$65,387 | 397.4 | 375.9 | 0.0107 | 13190 |
| 46 | C2B6C5S0 | \$66,736 | 401.2 | 382.6 | 0.0088 | 13881 |
| 47 | C2B6C5S20 | \$67,768 | 402.9 | 387.0 | 0.0071 | 14045 |
| 48 | C2B6C5S40 | \$68,800 | 404.4 | 389.9 | 0.0062 | 14098 |
| 49 | C2B6C7Smin | \$65,387 | 474.9 | 452.7 | 0.0064 | 14705 |
| 50 | C2B6C7S0 | \$66,736 | 476.7 | 457.5 | 0.0049 | 15447 |
| 51 | C2B6C7S20 | \$67,768 | 477.1 | 459.1 | 0.0044 | 15956 |
| 52 | C2B6C7S40 | \$68,800 | 477.5 | 460.7 | 0.0041 | 16102 |
| 53 | C2B7C5Smin | \$65,413 | 347.3 | 364.9 | 0.0127 | 10840 |
| 54 | C2B7C5S0 | \$66,762 | 356.5 | 373.9 | 0.0104 | 11317 |
| 55 | C2B7C5S20 | \$67,794 | 359.7 | 378.4 | 0.0089 | 11357 |
| 56 | C2B7C5S40 | \$68.826 | 361.7 | 382.6 | 0.0080 | 11400 |
| 57 | C2B7C7Smin | \$65,413 | 423.3 | 439.6 | 0.0080 | 12150 |
| 58 | C2B7C7S0 | \$66.762 | 426.5 | 446.8 | 0.0064 | 12867 |
| 59 | C2B7C7S20 | \$67.794 | 428.5 | 449.6 | 0.0057 | 13211 |
| 60 | C2B7C7S40 | \$68.826 | 429.8 | 451.4 | 0.0055 | 13266 |
| 61 | C3B2C5Smin | \$69.129 | 301.2 | 282.3 | 0.0086 | 11530 |
| 62 | C3B2C5S0 | \$70,717 | 303.5 | 284.7 | 0.0071 | 11725 |
| 63 | C3B2C5S20 | \$71,933 | 305.7 | 285.9 | 0.0059 | 11764 |
| 64 | C3B2C5S20 | \$73 148 | 306.9 | 286.8 | 0.0054 | 11859 |
| 65 | C3B2C7Smin | \$69 129 | 356.5 | 335.0 | 0.0053 | 13277 |
| 66 | C3B2C7S0 | \$70,717 | 357.6 | 336.3 | 0.0035 | 13653 |
| 67 | C3B2C7S20 | \$71.933 | 359.2 | 337.0 | 0.0043 | 13823 |
| 68 | C3B2C7S40 | \$73 148 | 360.4 | 338.0 | 0.0036 | 13846 |
| 69 | C3B6C5Smin | \$65,927 | 405.4 | 384.2 | 0.0030 | 14496 |
| 70 | C3B6C5S0 | \$67,275 | 407.0 | 388.7 | 0.0061 | 15421 |
| 71 | C3B6C5S20 | \$68 308 | 407.8 | 391.0 | 0.0054 | 15572 |
| 72 | C3B6C5S40 | \$69.340 | 407.3 | 392.1 | 0.0053 | 15798 |
| 73 | C3B6C7Smin | \$65,927 | 478.2 | 457.3 | 0.0035 | 16743 |
| 74 | C3B6C7S0 | \$67.275 | 478.9 | 460.3 | 0.0040 | 17204 |
| 75 | C3B6C7S20 | \$68 308 | 470.3 | 461.7 | 0.0037 | 17204 |
| 76 | C3B6C7S40 | \$69.340 | 479.5 | 462.6 | 0.0037 | 17828 |
| 77 | C3B7C5Smin | \$65.952 | 361.6 | 376.4 | 0.0037 | 17020 |
| 78 | C3B7C5S0 | \$67.301 | 363.8 | 381.7 | 0.0030 | 12589 |
| 70 | C3B7C5S20 | \$68 333 | 365.1 | 384.0 | 0.0070 | 12382 |
| 80 | C3B7C5S40 | \$69.366 | 366.1 | 385.5 | 0.0064 | 12702 |
| 81 | C3B7C7Smin | \$65,952 | 430.1 | <u> </u> | 0.0004 | 13962 |
| 82 | C3B7C7S0 | \$67.301 | 431.4 | 450.9 | 0.0035 | 14408 |
| 83 | C3B7C7S20 | \$68 333 | 431.8 | 452.1 | 0.0049 | 14566 |
| 84 | C3B7C7S40 | \$69.366 | 432.1 | 453.6 | 0.0048 | 14589 |
| 85 | C3B2C5G3 | \$70 573 | 301.0 | 283.0 | 0.0047 | 11144 |
| 86 | C3B2C5G4 | \$70,500 | 302.2 | 283.0 | 0.0079 | 11794 |
| 87 | C3B2C5G5 | \$70.632 | 302.2 | 283.5 | 0.0079 | 11/237 |
| 88 | C3B2C5G6 | \$70,670 | 302.0 | 283.7 | 0.007/ | 11568 |
| 80 | C3B6C5G3 | \$67 137 | 404.0 | 384 7 | 0.0074 | 14380 |
| 90 | C3B6C5G4 | \$67 162 | 404.0 | 385.4 | 0.0077 | 14458 |
| 01 | C3B6C5G5 | \$67.102 | 405.6 | 386.7 | 0.0071 | 14660 |
| 92 | C3B6C5G6 | \$67 230 | 406.4 | 387.6 | 0.0071 | 15141 |
| 93 | C3B7C5G3 | \$67.163 | 359.7 | 377 3 | 0.0007 | 11717 |
| 15 | 03070303 | $\psi_{01}, 105$ | 557.1 | 577.5 | 0.0075 | 11/1/ |

| No. | Name | Cost | Stiffness defined at D1 (10 ³ kip/in.) | Stiffness defined at D2 (10 ³ kip/in.) | Crack Width (in.) | Ultimate Load (kips) |
|-----|----------|----------|--|--|-------------------|-------------------------|
| 94 | C3B7C5G4 | \$67,188 | 361.0 | 378.1 | 0.0089 | 11983 |
| 95 | C3B7C5G5 | \$67,219 | 362.0 | 379.1 | 0.0084 | 12058 |
| 96 | C3B7C5G6 | \$67,256 | 362.9 | 380.2 | 0.0077 | 12391 |

Figure 3.18 shows the cost and stiffness comparison of the specimens. In Figure 3.18, each point stands for the result of a specimen in the parametric analysis. Case 1 is marked by blue, Case 2 is marked by gray, and Case 3 is marked by red. For Bent Cap 2, the stiffness value of Case 1 is slightly higher than that of both Case 2 and Case 3. For Bent Cap 6 and Bent Cap 7, the stiffness value of Case 1 is slightly lower than that of both Case 2 and Case 3. The cost of Case 1 is notably lower than that of both Case 2 and Case 3. The cost of Case 1 is notably lower than that of both Case 2 and Case 3.



(a) Cost versus stiffness of Bent 2 defined at D1



(c) Cost versus stiffness of Bent 6 defined at D1

(b) Cost versus stiffness of Bent 2 defined at D2



(d) Cost versus stiffness of Bent 6 defined at D2



(e) Cost versus stiffness of Bent 7 defined at D1
 (f) Cost versus stiffness of Bent 7 defined at D2
 Figure 3.18 Cost and Stiffness Comparison of Bent 2, Bent 6, and Bent 7

Figure 3.19 shows the cost and crack width comparisons of the specimens. Case 2 has the largest crack widths for all bent caps. For Bent Cap 2, the result of Case 1 and Case 3 are almost equal. For Bent Cap 6 and Bent Cap 7, specimens in Case 1 always have a smaller crack width than Case 3.





Figure 3.19 Cost and Crack Width Comparisons of Bent 2, Bent 6, and Bent 7

Figure 3.20 shows the cost and ultimate capacity comparisons of the specimens. As shown in Figure 3.20, Case 1 has a notably enhanced ultimate capacity than Case 2 and Case 3.





Figure 3.20 Cost and Ultimate Load Comparisons of Bent 2, Bent 6, and Bent 7

Figure 3.21 shows the influence of the S Bar area on the cost and performance of Bent 2 with 5 ksi concrete. As shown in Figure 3.21(a), the increase of the S Bar area contributes to the construction cost. As shown in Figure 3.21(b), the FE simulation results show that the stiffness notably increases with the S Bar area. As shown in Figure 3.21(c) and Figure 3.21(d), increasing the S Bar area reduces the maximum crack width significantly. As shown in Table 3.14, based on the parametric simulation results, the calculated maximum crack width of 0.0127 in. was observed in Specimen C2B7C5Smin. As recommended by the Article 5.6.7 of AASHTO LRFD Specifications (2017), the limit for crack width is 0.017 in. for Class 1 exposure condition and 0.013 in. for Class 2 exposure condition. Therefore, the minimum reinforcement area of S Bars based on the design service load and the AASHTO specifications (2014), which is 26% lower than the current design, is adequate for crack control. Based on the parametric simulation results, the current design of the S Bar area is adequate for structural safety and crack resistance.



(a) Influence of S Bar Area on Cost

(b) Influence of S Bar Area on Ultimate Capacity



Figure 3.21 Influence of S Bar Area on Cost and Performance of Bent 2 with 5 ksi concrete

Figure 3.22 shows the influence of the G Bar area on the cost and performance of Bent 2 with 5 ksi concrete. As shown in Figure 3.22(a), the increase of the G Bar area has little influence on the construction cost. As shown in Figure 3.22(b), the FE analysis results show that the G Bar area has little influence on the ultimate capacity. As shown in Figure 3.22(c) and Figure 3.22(d), increasing the G Bar area reduces the maximum crack width significantly. Based on the comparison between Figure 3.21 and Figure 3.22, the S Bar area has a more notable influence on the crack width than the G Bar area. As shown in Table 3.14, the maximum crack width of all specimens with the current design of G Bar (No. 7 Bars) is 0.0127 in. (Specimen C2B7C5Smin), which meets the AASHTO (2017) requirements for both Class 1 and Class 2 exposure conditions. In conclusion, the current design of G Bar (No. 7 Bars) is adequate for crack control.





Figure 3.22 Influence of G Bar Area on Cost and Performance of Bent 2 with 5 ksi concrete

3.6 SUMMARY

In Chapter 3 (Task 9a), three cases of reinforcement design for ITBCs are investigated to cover the majority of the design detailing in Texas bridges. Based on the parametric FE simulation of 96 specimens and the cost-benefit analysis results, the conclusions are summarized as follows:

- (1) The skew transverse reinforcement (Case 1) achieves better structural performance compared to traditional transverse reinforcement (Case 2 and Case 3) with notably reduced construction cost. Therefore, the skew transverse reinforcement can well be used for the design of skewed ITBCs.
- (2) For skew reinforcing, smaller number of cracks and smaller crack width will be achieved.
- (3) The increase of the S Bar area notably enhances the stiffness and ultimate strength. In addition, the increase of the S Bar area also reduces the crack width. The increase of the S Bar area will contribute notably to the construction cost. Based on the parametric simulation results, the current design of the S bar area is adequate for structural safety and crack resistance.
- (4) The increase of the G Bar area notably reduces the maximum crack width with a negligible influence on the stiffness, ultimate strength, and construction cost. The current design of the G Bar (No. 7 Bars) is adequate for crack control.
- (5) When the concrete strength increases from 5 ksi to 7 ksi, the ultimate strength and the stiffness of ITBCs increase with reduced crack width. In addition, the influence of concrete strength on the construction cost is negligible.

Task 9a will significantly leverage the impact of this project and solve the dearth of reliable design methods and reinforcement detailing in the design of skewed ITBCs.

CHAPTER 4: DESIGN RECOMMENDATIONS AND DESIGN EXAMPLES

Finite element models of the significant ITBCs explained in Chapter 2 and Chapter 3, show that all the bent caps with skew transverse reinforcing are safe under service and limit state loading. Moreover, from the cost-benefit analysis, it is observed that the skew transverse reinforcement achieves better structural performance compared to traditional transverse reinforcement with notably reduced construction cost. Therefore, the skew transverse reinforcement can well be used for the design of skewed ITBCs.

In this chapter, design recommendations for skewed ITBCs are explained and four different design examples are presented following AASHTO LRFD Bridge Design Specifications, 8th Ed. (2017) and TxDOT Bridge Manual - LRFD (January 2020). The previous ITBC design example published by TxDOT is in accordance with the AASHTO LRFD Bridge Design Specifications, 5th Ed. (2010) as prescribed by TxDOT Bridge Design Manual - LRFD (May 2009). The updates from AASHTO LRFD 2010 to AASHTO LRFD 2017 are provided in Appendix 1.

4.1 DESIGN RECOMMENDATIONS

According to AASHTO LRFD (2017), TxDOT BDM (2020), and finite element analysis results of the significant ITBCs (Task 9 and Task 9a), the design recommendations for skew reinforcing bars are suggested below:

1. It is recommended to use skew transverse reinforcement for the design of skewed ITBCs. As explained in detail in Chapter 3, the skew transverse reinforcement achieves better structural performance compared to traditional transverse reinforcement with notably reduced construction cost.



Figure 4.1 Skewed Transverse Reinforcement in skewed ITBCs

- 2. It is recommended to design double S Bars throughout the bent cap. The spacing of S Bars can be increased at the location of column support, no greater than 12".
- 3. For skewed ITBCs design, M Bars and N Bars are paired together with equal spacing, which needs to be equal to or an integer multiple of the spacing of S Bars.



Figure 4.2 Typical Section View of ITBCs

- 4. The stem width (b_{stem}) is at least 3" wider than the column diameter.
- 5. As a general rule of thumb, ledge depth (d_{ledge}) is greater than or equal to 2'-3", which is the depth at which a bent from a typical bridge will pass the punching shear check.
- 6. The distance from the face of the stem to center of bearing pad is 12" for TxGirders.
- 7. The end bars (U1 Bars, U2 Bars, U3 Bars, and G Bars) notably reduces the maximum crack width. It is recommended to place #6 U1 Bars, U2 Bars, and U3 Bars at the end faces and #7 G Bars at approximately 6in. spacing at the first 30" to 35" of the end of the bent cap. U1 Bars are vertical end reinforcements, U2 Bars, and U3 Bars are horizontal end reinforcements at the stem and the ledge, respectively. G Bars are the diagonal end reinforcement.
- 8. TxDOT Bridge Design Manual LRFD Ch. 4, Sect. 5 limits the minimum concrete compressive strength as $f'_c = 3.6$ ksi. However, finite element models in Task 9a shows that concrete strength notably increases the ultimate strength and the stiffness of ITBCs and reduces crack width. Therefore, it is recommended to have concrete compressive strength at least $f'_c = 5$ ksi.

4.2 **INVERTED-T BENT CAP DESIGN EXAMPLE 1 (0° SKEW ANGLE)**

Design example is in accordance with the AASHTO LRFD Bridge Design Specifications, 8th Ed. (2017) as prescribed by TxDOT Bridge Manual - LRFD (January 2020).

Design Parameters 4.2.1



Figure 4.3 Spans of the Bridge with 0 Degree Skewed ITBC

Span 1

54' Type TX54 Girders (0.851 k/ft) 6 Girders Spaced @ 8.00' with 3' overhangs

2" Haunch

Span 2

112' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 8.00' with 3' overhangs

3.75" Haunch

Span 3

54' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 8.00' with 3' overhangs

2" Haunch

All Spans

Deck is 46 ft wide Type T551 Rail (0.382 k/ft) 1974. 8" Thick Slab (0.100 ksf) Assume 2" Overlay @ 140 pcf (0.023 ksf) Use Class "C" Concrete $f_c' = 5 \text{ ksi}$ $w_c = 150 \text{ pcf}$ (for weight)

"AASHTO LRFD" refers to the ASSHTO LRFD Bridge Design Specification, 8th Ed. (2017)..

"BDM-LRFD" refers to the TxDOT Bridge Design Manual - LRFD (January 2020).

"TxSP" refers to TxDOT guidance, recommendations, and standard practice.

"Furlong & Mirza" refers to "Strength and Serviceability of Inverted T-Beam Bent Caps Subject to Combined Flexure, Shear, and Torsion", Center for Highway Research Research Report No. 153-1F, The University of Texas at Austin, August

The basic bridge geometry can be found on the Bridge Layout located in the Appendices. (BDM-LRFD, Ch. 4, Sect. 5, Materials)

 $w_c = 145 \text{ pcf}$ (for Modulus of Elasticity calculation)

Grade 60 Reinforcing

 $F_y = 60 \text{ ksi}$

(BDM-LRFD, Ch. 4, Sect. 5, Materials)

Bents

Use 36" Diameter Columns (Typical for Type TX54 Girders)

Define Variables

| <u>Forward Span</u> | |
|-----------------------------------|---|
| Span2 = 112ft | Span Length |
| GdrSpa2 = 8ft | Girder Spacing |
| GdrNo2 = 6 | Number of Girders in Span |
| GdrWt2 = 0.851klf | Weight of Girder |
| Haunch $2 = 3.75$ in | Size of Haunch |
| | |
| | Skew of Bents |
| | Width of Bridge Deck |
| | Width of Roadway |
| | Depth of Type TX54 Girder |
| | Bearing Seat Buildup |
| | Bearing Pad Thickness |
| | Thickness of Bridge Slab |
| | Thickness of Overlay |
| | Weight of Rail |
| | Unit Weight of Concrete for Loads |
| | Unit Weigh of Overlay |
| | |
| | Concrete Strength |
| | Unit Weight of Concrete for E. |
| | |
| $\overline{E_c}$ $E_c = 4074$ ksi | Modulus of Elasticity of Concrete (AASHTO LRFD Eq. C5.4.2.4-2) |
| | Yield Strength of Reinforcement |
| | Modulus of Elasticity of Steel |
| | Diameter of Columns |
| | Forward SpanSpan2 = 112ftGdrSpa2 = 8ftGdrNo2 = 6GdrWt2 = 0.851klfHaunch2 = 3.75in |

Other Variables

IM = 33%



Figure 4.4 Top View of the 0 Degree Skewed ITBC with Spans and Girders

4.2.2 Determine Cap Dimensions



Figure 4.5 Section View of 0 Degree Skewed ITBC

4.2.2.1 Stem Width

 $b_{stem} = D_{column} + 3in$

4.2.2.2 Stem Height

 $b_{stem} = 39$ in

The stem is typically at least 3" wider than the Diameter of the Column (36") to allow for the extension of the column reinforcement into the Cap. (TxSP)

Haunch2 is the larger of the two haunches.

 $D_{Slab to Ledge} = SlabThk + Haunch2 + GirderD + BrgPad + BrgSeat$

 $D_{Slab_to_Ledge} = 70.00$ in

Distance from Top of Slab to Top of Ledge:

StemHaunch = 3.75 in

The top of the stem must be 2.5" below the bottom of the slab. (BDM-LRFD, Ch. 4, Sect. 5, Geometric Constraints)

Accounting for the 1/2" of bituminous fiber, the top of the stem must have at least 2" of haunch on it, but the haunch should not be less than either of the haunches of the adjacent spans. $d_{stem} = D_{Slab_to_Ledge} - SlabThk - StemHaunch - 0.5in$

$$d_{stem} = 57.75$$
 in

Use: $d_{stem} = 57$ in

4.2.2.3 Ledge Width



Figure 4.6 Ledge Section of 0 Degree ITBC

cover = 2.5 in

L = 8 in

Determine the Required Development Length of Bar M:

Try # 6 Bar for Bar M.

$$d_{bar_M} = 0.750$$
 in

$$A_{bar_M} = 0.44 \text{ in}^2$$

Basic Development Length

$$L_{dh} = \frac{38.0 \cdot d_{bar_M}}{60} \cdot \left(\frac{f_y}{\sqrt{f_c}}\right) \qquad \qquad L_{dh} = 12.75 \text{ in}$$

(AASHTO LRFD Eq. 5.10.8.2.4a-2)

(AASHTO LRFD 5.10.8.2.4b)

Modification Factors for L_{dh}:

Is Top Cover greater than or equal to 2.5", and Side Cover greater than or equal to 2"?

The stem must accommodate $\frac{1}{2}$ " of bituminous fiber.

Round the Stem Height down to the nearest 1". (TxSP)

The Ledge Width must be adequate for Bar M to develop fully.

 $L_{dh,prov}$ "must be greater than or equal to " $L_{dh,reg}$ " for Bar M.

"cover" is measured from the center of the transverse bars.

"L" is the length of the Bearing Pad along the girder. A typical type TX54 bearing pad is 8" \times 21" as shown in the IGEB standard.

73

SideCover = cover
$$-\frac{d_{har_M}}{2} = 2.13$$
 in"Side Cover" and "Top Cover"
are the clear cover on the side
and top of the hook respectively.
The dimension "cover" is
measured from the center of Bar
M.No. Reinforcement Confinement Factor, $\lambda_{rc} = 1.0$
Coating Factor, $\lambda_{cw} = 1.0$ (AASHTO LRFD 5.4.2.8)The Required Development Length:
 $L_{dh_req} = max(L_{dh} \cdot \left(\frac{\lambda_{rc} \lambda_{cw}^2 \lambda_{er}}{\lambda}\right), 8 \cdot d_{bar_m}, 6in.)$ (AASHTO LRFD 5.10.8.2.4a)Therefore,
 $L_{dh_req} = max(L_{dh} \cdot \left(\frac{\lambda_{rc} \lambda_{cw}^2 \lambda_{er}}{\lambda}\right), 8 \cdot d_{bar_m}, 6in.)$ The distance from the face of
the stem to the center of
bearing is 12" for TxGirders
(IGEB).Width of Bottom Flange:
 $b_{re} = 2 \cdot b_{ledge} + b_{stem}$ $b_{re} = 87$ in4.2.2.4Ledge Depth
 $d_{ledge} = 28$ inAs a general rule of thumb,
Ledge Depth is greater than or
equal to 2'.3". This is the depth
at which a bent from a typical
bridge will pass the punching
shear check.4.2.2.5Summary of Cross-Sectional Dimensions

4.2.2.5 <u>Summary of Cross-Sectional Dimensio</u> b_{stem} = 39 in

$$d_{stem} = 57$$
 in
 $b_{ledge} = 24$ in
 $d_{ledge} = 28$ in
 $h_{cap} = 85$ in

4.2.2.6 Length of Cap

First define Girder Spacing and End Distance:



inverted T-beam shall not be less than 12in." (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria) replacing the statement in AASHTO LRFD 5.13.2.5.5 stating it shall not be less than d_f . Preferably, the stem should extend at least 3" beyond the edge of the bearing seat.

(IGEB standard)

Length of Bearing Pad

Width of Bearing Pad

Bearing Pad Dimensions:

L = 8 in

W = 21 in

4.2.3 Cross Sectional Properties of Cap

$$\begin{split} A_{g} &= d_{ledge} \cdot b_{f} + d_{stem} \cdot b_{stem} & A_{g} &= 4659 in^{2} \\ ybar &= \frac{d_{ledge} \cdot b_{f} \cdot \left(\frac{1}{2}d_{ledge}\right) + d_{stem} \cdot b_{stem} \cdot \left(d_{ledge} + \frac{1}{2}d_{stem}\right)}{A_{g}} & ybar &= 34.3 in \\ I_{g} &= \frac{b_{f} \cdot d_{ledge}^{3}}{12} + b_{f} \cdot d_{ledge} \cdot \left(ybar - \frac{1}{2}d_{ledge}\right)^{2} + \frac{b_{stem} \cdot d_{stem}}{12} + \cdots \\ b_{stem} \cdot d_{stem} \cdot \left[ybar - \left(d_{ledge} + \frac{1}{2}d_{stem}\right)\right]^{2} & I_{g} &= 2.86 \times 10^{6} in^{4} \end{split}$$

4.2.4 Cap Analysis

4.2.4.1 Cap Model

Assume:

4 Columns Spaced @ 12'-0"

The cap will be modeled as a continuous beam with simple supports using TxDOT's CAP18 program.



Figure 4.8 Continuous Beam Model for 0 Degree ITBC

TxDOT does not consider frame action for typical multi-column bents.

(BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis).





The circled numbers in Figure 4.9 are the stations that will be used in the CAP 18 input file. One station is 0.5 ft in the direction perpendicular to the pgl, not parallel to the bent.

Station increment for CAP 18

Recall:

station = 0.5 ft

$$\begin{split} & E_c = 4074 \text{ ksi} & I_g = 2.86 \times 10^6 \text{ in}^4 \\ & E_c I_g = 1.165 \times 10^{10} \text{ kip} \cdot \text{in}^2 / \left(12 \frac{\text{in}}{\text{ft}} \right)^2 & E_c I_g = 8.09 \times 10^7 \text{kip} \cdot \text{ft}^2 \end{split}$$

SPAN 1

 $Rail1 = \frac{2 \cdot RailWt \cdot \frac{Span1}{2}}{\min(GdrNo1,6)}$

$$Slab1 = w_c \cdot GdrSpa1 \cdot SlabThk \cdot \frac{Span1}{2} \cdot 1.10$$

Girder1 = GdrWt1 $\cdot \frac{\text{Span1}}{2}$

$$DLRxn1 = (Rail1 + Slab1 + Girder1)$$

$$Overlay1 = w_{Olay} \cdot GdrSpa1 \cdot OverlayThk \cdot \frac{Span1}{2}$$

SPAN 2

 $Rail2 = \frac{2 \cdot RailWt \cdot \frac{Span2}{2}}{\min(GdrNo2,6)}$

Slab2 =
$$w_c \cdot GdrSpa2 \cdot SlabThk \cdot \frac{Span2}{2} \cdot 1.10$$

Girder2 = GdrWt1
$$\cdot \frac{\text{Span2}}{2}$$
 Girder2 = 47.66 $\frac{\text{kip}}{\text{girder}}$

$$DLRxn2 = (Rail2 + Slab2 + Girder2)$$
 $DLRxn2 = 104.07 \frac{kip}{girder}$

Values used in the following equations can be found on "4.2.1 Design Parameters"

Rail Weight is distributed

evenly among stringers, up to 3 stringers per rail (TxSP).

Increase slab DL by 10% to

Overlay is calculated

different load factor than the rest of the dead loads.

 $DLRxn1 = 50.17 \frac{kip}{girder}$ Overlay is calculated separetely, because it has

 $Overlay1 = 5.04 \frac{kip}{girder}$ Design for future overlay.

account for haunch and thickened slab ends.

 $Rail1 = 3.44 \frac{kip}{girder}$

 $Slab1 = 23.76 \frac{kip}{girder}$

Girder1 = $22.98 \frac{\text{kip}}{\text{girder}}$

Rail2 = $7.13 \frac{\text{kip}}{\text{girder}}$

 $Slab2 = 49.28 \frac{kip}{girder}$

$$Overlay2 = w_{Olay} \cdot GdrSpa2 \cdot OverlayThk \cdot \frac{Span2}{2} \qquad Overlay2 = 10.45 \frac{kip}{girder}$$

CAP

$$Cap = w_c \cdot A_g = 4.853 \frac{kip}{ft} \cdot \frac{0.5ft}{station} \qquad Cap = 2.427 \frac{kip}{station}$$



Figure 4.10 Live Load Model of 0 Degree ITBC

LongSpan = max(Span1, Span2)
ShortSpan = min(Span1, Span2)
IM = 0.33
Lane =
$$0.64$$
klf $\cdot \left(\frac{\text{LongSpan+ShortSpan}}{2}\right)$

Lane =
$$53.12 \frac{\text{kip}}{\text{lane}}$$

$$Truck = 32kip + 32kip \cdot \left(\frac{LongSpan - 14}{LongSpan}\right) + \cdots$$
$$8kip \cdot \left(\frac{LongSpan - 2}{LongSpan}\right)$$

2)

1

Truck =
$$66.00 \frac{ki}{lane}$$

LLRxn = Lane + Truck
$$\cdot$$
 (1 + IM)
LLRxn = 140.90 $\frac{\text{kip}}{\text{lane}}$

LongSpan = 112 ftShortSpan = 54 ft

> Use HL-93 Live Load. For maximum reaction at interior bents, "Design Truck" will always govern over "Design Tandem". For the maximum reaction when the long span is more than twice as long as the short span, place the rear (32 kip) axle over the support and the middle (32 kip) and front (8 kip) axles on the long span. For the maximum reaction when the long span is less than twice as long as the short span, place the middle (32 kip) axle over the support, the front (8 kip) axle on the short span and the rear (32 kip) axle on the long span.

Combine "Design Truck" and "Design Lane" loadings (AASHTO LRFD 3.6.1.3). Dynamic load allowance, IM, does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4)



allowance with the reminder of the live load distributed over a 10 ft (AASHTO LRFD 3.6.1.2.1) design lane width. (TxSP) The Live Load applied to the slab is distributed to the begins

The Live Load is applied to the slab by two 16 kip wheel loads increased by the dynamic load

slab is distributed to the beams assuming the slab is hinged at each beam except the outside beam. (BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis)

Input "Multiple Presence Factors" into CAP18 as "Load Reduction Factors".

The cap design need only consider Strength I, Service I,

| No. of Lanes | Factor "m" |
|----------------------|-------------|
| 1 | 1.20 |
| 2 | 1.00 |
| 3 | 0.85 |
| >3 | 0.65 |
| Limit States (AASHTO | LRFD 3.4.1) |

4.2.4.1.3 Cap 18 Data Input

Multiple Presence Factors, m

Strength I

| | Live Load and Dynamic Load Allowance | LL+IM = 1.75 | and Service I with DL (TxSP). |
|---------|--------------------------------------|----------------|--|
| | Dead Load Components | DC = 1.25 | TrDOT allows the Overlay |
| | Dead Load Wearing Surface (Overlay) | DW = 1.50 | Factor to be reduced to 1.25 |
| Service | <u>e I</u> | | (TxSP), since overlay is typically used in design only to |
| | Live Load and Dynamic Load Allowance | LL+IM = 1.00 | increase the safety factor, but |
| | Dead Load and Wearing Surface | DC & DW = 1.00 | in this example we will use <i>DW=1.50</i> . |

(AASHTO LRFD Table 3.6.1.1.2-1)

Dead Load

TxDOT considers Service level Dead Load only with a limit reinforcement stress of 22 ksi to minimize cracking. (BDM-LRFD, Chapter 4, Section 5, Design Criteria)

4.2.4.1.4 Cap 18 Output

| | Max +M | Max -M |
|----------------|---|--|
| Dead Load: | $M_{posDL} = 249.2 \text{ kip} \cdot \text{ft}$ | $M_{negDL} = -378.5 \text{ kip} \cdot \text{ft}$ |
| Service Load: | $M_{posServ} = 491.6 \text{ kip} \cdot \text{ft}$ | $M_{negServ} = -590.0 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{posUlt} = 740.6 \text{ kip} \cdot \text{ft}$ | $M_{negUlt} = -851.0 \text{ kip} \cdot \text{ft}$ |

These loads are the maximum loads from the CAP 18 Output File Located in the Appendices.

4.2.4.2 Girder Reactions on Ledge





 $DLSpan1 = 50.17 \frac{kip}{girder}$

 $DLSpan2 = 104.07 \frac{kip}{girder}$

Dead Load

DLSpan1 = Rail1 + Slab1 + Girder1 Overlay1 = $5.04 \frac{\text{kip}}{\text{girder}}$

DLSpan2 = Rail2 + Slab2 + Girder2

 $Overlay2 = 10.45 \ \frac{kip}{girder}$

Live Load

Loads per Lane:



Use HL-93 Live Load. For maximum reaction at interior bents, "Design Truck" will always govern over "Design Tandem" for Spans greater than 26ft. For the maximum reaction, place the back (32 kips) axle over the support.

Figure 4.13 Live Load Model of 0 Degree Skewed ITBC

for Girder Reactions on Ledge

$$\begin{aligned} \text{LaneSpan1} &= 0.64 \text{klf} \cdot \left(\frac{\text{Span1}}{2}\right) & \text{LaneSpan1} &= 17.28 \frac{\text{kip}}{\text{lane}} \\ \text{LaneSpan2} &= 0.64 \text{klf} \cdot \left(\frac{\text{Span2}}{2}\right) & \text{LaneSpan2} &= 35.84 \frac{\text{kip}}{\text{lane}} \\ \text{TruckSpan1} &= 32 \text{kip} + 32 \text{kip} \cdot \left(\frac{\text{Span1-14ft}}{\text{Span1}}\right) + 8 \text{kip} \cdot \left(\frac{\text{Span1-28ft}}{\text{Span1}}\right) \end{aligned}$$

$$TruckSpan1 = 59.56 \frac{kip}{lane}$$

$$TruckSpan2 = 32kip + 32kip \cdot \left(\frac{Span2 - 14ft}{Span2}\right) + 8kip \cdot \left(\frac{Span2 - 28ft}{Span2}\right)$$

$$TruckSpan2 = 66.00 \frac{kip}{lane}$$

$$IM = 0.33$$

$$Combine "Design Truck" and "Design Truck" and$$

 $LLRxnSpan1 = LaneSpan1 + TruckSpan1 \cdot (1 + IM)$ $LLRxnSpan1 = 96.49 \frac{kip}{lane}$

 $LLRxnSpan2 = LaneSpan2 + TruckSpan2 \cdot (1 + IM)$ $LLRxnSpan2 = 123.62 \frac{kip}{girder}$

Lane" loadings (AASHTO LRFD 3.6.1.3).

Dynamic load allowance, IM, does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4).

The Live Load Reactions are assumed to be the Shear Live Load Distribution Factor multiplied by the Live Load Reaction per Lane. The Shear Live Load Distribution Factor is calculated using the "LRFD Live Load Distribution Factors" Spreadsheet found in the Appendices.

The Exterior Girders must have a Live Load Distribution Factor equal to or greater than the Interior Girders. This is to accommodate a possible future bridge widening. Widening the bridge would cause the exterior girders to become interior girders.

| $LLSpan1Int = gV_{Span1_Int} \cdot LLRxnSpan1$ | LLSpan1Int = $78.54 \frac{\text{kip}}{\text{girder}}$ |
|---|---|
| $LLSpan1Ext = gV_{Span1_Ext} \cdot LLRxnSpan1$ | LLSpan1Ext = $78.54 \frac{\text{kip}}{\text{girder}}$ |
| $LLSpan2Int = gV_{Span2_Int} \cdot LLRxnSpan2$ | $LLSpan2Int = 100.63 \frac{kip}{girder}$ |
| $LLSpan2Ext = gV_{Span2_Ext} \cdot LLRxnSpan2$ | $LLSpan2Ext = 100.63 \frac{kip}{girder}$ |
| | |

<u>Span 1</u>

Interior Girder

 $gV_{Span1_{Int}} = 0.814$

 $gV_{Span1 Ext} = 0.814$

 $gV_{\text{Span2 Int}} = 0.814$

 $gV_{Span2 Ext} = 0.814$

Service Load (Service I Limit State, AASHTO LRFD 3.4.1)

 $V_{s_Span1Int} = DLSpan1 + Overlay1 + LLSpan1Int$

 $V_{s_Span1Int} = 134 \text{ kip}$

Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1)

 $V_{u \text{ Span1Int}} = 1.25 \cdot \text{DLSpan1} + 1.5 \cdot \text{Overlay1} + 1.75 \cdot \text{LLSpan1Int}$

 $V_{u_{span1Int}} = 208 \text{ kip}$

Exterior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1) $V_{s_Span1Ext} = DLSpan1 + Overlay1 + LLSpan1Ext$ $V_{s_Span1Ext} = 134 \text{ kip}$ Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1) $V_{u_Span1Ext} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1 + 1.75 \cdot LLSpan1Ext$ $V_{u_Span1Ext} = 208 \text{ kip}$

Span 2

Interior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1)

 $V_{s_{Span2Int}} = DLSpan2 + Overlay2 + LLSpan2Int$

 $V_{s \text{ Span2Int}} = 215 \text{ kip}$

Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1)

 $V_{u_{span2Int}} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot LLSpan2Int$

 $V_{u \text{ Span2Int}} = 322 \text{ kip}$

Exterior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1)

V_{s Span2Ext} = DLSpan2 + Overlay2 + LLSpan2Ext

 $V_{s_Span2Ext} = 215 \text{ kip}$

Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1)

 $V_{u \text{ Span2Ext}} = 1.25 \cdot \text{DLSpan2} + 1.5 \cdot \text{Overlay2} + 1.75 \cdot \text{LLSpan2Ext}$

 $V_{u_{Span2Ext}} = 322 \text{ kip}$

4.2.4.3 Torsional Loads



To maximize the torsion, the live load only acts on the longer span.

Figure 4.14 Live Load Model of 0 Degree Skewed ITBC for Torsional Loads



Figure 4.15 Loads on the Ledge of 0 Degree Skewed ITBC for Torsion

 $a_v = 12$ in

" a_v " is the value for the distance from the face of the stem to the center of bearing for the girders. 12" is the typical values for TxGirders on ITBC (IGEB). The lever arm is the distance from the center line of bearing to the centerline of the cap.

 $b_{stem} = 39$ in

LeverArm = $a_v + \frac{1}{2}b_{stem}$

LeverArm = 31.5 in

Interior Girders

Girder Reactions

 $R_{u_{Span1}} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$

 $R_{u_Span1} = 70 \; kip$ $R_{u_Span2} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot gV_{Span2_Int}$

$$\cdot$$
 [LaneSpan2 + TruckSapn2 \cdot (1 + IM)]

 $R_{u Span2} = 322 \text{ kip}$

Torsional Load

$$T_{u_{Int}} = |R_{u_{Span1}} - R_{u_{Span2}}| \cdot LeverArm$$

 $T_{u_Int} = 660 \; kip \cdot ft$

Exterior Girders

Girder Reactions

$$R_{u \text{ Span1}} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$$

$$\begin{split} R_{u_Span2} &= 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot gV_{Span2_Ext} \\ &\cdot [LaneSpan2 + TruckSapn2 \cdot (1 + IM)] \end{split}$$

$$R_{u_{Span2}} = 322 \text{ kip}$$

Torsional Load

$$T_{u_Ext} = |R_{u_Span1} - R_{u_Span2}| \cdot LeverArm$$

$$T_{u_{Ext}} = 660 \text{ kip} \cdot \text{ft}$$

Torsion on Cap



Figure 4.16 Elevation View of 0 Degree ITBC with Torsion Loads





Analyzed assuming Bents are torsionally rigid at Effective Face of Columns.

 $T_u = 660 \; \text{kip} \cdot \text{ft}$

Maximum Torsion on Cap

Ledge Loads

Interior Girder

Service Load

$$V_{s_Int} = max(V_{s_Span1Int}, V_{s_Span2Int})$$
 $V_{s_Int} = 215.15 \text{ kip}$

Factored Load

$$V_{u_{Int}} = max(V_{u_{Span1Int}}, V_{u_{Span2Int}})$$
 $V_{u_{Int}} = 321.86 \text{ kip}$

Exterior Girder

Service Load

$$V_{s_Ext} = max(V_{s_Span1Ext}, V_{s_Span2Ext})$$
 $V_{s_Ext} = 215.15 \text{ kip}$

Factored Load

$$V_{u_Ext} = max(V_{u_Span1Ext}, V_{u_Span2Ext})$$
 $V_{u_Ext} = 321.86 \text{ kip}$

Cap Loads

Positive Moment (From CAP18)

| Dead Load: | $M_{posDL} = 249.2 \text{ kip} \cdot \text{ft}$ |
|----------------|---|
| Service Load: | $M_{posServ} = 491.6 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{posUlt} = 740.6 \text{ kip} \cdot \text{ft}$ |

Negative Moment (From CAP18)

| Dead Load: | $M_{negDL} = -378.5 \text{ kip} \cdot \text{ft}$ |
|----------------|--|
| Service Load: | $M_{negServ} = -590.0 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{negUlt} = -851.0 \text{ kip} \cdot \text{ft}$ |

Maximum Torsion and Concurrent Shear and Moment (Strength I)

| $T = 660 \text{ kin} \cdot \text{ft}$ | Located two stations away from |
|---|---------------------------------|
| $r_{\rm u} = 000 {\rm Mp}^{-1} {\rm c}$ | centerline of column. |
| $V_{\mu} = 447.4 \text{ kip}$ | U U |
| u i | V_u and M_u values are from |
| $M_u = 334.5 \text{ kip} \cdot \text{ft}$ | CAP18 |

.

4.2.5 Locate and Describe Reinforcing





Recall:

$$b_{stem} = 39 \text{ in}$$

$$d_{stem} = 57 \text{ in}$$

$$b_{ledge} = 24 \text{ in}$$

$$d_{ledge} = 28 \text{ in}$$

$$b_f = 87 \text{ in}$$

$$h_{cap} = 85 \text{ in}$$

$$cover = 2.5 \text{ in}$$

Measured from Center of bar

4.2.5.1 Describe Reinforcing Bars

| Use # 11 bars for Bar A | | | |
|----------------------------------|------------------------------|--|--|
| $A_{bar_A} = 1.56 \text{ in}^2$ | $d_{bar_A} = 1.410$ in | | |
| Use # 11 bars for Bar B | | | |
| $A_{bar_B} = 1.56 \text{ in}^2$ | $d_{bar_B}=1.410~\text{in}$ | | |
| Use # 6 bars for Bar M | | In the calculation of b_{ledge} , #6 | |
| $A_{bar_M} = 0.44 \text{ in}^2$ | $d_{bar_M} = 0.75$ in | Bar M was considered. Bar M | |
| Use # 6 bars for Bar N | | must be # 6 or smaller to allow it fully develop. | |
| $A_{bar_N} = 0.44 \text{ in}^2$ | $d_{bar_N}=0.75~\text{in}$ | To prevent confusion, use the | |
| Use # 6 bars for Bar S | | same bar size for Bar N as Bar | |
| $A_{bar_S} = 0.44 \text{ in}^2$ | $d_{bar_S} = 0.75$ in | М. | |
| Use # 6 bars for Bar T | | | |
| $A_{bar_T} = 0.44 \text{ in}^2$ | $d_{bar_T} = 0.75$ in | | |

4.2.5.2 <u>Calculate Dimensions</u>

| $d_{s_neg} = h_{cap} - cover - \frac{1}{2}d_{bar_s} - \frac{1}{2}d_{bar_A}$ | $d_{s_neg} = 81.42$ in |
|---|----------------------------|
| $d_{s_pos} = h_{cap} - cover - \frac{1}{2}max(d_{bar_s}, d_{bar_M}) - \frac{1}{2}d_{bar_B}$ | $d_{s_pos} = 81.42$ in |
| $a_v = 12$ in | |
| $a_f = a_v + cover$ | $a_{\rm f}=14.50$ in |
| $d_e = d_{ledge} - cover$ | $d_{e} = 25.50 \text{ in}$ |
| $d_{f} = d_{ledge} - cover - \frac{1}{2}d_{bar_{-}M} - \frac{1}{2}d_{bar_{-}B}$ | $d_{\rm f}=24.42$ in |
| $h = d_{ledge} + BrgSeat$ | h = 29.50 in |



Figure 4.19 Plan View of 0 Degree Skewed ITBC

 $\alpha = 90 \text{ deg}$

Angle of Bars S

Recall:

$$L = 8 in$$

 $W = 21 in$

4.2.6 Check Bearing

Resistance Factor (ϕ) = 0.7

 $A_1 = L \cdot W$

B = 8 in.

Interior Girders

The load on the bearing pad propagates along a truncated pyramid whose top has the area A_1 and whose base has the area A_2 . A_1 is the loaded area (the bearing pad area: L×W). A_2 is the area of the lowest rectangle contained wholly within the support (the Inverted Tee Cap). A_2 must not overlap the truncated pyramid of another load in either direction, nor can it extend beyond the edges of the cap in any direction.

 $B = \min\left[\left(b_{ledge} - a_v\right) - \frac{1}{2}L, \left(a_v + \frac{1}{2}b_{stem}\right)\right]$

 $-\frac{1}{2}L, 2d_{\text{ledge}}, \frac{1}{2}S - \frac{1}{2}W$

Dimension of Bearing Pad



Figure 4.20 Bearing Check for 0-degree Skew Angle

(AASHTO LRFD 5.5.4.2)

Area under Bearing Pad

"B" is the distance from perimeter of A_1 to the perimeter of A_2 as seen in the above figure

 $L_2 = L + 2 \cdot B$ $L_2 = 24.00$ in

 $W_2 = W + 2 \cdot B$ $W_2 = 37.00$ in

 $A_2 = L_2 \cdot W_2$ $A_2 = 888$ in²

 $A_1 = 168 \text{ in}^2$

Modification factor

$$m = \min\left(\sqrt{\frac{A_2}{A_1}}, 2\right) = 2.29 \text{ and } 2$$
 $m = 2$ AASHTO LRFD Eq. 5.6.5-3 $\phi V_n = \phi$ 0.85 fc A1 m $\phi V_n = 999.6 \text{ kips}$ AASHTO LRFD Eqs. 5.6.5-1 $V_{u_Int} = 321.86 < \phi V_n$ BearingChk = "OK!" V_{u_int} from "4.2.4.4Load
Summary".

Exterior Girders

$$B = \min\left[\left(b_{\text{ledge}} - a_v\right) - \frac{1}{2}L, \left(a_v + \frac{1}{2}b_{\text{stem}}\right) - \frac{1}{2}L, 2d_{\text{ledge}}, \frac{1}{2}S - \frac{1}{2}W, c - \frac{1}{2}W\right]$$

| | B= 8 in. | "B" is the distance from perimeter of A_1 to the perimeter of A_2 as seen in the above figure |
|-----------------|----------|--|
| $L_2 = L + 2 B$ | | $L_2 = 24.00 \text{ in}$ |
| $W_2 = W + 2 B$ | | $W_2 = 37.00$ in |
| $A_2 = L_2 W_2$ | | $A_2 = 888 \text{ in}^2$ |

Modification factor

$$m = min\left(\sqrt{\frac{A_2}{A_1}}, 2\right) = 2.29 \text{ and } 2 \quad m = 2$$
 AASHTO LRFD Eq. 5.6.5-3

| $\varphi V_n = \varphi 0.85 f_c A_1 m$ | $\phi V_n = 999.6 \text{ kips}$ | AASHTO LRFD Eqs. 5.6.5-1 and 5.6.5-2: |
|---|---------------------------------|--|
| $V_{u_ext} = 321.86 \text{ kips} < \Phi V_n$ | BearingChk= "OK!" | V _{u_ext} from "4.2.4.4 Load Summary". |

4.2.7 Check Punching Shear



AASHTO LRFD 5.8.4.3.4, the truncated pyramids assumed as failure surfaces for punching shear shall not overlap.

Figure 4.21 Punching Shear Check for 0degree Skew Angle

Resistance Factor (ϕ) = 0.90

1

Determine if the Shear Cones Intersect

Is
$$\frac{1}{2}S - \frac{1}{2}W \ge d_f$$
?
 $\frac{1}{2}S - \frac{1}{2}W = 37.5$ in
 $d_f = 24.42$ in

Is
$$\frac{1}{2}b_{stem} + a_v - \frac{1}{2}L \ge d_f$$
?
 $\frac{1}{2}b_{stem} + a_v - \frac{1}{2}L = 27.5$ in
 $d_f = 24.42$ in

AASHTO LRFD 5.5.4.2.

Yes. Therefore, shear cones do not intersect in the longitudinal direction of the cap.

TxDOT uses "df" instead of "de" for Punching Shear (BDM-LRFD, Ch. 4, Sect. 5, Design *Criteria*). This is because "df" has traditionally been used for inverted tee bents and was sed in the Inverted Tee Research (Furiong % Mirza pg. 58).

Yes. Therefore, shear cones do not intersect in the transverse direction of the cap.

Interior Girders

| $V_n = 0.125 \ \mathbb{P} \ \lambda \sqrt{f_c'} \ b_o \ d_f$ | $V_{\rm n} = 585.91 {\rm kips}$ | AASHTO LRFD 5.8.4.3.4-3 |
|--|----------------------------------|--|
| $b_o = W + 2L + 2d_f$ | $b_o = 84.84 \text{ in}$ | AASHTO LRFD 5.8.4.3.4-4 |
| $\phi V_n = 527.32 \text{ kips}$ | | |
| $V_{u_Int} = 321.86 \text{ kips} < \varphi V_n$ | PunchingShearChk= "OK!" | V _{u_int} from "4.2.4.4 Load Summary". |

Exterior Girders $V_n = \min[(0.125 \cdot \sqrt{f_c} \cdot (\frac{1}{2}W + L + d_f +$ $V_n = 545.15 \text{ kips}$ AASHTO LRFD 5.8.4.3.4-3 and $c \Big) * d_f, 0.125 \cdot \sqrt{f_c} \cdot (W + 2L + 2d_f) * d_f)]$ 5.8.4.3.4-5
| $\phi V_n = 411.09 \text{ kips}$ | | |
|---|-----------------------------|---|
| $V_{u_ext} = 321.86 \text{ kips} < \varphi V_n$ | PunchingShearCh | k= "OK!" V _{u_ext} from "4.2.4.4 Load Summary". |
| 4.2.8 Check Shear Friction | | |
| Resistance Factor (ϕ) =0.90 | AASHTO LRFD 5 | 5.4.2 |
| Determine the Distribution Width | | |
| $\frac{\text{Interior Girders}}{b_{s_{Int}}} = \min(W + 4a_{v}, S)$ $= \min(69 \text{ in, } 96 \text{ in})$ | "S" is the gird | er spacing. |
| $b_{c \text{ Int}} = 69 \text{ in}$ | | |
| $A_{cv} = b_{s_{Int}} \cdot d_{e}$ | $A_{cv} = 1759.$ | 5 in2 |
| $\frac{\text{Exterior Girders}}{b_{s_{\text{Ext}}}} = \min[W + 4a_{v}, S, 2]$ $= \min[69, 96, 48]$ | c) "S" is the gird | er spacing. |
| = 48 in | | |
| $A_{cv} = b_{s_ext} \cdot d_e$ | $A_{\rm cv} = 122$ | 24 in2 |
| Interior Girders | | |
| $V_{n} = \min(0.2 \cdot f_{c} \cdot A_{cv}, 0.8 \cdot A_{cv})$ = min (1759.5, 1408) | $V_n = 1408 \text{ kips}$ | AASHTO LRFD 5.8.4.2.2-1 and 5.8.4.2.2-2 |
| $\phi V_n = 1267 \text{ kips}$ | | |
| $V_{u_Int} = 321.86 \text{ kips } < \varphi V_n$ | ShearFrictionChk= "OK!" | V _{u_int} from "4.2.4.4 Load Summary". |
| Exterior Girders | | |
| $V_n = min(0.2 \cdot f_c \cdot A_{cv}, 0.8 \cdot A_{cv})$ = min (1224, 979.2) | V _n = 979.2 kips | AASHTO LRFD 5.8.4.2.2-1 and 5.8.4.2.2-2 |
| $\phi V_n = 881 \text{ kips}$ | | |
| $V_{u_ext} = 321.86 \text{ kips} < \varphi V_n$ | ShearFrictionChk= "OK!" | V _{u_ext} from "4.2.4.4 Load Summary". |

4.2.9 Flexural Reinforcement for Negative Bending (Bars A)

| $M_{dl} = M_{negDL} $ | $M_{dl} = 378.5 \text{ kip} \cdot \text{ft}$ | From Cap 18 Output |
|------------------------|--|---------------------|
| $M_s = M_{negServ} $ | $M_s = 590.0 \text{ kip} \cdot \text{ft}$ | Trom Cup 10 Output. |
| $M_u = M_{negUlt} $ | $M_u = 851.0 \text{ kip} \cdot \text{ft}$ | |

(AASHTO LRFD 5.6.3.3)

4.2.9.1 Minimum Flexural Reinforcement

Factored Flexural Resistance, M_r , must be greater than or equal to the lesser of $1.2M_{cr}$ (Cracking Moment) or $1.33M_u$ (Ultimate Moment).

| $I_{g} = 2.86 \times 10^{6} \text{ in}^{4}$ | | Gross Moment of Inertia |
|---|---|--|
| $h_{cap} = 85$ in | | Depth of Cap |
| ybar = 34.3 in | | Distance to the Center of Gravity of the Cap from the bottom of the Cap |
| $f_r=0.24\sqrt{f_c}$ | $f_r = 0.537$ ksi | Modulus of Rupture (BDM- LRFD, Ch. 4, Sect. 5, Design Criteria) |
| $y_t = h_{cap} - ybar$ | y _t = 50.70 in | <i>Distance from Center of Gravity</i> <i>to extreme tension fiber</i> |
| $S = \frac{I_g}{y_t}$ | $S = 5.64 \times 10^4 \text{ in}^3$ | Section Modulus for the extreme tension fiber |
| $M_{cr} = S \cdot f_r \cdot \frac{1ft}{12in}$ | $M_{cr} = 2523.9 \text{ kip} \cdot \text{ft}$ | Cracking Moment (AASHTO LRFD Eq. 5.6.3.3-1) |
| $M_f = minimum \text{ of:}$ $1.2M_{cr} = 3028.7 \text{ kip} \cdot \text{ft}$ $1.33M_u = 1131.8 \text{ kip} \cdot \text{ft}$ | | Design the lesser of $1.2M_{cr}$ or $1.33M_u$ when determining mininum area of steel required. |

Thus, M_r must be greater than $M_f = 1131.8 \ \text{kip} \cdot \text{ft}$

4.2.9.2 Moment Capacity Design

Try, 6 ~ #11's Top Number of bars in tension BarANo = 6Diameter of main reinforcing $d_{\text{bar A}} = 1.410$ in bars $A_{\text{bar A}} = 1.56 \text{ in}^2$ Area of main reinforcing bars Area of steel in tension $A_s = BarANo \cdot A_{bar_A}$ $A_{s} = 9.36 \text{ in}^{2}$ Diameter of shear reinforcing $d_{stirrup} = 0.75$ in $d_{stirrup} = d_{bar S}$ bars $d = d_{s neg}$ d = 81.42 in $b = b_f$ b = 87 inCompressive Strength of Concrete $f_c = 5.0 \text{ ksi}$ Yield Strength of Rebar $f_v = 60 \text{ ksi}$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.85 - 0.05(f_c - 4ksi)$ Bounded by: $0.65 \le \beta_1 \le 0.85$ $\beta_1 = 0.80$ Depth of Cross Section under $c=\frac{A_sf_y}{0.85f_c\beta_1b}$ c = 1.90 in Compression under Ultimate Load This "c" is the distance from the extreme compression fiber to the

neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.

$$a = c \cdot \beta_1$$
 $a = 1.52$ in

Note: "a" is less than "dledge". Therefore the equivalent stress block acts over a rectangular area. If "a" was greater than "dledge", it would act over a Tee shaped area.

$$\begin{split} M_n &= A_s f_y \left(d - \frac{a}{2} \right) \cdot \frac{1 \text{ft}}{12 \text{in}} & M_n &= 3774.9 \text{ kip} \cdot \text{ft} \\ \epsilon_s &= 0.003 \cdot \frac{d - c}{c} & \epsilon_s &= 0.126 \end{split}$$

 $\epsilon_{s} > 0.005$

 $\Phi_{\rm M} = 0.90$

FlexureBehavior = "Tension Controlled"

$$M_r = \Phi_M M_n \qquad M_r = 3397.4 \text{ kip} \cdot \text{ft}$$

$$M_f = 1131.8 \text{ kip} \cdot \text{ft} < M_r \qquad \text{MinReinfChk} = "OK!"$$

$$M_u = 851.0 \text{ kip} \cdot \text{ft} < M_r \qquad \text{UltimateMom} = "OK!"$$

(AASHTO LRFD Eq. 5.6.3.1.2-4)

Depth of Equivalent Stress Block (AASHTO LRFD 5.6.2.2)

Nominal Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.2-1)

Strain in Reinforcing at Ultimate

(AASHTO LRFD 5.6.2.1)

(AASHTO LRFD 5.5.4.2)

Factored Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.1-1)

4.2.9.3 Check Serviceability

To find s_{max}:

Modular Ratio:

$$n = \frac{E_s}{E_c} \qquad \qquad n = 7.12$$

Tension Reinforcement Ratio:

$$\rho = \frac{A_s}{b \cdot d} \qquad \qquad \rho = 0.0013$$
$$k = \sqrt{(2\rho n) + (\rho n)^2} - (\rho n) \qquad \qquad k = 0.127$$

 $d \cdot k = 10.34$ in $< d_{ledge} = 28$ in

Therefore, the compression force acts over a rectangular area.

$$j = 1 - \frac{\kappa}{3}$$
 $j = 0.958$

$$\begin{split} f_{ss} &= \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12 \text{in}}{1 \text{ft}} & f_{ss} &= 9.70 \text{ ksi} \\ f_a &= 0.6 f_y & f_a &= 36.00 \text{ ksi} \\ f_{ss} &< f_a & \text{ServiceStress} = ``OK!`` \\ d_c &= \text{cover} + \frac{1}{2} d_{\text{stirrup}} + \frac{1}{2} d_{\text{bar}_A} & d_c &= 3.58 \text{ in} \end{split}$$

Exposure Condition Factor:

 $\gamma_e = 1.00$

Check allowable M_{dl}:

$$\beta_{s} = 1 + \frac{d_{c}}{0.7(h_{cap} - d_{c})}$$
 $\beta_{s} = 1.06$

For service loads, the stress on the cross-section is located as shown in Figure 4.22.



Figure 4.22 Stresses on the Cross Section for Service Loads of 0 Degree Skewed ITBC

> If the compression force does not act over rectangular area, j will be different.

Service Load Bending Stress in outer layer of the reinforcing.

Allowable Bending Stress (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

For Class 1 Exposure Conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e = 0.75$). (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

| $s_{max} = min\left(rac{700\gamma_e}{\beta_s f_{ss}} - 2d_c, 12in. ight)$ | $s_{max} = 12$ in | (AASHTO LRFD Eq. 5.6.7-1) |
|--|--------------------------|--|
| $s_{Actual} = \frac{b_{stem} - 2d_c}{BarANo - 1}$ | $s_{Actual} = 6.37$ in | A good practice is to place a bar every 12 in along each surface of |
| $s_{Actual} < s_{max}$ | ServiceabilityCheck = "O | DK!" the bent. (TxSP) |
| 4.2.9.4 Check Dead Load | | TxDOT limits dead load stress to |

TxDOT limits dead load stress to 22 ksi, which is set to limit observed cracking under dead load.

Allowable Dead Load Moment

$$M_a = A_s \cdot d \cdot j \cdot f_{dl} \cdot \frac{1 f t}{12 i n} \qquad \qquad M_a = 1338.5 \text{ kip} \cdot f t$$

 $f_{d1} = 22 \text{ ksi}$

 $M_{dl} = 378.5 \text{ kip} \cdot \text{ft} < M_a$ DeadLoadMom = "OK!"

4.2.10 Flexural Reinforcement for Positive Bending (Bars B)

$$\begin{split} M_{dl} &= M_{posDL} & M_{dl} &= 249.2 \text{ kip} \cdot \text{ft} \\ M_s &= M_{posServ} & M_s &= 491.6 \text{ kip} \cdot \text{ft} \\ M_u &= M_{posUlt} & M_u &= 740.6 \text{ kip} \cdot \text{ft} \end{split}$$

4.2.10.1 Minimum Flexural Reinforcement

Factored Flexural Resistance, M_r , must be greater than or equal to the lesser of $1.2M_{cr}$ (Cracking Moment) or $1.33M_u$ (Ultimate Moment).

$$\begin{split} I_g &= 2.86 \times 10^6 \text{ in}^4 & Gross \ \text{Moment of Inertia} \\ y_t &= y \text{bar} & y_t &= 34.3 \text{ in} & Distance \ to \ the \ Center \ of \ Gravity \\ of \ the \ Cap \ from \ the \ top \ of \ the \\ Cap \\ \\ f_r &= 0.24 \sqrt{f_c} & f_r &= 0.537 \text{ ksi} & Modulus \ of \ Rupture \ (BDM-\\ LRFD, \ Ch. \ 4, \ Sect. \ 5, \ Design \\ Criteria \\ Section \ Modulus \ for \ the \ extreme \\ tension \ fiber \\ \\ M_{cr} &= S \cdot f_r \cdot \frac{1ft}{12\text{ in}} & M_{cr} &= 3732.2 \text{ kip} \cdot \text{ft} & Cracking \ Moment \ (AASHTO \\ LRFD \ Eq. \ 5.6.3.3-l) & Design \ the \ lesser \ of \ 1.2M_{cr} \ or \\ 1.33M_u &= 985.0 \text{ kip} \cdot \text{ft} & Distance \ tension \ fiber \\ \end{split}$$

Thus, M_r must be greater than $M_f = 985.0 \text{ kip} \cdot \text{ft}$

4.2.10.2 Moment Capacity Design

а

 $M_u = 740.6 \text{ kip} \cdot \text{ft} < M_r$

Try, $11 \sim #11$'s Bottom Number of bars in tension BarBNo = 11Diameter of main reinforcing $d_{\text{bar B}} = 1.41$ in bars $A_{\text{bar B}} = 1.56 \text{ in}^2$ Area of main reinforcing bars Area of steel in tension $A_s = BarBNo \cdot A_{bar B}$ $A_s = 17.16 \text{ in}^2$ d = 81.42 in $d = d_{s pos}$ $b = b_{stem}$ b = 39 inCompressive Strength of Concrete $f_{c} = 5.0 \text{ ksi}$ Yield Strength of Rebar $f_v = 60 \text{ ksi}$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.85 - 0.05(f_c - 4ksi)$ Bounded by: $0.65 \le \beta_1 \le 0.85$ $\beta_1 = 0.80$ Depth of Cross Section under $c = \frac{A_s f_y}{0.85\ _c\beta_1 b}$ c = 7.76 in Compression under Ultimate Load

(AASHTO LRFD Eq. 5.6.3.1.2-4)

Depth of Equivalent Stress Block

(AASHTO LRFD 5.6.2.2)

1 11

This "c" is the distance from the extreme compression fiber to the neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.

$$= \mathbf{c} \cdot \boldsymbol{\beta}_1$$
 $\mathbf{a} = 6.21 \text{ in}$

Note: "a" is less than "d_{stem}". Therefore the equivalent stress block acts over a rectangular area. If "a" was greater than "dstem", it would act over a Tee shaped area.

$$\begin{split} M_n &= A_s f_y \left(d - \frac{a}{2} \right) \cdot \frac{1 f t}{12 i n} & M_n = 6719.4 \text{ kip} \cdot f t \\ \varepsilon_s &= 0.003 \cdot \frac{d - c}{c} & \varepsilon_s = 0.028 \end{split} \qquad \begin{aligned} & \text{Nominal Flexural Resistance} \\ & (AASHTO LRFD Eq. 5.6.3.2.2-1) \\ & \varepsilon_s &= 0.005 \end{aligned} \qquad \\ & FlexureBehavior = "Tension Controlled" & (AASHTO LRFD 5.6.2.1) \\ & \Phi_M &= 0.90 & (AASHTO LRFD 5.5.4.2) \\ & M_r &= \Phi_M \cdot M_n & M_r &= 6047.5 \text{ kip} \cdot f t & Factored Flexural Resistance} \\ & (AASHTO LRFD Eq. 5.6.3.2.1) \\ & M_r &= 0.90 & (AASHTO LRFD 5.5.4.2) \\ & M_r &= 0.90 & (AASHTO LRFD 5.5.4.2) \\ & M_r &= 0.90 & (AASHTO LRFD Eq. 5.6.3.2.1-1) \\ & M_f &= 985.0 \text{ kip} \cdot f t < M_r & MinReinfChk = "OK!" \end{aligned}$$

UltimateMom = "OK!"

4.2.10.3 Check Serviceability

To find s_{max}:

k

Modular Ratio:

$$n = \frac{E_s}{E_c} \qquad \qquad n = 7.12$$

Tension Reinforcement Ratio:

$$\begin{split} \rho &= \frac{A_s}{b \cdot d} & \rho &= 0.0054 \\ &= \sqrt{(2\rho n) + (\rho n)^2} - (\rho n) & k &= 0.242 \end{split}$$

 $d \cdot k = 19.70$ in $< d_{stem} = 57.00$ in Therefore, the compression force acts over a rectangular area.

$$j = 1 - \frac{k}{3}$$
 $j = 0.919$

$$f_{ss} = \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12in}{1ft} \qquad \qquad f_{ss} = 4.59 \text{ ksi}$$

$$f_{a} = 0.6f_{y} \qquad f_{a} = 36.00 \text{ ksi}$$

$$f_{ss} < f_{a} \qquad \text{ServiceStress} = "OK"$$

$$d_c = cover + \frac{1}{2}d_{stirrup} + \frac{1}{2}d_{bar_B}$$
 $d_c = 3.58 in$

Exposure Condition Factor:

$$\begin{split} \gamma_e &= 1.00 \\ \beta_s &= 1 + \frac{d_c}{0.7(h_{cap} - d_c)} \end{split} \qquad \qquad \beta_s = 1.06 \end{split}$$

$$s_{max} = min\left(\frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c, 12in.\right)$$
 $s_{max} = 12 in$

Try: BarBInsideSNo = 5 $s_{Actual} = \frac{b_{stem} - 2\left(cover + \frac{1}{2}d_{bar_{_}S} + \frac{1}{2}d_{bar_{_}B}\right)}{BarBInsideSNo-}$

 $s_{Actual} < s_{max}$

For service loads, the stress on the cross-section is located as shown in Figure 4.23.



Figure 4.23 Stresses on the Cross Section for Bars B for Service Loads of 0 Degree Skewed ITBC

> If the compression force does not act over rectangular area, j will be different.

Service Load Bending Stress in outer layer of the reinforcing.

Allowable Bending Stress (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

"cover" is measured to center of shear reinforcement.

For Class 1 Exposure Conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e = 0.75$). (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

(AASHTO LRFD Eq. 5.6.7-1)

A good practice is to place a bar every 12 in along each surface of the bent. (TxSP)

Number of Bars B that are inside Stirrup Bar S.

 $s_{Actual} = 7.96$ in

ServiceabilityCheck = "OK

Bars Outside Stirrup Bar S

BarBOutsideSNo = 11 - BarBInsideSNo

BarBOutsideSNo = 6

 $s_{Actual} = \frac{2b_{ledge} + 2\left(cove \quad \frac{1}{2}d_{bar_S} + \frac{1}{2}d_{bar_B} - cove \quad \frac{1}{2}d_{bar_M} - \frac{1}{2}d_{bar_B}\right)}{BarBOutsideSNo}$

 $s_{Actual} = 8.0$ in $< s_{max}$

ServiceabilityCheck = "OK

Stirrup Bar S.

4.2.10.4 Check Dead Load

Check allowable M_{dl} : $f_{dl} = 22 \text{ ksi}$

TxDOT limits dead load stress to 22 ksi. This is due to observed cracking under dead load. Allowable Dead Load Moment

Number of Bars B that are inside

| $M_{a} = A_{s} \cdot d \cdot j \cdot f_{dl} \cdot \frac{1ft}{12in}$ | $M_a = 2354.00 \text{ kip} \cdot \text{ft}$ | |
|---|---|--|
| $M_{dl} = 249.2 \text{ kip} \cdot \text{ft} < M_a$ | DeadLoadMom = "OK!" | |

Flexural Steel Summary:

Use 6 ~ # 11 Bars on Top & 11 ~ # 11 Bars on Bottom

4.2.11 Ledge Reinforcement (Bars M & N)

Try Bars M and Bars N at a 4.90" spacing.

$$s_{bar_M} = 4.90$$
 in
 $s_{bar_N} = 4.90$ in

Use trial and error to determine the spacing needed for the ledge reinforcing.

It is typical for Bars M & N to be paired together.

4.2.11.1 Determine Distribution Widths

These distribution widths will be used on the following pages to determine the required ledge reinforcement per foot of cap.

| Distribution Width for Shear (AASHTO LRFD 5.8.4.3.2) | Note: These are the same | |
|--|-------------------------------------|--|
| Interior Girders | distribution widths used for the | |
| $b_{s_{Int}} = min(W + 4a_v, S)$ $b_{s_{Int}} = 69.00 in$ | "S" is the girder spacing. | |
| Exterior Girders | "c" is the distance from the center | |
| $b_{s_Ext} = min(W + 4a_v, 2c, S)$ | of bearing of the outside beam to | |
| $b_{s_{Ext}} = 48.00$ in | the end of the ledge. | |
| | | |

Distribution Width for Bending and Axial Loads (AASHTO LRFD 5.8.4.3.3)

Interior Girders

 $b_{m_{Int}} = min(W + 5a_f, S)$ $b_{m Int} = 93.50 in$

Exterior Girders

 $b_{m_Ext} = min(W + 5a_f, 2c, S)$ $b_{m_Ext} = 48.00 in$

| <u>Minimum Reinforcing</u> (AASHTO LRFD Eq. 5.7.4.2-1) | For clarity, the cohesion factor is labeled " c_1 ". This is to prevent confusion with "c", the distance from the last girder to the edge of the cap. c_1 is 0ksi for corbels and ledges. (AASHTO LRFD 5.7.4.4) |
|---|--|
| $A_{vf_min} = \frac{0.05 \text{ ksi} \cdot A_{cv}}{f_y}$ $A_{cv} = d_e \cdot b_s \text{and} \qquad a_{vf} = \frac{A_{vf}}{b_s}$ | "P _c " is zero as there is no axial compression. |
| $a_{vf_min} = \frac{0.05ksi \cdot d_e}{f_y} \qquad \qquad a_{vf_min} = 0.2$ | 26 ^{in²} / _{ft} Minimum Reinforcing required for Shear Friction |
| Interior Girders | |
| $A_{cv} = d_e \cdot b_{s_Int} \qquad \qquad A_{cv} = 1759$ | in ² |
| $V_{u_Int} = 322 \text{ kip}$ | From "4.2.4.4 Load Summaryry". |
| $V_{n} = c_{1}A_{cv} + \mu(A_{vf}f_{y} + P_{c})$ | (AASHTO LRFD Eq. 5.7.4.3-3) |
| $\begin{split} \varphi V_n &\geq V_u \\ \varphi \cdot \left[c_1 A_{cv} + \mu \left(A_{vf} f_y + P_c \right) \right] \geq V_u \end{split}$ | (AASHTO LRFD Eq. 5.7.4.3-1 & AASHTO LRFD Eq. 5.7.4.3-2) |
| $A_{vf} = \frac{\frac{V_{u_Int} - c_1 A_{cv}}{\Phi} - P_c}{\frac{\mu}{f_y}} \qquad A_{vf} = 4.26 \text{ in}$ | n ² Required Reinforcing for Shear Friction |
| $a_{vf_Int} = \frac{A_{vf}}{b_{s_Int}} \qquad a_{vf_Int} = 0.74$ | $4\frac{in^{2}}{ft} Required Reinforcing for Shear Friction per foot length of cap$ |

AASHTO LRFD 5.7.4.1

(AASHTO LRFD 5.5.4)

"µ" is 1.4 for monolithically placed concrete. (AASHTO LRFD

4.2.11.2 Reinforcing Required for Shear Friction

 $c_1 = 0$ ksi $P_c = 0$ kip

 $\phi = 0.90$

 $\mu = 1.4$

Exterior Girders

4.2.11.3

Exterior Girders

| $V_{u_Ext} = 322 \text{ kip}$ | | From "4.2.4.4 Load Summary". |
|--|--|-------------------------------|
| $N_{uc_Ext} = 0.2 \cdot V_{u_Ext}$ | $N_{uc_Ext} = 64.4 \text{ kip}$ | (AASHTO LRFD 5.8.4.2.1) |
| $M_{u_Ext} = V_{u_Ext} \cdot a_v + N_{uc_Ext}(h - d_e)$ | $M_{u_Ext} = 343.5 \text{ kip} \cdot \text{ft}$ | (AASHTO LRFD Eq. 5.8.4.2.1-1) |
| Use the following equations to solve for | : A _f : | |

 $\Phi M_n \geq M_{u_Ext}$ (AASHTO LRFD Eq. 1.3.2.1-1) $M_{n} = A_{f}f_{y}\left(d_{e} - \frac{a}{2}\right)$ (AASHTO LRFD Eq. 5.6.3.2.2-1) $c = \frac{A_f f_y}{\alpha_1 f_c \beta_1 b_{m Ext}}$ (AASHTO LRFD Eq. 5.6.3.1.2-4) $\alpha_1 = 0.85$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.80$ $a = c\beta_1$ $0.75 \le \Phi = 0.65 + 0.15 \left(\frac{d_e}{c} - 1\right) \le 0.90$ (AASHTO LRFD 5.5.4.2) $A_{f} = 3.05 \text{ in}^{2}$ Solve for A_f: Required Reinforcing for Flexure $a_{f_Ext} = 0.76 \frac{in^2}{ft}$ $a_{f_Ext} = \frac{A_f}{b_m Ext}$ Required Reinforcing for Flexure per foot length of cap

4.2.11.4 Reinforcing Required for Axial Tension

 $\Phi = 0.90$

Interior Girders:

$$\begin{split} N_{uc_Int} &= 0.2 V_{u_Int} & N_{uc_Int} &= 64.4 \text{ kip} \\ A_n &= \frac{N_{uc_Int}}{\Phi f_y} & A_n &= 1.19 \text{ in}^2 & Required Reinforcing for Axial Tension} \\ a_{n_Int} &= \frac{A_n}{b_{m_Int}} & a_{n_Int} &= 0.15 \frac{\text{in}^2}{\text{ft}} & Required Reinforcing for Axial Tension per foot length of cap} \end{split}$$

Exterior Girders:

$$\begin{split} N_{uc_Ext} &= 0.2 V_{u_Int} \\ A_n &= \frac{N_{uc_Ext}}{\Phi f_y} \\ a_{n_Ext} &= \frac{A_n}{b_{m_Ext}} \end{split}$$

 $N_{uc_{Ext}} = 64.4 \text{ kip}$

 $A_n = 1.19 \text{ in}^2$ Required Reinforcing for Axial Tension

(AASHTO LRFD 5.8.4.2.2)

AASHTO LRFD 5.5.4.2

 $a_{n_Ext} = 0.30 \frac{in^2}{ft}$ Required Reinforcing for Axial Tension per foot length of cap (AASHTO LRFD 5.8.4.2.1)

4.2.11.5 Minimum Reinforcing

$$a_{s_min} = 0.04 \frac{f_c}{f_y} d_e$$
 $a_{s_min} = 1.02 \frac{in^2}{ft}$ Minimum Required Reinforcing

4.2.11.6 Check Required Reinforcing

Actual Reinforcing:

$$a_{s} = \frac{A_{bar_{M}}}{s_{bar_{M}}} \qquad a_{s} = 1.08 \frac{in^{2}}{ft} \qquad Primary Ledge Reinforcing Provided$$
$$a_{h} = \frac{A_{bar_{N}}}{s_{bar_{N}}} \qquad a_{h} = 1.08 \frac{in^{2}}{ft} \qquad Auxiliary Ledge Reinforcing Provided$$

BarMCheck = "OK!"

<u>Checks:</u> $A_s \ge A_{s_min}$

$$A_{s} \ge A_{f} + A_{n}$$
$$A_{s} \ge \frac{2A_{vf}}{3} + A_{n}$$

$$A_h \ge 0.5(A_s - A_n)$$

Check if:

Check Interior Girders:

Bar M:

 $a_s \ge a_{s_min}$ $a_s \ge a_{f_Int} + a_{n_Int}$

 $a_{f_{Int}} + a_{n_{Int}} = 0.54 \frac{in^2}{ft} < a_s$

 $\frac{2a_{vf_{-}Int}}{3} + a_{n_{-}Int} = 0.64 \frac{in^2}{ft} < a_s$

$$a_{s} \ge \frac{2a_{vf_Int}}{3} + a_{n_Int}$$
$$a_{s} = 1.26 \frac{in^{2}}{ft}$$
$$a_{s_min} = 1.02 \frac{in^{2}}{ft} < a_{s}$$

 Primary Ledge Reinforcing Provided
 Auxiliary Ledge Reinforcing Provided (AASHTO LRFD 5.8.4.2.1)
 (AASHTO LRFD 5.8.4.2.2)
 (AASHTO LRFD Eq. 5.8.4.2.2-5)
 (AASHTO LRFD Eq. 5.8.4.2.2-6)

| (AASHTO LRFD 5.8.4.2.1) |
|-------------------------------|
| (AASHTO LRFD 5.8.4.2.2) |
| (AASHTO LRFD Eq. 5.8.4.2.2-5) |

Bar N:

$$a_{h} \ge 0.5 \cdot (a_{s} - a_{n_Int})$$
$$a_{s} = The \text{ maximum of:}$$
$$a_{f_Int} + a_{n_Int}$$
$$\frac{2a_{vf_Int}}{3} + a_{n_Int}$$

$$a_s = 0.64 \frac{in^2}{ft}$$

Check if:

(AASHTO LRFD Eq. 5.8.4.2.2-6)

" a_s " in this equation is the steel required for Bar M, based on the requirements for Bar M in AASHTO LRFD 5.8.4.2.2. This is derived from the suggestion that Ah should not be less than $A_{p/2}$ nor less than $A_{vp/3}$ (Furlong & Mirza pg. 73 & 74)

$$0.5 \cdot (a_s - a_{n_Int}) = 0.25 \frac{in^2}{ft} < a_h$$

BarNCheck = "OK!"

Check Exterior Girders:

Bar M:

Check if:

$$a_{s} \ge a_{s_min}$$

$$a_{s} \ge a_{f_Ext} + a_{n_Ext}$$

$$a_{s} \ge \frac{2a_{vf_Ext}}{3} + a_{n_Ext}$$

$$a_{s} = 1.26 \frac{in^{2}}{ft}$$

 $a_{s_min} = 1.02 \frac{in^2}{ft} < a_s$

 $a_{f_Ext} + a_{n_Ext} = 1.06 \frac{in^2}{ft} \ < \ a_s$

 $\frac{2a_{vf_Ext}}{3} + a_{n_Ext} = 1.01 \frac{in^2}{ft} < a_s$

LRFD Eq. 5.8.4.2.2-6)

& Mirza pg. 73 & 74)

BarMCheck = "OK!"

Bar N:

Check if:

$$a_{h} \ge 0.5 \cdot (a_{s} - a_{n_Ext}) \qquad (AASHTO LRFD Eq. 5.8.4.2.2-6)$$

$$a_{s} = \text{The maximum of:} \qquad "a_{s}" \text{ in this equation is the steel required}$$

$$a_{f_Ext} + a_{n_Ext} \qquad for Bar M, based on the requirements for$$

$$\frac{2a_{vf_Ext}}{3} + a_{n_Ext} \qquad is derived from the suggestion that Ah$$

$$a_{s} = 1.06 \frac{\text{in}^{2}}{\text{ft}} \qquad A_{vf}/3 (Furlong \& Mirza pg. 73 \& 74)$$

$$0.5 \cdot (a_{s} - a_{n_Ext}) = 0.38 \frac{\text{in}^{2}}{\text{ft}} < a_{h}$$
BarNCheck = "OK I"

Ledge Reinforcement Summary:

Use # 6 primary ledge reinforcing @ 4.90" maximum spacing & # 6 auxiliary ledge reinforcing @ 4.90" maximum spacing

4.2.12 Hanger Reinforcement (Bars S)

Try Double # 6 Stirrups at a 7.80" spacing.

 $s_{bar S} = 7.80$ in

Use trial and error to determine the spacing needed for the hanger reinforcing.

| $A_{hr} = 2 stirrups \cdot A_{bar_S}$ | $A_{\rm hr}=0.88{\rm in^2}$ |
|---------------------------------------|-----------------------------|
| $A_v = 2 legs \cdot A_{hr}$ | $A_v = 1.76 \text{ in}^2$ |

4.2.12.1 Check Minimum Transverse Reinforcement

| $b_v = b_{stem}$ | $b_v = 39$ in | |
|--|---------------|-----------------------------|
| $A_{v_{min}} = 0.0316\lambda \sqrt{f_c} \frac{b_v \cdot s_{bar_s}}{f_v}$ | | (AASHTO LRFD Eq. 5.7.2.5-1) |

 $\lambda = 1.0$ for normal weight concrete

 $A_v > A_{v \min}$

4.2.12.2 Check Service Limit State

(AASHTO LRFD 5.4.2.8)

 $A_{v min} = 0.36 in^2$

MinimumSteelCheck = "OK!"

AASHTO LRFD 5.8.4.3.5 with notifications from BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

Interior Girders

Vall

= minimum or:

$$\frac{A_{hr} \cdot \left(\frac{2}{3} f_{y}\right)}{\sum_{k=0}^{k} c_{k}} \cdot (W + 3a_{v}) = 217 \text{ kip}$$

s_{bar} s

(a)

TxDOT uses "2/3 f_v " from the original research (Furlong & Mirza Eq. 5.4) instead of "0.5 f_v " from AASHTO LRFD Eq. 5.8.4.3.5-1. (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)

Bounded by: $(W + 3a_v) \le \min(S, 2c)$

$$\frac{A_{hr} \cdot \left(\frac{2}{3} f_{y}\right)}{s_{bar_{s}}} \cdot S = 433 \text{ kip}$$

(BDM-LRFD Ch.4, Sect. 5, Design Criteria modified to limit the distribution width to the girder spacing. This will prevent distribution widths from overlapping)

$$V_{all} = 217 \text{ kip}$$

 $V_{s_{Int}} = 215 \text{ kip} < V_{all}$ ServiceCheck = "OK!"

Exterior Girders

 $V_{all} = minimum of:$

Vall for the Interior Girder

$$\frac{A_{hr} \cdot \left(\frac{2}{3} f_{y}\right)}{s_{bar_{-}S}} \cdot \left(\frac{W + 3a_{v}}{2} + c\right) = 217 \text{ kip}$$

Bounded by: $(W + 3a_v) \le \min(S, 2c)$

$$\frac{A_{hr} \cdot \left(\frac{2}{3} f_y\right)}{s_{bar_S}} \cdot \left(\frac{S}{2} + c\right) = 325 \text{ kip}$$

$$V_{all} = 217 \text{ kip}$$

 $V_{s \text{ Ext}} = 215 \text{ kip} < V_{all}$

 $\Phi = 0.90$

Interior Girders:

TxDOT uses "2/3 f_{y} " from the original research (Furlong & Mirza Eq. 5.4) instead of "0.5 f_{v} " from AASHTO LRFD Eq. 5.8.4.3.5-1. (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)

(BDM-LRFD Ch.4, Sect. 5, Design Criteria Modified to limit the distribution width to half the girder spacing and the distance to the edge of the cap. This will prevent distribution widths from overlapping or extending over the edge of the cap.)

ServiceCheck = "OK!"

(AASHTO LRFD 5.8.4.3.5)

 $\frac{A_{hr} \cdot f_y}{s_{har} s} \cdot S = 650 \text{ kip}$ (AASHTO LRFD Eq. 5.8.4.3.5-2) (AASHTO LRFD Eq. 5.8.4.3.5-3) $(0.063\sqrt{f_c} \cdot b_f \cdot d_f) + \frac{A_{hr} \cdot f_y}{S_{hrr} \cdot s}(W + 2d_f) = 772 \text{kip}$

UltimateCheck = "OK!"

Exterior Girders:

 $V_n = minimum of:$

 $\Phi V_n = 438 \text{ kip}$

 $V_{\text{u Int}} = 322 \text{ kip } < \Phi V_{\text{n}}$

 $V_n = minimum of:$

 $V_n = 650 \text{ kip}$

 $\Phi V_n = 585 \text{ kip}$

V_n for the Interior Girder $\frac{A_{hr} \cdot f_y}{s_{har} s} \cdot \left(\frac{s}{2} + c\right) = 487 \text{ kip}$ (AASHTO LRFD Eq. 5.8.4.3.5-2) $\left(0.063\sqrt{f_{c}} \cdot b_{f} \cdot d_{f}\right) + \frac{A_{hr} \cdot f_{y}}{s_{hars}} \left(\frac{W+2d_{f}}{2} + c\right) = 698 \text{ kip } (AASHTO LRFD Eq. 5.8.4.3.5-3)$ $V_n = 487 \text{ kip}$

(These equations are modified to limit the distribution width to the *edge of the cap)*

$$V_{u_{Ext}} = 322 \text{ kip } < \Phi V_n$$

UltimateCheck = "OK!"

4.2.12.4 Check Combined Shear and Torsion

The following calculations are for Station 36. All critical locations must be checked. See the Concrete Section Shear Capacity spreadsheet in the appendices for calculations at other locations. Shear and Moment were calculated using the CAP 18 program.

 $M_u = 334.5 \text{ kip} \cdot \text{ft}$ $V_u = 447.4 \text{ kip}$ $N_u = 0 \text{ kip}$ $T_u = 660 \text{ kip} \cdot \text{ft}$ Recall: $\beta_1 = 0.80$ $f_v = 60 \text{ ksi}$ $f_c = 5.0 \text{ ksi}$ $E_{s} = 29000 \text{ ksi}$ $h_{cap} = 85$ in $b_{stem} = 39$ in $b_f = 87$ in h = 29.50 in $b_{v} = 39$ in $b_v = b_{stem}$ Find d_v: (AASHTO LRFD 5.7.2.8) $A_{s} = 9.36 \text{ in}^{2}$ $A_s = A_{\text{bar }A} \cdot \text{BarANo}$ Shears are maximum near the $c = \frac{A_s f_y}{0.85 f_c \beta_1 b_f}$ column faces. In these regions the c = 1.90 in cap is in negative bending with tension in the top of the cap. $a = c \cdot \beta_1$ a = 1.52 in Therefore, the calculations are based $d_s = d_{s neg}$ $d_s = 81.42$ in on the steel in the top of the bent cap. $M_n = A_s f_v \left(d_s - \frac{a}{2} \right)$ $M_n = 3774.9 \text{ kip} \cdot \text{ft}$ $A_{ns} = 0 \text{ in}^2$ $d_e = \frac{A_{ps}f_{ps}d_p + A_sf_yd_s}{A_{ps}f_{ps} + A_sf_y}$ $d_e = 81.42$ in (AASHTO LRFD Eq. 5.7.2.8-2) $d_v = maximum of:$ $\frac{M_n}{A_s f_v + A_{ns} f_{ns}} = 80.66 \text{ in}$ $0.9d_e = 73.28$ in 0.72h = 21.24 in $d_v = 80.66$ in

The method for calculating θ and β used in this design example are from AASHTO LRFD Appendix B5. The method from AASHTO LRFD 5.7.3.4.2 may be used instead. The method from 5.7.3.4.2 is based on the method from Appendix B5; however, it is less accurate and more conservative (often excessively conservative). The method from Appendix B5 is preferred because it is more accurate, but it requires iterating to a solution.

Determine θ and β :

$$\Phi_{V} = 0.90$$

$$v_{u} = \frac{|v_{u} - (\Phi_{V} \cdot V_{p})|}{\Phi_{V} \cdot b_{v} \cdot d_{v}}$$

$$v_{u} = 0.16 \text{ ksi}$$

$$\frac{v_{u}}{f_{c}} = 0.03$$

Using Table B5.2-1 with $\frac{v_u}{f_c} = 0.03$ and $\varepsilon_x = 0.001$ $\theta = 36.4 \text{ deg}$ and $\beta = 2.23$

$$\varepsilon_{x} = \frac{\frac{|M_{u}|}{d_{v}} + 0.5N_{u} + 0.5|V_{u} - V_{p}|cot\theta - A_{ps}f_{po}}{2(E_{s}A_{s} + E_{p}A_{ps})}$$

where $|M_{u}| = 334.5$ kip · ft must be $> |V_{u} - V_{p}|d_{v} = 3012.12$ kip · ft

$$\epsilon_x = 1.38 \times 10^{-3} > 1.00 \times 10^{-3}$$

use $\epsilon_x = 1.00 \times 10^{-3}$.

 $V_p = 0 \text{ kip}$

 $A_{c} = b_{stem} \cdot \frac{h_{cap}}{2}$ $s = s_{bar S}$

(AASHTO LRFD Eq. 5.5.4.2)

Shear Stress on the Concrete (AASHTO LRFD Eq. 5.7.2.8-1)

Determining θ and β is an iterative process, therefore, assume initial shear strain value ε_x of 0.001 per LRFD B5.2 and then verify that the assumption was valid.

Strain halfway between the compressive and tensile resultants (AASHTO LRFD Eq. B5.2-3) If $\varepsilon_x < 0$, then use equation B5.2-5 and re-solve for ε_x .

For values of ε_x greater than 0.001, the tensile strain in the reinforcing, ε_t is greater than 0.002. ($\varepsilon_t = 2\varepsilon_x - \varepsilon_c$, where ε_c is < 0) Grade 60 steel yields at a strain of 60 ksi / 29,000 ksi = 0.002. By limiting the tensile strain in the steel to the yield strain and using the Modulus of Elasticity of the steel prior to yield, this limits the tensile stress of the steel to the yield stress.

"V_p" is zero as there is no prestressing.

 $\begin{aligned} A_c &= 1657.5 \text{ in}^2 & (AASHTO LRFD B5.2) "A_c" \text{ is the} \\ area of concrete on the flexural } \\ s &= 7.80 \text{ in} & tension side of the cap, from the} \\ extreme tension fiber to one half \\ the cap depth. \\ & "A_c" \text{ is needed if } AASHTO LRFD } \end{aligned}$

" A_c " is needed if AASHTO LRFL Eq. B5.2-3 is negative.



The transverse reinforcement, " A_v ", is double closed stirrups. The failure surface intersects four stirrup legs, therefore the area of the shear steel is four times the stirrup bar's area (0.44in2). See the sketch of the failure plane to the left.

Figure 4.24 Failure Surface of 0 Degree Skewed ITBC for Combined Shear and Torsion

$$\begin{split} A_v &= 2 \text{legs} \cdot 2 \text{stirrups} \cdot A_{\text{bar}_S} & A_v &= 1.76 \text{ in}^2 \\ A_t &= 1 \text{leg} \cdot A_{\text{bar}_S} & A_t &= 0.44 \text{ in}^2 \\ A_{\text{oh}} &= (d_{\text{stem}}) \cdot (b_{\text{stem}} - 2 \text{cover}) + (d_{\text{ledge}} - 2 \text{cover}) \cdot (b_f - 2 \text{cover}) \\ & A_{\text{oh}} &= 3496 \text{ in}^2 \\ A_0 &= 0.85A_{\text{oh}} & A_0 &= 2971.6 \text{in}^2 \\ p_h &= (b_{\text{stem}} - 2 \text{cover}) + 2(b_{\text{ledge}}) + (b_f - 2 \text{cover}) + 2(h_{\text{cap}} - 2 \text{cover}) \\ & p_h &= 324 \text{ in} \end{split}$$

Equivalent Shear Force

$$V_{u_{Eq}} = \sqrt{V_{u}^{2} + \left(\frac{0.9p_{h}T_{u}}{2A_{0}}\right)^{2}} \qquad V_{u_{Eq}} = 592.6 \text{ kip } (AASHTO LRFD Eq. B.5.2-1)$$

Shear Steel Required

 V_n = the lesser of:

$$V_c + V_s + V_p$$
(AASHTO LRFD Eq. 5.7.3.3-1) $0.25 \cdot f_c \cdot b_v \cdot d_v + V_p$ (AASHTO LRFD Eq. 5.7.3.3-2)

Check maximum ΦV_n for section:

 $\Phi V_{n_{max}} = \Phi \cdot \left(0.25 \cdot f_{c} \cdot b_{v} \cdot d_{v} + V_{p} \right)$

$$\Phi V_{n_{max}} = 3539 \text{ kip}$$

$$V_u = 447.4 \text{ kip} < \Phi V_{n_max}$$
 MaxShearCheck = "OK!"

Calculate required shear steel:

$$V_{u} < \Phi V_{n}$$

$$V_{c} = 0.0316 \cdot \beta \cdot \sqrt{f_{c}} \cdot b_{v} \cdot d_{v}$$

$$V_{u} < \Phi_{V} \cdot (V_{c} + V_{s} + V_{p})$$

$$V_{s} = \frac{A_{v} \cdot f_{y} \cdot d_{v} \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha}{s_{req}}$$

$$a_{v_{r}req} = \frac{\frac{V_{u}}{\Phi_{V}} - V_{c} - V_{p}}{f_{v} \cdot d_{v} \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha}$$

(AASHTO LRFD Eq. 1.3.2.1-1) V_c = 496 kip (AASHTO LRFD Eq. 5.7.3.3-3)

$$a_{v_req} = 0.002 \frac{\mathrm{in}^2}{\mathrm{ft}}$$

The transverse reinforcement is

$$a_{t_req} = 0.22 \frac{in^2}{ft}$$

Total Required Transverse Steel

 $T_n = \frac{2A_oA_tf_y cot\theta}{s_{bar_S}}$

 $a_{t_req} = \frac{T_u}{\Phi_T 2 A_o f_y cot \theta}$

Torsional Steel Required

 $\Phi_{\rm T} = 0.9$

 $T_u \leq \Phi_T T_n$

$$\begin{array}{ll} a_{req} = a_{v_req} + 2sides \cdot a_{t_req} & a_{req} = 0.44 \ \frac{in^2}{ft} & designed for the side of the section \\ a_{prov} = \frac{A_v}{s_{bar_S}} & a_{prov} = 2.71 \frac{in^2}{ft} & designed for the side of the section \\ a_{prov} = 2.71 \frac{in^2}{ft} & designed for the side of the section \\ designed for the section \\ designed for the side of the section \\ designed for the side of the section \\ designed for the section$$

Longitudinal Reinforcement

$$\begin{split} A_{ps}f_{ps} + A_{s}f_{y} &\geq \frac{|M_{u}|}{\Phi d_{v}} + \frac{0.5N_{u}}{\Phi} + \cdots \\ & cot\Theta \sqrt{\left(\left|\frac{V_{u}}{\Phi} - V_{p}\right| - 0.5V_{s}\right)^{2} + \left(\frac{0.45 \ h}{2A_{0}\Phi}\right)^{2}} \\ V_{s} &= a_{t_req} \cdot f_{y} \cdot d_{v} \cdot (cot\Theta + cot\alpha) \cdot sin\alpha \end{split} \qquad (AASHTO LRFD Eq. 5.7.3.3-4) \end{split}$$

Bounded By:
$$V_s < \frac{V_u}{\Phi_V}$$

 $V_s = 497.1 \text{ kip}$ (AASHTO LRFD Eq. 5.7.3.5-1)

$$\frac{|M_u|}{\Phi_f d_v} + \frac{0.5N_u}{\Phi_c} + \cot\theta \sqrt{\left(\left|\frac{V_u}{\Phi_V} - V_p\right| - 0.5V_s\right)^2 + \left(\frac{0.45 \text{ }_h T_u}{2A_0 \Phi_T}\right)^2} = 502 \text{ kip}$$

Provided Force:

$$A_s f_y = 561.6 \text{ kip} > 502 \text{ kip}$$
 Longitu

LongitudinalReinfChk = "OK!"

| 4.2.12.5 Maximum Spacing of Transverse Reinforcement | | (AASHTO LRFD 5.7.2.6) |
|---|----------------------|-----------------------------|
| Shear Stress | | |
| $v_u = \frac{ v_u - \Phi_V v_p }{\Phi_V b_v d_v}$ | $v_u = 0.158$ ksi | (AASHTO LRFD Eq. 5.7.2.8-1) |
| $0.125 \cdot f_c = 0.625 \text{ ksi}$ | | |
| If $v_u < 0.125 \cdot f_c$ | | (AASHTO LRFD Eq. 5.7.2.6-1) |
| $s_{max} = min(0.8d_v, 24in)$ | | |
| If $v_u \ge 0.125 \cdot f_c$ | | (AASHTO LRFD Eq. 5.7.2.6-2) |
| $s_{max} = min(0.4d_v, 12in)$ | | |
| Since $v_u < 0.125 \cdot f_c$ | $s_{max} = 24.00$ in | |
| TxDOT limits the maximum transverse reinforcement sp | pacing to 12". | (BDM-LRFD, Ch. 4, Sect. 5, |
| $s_{max} = 12.00$ in | | Detailing) |
| $s_{\text{bar}_S} = 7.80 \text{ in } < s_{\text{max}}$ | SpacingCheck= "C | <mark>K!"</mark> |

Hanger Reinforcement Summary:

Use double # 6 stirrups @ 7.80" maximum spacing

4.2.13 End Reinforcements (Bars U1, U2, U3, and G)

Extra vertical, horizontal, and diagonal reinforcing at the end surfaces is provided to reduce the maximum crack widths. According to the parametric analysis, it is recommended to place #6 U1 Bars, U2 Bars, and U3 Bars at the end faces and #7 G Bars at approximately 6in. spacing at the first 30" to 35" of the end of bent cap. U1 Bars are the vertical end reinforcements, U2 Bars and U3 Bars are the horizontal end reinforcements at the stem and the ledge, respectively. G Bars are the diagonal end reinforcement.



Figure 4.25 End Face Section View of 0 Degree ITBC



Figure 4.26 End Face Elevation View of 0 Degree ITBC

4.2.14 Skin Reinforcement (Bars T)

Try 7 ~ # 6 bars in Stem and 3 ~ # 6 bars in Ledge on each side



Figure 4.27 Section View for T Bars of 0 Degree Skewed ITBC

4.2.14.1 Required Area of Skin Reinforcement

(AASHTO LRFD 5.6.7)

 $A_{sk_Req} = 0.62 \frac{in^2}{ft}$ (AASHTO LRFD Eq. 5.6.7-3)

 $A_{sk_Req} = 0.012 \cdot (d - 30)$

 A_{sk} need not be greater than one quarter of the main reinforcing ($A_s/4$)per side face within d/2 of the main reinforcing. (AASHTO LRFD 5.6.7)

"d" is the distance from the extreme compression fiber to the centroid of the extreme tension steel element. In this example design, $d = d_{s_pos} = d_{s_neg} = 81.42$ in.

$$A_{sk_max} = max \left(\frac{\frac{A_{bar_A} \cdot BarANo}{4}}{\frac{d_{s_neg}}{2}}, \frac{\frac{A_{bar_B} \cdot BarBNo}{4}}{\frac{d_{s_pos}}{2}}\right)$$
$$A_{sk_max} = 1.26 \frac{in^2}{ft}$$
$$A_{skReq} = min(A_{sk_Req}, A_{sk_max})$$
$$A_{skReq} = 0.62 \frac{in^2}{ft}$$

4.2.14.2 Required Spacing of Skin Reinforcement

 $s_{req} = minimum of:$

$$\frac{A_{bar_T}}{A_{skReq}} = 8.52 \text{ in}$$

(AASHTO LRFD 5.6.7)

$$\frac{d_{s_neg}}{6} = 13.57 \text{ in}$$

 $\frac{d_{s_pos}}{6} = 13.57 \text{ in}$
& 12 in

 $s_{req} = 8.52$ in

4.2.14.3 Actual Spacing of Skin Reinforcement

Check T Bars spacing in Stem:

$$\begin{split} h_{top} &= d_{stem} - \left(cover + \frac{d_{bar_S}}{2} + \frac{d_{bar_A}}{2} \right) + \left(cover + \frac{d_{bar_M}}{2} + \frac{d_{bar_T}}{2} \right) \\ h_{top} &= 56.67 \text{ in} \end{split}$$

$$s_{skStem} = \frac{h_{top}}{NoTBarsStem+1}$$

$$s_{skStem} = 7.08 in$$

< Sreq

Check T Bars spacing in Ledge:

$$\begin{split} h_{bot} &= d_{ledge} - \left(cover + \frac{d_{bar_M}}{2} + \frac{d_{bar_T}}{2} \right) - \left(cover + \frac{d_{bar_S}}{2} + \frac{d_{bar_B}}{2} \right) \\ h_{bot} &= 21.17 \text{ in} \\ s_{skLedge} &= \frac{h_{bot} - a}{NoTBarsLedge -} \end{split}$$

$$s_{skLedge} < s_{req}$$
 $s_{kLedge} = 7.59 \text{ in}$
SkinSpacing = "OK!"

Check if "a" is less than s_{req}

$$a = 6 in < s_{req}$$

SkinSpacing = "OK!"

Skin Reinforcement Summary:

Use $7 \sim #6$ bars in Stem and $3 \sim #6$ bars in Ledge on each side

4.2.15 Design Details and Drawings

4.2.15.1 Bridge Layout



4.2.15.2 <u>CAP 18 Input File</u>

 \$File
 Proj
 User
 Date (Today

 \$ Num
 County
 Highway
 Num
 CSJ
 Init
 if Blank)
 Comment

 \$xxxx
 xxxxxxxxxxxxx
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 00001

 Highwy
 Pro#
 0000-00-000
 BRG
 Comment

 \$Header
 Card 2

 Comment
 CAP18 Version 6.00 ITBC Design Example 1, Skew = 0.00 \$Problem Card -----1 E 0 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay) STABLE 1 - CONTROL DATA -----Enter 1 to keep: Number cards Options: Env Tab2 Tab3 Tab4 on Table 4 Envelope Pt Ŝ Env Tab2 Tab3 Tab4 Env Tab2 Tab3 Tab4 on Table 4 Envelope Print Skew Angle X X X X X XX XX XXXXXXXXXX 16 0.0 Ś ŝ 16 0.0 STABLE 2 - CONSTANTS -----Anly Opt (1=Working, |-Movable Load Data--| 2=Load Factor,3=Both) TABLE 2a Num Increment |Num Start Stop Step|Anly| Load Factors: Ŝ Inc Sta Sta Size| Opt| Dead Live XXX XXX XXX X X X XXXXXXXX XXXXXXX 20 2 70 1 3 1.25 1.75 S Inc Length XX XXXXXXXXX ŝ 92 0.5 Ŝ TABLE 2b Max # |-----Live Load Reduction Factors----------Overlay Ŝ Str - Stringers, Sup - Supports MCP - Moment Control Points VCP - Shear Control Points Number of input values for S Lane Str Sup MCP VCP ŝ XX XX XX XX XX XX (Num Inputs) 3 6 4 11 8 Ŝ Ŝ Left Lane Boundary Stations S Right Lane Boundary Stations Ŝ Ś Station of Stringers (two rows max, may be at tenths of stations, XX.X) (Stringers) 6 22 38 54 70 26 ŝ \$ Station of Supports (two rows max) Ś ŝ (Supports) ŝ Moment Control Point Stations (two rows max) Ś 6 10 22 34 38 46 (Mom CP) 54 58 70 82 (Mom CP) 86 Shear Control Point Stations (two rows max) Ŝ
 XXX
 XXX</th Ŝ 56 60 \$TABLE 4 - STIFFNESS AND LOAD DATA -----Bending Sidewalk, Cap & Station 1 if Stiffness Slab Stringer Moving Overlav From To Cont'd of Cap Loads SComments Loads Loads Loads, DW \$XXXXXXXXXXXXXXX XXX 2 (CAP EI & DL) 90 8.09E+07 -2.427(DL Span1, Bm1) -50.17 6 6 -5.04 (DL Span1, Bm2) 22 22 -50.17 -5.04 (DL Span1, Bm3) 38 38 -50.17 -5.04 -50.17(DL Span1, Bm4) 54 54 -5.04 (DL Span1, Bm5) 70 70 -50.17-5.04 (DL Span1, Bm6) 86 86 -50.17 -5.04 (DL Span2, Bm1) 6 6 -104.1 -10.5 -10.5 (DL Span2, Bm2) 22 22 -104.1 (DL Span2, Bm3) 38 38 -104.1 -10.5 (DL Span2, Bm4) 54 54 -104.1-10.5 (DL Span2, Bm5) 70 70 -104.1-10.5 (DL Span2, Bm6) 86 86 -104.1 -10.5 0 4 -4.92 (Dist. Lane Ld) 20 (Conc. Lane Ld) -21.3 4 (Conc. Lane Ld) 16 16 -21.3

4.2.15.3 CAP 18 Output File

AUG 06, 2020 TEXAS DEPARTMENT OF TRANSPORTATION (TxDOT) PAGE 1 CAP18 BENT CAP ANALYSIS Ver. 6.2 (Jul, 2011) PSF HIGHWAY PD- CONTROL- CODED COUNTY NO IPE SECTION-JOB BY DATE NO 00001 ___County____ Highwy Pro# 0000-00-000 BRG AUG 06, 2020 Comment CAP18 Version 6.00 ITBC Design Example 1, Skew = 0.00 PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la ENGLISH SYSTEM UNITS TABLE 1. CONTROL DATA OPTION TO PRINT TABLE SRS (1=YES) 0 ENVELOPES TABLE NUMBER OF MAXIMUMS 2 3 4 KEEP FROM PRECEDING PROBLEM (1=YES) 0 0 0 0 CARDS INPUT THIS PROBLEM 16 OPTION TO CLEAR ENVELOPES BEFORE LANE LOADINGS (1=YES) 0 OPTION TO OMIT PRINT FOR TABLES (TABLE DESIGNATIONS IN PARENTHESES) -1(4A), -2(5) -3(4A,5), -4(4A,5,6), -5(4A,5,6,7): 0 SKEW ANGLE, DEGREES 0.000 TABLE 2. CONSTANTS NUMBER OF INCREMENTS FOR SLAB AND CAP 92 INCREMENT LENGTH, FT 0.500 NUMBER OF INCREMENTS FOR MOVABLE LOAD 20 START POSITION OF MOVABLE-LOAD STA ZERO 2 STOP POSITION OF MOVABLE-LOAD STA ZERO 70 NUMBER OF INCREMENTS BETWEEN EACH POSITION OF MOVABLE LOAD 1 ANALYSIS OPTION (1=WORKING STRESS, 2=LOAD FACTOR, 3=BOTH) 3 LOAD FACTOR FOR DEAD LOAD 1.25 LOAD FACTOR FOR OVERLAY LOAD 1.50 LOAD FACTOR FOR LIVE LOAD 1.75 MAXIMUM NUMBER OF LANES TO BE LOADED SIMULTANEOUSLY 3 LIST OF LOAD COEFFICIENTS CORRESPONDING TO NUMBER OF LANES LOADED 1 2 3 4 5 1.000 1.200 0.850

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la (CONTINUED)

TABLE 3. LISTS OF STATIONS

 NUM OF LANES
 NUM OF STRINGERS
 NUM OF SUPPORTS
 NUM MOM CONTR PTS
 NUM SHEAR CONTR PTS

 LANE LEFT
 2
 32
 60
 4
 11
 8

 LANE LEFT
 2
 32
 60
 90
 5
 5
 5

 LANE RIGHT
 32
 60
 90
 5
 5
 6
 90

 STRINGERS
 6.0
 22.0
 38.0
 5
 4.0
 70.0
 8
 0

 SUPPORTS
 10
 34
 58
 82
 9
 10
 34
 58
 70
 82

 MOM CONTR
 6
 10
 22
 34
 38
 46
 54
 58
 70
 82

 86
 5
 56
 60
 80
 84
 10
 10
 10
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TABLE 4. STIFFNESS AND LOAD DATA

| | | | | | | | - | | | |
|------|----------------|-----|-------------|---------|-----------|----------|----------|------|------------|----|
| FIXE | D-0 | R-N | IOVABLE | FD | XED-POSIT | ION DAT | A | - MO | VABLE- | |
| STA | ST/ | A C | ONTD CAP I | BENDING | G SIDEWA | LK, STR | INGER, C | VERL | AY POSITIC | ΟN |
| FRO | M ⁻ | ГО | IF=1 STIFFN | IESS SL | AB LOADS | S CAP LC | DADS LO | ADS | SLAB LOAD | DS |
| | | (K | (-FT*FT) (| K) (K |) (K) | (K) | | | | |
| | | | | | | | - | | | |
| 2 | 90 | 0 | 80900000.0 | 000 0. | 000 -2.4 | 27 0.0 | 0.00 | 00 | | |
| 6 | 6 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 22 | 22 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 38 | 38 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 54 | 54 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 70 | 70 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 86 | 86 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 6 | 6 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 | | | |
| 22 | 22 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0 0.000 | | | |
| 38 | 38 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0 0.000 | | | |
| 54 | 54 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0 0.000 | | | |
| 70 | 70 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0 0.000 | | | |
| 86 | 86 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0 0.000 | | | |
| 0 | 20 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -4.920 | | | |
| 4 | 4 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -21.300 | | | |
| 16 | 16 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -21.300 | | | |

TABLE 4A. DEAD LOAD RESULTS (WORKING STRESS)

| STA | DIST X (FT |) DEFLECTIO | N (FT) | MOMENT (K-FT) | SHEAR (K) |
|-----|------------|-------------|--------|---------------|-----------|
| -1 | -0.50 | 0.000000 | 0.0 | 0.0 | |
| 0 | 0.00 | 0.000000 | 0.0 | 0.0 | |
| 1 | 0.50 | -0.000034 | 0.0 | 0.0 | |
| 2 | 1.00 | -0.000029 | 0.0 | -0.6 | |
| 3 | 1.50 | -0.000025 | -0.6 | -2.4 | |
| 4 | 2.00 | -0.000021 | -2.4 | -4.9 | |
| 5 | 2.50 | -0.000017 | -5.5 | -7.3 | |
| 07 | 3.00 | -0.000013 | -9.7 | -94.0 | |
| 6 | 3.50 | -0.000009 | 101 | -101.9 | |
| 0 | 4.00 | -0.000003 | -191./ | -104.4 | |
| 10 | 4.50 | -0.000002 | -204.4 | -100.0 | |
| 11 | 5.50 | 0.000000 | -370. | 5 1167 | |
| 12 | 6.00 | 0.000001 | -261 | 7 1143 | |
| 13 | 6.50 | 0.000000 | -205 | 2 111.9 | |
| 14 | 7.00 | -0.000001 | -149. | 8 109.5 | |
| 15 | 7.50 | -0.000003 | -95.7 | 107.0 | |
| 16 | 8.00 | -0.000005 | -42.8 | 104.6 | |
| 17 | 8.50 | -0.000007 | 8.9 | 102.2 | |
| 18 | 9.00 | -0.000009 | 59.4 | 99.8 | |
| 19 | 9.50 | -0.000011 | 108. | 7 97.3 | |
| 20 | 10.00 | -0.000013 | 156 | .7 94.9 | |
| 21 | 10.50 | -0.000014 | 203 | .6 92.5 | |
| 22 | 11.00 | -0.000015 | 249 | .2 5.1 | |
| 23 | 11.50 | -0.000015 | 208 | .7 -82.2 | |
| 24 | 12.00 | -0.000014 | 167 | .0 -84.6 | |
| 25 | 12.50 | -0.000012 | 124 | .1 -87.0 | |
| 26 | 13.00 | -0.000011 | 80. | 0 -89.5 | |
| 27 | 13.50 | -0.000009 | 34. | 6 -91.9 | |
| 28 | 14.00 | -0.000006 | -11. | 9 -94.3 | |
| 29 | 14.50 | -0.000004 | -59. | 7 -96.8 | |
| 30 | 15.00 | -0.000003 | -108 | .7 -99.2 | |
| 31 | 15.50 | -0.000001 | -158 | .9 -101.6 | |
| 32 | 16.00 | 0.000000 | -210 | .3 -104.0 | |
| 34 | 17.00 | 0.000000 | -202 | 7 450 | |
| 34 | 17.00 | -0.000000 | -217 | 9 196.5 | |
| 36 | 18.00 | -0.000001 | -120 | 2 194.1 | |
| 37 | 18.50 | -0.000006 | -23 | 8 191.7 | |
| 38 | 19.00 | -0.000008 | 71. | 4 104.3 | |
| 39 | 19.50 | -0.000011 | 80. | 5 17.0 | |
| 40 | 20.00 | -0.000013 | 88. | 4 14.6 | |
| 41 | 20.50 | -0.000015 | 95. | 1 12.1 | |
| 42 | 21.00 | -0.000016 | 100 | .5 9.7 | |
| 43 | 21.50 | -0.000017 | 104 | .8 7.3 | |

TABLE 4A. DEAD LOAD RESULTS (WORKING STRESS)

| STA | DIST X (FT) | DEFLECTIO | N (FT) MO | MENT (K-FT) | SHEAR (K) |
|-----|-------------|-----------|-----------|-------------|-----------|
| 44 | 22.00 | -0.000018 | 107.8 | 4.9 | |
| 45 | 22.50 | -0.000019 | 109.6 | 2.4 | |
| 46 | 23.00 | -0.000019 | 110.2 | 0.0 | |
| 47 | 23.50 | -0.000019 | 109.6 | -2.4 | |
| 48 | 24.00 | -0.000018 | 107.8 | -4.9 | |
| 49 | 24.50 | -0.000017 | 104.8 | -7.3 | |
| 50 | 25.00 | -0.000016 | 100.5 | -9.7 | |
| 51 | 25.50 | -0.000015 | 95.1 | -12.1 | |
| 52 | 26.00 | -0.000013 | 88.4 | -14.6 | |
| 53 | 26.50 | -0.000011 | 80.5 | -17.0 | |
| 54 | 27.00 | -0.000008 | 71.4 | -104.3 | |
| 55 | 27.50 | -0.000006 | -23.8 | -191.7 | |
| 56 | 28.00 | -0.000003 | -120.2 | -194.1 | |
| 57 | 28.50 | -0.000001 | -217.9 | -196.5 | |
| 58 | 29.00 | 0.000000 | -316.7 | -45.0 | |
| 59 | 29.50 | 0.000000 | -262.9 | 106.5 | |
| 60 | 30.00 | 0.000000 | -210.3 | 104.0 | |
| 61 | 30.50 | -0.000001 | -158.9 | 101.6 | |
| 62 | 31.00 | -0.000003 | -108.7 | 99.2 | |
| 63 | 31.50 | -0.000004 | -59.7 | 96.8 | |
| 64 | 32.00 | -0.000006 | -11.9 | 94.3 | |
| 65 | 32.50 | -0.000009 | 34.6 | 91.9 | |
| 66 | 33.00 | -0.000011 | 80.0 | 89.5 | |
| 67 | 33.50 | -0.000012 | 124.1 | 87.0 | |
| 68 | 34.00 | -0.000014 | 167.0 | 84.6 | |
| 69 | 34.50 | -0.000015 | 208.7 | 82.2 | |
| 70 | 35.00 | -0.000015 | 249.2 | -5.1 | |
| 71 | 35.50 | -0.000014 | 203.6 | -92.5 | |
| 72 | 36.00 | -0.000013 | 156.7 | -94.9 | |
| 73 | 36.50 | -0.000011 | 108.7 | -97.3 | |
| 74 | 37.00 | -0.000009 | 59.4 | -99.8 | |
| 75 | 37.50 | -0.000007 | 8.9 | -102.2 | |
| 76 | 38.00 | -0.000005 | -42.8 | -104.6 | |
| 77 | 38.50 | -0.000003 | -95.7 | -107.0 | |
| 78 | 39.00 | -0.000001 | -149.8 | -109.5 | |
| 79 | 39.50 | 0.000000 | -205.2 | -111.9 | |
| 80 | 40.00 | 0.000001 | -261.7 | -114.3 | |
| 81 | 40.50 | 0.000001 | -319.5 | -116.7 | |
| 82 | 41.00 | 0.000000 | -378.5 | 35.0 | |
| 83 | 41.50 | -0.000002 | -284.4 | 186.8 | |
| 84 | 42.00 | -0.000005 | -191.7 | 184.4 | |
| 85 | 42.50 | -0.000009 | -100.1 | 181.9 | |
| 86 | 43.00 | -0.000013 | -9.7 | 94.6 | |
| 87 | 43.50 | -0.000017 | -5.5 | 7.3 | |
| 88 | 44.00 | -0.000021 | -2.4 | 4.9 | |
| 89 | 44.50 | -0.000025 | -0.6 | 2.4 | |
| 90 | 45.00 | -0.000029 | 0.0 | 0.6 | |

| 91 | 45.50 | -0.000034 | 0.0 | 0.0 |
|----|-------|-----------|-----|-----|
| 92 | 46.00 | 0.000000 | 0.0 | 0.0 |
| 93 | 46.50 | 0.000000 | 0.0 | 0.0 |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la (CONTINUED)

TABLE 5. MULTI-LANE LOADING SUMMARY (WORKING STRESS) (*--CRITICAL NUMBER OF LANE LOADS)

MOMENT (FT-K)

| AT STA | DEAD LD EFFECT | LANE ORDE | POSITIVE R MAXIMU | LOAD AT | STA | ANE NEGATIVE LOAD AT ORDER MAXIMUM LANE STA |
|-----------|----------------------------------|------------------------------|---------------------------------------|--|--------------|--|
| 6 | -9.7 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | | |
| 10 | -378.5 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | -176.2 -176.2 0.0 0.0 | 1 2 1 2 | |
| 22 | 249.2 0 1 2 3 0* | 202.0 201.2 9.3 0.0 | 0 13 1 12 3 62 2 3 0* | 0 -33.4 1 -33.4 0.0 0.0 | 2 2 | 36 36 |
| 34 | -316.7 0 1 2 3 0* | 18.7 18.7 0.0 0.0 | 3 62 0 3 62 1 2 3 2* | 0 -136.3 -116.6 -84.7 2 0.0 | 0 1 32 | 18 12 |
| 38 | 71.4 0 1 2 3 0* | 83.6 83.6 3.2 0.0 | 2 32 0 2 32 1 3 62 2 3 0* | 0 -58.8 I -58.8 0.0 0.0 | 1 | 9 9 |
| 46 | 110.2 0 1 2 3 0* | 69.4 69.4 0.0 0.0 | 2 36 0 2 36 1 2 3 2* |) -27.8 -27.8 -27.8 3 -27.8 3 | 1 1 63 | 9 9 |
| 54 | 71.4 0 1 2 3 0* | 83.6 83.6 3.2 0.0 | 2 40 0 2 40 1 1 10 2 3 0* | 0 -58.8 I -58.8 0.0 0.0 | 3 3 | 63 63 |
| 58 | -316.7 0 1 2 3 0* | 18.7 18.7 0.0 0.0 | 1 9 0 1 9 1 2 3 2* | -136.3 -116.6 -84.7 2 0.0 | 0 3 40 | 54 60 |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la (CONTINUED)

MOMENT (FT-K)

-----AT DEAD LD LANE POSITIVE LOAD AT LANE NEGATIVE LOAD AT STA EFFECT ORDER MAXIMUM LANE STA ORDER MAXIMUM LANE STA _____ 70 249.2 0 1 2 3 3 0.0 0.0 0* 0* 82 -378.5 0.0 0 -176.3 3 70 0 0.0 1 -176.3 3 70 1 2 0.0 2 0.0 3 0.0 3 0.0 0* 0* 86 -9.7 0 0.0 0 0.0 1 0.0 1 0.0 2 0.0 2 0.0 3 0.0 3 0.0 0* 0*

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SHEAR (K)

| AT STA | DEAD LD EFFECT | LANE POSITIVE LOAD AT LANE NEGATIVE LOAD AT ORDER MAXIMUM LANE STA ORDER MAXIMUM LANE S | ТА |
|-----------|----------------------------------|--|----|
| 8 | -184.4 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 12 | 114.3 0 1 2 3 0* | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ | |
| 32 | -104.0 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 36 | 194.1 0 1 2 3 2* | 87.6 0 28 0 -7.8 3 63 84.1 2 32 1 -7.8 3 63 30.7 1 12 2 0.0 0.0 3 0.0 0* | |
| 56 | -194.1 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 60 | 104.0 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 80 | -114.3 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 84 | 184.4 0 1 2 3 0* | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ | |

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REACTION (K)

| AT STA | DEAD LD EFFECT | ORDE | POSITIVE R MAXIMUN | LOAD A VI LANE | T LANE STA OR | NEGATIVE LOA DER MAXIMUM | D AT LANE STA |
|-----------|---------------------------------|------------------------------|---------------------------------------|----------------------------|------------------|-----------------------------|------------------|
| 10 | 308.4 0 1 2 3 0* | 127.9 127.9 1.6 0.0 | 1 2 0 1 2 1 3 62 2 3 0* | -5.6 -5.6 0.0 0.0 | 2 36 2 36 | | |
| 34 | 307.8 0 1 2 3 2* | 117.1 95.3 83.6 0.0 | 0 22 0 2 32 1 1 12 2 3 0* | -9.3 -9.3 0.0 0.0 | 3 63 3 63 | | |
| 58 | 307.8 0 1 2 3 2* | 117.1 95.3 83.6 0.0 | 0 50 0 2 40 1 3 60 2 3 0* | -9.3 -9.3 0.0 0.0 | 19 19 | | |
| 82 | 308.4 0 1 2 3 0* | 127.9 127.9 1.6 0.0 | 3 70 0 3 70 1 1 9 2 3 0* | -5.6 -5.6 0.0 0.0 | 2 36 2 36 | | |

TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | DIST X | MAX + I | мом м. | AX - MOM | MAX + SHEAR | MAX - SHEAR |
|-----|--------|---------|--------|----------|-------------|-------------|
| | (FT) (| FT-K) (| FT-K) | (K) (| (K) | |
| | -0.50 | 0.0 | 0.0 | 0.0 | | |
| 0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 1 | 0.50 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 2 | 1.00 | 0.0 | 0.0 | -0.6 | -0.6 | |
| 3 | 1.50 | -0.6 | -0.6 | -2.4 | -2.4 | |
| 4 | 2.00 | -2.4 | -2.4 | -4.9 | -4.9 | |
| 5 | 2.50 | -5.5 | -5.5 | -7.3 | -7.3 | |
| 6 | 3.00 | -9.7 | -9.7 | -94.6 | -147.5 | |
| 7 | 3.50 | -100.1 | -152.9 | -181.9 | -287.7 | |
| 8 | 4.00 | -191.7 | -297.4 | -184.4 | -290.1 | |
| 9 | 4.50 | -284.4 | -443.1 | -186.8 | -292.5 | |
| 10 | 5.00 | -378.5 | -590.0 | -18.1 | -64.1 | |
| 11 | 5.50 | -306.4 | -507.1 | 170.5 | 110.1 | |
| 12 | 6.00 | -230.8 | -425.5 | 168.1 | 107.6 | |
| 13 | 0.50 | -155.9 | -345.1 | 163.7 | 105.2 | |
| 14 | 7.00 | -82.2 | -205.9 | 160.9 | 102.8 | |
| 16 | 8.00 | 63.6 | -107.9 | 158.4 | 97.9 | |
| 17 | 8 50 | 136.3 | -35.6 | 156.0 | 95.5 | |
| 18 | 9.00 | 208.8 | 32.7 | 153.5 | 93.1 | |
| 19 | 9.50 | 280.5 | 78.6 | 151.1 | 90.7 | |
| 20 | 10.00 | 351.7 | 123.4 | 148.7 | 88.2 | |
| 21 | 10.50 | 422.0 | 166.9 | 146.3 | 85.8 | |
| 22 | 11.00 | 491.6 | 209.2 | 21.1 | -8.0 | |
| 23 | 11.50 | 418.8 | 165.0 | -80.3 | -147.7 | |
| 24 | 12.00 | 344.9 | 119.4 | -82.7 | -150.2 | |
| 25 | 12.50 | 270.2 | 72.4 | -85.2 | -152.6 | |
| 26 | 13.00 | 194.5 | 24.0 | -87.6 | -155.0 | |
| 27 | 13.50 | 118.3 | -26.0 | -90.0 | -157.5 | |
| 28 | 14.00 | 47.3 | -//.1 | -92.5 | -159.9 | |
| 29 | 14.50 | -23.4 | -129.5 | -94.9 | -162.3 | |
| 21 | 15.00 | -90.0 | -165.5 | -97.5 | -167.2 | |
| 37 | 16.00 | -139.5 | -204.0 | -99.7 | -107.2 | |
| 33 | 16.50 | -741 4 | -432.1 | -102.2 | -172.0 | |
| 34 | 17.00 | -294.3 | -518.0 | 88.8 | 27.4 | |
| 35 | 17.50 | -200.1 | -361.7 | 311.3 | 187.2 | |
| 36 | 18.00 | -107.1 | -224.4 | 308.9 | 184.8 | |
| 37 | 18.50 | 26.9 | -108.8 | 306.5 | 182.4 | |
| 38 | 19.00 | 171.7 | 0.8 | 162.8 | 95.0 | |
| 39 | 19.50 | 177.8 | 14.6 | 26.3 | 7.7 | |
| 40 | 20.00 | 183.1 | 27.1 | 23.9 | 5.3 | |
| 41 | 20.50 | 187.3 | 38.4 | 21.4 | 2.8 | |
| 42 | 21.00 | 190.7 | 44.9 | 19.0 | 0.4 | |

TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | | MAX + I | MOM MA | X - MOM | MAX + SHEAR | MAX - SHEAR |
|------|--------|---------|--------|---------|-------------|-------------|
| 5.17 | (FT) (| FT-K) (| FT-K) | (K) (I | () | |
| | | | | | | |
| 43 | 21.50 | 192.9 | 49.1 | 16.6 | -2.0 | |
| 44 | 22.00 | 193.8 | 52.2 | 14.2 | -4.4 | |
| 45 | 22.50 | 193.6 | 54.0 | 11.7 | -6.9 | |
| 46 | 23.00 | 193.5 | 54.6 | 9.3 | -9.3 | |
| 47 | 23.50 | 193.6 | 54.0 | 6.9 | -11.7 | |
| 48 | 24.00 | 193.8 | 52.2 | 4.4 | -14.2 | |
| 49 | 24.50 | 192.9 | 49.1 | 2.0 | -16.6 | |
| 50 | 25.00 | 190.7 | 44.9 | -0.4 | -19.0 | |
| 51 | 25.50 | 187.3 | 38.4 | -2.8 | -21.4 | |
| 52 | 26.00 | 183.1 | 27.1 | -5.3 | -23.9 | |
| 53 | 26.50 | 177.8 | 14.6 | -7.7 | -26.3 | |
| 54 | 27.00 | 171.7 | 0.8 | -95.0 | -162.8 | |
| 55 | 27.50 | 26.9 | -108.8 | -182.4 | -306.5 | |
| 56 | 28.00 | -107.1 | -224.4 | -184.8 | -308.9 | |
| 57 | 28.50 | -200.1 | -361.7 | -187.2 | -311.3 | |
| 58 | 29.00 | -294.3 | -518.0 | -27.4 | -88.8 | |
| 59 | 29.50 | -241.4 | -432.1 | 172.0 | 104.6 | |
| 60 | 30.00 | -189.7 | -347.4 | 169.6 | 102.2 | |
| 61 | 30.50 | -139.3 | -264.0 | 167.2 | 99.7 | |
| 62 | 31.00 | -90.0 | -183.5 | 164.7 | 97.3 | |
| 63 | 31.50 | -23.4 | -129.5 | 162.3 | 94.9 | |
| 64 | 32.00 | 47.3 | -77.1 | 159.9 | 92.5 | |
| 65 | 32.50 | 118.3 | -26.0 | 157.5 | 90.0 | |
| 66 | 33.00 | 194.5 | 24.0 | 155.0 | 87.6 | |
| 67 | 33.50 | 270.2 | 72.4 | 152.6 | 85.2 | |
| 68 | 34.00 | 344.9 | 119.4 | 150.2 | 82.7 | |
| 69 | 34.50 | 418.8 | 165.0 | 147.7 | 80.3 | |
| 70 | 35.00 | 491.6 | 209.2 | 8.0 | -21.1 | |
| 71 | 35.50 | 422.0 | 166.9 | -85.8 | -146.3 | |
| 72 | 36.00 | 351.7 | 123.4 | -88.2 | -148.7 | |
| 73 | 36.50 | 280.5 | 78.6 | -90.7 | -151.1 | |
| 74 | 37.00 | 208.8 | 32.7 | -93.1 | -153.5 | |
| 75 | 37.50 | 136.3 | -35.6 | -95.5 | -156.0 | |
| 76 | 38.00 | 63.6 | -111.2 | -97.9 | -158.4 | |
| 77 | 38.50 | -9.3 | -187.9 | -100.4 | -160.8 | |
| 78 | 39.00 | -82.2 | -265.9 | -102.8 | -163.3 | |
| 79 | 39.50 | -155.9 | -345.1 | -105.2 | -165.7 | |
| 80 | 40.00 | -230.8 | -425.5 | -107.6 | -168.1 | |
| 81 | 40.50 | -306.4 | -507.1 | -110.1 | -170.5 | |
| 82 | 41.00 | -378.5 | -590.0 | 64.1 | 18.1 | |
| 83 | 41.50 | -284.4 | -443.1 | 292.5 | 186.8 | |
| 84 | 42.00 | -191.7 | -297.4 | 290.1 | 184.4 | |
| 85 | 42.50 | -100.1 | -152.9 | 287.7 | 181.9 | |
| 86 | 43.00 | -9.7 | -9.7 | 147.5 | 94.6 | |
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TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | DIST X | MAX | + MOM | MAX - MO | DM MAX | + SHEAR | MAX - SHEAR |
|-----|--------|--------|--------|----------|--------|---------|-------------|
| | (FT) | (FT-K) | (FT-K) | (K) | (K) | | |
| 87 | 43.50 | -5.5 | -5.5 | 7.3 | 7.3 | | |
| 88 | 44.00 | -2.4 | -2.4 | 4.9 | 4.9 | | |
| 89 | 44.50 | -0.6 | -0.6 | 2.4 | 2.4 | | |
| 90 | 45.00 | 0.0 | 0.0 | 0.6 | 0.6 | | |
| 91 | 45.50 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 92 | 46.00 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 93 | 46.50 | 0.0 | 0.0 | 0.0 | 0.0 | | |

TABLE 7. MAXIMUM SUPPORT REACTIONS (WORKING STRESS)

| STA | DIST X | MAX + | REACT | MAX - REACT |
|-----|--------|-------|-------|-------------|
| (F | ·T) | (K) | (K) | |
| | | | | |
| 10 | 5.00 | 461.8 | 301. | 7 |
| 34 | 17.00 | 486.7 | 296 | .7 |
| 58 | 29.00 | 486.7 | 296 | .7 |
| 82 | 41.00 | 461.8 | 301 | .7 |

TABLE 5. MULTI-LANE LOADING SUMMARY (LOAD FACTOR) (*--CRITICAL NUMBER OF LANE LOADS)

MOMENT (FT-K)

| AT STA | DEAD LE EFFECT | D LANE ORDER | POSITIV | /E LOAI IUM LA | D AT ANE S | LA TA | NE | NEG. DER I | ATIVE MAXI | E LO. MUM | AD AT LAI | - NE STA |
|-----------|----------------------------------|-------------------------------|-----------------------------------|-----------------------------------|-------------------|------------------|----------|---------------|---------------|--------------|--------------|-------------|
| 6 | -12.1 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | | | | | | | | |
| 10 | -480.8 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | -308.4 -308.4 0.0 0.0 | 1 1 1 | 2 | | | | | | |
| 22 | 316.4 0 1 2 3 0* | 353.5 352.1 16.3 0.0 | 0 13 1 12 3 62 3 0* | 0 -5 1 -5 2 0. 0.0 | 8.4 8.4 .0 | 2 2 | 36 36 | | | | | |
| 34 | -401.8 0 1 2 3 0* | 32.7 32.7 0.0 0.0 | 3 62 3 62 2 3 2* | 0 -23 1 -20 -148.2 0.0 | 8.5 4.0 2 2 | 0 1 32 | 18 12 | | | | | |
| 38 | 91.2 0 1 2 3 0* | 146.3 146.3 5.6 0.0 | 2 32 2 32 3 62 3 0* | 0 -10 1 -10 2 0.0 0.0 |)2.9)2.9) | 1 1 | 9 9 | | | | | |
| 46 | 139.7 0 1 2 3 0* | 121.4 121.4 0.0 0.0 | 2 36 2 36 2 3 2* | 0 -4 1 -4 -48.7 0.0 | 8.7 8.7 3 | 1 1 63 | 9 9 | | | | | |
| 54 | 91.2 0 1 2 3 0* | 146.3 146.3 5.6 0.0 | 2 40 2 40 1 10 2 3 0* | 0 -10 1 -10 2 0.0 0.0 | 2.9 2.9 | 3 3 | 63 63 | | | | | |
| 58 | -401.8 0 1 2 3 0* | 32.7 32.7 0.0 0.0 | 1 9 0 1 9 1 2 3 2* |) -238. -204. -148.2 0.0 | .5 (.0 3 2 |) 5 3 6 40 | 4 | | | | | |

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MOMENT (FT-K)

| AT | DEAD LD | LANE | POSITI | VE L | OAD A | ΛT | LA | NE | NEG | ATIVE | LOA | D AT |
|-----|---------|-------|--------|------|-------------|----|----|----|-------|-------|-----|----------|
| STA | EFFECT | ORDER | MAXIN | /UM | LAN | ES | ΓA | OR | DER I | MAXIN | MUM | LANE STA |
| | | | | | | | | | | | | |
| 70 | 216.4 | | | | | | | | | | | |
| /0 | 510.4 | 2525 | 0 50 | 0 | FO A | | 2 | 20 | | | | |
| | 0 | 353.5 | 0 59 | 0 | -58.4 | • | 2 | 30 | | | | |
| | 1 | 352.1 | 3 60 | 1 | -58.4 | ł | 2 | 36 | | | | |
| | 2 | 16.3 | 19 | 2 | 0.0 | | | | | | | |
| | 3 | 0.0 | 3 | C | 0.0 | | | | | | | |
| | 0* | | 0* | | | | | | | | | |
| | | | | | | | | | | | | |
| 82 | -480.8 | | | | | | | | | | | |
| | 0 | 0.0 | 0 | -30 | 08.4 | 3 | 70 |) | | | | |
| | 1 | 0.0 | 1 | -30 | 08.4 | 3 | 70 |) | | | | |
| | 2 | 0.0 | 2 | C | 0 | - | | | | | | |
| | 3 | 0.0 | 3 | 0 | 0 | | | | | | | |
| | 0* | 0.0 | 0* | | | | | | | | | |
| | 0 | | 0. | | | | | | | | | |
| 96 | 12.1 | | | | | | | | | | | |
| 80 | -12.1 | 0.0 | 0 | ~ | 0 | | | | | | | |
| | 0 | 0.0 | 0 | L L | .0 | | | | | | | |
| | 1 | 0.0 | 1 | C | 0.0 | | | | | | | |
| | 2 | 0.0 | 2 | C | 0.0 | | | | | | | |
| | 3 | 0.0 | 3 | C | 0.0 | | | | | | | |
| | 0* | | 0* | | | | | | | | | |
| | 0* | | 0* | | | | | | | | | |

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SHEAR (K)

| AT STA | DEAD LD EFFECT | O LANE POSITIVE LOAD AT LANE NEGATIVE LOAD AT ORDER MAXIMUM LANE STA ORDER MAXIMUM LANE STA |
|-----------|----------------------------------|--|
| 8 | -234.3 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 12 | 145.0 0 1 2 3 0* | 78.4 1 6 0 -9.7 2 36 78.4 1 6 1 -9.7 2 36 2.7 3 62 2 0.0 0.0 3 0.0 0* |
| 32 | -131.8 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 36 | 246.5 0 1 2 3 2* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 56 | -246.5 0 1 2 3 0* | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ |
| 60 | 131.8 0 1 2 3 0* | 95.6 0 57 0 -2.7 1 9 92.7 3 60 1 -2.7 1 9 19.5 2 40 2 0.0 0.0 3 0.0 0* |
| 80 | -145.0 0 1 2 3 0* | 9.7 2 36 0 -78.4 3 66 9.7 2 36 1 -78.4 3 66 0.0 2 -2.7 1 9 0.0 3 0.0 0* |
| 84 | 234.3 0 1 2 3 0* | 154.2 3 70 0 0.0 154.2 3 70 1 0.0 0.0 2 0.0 0.0 3 0.0 0* |

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REACTION (K)

| | | | | | | - | |
|-----------|---------------------------------|--------------------------------|-------------------------------------|------------------------------------|-----------------|--------------------------------|------------------|
| AT STA | DEAD LI EFFECT | D LANE ORDE | e positive R Maximu | E LOAD A JM LANE | t lane Sta o | E NEGATIVE LOA RDER MAXIMUM | D AT LANE STA |
| 10 | 391.5 0 1 2 3 0* | 223.8 223.8 2.7 0.0 | 1 2 0 1 2 - 3 62 2 3 0* | 0 -9.7 1 -9.7 0.0 0.0 | 2 36 2 36 | | |
| 34 | 390.4 0 1 2 3 2* | 205.0 166.8 146.3 0.0 | 0 22 2 32 1 12 3 0* | 0 -16.3 1 -16.3 2 0.0 0.0 | 3 63 3 63 | 3 | |
| 58 | 390.4 0 1 2 3 2* | 205.0 166.8 146.3 0.0 | 0 50 2 40 3 60 3 0* | 0 -16.3 1 -16.3 2 0.0 0.0 | 19 19 | | |
| 82 | 391.5 0 1 2 3 0* | 223.8 223.8 2.7 0.0 | 3 70 3 70 1 9 2 3 0* | 0 -9.7 1 -9.7 0.0 0.0 | 2 36 2 36 | | |

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| TABLE 0. LIVELOI LO OF MAXIMON VALUES (LOAD FACTOR | TABLE 6. | ENVELOPES | OF MAXIMUM VALUES | (LOAD FACTOR |
|--|----------|-----------|-------------------|---------------|
|--|----------|-----------|-------------------|---------------|

| STA | DIST X | MAX + I | MOM N | AX - MON | 1 MAX + S | HEAR | MAX - SHEAR |
|-----|--------|----------|--------|----------|-----------|------|-------------|
| | (FT) | (FT-K) (| FT-K) | (K) | (K) | | |
| | 0.50 | | | 0.0 | 0.0 | | |
| -1 | -0.50 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 1 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 2 | 1.00 | 0.0 | 0.0 | -0.8 | -0.8 | | |
| 2 | 1.00 | -0.8 | -0.8 | -3.0 | -3.0 | | |
| 4 | 2.00 | -3.0 | -3.0 | -5.0 | -5.0 | | |
| 5 | 2.00 | -6.8 | -6.8 | -9.1 | -9.1 | | |
| 6 | 3.00 | -12.1 | -12.1 | -120.2 | -212 7 | | |
| 7 | 3.50 | -127.0 | -219.6 | -231.3 | -416.4 | | |
| 8 | 4.00 | -243.5 | -428.5 | -234.3 | -419.4 | | |
| 9 | 4.50 | -361.4 | -639.0 | -237.4 | -422.4 | | |
| 10 | 5.00 | -480.8 | -851.0 | -15.1 | -95.5 | | |
| 11 | 5.50 | -383.1 | -734.4 | 242.2 | 136.4 | | |
| 12 | 6.00 | -278.8 | -619.5 | 239.1 | 133.3 | | |
| 13 | 6.50 | -174.8 | -506.0 | 236.1 | 130.3 | | |
| 14 | 7.00 | -72.4 | -394.0 | 233.1 | 127.3 | | |
| 15 | 7.50 | 29.0 | -283.6 | 230.0 | 124.2 | | |
| 16 | 8.00 | 131.2 | -174.6 | 227.0 | 121.2 | | |
| 17 | 8.50 | 233.6 | -67.2 | 224.0 | 118.2 | | |
| 18 | 9.00 | 336.3 | 28.2 | 220.9 | 115.1 | | |
| 19 | 9.50 | 438.2 | 85.0 | 217.9 | 112.1 | | |
| 20 | 10.00 | 539.8 | 140.3 | 214.9 | 109.1 | | |
| 21 | 10.50 | 640.4 | 194.0 | 211.8 | 106.0 | | |
| 22 | 11.00 | 740.6 | 246.3 | 34.5 | -16.4 | | |
| 23 | 12.00 | 632.4 | 100.3 | -101.2 | -219.2 | | |
| 24 | 12.00 | 525.T | 66.0 | -104.3 | -222.3 | | |
| 25 | 12.50 | 301.6 | 23 | -107.5 | -225.5 | | |
| 20 | 13.00 | 190.1 | -62.3 | -113.4 | -220.5 | | |
| 28 | 14.00 | 88.3 | -129 5 | -116.4 | -234.4 | | |
| 29 | 14 50 | -12.5 | -198.1 | -119 5 | -237.4 | | |
| 30 | 15.00 | -105.4 | -269.1 | -122.5 | 5 -240.5 | | |
| 31 | 15.50 | -167.4 | -385.7 | -125.5 | -243.5 | | |
| 32 | 16.00 | -230.9 | -506.9 | -128.0 | -246.5 | | |
| 33 | 16.50 | -296.0 | -629.7 | -131.6 | -249.6 | , | |
| 34 | 17.00 | -362.5 | -754.0 | 134.0 | 26.6 | | |
| 35 | 17.50 | -245.1 | -528.0 | 450.4 | 233.2 | | |
| 36 | 18.00 | -129.3 | -334.5 | 447.4 | 230.2 | | |
| 37 | 18.50 | 59.0 | -178.5 | 444.4 | 227.2 | | |
| 38 | 19.00 | 266.8 | -32.3 | 234.6 | 116.1 | | |
| 39 | 19.50 | 272.9 | -12.8 | 37.5 | 5.0 | | |
| 40 | 20.00 | 278.1 | 5.2 | 34.5 | 1.9 | | |
| 41 | 20.50 | 282.2 | 21.7 | 31.4 | -1.1 | | |
| 42 | 21.00 | 285.4 | 30.2 | 28.4 | -4.1 | | |
| 43 | 21.50 | 287.1 | 35.5 | 25.4 | -/.2 | | |
| 44 | 22.00 | 207.2 | 59.5 | 22.5 | -10.Z | | |

| 45 | 22.50 | 285.9 | 41.6 | 19.3 | -13.2 | |
|--------|--------|-----------|----------|---------|---------------------|---------|
| 46 | 23.00 | 285.4 | 42.4 | 16.3 | -16.3 | |
| 47 | 23.50 | 285.9 | 41.6 | 13.2 | -19.3 | |
| 48 | 24.00 | 287.2 | 39.3 | 10.2 | -22.3 | |
| | | | | | | |
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TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA | DIST X | MAX + N | IOM MA | AX - MOM | MAX + SHEAR | MAX - SHEAR |
|-----|--------|----------|---------|----------|-------------|-------------|
| (| FT) (| FT-K) (I | -T-K) (| (K) (I | <) | |
| 49 | 24.50 | 287.1 | 35.5 | 7.2 | -25.4 | |
| 50 | 25.00 | 285.4 | 30.2 | 4.1 | -28.4 | |
| 51 | 25.50 | 282.2 | 21.7 | 1.1 | -31.4 | |
| 52 | 26.00 | 278.1 | 5.2 | -1.9 | -34.5 | |
| 53 | 26.50 | 272.9 | -12.8 | -5.0 | -37.5 | |
| 54 | 27.00 | 266.8 | -32.3 | -116.1 | -234.6 | |
| 55 | 27.50 | 59.0 | -178.5 | -227.2 | -444.4 | |
| 56 | 28.00 | -129.3 | -334.5 | -230.2 | -447.4 | |
| 57 | 28.50 | -245.1 | -528.0 | -233.2 | -450.4 | |
| 58 | 29.00 | -362.5 | -754.0 | -26.6 | -134.0 | |
| 59 | 29.50 | -296.0 | -629.7 | 249.6 | 131.6 | |
| 60 | 30.00 | -230.9 | -506.9 | 246.5 | 128.6 | |
| 61 | 30.50 | -167.4 | -385.7 | 243.5 | 125.5 | |
| 62 | 31.00 | -105.4 | -269.1 | 240.5 | 122.5 | |
| 63 | 31.50 | -12.5 | -198.1 | 237.4 | 119.5 | |
| 64 | 32.00 | 88.3 | -129.5 | 234.4 | 116.4 | |
| 65 | 32.50 | 190.1 | -62.3 | 231.4 | 113.4 | |
| 66 | 33.00 | 301.6 | 3.3 | 228.3 | 110.3 | |
| 67 | 33.50 | 413.0 | 66.9 | 225.3 | 107.3 | |
| 68 | 34.00 | 523.1 | 128.6 | 222.3 | 104.3 | |
| 69 | 34.50 | 632.4 | 188.3 | 219.2 | 101.2 | |
| 70 | 35.00 | 740.6 | 246.3 | 16.4 | -34.5 | |
| 71 | 35.50 | 640.4 | 140.2 | -106.0 | -211.8 | |
| 72 | 36.00 | 239.8 | 140.3 | -109.1 | -214.9 | |
| 75 | 27.00 | 430.2 | 202 | -112.1 | -217.9 | |
| 74 | 37.00 | 222.5 | 20.2 | 110.1 | -220.9 | |
| 75 | 32.00 | 121 2 | -07.2 | -110.2 | -224.0 | |
| 70 | 38.50 | 29.0 | -174.0 | -121.2 | -227.0 | |
| 78 | 39.00 | -72.4 | -205.0 | -124.2 | -233.1 | |
| 79 | 39.50 | -174.8 | -506.0 | -130.3 | -236.1 | |
| 80 | 40.00 | -278.8 | -619.5 | -133.3 | -239.1 | |
| 81 | 40.50 | -383.1 | -734.4 | -136.4 | -242.2 | |
| 82 | 41.00 | -480.8 | -851.0 | 95.5 | 15.1 | |
| 83 | 41.50 | -361.4 | -639.0 | 422.4 | 237.4 | |
| 84 | 42.00 | -243.5 | -428.5 | 419.4 | 234.3 | |
| 85 | 42.50 | -127.0 | -219.6 | 416.4 | 231.3 | |
| 86 | 43.00 | -12.1 | -12.1 | 212.7 | 120.2 | |
| 87 | 43.50 | -6.8 | -6.8 | 9.1 | 9.1 | |
| 88 | 44.00 | -3.0 | -3.0 | 6.1 | 6.1 | |
| 89 | 44.50 | -0.8 | -0.8 | 3.0 | 3.0 | |

| 90 | 45.00 | 0.0 | 0.0 | 0.8 | 0.8 | |
|----|-------|-----|-----|-----|-----|--|
| 91 | 45.50 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 92 | 46.00 | 0.0 | 0.0 | 0.0 | 0.0 | |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la (CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA | DIST X | MAX · | + MOM | MAX - MO | DM MAX + S | SHEAR | MAX - SHEAR |
|-----|--------|--------|--------|----------|------------|-------|-------------|
| (| FT) | (FT-K) | (FT-K) | (K) | (K) | | |
| | | | | | | | |
| 93 | 46.50 | 0.0 | 0.0 | 0.0 | 0.0 | | |

TABLE 7. MAXIMUM SUPPORT REACTIONS (LOAD FACTOR)

| | | | | - |
|----------|----------------|----------------|----------------|-------------|
| STA (| DIST X FT) | MAX + (K) | REACT (K) | MAX - REACT |
| | | | | - |
| 10 | 5.00 | 660.0 | 379 | .8 |
| 34 | 17.00 | 703.5 | 370 | .9 |
| 58 | 29.00 | 703.5 | 370 | .9 |
| 82 | 41.00 | 660.0 | 379 | .8 |
| | | | | |

4.2.15.4 Live Load Distribution Factor Spreadsheet

4.2.15.4.1 Spans 1 & 3



| DDIDGE | County. | ANY VY VYVVV | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 Rev. 10112 | LRFD Spe |
|----------|--------------------|--------------------------|---|------------------------------|--------------|-----------------------|----------------------|--------------------------------------|--------------------|----------|
| DIVISION | C-S-J: Descrip: | ITBC Design Exar | nple 1, Span 1 8 | 3 | File: | Ex1 Sp | Date: an1 distrib | ution factors.x | Sheet: | 2 of 8 |
| INTER | IOR BE | AM: | | | | | | | | |
| Shear L | L Distrib | ution Per Lane (| Table 4.6.2.2 | .3a-1): | | | | | | |
| _ | One La | ne Loaded | | | | | | | | |
| | | Lever Rule | (Table 3.6.) | 1.1.2) | | | | | | |
| | | ma = 0.6 | 25 * 1.2 = | 0.750 | | | | | | |
| | | Modify fo | r Skew: | | | | | | | |
| | | | skew corre | ction = | 1.000 | | | | | |
| | | | mg = 0.750 | * 1.000 = | 0.750 | | | | | |
| | | Equation | | | | | | | | |
| | | g = 0.36 | $5 + \left(\frac{S}{25}\right)$ | | | | | | | |
| | | g = 0.36 | + (8 / 25) = | 0.680 | | | | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew corre | ction = | 1.000 | | | | | |
| | | | g = 0.680 * | 1.000 = | 0.680 | | | | | |
| | | Range of Appl | icability (RO/ | A) Checks | | | | | | |
| | | Check S | 3.5' ≤ 8.0' : | ≤ 16.0' | OK | | | | | |
| | | Check ts | 4.5" ≤ 8.0" | ≤ 12.0" | OK | | | | | |
| | | Check L: | 20' ≤ 50.4' | ≤ 240' | OK | | | | | |
| | | Check N | 5; 6≥4 | | OK | | | | | |
| | | Use Equation | from Table 4. | 6.2.2.3a-1 b | ecause all | criteria i | S OK | | | |
| | | gV _{int1} = | 0.680 | | | | | | | |
| | Two or | More Lanes Lo | aded | | | | | | | |
| | | Lever Rule | (Table 3.6.) | 1.1.2) | | | | | | |
| | | mg = Ma | x(0.875 * 1.0 | 0.875 * 0.8 | 5, 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew corre | ction = | 1.000 | | | | | |
| | | | mg = 0.875 | * 1.000 = | 0.875 | | | | | |
| | | Equation | 10) 10 | 2.0 | | | | | | |
| | | g = 0.2 - | $+\left(\frac{3}{12}\right) - \left(\frac{3}{2}\right)$ | 2 | | | | | | |
| | | a = 0.2 · | (12) (3 | 25\42.0 - | 0.014 | | | | | |
| | | g = 0.2 + Modify fo | (0/12) - (0/ | 55) 2.0 = | 0,014 | | | | | |
| | | would be the | skew corre | ction - | 1 000 | | | | | |
| | | | a = 0.814 * | 1.000 = | 0.814 | | | | | |
| | | Bange of Appl | icability (BO) | A) Checks | (same as | or one l | ane loade | (be | | |
| | | Use Equation | from Table 4 | 62239-1 h | ecause all | riteria i | s OK | , u) | | |
| | | gV _{int2+} = | 0.814 | 0.2.2.00 1 0 | course an | | 5 611. | | | |
| | TXDOT | Policy states gV | Interior must be | $\geq m \cdot N_L \div N_b$ | | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85*3/6 | = | 0.425 | | | | | |
| | ls W≥2 | 20ft ? Yes | | | | | | | | |
| | TXDOT | Policy states the | at if $W < 20$ ft, | gV _{intenior} is th | e Maximun | n of: gV _# | in and m | N _L +N _b | | |
| >> | TXDOT | Policy states that | at if $W \ge 20$ ft, | gV _{Interior} is th | e Maximun | n of: gV | n11, gVint2+ | , m-N _L ÷N _b . | | |
| | aV | - 0.014 | | | | | | | | |

| TXDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spee |
|----------|--------------------|--------------------------|---------------------------------------|--|--------------------------------------|-------------|---------------------------|----------------|------------|-----------|
| DIVISION | C-S-J: Descrip: | ITBC Design Ex | ID #: ample 1. Span 1 | 8 3 | Ck Dsn: File: | Ex1 Sp | Date: an1 distribution | ution factors. | Rev. 10/18 | 3 of 8 |
| INTER | IOR BE | AM: | | | 11 Hor | | | | onood | |
| Momen | t I I Dist | ribution Per Lar | e (Table 4.6. | 2 2 2h-1): | | | | | | |
| Momen | Onela | ne Loaded | 10 (14010 4.0.1 | L.L.L.U (). | | | | | | |
| | One Eu | Lever Bule | (Table 3.6 | 112) | | | | | | |
| | | ma = 0 | 625 * 1.2 = | 0.750 | | | | | | |
| | | Modify 1 | or Skew: | 0.100 | | | | | | |
| | | incomy i | skew corre | ection = | 1.000 | | | | | |
| | | | ma = 0.750 | 0 * 1.000 = | 0.750 | | | | | |
| | | Equation | | | 1.0 | | | | | |
| | | g = 0.0 | $6 + \left(\frac{S}{14}\right)^{0.4}$ | $\left(\frac{S}{L}\right)^{0.5} \left(\frac{K_s}{12Lt}\right)^{0.5}$ | | | | | | |
| | | q = 0.06 | 5 + (8/14)^0.4 | * (8/50.4)^0.3 | 3* (1,271,6 | 11/(12*5 | 50.4*8^3) |)^0.1 = | 0.590 | |
| | | Modify I | or Skew: | | . Veries | | | | | |
| | | 1.1.2.2 | skew corre | ection = | 1.000 | | | | | |
| | | | g = 0.590 ' | 1.000 = | 0.590 | | | | | |
| | | Range of App | olicability (RO | A) Checks | | | | | | |
| | | Check S | S: 3.5' ≤ 8.0' | ≤ 16.0' | | OK | | | | |
| | | Check t | s: 4.5" ≤ 8.0 | " ≤ 12.0" | | OK | | | | |
| | | Check I | .: 20' ≤ 50.4 | '≤240' | | OK | | | | |
| | | Check I | N _b : 6≥4 | | | OK | | | | |
| | | Check I | Kg: 10,000 ≤ 1 | 1,271,611 ≤ 7 | ,000,000 | OK | | | | |
| | | Use Equation | from Table 4 | 6.2.2.2b-1 b | ecause all | criteria is | s OK. | | | |
| | | gM _{int1} = | 0.590 | | | | | | | |
| | Two or | More Lanes L | oaded | | | | | | | |
| | | Lever Rule | (Table 3.6 | 1.1.2) | | | | | | |
| | | mg = M | ax(0.875 * 1.0 | 0.875 * 0.85 | 5, 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify 1 | or Skew: | | | | | | | |
| | | | skew corre | ection = | 1.000 | | | | | |
| | | | mg = 0.875 | 5 * 1.000 = | 0.875 | | | | | |
| | | Equation | (= > 9 | 6 (-> 0.2 () | 10.1 | | | | | |
| | | g = 0.0 | $75 + \left(\frac{S}{9.5}\right)$ | $\left(\frac{S}{L}\right) \left(\frac{1}{12}\right)$ | $\left(\frac{\chi_g}{Lt_s^3}\right)$ | | | | | |
| | | g = 0.07 | 75 + (8/9.5)^0. | .6 * (8/50.4)^0 |).2 * (1,271 | ,611/(12 | *50.4*8* | 3))^0.1 = | 0.794 | |
| | | Modify 1 | for Skew: | | | | | | | |
| | | | skew corre | ection = | 1.000 | | | | | |
| | | | g = 0.794 ' | * 1.000 = | 0.794 | | | | | |
| | | Range of App | olicability (RO | A) Checks | (same as l | or one I | ane loade | ed) | | |
| | | Use Equation | from Table 4 | .6.2.2.2b-1 b | ecause all | oriteria i | s OK. | | | |
| | | gM _{int2+} = | 0.794 | | | | | | | |
| | TXDOT | Policy states gl | Mutanor must b | e≥m/N _L ÷N _N | | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85 * 3 / 6 | 6 = | 0,425 | | | | | |
| | Is W 22 | 20ft ? Yes | | | | | | | | |
| | TXDOT | Policy states th | at if W < 20ft | gMinterior is th | e Maximur | n of: gM | int and m | NL+NL+Nb- | | |
| >> | TXDOT | Policy states th | at if W ≥ 20ft. | gMinterior is Un | e Maximun | n oli gM | gMiniz | m-NL=N | y | |
| | gMin | ation = 0.794 | | | | 1.1 | | | | |

| TXDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 LRFD Specs |
|--------|--------------------|--------------------------|--------------------------------|---------------------------------|-------------------------------|-------------|-------------|----------------------------|--|
| BRIDGE | C-S-J: | ITBC Design Exa | ID #: | XXXX & 3 | Ck Dsn: | Ex1 So | Date: | ition factors x | Rev. 10/18 - (No Interim) Sheet: 4 of 8 |
| EXTER | BIOR BE | AM: | inple it opart i | | pi na. | Last op | | | |
| Shearl | 1 Distrib | ution Per Lane | (Table 4.6.2 : | 2 3h-11 | | | | | |
| onour | Onela | ne Loaded | 14010 1.0.2.1 | | | | | | |
| | one Lu | Lever Bule | (Table 3.6 | 112) | | | | | |
| | | ma = 0.0 | 525 * 1.0 = | 0.625 | TyDOT us | es a mil | Itiole ores | sence factor | of 1.0 for one |
| | | Modify f | or Skew: | 0.020 | lane loade | d on the | exterior | beam. | |
| | | | skew corre | ection = | 1.000 | | | | |
| | | | ma = 0.62 | 5*1.000 = | 0.625 | | | | |
| | | Use Lever Bi | le as per AA | SHTOLBE | Table 4.6.2 | 2.3b-1 | | | |
| | | aVert = | 0.625 | and or crime | S TELED TELE | | | | |
| | - | S . Exti | M.M.S | | | | | | |
| | Iwo or | More Lanes Lo | baded | 1.1.01 | | | | | |
| | | Lever Rule | (Table 3.6 | .1.1.2) | | 051 | 0.005 | | |
| | | mg = Ma Modify f | ax(0.625 * 1.0 or Skew: |), 0.625 * 0.8 | 35, 0.625 " 0 | = (60. | 0.625 | | |
| | | | skew corre | ection = | 1.000 | | | | |
| | | | ma = 0.623 | 5 * 1.000 = | 0.625 | | | | |
| | | Equation | | | | | | | |
| | | d _e = dist | b/w CL web | to curb | | | | | |
| | | $d_e = OH$ | - Rail Width | | | | | | |
| | | d _e = | 3ft - 1ft = | 2.01 | tt. | | | | |
| | | | (d) | | | | | | |
| | | e = 0.6 | $+\left(\frac{\pi}{10}\right)$ | | | | | | |
| | | e = 0.6 · | + (2.0/10) = | 0.800 | | | | | |
| | | g = e*g\ | /int2+Eq | | | | | | |
| | | g = 0.80 | 0 * 0.814 = | 0.651 | | | | | |
| | | Skew C | orrection is in | cluded in gV | (interior). | | | | |
| | | Range of App | licability (RO | A) Checks | Interior | ROA is | implicitly | applied to th | he exterior beam. |
| | | Check I | nterior Beam | ROA: | OK | | 1.1.3 | | |
| | | Check d | l _e : -1.0' ≤ 2.0 | '≤ 5.5' | OK | | | | |
| | | Check N | l _b : 6≠3 | | OK | | | | |
| | | Use Equation | from Table 4 | .6.2.2.3b-1 | because all o | criteria is | s OK. | | |
| | | $gV_{ext2+} =$ | 0.651 | | | | | | |
| | TXDOT | Policy states a | / must h | e ≥ aV | | | | | |
| | 1.45.5.1 | aVistarias = | 0.814 | - 3 · menor | | | | | |
| | TXDOT | Policy states a | /Entering must b | $m \ge m \cdot N \Rightarrow N$ | | | | | |
| | | $m \cdot N_1 \div N_h =$ | 0.85*3/6 | 3 = | 0.425 | | | | |
| | ls OH ≤ | S/2 ? Yes | 1122 24 | | | | | | |
| | ls W≥2 | 20ft? Yes | | | | | | | |
| >> | TXDOT | Policy states th | at if $OH \le S/2$ | 2, gV _{Exterior} is | gVintenor. | | | | |
| | TXDOT | Policy states th | at if OH > S/a | 2 and W < 20 | off, gV _{Exterior} | s the Ma | aximum c | f: gV _{ext1} , gV | interior, and |
| | | $m \cdot N_L \div N_b$. | | | | | | | |
| | TXDOT | Policy states th | at if OH > S/2 | 2 ans W ≥ 20 | oft, gV _{Exterior} i | s the Ma | aximum o | f: gV _{ext1} , gV | ext2+, gVinterior |
| | | and m·NL+Nb | | | | | | | |
| | gV _{exte} | erior = 0.814 | | | | | | | |

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TXDOT
BRIDGE
                     ANY
           County:
                                       Highway
                                                      Any
XXXX
                                                                      Design:
                                                                                          Date
                                                                                                                      2017 LRFD Spel
                     XXX-XX-XXXX
                                                                                                                     10/18 - (No Inte
                                                                      Ck Dsn:
                                      ID #
                                                                                         Date
                                     mple 1, Span 1 &
                    ITBC Design Exa
DIVISION
                                                                                                                              5 of 8
 EXTERIOR BEAM:
Moment LL Distribution Per Lane (Table 4.6.2.2.2d-1):
          One Lane Loaded
                     Lever Rule
                           mg = 0.625 * 1.0 =
                                                     0.625
                                                                  TxDOT uses a multiple presence factor of 1,0 for one
                                                                  lane loaded on the exterior beam.
                           Modify for Skew:
                                       skew correction =
                                                                     1.000
                                       mg = 0.625 * 1.000 =
                                                                     0.625
                     Use Lever Rule as per AASHTO LRFD Table 4.6.2.2.2d-1.
                     gMext1 =
                                       0.625
          Two or More Lanes Loaded
                     Lever Rule
                                       (Table 3.6.1.1.2)
                           mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) =
                                                                                          0.625
                           Modify for Skew:
                                       skew correction =
                                                                     1.000
                                       mg = 0.625 * 1.000 =
                                                                      0.625
                     Equation
                           e = 0.77 + \left(\frac{d_e}{9.1}\right)
                           e = 0.77 + (2.0/9.1) =
                                                                  0.990
                           g = e^*gM_{int2+Eq}
                           g = 0.99 * 0.794 =
                                                     0.786
                           Skew Correction included in gM(interior).
                     Range of Applicability (ROA) Checks
                                                                      Interior ROA is implicitly applied to the exterior beam.
                           Check Interior Beam ROA:
                                                                  OK
                           Check d_e: -1.0' \leq 2.0' \leq 5.5'
                                                                 OK
                           Check N<sub>b</sub>: 6 ≠ 3
                                                                  OK
                     Use Equation from Table 4.6.2.2.2d-1 because all criteria is OK.
                     gM<sub>ext2+</sub> =
                                      0.786
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ gM<sub>interior</sub>
                     gMinterior =
                                      0.794
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ m·N<sub>L</sub>÷N<sub>b</sub>
                     m \cdot N_L \div N_b = 0.85 * 3 / 6 =
                                                                     0.425
          Is OH ≤ S/2 ? Yes
          Is W ≥ 20ft ? Yes
      >> TxDOT Policy states that if OH ≤ S/2, gMExterior is gMinterior.
          TxDOT Policy states that if OH > S/2 and W < 20ft, gM<sub>Exterior</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>interior</sub>, and
                     m·NI ÷Nn
          TxDOT Policy states that if OH > S/2 ans W \ge 20ft, gM_{\text{Extension}} is the Maximum of: gM_{\text{ext1}}, gM_{\text{ext2+r}} gM_{\text{mienormatication}}
                     and m·NL+NE
            gM<sub>exterior</sub> = 0.794
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| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|--------------------------------|---|----------------------------------|-------------------------------|-----------------------------------|-------------------|------------|------------------|-----------------------|----------------------------|
| DIVISION Descrip: | ITBC Design Exa | mple 1, Span 1 & | 3 | File: | Ex1 Span | 1 distribu | ution_factors.xl | Sheet: | 7 of 8 |
| LEVER RULE | s | = 8.0 ft | | | | | | | |
| INTERIOR (con't) | | | | | | | | | |
| For 18 ≤ S < 22: One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{-18}{S}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S-16}{S}$ |) | | = 0.625 | | |
| For 22 ≤ S ≤ 24: One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{s-18}{s}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{S-18}{S} + \frac{S-16}{S}$ | $+\frac{S-22}{S}$ | | = -1.500 | | |
| | | | | ed hinge | | | Rail Width | S = OH = = RW = | 8.0 ft 3.0 ft 1.0 ft |
| For X < 6 | он — — — — — | - s | 1 | | | | x = 0+0111 | W. 21, - | 0.0 1 |
| One Lane = | $\frac{16}{32}\left(\frac{X}{S}\right)$ | | | | | | = 0.500 | | |
| :For 6 ≤ X < 12; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | 5) | | | | | = 0.625 | | |
| For 12 ≤ X < 18; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-S}{S}\right)$ | 5) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $+\frac{X-12}{S}$ | | | | | = 0.375 | | |

| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spece |
|------------------|---|---|-----------------------------------|--|------------------|------------|------------------|-----------|------------|
| IVISION Descrip: | ITBC Design Exa | mple 1, Span 1 | 83 | File: | Ex1 Spa | n1 distrib | ution_factors.xl | Sheet: | 8 of 8 |
| Carlos Santa | | | | | | | | | |
| LEVER RULE | | | | | | | | | |
| EXTERIOR (con't) | S- | 8.0 1 | ť. | OH = | 3.0 f | t | | | |
| | RW = | 1.0 f | t X = S+0 | OH-RW-2ft = | 8.0 f | t | | | |
| For 18 < Y < 24. | | | | | | | | | |
| One Lane = | $\frac{16}{22}\left(\frac{X}{x} + \frac{X-6}{x}\right)$ | <u>5</u>) | | | | | = 0.625 | | |
| | 32(3 3 | . v . r . | 2 103 | | | | | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x-c}{s}\right)$ | $\frac{x-12}{S} + \frac{x-12}{S} + \frac{3}{2}$ | $\left(\frac{c-18}{s}\right)$ | | | | = -0.250 | | |
| For 24 < X < 30 | | . · · · · | 0.00 | | | | | | |
| One Lane = | $\frac{16}{22}\left(\frac{X}{5} + \frac{X-6}{5}\right)$ | 5) | | | | | = 0.625 | | |
| | 16(V V 6 | × 10 | 191 | | | | | | |
| Two Lanes = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-x}{s}\right)$ | $+\frac{x-12}{s}+\frac{3}{s}$ | 5 | | | | = -0.250 | | |
| - | 16 (X X - 0 | 5 X-12 | x -18 x -3 | 24) | | | | | |
| Three Lanes = | 32 5 5 | \$ | \$ \$ | _) | | | = -1.250 | | |
| For 30 ≤ X < 36: | 15/ X X-1 | 12 | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-s}{s}\right)$ | -) | | | | | = 0.625 | | |
| ÷ | 16 (X . X - 6 | x -12 | (-18) | | | | | | |
| Two Lanes = | $\overline{32}\sqrt{s}$ | * <u>s</u> | S) | | | | = -0.250 | | |
| Three Lanes - | $\frac{16}{X} + \frac{X-6}{X}$ | $5 + \frac{X - 12}{4} + \frac{3}{4}$ | x - 18 + x - 2 | $\frac{14}{4} + \frac{X - 30}{2}$ | | | 2 625 | | |
| Thee Lanes - | 321 5 5 | S | S S | S) | | | | | |
| For 36 ≤ X < 42: | 16 (X _ X - 6 | 5) | | | | | 0.005 | | |
| One Lane = | $\overline{32}(s+s)$ | 1 | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{16}\left(\frac{X}{X}+\frac{X-6}{6}\right)$ | $x + \frac{x - 12}{x} + 2$ | (-18) | | | | = -0.250 | | |
| The Lands | 32(8 8 | S | \$) | | | | United | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{5} + \frac{X-6}{5}\right)$ | $\frac{5}{5} + \frac{X-12}{5} + \frac{3}{5}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{14}{4} + \frac{X-30}{5}$ | | | = -2.625 | | |
| | JACV V | | 5 5 7 7 7 7 | U V 20 | (35. 9 | | | | |
| Four Lanes = | $\frac{10}{32}\left(\frac{x}{s}+\frac{x-c}{s}\right)$ | $\frac{1}{s} + \frac{x - 12}{s} + \frac{1}{s}$ | $\frac{1}{S} + \frac{\lambda}{S}$ | $\frac{4}{5} + \frac{x-30}{5} + \frac{1}{5}$ | $\frac{x-30}{s}$ | | = -4.375 | | |
| For 42 < X < 48 | | 100 | | | | | | | |
| One Lane = | $\frac{16}{22}\left(\frac{X}{x} + \frac{X-6}{5}\right)$ | 5) | | | | | = 0.625 | | |
| | 3410 0 16(V V V | × 12 1 | 10) | | | | | | |
| Two Lanes = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-c}{s}\right)$ | $+\frac{x-12}{s}+\frac{3}{s}$ | $\frac{1}{s}$ | | | | = -0.250 | | |
| - | 16 (X X-0 | 5 X-12 | x-18 x-2 | (4 - X - 30) | | | 0.005 | | |
| Inree Lanes = | 32 5 5 | \$ | S S | s) | | | = -2.625 | | |
| Four Lanes = | $\frac{16}{X} + \frac{X-6}{X}$ | $5 + \frac{X - 12}{4} + \frac{3}{4}$ | x - 18 + x - 2 | $\frac{24}{4} + \frac{x - 30}{4} + x - 30$ | X-36+ | (x - 42) | -6.500 | | |
| , ss, curios - | 32\\$ \$ | S | <i>S S</i> | S | S | S) | 0.000 | | |
| INTERIOR | | | | EXTER | IOR | | | | |
| One Lane Loaded | | = 0.625 | | One La | ne Loade | d | - | 0.625 | |
| Two Lanes Loade | d | = 0.875 | | Two La | nes Load | led | - | 0.625 | |
| Three Lanes Load | led | - 0.875 | | Three L | anes Loa | aded | - | 0.625 | |
| Four Lanes Loade | d | = 0.875 | | Fourla | ines Load | ded | | 0.625 | |
| | 7 | 1.010 | | | Louit | | | - Colored | |

4.2.15.4.2 Span 2



| TXDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/14/20 | 2017 | LRFD Spec |
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| BRIDGE | C-S-J: | ITBC Design Fra | ID #: mole 1. Span 2 | XXXX | Ck Dsn: | Ex1 So | Date: | tion factors vi | Rev. 10/18 | 2 of 8 |
| INTER | IOR BE | AM. | inple it opart a | | Trings | Lent op | | | Onder | 2010 |
| Shoarl | L Dictrib | ution Por Lana | Table 4622 | 20.11 | | | | | | |
| Sheart | Orala | and rei care | Table 4.0.2.2. | <u>5d-1).</u> | | | | | | |
| | One La | Lever Dula | (Table 2.C.1 | 1 01 | | | | | | |
| | | Lever Hule | (Table 3.6.1 | .1.2) | | | | | | |
| | | mg = 0.6 | 25 1.2 = | 0.750 | | | | | | |
| | | Modify to | or Skew: | | | | | | | |
| | | | skew correc | | 1.000 | | | | | |
| | | 42.120 | mg = 0.750 | 1.000 = | 0.750 | | | | | |
| | | Equation | (5) | | | | | | | |
| | | g = 0.30 | 5+ 25 | | | | | | | |
| | | a = 0.36 | +(8/25) = | 0.680 | | | | | | |
| | | Modify to | or Skew: | | | | | | | |
| | | | skew correc | tion = | 1.000 | | | | | |
| | | | q = 0.680 * | 1.000 = | 0.680 | | | | | |
| | | Bange of App | licability (ROA |) Checks | | | | | | |
| | | Check S | 35'<80'< | 16.0' | OK | | | | | |
| | | Check t | 45"<80" | < 12.0" | OK | | | | | |
| | | Check I | 20' < 106.8' | < 240' | OK | | | | | |
| | | Check N | 6>4 | 5 240 | OK | | | | | |
| | | Use Equation | from Table 44 | | haballas all. | intente to | - OK | | | |
| | | Use Equation | nom rable 4.0 | 0.2.2.38-1 | oecause an | snteria is | s Un. | | | |
| | | gvint1 = | 0.660 | | | | | | | |
| | Two or | More Lanes Lo | baded | | | | | | | |
| | | Lever Rule | (Table 3.6.1 | .1.2) | | | | | | |
| | | mg = Ma | ax(0.875 * 1.0, | 0.875 * 0.8 | 35, 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correc | tion = | 1.000 | | | | | |
| | | | mg = 0.875 | * 1.000 = | 0.875 | | | | | |
| | | Equation | 10) 10 | >2.0 | | | | | | |
| | | g = 0.2 | $+\left \frac{3}{12}\right - \left \frac{3}{25}\right $ | | | | | | | |
| | | 0-02 | (12) (33 | 25\42.0 - | 0.014 | | | | | |
| | | y = 0.2 4 | - (0/12) - (0/ | 55) 2.0 = | 0,014 | | | | | |
| | | would be the | skow corros | tion | 1 000 | | | | | |
| | | | Skew conec | 1 000 | 0.914 | | | | | |
| | | Damas of Ass | g = 0.014 | Cheeke | 0.014 | avera l | ana landa | (h) | | |
| | | Hange of App | icability (ROA |) Checks | (same as i | or one is | ane loade | ia) | | |
| | | Use Equation | from Table 4.6 | 5.2.2.3a-1 | because all | criteria is | SOK. | | | |
| | | $gV_{int2+} =$ | 0.814 | | | | | | | |
| | TXDOT | Policy states gV | Interior must be | $\geq m \cdot N_L \neq N_L$ | 2 | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85 * 3 / 6 = | - | 0.425 | | | | | |
| | ls W≥ | 20ft? Yes | | | | | | | | |
| | TXDOT | Policy states the | at if $W < 20$ ft, g | Vintenor is t | he Maximun | n of: gV | iti and m- | NL+Nb | | |
| >> | TXDOT | Policy states the | at if $W \ge 20$ ft, g | V _{Interior} is t | he Maximun | n of: gV | 11, gVint2+, | $m{\cdot}N_L{\div}N_0.$ | | |
| | gVinte | arior = 0.814 | | | | | | | | |
| | | | | | | | | | | |

| XDOT | County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/14/20 | 2017 | LRFD Spec |
|--------|-------------------|----------------------|----------------------------------|---|--------------------------------|-------------|---------------------------|-----------------|--------|-----------|
| VISION | C-S-J: Descrip | ITBC Design Exc | ample 1. Span 2 | IXXXX | Elle: | Ex1 So | Date: an2 distribution | ution factors. | Sheet: | 3 of 8 |
| NTER | IOR BE | AM: | | | | | | | | |
| Iomen | nt LL Dist | ribution Per Lan | e (Table 4.6 | 2.2.2b-1): | | | | | | |
| | One La | ne Loaded | | | | | | | | |
| | | Lever Rule | (Table 3.6 | 5.1.1.2) | | | | | | |
| | | mg = 0. | 625 * 1.2 = | 0.750 | | | | | | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corr | ection = | 1,000 | | | | | |
| | | | mg = 0.75 | 50 * 1.000 = | 0.750 | | | | | |
| | | Equation | 6 - 5 0.4 | C=>0.3/ F | 2.0.1 | | | | | |
| | | g = 0.0 | $6 + \left(\frac{S}{14}\right)$ | $\left(\frac{S}{L}\right) \left(\frac{\Lambda_s}{12L}\right)$ | $\left(\frac{r}{r_s^3}\right)$ | | | | | |
| | | g = 0.06 | 5 + (8/14)^0.4 | * (8/106.8)^0 | .3 * (1,271, | 611/(12 | *106.8*8* | 3))^0.1 = | 0.453 | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corr | ection = | 1.000 | | | | | |
| | | | g = 0.453 | * 1,000 = | 0.453 | | | | | |
| | | Range of App | olicability (RC | DA) Checks | | | | | | |
| | | Check S | S: 3.5'≤8.0 | '≤ 16.0' | | OK | | | | |
| | | Check t | s: 4.5" ≤ 8.0 |)" ≤ 12.0" | | OK | | | | |
| | | Check L | .: 20'≤106 | .8' ≤ 240' | | OK | | | | |
| | | Check M | N _b : 6≥4 | | | OK | | | | |
| | | Check H | Kg: 10,000 ≤ | 1,271,611 ≤ 7 | ,000,000 | OK | | | | |
| | | Use Equation | from Table | 4.6.2.2.2b-1 b | ecause all | criteria i | s OK. | | | |
| | | gM _{int1} = | 0.453 | | | | | | | |
| | Two or | More Lanes L | oaded | | | | | | | |
| | | Lever Rule | (Table 3.6 | 5.1.1.2) | | | | | | |
| | | mg = M | ax(0.875 * 1. | 0, 0.875 * 0.8 | 5, 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corr | ection = | 1.000 | | | | | |
| | | | mg = 0.87 | 5 * 1.000 = | 0.875 | | | | | |
| | | Equation | (5) | 0.6 (5)0.2 (| K)0.1 | | | | | |
| | | g = 0.0 | $75 + \left(\frac{5}{95}\right)$ | $\left \frac{3}{L}\right \left \frac{3}{12}\right $ | $\frac{1}{1+3}$ | | | | | |
| | | q = 0.07 | 25 + (8/9 5)^(| 6* (8/106.8) | 0 2 * (1 27 | 1 611/(1 | 2*106.8* | 8^3))^0.1 = | 0.649 | |
| | | Modify f | or Skew: | (0/100.0) | 0.2 (1,2) | no ma | 100.0 | 0 0)/ 0.1 = | 0.040 | |
| | | inearly i | skew corr | ection = | 1.000 | | | | | |
| | | | q = 0.649 | * 1.000 = | 0.649 | | | | | |
| | | Range of Apr | licability (RC | DA) Checks | (same as I | for one l | ane loade | ed) | | |
| | | Use Equation | from Table | 46222b-1b | ecause all i | oriteria i | s OK | | | |
| | | aMinta, = | 0.649 | 1.0.2.2.2.0 1 0 | occorr and | ontena i | 0.010 | | | |
| | TYDOT | Poliov states - | Market I | A D IN AL AL | | | | | | |
| | 1XDO1 | m.N. M. | O PE # O / | C ≤ HINNL÷IND | 0.405 | | | | | |
| | 10 14/ - | DOff 2 Vec | 0.05 37 | 0 = | 0.420 | | | | | |
| | TYDOT | Policy states the | at if W - 200 | M. is the | e Maximur | n of all | and | NI =NI | | |
| 60 | TYDOT | Policy states th | at if W > 201 | I aM. is the | e Maximun | n ol: aM | ni anu n | miNLaN | | |
| >> | COM | roncy states in | 1 1 Y 2 201 | a Sumintation is th | e maannun | in our give | Alta Atauuts | ++ ULLIAF = IAP | | |
| | givinte | arior = 0.649 | | | | | | | | |

| TXDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/14/20 | 2017 | LRFD Specs |
|---------------|--------------------|--------------------------------------|------------------------------|------------------------------|-------------------------------|-------------|------------|----------------------------|------------------|--------------|
| BRIDGE | C-S-J: | XXX-XX-XXXX | ID #: | XXXX | Ck Dsn: | Ex1 So | Date: | tion factors v | Rev. 10/18 - | (No Interim) |
| FYTER | NOR BE | AM. | inple 1, opan z | | It no. | Lest opt | | | Sildet. | 4010 |
| Shoarl | I Dietrib | ution Per Lane | Table 462 | 2 3h-11. | | | | | | |
| <u>Silear</u> | Onela | ne Loaded | 114010 4.0.2.1 | 2.50-17. | | | | | | |
| | One La | Lever Bule | (Table 3.6 | 112) | | | | | | |
| | | ma = 0.1 | (1 able 0,0 | 0.625 | TYDOT | | liele erer | ance Factor | of 1 D for a | 00 |
| | | Modify f | or Skow: | 0.025 | lane loade | d on the | exterior | beam. | | ille. |
| | | woony i | skew corre | ection - | 1.000 | | | | | |
| | | | mg = 0.62 | 5*1.000 = | 0.625 | | | | | |
| | | Lise Lever Bi | ile as per AA | SHTOLEE | Table 4 6 | 2.2 sh.1 | | | | |
| | | aV = | 0.625 | GIN O LINA | 1 1 auto 4.01 | SPACE I | | | | |
| | S | 9 vext1 - | 0.023 | | | | | | | |
| | Two or | More Lanes Lo | oaded | 1.55 | | | | | | |
| | | Lever Rule | (Table 3.6 | .1.1.2) | | | | | | |
| | | mg = Ma Modify f | ax(0.625 * 1.0 or Skew: | 0, 0.625 * 0.8 | 35, 0.625 * 0 | .65) = | 0.625 | | | |
| | | | skew corre | ection = | 1.000 | | | | | |
| | | | mg = 0.62 | 5 * 1.000 = | 0.625 | | | | | |
| | | Equation | | | | | | | | |
| | | d _e = dist | . b/w CL web | to curb | | | | | | |
| | | $d_e = OH$ | - Rail Width | | | | | | | |
| | | d _e = | 3ft - 1ft = | 2.0 | tt | | | | | |
| | | | (d_{c}) | | | | | | | |
| | | e = 0.6 | $+(\frac{1}{10})$ | | | | | | | |
| | | e = 0.6 · | + (2.0/10) = | 0.800 | | | | | | |
| | | g = e*g\ | /int2+Eq | | | | | | | |
| | | g = 0.80 | 0 * 0.814 = | 0.651 | | | | | | |
| | | Skew C | orrection is in | icluded in gV | /(interior). | | | | | |
| | | Range of App | blicability (RC | A) Checks | Interior | ROA is | implicitly | applied to the | he exterior b | beam. |
| | | Check I | nterior Beam | ROA: | OK | | | | | |
| | | Check d | l _e : -1.0' ≤ 2.0 |)' ≤ 5.5' | OK | | | | | |
| | | Check N | N _b : 6≠3 | | OK | | | | | |
| | | Use Equation | from Table 4 | 1.6.2.2.3b-1 | because all | criteria is | OK. | | | |
| | | $gV_{ext2+} =$ | 0.651 | | | | | | | |
| | TXDOT | Policy states g | VExterior must b | $be \ge gV_{interior}$ | | | | | | |
| | | gV _{interior} = | 0.814 | | | | | | | |
| | TXDOT | Policy states g | Exterior must b | e≥m·N _L ÷N | b | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85*3/6 | 5 = | 0.425 | | | | | |
| | Is OH ≤ | S/2 ? Yes | | | | | | | | |
| | ls W ≥ 2 | 20ft? Yes | | | | | | | | |
| >> | TXDOT | Policy states th | at if OH ≤ S/2 | 2, gV _{Exterior} is | gV _{intenior} . | | | | | |
| | TXDOT | Policy states th | at if $OH > S/2$ | 2 and W < 20 | Off, gV _{Exterior} | is the Ma | aximum o | f: gV _{ext1} , gV | interior, and | |
| | | m·NL÷N _b . | | and the second | | | | and the second | | |
| | TXDOT | Policy states th | at if OH > S/ | $2 \text{ ans } W \ge 20$ | oft, gV _{Exterior} i | s the Ma | aximum o | ft gV _{ext1} , gV | ext2+, gVinteric | it). |
| | | and m·N _L ÷N _b | | | | | | | | |
| | gV _{exte} | erior = 0.814 | | | | | | | | |

```
TXDOT
BRIDGE
                     ANY
           County:
                                       Highway
                                                      Any
XXXX
                                                                      Design:
                                                                                          Date
                                                                                                                       2017 LRFD Spe
                                                                                                     8/14/20
                     XXX-XX-XXXX
                                                                                                                      10/18 - (No Inte
                                                                      Ck Dsn:
                                       ID #
                                                                                          Date
                     ITBC Design Exa
                                     mple 1 Sr
DIVISION
                                                                                                                               5 of 8
 EXTERIOR BEAM:
Moment LL Distribution Per Lane (Table 4.6.2.2.2d-1):
          One Lane Loaded
                     Lever Rule
                           mg = 0.625 * 1.0 =
                                                     0.625
                                                                   TxDOT uses a multiple presence factor of 1,0 for one
                                                                   lane loaded on the exterior beam.
                           Modify for Skew:
                                       skew correction =
                                                                     1.000
                                       mg = 0.625 * 1.000 =
                                                                     0.625
                     Use Lever Rule as per AASHTO LRFD Table 4.6.2.2.2d-1.
                     gMext1 =
                                       0.625
          Two or More Lanes Loaded
                     Lever Rule
                                       (Table 3.6.1.1.2)
                           mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) =
                                                                                          0.625
                           Modify for Skew:
                                       skew correction =
                                                                     1.000
                                       mg = 0.625 * 1.000 =
                                                                      0.625
                     Equation
                           \mathbf{e} = 0.77 + \left(\frac{d_e}{9.1}\right)
                           e = 0.77 + (2.0/9.1) =
                                                                   0.990
                           g = e^*gM_{int2+Eq}
                           g = 0.99 * 0.649 =
                                                     0.643
                           Skew Correction included in gM(interior).
                     Range of Applicability (ROA) Checks
                                                                      Interior ROA is implicitly applied to the exterior beam.
                           Check Interior Beam ROA:
                                                                   OK
                           Check d_e: -1.0' \leq 2.0' \leq 5.5'
                                                                  OK
                           Check N<sub>b</sub>: 6 ≠ 3
                                                                   OK
                     Use Equation from Table 4.6.2.2.2d-1 because all criteria is OK.
                     gM_{ext2+} =
                                       0.643
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ gM<sub>interior</sub>
                     gMinterior =
                                      0.649
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ m·N<sub>L</sub>÷N<sub>b</sub>
                     m \cdot N_L \div N_b = 0.85 * 3 / 6 =
                                                                      0.425
          Is OH ≤ S/2 ? Yes
          Is W ≥ 20ft ? Yes
      >> TxDOT Policy states that if OH ≤ S/2, gM<sub>Exterior</sub> is gM<sub>interior</sub>.
          TxDOT Policy states that if OH > S/2 and W < 20ft, gM<sub>Exterior</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>interior</sub>, and
                     m·NI ÷Nn
          TxDOT Policy states that if OH > S/2 ans W ≥ 20ft, gM<sub>Extense</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>ext2+</sub>, gM<sub>menor</sub>
                     and m·NL+Nb
            gM<sub>exterior</sub> = 0.649
```



| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/14/20 | 2017 | LRFD Spec |
|--------------------------------|---|----------------------------------|-------------------------------|------------------------------------|-------------------|-------------|------------------|--------------------|------------------|
| DIVISION Descrip: | ITBC Design Exar | nple 1, Span 2 | 0000 | File: | Ex1 Spar | 12_distribu | ition factors.xl | Sheet: | 7 of 8 |
| LEVER RULE | S | = 8.0 ft | | | | | | | |
| INTERIOR (con't) | | | | | | | | | |
| For 18 ≤ S < 22: One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{s}$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{s-4}{s} + \frac{s-10}{s}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S-16}{S}$ | | | = 0.625 | | |
| For 22 ≤ S ≤ 24; One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{-18}{s}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S - 16}{S}$ | $+\frac{S-22}{S}$ | | = -1.500 | | |
| | | | | d hinge | | | Dail Witze | S = OH = | 8.0 ft 3.0 ft |
| L | он — Т | - s | 1 | | | | X = S+OH-I | = HW = RW-2ft = | 1.0 ft 8.0 ft |
| For X < 6: One Lane = | $\frac{16}{32}\left(\frac{X}{S}\right)$ | | | | | | = 0.500 | | |
| For 6 ≤ X < 12: One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ |) | | | | | ⇒ 0.625 | | |
| For 12 ≤ X < 18; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ |) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $+\frac{X-12}{S}$ | | | | | = 0.375 | | |

| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/14/20 | 2017 LRFD Sp | pece |
|-------------------------|---|----------------------------------|---------------------------------|---|------------|-----------|-----------------|---------------|-----------|
| IVISION Descrip: | ITBC Design Exan | nple 1, Span 2 | 17777 | File: | Ex1 Span | 2_distrib | ution_factors.a | Sheet: 8 of 8 | erim 3 |
| 16.121 Z.112 | | | | | | | | | |
| LEVER RULE | | | | | | | | | |
| EXTERIOR (con't | S = | 8.0 ft | | OH = | 3.0 ft | 6 | | | |
| | RW = | 1.0 ft | X = S+C | H-RW-2ft = | 8.0 ft | 9 | | | |
| For 18 ≤ X < 24: | 1000 00 00 00 | | | | | | | | |
| One Lane = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x-6}{s}\right)$ |) | | | | | = 0.625 | | |
| ÷ | 16 (X . X -6 | X -12 X | -18) | | | | | | |
| Two Lanes = | 32 8 5 | S | S) | | | | = -0.250 | | |
| For 24 ≤ X < 30: | 16 (X X - 6 | 1 | | | | | | | |
| One Lane = | $32 \left(\frac{s}{s} \right)^+ \frac{s}{s}$ | Į | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{22}\left(\frac{X}{2}+\frac{X-6}{2}\right)$ | $+\frac{X-12}{2}+\frac{X}{2}$ | -18 | | | | = -0.250 | | |
| | 3215 5 | S | 5 / -10 V-7 | a's . | | | | | |
| Three Lanes = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-0}{s}\right)$ | $+\frac{x-12}{S}+\frac{x}{S}$ | $\frac{-10}{S} + \frac{x-2}{S}$ | ") | | | = -1.250 | | |
| For 30 ≤ X < 36: | IETV V C | 1 | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-0}{s}\right)$ |) | | | | | = 0.625 | | |
| Two Lange - | $\frac{16}{X} + \frac{X-6}{X}$ | $+ \frac{X - 12}{+} \frac{X}{+}$ | -18 | | | | - 0 250 | | |
| Two Lanes = | 32 5 5 | S | S J | 1.00 | | | = -0.200 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $+\frac{X-12}{S}+\frac{X}{S}$ | $\frac{-18}{S} + \frac{X-2}{S}$ | $\frac{4}{s} + \frac{X - 30}{s}$ | | | = -2.625 | | |
| For $36 \le X < 42$: | | | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-6}{s}\right)$ |) | | | | | = 0.625 | | |
| Two Longe | 16(X + X - 6) | X -12 X | -18) | | | | 0.050 | | |
| Two Lanes = | 32 8 8 | s | S) | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{5} + \frac{X-6}{5}\right)$ | $+\frac{X-12}{S}+\frac{X}{S}$ | $\frac{-18}{s} + \frac{x-2}{s}$ | $\frac{4}{4} + \frac{X-30}{S}$ | | | = -2.625 | | |
| | 16(X X-6 | X-12 X | -18 X-2 | 4 X - 30 | 8 - 36) | | | | |
| Four Lanes = | $\frac{1}{32}\left(\frac{1}{s} + \frac{1}{s}\right)$ | + - + - + + | s + <u>s</u> | ++ | s) | | = -4.375 | | |
| For $42 \le X \le 48$: | 16/X X-6 | 1 | | | | | | | |
| One Lane = | $\frac{11}{32}\left(\frac{1}{s} + \frac{1}{s}\right)$ | J | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{16}\left(\frac{X}{x}+\frac{X-6}{6}\right)$ | $+\frac{X-12}{+}$ | -18 | | | | = -0.250 | | |
| A TOP (Heavily State) | 32 8 8 | S IN IN | S J | | | | | | |
| Three Lanes = | $\frac{10}{32}\left(\frac{x}{s}+\frac{x-6}{s}\right)$ | $+\frac{x-12}{S}+\frac{x}{S}$ | $\frac{-18}{S} + \frac{X-2}{S}$ | $\left(\frac{x-30}{s}\right)$ | | | = -2.625 | | |
| Four Lange - | $\frac{16}{X + X - 6}$ | $+\frac{X-12}{1}+\frac{X}{1}$ | -18 + x - 2 | $\frac{4}{4} + \frac{x - 30}{x - 30} + \frac{x - 30}{x - 30}$ | x - 36 + x | (-42) | 6 500 | | |
| rour canes = | 32 5 5 | S | 5 5 | S | S | s) | - 0.000 | | |
| INTERIOR | | | | EXTER | IOR | | | | |
| One Lane Loaded | | 0.625 | | One La | ne Loade | d | 1.14 | 0.625 | |
| Two Lanes Loade | d = | 0.875 | | Two La | nes Load | ed | (= | 0.625 | |
| Three Lanes Load | led = | 0.875 | | Three L | anes Loa | ded | 15 | 0.625 | |
| Four Lanes Loade | d = | 0.875 | | Fourla | nes Load | ed | 1.1.1 | 0.625 | |

| | Highway: | ANY | | | - | and la | | - | |
|--------------------------------|-----------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|----------------|
| Texas | C-S-J! | XXXXXX | | | Design: | BRGC | k Dsn: | BRG | |
| of Transportation | Bridge | Division | R | ev: 09/26/08 | | t | Date: | Aug-20 | |
| CONCRETE SECTION SHE | AR CAPA | CITY BY A | ASHTO L | RFD BRID | GE DESIG | N SPECIFIC | ATIONS, FO | URTH EDIT | ION, 2007 |
| Resistance Factors: | | | Units: | US | | | | | |
| φ _V = | 0.9 | | | | | | | | |
| φ _M = | 0.9 | | | | | | | | |
| φ _N = | 0.75 | | | | | | | | |
| Concrete: | | | Mild Steel: | | - | Prestressed | Steel: | | |
| fc =[| 5 | ksi | fy = | 60 | ksi | fpu = | 270 k | si | |
| Ec = | 4070 | ksi | Es = | 29000 | ksi | Ep = | 28500 k | si | |
| | | - | | | SECTIONS | | | | |
| | Units | 8 | 12 | 32 | 36 | 56 | 60 | 80 | 84 |
| Input Data | | | | | | | | | |
| Bending moment, Mu | kip-ft | 428.5 | 619.5 | 506.9 | 334.5 | 334.5 | 506.9 | 619.5 | 42 |
| Shear force, Vu | kip | 234.3 | 239.1 | 128.6 | 447.4 | 230.2 | 246.5 | 133.3 | 419 |
| Axial force, Nu (+ if tensile) | kip | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Web width, bv | in | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 | 39.0 |
| Shear depth, dv | in | 80.79 | 80.79 | 80.79 | 80.79 | 80.79 | 80.79 | 80.79 | 80.7 |
| Mild steel reinf. area, As | in^2 | 9.36 | 9.36 | 9.36 | 9.36 | 9.36 | 9.36 | 9.36 | 9.3 |
| Conc area on tension side, Ac | in^2 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657. |
| Area of stirrups, Av | in^2 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.7 |
| Stirrup spacing, s | in | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7.8 | 7. |
| Prestressed steel area, Aps | in^2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Prestress shear, Vp | kip | D | 0 | 0 | 0 | 0 | 0 | D | |
| Average prestress, fps | ksi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Torsional moment, Tu | kip-ft | 660 | 330 | 330 | 660 | 660 | 330 | 330 | 66 |
| Shear flow area, Ao | in^2 | 2971.6 | 2971.6 | 2971.6 | 2971.6 | 2971.6 | 2971.6 | 2971.6 | 2971. |
| Area of one leg of stirrup, At | in^2 | 0.44 | 0.44 | 0,44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.4 |
| Perimeter of stirrup, Ph | in | 324 | 324 | 324 | 324 | 324 | 324 | 324 | 32 |
| Calculated Values | _ | | - | - | | | | | - |
| Vc | kip | 529.9 | 527.6 | 594.4 | 496.5 | 532.1 | 525.4 | 590.0 | 496. |
| Vs | kip | 1517.9 | 1567.9 | 1865.6 | 1363.9 | 1526.6 | 1555.7 | 1842.3 | 1363. |
| ¢Vn €v | kip | 1843 7.55E-04 | 1886 7.68E-04 | 2214 4.45E-04 | 1674 1.00E-03 | 1853 7.43E-04 | 1873 7.89E-04 | 2189 4.59E-04 | 167 1.00E-0 |
| â | dea | 33.74 | 33.90 | 29.60 | 36.40 | 33.60 | 34.10 | 29 90 | 36 4 |
| R | ocg | 2.380 | 2.370 | 2 670 | 2,230 | 2 390 | 2.360 | 2.650 | 2.25 |
| Reg'd Shear reinf. Av/S | in^2/in | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.00 |
| Reg'd Torsion reinf. At/S | in^2/in | 0.016 | 0.008 | 0.007 | 0.018 | 0.016 | 0.008 | 0.007 | 0.01 |
| Maximum stirrup spacing, Smax | in | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24. |
| Conclusion | | | | | | | | | |
| Shear Be | inforcing | OK | OK |
| onearne | | 011 | OK | OK | OK | OK | OK | OK | OK |

4.2.15.5 Concrete Section Shear Capacity Spreadsheet

4.2.15.6 Bent Cap Details





4.3 INVERTED-T BENT CAP DESIGN EXAMPLE 2 (30° SKEW ANGLE)

Design example is in accordance with the AASHTO LRFD Bridge Design Specifications, 8th Ed. (2017) as prescribed by TxDOT Bridge Manual - LRFD (January 2020).

4.3.1 Design Parameters



Figure 4.28 Spans of the Bridge with 30 Degree Skewed ITBC

<u>Span 1</u>

54' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 9.24' along the axis of bent with 3' overhangs

2" Haunch

Span 2

112' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 9.24' along the axis of bent with 3' overhangs

3.75" Haunch

<u>Span 3</u>

54' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 9.24' along the axis of bent with 3' overhangs

2" Haunch

All Spans

Deck is 46 ft wide

Type T551 Rail (0.382 k/ft)

8" Thick Slab (0.100 ksf)

Assume 2" Overlay @ 140 pcf (0.023 ksf)

Use Class "C" Concrete

 $f'_c = 5 \text{ ksi}$

 $w_c = 150 \text{ pcf}$ (for weight)

 $w_c = 145 \text{ pcf}$ (for Modulus of Elasticity calculation)

"AASHTO LRFD" refers to the ASSHTO LRFD Bridge Design Specification, 8th Ed. (2017)..

"BDM-LRFD" refers to the TxDOT Bridge Design Manual -LRFD (January 2020).

"TxSP" refers to TxDOT guidance, recommendations, and standard practice.

"Furlong & Mirza" refers to "Strength and Serviceability of Inverted T-Beam Bent Caps Subject to Combined Flexure, Shear, and Torsion", Center for Highway Research Research Report No. 153-1F, The University of Texas at Austin, August 1974.

The basic bridge geometry can be found on the Bridge Layout located in the Appendices.

(TxSP)

(BDM-LRFD, Ch. 4, Sect. 5, Materials)

Grade 60 Reinforcing

 $f_y = 60 \text{ ksi}$

Bents

Use 36" Diameter Columns (Typical for Type TX54 Girders)

Define Variables

| <u>Back Span</u> | <u>Forward Span</u> | |
|--|-----------------------------------|---|
| Span1 = 54 ft | Span2 = 112ft | Span Length |
| GdrSpa1 = 8ft | GdrSpa2 = 8ft | Girder Spacing (Normalized values) |
| GdrNo1 = 6 | GdrNo2 = 6 | Number of Girders in Span |
| GdrWt1 = 0.851klf | GdrWt2 = 0.851klf | Weight of Girder |
| Haunch1 = 2in | Haunch $2 = 3.75$ in | Size of Haunch |
| Bridge | | |
| Skew = 30deg | | Skew of Bents |
| BridgeW = 46ft | | Width of Bridge Deck |
| RdwyW = 44ft | | Width of Roadway |
| GirderD = 54in | | Depth of Type TX54 Girder |
| BrgSeat = 1.5in | | Bearing Seat Buildup |
| BrgPad = 2.75in | | Bearing Pad Thickness |
| SlabThk = 8in | | Thickness of Bridge Slab |
| OverlavThk = 2in | | Thickness of Overlay |
| RailWt = 0.372klf | | Weight of Rail |
| w = 0.150 kcf | | Unit Weight of Concrete for Loads |
| $w_c = 0.140 \text{kcf}$ | | Unit Weigh of Overlay |
| B onts | | |
| <u>bents</u> | | Concrete Strength |
| $I_c = 5KSI$ | | Unit Weight of Concrete for E. |
| $w_{cE} = 0.145 \text{KCI}$ $E_c = 33000 \cdot w_{cE}^{1.5} \cdot \sqrt{2}$ | $\overline{f_c}$ $E_c = 4074$ ksi | Modulus of Elasticity of Concrete (AASHTO LRFD Eq. C5.4.2.4-2) |
| $f_y = 60$ ksi | | Yield Strength of Reinforcement |
| $E_s = 29000 \text{ksi}$ | | Modulus of Elasticity of Steel |
| D _{column} = 36in | | Diameter of Columns |

(BDM-LRFD, Ch. 4, Sect. 5, Materials)

Other Variables

Dynamic Load Allowance (AASHTO LRFD Table 3.6.2.1-1)

IM = 33%



Figure 4.29 Top View of the 30 Degrees Skewed ITBC with Spans and Girders

4.3.2 Determine Cap Dimensions



Figure 4.30 Section View of 30 Degrees Skewed ITBC

4.3.2.1 Stem Width

 $b_{stem} = D_{column} + 3in$

 $b_{stem} = 39$ in

The stem is typically at least 3" wider than the Diameter of the Column (36") to allow for the extension of the column reinforcement into the Cap. (TxSP)

4.3.2.2 Stem Height

Distance from Top of Slab to Top of Ledge:

Haunch2 is the larger of the two haunches.

 $D_{Slab_{to_Ledge}} = SlabThk + Haunch2 + GirderD + BrgPad + BrgSeat$

 $D_{Slab_to_Ledge} = 70.00$ in

StemHaunch = 3.75 in

The top of the stem must be 2.5" below the bottom of the slab. (BDM-LRFD, Ch. 4, Sect. 5, Geometric Constraints)

Accounting for the 1/2" of bituminous fiber, the top of the stem must have at least 2" of haunch on it, but the haunch should not be less than either of the haunches of the adjacent spans. $d_{stem} = D_{Slab_to_Ledge} - SlabThk - StemHaunch - 0.5in$

$$d_{stem} = 57.75$$
 in

Use: $d_{stem} = 57$ in

4.3.2.3 Ledge Width



Figure 4.31 Ledge Section of 30 Degrees ITBC

cover = 2.5 in

L = 8 in

Determine the Required Development Length of Bar M:

Try # 6 Bar for Bar M.

$$d_{bar_M} = 0.750$$
 in

 $A_{bar_M} = 0.44 \text{ in}^2$

Basic Development Length

$$L_{dh} = \frac{38.0 \cdot d_{bar_M}}{60} \cdot \left(\frac{f_y}{\sqrt{f_c}}\right) \qquad \qquad L_{dh} = 12.75 \text{ in}$$

Modification Factors for L_{dh}:

Is Top Cover greater than or equal to 2.5", and Side Cover greater than or equal to 2"?

The stem must accommodate ¹/₂" of bituminous fiber.

Round the Stem Height down to the nearest 1". (TxSP)

The Ledge Width must be adequate for Bar M to develop fully.

> " $L_{dh,prov}$ " must be greater than or equal to " $L_{dh,req}$ " for Bar M.

"cover" is measured from the center of the transverse bars.

"L" is the length of the Bearing Pad along the girder. A typical type TX54 bearing pad is $8" \times 21"$ as shown in the IGEB standard.

(AASHTO LRFD Eq. 5.10.8.2.4a-2)

(AASHTO LRFD 5.10.8.2.4b)

SideCover = cover
$$-\frac{d_{bar_M}}{2} = 2.13$$
 in"Side Cover" and "Top Cover"
are the clear cover on the side
and top of the hook respectively.
The dimension "cover" is
measured from the center of Bar
M.No. Reinforcement Confinement Factor, $\lambda_{rc} = 1.0$
Coating Factor, $\lambda_{cw} = 1.0$ The dimension "cover" is
measured from the center of Bar
M.Coating Factor, $\lambda_{cw} = 1.0$ Concrete Density Modification Factor, $\lambda = 1.0$ (AASHTO LRFD 5.4.2.8)The Required Development Length:
 $L_{dh_req} = max(L_{dh} \cdot (\frac{\lambda_{rc} \cdot \lambda_{cw} \cdot \lambda_{er}}{\lambda}), 8 \cdot d_{bar_M}, 6in.)$ (AASHTO LRFD 5.10.8.2.4a)Therefore,
 $L_{dh_req} = 12.75$ in
 $b_{ledge_min} = L_{dh_req} + cover + 12in - \frac{L}{2}$ $b_{ledge_min} = 23.25$ in
 b_{ledge_min} is 12" for TxGirders
(IGEB).Width of Bottom Flange:
 $b_f = 2 \cdot b_{ledge} + b_{stem}$ $b_f = 87$ in4.3.2.4Ledge Depth
Use a Ledge Depth of 28".
 $d_{ledge} = 28$ inAs a general rule of thumb,
Ledge Depth is greater than or
equal to 2'-3". This is the depth
or which a bar from a terminal

at which a bent from a typical

bridge will pass the punching

shear check.

Total Depth of Cap:

 $h_{\text{cap}} = d_{\text{stem}} + d_{\text{ledge}}$ $h_{cap} = 85$ in

4.3.2.5 <u>Summary of Cross Sectional Dimensions</u>

$$b_{stem} = 39$$
 in
 $d_{stem} = 57$ in
 $b_{ledge} = 24$ in
 $d_{ledge} = 28$ in
 $h_{cap} = 85$ in

4.3.2.6 Length of Cap

First define Girder Spacing and End Distance:



Figure 4.32 Elevation View of 30 Degrees Skewed ITBC

$$\begin{split} S &= 8 \text{ ft} & Girder Spacing \\ c &= 2 \text{ ft} & ``c`` is the distance from the Center \\ Line of the Exterior Girder to the \\ Edge of the Cap measured along \\ the Cap. \\ L_{Cap} &= S \cdot (GdrNo1 - 1) + 2c & L_{Cap} &= 44 \text{ ft} & Length of Cap \end{split}$$

TxDOT policy is as follows, "The edge distance between the exterior bearing pad and the end of the inverted T-beam shall not be less than 12in." (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria) replacing the statement in AASHTO LRFD 5.13.2.5.5 stating it shall not be less than d_f . Preferably, the stem should extend at least 3" beyond the edge of the bearing seat.

| Bearing Pad Dimensions: | (IGEB standard) |
|-------------------------|-----------------------|
| L = 8 in | Length of Bearing Pad |
| W = 21 in | Width of Bearing Pad |

4.3.3 Cross Sectional Properties of Cap

$$\begin{split} A_{g} &= d_{ledge} \cdot b_{f} + d_{stem} \cdot b_{stem} & A_{g} &= 4659 \text{in}^{2} \\ ybar &= \frac{d_{ledge} \cdot b_{f} \cdot \left(\frac{1}{2}d_{ledge}\right) + d_{stem} \cdot b_{stem} \cdot \left(d_{ledge} + \frac{1}{2}d_{stem}\right)}{A_{g}} & ybar &= 34.3 \text{ in } \begin{array}{c} Distance \text{ from bottom of the cap to} \\ the center of \text{ gravity of the cap} \end{array} \\ I_{g} &= \frac{b_{f} \cdot d_{ledge}^{3}}{12} + b_{f} \cdot d_{ledge} \cdot \left(ybar - \frac{1}{2}d_{ledge}\right)^{2} + \frac{b_{stem} \cdot d_{stem}}{12} + \cdots \\ b_{stem} \cdot d_{stem} \cdot \left[ybar - \left(d_{ledge} + \frac{1}{2}d_{stem}\right)\right]^{2} & I_{g} &= 2.86 \times 10^{6} \text{ in}^{4} \end{split}$$

4.3.4 Cap Analysis

4.3.4.1 Cap Model

Assume:

4 Columns Spaced @ 12'-0"

The cap will be modeled as a continuous beam with simple supports using TxDOT's CAP18 program.



Figure 4.33 Continuous Beam Model for 30 Degrees Skewed ITBC

TxDOT does not consider frame action for typical multi-column bents (BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis).



Figure 4.34 Cap 18 Model of 30 Degrees Skewed ITBC

The circled numbers in Figure 4.34 are the stations that will be used in the CAP 18 input file. One station is 0.5 ft in the direction perpendicular to the pgl, not parallel to the bent.

Station increment for CAP 18

Recall:

station = 0.5 ft

$$\begin{split} E_c &= 4074 \text{ ksi} & I_g = 2.86 \times 10^6 \text{ in}^4 \\ E_c I_g &= 1.165 \times 10^{10} \text{ kip} \cdot \text{in}^2 / \left(12 \frac{\text{in}}{\text{ft}} \right)^2 & E_c I_g = 8.09 \times 10^7 \text{kip} \cdot \text{ft}^2 \end{split}$$
SPAN 1

 $Rail1 = \frac{2 \cdot RailWt \cdot \frac{Span1}{2}}{\min(GdrNo1,6)}$

$$Slab1 = w_c \cdot GdrSpa1 \cdot SlabThk \cdot \frac{Span1}{2} \cdot 1.10$$

 $Girder1 = GdrWt1 \cdot \frac{Span1}{2}$

$$DLRxn1 = (Rail1 + Slab1 + Girder1)$$

 $Overlay1 = w_{Olay} \cdot GdrSpa1 \cdot OverlayThk \cdot \frac{Span1}{2}$

SPAN 2

 $Rail2 = \frac{2 \cdot RailWt \cdot \frac{Span2}{2}}{\min(GdrNo2,6)}$

$$Slab2 = w_c \cdot GdrSpa2 \cdot SlabThk \cdot \frac{Span2}{2} \cdot 1.10$$

Girder2 = GdrWt1
$$\cdot \frac{\text{Span2}}{2}$$
 Girder2 = 47.66 $\frac{\text{kip}}{\text{girder}}$

$$DLRxn2 = (Rail2 + Slab2 + Girder2)$$
 $DLRxn2 = 104.07 \frac{kip}{girder}$

Values used in the following equations can be found on "4.3.1 Design Parameters"

Rail Weight is distributed

thickened slab ends.

Slab1 = $23.76 \frac{\text{kip}}{\text{girder}}$ Increase slab DL by 10% to account for haunch and

evenly among stringers, up to 3 stringers per rail (TxSP).

Overlay is calculated

separetely, because it has different load factor than the rest of the dead loads.

Design for future overlay.

 $Rail1 = 3.44 \frac{kip}{girder}$

Girder1 = $22.98 \frac{\text{kip}}{\text{girder}}$

 $DLRxn1 = 50.17 \frac{kip}{girder}$

 $Overlay1 = 5.04 \frac{kip}{girder}$

Rail2 = $7.13 \frac{\text{kip}}{\text{girder}}$

 $Slab2 = 49.28 \frac{kip}{girder}$

$$Overlay2 = w_{Olay} \cdot GdrSpa2 \cdot OverlayThk \cdot \frac{Span2}{2} \qquad Overlay2 = 10.45 \frac{kip}{girder}$$

CAP

$$Cap = w_{c} \cdot A_{g} = 4.853 \frac{kip}{ft} \cdot \frac{0.5ft}{station} \qquad Cap = 2.427 \frac{kip}{station}$$

AASHTO LRFD 3.6.1.2.2 and 3.6.1.2.4)





LongSpan = 112 ft

ShortSpan = 54 ft

LongSpan

ShortSpan = min(Span1, Span2)
IM = 0.33
Lane =
$$0.64$$
klf $\cdot \left(\frac{\text{LongSpan+ShortSpan}}{2}\right)$
Lane = $53.12 \frac{\text{kip}}{\text{lane}}$
Truck = 32 kip + 32 kip $\cdot \left(\frac{\text{LongSpan-14ft}}{\text{LongSpan}}\right) + 8$ kip $\cdot \left(\frac{\text{LongSpan-28ft}}{\text{LongSpan}}\right)$

LongSpan = max(Span1, Span2)

Truck =
$$66.00 \frac{\text{kip}}{\text{lane}}$$

LLRxn = Lane + Truck
$$\cdot$$
 (1 + IM)
LLRxn = 140.90 $\frac{\text{kip}}{\text{lane}}$

Use HL-93 Live Load. For *maximum reaction at interior* bents, "Design Truck" will always govern over "Design Tandem". For the maximum reaction when the long span is more than twice as long as the short span, place the rear (32 kip) axle over the support and the middle (32 kip) and front (8 kip) axles on the long span. For the maximum reaction when the long span is less than twice as long as the short span, place the middle (32 kip) axle over the support, the front (8 kip) axle on the short span and the rear (32 kip) axle on the Combine "Design Truck" and "Design Lane" loadings (AASHTO LRFD 3.6.1.3). Dynamic load allowance, IM, does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4)



4.3.4.1.3 Cap 18 Data Input

Multiple Presence Factors, m (AASHTO LRFD Table 3.6.1.1.2-1)

| No. of Lanes | Factor "m" |
|----------------------|-------------|
| 1 | 1.20 |
| 2 | 1.00 |
| 3 | 0.85 |
| >3 | 0.65 |
| Limit States (AASHTO | LRFD 3.4.1) |

Strength I

| | Live Load and Dynamic Load Allowance | LL+IM = 1.75 | and Service I with DL (TxSP). |
|---------|--------------------------------------|----------------|---|
| | Dead Load Components | DC = 1.25 | TrDOT allows the Overlay |
| | Dead Load Wearing Surface (Overlay) | DW = 1.50 | Factor to be reduced to 1.25 |
| Service | <u>e I</u> | | (TxSP), since overlay is typically used in design only to |
| | Live Load and Dynamic Load Allowance | LL+IM = 1.00 | increase the safety factor, but |
| | Dead Load and Wearing Surface | DC & DW = 1.00 | in this example we will use <i>DW=1.50</i> . |
| | | | |

Dead Load

TxDOT considers Service level Dead Load only with a limit reinforcement stress of 22 ksi to minimize cracking. (BDM-LRFD, Chapter 4, Section 5, Design Criteria)

The Live Load is applied to the slab by two 16 kip wheel loads increased by the dynamic load allowance with the reminder of the live load distributed over a 10 ft (AASHTO LRFD 3.6.1.2.1) design lane width. (TxSP)

The Live Load applied to the slab is distributed to the beams assuming the slab is hinged at each beam except the outside beam. (BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis)

Input "Multiple Presence Factors" into CAP18 as "Load Reduction Factors".

consider Strength I, Service I,

The cap design need only

4.3.4.1.4 Cap 18 Output

| | <u>Max +M</u> | Max -M |
|----------------|---|--|
| Dead Load: | $M_{posDL} = 294.2 \text{ kip} \cdot \text{ft}$ | $M_{negDL} = -443.9 \text{ kip} \cdot \text{ft}$ |
| Service Load: | $M_{posServ} = 574.3 \text{ kip} \cdot \text{ft}$ | $M_{negServ} = -688.2 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{posUlt} = 863.4 \text{ kip} \cdot \text{ft}$ | $M_{negUlt} = -991.3 \text{ kip} \cdot \text{ft}$ |

4.3.4.2 Girder Reactions on Ledge



Figure 4.37 Girder Reactions on the Ledge of 30 Degrees Skewed ITBC

Dead Load

DLSpan1 = Rail1 + Slab1 + Girder1 Overlay1 = $5.04 \frac{\text{kip}}{\text{girder}}$ DLSpan2 = Rail2 + Slab2 + Girder2 Overlay2 = $10.45 \frac{\text{kip}}{\text{girder}}$ $DLSpan1 = 50.17 \frac{kip}{girder}$

$$DLSpan2 = 104.07 \frac{kip}{girder}$$

Live Load

Loads per Lane:

Use HL-93 Live Load. For maximum reaction at interior bents, "Design Truck" will always govern over "Design Tandem" for Spans greater than 26ft. For the maximum reaction, place the back (32 kips) axle over the support.



Figure 4.38 Live Load Model of 30 Degrees Skewed ITBC

for Girder Reactions on Ledge LaneSpan1 = 0.64klf $\cdot \left(\frac{\text{Span1}}{2}\right)$ LaneSpan1 = 17.28 $\frac{\text{kip}}{\text{lane}}$ LaneSpan2 = 0.64klf $\cdot \left(\frac{\text{Span2}}{2}\right)$ LaneSpan2 = 35.84 $\frac{\text{kip}}{\text{lane}}$ TruckSpan1 = 32kip + 32kip $\cdot \left(\frac{\text{Span1-14ft}}{\text{Span1}}\right)$ + 8kip $\cdot \left(\frac{\text{Span1-28ft}}{\text{Span1}}\right)$ TruckSpan1 = 59.56 $\frac{\text{kip}}{\text{lane}}$ TruckSpan2 = 32kip + 32kip $\cdot \left(\frac{\text{Span2-14ft}}{\text{Span2}}\right)$ + 8kip $\cdot \left(\frac{\text{Span2-28ft}}{\text{Span2}}\right)$ TruckSpan2 = 66.00 $\frac{\text{kip}}{\text{lane}}$

$$\begin{split} IM &= 0.33\\ LLRxnSpan1 &= LaneSpan1 + TruckSpan1 * (1 + IM)\\ LLRxnSpan1 &= 96.49 \frac{kip}{lane}\\ LLRxnSpan2 &= LaneSpan2 + TruckSpan2 * (1 + IM)\\ LLRxnSpan2 &= 123.62 \frac{kip}{girder} \end{split}$$

 $gV_{Span1_Int} = 0.876$ $gV_{Span1_Ext} = 0.876$ $gV_{Span2_Int} = 0.891$ $gV_{Span2_Ext} = 0.891$ Combine "Design Truck" and "Design Lane" loadings (AASHTO LRFD 3.6.1.3).

Dynamic load allowance, IM, does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4).

The Live Load Reactions are assumed to be the Shear Live Load Distribution Factor multiplied by the Live Load Reaction per Lane. The Shear Live Load Distribution Factor is calculated using the "LRFD Live Load Distribution Factors" Spreadsheet found in the Appendices.

The Exterior Girders must have a Live Load Distribution Factor equal to or greater than the Interior Girders. This is to

| $LLSpan1Int = gV_{Span1_Int} \cdot LLRxnSpan1$ | LLSpan1Int = $84.53 \frac{\text{kip}}{\text{girder}}$ |
|---|--|
| $LLSpan1Ext = gV_{Span1_Ext} \cdot LLRxnSpan1$ | LLSpan1Ext = $84.53 \frac{\text{kip}}{\text{girder}}$ |
| $LLSpan2Int = gV_{Span2_Int} \cdot LLRxnSpan2$ | LLSpan2Int = $110.15 \frac{\text{kip}}{\text{girder}}$ |
| $LLSpan2Ext = gV_{Span2_Ext} \cdot LLRxnSpan2$ | LLSpan2Ext = $110.15 \frac{\text{kip}}{\text{girder}}$ |

<u>Span 1</u>

Interior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1)

 $V_{s_Span1Int} = DLSpan1 + Overlay1 + LLSpan1Int$

 $V_{s_{Span1Int}} = 140 \text{ kip}$

Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1)

$$V_{u_Span1Int} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1 + 1.75 \cdot LLSpan1Int$$

 $V_{u_{Span1Int}} = 218 \text{ kip}$

Exterior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1)

 $V_{s_Span1Ext} = DLSpan1 + Overlay1 + LLSpan1Ext$ $V_{s_Span1Ext} = 140 \text{ kip}$ Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1) $V_{u_Span1Ext} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1 + 1.75 \cdot LLSpan1Ext$ $V_{u_Span1Ext} = 218 \text{ kip}$

Span 2

Interior Girder

```
Service Load (Service I Limit State, AASHTO LRFD 3.4.1)
```

```
V_{s_Span2Int} = DLSpan2 + Overlay2 + LLSpan2Int
```

 $V_{s \text{ Span2Int}} = 225 \text{ kip}$

Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1)

 $V_{u_Span2Int} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot LLSpan2Int$

 $V_{u_Span2Int} = 339 \text{ kip}$

Exterior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1)

 $V_{s \ Span2Ext} = DLSpan2 + Overlay2 + LLSpan2Ext$

 $V_{s \ Span2Ext} = 225 \ kip$

Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1)

 $V_{u \ Span2Ext} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot LLSpan2Ext$

 $V_{u_Span2Ext} = 339 \, kip$

4.3.4.3 Torsional Loads



To maximize the torsion, the live load only acts on the longer span.

Figure 4.39 Live Load Model of 30 Degrees Skewed ITBC for Torsional Loads





 $a_v = 12$ in

" a_v " is the value for the distance from the face of the stem to the center of bearing for the girders. 12" is the typical values for TxGirders on ITBC (IGEB). The lever arm is the distance from the center line of bearing to the centerline of the cap.

LeverArm = 31.5 in

 $b_{stem} = 39$ in

LeverArm = $a_v + \frac{1}{2}b_{stem}$

Interior Girders

Girder Reactions

 $R_{u_{Span1}} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$

 $R_{u_{span1}} = 70 \text{ kip}$

$$\begin{split} R_{u_Span2} &= 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot gV_{Span2_Int} \\ &\cdot [LaneSpan2 + TruckSapn2 \cdot (1 + IM)] \end{split}$$

 $R_{u_{Span2}} = 339 \text{ kip}$

Torsional Load

$$\mathbf{T}_{\mathbf{u}_{\perp}\mathbf{Int}} = \left| \mathbf{R}_{\mathbf{u}_{\perp}\mathbf{Span1}} - \mathbf{R}_{\mathbf{u}_{\perp}\mathbf{Span2}} \right| \cdot \mathbf{LeverArm}$$

$$T_{u \text{ Int}} = 706 \text{ kip} \cdot \text{ft}$$

Exterior Girders

Girder Reactions

$$R_{u \text{ Span1}} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$$

$$\begin{split} R_{u_Span2} &= 1.25 \cdot \text{DLSpan2} + 1.5 \cdot \text{Overlay2} + 1.75 \cdot \text{gV}_{Span2_Ext} \\ &\cdot [\text{LaneSpan2} + \text{TruckSapn2} \cdot (1 + \text{IM})] \end{split}$$

$$R_{u_{Span2}} = 339 \text{ kip}$$

Torsional Load

$$T_{u_Ext} = |R_{u_Span1} - R_{u_Span2}| \cdot LeverArm$$

$$T_{u Ext} = 706 \text{ kip} \cdot \text{ft}$$

Torsion on Cap



Figure 4.41 Elevation View of 30 Degrees Skewed ITBC with Torsion Loads



Figure 4.42 Torsion Diagram of 30 Degrees Skewed ITBC

Analyzed assuming Bents are torsionally rigid at Effective Face of Columns.

 $T_u = 706 \ \text{kip} \cdot \text{ft}$

Maximum Torsion on Cap

4.3.4.4 Load Summary

Ledge Loads

Interior Girder

Service Load

$$V_{s_Int} = max(V_{s_Span1Int}, V_{s_Span2Int}) \qquad \qquad V_{s_Int} = 224.67 \text{ kip}$$

Factored Load

$$V_{u_{Int}} = max(V_{u_{Span1Int}}, V_{u_{Span2Int}})$$
 $V_{u_{Int}} = 338.53 \text{ kip}$

Exterior Girder

Service Load

$$V_{s_Ext} = max(V_{s_Span1Ext}, V_{s_Span2Ext})$$
 $V_{s_Ext} = 224.67 \text{ kip}$

Factored Load

$$V_{u_Ext} = max(V_{u_Span1Ext}, V_{u_Span2Ext})$$
 $V_{u_Ext} = 338.53 \text{ kip}$

Cap Loads

Positive Moment (From CAP18)

| Dead Load: | $M_{posDL} = 294.4 \text{ kip} \cdot \text{ft}$ |
|----------------|---|
| Service Load: | $M_{posServ} = 574.3 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{posUlt} = 863.4 \text{ kip} \cdot \text{ft}$ |

Negative Moment (From CAP18)

| Dead Load: | $M_{negDL} = -443.9 \text{ kip} \cdot \text{ft}$ |
|---------------|--|
| Service Load: | $M_{negServ} = -688.2 \text{ kip} \cdot \text{ft}$ |

| Factored Load: | $M_{negUlt} = -991.3 \text{ kip} \cdot \text{ft}$ | |
|---|---|--|
| Maximum Torsion and Concur | rrent Shear and Moment (Strength I) | |
| $T_u = 706 \text{ kip} \cdot \text{ft}$ | | Located two stations away from centerline of column. |
| $V_u = 452.1 \text{ kip}$ | | V., and M., values are from |
| $M_u = 394.2 \text{ kip} \cdot \text{ft}$ | | CAP18 |

4.3.5 Locate and Describe Reinforcing



Figure 4.43 Section View of 30 Degrees Skewed ITBC

Recall:

 $b_{stem} = 39 \text{ in}$ $d_{stem} = 57 \text{ in}$ $b_{ledge} = 24 \text{ in}$ $d_{ledge} = 28 \text{ in}$ $b_{f} = 87 \text{ in}$

$$h_{cap} = 85$$
 in
cover = 2.5 in

4.3.5.1 Describe Reinforcing Bars

| $d_{bar_A} = 1.410$ in | |
|------------------------|---|
| | |
| $d_{bar_B} = 1.410$ in | |
| | In the calculation of b_{ledge} , #6 |
| $d_{bar_M} = 0.75$ in | Bar M was considered. Bar M |
| | must be #6 or smaller to allow it fullv develop. |
| $d_{bar_N} = 0.75$ in | To prevent confusion. use the |
| | same bar size for Bar N as Bar |
| $d_{bar_S} = 0.75$ in | М. |
| | |
| $d_{bar_T} = 0.75$ in | |
| | $d_{bar_A} = 1.410 \text{ in}$ $d_{bar_B} = 1.410 \text{ in}$ $d_{bar_M} = 0.75 \text{ in}$ $d_{bar_N} = 0.75 \text{ in}$ $d_{bar_S} = 0.75 \text{ in}$ $d_{bar_T} = 0.75 \text{ in}$ |

4.3.5.2 <u>Calculate Dimensions</u>

$$\begin{split} d_{s_neg} &= h_{cap} - cover - \frac{1}{2} d_{bar_S} - \frac{1}{2} d_{bar_A} & d_{s_neg} = 81.42 \text{ in} \\ d_{s_pos} &= h_{cap} - cover - \frac{1}{2} max(d_{bar_S}, d_{bar_M}) - \frac{1}{2} d_{bar_B} & d_{s_pos} = 81.42 \text{ in} \\ a_v &= 12 \text{ in} & & \\ a_f &= a_v + cover & a_f = 14.50 \text{ in} \\ d_e &= d_{ledge} - cover & d_e = 25.50 \text{ in} \\ d_f &= d_{ledge} - cover - \frac{1}{2} d_{bar_M} - \frac{1}{2} d_{bar_B} & d_f = 24.42 \text{ in} \\ h &= d_{ledge} + BrgSeat & h = 29.50 \text{ in} \end{split}$$



Figure 4.44 Plan View of 30 Degrees Skewed ITBC

 $\alpha = 60 \text{ deg}$

Recall:

L = 8 inW = 21 in Angle of Bars S (Angle from the horizontal) Dimension of Bearing Pad

4.3.6 Check Bearing

The load on the bearing pad propagates along a truncated pyramid whose top has the area A_1 and whose base has the area A_2 . A_1 is the loaded area (the bearing pad area: L×W). A_2 is the area of the lowest rectangle contained wholly within the support (the Inverted Tee Cap). A_2 must not overlap the truncated pyramid of another load in either direction, nor can it extend beyond the edges of the cap in any direction.



Figure 4.45. Bearing Check for 30 Degrees Skew Angle

(AASHTO LRFD 5.5.4.2) Area under Bearing Pad

 $\begin{array}{l} \frac{1}{2} \mathbf{b}_{\text{stem}} \end{array} \qquad \qquad \begin{array}{l} "B" \text{ is the distance from perimeter} \\ of A_1 \text{ to the perimeter of } A_2 \text{ as seen} \\ \\ \hline \mathbf{w} \end{array} \qquad \qquad \begin{array}{l} \text{in the above figure} \end{array}$

 $A_1 = 168 \text{ in}^2$

 $L_2 = 24.00$ in

Resistance Factor (
$$\phi$$
) = 0.7

Interior Girders

 $A_1 = L \cdot W$

$$\begin{split} B &= \min\left[\left(b_{ledge} - a_v\right) - \frac{1}{2}L, \left(a_v + \frac{1}{2}b_{stem}\right) \\ &- \frac{1}{2}L, 2d_{ledge}, \frac{1}{2}S - \frac{1}{2}W\right] \end{split}$$

B = 8 in. $L_2 = L + 2 \cdot B$

175

$$W_2 = W + 2 \cdot B$$
 $W_2 = 37.00 \text{ in}$
 $A_2 = L_2 \cdot W_2$ $A_2 = 888 \text{ in}^2$

Modification factor

$$m = \min(\sqrt{\frac{A_2}{A_1}}, 2) = 2.29 \text{ and } 2$$
 $m = 2$
 AASHTO LRFD Eq. 5.6.5-3

 $\phi V_n = \phi$
 $0.85 f_c$
 A_1
 m
 $\phi V_n = 999.6 \text{ kips}$
 AASHTO LRFD Eqs. 5.6.5-1

 $v_{u_{\text{Int}}} = 338.53 < \phi V_n$
 BearingChk = "OK!"
 $V_{u_{\text{int}}} from "4.3.4.4 Load Summary".$

$$B = \min\left[\left(b_{\text{ledge}} - a_{v}\right) - \frac{1}{2}L, \left(a_{v} + \frac{1}{2}b_{\text{stem}}\right) - \frac{1}{2}L, 2d_{\text{ledge}}, \frac{1}{2}S - \frac{1}{2}W, c - \frac{1}{2}W\right]$$

| | $B = 8 \text{ in.} \begin{array}{l} "B" \text{ is the distance from} \\ perimeter of A_1 \text{ to the} \\ perimeter of A_2 \text{ as seen} \\ \text{ in the above figure} \end{array}$ |
|------------------|---|
| $L_2 = L + 2 B$ | $L_2 = 24.00 \text{ in}$ |
| $W_2 = W + 2 B$ | $W_2 = 37.00$ in |
| $A_2 = L_2 W_2$ | $A_2 = 888 \text{ in}^2$ |

Modification factor

$$m = min\left(\sqrt{\frac{A_2}{A_1}}, 2\right) = 2.29 \text{ and } 2 \quad m = 2$$
 AASHTO LRFD Eq. 5.6.5-3

$$\phi V_n = \phi \quad 0.85 \quad f_c \quad A_1 \quad m \qquad \phi V_n = 999.6 \text{ kips} \qquad AASHTO \ LRFD \ Eqs. 5.6.5-1 \\ and 5.6.5-2: \\ V_{u_ext} = 338.53 \text{ kips} < \Phi V_n \qquad BearingChk="OK!" \qquad V_{u_ext} \ from ``4.3.4.4 \ Load \\ Summary''.$$

4.3.7 Check Punching Shear



AASHTO LRFD 5.8.4.3.4, the truncated pyramids assumed as failure surfaces for punching shear shall not overlap.

AASHTO LRFD 5.5.4.2.

Figure 4.46 Punching Shear Check for 30 Degrees **Skew Angle**

Resistance Factor (ϕ) = 0.90

Is $\frac{1}{2}$

 $\frac{1}{2}S$

 d_{f}

Determine if the Shear Cones Intersect

$$Is \frac{1}{2}S - \frac{1}{2}W \ge d_{f}?$$

$$\frac{1}{2}S - \frac{1}{2}W = 37.5 \text{ in}$$

$$d_{f} = 24.42 \text{ in}$$

$$Is \frac{1}{2}b_{stem} + a_{v} - \frac{1}{2}L \ge d_{f}?$$

$$Yes. Therefore, shear cones do not intersect in the longitudinal direction of the cap.$$

$$TxDOT uses "df" instead of "de" for Punching Shear (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria). This is because "df" has traditionally been used for inverted tee bents and was sed in the Inverted Tee Research (Furiong % Mirza pg. 58).$$

$$Is \frac{1}{2}b_{stem} + a_{v} - \frac{1}{2}L \ge d_{f}?$$

$$Yes. Therefore, shear cones do not intersect in the transverse direction of the cap.$$

$$\frac{1}{2}b_{stem} + a_v - \frac{1}{2}L = 27.5$$
 in
d_f = 24.42 in

Interior Girders

| $V_n = 0.125 \boxtimes \lambda \sqrt{f_c'} \ b_o \ d_f$ | $V_{\rm n} = 585.91 {\rm kips}$ | AASHTO LRFD 5.8.4.3.4-3 |
|---|----------------------------------|---|
| $b_o = W + 2L + 2d_f$ | $b_o = 84.84 in$ | AASHTO LRFD 5.8.4.3.4-4 |
| $\phi V_n = 527.32 \text{ kips}$ | | |
| $V_{u_Int} = 338.53 \text{ kips} < \varphi V_n$ | PunchingShearChk= "OK!" | V _{u_int} from "4.3.4.4 Load Summary" |

•

| Exterior Girders | | |
|--|-------------------------------|---|
| $V_{n} = \min[(0.125 \cdot \sqrt{f_{c}} \cdot \left(\frac{1}{2}W + L + d_{f} + c\right) * d_{f}, 0.125 \cdot \sqrt{f_{c}} \cdot (W + 2L + 2d_{f}) * d_{f})]$ | $V_{n} = 545.15 \text{ kips}$ | AASHTO LRFD 5.8.4.3.4-3 and 5.8.4.3.4-5 |

| $\phi V_n = 411.09 \text{ kips}$ | | |
|--|-------------------------|----------------------------------|
| $V_{u_ext} = 338.53 \text{ kips} < \varphi V_n$ | PunchingShearChk= "OK!" | V _{u_ext} "4.3.4.4 Load |
| | | Summary". |

4.3.8 Check Shear Friction

Determine the Distribution Width

 $= \min[69, 96, 48]$

Interior Girders"S" is the girder spacing. $b_{s_{Int}} = min(W + 4a_v, S)$ "S" is the girder spacing.= min (69 in, 96 in) $b_{s_{Int}} = 69 in$ $A_{cv} = b_{s_{Int}} \cdot d_e$ $A_{cv} = 1759.5 in2$ Exterior Girders $b_{s_{ext}} = min(W + 4a_v, S, 2c)$ "S" is the girder spacing.

= 48 in $A_{cv} = b_{s ext} \cdot d_e$ $A_{cv} = 1224 in2$

Interior Girders

 $V_{n} = \min(0.2 \cdot f_{c} \cdot A_{cv}, 0.8 \cdot A_{cv}) \quad V_{n} = 1408 \text{ kips}$ $= \min(1759.5, 1408)$ $\phi V_{n} = 1267 \text{ kips}$ $V_{u_{int}} = 338.53 \text{ kips} < \phi V_{n}$ ShearFrictionChk="OK!" $V_{u_{int}} from "4.3.4.4 \text{ Load}$ Summary".

Exterior Girders

| $V_n = min(0.2 \cdot f_c \cdot A_{cv}, 0.8 \cdot A_{cv})$ = min (1224, 979.2) | V _n = 979.2 kips | AASHTO LRFD 5.8.4.2.2-1 and 5.8.4.2.2-2 |
|--|-----------------------------|--|
| $\phi V_n = 881 \text{ kips}$ | | |
| $V_{u_ext} = 338.53 \text{ kips} < \varphi V_n$ | ShearFrictionChk= "OK!" | V _{u_ext} from "4.3.4.4 Load Summary". |

4.3.9 Flexural Reinforcement for Negative Bending (Bars A)

| $M_{dl} = M_{negDL} $ | $M_{dl} = 443.9 \text{ kip} \cdot \text{ft}$ |
|------------------------|--|
| $M_s = M_{negServ} $ | $M_s = 688.2 \text{ kip} \cdot \text{ft}$ |
| $M_{u} = M_{negUlt} $ | $M_u = 991.3 \text{ kip} \cdot \text{ft}$ |

4.3.9.1 Minimum Flexural Reinforcement

Factored Flexural Resistance, M_r , must be greater than or equal to the lesser of $1.2M_{cr}$ (Cracking Moment) or $1.33M_u$ (Ultimate Moment).

| enter of Gravity he bottom of the |
|--------------------------------------|
| ure (BDM- et. 5, Design |
| enter of Gravity n fiber |
| for the extreme |
| t (AASHTO 3-1) |
| of 1.2M _{cr} or |
| termining |
| steel required. |
| |

Thus, M_r must be greater than $M_f = 1318.4 \ \text{kip} \cdot \text{ft}$

4.3.9.2 Moment Capacity Design

Try, 7 ~ #11's Top Number of bars in tension BarANo = 7Diameter of main reinforcing $d_{bar A} = 1.410$ in bars $A_{\text{bar A}} = 1.56 \text{ in}^2$ Area of main reinforcing bars Area of steel in tension $A_s = BarANo \cdot A_{bar_A}$ $A_s = 10.92 \text{ in}^2$ Diameter of shear reinforcing $d_{stirrup} = 0.75$ in $d_{stirrup} = d_{bar_S}$ bars $d = d_{s neg}$ d = 81.42 in $b = b_f$ b = 87 inCompressive Strength of Concrete $f_{c} = 5.0 \text{ ksi}$ Yield Strength of Rebar $f_v = 60 \text{ ksi}$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.85 - 0.05(f_c - 4ksi)$ Bounded by: $0.65 \le \beta_1 \le 0.85$ $\beta_1 = 0.80$ Depth of Cross Section under $c = \frac{A_s f_y}{0.85\ _c\beta_1 b}$ c = 2.22 in Compression under Ultimate Load This "c" is the distance from the extreme compression fiber to the (AASHTO LRFD Eq. 5.6.3.1.2-4)

neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.

$$a = c \cdot \beta_1$$
 $a = 1.78 in$

Note: "a" is less than " d_{ledge} ". Therefore the equivalent stress block acts over a rectangular area. If "a" was greater than " d_{ledge} ", it would act over a Tee shaped area.

$$\begin{split} M_n &= A_s f_y \left(d - \frac{a}{2} \right) \cdot \frac{1 \text{ft}}{12 \text{in}} & M_n &= 4397 \text{ kip} \cdot \text{ft} \\ \epsilon_s &= 0.003 \cdot \frac{d-c}{c} & \epsilon_s &= 0.107 \end{split}$$

 $\epsilon_{s} > 0.005$

FlexureBehavior = "Tension Controlled"

$$\Phi_{M} = 0.90$$

$$M_{r} = \Phi_{M}M_{n}$$

$$M_{r} = 3957.3 \text{ kip} \cdot \text{ft}$$

$$M_{f} = 1318.4 \text{ kip} \cdot \text{ft} < M_{r}$$

$$M_{n} = 991.3 \text{ kip} \cdot \text{ft} < M_{r}$$

$$UltimateMom = "OK!"$$

Depth of Equivalent Stress Block (AASHTO LRFD 5.6.2.2)

Nominal Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.2-1)

Strain in Reinforcing at Ultimate

(AASHTO LRFD 5.6.2.1)

(AASHTO LRFD 5.5.4.2)

Factored Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.1-1)

4.3.9.3 Check Serviceability

To find s_{max}:

Modular Ratio:

$$n = \frac{E_s}{E_c} \qquad n = 7.12$$

Tension Reinforcement Ratio:

$$\rho = \frac{A_s}{b \cdot d} \qquad \rho = 0.0015$$

$$k = \sqrt{(2\rho n) + (\rho n)^2} - (\rho n) \qquad k = 0.136$$

 $d \cdot k = 11.07$ in $< d_{ledge} = 28$ in

Therefore, the compression force acts over a rectangular area.

$$j = 1 - \frac{\kappa}{3}$$
 $j = 0.955$

$$\begin{split} f_{ss} &= \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12 \text{in}}{1 \text{ft}} & f_{ss} &= 9.73 \text{ ksi} \\ f_a &= 0.6 f_y & f_a &= 36.00 \text{ ksi} \\ f_{ss} &< f_a & \text{ServiceStress} = ``OK!`` \\ d_c &= \text{cover} + \frac{1}{2} d_{\text{stirrup}} + \frac{1}{2} d_{\text{bar}_A} & d_c &= 3.58 \text{ in} \end{split}$$

Exposure Condition Factor:

$$\begin{split} \gamma_e &= 1.00 \\ \beta_s &= 1 + \frac{d_c}{0.7(h_{cap} - d_c)} & \beta_s &= 1.06 \\ s_{max} &= \min\left(\frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c, 12in.\right) & s_{max} &= 12 \text{ in} \\ s_{Actual} &= \frac{b_{stem} - 2d_c}{BarANo - 1} & s_{Actual} &= 5.31 \text{ in} \\ s_{actual} &< s_{max} & \text{ServiceabilityCheck} = "OI" \end{split}$$

4.3.9.4 Check Dead Load

Check allowable M_{dl} : $f_{dl} = 22 \text{ ksi}$

$$\begin{split} M_{a} &= A_{s} \cdot d \cdot j \cdot f_{dl} \cdot \frac{1 f t}{12 i n} & M_{a} &= 1556.7 \text{ kip} \cdot f t \\ M_{dl} &= 443.9 \text{ kip} \cdot f t < M_{a} & \text{DeadLoadMom} = "OK!" \end{split}$$

For service loads, the stress on the cross-section is located as shown in Figure 4.47.



Figure 4.47 Stresses on the Cross Section for Service Loads of 30 Degrees Skewed ITBC

If the compression force does not act over rectangular area, j will be different.

Service Load Bending Stress in outer layer of the reinforcing.

Allowable Bending Stress (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

For Class 1 Exposure Conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e = 0.75$). (BDM-LRFD Ch. 4, Sect. 5, Design Criteria) (AASHTO LRFD Eq. 5.6.7-1)

A good practice is to place a bar every 12 in along each surface of the bent. (TxSP)

TxDOT limits dead load stress to 22 ksi, which is set to limit observed cracking under dead load.

Allowable Dead Load Moment

4.3.10 Flexural Reinforcement for Positive Bending (Bars B)

| $M_{dl} = M_{posDL}$ | $M_{dl} = 294.4 \text{ kip} \cdot \text{ft}$ |
|----------------------|--|
| $M_s = M_{posServ}$ | $M_s = 574.3 \text{ kip} \cdot \text{ft}$ |
| $M_u = M_{posUlt}$ | $M_u = 863.4 \text{ kip} \cdot \text{ft}$ |

4.3.10.1 Minimum Flexural Reinforcement

Factored Flexural Resistance, M_r , must be greater than or equal to the lesser of $1.2M_{cr}$ (Cracking Moment) or $1.33M_u$ (Ultimate Moment).

| $I_g = 2.86 \times 10^6 \text{ in}^4$ | | Gross Moment of Inertia |
|--|---|---|
| y _t = ybar | y _t = 34.3 in | <i>Distance to the Center of Gravity of the Cap from the top of the Cap from the top of the Cap</i> |
| $f_r = 0.24\sqrt{f_c}$ | $f_r = 0.537$ ksi | Modulus of Rupture (BDM- LRFD, Ch. 4, Sect. 5, Design Criteria) |
| $S = \frac{I_g}{y_t}$ | $S = 8.34 \times 10^4 \text{ in}^3$ | Section Modulus for the extreme tension fiber |
| $M_{cr} = S \cdot f_r \cdot \frac{1ft}{12in}$ | $M_{cr} = 3732.2 \text{ kip} \cdot \text{ft}$ | Cracking Moment (AASHTO LRFD Eq. 5.6.3.3-1) |
| $M_f = minimum of:$ | | Design the lesser of $1.2M_{cr}$ or |
| $1.2M_{cr} = 4478.6 \text{ kip} \cdot \text{ft}$ | | $1.33M_u$ when determining |
| $1.33M_u = 1148.3 \text{ kip} \cdot \text{ft}$ | | mininum area of steel required. |
| | | |

Thus, M_r must be greater than $M_f = 1148.3 \; \text{kip} \cdot \text{ft}$

4.3.10.2 Moment Capacity Design

Try,
$$11 \sim \#11^{\circ}s$$
 BottomNumber of bars in tensionBarBNo = 11Diameter of main reinforcing $d_{bar_B} = 1.41$ inDiameter of main reinforcing bars $A_{bar_B} = 1.56$ in²Area of main reinforcing bars $A_s = BarBNo \cdot A_{bar_B}$ $A_s = 17.16$ in² $d = d_{s,pos}$ $d = 81.42$ in $b = b_{stem}$ $b = 39$ in $f_c = 5.0$ ksiCompressive Strength of Concrete $f_y = 60$ ksiYield Strength of Rebar $\beta_1 = 0.85 - 0.05(f_c - 4ksi)$ $\beta_1 = 0.80$ $c = \frac{A_s f_y}{0.85 f_c \beta_1 b}$ $c = 7.76$ inDepth of Cross Section under
Compression under Ultimate Load

(AASHTO LRFD Eq. 5.6.3.1.2-4)

Depth of Equivalent Stress Block

(AASHTO LRFD 5.6.2.2)

This "c" is the distance from the extreme compression fiber to the neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.

$$a = c \cdot \beta_1 \qquad \qquad a = 6.21 \text{ in}$$

Note: "a" is less than " d_{stem} ". Therefore the equivalent stress block acts over a rectangular area. If "a" was greater than " d_{stem} ", it would act over a Tee shaped area.

 $M_f = 1148.3 \text{ kip} \cdot \text{ft} < M_r$

 $M_u = 863.4 \text{ kip} \cdot \text{ft} < M_r$

$$\begin{split} M_n &= A_s f_y \left(d - \frac{a}{2} \right) \cdot \frac{1 \text{ft}}{12 \text{in}} & M_n = 6719.4 \text{ kip} \cdot \text{ft} & Nominal Flexural Resistance} \\ \epsilon_s &= 0.003 \cdot \frac{d - c}{c} & \epsilon_s = 0.028 & Strain in Reinforcing at Ultimate \\ \epsilon_s &> 0.005 & \\ \hline FlexureBehavior = "Tension Controlled" & (AASHTO LRFD 5.6.2.1) \\ \Phi_M &= 0.90 & (AASHTO LRFD 5.5.4.2) \\ M_r &= \Phi_M \cdot M_n & M_r = 6047.5 \text{ kip} \cdot \text{ft} & Factored Flexural Resistance} \\ (AASHTO LRFD Eq. 5.6.3.2.1-1) & \\ \hline FlexureBehavior = 0.90 & (AASHTO LRFD 5.5.4.2) \\ \hline FlexureBehavior = 0.90$$

MinReinfChk = "OK!"

UltimateMom = "OK!"

4.3.10.3 Check Serviceability

To find s_{max}:

Modular Ratio:

$$n = \frac{E_s}{E_c} \qquad \qquad n = 7.12$$

Tension Reinforcement Ratio:

$$\rho = \frac{A_s}{b \cdot d} \qquad \qquad \rho = 0.0054$$

$$\overline{(2on) + (on)^2} - (on) \qquad \qquad k = 0.242$$

$$k = \sqrt{(2\rho n) + (\rho n)^2} - (\rho n)$$
 $k =$

 $d \cdot k = 19.70$ in $< d_{stem} = 57.00$ in

Therefore, the compression force acts over a rectangular

$$j = 0.919$$

$$\begin{split} f_{ss} &= \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12 i n}{1 f t} & f_{ss} &= 5.37 \text{ ksi} \\ f_a &= 0.6 f_y & f_a &= 36.00 \text{ ksi} \\ f_{ss} &< f_a & \text{ServiceStress} = "OK" \end{split}$$

$$d_{c} = cover + \frac{1}{2}d_{stirrup} + \frac{1}{2}d_{bar_B} \qquad d_{c} = 3.58 in$$

Exposure Condition Factor:

$$\begin{split} \gamma_e &= 1.00 \\ \beta_s &= 1 + \frac{d_c}{_{0.7(h_{cap} - d_c)}} \qquad \qquad \beta_s = 1.06 \end{split}$$

$$s_{max} = min\left(\frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c, 12in.\right)$$
 $s_{max} = 12 in$

Bars Inside Stirrup Bar S

Try: BarBInsideSNo = 5 $s_{Actual} = \frac{b_{stem} - 2\left(cover + \frac{1}{2}d_{bar_{-}S} + \frac{1}{2}d_{bar_{-}B}\right)}{BarBInsideSNo-1}$

For service loads, the stress on the cross-section is located as shown in Figure 4.48.



Figure 4.48 Stresses on the Cross Section for Bars **B** for Service Loads of 30 Degrees Skewed ITBC

> If the compression force does not act over rectangular area, j will be different.

Service Load Bending Stress in outer layer of the reinforcing.

Allowable Bending Stress (BDM-LRFD Ch. 4, Sect. 5, Design *Criteria*)

For Class 1 Exposure Conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e = 0.75$). (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

(AASHTO LRFD Eq. 5.6.7-1)

A good practice is to place a bar every 12 in along each surface of the bent. (TxSP)

Number of Bars B that are inside Stirrup Bar S.

 $s_{Actual} = 7.96$ in

!"

ServiceabilityCheck = "OK

Bars Outside Stirrup Bar S

BarBOutsideSNo = 11 - BarBInsideSNoNumber of Bars B that are inside
Stirrup Bar S.BarBOutsideSNo = 6 $s_{Actual} = \frac{2b_{ledge} + 2(cover + \frac{1}{2}d_{bar_S} + \frac{1}{2}d_{bar_B} - cove}{BarBOutsideSNo}$ $\frac{1}{2}d_{bar_M} - \frac{1}{2}d_{bar_B}}{BarBOutsideSNo}$ $s_{actual} = 8.00$ in $< s_{max}$ ServiceabilityCheck = "OK

4.3.10.4 Check Dead Load

| Check allowable M _{dl} : | $f_{dl} = 22 \text{ ksi}$ | | <i>TxDOT limits dead load stress to 22 ksi. This is due to observed cracking under dead load.</i> |
|---|---------------------------|-----------------------------|---|
| $M_{a} = A_{s} \cdot d \cdot j \cdot f_{dl} \cdot \frac{1}{12}$ | ft 2in | $M_a = 2354.00 \text{ kip}$ | Allowable Dead Load Moment |
| $M_{dl} = 294.4 \text{ kip} \cdot \text{ft}$ | < M _a | DeadLoadMom = "(| <mark>OK!"</mark> |

Flexural Steel Summary:

Use 7 ~ # 11 Bars on Top & 11 ~ # 11 Bars on Bottom

4.3.11 Ledge Reinforcement (Bars M & N)

Try Bars M and Bars N at a 4.70" spacing.

$$s_{bar_M} = 4.70$$
 in
 $s_{bar_N} = 4.70$ in

Use trial and error to determine the spacing needed for the ledge reinforcing.

It is typical for Bars M & N to be paired together

4.3.11.1 Determine Distribution Widths

These distribution widths will be used on the following pages to determine the required ledge reinforcement per foot of cap.

| Distribution Width for Shear (AASHTO LRFD 5.8.4.3.2) | Note: These are the same | |
|--|---|--|
| Interior Girders | distribution widths used for the Shear Friction check | |
| $b_{s_{Int}} = \min(W + 4a_v, S)$ | "S" is the girder spacing. | |
| $b_{s_{Int}} = 69.00$ in | | |
| Exterior Girders | "c" is the distance from the center | |
| $b_{s_Ext} = min(W + 4a_v, 2c, S)$ | of bearing of the outside beam to | |
| $b_{s_Ext} = 48.00$ in | the end of the ledge. | |
| Distribution Width for Bending and Axial Loads (AASHTO LRFD 5.8.4.3.3) | | |

Interior Girders

 $b_{m_{Int}} = min(W + 5a_f, S)$ $b_{m Int} = 93.50 in$

Exterior Girders

 $b_{m_{Ext}} = min(W + 5a_f, 2c, S)$ $b_{m_{Ext}} = 48.00 in$

4.3.11.2 Reinforcing Required for Shear Friction

| $\Phi = 0.90$ | |
|---------------|--|
| | |

| $\mu = 1.4$ | $c_1 = 0$ ksi | $P_c = 0 \text{ kip}$ |
|-------------|------------------|-----------------------|
| Recall: | $d_e = 25.50$ in | |

Minimum Reinforcing (AASHTO LRFD Eq. 5.7.4.2-1)

 $\begin{aligned} A_{vf_min} &= \frac{0.05 \text{ ksi} \cdot A_{cv}}{f_y} \\ A_{cv} &= d_e \cdot b_s \quad \text{and} \qquad a_{vf} = \frac{A_{vf}}{b_c} \end{aligned}$

 $a_{vf_min} = \frac{0.05 k si \cdot d_e}{f_v}$

(AASHTO LRFD 5.5.4)

"µ" is 1.4 for monolithically placed concrete. (AASHTO LRFD 5.7.4.4)

For clarity, the cohesion factor is labeled " c_1 ". This is to prevent confusion with "c", the distance from the last girder to the edge of the cap. c_1 is 0ksi for corbels and ledges. (AASHTO LRFD 5.7.4.4)

" P_c " is zero as there is no axial compression.

 $a_{vf_min} = 0.26 \frac{in^2}{ft}$ Minimum Reinforcing required for Shear Friction

Interior Girders

 $A_{cv} = 1759 \text{ in}^2$ $A_{cv} = d_e \cdot b_{s \text{ Int}}$ V_{11} Int = 338.5 kip From "4.3.4.4 Load Summarv". $V_n = c_1 A_{cv} + \mu (A_{vf} f_v + P_c)$ (AASHTO LRFD Eq. 5.7.4.3-3) (AASHTO LRFD Eq. 5.7.4.3-1 & $\Phi V_n \ge V_n$ AASHTO LRFD Eq. 5.7.4.3-2) $\Phi \cdot \left[c_1 A_{cv} + \mu (A_{vf} f_v + P_c) \right] \ge V_{u}$ $A_{vf} = \frac{\frac{\nabla u_{\perp}Int}{\Phi} - c_{\perp}A_{cv}}{\frac{\mu}{f_{\perp}}} - P_{c}$ $A_{\rm vf} = 4.48 \text{ in}^2$ Required Reinforcing for Shear Friction $a_{vf_{Int}} = 0.78 \frac{in^2}{ft}$ Required Reinforcing for Shear $a_{vf_{Int}} = \frac{A_{vf}}{b_{s_{Int}}}$ Friction per foot length of cap

AASHTO LRFD 5.7.4.1

Exterior Girders

$$\begin{array}{ll} A_{cv} = d_{e} \cdot b_{s_Ext} & A_{cv} = 1224 \ \text{in}^{2} \\ V_{u_Ext} = 338.5 \ \text{kip} & From ``4.3.4.4 \ Load \ Summary ``. \\ V_{n} = c_{1}A_{cv} + \mu(A_{vf}f_{y} + P_{c}) & (AASHTO \ LRFD \ Eq. \ 5.7.4.3-3) \\ \Phi V_{n} \geq V_{u} & (AASHTO \ LRFD \ Eq. \ 5.7.4.3-1 \ \& AASHTO \ LRFD \ Eq. \ 5.7.4.3-2) \\ \Phi \cdot \left[c_{1}A_{cv} + \mu(A_{vf}f_{y} + P_{c})\right] \geq V_{u} & A_{vf} = 4.48 \ \text{in}^{2} & Required \ Reinforcing \ for \ Shear \ Friction \\ a_{vf_Ext} = \frac{A_{vf}}{b_{s_Ext}} & a_{vf_Ext} = 1.12 \ \frac{\text{in}^{2}}{\text{ft}} & Required \ Reinforcing \ for \ Shear \ Friction \ Parton \ LRFD \ 5.8.4.2.1 \end{array}$$

4.3.11.3 Rein

Recall: h = 29.50 in $d_e = 25.50$ in $a_v = 12$ in From "4.3.5.2 Calculate Dimensions" Interior Girders $V_{u \text{ Int}} = 338.5 \text{ kip}$ From "4.3.4.4 Load Summary". $N_{uc Int} = 67.7 \text{ kip}$ $N_{uc Int} = 0.2 \cdot V_{u Int}$ (AASHTO LRFD 5.8.4.2.1) $M_{u Int} = V_{u Int} \cdot a_v + N_{uc Int}(h - d_e)$ $M_{u Int} = 361.1 \text{ kip} \cdot \text{ft}$ (AASHTO LRFD Eq. 5.8.4.2.1-1) Use the following equations to solve for A_f: $\Phi M_n \ge M_{u \text{ Int}}$ (AASHTO LRFD Eq. 1.3.2.1-1) $M_n = A_f f_y \left(d_e - \frac{a}{2} \right)$ (AASHTO LRFD Eq.5.6.3.2.2-1) $c = \frac{A_f f_y}{\alpha_1 f_c \beta_1 b_{m \text{ Int}}}$ (AASHTO LRFD Eq. 5.6.3.1.2-4) $\alpha_1 = 0.85$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.80$ $a = c\beta_1$ $0.75 \le \Phi = 0.65 + 0.15 \left(\frac{d_e}{c} - 1\right) \le 0.90$ AASHTO LRFD 5.5.4.2 $A_{f} = 3.18 \text{ in}^{2}$ Solve for A_f: Required Reinforcing for Flexure $a_{f_Int} = 0.41 \frac{in^2}{ft}$ $a_{f_{Int}} = \frac{A_f}{b_{m Int}}$ Required Reinforcing for Flexure per foot length of cap

Exterior Girders

 $V_{u_Ext} = 338.5 \text{ kip}$ $V_{u_Ext} = 338.5 \text{ kip}$ $V_{u_Ext} = 0.2 \cdot V_{u_Ext}$ $V_{u_Ext} = 0.2 \cdot V_{u_Ext}$ $V_{u_Ext} = 67.7 \text{ kip}$ (AASHTO LRFD 5.8.4.2.1) $M_{u_Ext} = V_{u_Ext} \cdot a_v + N_{uc_Ext}(h - d_e)$ $M_{u_Ext} = 361.1 \text{ kip} \cdot \text{ft}$ (AASHTO LRFD Eq. 5.8.4.2.1-1)Use the following equations to solve for A_f:

 $\Phi M_n \ge M_{u Ext}$ (AASHTO LRFD Eq. 1.3.2.1-1) $M_{n} = A_{f}f_{y}\left(d_{e} - \frac{a}{2}\right)$ (AASHTO LRFD Eq. 5.6.3.2.2-1) $c = \frac{A_f f_y}{\alpha_1 f_c \beta_1 b_{m Ext}}$ (AASHTO LRFD Eq. 5.6.3.1.2-4) $\alpha_1 = 0.85$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.80$ $a = c\beta_1$ $0.75 \le \Phi = 0.65 + 0.15 \left(\frac{d_e}{c} - 1\right) \le 0.90$ AASHTO LRFD 5.5.4.2 $A_{f} = 3.21 \text{ in}^{2}$ Solve for A_f: Required Reinforcing for Flexure $a_{f_Ext} = 0.80 \frac{in^2}{ft}$ $a_{f_Ext} = \frac{A_f}{b_m Ext}$ Required Reinforcing for Flexure per foot length of cap

(AASHTO LRFD 5.8.4.2.2)

AASHTO LRFD 5.5.4.2

4.3.11.4 Reinforcing Required for Axial Tension

 $\Phi = 0.90$

Interior Girders:

$$\begin{split} N_{uc_Int} &= 0.2 V_{u_Int} & N_{uc_Int} &= 67.7 \ \text{kip} \\ A_n &= \frac{N_{uc_Int}}{\Phi f_y} & A_n &= 1.25 \ \text{in}^2 & \begin{array}{c} \textit{Required Reinforcing for Axial} \\ \textit{Tension} \\ a_{n_Int} &= \frac{A_n}{b_{m_Int}} & a_{n_Int} &= 0.16 \frac{\text{in}^2}{\text{ft}} & \begin{array}{c} \textit{Required Reinforcing for Axial} \\ \textit{Tension per foot length of cap} \\ \end{array} \end{split}$$

Exterior Girders:

$$\begin{split} N_{uc_Ext} &= 0.2V_{u_Int} & N_{uc_Ext} &= 67.7 \text{kip} \\ A_n &= \frac{N_{uc_Ext}}{\Phi f_y} & A_n &= 1.25 \text{ in}^2 & Required Reinforcing for Axial \\ a_{n_Ext} &= \frac{A_n}{b_{m_Ext}} & a_{n_Ext} &= 0.31 \frac{\text{in}^2}{\text{ft}} & Required Reinforcing for Axial \\ Tension per foot length of cap \end{split}$$

4.3.11.5 Minimum Reinforcing

$$a_{s_min} = 0.04 \frac{f_c}{f_y} d_e$$

4.3.11.6 Check Required Reinforcing

Actual Reinforcing:

$$a_{s} = \frac{A_{bar_{M}}}{s_{bar_{M}}}$$

$$a_{s} = 1.12 \frac{in^{2}}{ft}$$

$$Primary Ledge Reinform Provided$$

$$a_{h} = \frac{A_{bar_{N}}}{s_{bar_{N}}}$$

$$a_{h} = 1.12 \frac{in^{2}}{ft}$$

$$Auxiliary Ledge Reinform Provided$$

$$Provided$$

<u>Checks:</u> $A_s \ge A_{s_min}$

$$A_{s} \ge A_{f} + A_{n}$$
$$A_{s} \ge \frac{2A_{vf}}{3} + A_{n}$$

$$A_{\rm h} \ge 0.5(A_{\rm s} - A_{\rm n})$$

Check if:

Check Interior Girders:

Bar M:

 $a_{s} \ge a_{s_min}$ $a_{s} \ge a_{f_Int} + a_{n_Int}$ $a_{s} \ge \frac{2a_{vf_Int}}{3} + a_{n_Int}$

$$\begin{aligned} a_{s} &= 1.12 \frac{in^{2}}{ft} \\ a_{s_min} &= 1.02 \frac{in^{2}}{ft} < a_{s} \\ a_{f_Int} &+ a_{n_Int} = 0.57 \frac{in^{2}}{ft} < a_{s} \\ \frac{2a_{vf_Int}}{3} + a_{n_Int} = 0.68 \frac{in^{2}}{ft} < a_{s} \end{aligned}$$

BarMCheck = "OK!"

Bar N:

$$a_{h} \ge 0.5 \cdot (a_{s} - a_{n_Int})$$
$$a_{s} = The maximum of:$$
$$a_{f_Int} + a_{n_Int}$$
$$\frac{2a_{vf_Int}}{3} + a_{n_Int}$$

$$a_{\rm s} = 0.68 \frac{\rm in^2}{\rm ft}$$

Check if:

(AASHTO LRFD 5.8.4.2.1)
$$a_{s_min} = 1.02 \frac{in^2}{ft} \quad Minimum \ Required \ Reinforcing$$

..12
$$\frac{in^2}{ft}$$
 Primary Ledge Reinforcing
Provided
1.12 $\frac{in^2}{ft}$ Auxiliary Ledge Reinforcing
Provided
(AASHTO LRFD 5.8.4.2.1)
(AASHTO LRFD 5.8.4.2.2)
(AASHTO LRFD Eq. 5.8.4.2.2-5)
(AASHTO LRFD Eq. 5.8.4.2.2-6)

(AASHTO LRFD Eq. 5.8.4.2.2-6)

" a_s " in this equation is the steel required for Bar M, based on the requirements for Bar M in AASHTO LRFD 5.8.4.2.2. This is derived from the suggestion that Ah should not be less than $A_{f}/2$ nor less than $A_{vf}/3$ (Furlong & Mirza pg. 73 & 74)

$$0.5 \cdot (a_s - a_{n_Int}) = 0.26 \frac{in^2}{ft} < a_h$$

BarNCheck = "OK!"

Check Exterior Girders:

Bar M:

Check if:

$$a_{s} \ge a_{s_min}$$

$$a_{s} \ge a_{f_Ext} + a_{n_Ext}$$

$$a_{s} \ge \frac{2a_{vf_Ext}}{3} + a_{n_Ext}$$

$$a_{s} = 1.12\frac{in^{2}}{ft}$$

 $a_{s_min} = 1.02 \frac{in^2}{ft} < a_s$

 $a_{f_Ext} + a_{n_Ext} = 1.11 \frac{in^2}{ft} ~<~ a_s$

 $\frac{2a_{vf_Ext}}{3} + a_{n_Ext} = 1.06 \frac{in^2}{ft} < a_s$

BarMCheck = "OK!"

Bar N:

Check if:

$$a_{h} \ge 0.5 \cdot (a_{s} - a_{n_Ext})$$
 (AASHTO LRFD Eq. 5.8.4.2.2-6)
 $a_{s} =$ The maximum of:
 $a_{f_Ext} + a_{n_Ext}$
 $\frac{2a_{vf_Ext}}{3} + a_{n_Ext}$ (arrow and arrow arrow and arrow and arrow ar

Ledge Reinforcement Summary:

Use # 6 primary ledge reinforcing @ 4.70" maximum spacing & # 6 auxiliary ledge reinforcing @ 4.70" maximum spacing

4.3.12 Hanger Reinforcement (Bars S)

Try Double # 6 Stirrups at a 7.40" spacing.

| $s_{\text{bar}_S} = 7.40$ in | | the spacing needed for the hanger reinforcing. |
|--------------------------------------|------------------------------|--|
| $A_{hr} = 2stirrups \cdot A_{bar_s}$ | $A_{hr} = 0.88 \text{ in}^2$ | It is typical for Bars S to have an |
| $A_v = 2 legs \cdot A_{hr}$ | $A_v = 1.76 \text{ in}^2$ | integer multiple of the spacing of |
| | | Bars M & N for practical reasons. |

4.3.12.1 Check Minimum Transverse Reinforcement

| $b_v = b_{stem}$ | $b_v = 39$ in | |
|--|---------------|-----------------------------|
| $A_{v_min} = 0.0316\lambda \sqrt{f_c} \frac{b_v \cdot s_{bar_S}}{f_y}$ | | (AASHTO LRFD Eq. 5.7.2.5-1) |
| | | (AASHTO LRFD 5.4.2.8) |

 $A_{v min} = 0.34 in^2$

MinimumSteelCheck = "OK!"

 $\lambda = 1.0$ for normal weight concrete

 $A_v > A_{v \min}$

4.3.12.2 Check Service Limit State

AASHTO LRFD 5.8.4.3.5 with notifications from BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

Interior Girders

$$V_{all} = minimum of:$$

$$\frac{A_{hr} \cdot \left(\frac{1}{3} f_y\right)}{s_{bar_s}} \cdot (W + 3a_v) = 228 \text{ kip}$$

TxDOT uses "2/3 f_y " from the original research (Furlong & Mirza Eq. 5.4) instead of "0.5 f_y " from AASHTO LRFD Eq. 5.8.4.3.5-1. (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)

Use trial and error to determine

Bounded by: $(W + 3a_v) \le \min(S, 2c)$

$$\frac{A_{\rm hr} \cdot \left(\frac{z}{3} f_{\rm y}\right)}{s_{\rm bar_S}} \cdot S = 457 \, \rm kip$$

 $V_{all} = 228 \text{ kip}$ $V_{s_Int} = 225 \text{ kip} \ < \ V_{all}$

(2)

(BDM-LRFD Ch.4, Sect. 5, Design Criteria modified to limit the distribution width to the girder spacing. This will prevent distribution widths from overlapping)

ServiceCheck = "OK!"

Exterior Girders

 V_{all} = minimum of: V_{all} for the Interior Girder

$$\frac{A_{hr}\left(\frac{2}{3}f_{y}\right)}{s_{bar_{s}}}\cdot\left(\frac{W+3a_{v}}{2}+c\right)=228\ \text{kip}$$

Bounded by: $(W + 3a_v) \le \min(S, 2c)$

$$\frac{A_{hr} \cdot \left(\frac{2}{3} f_{y}\right)}{s_{bar_{s}}} \cdot \left(\frac{s}{2} + c\right) = 342 \text{ kip}$$

$$V_{all} = 228 \text{ kip}$$

 $V_{s_Ext} = 225 \text{ kip} < V_{all}$

4.3.12.3 Check Strength Limit State

 $\Phi = 0.90$

Interior Girders:

TxDOT uses "2/3 f_y " from the original research (Furlong & Mirza Eq. 5.4) instead of "0.5 f_y " from AASHTO LRFD Eq. 5.8.4.3.5-1. (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)

(BDM-LRFD Ch.4, Sect. 5, Design Criteria Modified to limit the distribution width to half the girder spacing and the distance to the edge of the cap. This will prevent distribution widths from overlapping or extending over the edge of the cap.)

ServiceCheck = "OK!"

(AASHTO LRFD 5.8.4.3.5)

(AASHTO LRFD Eq. 5.8.4.3.5-2)

$$(0.063\sqrt{f_c} \cdot b_f \cdot d_f) + \frac{A_{hr} \cdot f_y}{S_{har} s} (W + 2d_f) = 798 \text{ kip} \quad (AASHTO LRFD Eq. 5.8.4.3.5-3)$$

$$V_n = 685 \text{ kip}$$

 $\Phi V_n = 617 \text{ kip}$
 $V_{u_{\text{Int}}} = 339 \text{ kip} < \Phi V_n$
UltimateCheck = "OK!"

Exterior Girders:

 $V_n = minimum of:$

 $V_n = minimum of:$

 $\frac{A_{hr} \cdot f_y}{s_{bar S}} \cdot S = 685 \text{ kip}$

 $V_{n} \text{ for the Interior Girder}$ $\frac{A_{hr} \cdot f_{y}}{s_{bar_{-}S}} \cdot \left(\frac{S}{2} + c\right) = 514 \text{ kip} \qquad (AASHTO LRFD Eq. 5.8.4.3.5-2)$ $(0.063\sqrt{f_{c}} \cdot b_{f} \cdot d_{f}) + \frac{A_{hr} \cdot f_{y}}{s_{bar_{-}S}} \left(\frac{W+2d_{f}}{2} + c\right) = 720 \text{ kip} \qquad (AASHTO LRFD Eq. 5.8.4.3.5-3)$ (These equations are modified to limit the distribution width to the edge of the cap) $V_{u,Ext} = 339 \text{ kip} < \Phi V_{n}$ UltimateCheck = "OK!"

4.3.12.4 Check Combined Shear and Torsion

The following calculations are for Station 36. All critical locations must be checked. See the Concrete Section Shear Capacity spreadsheet in the appendices for calculations at other locations. Shear and Moment were calculated using the CAP 18 program.

 $M_u = 394.2 \text{ kip} \cdot \text{ft}$ $V_u = 452.1 \text{ kip}$ $N_u = 0 \text{ kip}$ $T_u = 706 \text{ kip} \cdot \text{ft}$ Recall: $\beta_1 = 0.80$ $f_v = 60 \text{ ksi}$ $f_c = 5.0 \text{ ksi}$ $E_{s} = 29000 \text{ ksi}$ $h_{cap} = 85$ in $b_{stem} = 39$ in $b_f = 87$ in h = 29.50 in $b_{v} = 39$ in $b_v = b_{stem}$ Find d_v: (AASHTO LRFD 5.7.2.8) $A_s = 10.92 \text{ in}^2$ $A_s = A_{\text{bar }A} \cdot \text{BarANo}$ Shears are maximum near the column $c = \frac{A_s f_y}{0.85 f_c \beta_1 b_f}$ faces. In these regions the cap is in c = 2.21 in negative bending with tension in the top of the cap. Therefore, the $a = c \cdot \beta_1$ a = 1.77 in calculations are based on the steel in $d_s = d_{s neg}$ $d_s = 81.42$ in the top of the bent cap. $M_n = A_s f_v \left(d_s - \frac{a}{2} \right)$ $M_n = 4397.2 \text{ kip} \cdot \text{ft}$ $A_{ns} = 0 \text{ in}^2$ $d_e = \frac{A_{ps}f_{ps}d_p + A_sf_yd_s}{A_{ps}f_{ps} + A_sf_y}$ $d_e = 81.42$ in (AASHTO LRFD Eq. 5.7.2.8-2) $d_v = maximum of:$ $\frac{M_n}{A_s f_v + A_{ns} f_{ns}} = 80.53 \text{ in}$ $0.9d_e = 73.28$ in 0.72h = 21.24 in $d_v = 80.53$ in

The method for calculating θ and β used in this design example are from AASHTO LRFD Appendix B5. The method from AASHTO LRFD 5.7.3.4.2 may be used instead. The method from 5.7.3.4.2 is based on the method from Appendix B5; however, it is less accurate and more conservative (often excessively conservative). The method from Appendix B5 is preferred because it is more accurate, but it requires iterating to a solution.

Determine θ and β :

$$\Phi_{V} = 0.90$$

$$v_{u} = \frac{|V_{u} - (\Phi_{V} \cdot V_{p})|}{\Phi_{V} \cdot b_{v} \cdot d_{v}}$$

$$v_{u} = 0.16 \text{ ksi}$$

$$\frac{v_{u}}{f_{c}} = 0.03$$

Using Table B5.2-1 with $\frac{v_u}{f_c} = 0.03$ and $\varepsilon_x = 0.001$ $\theta = 36.4 \text{ deg}$ and $\beta = 2.23$

$$\begin{split} \epsilon_{x} &= \frac{\frac{|M_{u}|}{d_{v}} + 0.5 N_{u} + 0.5 |V_{u} - V_{p}| \cot \theta - A_{ps} f_{po}}{2(E_{s}A_{s} + E_{p}A_{ps})} \\ \text{where } |M_{u}| &= 394.2 \text{ kip} \cdot \text{ft must be} > |V_{u} - V_{p}| d_{v} = 3034 \text{ kip} \cdot \text{ft} \\ \epsilon_{x} &= 1.20 \times 10^{-3} > 1.00 \times 10^{-3} \end{split}$$

use
$$\varepsilon_{\rm x} = 1.00 \times 10^{-3}$$
.

(AASHTO LRFD Eq. 5.5.4.2)

Shear Stress on the Concrete (AASHTO LRFD Eq. 5.7.2.8-1)

Determining θ and β is an iterative process, therefore, assume initial shear strain value ε_x of 0.001 per LRFD B5.2 and then verify that the assumption was valid.

Strain halfway between the compressive and tensile resultants (AASHTO LRFD Eq. B5.2-3) If $\varepsilon_x < 0$, then use equation B5.2-5 and re-solve for ε_x .

For values of ε_x greater than 0.001, the tensile strain in the reinforcing, ε_t is greater than 0.002. ($\varepsilon_t = 2\varepsilon_x - \varepsilon_c$, where ε_c is < 0) Grade 60 steel yields at a strain of 60 ksi / 29,000 ksi = 0.002. By limiting the tensile strain in the steel to the yield strain and using the Modulus of Elasticity of the steel prior to yield, this limits the tensile stress of the steel to the yield stress. ε_x has not changed from the assumed value, therefore no iterations are required.

"V_p" is zero as there is no prestressing.

 $A_{c} = 1657.5 \text{ in}^{2}$ (AASHTO LRFD B5.2) "A_c" is the area of concrete on the flexural s = 7.40 in tension side of the cap, from the extreme tension fiber to one half the cap depth. "A_c" is needed if AASHTO LRFD

Eq. B5.2-3 is negative.

 $V_p = 0 \text{ kip}$

 $A_{c} = b_{stem} \cdot \frac{h_{cap}}{2}$ $s = s_{bar S}$



The transverse reinforcement, " A_v ", is double closed stirrups. The failure surface intersects four stirrup legs, therefore the area of the shear steel is four times the stirrup bar's area (0.44in2). See the sketch of the failure plane to the left.

Figure 4.49 Failure Surface of 30 Degrees Skewed ITBC for Combined Shear and Torsion

$$\begin{split} A_v &= 2 \text{legs} \cdot 2 \text{stirrups} \cdot A_{\text{bar}_S} & A_v &= 1.76 \text{ in}^2 \\ A_t &= 1 \text{leg} \cdot A_{\text{bar}_S} & A_t &= 0.44 \text{ in}^2 \\ A_{\text{oh}} &= (d_{\text{stem}}) \cdot (b_{\text{stem}} - 2 \text{cover}) + (d_{\text{ledge}} - 2 \text{cover}) \cdot (b_f - 2 \text{cover}) \\ & A_{\text{oh}} &= 3496 \text{ in}^2 \\ A_0 &= 0.85A_{\text{oh}} & A_0 &= 2971.6\text{in}^2 \\ p_h &= (b_{\text{stem}} - 2 \text{cover}) + 2(b_{\text{ledge}}) + (b_f - 2 \text{cover}) + 2(h_{\text{cap}} - 2 \text{cover}) \\ & p_h &= 324 \text{ in} \end{split}$$

Equivalent Shear Force

$$V_{u_{Eq}} = \sqrt{V_{u}^{2} + \left(\frac{0.9p_{h}T_{u}}{2A_{0}}\right)^{2}} \qquad V_{u_{Eq}} = 614.2 \text{ kip } (AASHTO LRFD Eq. B.5.2-1)$$

Shear Steel Required

 V_n = the lesser of:

$$V_c + V_s + V_p$$
(AASHTO LRFD Eq. 5.7.3.3-1) $0.25 \cdot f_c \cdot b_v \cdot d_v + V_p$ (AASHTO LRFD Eq. 5.7.3.3-2)

Check maximum ΦV_n for section:

 $\Phi V_{n_{max}} = \Phi \cdot \left(0.25 \cdot f_{c} \cdot b_{v} \cdot d_{v} + V_{p} \right)$

 $\Phi V_{n max} = 3533 \text{ kip}$

$$V_u = 452.1 \text{ kip } < \Phi V_{n_max}$$
 MaxShearCheck = "OK!"

Calculate required shear steel:

$$V_{u} < \Phi V_{n}$$

$$V_{c} = 0.0316 \cdot \beta \cdot \sqrt{f_{c}} \cdot b_{v} \cdot d_{v}$$

$$V_{u} < \Phi_{V} \cdot (V_{c} + V_{s} + V_{p})$$

$$V_{s} = \frac{A_{v} \cdot f_{y} \cdot d_{v} \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha}{s_{req}}$$

$$a_{v_{r}req} = \frac{\frac{V_{u}}{\Phi_{V}} - V_{c} - V_{p}}{f_{v} \cdot d_{v} \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha}$$

(AASHTO LRFD Eq. 1.3.2.1-1) V_c = 495 kip (AASHTO LRFD Eq. 5.7.3.3-3)

$$a_{v_req} = 0.011 \frac{in^2}{ft}$$

$$a_{t_req} = 0.23 \frac{in^2}{ft}$$

Total Required Transverse Steel

 $T_n = \frac{2A_oA_tf_y \cot\theta}{s_{bar_S}}$

 $a_{t_req} = \frac{T_u}{\Phi_T 2 A_o f_y cot \theta}$

Torsional Steel Required

 $\Phi_{\rm T} = 0.9$

 $T_u \leq \Phi_T T_n$

$$a_{req} = a_{v_req} + 2sides \cdot a_{t_req} \qquad a_{req} = 0.47 \frac{in^2}{ft} \qquad \frac{dest}{whe}$$

$$a_{prov} = \frac{A_v}{s_{bar_s}} \qquad a_{prov} = 2.85 \frac{in^2}{ft} \qquad \frac{are}{C5}$$

$$a_{prov} > a_{req} \qquad TransverseSteelCheck = "OK!"$$

The transverse reinforcement is designed for the side of the section where the effects of shear and torsion are additive. (AASHTO LRFD C5.7.3.6.1)

Longitudinal Reinforcement

$$\begin{split} A_{ps}f_{ps} + A_{s}f_{y} &\geq \frac{|M_{u}|}{\Phi d_{v}} + \frac{0.5N_{u}}{\Phi} + \cdots \\ & cot\Theta\sqrt{\left(\left|\frac{V_{u}}{\Phi} - V_{p}\right| - 0.5V_{s}\right)^{2} + \left(\frac{0.45p_{h}T_{u}}{2A_{0}\Phi}\right)^{2}} \\ V_{s} &= a_{t_req} \cdot f_{y} \cdot d_{v} \cdot (cot\Theta + cot\alpha) \cdot sin\alpha \end{split} \qquad (AASHTO LRFD Eq. 5.7.3.3-4)$$

Bounded By:
$$V_s < \frac{V_u}{\Phi_V}$$

 $V_{\rm s} = 502.3 \, {\rm kip}$ (AASHTO LRFD Eq. 5.7.3.5-1)

$$\frac{|M_u|}{\Phi_f d_v} + \frac{0.5N_u}{\Phi_c} + \cot\theta \sqrt{\left(\left|\frac{V_u}{\Phi_V} - V_p\right| - 0.5V_s\right)^2 + \left(\frac{0.45p_h T_u}{2A_0 \Phi_T}\right)^2} = 528 \text{ kip}$$

Provided Force:

$$A_s f_y = 655.2 \text{ kip} > 528 \text{ kip}$$
 LongitudinalReinfChk = "OK!"

| 4.3.12.5 Maximum Spacing of Transverse Reinforcement | | (AASHTO LRFD 5.7.2.6) | |
|---|------------------------------|-----------------------------|--|
| Shear Stress | | | |
| $v_u = \frac{ v_u - \Phi_V v_p }{\Phi_V b_v d_v}$ | $v_u = 0.16$ ksi | (AASHTO LRFD Eq. 5.7.2.8-1) | |
| $0.125 \cdot f_c = 0.625 \text{ ksi}$ | | | |
| If $v_u < 0.125 \cdot f_c$ | | (AASHTO LRFD Eq. 5.7.2.6-1) | |
| $s_{max} = min(0.8d_v, 24in)$ | | | |
| If $v_u \ge 0.125 \cdot f_c$ | | (AASHTO LRFD Eq. 5.7.2.6-2) | |
| $s_{max} = min(0.4d_v, 12in)$ | | | |
| Since $v_u < 0.125 \cdot f_c$ | $s_{max} = 24.00 \text{ in}$ | | |
| TxDOT limits the maximum transverse reinforcement spacing to 12". | | (BDM-LRFD, Ch. 4, Sect. 5, | |
| $s_{max} = 12.00$ in | | Detailing) | |
| $s_{bar_S} = 7.40 \text{ in } < s_{max}$ SpacingCheck= "OK!" | | | |

Hanger Reinforcement Summary:

Use double # 6 stirrups @ 7.40" maximum spacing
4.3.13 End Reinforcements (Bars U1, U2, U3, and G)

Extra vertical, horizontal, and diagonal reinforcing at the end surfaces is provided to reduce the maximum crack widths. According to the parametric analysis, it is recommended to place #6 U1 Bars, U2 Bars, and U3 Bars at the end faces and #7 G Bars at approximately 6in. spacing at the first 30" to 35" of the end of bent cap. U1 Bars are the vertical end reinforcements, U2 Bars and U3 Bars are the horizontal end reinforcements at the stem and the ledge, respectively. G Bars are the diagonal end reinforcement.



Figure 4.50 End Face Section View of 30 Degrees Skewed ITBC



Figure 4.51 End Face Elevation View of 30 Degrees Skewed ITBC

4.3.14 Skin Reinforcement (Bars T)

Try 7 ~ # 6 bars in Stem and 3 ~ # 6 bars in Ledge on each side



ITBC

(AASHTO LRFD 5.6.7)

4.3.14.1 Required Area of Skin Reinforcement

 $A_{sk_Req} = 0.012 \cdot (d - 30)$

 $A_{sk_Req} = 0.62 \frac{in^2}{ft}$ (AASHTO LRFD Eq. 5.6.7-3)

 A_{sk} need not be greater than one quarter of the main reinforcing $(A_s/4)$ per side face within d/2 of the main reinforcing. (AASHTO LRFD 5.6.7)

"d" is the distance from the extreme compression fiber to the centroid of the extreme tension steel element. In this example design, $d = d_{s_pos} = d_{s_neg} = 81.42$ in.

$$A_{sk_max} = max \left(\frac{\frac{A_{bar_A} \cdot Bar A No}{4}}{\frac{d_{s_neg}}{2}}, \frac{\frac{A_{bar_B} \cdot Bar B No}{4}}{\frac{d_{s_pos}}{2}}\right)$$
$$A_{sk_max} = 1.26 \frac{in^2}{ft}$$
$$A_{skReq} = min(A_{sk_Req}, A_{sk_max})$$
$$A_{sk_max} = 0.62 \frac{in^2}{ft}$$

 $A_{skReq} = 0.62 \frac{1}{ft}$

4.3.14.2 Required Spacing of Skin Reinforcement

(AASHTO LRFD 5.6.7)

 $s_{req} = minimum of:$

$$\frac{A_{bar_T}}{A_{skReq}} = 8.52 \text{ in}$$
$$\frac{d_{s_neg}}{6} = 13.57 \text{ in}$$

$$\frac{d_{s_pos}}{6} = 13.57$$
 in & 12 in

 $s_{req} = 8.52$ in

4.3.14.3 Actual Spacing of Skin Reinforcement

Check T Bars spacing in Stem:

$$\begin{split} h_{top} &= d_{stem} - \left(cover + \frac{d_{bar_S}}{2} + \frac{d_{bar_A}}{2} \right) + \left(cover + \frac{d_{bar_M}}{2} + \frac{d_{bar_T}}{2} \right) \\ h_{top} &= 56.67 \text{ in} \end{split}$$

 $s_{skStem} = \frac{h_{top}}{NoTBarsSte}$

 $s_{skStem} < s_{req}$

 $s_{skStem} = 7.08$ in

SkinSpacing = "OK!"

Check T Bars spacing in Ledge:

$$h_{bot} = d_{ledge} - \left(cover + \frac{d_{bar_M}}{2} + \frac{d_{bar_T}}{2}\right) - \left(cover + \frac{d_{bar_S}}{2} + \frac{d_{bar_B}}{2}\right)$$
$$h_{bot} = 21.17 \text{ in}$$

 $s_{skLedge} = \frac{n_{bot} - a}{NoTBarsLedge}$

SkinSpacing = "OK!"

 $s_{skLedge} = 7.59$ in

Check if "a" is less than s_{req}

$$a = 6 \text{ in } < s_{req}$$
 SkinSpacing = "OK!"

Skin Reinforcement Summary:

Use $7 \sim #6$ bars in Stem and $3 \sim #6$ bars in Ledge on each side

4.3.15 Design Details and Drawings

4.3.15.1 Bridge Layout



4.3.15.2 CAP 18 Input File

_____ CAP18 Version 6.00 ITBC Design Example 2, Skew = 30.00 SProblem Card -----1 E 0 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay) STABLE 1 - CONTROL DATA -----Enter 1 to keep: Number cards Options: ŝ Env Tab2 Tab3 Tab4 on Table 4 Envelope Print Skew Angle Ş Ŝ X X X X XX x xx xxxxxxxx 16 30.0 \$TABLE 2 - CONSTANTS ------Anly Opt (1=Working, |-Movable Load Data--| 2=Load Factor,3=Both) Num Increment |Num Start Stop Step|Anly| Load Factors: TABLE 2a ŝ Ś
 Inc
 Length
 |Inc
 Sta
 Size
 Opt
 Dead
 Live

 XX
 XXXXXXXXX
 XXX
 XXX
 XXX
 X
 XXXXXXXXXX

 92
 0.5
 20
 2
 70
 1
 3
 1.25
 1.75
 Ś Ŝ ŝ TABLE 2b Overlay Ś \$ Load Factor Lanes | 1 lane 2 lanes 3 lanes 4 lanes 5 lanes XXXXX X XXXX XXXX XXXX XXXX XXXX 1.50 3 1.2 1.0 0.85 0.65 0.65 \$ STABLE 3 - LIST OF STATIONS -----

 Number of input values for
 Str - Stringers, Sup - Supports

 Lane Str Sup MCP VCP
 MCP - Moment Control Points

 XX
 XX
 XX

 VCP - Shear Control Points
 Str - Stringers, Sup - Supports

 \$ Ś XX XX XX XX XX 3 6 4 11 8 Ŝ (Num Inputs) 8 Left Lane Boundary Stations S Ş Ś Ŝ (Stringers) 6 22 38 54 70 00 (Stringers) 6 22 38 54 70 00 Ś Station of Stringers (two rows max, may be at tenths of stations, XX.X) \$ Ŝ Station of Supports (two rows max) Ś (Supports) 10 34 58 82 Moment Control Point Stations (two rows max) Ś Ŝ 6 86 (Mom CP) 10 22 34 38 46 54 58 70 82 (Mom CP) ŝ Shear Control Point Stations (two rows max) (Shear CP) 8 12 32 36 56 60 80 84 Ś 36 56 60 80 84 \$TABLE 4 - STIFFNESS AND LOAD DATA -----Bending Sidewalk, Cap & Station 1 if Stiffness Slab Stringer Moving \$ Ś Overlav From To Cont'd of Cap SComments Loads Loads Loads Loads, DW \$XXXXXXXXXXXXXXX XXX XXX 2 8.09E+07 (CAP EI & DL) 90 -2.427 (DL Span1, Bm1) -50.17 -5.04 6 (DL Span1, Bm2) 22 22 -50.17 -5.04 (DL Span1, Bm3) 38 -50.17-5.04 38 (DL Span1, Bm4) 54 54 -50.17-5.04 (DL Span1, Bm5) 70 70 -50.17-5.04 (DL Span1, Bm6) 86 86 -50.17-5.04 (DL Span2, Bm1) 6 6 -104.1 -10.5 (DL Span2, Bm2) 22 22 -104.1-10.5 38 (DL Span2, Bm3) 38 -104.1 -10.5 (DL Span2, Bm4) 54 54 -104.1 -10.5 (DL Span2, Bm5) 70 70 -104.1 -10.5 (DL Span2, Bm6) 86 86 -104.1-10.5 (Dist. Lane Ld) 0 20 -4.92 (Conc. Lane Ld) -21.3 4 4 (Conc. Lane Ld) -21.3 16 16

4.3.15.3 CAP 18 Output File

AUG 07, 2020 TEXAS DEPARTMENT OF TRANSPORTATION (TxDOT) PAGE 1 CAP18 BENT CAP ANALYSIS Ver. 6.2 (Jul, 2011) PSF HIGHWAY PD- CONTROL- CODED NO COUNTY NO IPE SECTION-JOB BY DATE 00001 __County___ Highwy Pro# 0000-00-000 BRG AUG 07, 2020 Comment CAP18 Version 6.00 ITBC Design Example 2, Skew = 30.00 PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la ENGLISH SYSTEM UNITS TABLE 1. CONTROL DATA **OPTION TO PRINT TABLE SRS (1=YES)** 0 ENVELOPES TABLE NUMBER OF MAXIMUMS 2 3 4 KEEP FROM PRECEDING PROBLEM (1=YES) 0 0 0 0 CARDS INPUT THIS PROBLEM 16 OPTION TO CLEAR ENVELOPES BEFORE LANE LOADINGS (1=YES) 0 OPTION TO OMIT PRINT FOR TABLES (TABLE DESIGNATIONS IN PARENTHESES) -1(4A), -2(5) -3(4A,5), -4(4A,5,6), -5(4A,5,6,7): 0 SKEW ANGLE, DEGREES 30.000 TABLE 2. CONSTANTS NUMBER OF INCREMENTS FOR SLAB AND CAP 92 **INCREMENT LENGTH, FT** 0.500 NUMBER OF INCREMENTS FOR MOVABLE LOAD 20 START POSITION OF MOVABLE-LOAD STA ZERO 2 STOP POSITION OF MOVABLE-LOAD STA ZERO 70 NUMBER OF INCREMENTS BETWEEN EACH POSITION OF MOVABLE LOAD 1 ANALYSIS OPTION (1=WORKING STRESS, 2=LOAD FACTOR, 3=BOTH) 3 LOAD FACTOR FOR DEAD LOAD 1.25 LOAD FACTOR FOR OVERLAY LOAD 1.50 LOAD FACTOR FOR LIVE LOAD 1.75 MAXIMUM NUMBER OF LANES TO BE LOADED SIMULTANEOUSLY 3 LIST OF LOAD COEFFICIENTS CORRESPONDING TO NUMBER OF LANES LOADED 2 3 1.000 5 4 0.850 1.200

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la (CONTINUED)

TABLE 3. LISTS OF STATIONS

 NUM OF LANES
 NUM OF STRINGERS
 NUM OF 6
 NUM OF 4
 NUM OF SUPPORTS
 NUM MOM CONTR PTS
 NUM SHEAR CONTR PTS

 LANE LEFT
 2
 32
 60
 90
 5
 5
 5
 5
 5
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TABLE 4. STIFFNESS AND LOAD DATA

| FIXE | D-O | R-N | IOVABLE | FD | XED-POSIT | ION DAT | A | - MOVAE | BLE- |
|------|-----|-------------|-------------|---------|---------------|----------|---------|---------|----------|
| STA | ST | A C | ONTD CAP I | BENDING | SIDEWA | LK, STRI | NGER, C | VERLAY | POSITION |
| FRO | M | ТО | IF=1 STIFFN | IESS SL | AB LOADS | CAP LO | ADS LO | ADS SL | AB LOADS |
| | | (1 | (-FT*FT) (| K) (K |) (K) | (K) | | | |
| | | · · · · · · | | | | | | | |
| 2 | 90 | 0 | 80900000.0 | 000 0. | 000 -2.4 | 27 0.0 | 00 0.00 | 00 | |
| 6 | 6 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | |
| 22 | 22 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | |
| 38 | 38 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | |
| 54 | 54 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | |
| 70 | 70 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | |
| 86 | 86 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | |
| 6 | 6 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 | | |
| 22 | 22 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 | | |
| 38 | 38 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 | | |
| 54 | 54 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 | | |
| 70 | 70 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 | | |
| 86 | 86 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 | | |
| 0 | 20 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -4.920 | | |
| 4 | 4 | 0 | 0.000 | 0.000 | 0.000 | 0.000 - | 21.300 | | |
| 16 | 16 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -21.300 | | |

TABLE 4A. DEAD LOAD RESULTS (WORKING STRESS)

| STA | DIST X (F | T) DEFLECTIO | N (FT) MO | MENT (K-FT) | SHEAR (K) |
|-----|-----------|--------------|-----------|-------------|-----------|
| -1 | -0.58 | 0.000000 | 0.0 | 0.0 | |
| 0 | 0.00 | 0.000000 | 0.0 | 0.0 | |
| 1 | 0.58 | -0.000051 | 0.0 | 0.0 | |
| 2 | 1.15 | -0.000045 | 0.0 | -0.7 | |
| 3 | 1.73 | -0.000039 | -0.8 | -2.8 | |
| 4 | 2.31 | -0.000032 | -3.2 | -5.6 | |
| 5 | 2.89 | -0.000026 | -7.3 | -8.4 | |
| 6 | 3.46 | -0.000020 | -12.9 | -96.1 | |
| 7 | 4.04 | -0.000014 | -118.3 | -183.8 | |
| 8 | 4.62 | -0.000008 | -225.2 | -186.6 | |
| 9 | 5.20 | -0.000003 | -333.8 | -189.4 | |
| 10 | 5.77 | 0.000000 | -443.9 | -34.4 | |
| 11 | 6.35 | 0.000002 | -373.5 | 120.6 | |
| 12 | 6.93 | 0.000002 | -304.7 | 117.8 | |
| 13 | 7.51 | 0.000000 | -237.5 | 115.0 | |
| 14 | 8.08 | -0.000002 | -172.0 | 112.2 | |
| 15 | 8.66 | -0.000005 | -108.0 | 109.4 | |
| 16 | 9.24 | -0.000008 | -45.7 | 106.6 | |
| 17 | 9.81 | -0.000012 | 15.0 | 103.8 | |
| 18 | 10.39 | -0.000015 | 74.1 | 101.0 | |
| 19 | 10.97 | -0.000018 | 131.6 | 98.2 | |
| 20 | 11.55 | -0.000021 | 187.5 | 95.4 | |
| 21 | 12.12 | -0.000023 | 241.7 | 92.6 | |
| 22 | 12.70 | -0.000024 | 294.4 | 4.8 | |
| 23 | 13.28 | -0.000024 | 247.3 | -82.9 | |
| 24 | 13.86 | -0.000022 | 198.7 | -85.7 | |
| 25 | 14.43 | -0.000020 | 148.4 | -88.5 | |
| 26 | 15.01 | -0.000017 | 96.5 | -91.3 | |
| 27 | 15.59 | -0.000014 | 43.0 | -94.1 | |
| 28 | 16.17 | -0.000011 | -12.1 | -96.9 | |
| 29 | 16.74 | -0.000007 | -68.8 | -99.7 | |
| 30 | 17.32 | -0.000004 | -127.2 | -102.5 | |
| 31 | 17.90 | -0.000002 | -187.2 | -105.3 | |
| 32 | 18.48 | 0.000000 | -248.8 | -108.1 | |
| 33 | 19.05 | 0.000001 | -312.0 | -110.9 | |
| 34 | 19.63 | 0.000000 | -3/6.8 | 44.9 | |
| 35 | 20.21 | -0.000002 | -200.2 | 200.6 | |
| 30 | 20.78 | -0.000005 | -145.1 | 197.8 | |
| 3/ | 21.30 | -0.000009 | -51.7 | 195.0 | |
| 20 | 21.94 | -0.000013 | 00.1 | 107.5 | |
| 39 | 22.52 | -0.000017 | 102.2 | 16.0 | |
| 40 | 23.09 | -0.000020 | 1116 | 14.0 | |
| 41 | 23.07 | -0.000023 | 112.0 | 14.0 | |
| 42 | 24.20 | -0.000025 | 1246 | 0 / | |
| 45 | 24.63 | -0.000027 | 124.0 | 0.4 | |

TABLE 4A. DEAD LOAD RESULTS (WORKING STRESS)

| STA | DIST X (FT) | DEFLECTION | (FT) | MON | IENT (K-FT) | SHEAR (K) |
|-----|-------------|------------|------|-----|-------------|-----------|
| 44 | 25.40 | -0.000028 | 128 | 8.6 | 5.6 | |
| 45 | 25.98 | -0.000029 | 131 | 1.0 | 2.8 | |
| 46 | 26.56 | -0.000029 | 13 | 1.8 | 0.0 | |
| 47 | 27.14 | -0.000029 | 13 | 1.0 | -2.8 | |
| 48 | 27.71 | -0.000028 | 128 | 8.6 | -5.6 | |
| 49 | 28.29 | -0.000027 | 124 | 4.6 | -8.4 | |
| 50 | 28.87 | -0.000025 | 118 | 8.9 | -11.2 | |
| 51 | 29.44 | -0.000023 | 111 | 1.6 | -14.0 | |
| 52 | 30.02 | -0.000020 | 102 | 2.7 | -16.8 | |
| 53 | 30.60 | -0.000017 | 92 | .2 | -19.6 | |
| 54 | 31.18 | -0.000013 | 80 | .1 | -107.3 | |
| 55 | 31.75 | -0.000009 | -31 | .7 | -195.0 | |
| 56 | 32.33 | -0.000005 | -14 | 5.1 | -197.8 | |
| 57 | 32.91 | -0.000002 | -26 | 0.2 | -200.6 | |
| 58 | 33.49 | 0.000000 | -376 | 5.8 | -44.9 | |
| 59 | 34.06 | 0.000001 | -312 | 2.0 | 110.9 | |
| 60 | 34.64 | 0.000000 | -248 | 8.8 | 108.1 | |
| 61 | 35.22 | -0.000002 | -18 | 7.2 | 105.3 | |
| 62 | 35.80 | -0.000004 | -12 | 7.2 | 102.5 | |
| 63 | 36.37 | -0.000007 | -68 | 8.8 | 99.7 | |
| 64 | 36.95 | -0.000011 | -12 | .1 | 96.9 | |
| 65 | 37.53 | -0.000014 | 43 | .0 | 94.1 | |
| 66 | 38.11 | -0.000017 | 96 | .5 | 91.3 | |
| 67 | 38.68 | -0.000020 | 148 | 8.4 | 88.5 | |
| 68 | 39.26 | -0.000022 | 198 | 8.7 | 85.7 | |
| 69 | 39.84 | -0.000024 | 247 | 7.3 | 82.9 | |
| 70 | 40.41 | -0.000024 | 294 | 4.4 | -4.8 | |
| 71 | 40.99 | -0.000023 | 24 | 1.7 | -92.6 | |
| 72 | 41.57 | -0.000021 | 187 | 7.5 | -95.4 | |
| 73 | 42.15 | -0.000018 | 131 | 1.6 | -98.2 | |
| 74 | 42.72 | -0.000015 | 74 | .1 | -101.0 | |
| 75 | 43.30 | -0.000012 | 15 | .0 | -103.8 | |
| 76 | 43.88 | -0.000008 | -45 | .7 | -106.6 | |
| 77 | 44.46 | -0.000005 | -10 | 8.0 | -109.4 | |
| 78 | 45.03 | -0.000002 | -17 | 2.0 | -112.2 | |
| 79 | 45.61 | 0.000000 | -23 | 7.5 | -115.0 | |
| 80 | 46.19 | 0.000002 | -304 | 4.7 | -117.8 | |
| 81 | 46.77 | 0.000002 | -373 | 3.5 | -120.6 | |
| 82 | 47.34 | 0.000000 | -443 | 3.9 | 34.4 | |
| 83 | 47.92 | -0.000003 | -33 | 3.8 | 189.4 | |
| 84 | 48.50 | -0.000008 | -22 | 5.2 | 186.6 | |
| 85 | 49.07 | -0.000014 | -118 | 8.3 | 183.8 | |
| 86 | 49.65 | -0.000020 | -12 | .9 | 96.1 | |
| 87 | 50.23 | -0.000026 | -7. | 3 | 8.4 | |
| 88 | 50.81 | -0.000032 | -3. | 2 | 5.6 | |
| 89 | 51.38 | -0.000039 | -0. | 8 | 2.8 | |
| 90 | 51.96 | -0.000045 | 0. | 0 | 0.7 | |
| | | | | | | |

| 91 | 52.54 | -0.000051 | 0.0 | 0.0 |
|----|-------|-----------|-----|-----|
| 92 | 53.12 | 0.000000 | 0.0 | 0.0 |
| 93 | 53.69 | 0.000000 | 0.0 | 0.0 |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la (CONTINUED)

TABLE 5. MULTI-LANE LOADING SUMMARY (WORKING STRESS) (*--CRITICAL NUMBER OF LANE LOADS)

MOMENT (FT-K)

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIV MAXIM | e load Um lan | AT NE ST | LAI A | NE NEG ORDER | MAXIMU | OAD AT M LAN | E STA |
|-----------|----------------------------------|-------------------------------|-----------------------------------|--------------------------------------|-------------------|--------------|---------------------|--------|-----------------|-------|
| 6 | -12.9 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | | | | | | |
| 10 | -443.9 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | -203.5 -203.5 0.0 0.0 | 1 1 | 2 | | | | |
| 22 | 294.4 0 1 2 3 0* | 233.3 232.3 10.8 0.0 | 0 13 1 12 3 62 3 0* | 0 -38. 1 -38. 2 0.0 0.0 | .5 .5 | 2 | 36 36 | | | |
| 34 | -376.8 0 1 2 3 0* | 21.6 21.6 0.0 0.0 | 3 62 3 62 2 3 2* | 0 -157. 1 -134. -97.8 0.0 | .4 .6 23 | 0 1 32 | 18 12 | | | |
| 38 | 80.1 0 1 2 3 0* | 96.5 96.5 3.7 0.0 | 2 32 2 32 3 62 3 3 0* | 0 -67.9 1 -67.9 2 0.0 0.0 | 9 1 9 1 | | 9 | | | |
| 46 | 131.8 0 1 2 3 0* | 80.1 80.1 0.0 0.0 | 2 36 2 36 2 3 2* | 0 -32.1 1 -32.1 -32.1 0.0 | 1 1 1 1 3 6 | 53 | 9 | | | |
| 54 | 80.1 0 1 2 3 0* | 96.5 96.5 3.7 0.0 | 2 40 2 40 1 10 2 3 0* | 0 -67.9 1 -67.9 2 0.0 0.0 |) 3) 3 | 6 | 3 3 | | | |
| 58 | -376.8 0 1 2 3 0* | 21.6 21.6 0.0 0.0 | 1 9 (1 9 1 2 3 2* | 0 -157.4 I -134.6 -97.8 0.0 | 1 0 5 3 2 4 | 5 6 10 | 4 0 | | | |

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MOMENT (FT-K)

| AT | |) LANF | POSITIV | F LOAD | AT | IA | NF | NEGATI | /F LOA | DAT |
|-----|---------|--------|---------|--------|------|----|----|---------|--------|----------|
| STA | EFFECT | ORDE | R MAXIM | UM LAN | IE S | TA | OR | DER MAX | KIMUM | LANE STA |
| | | | | | | | | | | |
| | | | | | | | | | | |
| 70 | 294.4 | | | | | | | | | |
| | 0 | 233.3 | 0 59 | 0 -38. | 5 | 2 | 36 | | | |
| | 1 | 232.3 | 3 60 | 1 -38. | 5 | 2 | 36 | | | |
| | 2 | 10.8 | 19. | 2 0.0 | | | | | | |
| | 3 0* | 0.0 | 3 0* | 0.0 | | | | | | |
| | 0. | | 0 | | | | | | | |
| 82 | -443.9 | | | | | | | | | |
| | 0 | 0.0 | 0 | -203.5 | 3 | 70 |) | | | |
| | 1 | 0.0 | 1 | -203.5 | 3 | 70 |) | | | |
| | 2 | 0.0 | 2 | 0.0 | | | | | | |
| | 3 | 0.0 | 3 | 0.0 | | | | | | |
| | 0* | | 0* | | | | | | | |
| 0.0 | 12.0 | | | | | | | | | |
| 86 | -12.9 | 0.0 | 0 | 0.0 | | | | | | |
| | 1 | 0.0 | 0 | 0.0 | | | | | | |
| | 2 | 0.0 | 2 | 0.0 | | | | | | |
| | 2 | 0.0 | 2 | 0.0 | | | | | | |
| | 0* | 0.0 | 0* | 0.0 | | | | | | |
| | | | | | | | | | | |

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SHEAR (K)

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIVE MAXIMUI | LOAD / M LAN | AT L | ANE OR | NEGA DER N | ATIVE MAXIMI | LOA[UM | D AT LANE S | ТA |
|-----------|----------------------------------|------------------------------|---------------------------------------|--------------------------------|--------------------|---------------|---------------|-----------------|------------|----------------|----|
| 8 | -186.6 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | -88.1 -88.1 0.0 0.0 | 1 2 1 2 | | | | | | |
| 12 | 117.8 0 1 2 3 0* | 44.8 44.8 1.6 3 0.0 | 1 6 0 1 6 1 3 62 2 3 0* | -5.6 -5.6 0.0 0.0 | 2 3 | 36 36 | | | | | |
| 32 | -108.1 0 1 2 3 0* | 1.6 3 1.6 3 0.0 0.0 | 8 62 0 8 62 1 2 3 0* | -54.6 -53.0 -11.2 0.0 | 0 1 2 32 | 15 12 2 | | | | | |
| 36 | 197.8 0 1 2 3 2* | 87.6 84.1 30.7 0.0 | 0 28 0 2 32 1 1 12 2 3 0* | -7.8 -7.8 0.0 0.0 | 3 3 | 63 63 | | | | | |
| 56 | -197.8 0 1 2 3 0* | 7.8 1 7.8 1 0.0 0.0 | 9 0 9 1 2 3 2* | -87.6 -84.1 -30.7 0.0 | 0 4 2 4 3 60 | 14 40) | | | | | |
| 60 | 108.1 0 1 2 3 0* | 54.6 53.0 11.2 0.0 | 0 57 0 3 60 1 2 40 2 3 0* | -1.6 -1.6 0.0 0.0 | 1 1 | 9 9 | | | | | |
| 80 | -117.8 0 1 2 3 0* | 5.6 2 5.6 2 0.0 0.0 | 2 36 0 2 36 1 2 3 0* | -44.8 -44.8 -1.6 0.0 | 3 3 19 | 66 66 | | | | | |
| 84 | 186.6 0 1 2 3 0* | 88.1 88.1 0.0 0.0 | 3 70 0 3 70 1 2 3 0* | 0.0 0.0 0.0 0.0 | | | | | | | |

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REACTION (K)

| AT STA | DEAD LI EFFECT | D LANE ORDE | POSITIVE R MAXIMUN | LOAD A M LANE | T LANE STA OR | NEGATIVE LOA DER MAXIMUM | AD AT LANE STA | | | |
|-----------|---------------------------------|------------------------------|---------------------------------------|----------------------------|------------------|-----------------------------|-------------------|--|--|--|
| 10 | 315.6 0 1 2 3 0* | 127.9 127.9 1.6 0.0 | 1 2 0 1 2 1 3 62 2 3 0* | -5.6 -5.6 0.0 0.0 | 2 36 2 36 | | | | | |
| 34 | 317.1 0 1 2 3 2* | 117.1 95.3 83.6 0.0 | 0 22 0 2 32 1 1 12 2 3 0* | -9.3 -9.3 0.0 0.0 | 3 63 3 63 | | | | | |
| 58 | 317.1 0 1 2 3 2* | 117.1 95.3 83.6 0.0 | 0 50 0 2 40 1 3 60 2 3 0* | -9.3 -9.3 0.0 0.0 | 19 19 | | | | | |
| 82 | 315.6 0 1 2 3 0* | 127.9 127.9 1.6 0.0 | 3 70 0 3 70 1 1 9 2 3 0* | -5.6 -5.6 0.0 0.0 | 2 36 2 36 | | | | | |

TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| | DICT | · • • • • • • • • | | | | CUEAD | |
|-----|-------|-------------------|--------|-----------|---------|-------|-------------|
| SIA | | | FMOM N | IAX - MOM | I MAX + | SHEAR | MAX - SHEAR |
| | | (FI-K) | (| (() | (| | |
| -1 | -0.58 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 1 | 0.58 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 2 | 1.15 | 0.0 | 0.0 | -0.7 | -0.7 | | |
| 3 | 1.73 | -0.8 | -0.8 | -2.8 | -2.8 | | |
| 4 | 2.31 | -3.2 | -3.2 | -5.6 | -5.6 | | |
| 5 | 2.89 | -7.3 | -7.3 | -8.4 | -8.4 | | |
| 6 | 3.46 | -12.9 | -12.9 | -96.1 | -149.0 | | |
| 7 | 4.04 | -118.3 | -179.3 | -183.8 | -289.0 | 5 | |
| 8 | 4.62 | -225.2 | -347.3 | -186.6 | -292.4 | 4 | |
| 9 | 5.20 | -333.8 | -516.9 | -189.4 | -295. | 2 | |
| 10 | 5.77 | -443.9 | -688.2 | -17.5 | -63.5 | | |
| 11 | 6.35 | -358.4 | -590.2 | 174.4 | 113. | 9 | |
| 12 | 6.93 | -269.0 | -493.8 | 171.6 | 111. | 1 | |
| 13 | 7.51 | -180.6 | -399.1 | 168.8 | 108. | 3 | |
| 14 | 8.08 | -93.8 | -306.0 | 166.0 | 105.5 | 5 | |
| 15 | 8.66 | -8.3 | -214.5 | 163.2 | 102.7 | | |
| 16 | 9.24 | 77.1 | -124.7 | 160.4 | 99.9 | | |
| 17 | 9.81 | 162.1 | -36.4 | 157.6 | 97.1 | | |
| 18 | 10.39 | 246.6 | 43.3 | 154.7 | 94.3 | 5 | |
| 19 | 10.97 | 330.0 | 97.0 | 151.9 | 91.5 | | |
| 20 | 11.55 | 412.6 | 149.0 | 149.1 | 88. | 7 | |
| 21 | 12.12 | 493.9 | 199.4 | 146.3 | 85. | 9 | |
| 22 | 12.70 | 574.3 | 248.1 | 20.8 | -8.3 | | |
| 23 | 13.28 | 489.9 | 196.8 | -81.0 | -148. | 4 | |
| 24 | 13.86 | 404.1 | 143.7 | -83.8 | -151. | 2 | |
| 25 | 14.43 | 317.1 | 88.7 | -86.6 | -154.0 |) | |
| 26 | 15.01 | 228.7 | 31.9 | -89.4 | -156.8 | 3 | |
| 27 | 15.59 | 139.6 | -26.9 | -92.2 | -159.6 | 5 | |
| 28 | 16.17 | 56.3 | -87.4 | -95.0 | -162.4 | | |
| 29 | 16.74 | -27.0 | -149.4 | -97.8 | -165. | 2 | |
| 30 | 17.32 | -105.6 | -213.6 | -100.6 | 5 -168 | 3.0 | |
| 31 | 17.90 | -164.5 | -308.5 | -103.4 | 4 -170 |).8 | |
| 32 | 18.48 | -225.0 | -407.1 | -106.2 | 2 -173 | 3.6 | |
| 33 | 19.05 | -287.2 | -507.4 | -109.0 | J -176 | .4 | |
| 34 | 19.63 | -350.9 | -609.2 | . 88.7 | 27.5 | 3 | |
| 35 | 20.21 | -239.6 | -426.3 | 315.4 | 1 191 | .3 | |
| 36 | 20.78 | -130.0 | -265.4 | 312.6 | 188 | .5 | |
| 37 | 21.36 | 26.8 | -129.9 | 309.8 | 185. | / | |
| 38 | 21.94 | 195.9 | -1.5 | 165.8 | 98.0 | | |
| 39 | 22.52 | 204.6 | 16.1 | 28.9 | 10.3 | | |
| 40 | 23.09 | 212.0 | 31.9 | 26.1 | 7.5 | | |
| 41 | 23.67 | 218.1 | 46.2 | 23.3 | 4.7 | | |
| 42 | 24.25 | 223.0 | 54.6 | 20.5 | 1.9 | | |

TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | DIST X | MAX + M | MOM MA | AX - MOM | MAX + SHEAR | MAX - SHEAR |
|------|---|---------|--------|-----------|-------------|-------------|
| 5171 | (FT) (| FT-K) (| FT-K) | (K) (F | () | NOV DITEXT |
| | (,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | 11-K) (| 1 1-K) | (() () | <) | |
| 13 | 24.83 | 226.3 | 60.3 | 177 | -0.9 | |
| 45 | 24.05 | 220.5 | 64.3 | 14.0 | -0.9 | |
| 44 | 25.40 | 227.9 | 66.8 | 12.1 | -5.7 | |
| 45 | 25.50 | 227.9 | 67.6 | 0.2 | 0.2 | |
| 40 | 20.50 | 227.9 | 67.0 | 9.5 | -9.5 | |
| 47 | 27.14 | 227.9 | 64.2 | 0.5 | -12.1 | |
| 48 | 27.71 | 227.9 | 64.3 | 3.7 | -14.9 | |
| 49 | 28.29 | 226.3 | 60.3 | 0.9 | -17.7 | |
| 50 | 28.87 | 223.0 | 54.6 | -1.9 | -20.5 | |
| 51 | 29.44 | 218.1 | 46.2 | -4.7 | -23.3 | |
| 52 | 30.02 | 212.0 | 31.9 | -7.5 | -26.1 | |
| 53 | 30.60 | 204.6 | 16.1 | -10.3 | -28.9 | |
| 54 | 31.18 | 195.9 | -1.5 | -98.0 | -165.8 | |
| 55 | 31.75 | 26.8 | -129.9 | -185.7 | -309.8 | |
| 56 | 32.33 | -130.0 | -265.4 | -188.5 | -312.6 | |
| 57 | 32.91 | -239.6 | -426.3 | -191.3 | -315.4 | |
| 58 | 33.49 | -350.9 | -609.2 | -27.3 | -88.7 | |
| 59 | 34.06 | -287.2 | -507.4 | 176.4 | 109.0 | |
| 60 | 34.64 | -225.0 | -407.1 | 173.6 | 106.2 | |
| 61 | 35.22 | -164.5 | -308.5 | 170.8 | 103.4 | |
| 62 | 35.80 | -105.6 | -213.6 | 168.0 | 100.6 | |
| 63 | 36.37 | -27.0 | -149.4 | 165.2 | 97.8 | |
| 64 | 36.95 | 56.3 | -87.4 | 162.4 | 95.0 | |
| 65 | 37.53 | 139.6 | -26.9 | 159.6 | 92.2 | |
| 66 | 38.11 | 228.7 | 31.9 | 156.8 | 89.4 | |
| 67 | 38.68 | 317.1 | 88.7 | 154.0 | 86.6 | |
| 68 | 39.26 | 404.1 | 143.7 | 151.2 | 83.8 | |
| 69 | 39.84 | 489.9 | 196.8 | 148.4 | 81.0 | |
| 70 | 40.41 | 574 3 | 248 1 | 83 | -20.8 | |
| 71 | 40.99 | 493.9 | 199.4 | -85.9 | -146 3 | |
| 72 | 41 57 | 412.6 | 149.0 | -88.7 | -149 1 | |
| 73 | 42.15 | 330.0 | 97.0 | -91 5 | -151.9 | |
| 74 | 42.13 | 246.6 | 43.3 | -94.3 | -154.7 | |
| 75 | 43 30 | 162.1 | -36.4 | -97.1 | -157.6 | |
| 76 | 13.88 | 77.1 | -124.7 | -99.9 | -160.4 | |
| 77 | 45.00 | -83 | -714.7 | -102.7 | -163.2 | |
| 78 | 44.40 | -0.5 | -214.5 | -102.7 | -166.0 | |
| 70 | 45.61 | 180.6 | -300.0 | 109.3 | 168.8 | |
| 20 | 45.01 | -160.0 | 102.0 | -108.5 | 171.6 | |
| 01 | 40.19 | -209.0 | -495.0 | 112.0 | 174.4 | |
| 01 | 40.77 | -336.4 | -390.Z | -115.9 | -174.4 | |
| 02 | 47.34 | 222.0 | -000.2 | 205.2 | 100 4 | |
| 04 | 47.92 | -333.8 | -510.9 | 295.2 | 109.4 | |
| 84 | 48.50 | -225.2 | -347.3 | 292.4 | 186.6 | |
| 85 | 49.07 | -118.3 | -1/9.3 | 289.6 | 183.8 | |
| 86 | 49.65 | -12.9 | -12.9 | 149.0 | 96.1 | |

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TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | DIST X | MAX | + MOM | MAX - MC | MAX + S | HEAR | MAX - SHEAR |
|-----|--------|-------------|--------|----------|---------|------|-------------|
| | () | (- 1 - K) | (FI-K) | (<) | (K) | | |
| 87 | 50.23 | -7.3 | -7.3 | 8.4 | 8.4 | | |
| 88 | 50.81 | -3.2 | -3.2 | 5.6 | 5.6 | | |
| 89 | 51.38 | -0.8 | -0.8 | 2.8 | 2.8 | | |
| 90 | 51.96 | 0.0 | 0.0 | 0.7 | 0.7 | | |
| 91 | 52.54 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 92 | 53.12 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 93 | 53.69 | 0.0 | 0.0 | 0.0 | 0.0 | | |

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TABLE 7. MAXIMUM SUPPORT REACTIONS (WORKING STRESS)

| | | | | - |
|-----|--------|-------|-------|-------------|
| STA | DIST X | MAX + | REACT | MAX - REACT |
| (| FT) | (K) | (K) | |
| | | | | - |
| 10 | 5.77 | 469.1 | 308 | .9 |
| 34 | 19.63 | 496.0 | 306 | 5.0 |
| 58 | 33.49 | 496.0 | 306 | 5.0 |
| 82 | 47.34 | 469.1 | 308 | 3.9 |

TABLE 5. MULTI-LANE LOADING SUMMARY (LOAD FACTOR) (*--CRITICAL NUMBER OF LANE LOADS)

MOMENT (FT-K)

| AT STA | DEAD LD EFFECT | ORDE | POSITIVE LOAD AT LANE MAXIMUM LANE STA OF | NEGATIVE LOAD AT RDER MAXIMUM LANE STA |
|-----------|----------------------------------|-------------------------------|--|---|
| 6 | -16.2 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 0.0 1 0.0 2 0.0 3 0.0 0* | |
| 10 | -563.9 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 -356.2 1 2 1 -356.2 1 2 2 0.0 3 0.0 0* | |
| 22 | 373.6 0 1 2 3 0* | 408.2 406.5 18.9 0.0 | 0 13 0 -67.4 2 36 1 12 1 -67.4 2 36 3 62 2 0.0 3 0.0 0* | |
| 34 | -477.8 0 1 2 3 0* | 37.8 37.8 0.0 0.0 | 3 62 0 -275.4 0 18 3 62 1 -235.5 1 12 2 -171.1 2 32 3 0.0 2* | |
| 38 | 102.3 0 1 2 3 0* | 168.9 168.9 6.5 0.0 | 2 32 0 -118.9 1 9 2 32 1 -118.9 1 9 3 62 2 0.0 3 0.0 0* | |
| 46 | 167.0 0 1 2 3 0* | 140.1 140.1 0.0 0.0 | 2 36 0 -56.2 1 9 2 36 1 -56.2 1 9 2 -56.2 3 63 3 0.0 2* | |
| 54 | 102.3 0 1 2 3 0* | 168.9 168.9 6.5 0.0 | 2 40 0 -118.9 3 63 2 40 1 -118.9 3 63 10 2 0.0 3 0.0 0* | |
| 58 | -477.8 0 1 2 3 0* | 37.8 37.8 0.0 0.0 | 1 9 0 -275.4 0 54 1 9 1 -235.5 3 60 2 -171.1 2 40 3 0.0 2* | |

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MOMENT (FT-K)

| AT | DEAD LD |) LANE | POSITIV | E LOA | AD AT | LA | NE | NEGATIVE I | LOAD AT |
|-----|---------|--------|---------|-------|-------|----|----|------------|------------|
| STA | FEFECT | OPDER | MAXIN | | ANES | ТΔ | OP | DER MAXIMI | IM LANESTA |
| 217 | LITECT | ONDER | | | | 17 | UN | | |
| | | | | | | | | | |
| | | | | | | | | | |
| 70 | 373.6 | | | | | | | | |
| | 0 | 108.2 | 0 59 | 0 - | 67.4 | 2 | 36 | | |
| | 1 | 400.2 | 2 60 | 4 | C7.4 | 2 | 20 | | |
| | 1 | 406.5 | 3 60 | - | 67.4 | 2 | 30 | | |
| | 2 | 18.9 | 19 | 2 0 | .0 | | | | |
| | 3 | 0.0 | 3 | 0.0 | | | | | |
| | 0* | | 0* | | | | | | |
| | 0 | | 0 | | | | | | |
| 0.7 | 563.0 | | | | | | | | |
| 82 | -563.9 | | | | | | | | |
| | 0 | 0.0 | 0 | -356. | 2 3 | 70 | | | |
| | 1 | 0.0 | 1 | -356. | 2 3 | 70 | | | |
| | 2 | 0.0 | 2 | 0.0 | _ | | | | |
| | 2 | 0.0 | 2 | 0.0 | | | | | |
| | 3 | 0.0 | 3 | 0.0 | | | | | |
| | 0* | | 0* | | | | | | |
| | | | | | | | | | |
| 86 | -16.2 | | | | | | | | |
| 00 | 10.2 | 0.0 | 0 | 0.0 | | | | | |
| | 0 | 0.0 | 0 | 0.0 | | | | | |
| | 1 | 0.0 | 1 | 0.0 | | | | | |
| | 2 | 0.0 | 2 | 0.0 | | | | | |
| | 3 | 0.0 | 3 | 0.0 | | | | | |
| | 0* | 0.0 | 0* | 0.0 | | | | | |
| | 0 | | 0 | | | | | | |

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SHEAR (K)

| AT STA | DEAD LD EFFECT | LANE POSITIVE LOAD AT LANE NEGATIVE LOAD AT ORDER MAXIMUM LANE STA ORDER MAXIMUM LANE STA |
|-----------|----------------------------------|---|
| 8 | -237.2 0 1 2 3 0* | 0.0 0 -154.2 1 2 0.0 1 -154.2 1 2 0.0 2 0.0 0.0 3 0.0 0* |
| 12 | 149.3 0 1 2 3 0* | 78.4 1 6 0 -9.7 2 36 78.4 1 6 1 -9.7 2 36 2.7 3 62 2 0.0 0.0 3 0.0 0* |
| 32 | -136.9 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 36 | 251.2 0 1 2 3 2* | 153.2 0 28 0 -13.6 3 63 147.2 2 32 1 -13.6 3 63 53.7 1 12 2 0.0 0.0 3 0.0 0* |
| 56 | -251.2 0 1 2 3 0* | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ |
| 60 | 136.9 0 1 2 3 0* | 95.6 0 57 0 -2.7 1 9 92.7 3 60 1 -2.7 1 9 19.5 2 40 2 0.0 0.0 3 0.0 0* |
| 80 | -149.3 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 84 | 237.2 0 1 2 3 0* | 154.2 3 70 0 0.0 154.2 3 70 1 0.0 0.0 2 0.0 0.0 3 0.0 0* |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la (CONTINUED)

REACTION (K)

| AT STA | DEAD LE EFFECT | O LANE ORDE | POSITIVE R MAXIMUI | LOAD A ⁻ M LANE | T LANE STA OF | NEGATIVE LOA DER MAXIMUM | D AT LANE STA |
|-----------|---------------------------------|--------------------------------|---------------------------------------|-------------------------------|------------------|-----------------------------|------------------|
| 10 | 400.5 0 1 2 3 0* | 223.8 223.8 2.7 0.0 | 1 2 0 1 2 1 3 62 2 3 0* | -9.7 -9.7 0.0 0.0 | 2 36 2 36 | | |
| 34 | 402.1 0 1 2 3 2* | 205.0 166.8 146.3 0.0 | 0 22 0 2 32 1 1 12 2 3 0* | -16.3 -16.3 0.0 0.0 | 3 63 3 63 | | |
| 58 | 402.1 0 1 2 3 2* | 205.0 166.8 146.3 0.0 | 0 50 0 2 40 1 3 60 2 3 0* | -16.3 -16.3 0.0 0.0 | 19 19 | | |
| 82 | 400.5 0 1 2 3 0* | 223.8 223.8 2.7 0.0 | 3 70 0 3 70 1 1 9 2 3 0* | -9.7 -9.7 0.0 0.0 | 2 36 2 36 | | |

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TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA | DIST) | K MAX - | MOM N | MAX - M | ОМ | MAX + SH | IEAR | MAX - SH | IEAR |
|-----|--------|---------|--------|---------|-----|----------|------|----------|------|
| | (FT) | (FT-K) | (FT-K) | (K) | (K |) | | | |
| | | | | | | | | | |
| -1 | -0.58 | 0.0 | 0.0 | 0.0 | 0. | .0 | | | |
| 0 | 0.00 | 0.0 | 0.0 | 0.0 | 0. | 0 | | | |
| 1 | 0.58 | 0.0 | 0.0 | 0.0 | 0. | 0 | | | |
| 2 | 1.15 | 0.0 | 0.0 | -0.9 | -0. | .9 | | | |
| 3 | 1.73 | -1.0 | -1.0 | -3.5 | -3 | .5 | | | |
| 4 | 2.31 | -4.0 | -4.0 | -7.0 | -7 | .0 | | | |
| 5 | 2.89 | -9.1 | -9.1 | -10.5 | -1 | 0.5 | | | |
| 6 | 3.46 | -16.2 | -16.2 | -122.1 | | 214.6 | | | |
| 7 | 4.04 | -150.1 | -256.9 | -233 | .7 | -418.7 | | | |
| 8 | 4.62 | -286.0 | -499.7 | -23/ | .2 | -422.2 | | | |
| 9 | 5.20 | -423.9 | -744.5 | -240 | ./ | -425.7 | | | |
| 10 | 5.77 | -563.9 | -991.3 | -14 | .3 | -94.7 | | | |
| 11 | 6.35 | -448.1 | -853.8 | 24 | /.0 | 141.1 | | | |
| 12 | 6.93 | -325.0 | -/18.4 | 24: | 5.5 | 137.6 | | | |
| 13 | 7.51 | -202.7 | -585.0 | 240 | J.U | 134.1 | | | |
| 14 | 8.08 | -82.3 | -453.7 | 236 | .4 | 130.6 | | | |
| 12 | 0.00 | 156 1 | -524.5 | 232 | .9 | 127.1 | | | |
| 10 | 9,24 | 100.1 | -197.0 | 225 | 0 | 120.1 | | | |
| 10 | 10.20 | 205.2 | -/1./ | 225 | .9 | 116.6 | | | |
| 19 | 10.39 | 513.7 | 105.8 | 222 | 2 Q | 113 1 | | | |
| 20 | 11 55 | 621 5 | 170.1 | 21 | 5.J | 100.6 | | | |
| 20 | 12 12 | 747.8 | 232.4 | 21 | 19 | 105.0 | | | |
| 22 | 12.12 | 863.4 | 292.4 | 34 | 1.5 | -16.8 | | | |
| 23 | 13.28 | 738.2 | 225 3 | -10 | 21 | -220.1 | | | |
| 24 | 13.86 | 611 3 | 155.8 | -10 | 5.6 | -223.6 | | | |
| 25 | 14.43 | 483.2 | 83.6 | -109 | 9.1 | -227.1 | | | |
| 26 | 15.01 | 353.5 | 9.0 | -112 | 6 | -230.6 | | | |
| 27 | 15.59 | 223.3 | -68.2 | -116 | 5.1 | -234.1 | | | |
| 28 | 16.17 | 104.0 | -147.4 | -11 | 9.6 | -237.6 | | | |
| 29 | 16.74 | -14.4 | -228.7 | -123 | 3.1 | -241.1 | | | |
| 30 | 17.32 | -123.9 | -312.9 | -12 | 6.6 | -244.6 | | | |
| 31 | 17.90 | -198.0 | -450.0 | -13 | 0.1 | -248.1 | | | |
| 32 | 18.48 | -274.1 | -592.8 | -13 | 3.6 | -251.6 | | | |
| 33 | 19.05 | -352.3 | -737.6 | 5 -13 | 7.1 | -255.1 | | | |
| 34 | 19.63 | -432.5 | -884.4 | 13 | 3.8 | 26.4 | | | |
| 35 | 20.21 | -293.8 | -620.4 | 45 | 5.6 | 238.4 | | | |
| 36 | 20.78 | -157.1 | -394.2 | . 45 | 2.1 | 234.9 | | | |
| 37 | 21.36 | 62.8 | -211.4 | 448 | 3.6 | 231.4 | | | |
| 38 | 21.94 | 305.0 | -40.3 | 238 | 3.4 | 119.8 | | | |
| 39 | 22.52 | 314.2 | -15.8 | 40 | .8 | 8.2 | | | |
| 40 | 23.09 | 321.9 | 6.8 | 37.3 | 3 | 4.7 | | | |
| 41 | 23.67 | 328.2 | 27.3 | 33. | .8 | 1.2 | | | |
| 42 | 24.25 | 333.1 | 38.4 | 30. | .3 | -2.3 | | | |
| 43 | 24.83 | 335.9 | 45.5 | 26. | .8 | -5.8 | | | |
| 44 | 25.40 | 336.8 | 50.6 | 23. | .3 | -9.3 | | | |

| 45 | 25.98 | 335.6 | 53.6 | 19.8 | -12.8 | |
|----|-------|-------|------|------|-------|--|
| 46 | 26.56 | 335.2 | 54.6 | 16.3 | -16.3 | |
| 47 | 27.14 | 335.6 | 53.6 | 12.8 | -19.8 | |
| 48 | 27.71 | 336.8 | 50.6 | 9.3 | -23.3 | |
| | | | | | | |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la (CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA | DIST X | MAX + N | IOM MA | X - MOM | MAX + SHEAR | MAX - SHEAR |
|-----|--------|----------|---------|---------|-------------|-------------|
| (| (FT) (| FT-K) (F | -T-K) (| (K) (H | <) | |
| | | | | | | |
| 49 | 28.29 | 335.9 | 45.5 | 5.8 | -26.8 | |
| 50 | 28.87 | 333.1 | 38.4 | 2.3 | -30.3 | |
| 51 | 29.44 | 328.2 | 27.3 | -1.2 | -33.8 | |
| 52 | 30.02 | 321.9 | 6.8 | -4.7 | -37.3 | |
| 53 | 30.60 | 314.2 | -15.8 | -8.2 | -40.8 | |
| 54 | 31.18 | 305.0 | -40.3 | -119.8 | -238.4 | |
| 55 | 31.75 | 62.8 | -211.4 | -231.4 | -448.6 | |
| 56 | 32.33 | -157.1 | -394.2 | -234.9 | -452.1 | |
| 57 | 32.91 | -293.8 | -620.4 | -238.4 | -455.6 | |
| 58 | 33.49 | -432.5 | -884.4 | -26.4 | -133.8 | |
| 59 | 34.06 | -352.3 | -737.6 | 255.1 | 137.1 | |
| 60 | 34.64 | -274.1 | -592.8 | 251.6 | 133.6 | |
| 61 | 35.22 | -198.0 | -450.0 | 248.1 | 130.1 | |
| 62 | 35.80 | -123.9 | -312.9 | 244.6 | 126.6 | |
| 63 | 36.37 | -14.4 | -228.7 | 241.1 | 123.1 | |
| 64 | 36.95 | 104.0 | -147.4 | 237.6 | 119.6 | |
| 65 | 37.53 | 223.3 | -68.2 | 234.1 | 116.1 | |
| 66 | 38.11 | 353.5 | 9.0 | 230.6 | 112.6 | |
| 67 | 38.68 | 483.2 | 83.6 | 227.1 | 109.1 | |
| 68 | 39.26 | 611.3 | 155.8 | 223.6 | 105.6 | |
| 69 | 39.84 | 738.2 | 225.3 | 220.1 | 102.1 | |
| 70 | 40.41 | 863.4 | 292.7 | 16.8 | -34.2 | |
| 71 | 40.99 | 747.8 | 232.4 | -106.1 | -211.9 | |
| 72 | 41.57 | 631.5 | 170.1 | -109.6 | -215.4 | |
| 73 | 42.15 | 513.7 | 105.8 | -113.1 | -218.9 | |
| 74 | 42.72 | 395.2 | 39.5 | -116.6 | -222.4 | |
| 75 | 43.30 | 275.7 | -71.7 | -120.1 | -225.9 | |
| 76 | 43.88 | 156.1 | -197.0 | -123.6 | -229.4 | |
| 77 | 44.46 | 36.6 | -324.3 | -127.1 | -232.9 | |
| 78 | 45.03 | -82.3 | -453.7 | -130.6 | -236.4 | |
| 79 | 45.61 | -202.7 | -585.0 | -134.1 | -240.0 | |
| 80 | 46.19 | -325.0 | -718.4 | -137.6 | -243.5 | |
| 81 | 46.77 | -448.1 | -853.8 | -141.1 | -247.0 | |
| 82 | 47.34 | -563.9 | -991.3 | 94.7 | 14.3 | |
| 83 | 47.92 | -423.9 | -744.5 | 425.7 | 240.7 | |
| 84 | 48.50 | -286.0 | -499.7 | 422.2 | 237.2 | |
| 85 | 49.07 | -150.1 | -256.9 | 418.7 | 233.7 | |
| 86 | 49.65 | -16.2 | -16.2 | 214.6 | 122.1 | |
| 87 | 50.23 | -9.1 | -9.1 | 10.5 | 10.5 | |
| 88 | 50.81 | -4.0 | -4.0 | 7.0 | 7.0 | |
| 89 | 51.38 | -1.0 | -1.0 | 3.5 | 3.5 | |

| 90 | 51.96 | 0.0 | 0.0 | 0.9 | 0.9 | |
|----|-------|-----|-----|-----|-----|--|
| 91 | 52.54 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 92 | 53.12 | 0.0 | 0.0 | 0.0 | 0.0 | |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'la (CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA DIST X MAX + MOM MAX - MOM MAX + SHE | AR MAX - SHEAR |
|--|----------------|
| (FT) (FT-K) (FT-K) (K) (K) | |
| | |
| 93 53 69 0.0 0.0 0.0 0.0 | |

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|--------------|-----------------------|-----------------------|---------|
| CAP18 | BENT CAP ANALYSIS | Ver. 6.2 (Jul, 2011) | |

TABLE 7. MAXIMUM SUPPORT REACTIONS (LOAD FACTOR)

| | | | | - |
|-----|--------|-------|-------|-------------|
| STA | DIST X | MAX + | REACT | MAX - REACT |
| (| FT) | (K) | (K) | |
| | | | | - |
| 10 | 5.77 | 669.0 | 388 | .8 |
| 34 | 19.63 | 715.2 | 382 | 2.5 |
| 58 | 33.49 | 715.2 | 382 | 2.5 |
| 82 | 47.34 | 669.0 | 388 | 8.8 |
| | | | | |

4.3.15.4 Live Load Distribution Factor Spreadsheet

4.3.15.4.1 Spans 1 & 3



| TXDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spe |
|----------|--------------------|--------------------------|------------------------------------|----------------|------------------|-------------|---------------------------|-----------------|--------------|-----------------------|
| DIVISION | C-S-J: Descrip: | ITBC Design Exar | ID #: mole 2. Span 1 & | 3 | Ck Dsn: File: | Ex2 So | Date: an1 distribution | ution factors x | Rev. 10/18 - | (No Interir 2 of 8 |
| INTER | IOR BE | AM. | | | It lids | Leve ob | | | Ondota | 2.010 |
| Choorl | L Distrib | ution Par Lana / | Table 46 2 2 3 | 10.11 | | | | | | |
| Sneart | One Le | unon Per Lane (| 14010 4.0.2.2.3 | <u>ba-1).</u> | | | | | | |
| | One La | ne Loaded | (T-b)- 0.5 1 | 1.01 | | | | | | |
| | | Lever Hule | (Table 3.6.1. | 1.2) | | | | | | |
| | | mg = 0.6 | 25 " 1.2 = | 0.750 | | | | | | |
| | | Modify to | or Skew: | | | | | | | |
| | | | skew correct | 101 = | 1.076 | | | | | |
| | | Sec. 13.05 | mg = 0.750 * | 1.076 = | 0.807 | | | | | |
| | | Equation | (s) | | | | | | | |
| | | g = 0.36 | $5 + \left(\frac{2}{25}\right)$ | | | | | | | |
| | | g = 0.36 | + (8 / 25) = | 0.680 | | | | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correct | ion = | 1.076 | | | | | |
| | | | g = 0.680 * 1 | .076 = | 0.732 | | | | | |
| | | Range of Appl | licability (ROA) | Checks | | | | | | |
| | | Check S | : 3.5' ≤ 8.0' ≤ | 16.0' | OK | | | | | |
| | | Check ts | 4.5" ≤ 8.0" ≤ | 12.0" | OK | | | | | |
| | | Check L: | 20' ≤ 50.4' ≤ | 240' | OK | | | | | |
| | | Check N | b; 6≥4 | | OK | | | | | |
| | | Use Equation | from Table 4.6 | 2.2.38-11 | because all | criteria is | S OK. | | | |
| | | gV _{int1} = | 0.732 | | | | | | | |
| | Two or | More Lanes Lo | aded | | | | | | | |
| | | Lever Rule | (Table 3.6.1. | 1.2) | | | | | | |
| | | mg = Ma | x(0.875 * 1.0, 0 | 0.875 * 0.8 | 35, 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correct | ion = | 1.076 | | | | | |
| | | | mg = 0.875 * | 1.076 = | 0.942 | | | | | |
| | | Equation | | . 20 | | | | | | |
| | | a - 0.2 - | $+(\underline{S})-(\underline{S})$ |) | | | | | | |
| | | 9 | (12) (35 |) | | | | | | |
| | | g = 0.2 + | (8 / 12) - (8 / 3 | 35)^2.0 = | 0,814 | | | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correct | ion = | 1,076 | | | | | |
| | | | g = 0.814 * 1 | .076 = | 0.876 | | | | | |
| | | Range of Appl | licability (ROA) | Checks | (same as | for one I | ane loade | ed) | | |
| | | Use Equation | from Table 4.6 | .2.2.3a-1 | because all | criteria i | s OK. | | | |
| | | $gV_{int2+} =$ | 0.876 | | | | | | | |
| | TXDOT | Policy states gV | Interior must be a | ≥ m·NL÷N | | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85*3/6= | | 0.425 | | | | | |
| | ls W≥: | 20ft ? Yes | | | | | | | | |
| | TXDOT | Policy states the | at II W < 20ft, g | Vinterior is t | he Maximun | not: gV | and m. | NL+Np. | | |
| >> | TXDOT | Policy states that | at if W≥20ft, g | Vinterior is t | he Maximun | of: gV | III. gVint2+ | m-NL÷Np. | | |
| | QV _{int} | arior = 0.876 | ٦ | | | | | | | |
| | p | | | | | | | | | |

| And Set [CS_2]: INXEXAXXXX (10)/m (2XX (2X)/m (2X)/m <th< th=""><th>FD Spec</th></th<> | FD Spec |
|--|---------|
| INTERIOR BEAM: Moment LL Distribution Per Lane (Table 4.6.2.2.2b-1): One Lane Loaded Lever Rule (Table 3.6.1.1.2) mg = 0.625 * 1.2 = 0.750 Modify for Skew: skew correction = 0.938 mg = 0.750 * 0.938 = 0.704 Equation g = 0.06 + $\left(\frac{5}{14}\right)^{0.4} \left(\frac{5}{L}\right)^{0.3} \left(\frac{K_x}{12Lt_x^3}\right)^{0.1}$ g = 0.06 + $(0.4)^{0.0.4} * (0.50.4)^{0.3.3} * (1.271.611/(12*50.4*8^{-3}))^{0.1.1} = 0.590$ Modify for Skew: skew correction = 0.938 g = 0.590 * 0.938 = 0.553 Range of Applicability (ROA) Checks Check 15: 3.5' 5.8.0' 516.0' OK Check 15: 3.5' 5.8.0' 512.0'' OK Check 15: 3.5' 5.8.0' 512.0'' OK Check 15: 3.5' 5.8.0' 512.0'' OK Check 15: 20' 550.4' 5240' OK Check 16: 20' 550.4' 524.0' DK Check 16: 20' 550.4' 524.0' DK Check 10: 20' 550.4' 524.0' DK Check 10: 20' 550.4' 524.0' DK Check 10: 20' 550.4'' 520.1'' Decause all criteria is OK. gM _{tot} = 0.553 Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.875 * 1.0.0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 Equation g = 0.075 + $\left(\frac{5}{9.5}\right)^{0.6} \left(\frac{5}{12}\right)^{0.2} \left(\frac{K_x}{12Lt_x}\right)^{0.1}$ g = 0.075 + $\left(\frac{8}{9.5}\right)^{0.6} \cdot \left(\frac{8}{150.4}\right)^{0.2} + (1.271.611/(12*50.4*8*3))^{0.1} = 0.794$ Modify for Skew: skew correction = 0.938 g = 0.734 * 0.338 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2.2.1 because all criteria is OK. gM _{tot} , = 0.7245 TxDOT Policy states gM _{tot} core must be 2 m N ₄ + N ₆ m N ₄ + N ₆ = 0.85 * 3.76 = 0.425 | 3 of 8 |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | 0010 |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | |
| Cite Life Looded $\begin{aligned} & \text{Lever Rule} (\text{Table 3.6.1.1.2}) \\ & \text{mg} = 0.625^{+}1.2 = 0.750 \\ & \text{Modify for Skew:} \\ & \text{skew correction} = 0.938 \\ & \text{mg} = 0.750^{+}0.938 = 0.704 \\ \hline \\ & \text{Equation} \\ & g = 0.06 + \left(\frac{S}{14}\right)^{0.4} \left(\frac{S}{12}\right)^{0.3} \left(\frac{K_x}{12LL_x^{+3}}\right)^{0.11} \\ & g = 0.06 + (8/14)^{0.0.4^{+}} (8/50.4)^{0.0.3^{+}}(1.271.611/(12^{+}50.4^{+}8^{+}3))^{+}0.1 = 0.590 \\ & \text{Modify for Skew:} \\ & \text{skew correction} = 0.938 \\ & g = 0.590^{+}0.838 = 0.553 \\ \hline \\ & \text{Range of Applicability (ROA) Checks} \\ & \text{Check K}_3: 4.5^{+} \le 8.0^{+} \le 16.0^{+} \text{OK} \\ & \text{Check K}_4: 4.5^{+} \le 8.0^{+} \le 16.0^{+} \text{OK} \\ & \text{Check K}_4: 4.5^{+} \le 8.0^{+} \le 16.0^{+} \text{OK} \\ & \text{Check K}_5: 0.590^{+} \le 12.0^{+} \text{OK} \\ & \text{Check K}_5: 0.590^{+} \le 12.0^{+} \text{OK} \\ & \text{Check K}_5: 10.000 \le 1.271.611 \le 7.000,000 \text{OK} \\ & \text{Check K}_5: 10.000 \le 1.271.611 \le 7.000,000 \text{OK} \\ & \text{Check K}_5: 10.000 \le 1.271.611 \le 7.000,000 \text{OK} \\ & \text{Use Equation from Table 4.6.2.2.20^{+}1 because all criteria is OK. \\ & gM_{wa,1} = 0.553 \\ \hline \\ & \text{Two or More Lanes Loaded} \\ & \text{Lever Rule} (\text{Table 3.6.1.1.2}) \\ & \text{mg} = 0.875^{+}0.938 = 0.821 \\ \hline \\ & \text{Equation} \\ & g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6^{+}} \left(\frac{S}{2}\right)^{0.2} \left(\frac{K_x}{12LL_x^{+3}}\right)^{0.4} \\ & g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6^{+}} \left(\frac{S}{20.2^{+}1.2^{+}1.5^{+}1.0^{+}1.1^{+}1.1^{+}1.5^{+}1.0^{+}1.1^{+}1.5^{+}1.$ | |
| $\begin{aligned} & \text{mg} = 0.625 \cdot 1.2 = 0.750 \\ & \text{Modify for Skew:} \\ & \text{skew correction} = 0.938 \\ & \text{mg} = 0.750 \cdot 0.938 = 0.704 \\ & \frac{\text{Equation}}{g = 0.06} + \left(\frac{S}{14}\right)^{0.4} \left(\frac{S}{2}\right)^{0.3} \left(\frac{K_{x}}{12Lr_{x}^{-3}}\right)^{0.1} \\ & g = 0.06 + \left(\frac{S}{14}\right)^{0.4} \cdot \left(\frac{S}{25}\right)^{0.3} \left(\frac{K_{x}}{12Lr_{x}^{-3}}\right)^{0.1} \\ & g = 0.06 + \left(\frac{S}{14}\right)^{0.4} \cdot \left(\frac{S}{250.4}\right)^{0.23} \cdot \left(1,271.611/(12^{+}50.4^{+}8^{+}3)\right)^{+}0.1 = 0.590 \\ & \text{Modify for Skew:} \\ & \text{skew correction} = 0.938 \\ & g = 0.590 \cdot 0.938 = 0.553 \\ \hline \text{Rance of Applicability (ROA) Checks} \\ & \text{Check S: } 3.5' \leq 8.0' \leq 16.0' \\ & \text{Check S: } 3.5' \leq 8.0' \leq 12.0' \\ & \text{OK} \\ & \text{Check K: } 20' \leq 50.4' \leq 240' \\ & \text{OK} \\ & \text{Check K: } 20' \leq 50.4' \leq 240' \\ & \text{OK} \\ & \text{Check K: } 0.553 \\ \hline \text{Two or More Lanes Loaded} \\ \hline & \text{Lever Rule} \\ & \text{(Table 3.6.1.1.2)} \\ & \text{mg} = 0.875 \cdot 0.938 = 0.821 \\ \hline & \text{Equation from Table 4.6.2.2.2.b^{-1} because all criteria is OR. \\ & gM_{wat} = 0.553 \\ \hline & \text{Modify for Skew:} \\ & \text{skew correction} = 0.938 \\ & \text{mg} = 0.875 \cdot 0.938 = 0.821 \\ \hline & \text{Equation} \\ & g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{2}\right)^{0.2} \left(\frac{K_{x}}{12Lt_{x}^{-3}}\right)^{0.4} \\ & g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \cdot (8/50.4)^{0.2} \cdot (1,271.611/(12^{+}50.4^{+}8^{+}3))^{0.1} = 0.794 \\ & \text{Modify for Skew:} \\ & \text{skew correction} = 0.938 \\ & g = 0.794 \cdot 0.338 = 0.745 \\ \hline & \text{Rance of Applicability (ROA) Checks} \\ & \text{(same as for one lane loaded)} \\ & \text{Use Equation from Table 4.6.2.2.2.2.1 because all criteria is OK. \\ & gM_{wa2} = 0.794 \cdot 0.338 = 0.745 \\ \hline & \text{Rance of Applicability (ROA) Checks} \\ & \text{(same as for one lane loaded)} \\ & \text{Use Equation from Table 4.6.2.2.2.2.1 because all criteria is OK. \\ & gM_{wa2} = 0.745 \\ \hline & \text{Rance of Applicability (ROA) Checks} \\ & \text{(same as for one lane loaded)} \\ & \text{Use Equation from Table 4.6.2.2.2.2.1 because all criteria is OK. \\ & gM_{wa2} = 0.745 \\ \hline & \text{Rance of Applicability Row must be 2 m N_{w} + N_{w} \\ & \text{m} N_{w} + N_{b} = 0.85 \cdot 3/6 = 0.425 \\ \hline \end{cases}$ | |
| $\label{eq:response} \begin{array}{llllllllllllllllllllllllllllllllllll$ | |
| $\begin{aligned} \sup_{x \in W} \operatorname{correction} &= 0.938 \\ \operatorname{mg} = 0.750^{\circ} 0.938 = 0.704 \\ \hline \\ &= \underbrace{ Equation \\ g = 0.06 + \left(\frac{S}{14} \right)^{0.4} \left(\frac{S}{L} \right)^{0.3} \left(\frac{K_x}{12L_x^{\circ,2}} \right)^{0.1} \\ g = 0.06 + (8/14)^{\circ} 0.4^{\circ} (8/50.4)^{\circ} 0.3^{\circ} (1,271.611/(12^{\circ}50.4^{\circ}8^{\circ}3))^{\circ} 0.1 = 0.590 \\ \operatorname{Modily for Skew:} \\ &= \underbrace{ skew correction = 0.938 \\ g = 0.590^{\circ} 0.938 = 0.553 \\ \hline \\ &= \underbrace{ Range of Applicability (\mathsf{ROA) Checks } \\ \operatorname{Check S: } 3.5' \leq 8.0^{\circ} 16.0^{\circ} \\ \operatorname{Check S: } 3.5' \leq 8.0^{\circ} 12.0^{\circ} \\ \operatorname{Check S: } 3.5' \leq 8.0^{\circ} 216.0^{\circ} \\ \operatorname{Check S: } 3.5' \leq 8.0^{\circ} 212.0^{\circ} \\ \operatorname{Check S: } 3.5' \leq 8.0^{\circ} 216.0^{\circ} \\ \operatorname{Check S: } 0.000 \leq 1.271,611 \leq 7,000,000 \\ \operatorname{Check S: } 0.000 \leq 1.271,611 \leq 7,000,000 \\ \operatorname{Check S: } 0.553 \\ \hline \\ \mathbf{Two or More Lanes Loaded} \\ \underbrace{ Lever Rule (Table 3.6.1.1.2) \\ \operatorname{mg = Max}(0.875^{\circ} 1.0, 0.875^{\circ} 0.85, 0.875^{\circ} 0.65) = 0.875 \\ \operatorname{Modily for Skew: } \\ \operatorname{skew correction = } 0.938 \\ \operatorname{mg = 0.875^{\circ} 0.938 = 0.022 \\ \hline \\ g = 0.075 + \left(\frac{S}{9.5} \right)^{0.6} \left(\frac{S}{9.0} \right)^{0.2} \left(\frac{K_x}{(12L_x)^3} \right)^{0.1} \\ g = 0.075 + \left(\frac{S}{9.5} \right)^{0.6} \left(\frac{S}{9.04} \right)^{0.2} (1.271,611/(12^{\circ}50.4^{\circ}8^{\circ}3))^{\circ} 0.1 = 0.794 \\ \operatorname{Modily for Skew: } \\ \operatorname{skew correction = } 0.938 \\ g = 0.794^{\circ} 0.338 = 0.745 \\ \hline \\ \operatorname{Range of Apollocibility} (\operatorname{ROA}) \operatorname{Checks} (same as for one lane loaded) \\ \operatorname{Lse Equation from Table 4.6.2.2.2b - 1 because all criteria is OK. \\ g M_{\operatorname{Mez}} = 0.745 \\ \operatorname{Made } 0.745 \\ \operatorname{Made } 0.745 \\ \operatorname{Made } 0.745 \\ \end{array}$ | |
| $\begin{aligned} \begin{array}{llllllllllllllllllllllllllllllllllll$ | |
| Equation $g = 0.06 + \left(\frac{S}{14}\right)^{0.4} \left(\frac{S}{L}\right)^{0.5} \left(\frac{K_x}{12Lt_x^3}\right)^{0.1}$ $g = 0.06 + (8/14)^{0.04} \cdot (8/50.4)^{0.03} \cdot (1,271,611/(12^{+}50.4^{+}8^{+}3))^{+}0.1 = 0.590$ Modify for Skew: skew correction = 0.938 $g = 0.590^{+}0.938 = 0.553$ Rance of Applicability (ROA) Checks Check S: 3.5' ≤ 8.0' ≤ 16.0' OK Check L; 20' ≤ 50.4' ≤ 240' OK Check L; 20' ≤ 50.4' ≤ 2.2:2:b-1 because all criteria is OK. gM _{but1} = 0.553 Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = 0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 Equation g = 0.075 + $\left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12Lt_x^3}\right)^{0.1}$ g = 0.075 + (8/9.5)*0.6 * (8/50.4)*0.2 * (1.271,611/(12*50.4*8*3))*0.1 = 0.794 Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.245 Rance of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2 · 2b-1 because all criteria is OK. gM _{mb2} = 0.245 TxDOT Policy states gM _{jettoro} must be $\ge m \cdot N_L \in N_0$ m·N _k $\approx N_b = 0.85 * 3/6 = 0.425$ | |
| $\frac{1}{g} = 0.06 + \left(\frac{S}{14}\right)^{0.4} \left(\frac{S}{L}\right)^{0.5} \left(\frac{K_x}{12LL_x^3}\right)^{0.5}$ $g = 0.06 + (8/14)^{0.4} \cdot (8/50.4)^{0.3} \cdot (1,271.611/(12^{+}50.4^{+}8^{+}3))^{0.1} = 0.590$ Modify for Skew: skew correction = 0.938 $g = 0.590^{+} 0.938 = 0.553$ Range of Applicability (ROA) Checks Check S: 3.5' $\leq 8.0' \leq 16.0'$ OK Check L: 4.5'' $\leq 8.0' \leq 16.0'$ OK Check L: 20' $\leq 50.4' \leq 240'$ OK Check L: 20' $\leq 50.4' \leq 240'$ OK Check N ₂ : $6 \geq 4$ OK Check N ₃ : $6 \geq 4$ OK Check N ₄ : $10,000 \leq 1,271.611 \leq 7,000,000$ OK Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{wat} = 0.553$ Two or More Lanes Loaded Lever Rule (Table 3.6.1.2) mg = Max(0.875^{+}1.0, 0.875^{+}0.85, 0.875^{+}0.65) = 0.875 Modify for Skew: skew correction = 0.933 mg = 0.875^{+}0.938 = 0.821 Equation $g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{K_x}{L}\right)^{0.2} \left(\frac{K_x}{12LL_1^{+3}}\right)^{0.1}$ $g = 0.075 + (8/9.5)^{0.6} \cdot (8/50.4)^{0.2} \cdot (1,271.611/(12^{+}50.4^{+}8^{+}3))^{*}0.1 = 0.794$ Modify for Skew: skew correction = 0.938 $g = 0.794^{+}0.938 = 0.745$ Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{wde} = 0.7245$ TxDOT Policy states $gM_{intenor}$ must be $\geq m^{+}N_{L}$ +N ₆ $m \cdot N_{L}$ +N _b = 0.85^{+}3.76 = 0.425 | |
| $ \begin{array}{rcl} g = 0.06 + (8/14)^{\circ}0.4 * (8/50.4)^{\circ}0.3 * (1,271.611/(12*50.4*8^{\circ}3))^{\circ}0.1 = & 0.590 \\ \mbox{Modify for Skew:} & & & & & & & & & & & & & & & & & & &$ | |
| $\label{eq:second} \begin{array}{llllllllllllllllllllllllllllllllllll$ | |
| $\begin{array}{rcl} skew correction = & 0.938\\ g = 0.590 * 0.938 = & 0.553\\ \hline \\ \hline Range of Applicability (ROA) Checks\\ \hline \\ Check S: & 3.5' \le 8.0' \le 16.0' & OK\\ \hline \\ Check S: & 3.5' \le 8.0'' \le 12.0'' & OK\\ \hline \\ Check L: & 20' \le 50.4' \le 240' & OK\\ \hline \\ Check N_{5}: & 6 \ge 4 & OK\\ \hline \\ Check N_{5}: & 6 \ge 4 & OK\\ \hline \\ Check N_{5}: & 10,000 \le 1,271,611 \le 7,000,000 & OK\\ \hline \\ Use Equation from Table 4.6.2.2.2.5-1 because all criteria is OK.\\ gM_{eff} = & 0.553\\ \hline \\ \hline \\ Two or More Lanes Loaded\\ \hline \\ \hline \\ Lever Rule & (Table 3.6.1.1.2) & mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = & 0.875\\ \hline \\ Modify for Skew: & skew correction = & 0.938\\ mg = 0.875 * 0.938 = & 0.821\\ \hline \\ Cruation & g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6'} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{(12LI_x)^3}\right)^{0.1}\\ g = 0.075 + (8/9.5)^{0.6''} (8/9.5)^{0.0''} (1.271,611/(12^*50.4^*8^*3))^{0.1} = & 0.794\\ \hline \\ Modify for Skew: & skew correction = & 0.938\\ g = 0.794 * 0.938 = & 0.745\\ \hline \\ \hline$ | |
| $\begin{split} g = 0.590^{\circ} 0.938 = 0.553 \\ \hline Rance of Applicability (ROA) Checks \\ Check S: 3.5' \le 8.0' \le 16.0' OK \\ Check L: 4.5'' \le 8.0'' \le 12.0'' OK \\ Check L: 20' \le 50.4' \le 240' OK \\ Check N_0': 6 \ge 4 OK \\ Check N_0': 6 \ge 4 OK \\ Check N_0': 10,000 \le 1,271,611 \le 7,000,000 OK \\ Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK \\ gM_{ret1} = 0.553 \\ \hline Mod of More Lanes Loaded \\ Lever Rule (Table 3.6.1.1.2) \\ mg = Max(0.875^{\circ} 10.875^{\circ} 0.85, 0.875^{\circ} 0.65) = 0.875 \\ Modify for Skew: \\ skew correction = 0.938 \\ mg = 0.875^{\circ} 0.938 = 0.821 \\ \hline Equation \\ g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12Lt_x^3}\right)^{0.1} \\ g = 0.075 + (8/3.5)/0.6 (8/50.4)/0.2 (1.271,611/(12^{\circ}50.4^{\circ}8^{\circ}3))/0.1 = 0.794 \\ Modify for Skew: \\ skew correction = 0.938 \\ g = 0.794^{\circ} 0.938 = 0.745 \\ \hline Range of Applicability (ROA) Checks (same as for one lane loaded) \\ Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK \\ gM_{ret2} = 0.724 \\ \hline TXDOT Policy states gM_{intensor}$ must be $\ge m \cdot N_L \in N_0$ $m \cdot N_L = 0.85^{\circ} 3 / 6 = 0.425 \\ \hline$ | |
| Bange of Applicability (ROA) ChecksCheck S:3.5' ≤ 8.0' ≤ 16.0'OKCheck L:4.5" ≤ 8.0" ≤ 12.0"OKCheck L:20' ≤ 50.4' ≤ 240'OKCheck N ₅ :6 ≥ 4OKCheck K ₃ :10,000 ≤ 1,271,611 ≤ 7,000,000OKUse Equation from Table 4.6.2.2.2b-1 because all criteria is OK.gMmet =0.5530.553Two or More Lanes LoadedLever Rule(Table 3.6.1.1.2)mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) =0.875Modify for Skew:skew correction =0.938mg = 0.075 + $\left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12Lt_x^3}\right)^{0.1}$ g = 0.075 + (8/9.5) * 0.65.4(9.2) * 0.24*8*3))*0.1 =0.794Modify for Skew:skew correction =0.938g = 0.075 + (8/9.5) * 0.6 * (8/5.0.4)*0.2 * (1.271,611/(12*50.4*8*3))*0.1 =0.794Modify for Skew:skew correction =0.938g = 0.794 * 0.938 =0.7450.745Range of Applicability (ROA) Checks (same as for one lane loaded)Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK.gMmet_* =0.7450.745TxDOT Policy states gMmeteror must be ≥ m*N_c+N_cm·N_c+N_b =m.N_c+N_b =0.85 * 3/6 =0.425 | |
| Check S: 3.5' ≤ 8.0' ≤ 16.0' OK Check I ₅ : 4.5" ≤ 8.0' ≤ 12.0" OK Check I ₅ : 20' ≤ 50.4' ≤ 240' OK Check N ₅ : 6 ≥ 4 OK Check N ₅ : 6 ≥ 4 OK Check N ₅ : 6 ≥ 4 OK Check N ₅ : 10,000 ≤ 1,271,611 ≤ 7,000,000 OK Use Equation from Table 4,6.2.2.2b-1 because all criteria is OR gM _{int} = 0.553 Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 Equation g = 0.075 + $\left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{(12Lt_x^3)}\right)^{0.1}$ g = 0.075 + (8/9.5)^{0.6 * (8/50.4)^{0.2 * (1,271,611/(12*50.4*8^3))^{0.1} = 0.794 Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. gM _{int2*} 0.745 TxDOT Policy states gM _{intenor} must be ≥ m·N _L =N _b m·N _L +N _b 0.85 * 3/6 = 0.425 | |
| Check t,: 4.5" $\leq 8.0" \leq 12.0"$ OK Check L: 20' $\leq 50.4' \leq 240'$ OK Check N ₀ : $6 \geq 4$ OK Check N ₀ : $6 \geq 4$ OK Check K ₂ : 10,000 $\leq 1,271,611 \leq 7,000,000$ OK Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. gM _{int} = 0.553 Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 Equation g = 0.075 + $\left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12LL_x}\right)^{0.1}$ g = 0.075 + $(8/9.5)^{\circ}0.6$ * $(8/50.4)^{\circ}0.2$ * $(1,271,611/(12*50.4*8^{\circ}3))^{\circ}0.1 = 0.794$ Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. gM _{int2*} = 0.745 TxDOT Policy states gM _{intence} must be $\geq m \cdot N_L + N_b$ $m \cdot N_L + N_b = 0.85 * 3/6 = 0.425$ | |
| Check L: $20^{\circ} \le 50.4^{\circ} \le 240^{\circ}$ OK Check N ₀ : $6 \ge 4$ OK Check K ₀ : 10,000 \le 1,271,611 \le 7,000,000 OK Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{net} = 0.553$ Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 Equation $g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12LL_x^3}\right)^{0.1}$ $g = 0.075 + (8/9.5)^{\circ}0.6 * (8/50.4)^{\circ}0.2 * (1,271,611/(12*50.4*8^3))^{\circ}0.1 = 0.794$ Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{int2*} = 0.745$ TxDOT Policy states $gM_{intenor}$ must be $\ge m \cdot N_L \div N_b$ $m \cdot N_L \div N_b = 0.85 * 3.76 = 0.425$ | |
| Check N ₉ : 6 ≥ 4 OK Check K ₉ : 10,000 ≤ 1,271,611 ≤ 7,000,000 OK Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. gM _{net} = 0.553 Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 Equation g = 0.075 + $\left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12Lt_x^3}\right)^{0.4}$ g = 0.075 + (8/9.5)^{0.6} * (8/50.4)^{0.2} * (1,271,611/(12*50.4*8^3))^{0.1} = 0.794 Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. gM _{int2*} = 0.745 TxDOT Policy states gM _{intenor} must be ≥ m·N _L ÷N _b m·N _L ÷N _b = 0.85 * 3 / 6 = 0.425 | |
| Check K _g : 10,000 ≤ 1,271,611 ≤ 7,000,000 OK Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. gM _{int1} = 0.553 Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 Equation g = 0.075 + $\left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12LL_x}\right)^{0.1}$ g = 0.075 + (8/9.5)^{0.6 * (8/50.4)^{0.2 * (1,271,611/(12*50.4*8^3))^{0.1 = 0.794}} Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. gM _{int2*} = 0.745 TxDOT Policy states gM _{intenor} must be ≥ m·N _L =N _b m·N _L +N _b = 0.85 * 3 / 6 = 0.425 | |
| Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{int1} = 0.553$ Two or More Lanes Loaded <u>Lever Rule</u> (Table 3.6.1.1.2) mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 <u>Equation</u> $g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12LI_x^3}\right)^{0.1}$ $g = 0.075 + (8/9.5)^{0.6} \cdot (8/50.4)^{0.2} \cdot (1.271,611/(12*50.4*8^{3}))^{0.1} = 0.794$ Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 <u>Range of Applicability (ROA) Checks</u> (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{int2*} = 0.745$ TxDOT Policy states $gM_{intenor}$ must be $\ge m\cdotN_L \le N_b$ $m\cdotN_L \le N_b = 0.85 * 3/6 = 0.425$ | |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | |
| Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 Equation $g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12LL_x^3}\right)^{0.1}$ g = 0.075 + (8/9.5)^{0.6} * (8/50.4)^{0.2} * (1.271,611/(12*50.4*8^3))^{0.1} = 0.794 Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. gM _{int2*} = 0.745 TxDOT Policy states gM _{intenor} must be ≥ m·N _L =N _b m·N _L +N _b = 0.85 * 3 / 6 = 0.425 | |
| $\frac{\text{Lever Rule}}{\text{Lever Rule}} (Table 3.6.1.1.2)$ mg = Max(0.875 * 1.0, 0.875 * 0.85, 0.875 * 0.65) = 0.875 Modify for Skew: skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 $\frac{\text{Equation}}{g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_s}{12Lt_s}\right)^{0.1}$ g = 0.075 + (8/9.5)^{0.6} * (8/50.4)^{0.2} * (1.271,611/(12*50.4*8^3))^{0.1} = 0.794 Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. gM _{int2*} = 0.745 TxDOT Policy states gM _{intenor} must be ≥ m·N _L = N ₀ m·N _L + N _b = 0.85 * 3 / 6 = 0.425 | |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | |
| $\begin{aligned} & \text{Modify for Skew:} \\ & \text{Skew correction} = 0.938 \\ & \text{mg} = 0.875 * 0.938 = 0.821 \\ \hline \\ & \text{Equation} \\ & g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12Lt_x^3}\right)^{0.1} \\ & g = 0.075 + (8/9.5)^{0.6} * (8/50.4)^{0.2} * (1.271,611/(12*50.4*8^{-3}))^{-0.1} = 0.794 \\ & \text{Modify for Skew:} \\ & \text{skew correction} = 0.938 \\ & g = 0.794 * 0.938 = 0.745 \\ \hline \\ & \text{Range of Applicability (ROA) Checks} \text{(same as for one lane loaded)} \\ & \text{Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK.} \\ & gM_{\text{int2*}} = 0.745 \\ \hline \\ & \text{TxDOT Policy states gM_{\text{interior}} must be ≥ m \cdot N_L = N_0 \\ & m \cdot N_L + N_b = 0.85 * 3 / 6 = 0.425 \\ \hline \end{aligned}$ | |
| skew correction = 0.938 mg = 0.875 * 0.938 = 0.821 Equation $g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12Lt_s^3}\right)^{0.1}$ $g = 0.075 + (8/9.5)^{0.6} * (8/50.4)^{0.2} * (1.271,611/(12*50.4*8^3))^{0.1} = 0.794$ Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{int2*} = 0.745$ TxDOT Policy states $gM_{intenor}$ must be ≥ m·N _L =N _b m·N _L =N _b = 0.85 * 3 / 6 = 0.425 | |
| $mg = 0.875 * 0.938 = 0.821$ $\frac{Equation}{g = 0.075 + (\frac{S}{9.5})^{0.6} (\frac{S}{L})^{0.2} (\frac{K_x}{12Lt_s^3})^{0.1}$ $g = 0.075 + (8/9.5)^{\circ}0.6 * (8/50.4)^{\circ}0.2 * (1.271,611/(12*50.4*8^{\circ}3))^{\circ}0.1 = 0.794$ Modify for Skew: $skew \text{ correction} = 0.938$ $g = 0.794 * 0.938 = 0.745$ Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{int2*} = 0.745$ TxDOT Policy states $gM_{intenor}$ must be $\ge m \cdot N_L \div N_b$ $m \cdot N_L \div N_b = 0.85 * 3 / 6 = 0.425$ | |
| $\begin{array}{l} \displaystyle \frac{\text{Equation}}{\text{g}=0.075+\left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12L{I_s}^3}\right)^{0.1}} \\ \displaystyle \text{g}=0.075+(8/9.5)^{\circ}0.6^{\circ}(8/50.4)^{\circ}0.2^{\circ}(1.271,611/(12^{\circ}50.4^{\circ}8^{\circ}3))^{\circ}0.1=0.794 \\ \displaystyle \text{Modify for Skew:} \\ & \text{skew correction}=0.938 \\ \displaystyle \text{g}=0.794^{\circ}0.938=0.745 \\ \hline \text{Range of Applicability (ROA) Checks} (\text{same as for one lane loaded}) \\ \displaystyle \text{Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK.} \\ \displaystyle \text{gM}_{\text{int2*}}=0.745 \\ \hline \text{TxDOT Policy states gM}_{\text{interior}} \text{ must be} \geq \text{m}\cdot\text{N}_{\text{L}}\text{=}\text{N}_{\text{b}} \\ \hline \text{m}\cdot\text{N}_{\text{L}}\text{+}\text{N}_{\text{b}}=0.85^{\circ}3/6=0.425 \\ \end{array}$ | |
| $g = 0.075 + \left(\frac{S}{9.5}\right)^{0.4} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_x}{12Lt_x}\right)^3$ $g = 0.075 + (8/9.5)^{0.6} * (8/50.4)^{0.2} * (1.271,611/(12*50.4*8^{-3}))^{0.1} = 0.794$ Modify for Skew: skew correction = 0.938 g = 0.794 * 0.938 = 0.745 Range of Applicability (ROA) Checks (same as for one lane loaded) Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{int2*} = 0.745$ TxDOT Policy states $gM_{interior}$ must be $\ge m \cdot N_L \div N_b$ $m \cdot N_L \div N_b = 0.85 * 3 / 6 = 0.425$ | |
| $\begin{array}{rcl} g = 0.075 + (8/9.5)^{h} 0.6 & (8/50.4)^{h} 0.2 & (1.271,611/(12*50.4*8^{h} 3))^{h} 0.1 = & 0.794 \\ & & \text{Modify for Skew:} & & & & & \\ & & & & \text{skew correction} = & & 0.938 \\ & & & & & & & & \\ g = 0.794 & 0.938 = & & & & & \\ & & & & & & & & \\ \hline & & & &$ | |
| $\begin{array}{rcl} \mbox{Modify for Skew:} & & & & & & & & & & & & & & & & & & &$ | |
| $skew \ correction = 0.938$ $g = 0.794 * 0.938 = 0.745$ $Range \ of \ Applicability \ (ROA) \ Checks \qquad (same \ as \ for \ one \ lane \ loaded)$ $Use \ Equation \ from \ Table \ 4.6.2.2.2b-1 \ because \ all \ criteria \ is \ OK.$ $gM_{int2+} = 0.745$ $TxDOT \ Policy \ states \ gM_{interior} \ must \ be \ \ge \ m\cdot N_L \div N_b$ $m\cdot N_L \div N_b = 0.85 * 3 / 6 = 0.425$ | |
| $\begin{array}{rcl} g=0.794 \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ | |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | |
| Use Equation from Table 4.6.2.2.2b-1 because all criteria is OK. $gM_{int2*} = 0.745$ TxDOT Policy states $gM_{interior}$ must be $\ge m \cdot N_L \div N_b$ $m \cdot N_L \div N_b = 0.85 * 3 / 6 = 0.425$ | |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | |
| TxDOT Policy states $gM_{interior}$ must be $\ge m \cdot N_L \div N_b$ $m \cdot N_L \div N_b = 0.85 * 3 / 6 = 0.425$ | |
| $m \cdot N_{\rm L} \div N_{\rm b} = 0.85 * 3 / 6 = 0.425$ | |
| | |
| Is W ≥ 20ft ? Yes | |
| TxDOT Policy states that if W < 20/t, gMindation is the Maximum of: gMint and m Ni +Ni. | |
| >> TxDOT Policy states that if W ≥ 20ft, gMinterior is the Maximum of gMinta, gMintz+, m·Ni+Ne | |
| $qM_{interior} = 0.745$ | |

| BRIDGE [C.S1; XXXXXXXXX [L0 pr:] DXXX [Ck Derk:] Date:] Date:] Pev. 1018. (Note:] TREO Ceship Example 2, Span 1 8.3 Price:] Er2 Span 1 distribution [actors.d] Sheet [4 of 8 Sheet LL Distribution Per Lane (Table 4.6.2.2.3b-1); One Lane Loaded Lever Rule (Table 3.6.1.1.2) mg = 0.625 1, 0.625 Tx DOT uses a multiple presence factor of 1,0 for one Modify for Skew:] lane loaded on the exterior beam. skew correction = 1.076 mg = 0.625 1, 0.76 0, 0.673 Use Lever Rule, as per AASHTO LRED Table 4.6.2.2.3b-1. 9 Vext = 0.673 Use Lever Rule, as per AASHTO LRED Table 4.6.2.2.3b-1. 9 Vext = 0.673 Use Lever Rule, as per AASHTO LRED Table 4.6.2.2.3b-1. 9 Vext = 0.673 Use Lever Rule, as per AASHTO LRED Table 4.6.2.2.3b-1. 9 Vext = 0.673 Use Lever Rule, as per AASHTO LRED Table 4.6.2.2.3b-1. 9 Vext = 0.673 Use Lever Rule, as per AASHTO LRED Table 4.6.2.2.3b-1. 9 Vext = 0.673 Use Lever Rule, as per AASHTO LRED Table 4.6.2.2.3b-1. 9 Vext = 0.673 Use Lever Rule, as per AASHTO LRED Table 4.6.2.2.3b-1. 9 Vext = 0.673 Use 3.6.11.2 mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * Modify for Skew: skew correction = 1.076 g. mg = 0.625 * 1.076 0.573 Equation d_e = dist. biw CL web to curb d_e = 0.6 + $\left(\frac{d_e}{10}\right)$ $e = 0.6 + \left(\frac{d_e}{10}\right)$ $e = 0.6 + (2.010) = 0.800 g = e^*gV_{max}$ g = 0.800 * 0.876 = 0.701 Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check Ab; i -1.0*2.0*5.5 OK Check Ab; i -0.5.5 OK Check Ab; i -0.5.5 OK Check Ab; i -0.701 TxDOT Policy states gVexterner must be 2 gVexterner 9 Vexter = 0.701 TxDOT Policy states gVexterner must be 2 gVexterner 9 Vexter = 0.701 TxDOT Policy states gVexterner must be 2 gVexterner 9 Vexter = 0.8076 must be 2 mN+Ne. | TXDOT | County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Specs |
|--|----------------|--------------------|------------------------------------|--------------------------------|------------------------------|-------------------------------|-------------|------------|----------------------------|--------------------|------------------------|
| EXTERIOR BEAM: Shear LL Distribution Per Lane (Table 4.6.2.2.3b-1): One Lane Loaded Lever Rule (Table 3.6.1.1.2) mg = 0.625 * 1.0 = 0.625 TxDOT uses a multiple presence factor of 1.0 for one Modify for Skew: skew corraction = 1.076 mg = 0.625 * 1.076 = 0.673 Use Lever Rule, as per AASHTO LRFD Table 4.6.2.2.3b-1. $gV_{ext1} = 0.673$ Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = 0.625 * 1.076 = 0.673 Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = 0.625 * 1.076 = 0.673 Equation $d_{e} = 0.612 * 1.076 = 0.673$ Equation $d_{e} = 0.625 * 1.076 = 0.673$ Equation $d_{e} = 0.625 * 1.076 = 0.673$ Equation $d_{e} = 0.61 + (\frac{1}{10})$ $e = 0.6 + (\frac{1}{2})$ $e = 0.6 + (\frac{1}{2})$ g = 0.800 is more than a start of the exterior beam. Check Interior Beam ROA: Check Age: -1.0' 2.0' 5.5 OK Check Ng: 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{exc2} = 0.201$ TxDOT Policy states $gV_{Excaver}$ must be $\ge gV_{extaver}$ $gV_{exc2} = 0.825$ | BRIDGE | C-S-J: Descrip: | ITBC Design Exa | ID #: mole 2. Soan 1 | & 3 | Ck Dsn: | Ex2 So | Date: | ition factors x | Rev. 10/18 - | (No Interim) 4 of 8 |
| Shear (LL Distribution Per Lane (Table 4.6.2.2.3b-1): One Lane Loaded Lever Rule (Table 3.6.1.1.2) mg = 0.625 * 1.0 = 0.625 TxDOT uses a multiple presence factor of 1.0 for one Modify for Skew: lane loaded on the exterior beam. skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Use Lever Rule, as per AASHTO LRFD Table 4.6.2.2.3b-1. gV _{ext1} = 0.673 Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.625 * 1.0, 0.625 * 0.65, 0.625 * 0.65) = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Equation d _a = dist. b/w CL web to curb d _a = OH - Rail Width d _a = 31t - 11t = 2.0 ft. e = 0.6 + $\left(\frac{d_x}{10}\right)$ e = 0.6 + $\left(\frac{d_x}{10}\right)$ e = 0.6 + $\left(\frac{d_x}{10}\right)$ find the for Beam ROA: Check Ag: -1.0' 5.5 OK Check Ag: -1.0' 5.5' OK Check N; 6 + 3 OK TxDOT Policy states gV _{Examp} must be ≥ gV _{examp} . | EXTER | BIOR BE | AM: | | | D. no. | Land_opt | | | Ondot. | 1010 |
| One Lane Loaded Lever Rule (Table 3.6.1.1.2) mg = 0.625 * 1.0 = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Use Lever Rule, as per AASHTO LRFD Table 4.6.2.2.3b-1. gVert = 0.673 Use Lever Rule (Table 3.6.1.1.2) mg = Max(0.625 * 1.0, 0.625 * 0.65, 0.625 * 0.65) = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Equation d _e = dist. b/w CL web to curb d _e = 0H - Rall Width d _e = 3H - 1H = 2.0 H e = 0.6 + $\left(\frac{d_x}{10}\right)$ e = 0.6 + (2.0/10) = 0.800 g = e [*] gV _{wa2-ka} g = 0.800 * 0.876 = 0.701 Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check N ₂ : 6 + 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. gV _{ext2} = 0.701 TxDOT Policy states gV _{Extates} must be ≥ gV _{attates} g V _{bettor} = 0.875 TxDOT Policy states gV _{Extates} must be ≥ gV _{attates} | Shear I | 1 Distrib | ution Per Lane | (Table 4.6.2.) | 2 3h-11 | | | | | | |
| Circle Line Verific III (Table 3.6.1.1.2) mg = 0.625 * 1.0 = 0.625 mg = 0.625 * 1.0 = 0.625 mg = 0.625 * 1.076 = 0.673 Use Lever Rule, as par AASHTO LRFD Table 4.6.2.2.3b-1. gV _{ext1} = 0.673 Two or More Lanes Loaded Lever Rule (Table 3.6.1.2) mg = Max(0.625 * 1.0, 0.625 * 0.65) = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Equation d _e = dist. b/w CL web to curb d _e = Off - Rall Width d _e = 3ft - 1ft = 2.0 ft e = 0.6 + $\left(\frac{d_x}{10}\right)$ e = 0.6 + $\left(\frac{d_x}{10}\right)$ g = o ² 9V _{m22Eq} g = 0.800 * 0.876 = 0.201 Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Check N ₂ : 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b - 1 because all criteria is OK. gV _{max2} = 0.201 TxDOT Policy states gV _{extency} must be ≥ gV _{mintery} g V _{max1} = 0.65 = 0.875 | <u>oncur c</u> | Onela | ne Loaded | 14010 110.6.1 | | | | | | | |
| $\begin{split} \textbf{mg} &= 0.625^{+}1.0 = 0.625 & \text{TxDOT uses a multiple presence factor of 1.0 for one lane loaded on the exterior beam.} \\ & \text{skew correction} = 1.076 & 0.673 \\ & \text{mg} = 0.625^{+}1.076 = 0.673 \\ & \text{Use Lever Rule, as par AASHTO LRED Table 4.6.2.2.3b-1.} \\ & \textbf{gV}_{ext1} = 0.673 \\ \hline \textbf{Two or More Lanes Loaded} \\ & \underline{\textbf{Lever Rule}} & (Table 3.6.11.2) \\ & \textbf{mg} = Max(0.625^{+}1.0, 0.625^{+}0.85, 0.625^{+}0.65) = 0.625 \\ & \text{Modify for Skew:} \\ & \text{skew correction} = 1.076 \\ & \textbf{mg} = 0.625^{+}1.076 = 0.673 \\ \hline \textbf{Equation} \\ & \textbf{d}_{e} = \text{dist. b/w GL web to curb} \\ & \textbf{d}_{e} = \text{dist. b/w GL web to curb} \\ & \textbf{d}_{e} = 0.6 + \left(\frac{d_{e}}{10}\right) \\ & \textbf{e} = 0.6 + \left(\frac{d_{e}}{10}\right) \\ & \textbf{e} = 0.6 + (2.0/10) = 0.800 \\ & \textbf{g} = e^{+}\textbf{g} \textbf{V}_{mathed} \\ & \textbf{g} = 0.800^{+}.0.876 = 0.201 \\ & \text{Skew Correction is included in gV(interior).} \\ \hline \textbf{Range of Applicability (ROA) Checks} \qquad \text{Interior ROA is implicitly applied to the exterior beam.} \\ & \text{Check May: 6 # 3 } OK \\ & \text{Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK.} \\ & \textbf{gV}_{mathed} = 0.701 \\ \hline \textbf{TxDOT Policy states gV}_{exteure} \text{ must be } \geq \textbf{gV}_{wintere} \\ & \textbf{gV}_{exteure} = 0.876 \\ \hline \textbf{TxDOT Policy states gV}_{exteure} \text{ must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure} \text{ must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure} \text{ must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure} \text{ must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure} \text{ must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure} \text{ must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure} \text{ must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure} \text{ must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure} \text{ must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure must be } \geq \textbf{mV}_{h} \text{-N}. \\ \hline \textbf{Kot Policy states gV}_{exteure m$ | | | Lever Bule | (Table 3.6 | 1.1.2) | | | | | | |
| Modify for Skew: Inne loaded on the exterior beam. skew correction = 1.076 mg = 0.625 * 1.076 = 0.623 Use Lever Rule, as per ASHTO LRFD Table 4.6.2.2.3b-1. $gV_{ext} = 0.623$ Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.625 * 1.0, 0.625 * 0.65) = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Equation $d_e = dist. b/w CL web to curb$ $d_e = 0H - Rall Width$ $d_e = 3tt - 1tt = 2.0 tt$ $e = 0.6 + (\frac{d}{10})$ $e = 0.6 + (\frac{d}{10})$ $e = 0.6 + (\frac{d}{10})$ $e = 0.6 + (\frac{d}{10})$ e = 0.68 + (2.0/10) = 0.800 $g = e^*gV_{m2.66}$ g = 0.800 * 0.876 = 0.701 Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check Ng: 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2} = 0.701$ TXDOT Policy states $gV_{Externor}$ must be $\ge gV_{interior}$ | | | ma = 0.6 | 525 * 1.0 = | 0.625 | TXDOT US | es a mul | tiple pres | sence factor | of 1.0 for a | ne |
| skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Use Lever Rule; as per AASHTO LRFD Table 4.6.2.2.3b-1. $gV_{ext1} = 0.673$ Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Equation d _e = dit. b/w CL web to curb d _e = OH - Rall Width d _e = OH - Rall Width d _e = 3ft - 1ft = 2.0 ft e = 0.6 + $\left(\frac{d_e}{10}\right)$ e = 0.6 + (2.0/10) = 0.800 g = e*gV_{int2+Eq} g = 0.800 * 0.876 = 0.701 Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d _g : -1.0* ≤ 2.0* ≤ 5.5' OK Check N _b : 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ender} = 0.2701$ TxDOT Policy states $gV_{Externer}$ must be ≥ $gV_{interior}$ $gV_{interior} = 0.876$ | | | Modify f | or Skew: | 10000 | lane loade | d on the | exterior | beam. | of the lot of | |
| mg = 0.625 * 1.076 = 0.673 Use Lever Rule, as per AASHTO LRFD Table 4.6.2.2.3b-1. $gV_{ext1} = 0.673$ Two or More Lanes Loaded $\frac{Lever Rule}{(Table 3.6.1.1.2)}$ $mg = Max(0.625 * 1.0, 0.625 * 0.65, 0.625 * 0.65) = 0.625$ Modify for Skew: skew correction = 1.076 $mg = 0.625 * 1.076 = 0.673$ Equation $d_{e} = 0.61 + Rail Width$ $d_{e} = 0.6 + (\frac{d_{e}}{10})$ $e = 0.6 + (2.0/10) = 0.800$ $g = e^{*}gV_{m22-Eq}$ $g = 0.800 * 0.876 = 0.701$ Skew Correction is included in gV(interior). Planae of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check $d_{e}^{*} = 1.0 \le 2.0 \le 5.5$ Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2} = 0.201$ TxDOT Policy states $gV_{Externer}$ must $b \ge gV_{interior}$ | | | | skew corre | ection = | 1.076 | | | | | |
| Use Lever Rule, as per AASHTO LRFD Table 4.6.2.2.3b-1. $gV_{writ} = 0.673$ Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Equation $d_e = dist. b/w CL web to curb$ $d_e = 0H - Rail Width$ $d_g = 3ft - 1ft = 2.0 ft$ $e = 0.6 + (\frac{d_e}{10})$ e = 0.6 + (2.0/10) = 0.800 $g = e^*gV_{im2-463}$ g = 0.800 * 0.876 = 0.701 Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check No: 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{write} = 0.201$ TXDOT Policy states $gV_{interior}$ $gV_{interior} = 0.876$ TXDOT Policy states $gV_{interior}$ | | | | mg = 0.62 | 5*1.076 = | 0.673 | | | | | |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | | | Use Lever Ru | le, as per AA | SHTO LRFD | Table 4.6.2 | 2.2.3b-1. | | | | |
| Two or More Lanes Loaded Lever Rule (Table 3.6.1.1.2) mg = Max(0.625 * 1.0, 0.625 * 0.65) = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Equation $d_o = \text{dist. b/w CL web to curb}$ $d_o = \text{dist. b/w CL web to curb}$ $d_o = \text{dist. b/w CL web to curb}$ $d_o = 0.6 + \text{Rall Width}$ $d_o = 3 \text{ft} - 1 \text{ft} = 2.0 \text{ft}$ $e = 0.6 + \left(\frac{2}{10}\right)$ e = 0.6 + (2.0/10) = 0.800 $g = e^*gV_{int2+Eq}$ g = 0.800 * 0.876 = 0.701 Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check $d_s: -1.0' \le 2.0' \le 5.5'$ OK Check $N_b: 6 \ne 3$ OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2,e} = 0.701$ TxDOT Policy states gV _{Exterior} must be \ge gV _{interior} $gV_{interior} = 0.876$ | | | gV _{ext1} = | 0.673 | | | | | | | |
| Lever Rule (Table 3.6.1.1.2) mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) = 0.625 Modify for Skew: skew correction = 1.076 mg = 0.625 * 1.076 = 0.673 Equation d _e = dist. b/w CL web to curb d _e = OH - Rall Width d _e = OH - Rall Width d _e = 0.6 + $\left(\frac{d_e}{10}\right)$ e = 0.6 + $\left(\frac{d_e}{10}\right)$ e = 0.6 + $\left(\frac{d_e}{10}\right)$ 0.800 g = e*gV _{im2×Eq} g = 0.800 * 0.876 = g = 0.800 * 0.876 = 0.701 Skew Correction is included in gV(interior). Parage of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check Interior Beam ROA: OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. gV _{ext2*} = Q.701 TxDOT Policy states gV _{Extence} Must be ≥ gV _{interior} gV _{interior} = gV _{interior} = Q.8276 TxDOT Policy states g | | T.u.e. e.s. | Maralanaala | and and | | | | | | | |
| $\frac{1}{1} \frac{1}{1} \frac{1}$ | | I WO OF | Nore Lanes Lo | /Table 3.6 | 110 | | | | | | |
| Modify for Skew: skew correction = 1,076 mg = 0.625 * 1.076 = 0.673 Equation $d_e = \text{dist. b/w CL web to curb}$ $d_e = OH - Rail Width$ $d_e = OH - Rail Width$ $d_e = 3ft - 1ft = 2.0 ft$ $e = 0.6 + \left(\frac{d_e}{10}\right)$ e = 0.6 + (2.0/10) = 0.800 $g = e^*gV_{\text{int2}-Eq}$ g = 0.800 * 0.876 = 0.701 Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d_e^: -1.0' ≤ 2.0' ≤ 5.5' OK Check d_e^: -1.0' | | | Lever Hule | (1able 3.0 | 0.625*0.6 | 25 0 625 * 0 | 65) - | 0 695 | | | |
| skew correction = 1,076 mg = 0.625 * 1.076 = 0.673 Equation $d_e = \text{dist. b/w CL web to curb}$ $d_e = OH - \text{Rail Width}$ $d_e = 3\text{ft} - 1\text{ft} = 2.0 \text{ ft}$ $e = 0.6 + \left(\frac{d_e}{10}\right)$ e = 0.6 + (2.0/10) = 0.800 $g = e^*gV_{\text{int2-Eq}}$ g = 0.800 * 0.876 = 0.701 Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check Interior Beam ROA: OK Check N _b : 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{\text{interior}} = 0.701$ TxDOT Policy states gV _{Extercer} must be ≥ gV _{interior} $gV_{\text{interior}} = 0.876$ TxDOT Policy states gV _{Extercer} must be ≥ gV _{interior} | | | Modify f | or Skow | , 0.025 0.0 | 5, 0.025 0 | .00) - | 0.02.0 | | | |
| $mg = 0.625 * 1.076 = 0.673$ Equation $d_{e} = dist. b/w CL web to curb$ $d_{e} = 0H - Rall Width$ $d_{e} = 3ft - 1ft = 2.0 ft$ $e = 0.6 + \left(\frac{d_{e}}{10}\right)$ $e = 0.6 + (2.0/10) = 0.800$ $g = e^{e}gV_{int2+Eq}$ $g = 0.800 * 0.876 = 0.701$ Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d_{e^{i}} - 1.0' \le 2.0' \le 5.5' OK Check N_{b^{i}} 6 \neq 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2*} = 0.701$ TxDOT Policy states gV _{Extercer} must be $\ge gV_{interior}$ TxDOT Policy states gV _{Extercer} must be $\ge m \cdot N_{1} \le N_{2}$ | | | woony i | skew corre | ection - | 1.076 | | | | | |
| Equation $d_{e} = \text{dist. b/w CL web to curb}$ $d_{e} = \text{OH} \cdot \text{Rall Width}$ $d_{e} = 3\text{H} \cdot 1\text{H} = 2.0 \text{H}$ $e = 0.6 + \left(\frac{d_{e}}{10}\right)$ $e = 0.6 + (2.0/10) = 0.800$ $g = e^{*}gV_{\text{int2+Eq}}$ $g = 0.800 * 0.876 = 0.701$ Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d_{e^{:}} -1.0' \le 2.0' \le 5.5' OK Check N_{b}: 6 \neq 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{\text{ext2+}} = 0.701$ TxDOT Policy states gV _{Extercer} must be $\ge \text{gV}_{\text{interior}}$ TxDOT Policy states gV _{Extercer} must be $\ge \text{gV}_{\text{interior}}$ | | | | mn = 0.62 | 5 1 076 - | 0.673 | | | | | |
| $d_{e} = \text{dist. b/w CL web to curb}$ $d_{e} = \text{dist. b/w CL web to curb}$ $d_{e} = \text{OH} \cdot \text{Rall Width}$ $d_{e} = 3\text{It} \cdot 1\text{It} = 2.0 \text{It}$ $e = 0.6 + \left(\frac{d_{e}}{10}\right)$ $e = 0.6 + (2.0/10) = 0.800$ $g = e^{*}gV_{\text{int2+Eq}}$ $g = 0.800 * 0.876 = 0.701$ Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d_{e}: -1.0' \le 2.0' \le 5.5' OK Check N_{b}: 6 \neq 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{\text{ext2+}} = 0.701$ TxDOT Policy states gV _{Externor} must be \ge gV _{interior} $gV_{\text{interior}} = 0.876$ TxDOT Policy states gV _{Externor} must be \ge m·N ₁ ÷N ₂ . | | | Equation | ing - oron | | 01010 | | | | | |
| $d_e = OH - Rail Width$ $d_e = 3ft - 1ft = 2.0 ft$ $e = 0.6 + \left(\frac{d_e}{10}\right)$ $e = 0.6 + (2.0/10) = 0.800$ $g = e^*gV_{int2+Eq}$ $g = 0.800 * 0.876 = 0.701$ Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d_e: -1.0' ≤ 2.0' ≤ 5.5' OK Check N_b: 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2+} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must be ≥ gV _{interior} $gV_{interior} = 0.876$ TxDOT Policy states $gV_{extarear}$ must be ≥ m·N ₁ ÷N ₂ | | | d. = dist | b/w CL web | to curb | | | | | | |
| $d_{e} = 3ft - 1ft = 2.0 ft$ $e = 0.6 + \left(\frac{d_{e}}{10}\right)$ $e = 0.6 + (2.0/10) = 0.800$ $g = e^*gV_{int2+Eq}$ $g = 0.800 * 0.876 = 0.701$ Skew Correction is included in gV(interior). <u>Range of Applicability (ROA) Checks</u> Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d_{ei}: -1.0' \le 2.0' \le 5.5' OK Check N_{bi}: 6 \neq 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext24} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must $b \ge gV_{interior}$ TxDOT Policy states $gV_{Exterior}$ must $b \ge gV_{interior}$ | | | $d_a = OH$ | - Rail Width | | | | | | | |
| $e = 0.6 + \left(\frac{d_e}{10}\right)$ $e = 0.6 + (2.0/10) = 0.800$ $g = e^*gV_{int2+Eq}$ $g = 0.800 * 0.876 = 0.701$ Skew Correction is included in gV(interior). <u>Range of Applicability (ROA) Checks</u> Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d_e: -1.0' \le 2.0' \le 5.5' OK Check N_b: 6 \neq 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2*} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must $be \ge gV_{interior}$ $gV_{interior} = 0.876$ TxDOT Policy states $dV_{Exterior}$ must $be \ge m \cdot N_{c} \div N_{D}$ | | | d _e = | 3ft - 1ft = | 2.01 | ti. | | | | | |
| $e = 0.6 + \left(\frac{\pi}{10}\right)$ $e = 0.6 + (2.0/10) = 0.800$ $g = e^*gV_{int2+Eq}$ $g = 0.800 * 0.876 = 0.701$ Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d _g : -1.0' ≤ 2.0' ≤ 5.5' OK Check N _b : 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2*} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must $be \ge gV_{interior}$ $gV_{interior} = 0.876$ TxDOT Policy states $dV_{Exterior}$ must $be \ge m \cdot N_{1} \div N_{D}$ | | | | (d) | | | | | | | |
| $e = 0.6 + (2.0/10) = 0.800$ $g = e^*gV_{int2+Eq}$ $g = 0.800 * 0.876 = 0.701$ Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check Interior Beam ROA: OK Check Interior Beam ROA: OK Check dg: -1.0' ≤ 2.0' ≤ 5.5' OK Check Nb: 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. gV _{ext2+} = 0.701 TxDOT Policy states gV _{Extercer} must be ≥ gV _{interior} gV _{interior} = 0.876 TxDOT Policy states gV _{Extercer} must be ≥ m·N ₁ ÷N _b | | | e = 0.6 | $+\left[\frac{\pi}{10}\right]$ | | | | | | | |
| $\begin{array}{l} g = e^*gV_{\text{interver}}\\ g = 0.800 * 0.876 = & \underline{0.701}\\ \text{Skew Correction is included in gV(interior).}\\ \hline \\ \hline Range of Applicability (ROA) Checks & Interior ROA is implicitly applied to the exterior beam.\\ \hline \\ Check Interior Beam ROA: & OK\\ \hline \\ Check d_{g^1} - 1.0' \leq 2.0' \leq 5.5' & OK\\ \hline \\ Check d_{g^1} - 1.0' \leq 2.0' \leq 5.5' & OK\\ \hline \\ Check N_b: 6 \neq 3 & OK\\ \hline \\ \text{Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK.}\\ gV_{\text{ext2*}} = & \underline{0.701}\\ \hline \\ \text{TxDOT Policy states gV}_{\text{Exterior}} \text{ must be } \geq gV_{\text{interior}}\\ gV_{\text{interior}} = & \underline{0.876}\\ \hline \\ \text{TxDOT Policy states oV}_{\text{Exterior}} \text{ must be } \geq m\cdotN_{1} \div N_{\text{P}}\\ \hline \end{array}$ | | | e = 0.6 | +(2.0/10) = | 0.800 | | | | | | |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | | | a o*a) | / | | | | | | | |
| $g = 0.800 0.876 = \underline{0.701}$ Skew Correction is included in gV(interior). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check d _e : -1.0' ≤ 2.0' ≤ 5.5' OK Check N _b : 6 ≠ 3 OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. gV _{ext2+} = <u>0.701</u> TxDOT Policy states gV _{Exterior} must be ≥ gV _{interior} gV _{interior} = <u>0.876</u> TxDOT Policy states dV _{Exterior} must be ≥ m·N ₁ ÷N _b | | | g = e gv | int2+Eq | 0 701 | | | | | | |
| Skew Confection is included in g v (intend). Range of Applicability (ROA) Checks Interior ROA is implicitly applied to the exterior beam. Check Interior Beam ROA: OK Check dg: -1.0' $\leq 2.0' \leq 5.5'$ OK Check Nb: $6 \neq 3$ OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2*} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must $be \geq gV_{interior}$ $gV_{interior} = 0.876$ TxDOT Policy states $gV_{Exterior}$ must $be \geq m \cdot N_1 \div N_p$ | | | g = 0.60 | orraction is in | cluded in al | //interior\ | | | | | |
| Interior ROA is implicitly applied to the extentor beam. Check Interior Beam ROA: OK Check $d_{e^i} - 1.0' \le 2.0' \le 5.5'$ OK Check Nb: $6 \ne 3$ OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2*} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must be $\ge gV_{interior}$ $gV_{interior} = 0.876$ TxDOT Policy states $dV_{Exterior}$ must be $\ge m \cdot N_1 \div N_p$ | | | Dance of Apr | licebility (DO | A) Chacks | Interior). | DOA in i | molinithy | opplied to th | ha autorior h | 0.000 |
| Check $d_{e^i} -1.0^i \le 2.0^i \le 5.5^i$ OK Check $N_{b^i}: 6 \ne 3$ OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2+} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must $be \ge gV_{interior}$ $gV_{interior} = 0.876$ TxDOT Policy states $dV_{Exterior}$ must $be \ge m \cdot N_1 \div N_p$ | | | Check l | nterior Beam | ROA. | OK | HUAISI | mplicitiy | applied to ti | ne exterior L | leant. |
| Check N _b : $6 \neq 3$ OK Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2*} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must be $\geq gV_{interior}$ $gV_{interior} = 0.876$ TxDOT Policy states $gV_{Exterior}$ must be $\geq m \cdot N_{1} \div N_{2}$ | | | Check d | 1.0'<20 | 1 < 5 5' | OK | | | | | |
| Use Equation from Table 4.6.2.2.3b-1 because all criteria is OK. $gV_{ext2*} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must be $\geq gV_{interior}$ $gV_{interior} = 0.876$ TxDOT Policy states $gV_{Exterior}$ must be $\geq m \cdot N_1 \div N_D$ | | | Check N | L: 6 ± 3 | 0.0 | OK | | | | | |
| $gV_{ext2+} = 0.701$ TxDOT Policy states $gV_{Exterior}$ must be $\geq gV_{interior}$ $gV_{interior} = 0.876$ TxDOT Policy states $gV_{Exterior}$ must be $\geq m \cdot N_1 \div N_p$ | | | Lise Equation | from Table 4 | 6223h-11 | hacause all | oritoria is | OK | | | |
| TxDOT Policy states gV_{Exterior} must be $\geq gV_{\text{interior}}$ $gV_{\text{interior}} = 0.876$ TxDOT Policy states gV_{Exterior} must be $\geq m \cdot N_1 \div N_p$ | | | aV- | 0 701 | F.U.E.E.UD-11 | Decause an | uniona is | OR. | | | |
| $\mathbf{gV}_{\text{interior}} = \frac{0.876}{\text{TxDOT Policy states gV}_{\text{interior}}}$ TxDOT Policy states gV_{exterior} must be $\geq \text{m} \cdot \text{N}_{1} \div \text{N}_{2}$ | | TUDOT | 9 · ext2+ - | V.L.V.L | | | | | | | |
| $gv_{intenior} = 0.876$ TxDOT Policy states $gv_{\text{Extension}}$ must be $\ge m \cdot N_i \div N_b$ | | IXDOI | Policy states gv | Edenar Must c | e < gv interior | | | | | | |
| $1 \times D \cup 1 = 0 = 0 \times States \cup V = define H USI D = 2 = 11 + 0 \oplus 10 \times States = 0 \times $ | | TYDOT | gvinterior = | 0.876 | A. M.m.C. | | | | | | |
| $mN + N = 0.95 \pm 2/6 = 0.425$ | | TADOT | m.N. +N. = | 0.95 * 2 / 6 | A THINK THE | 0 425 | | | | | |
| $10^{-14} = 0.03^{-3} = 0.423$ | | IS OH S | C/2 2 Voc | 0.05 370 |) = | 0.420 | | | | | |
| Is W ≥ 20ft ? Yes | | Is W≥2 | 20ft ? Yes | | | | | | | | |
| >> TxDOT Policy states that if $OH \leq S/2$, $gV_{Extensor}$ is $gV_{intensor}$. | >> | TXDOT | Policy states th | at if OH ≤ S/2 | 2, gV _{Exterior} is | gVintenior. | | | | | |
| TxDOT Policy states that if OH > S/2 and W < 20It, gV _{Extensor} is the Maximum of; gV _{ext1} , gV _{interior} , and | | TXDOT | Policy states th | at if OH > S/a | 2 and W < 20 | Dit, gV _{Exterior} | is the Ma | ximum c | f: gV _{ext1} , gV | interior, and | |
| $m \cdot N_L \div N_b$. | | | m·N _L ÷N _b . | | | | | | | all and the second | |
| TxDOT Policy states that if OH > S/2 ans W ≥ 20ft, gV _{Exterior} is the Maximum of: gV _{ext1} , gV _{ext2+} , gV _{interior} | | TXDOT | Policy states th | at if OH > S/2 | 2 ans W ≥ 20 | oft, gV _{Exterior} i | s the Ma | ximum o | f: gV _{ext1} , gV | exi2+, gVinterio | |
| and m·N _L ÷N _b . | | | and m NL+Nb | | | | | | A Court of | | |
| gV _{exterior} = 0.876 | | gV _{exte} | erior = 0.876 | | | | | | | | |

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TXDOT
BRIDGE
                      ANY
                                                                       Design:
Ck Dsn:
           County:
                                        Highway
                                                       Any
XXXX
                                                                                           Date
                                                                                                                        2017 LRFD Spel
                      XXX-XX-XXXX
                                                                                                                       10/18 - (No Inte
                                       ID #
                                                                                           Date
                                      mple 2. S.
                     ITBC Design Exa
DIVISION
                                                                                                                                5 of 8
 EXTERIOR BEAM:
Moment LL Distribution Per Lane (Table 4.6.2.2.2d-1):
          One Lane Loaded
                     Lever Rule
                           mg = 0.625 * 1.0 =
                                                      0.625
                                                                   TxDOT uses a multiple presence factor of 1,0 for one
                                                                   lane loaded on the exterior beam.
                            Modify for Skew:
                                       skew correction =
                                                                      0.938
                                       mg = 0.625 * 0.938 =
                                                                      0.586
                     Use Lever Rule as per AASHTO LRFD Table 4.6.2.2.2d-1.
                     gMext1 =
                                        0.586
          Two or More Lanes Loaded
                     Lever Rule
                                        (Table 3.6.1.1.2)
                           mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) =
                                                                                           0.625
                           Modify for Skew:
                                       skew correction =
                                                                       0.938
                                       mg = 0.625 * 0.938 =
                                                                       0.586
                     Equation
                           \mathbf{e} = 0.77 + \left(\frac{d_e}{9.1}\right)
                           e = 0.77 + (2.0/9.1) =
                                                                   0.990
                           g = e^*gM_{int2+Eq}
                           g = 0.99 * 0.745 =
                                                       0.738
                            Skew Correction included in gM(interior).
                     Range of Applicability (ROA) Checks
                                                                       Interior ROA is implicitly applied to the exterior beam.
                           Check Interior Beam ROA:
                                                                   OK
                           Check d_e: -1.0' \leq 2.0' \leq 5.5'
                                                                  OK
                           Check N<sub>b</sub>: 6 ≠ 3
                                                                   OK
                     Use Equation from Table 4.6.2.2.2d-1 because all criteria is OK.
                     gM<sub>ext2+</sub> =
                                       0.738
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ gM<sub>interior</sub>
                     gMinterior =
                                      0.745
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ m·N<sub>L</sub>÷N<sub>b</sub>
                     m \cdot N_L \div N_b = 0.85 * 3 / 6 =
                                                                      0.425
          Is OH ≤ S/2 ? Yes
          Is W ≥ 20ft ? Yes
      >> TxDOT Policy states that if OH ≤ S/2, gM<sub>Exterior</sub> is gM<sub>interior</sub>.
          TxDOT Policy states that if OH > S/2 and W < 20ft, gM<sub>Exterior</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>interior</sub>, and
                     m·NI ÷Nn
          TxDOT Policy states that if OH > S/2 ans W \ge 20ft, gM<sub>Extensi</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>ext2+1</sub> gM<sub>mienor</sub>
                     and m·NL+NE
            gM<sub>exterior</sub> = 0.745
```



| BIDGE County: | ANY XXX-XX-XXXX | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 I | RFD Spe |
|---------------------------------------|---|----------------------------------|-------------------------------|-----------------------------------|-------------------|----------|-----------------|-----------------------|----------------------------|
| IVISION Descrip: | ITBC Design Exar | nple 2, Span 1 & | 3 | File: | Ex2 Spant | distribu | tion_factors.xl | Sheet: | 7 01 8 |
| LEVER RULE | S | = 8.0 ft | | | | | | | |
| INTERIOR (con't) | | | | | | | | | |
| For 18 ≤ S < 22: One Lane = | $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ | | | | | - | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{s-4}{s} + \frac{s-10}{s}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{s}$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{s-4}{s} + \frac{s-10}{s}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S-16}{S}$ | | Ľ. | = 0.625 | | |
| For $22 \le S \le 24$; One Lane = | $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ | | | | | i. | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | (| | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1 + \frac{S-6}{S} + \frac{1}{S}\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{-18}{s}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{S-18}{S} + \frac{S-16}{S}$ | $+\frac{S-22}{S}$ | | = -1.500 | | |
| | | | | Hinge | | | Rail Width | S = OH = = RW = | 8.0 ft 3.0 ft 1.0 ft |
| For X < 6: | 16(X) | - S | | | | | A = 0+UH+ | 1vv-∠i[= | 0.U N |
| One Lane = | $\overline{32}(\overline{s})$ | | | | | | = 0.500 | | |
| For 6 ≤ X < 12; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ |) | | | | | = 0.625 | | |
| For 12 ≤ X < 18; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ |) | | | | | = 0.625 | | |
| | 12/12 12 1 | 8 123 | | | | | | | |

| RIDGE County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 LRF | D Spece |
|--------------------------------|--|--|----------------------------------|--|--------------------------------|------------------------------|------------------|----------|---------|
| IVISION Descrip: | ITBC Design Exa | mple 2, Span 1 | & 3 | File: | Ex2 Span | 1 distrib | ution factors.xl | Sheet: 8 | of 8 |
| | | | | | | | | | |
| LEVER RULE | | | | | | | | | |
| EXTERIOR (con't |) S: | = 8.0 ft | | OH = | 3.0 ft | | | | |
| | RW = | = 1.0 ft | X = S+0 | OH-RW-2ft = | 8.0 ft | | | | |
| For 18 ≤ X < 24: | ICT V V | 63 | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-s}{s}\right)$ | <u>-</u>) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{5} + \frac{X - 12}{S} + \frac{X}{S}$ | $\left(\frac{1}{S}\right)$ | | | | = -0.250 | | |
| For $24 \le X < 30$: | 167 × × | (1 | | | | | | | |
| One Lane = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x-1}{s}\right)$ | <u> </u> | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\left(\frac{-18}{s}\right)$ | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-1}{S}\right)$ | $\frac{6}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{x-18}{S} + \frac{x-2}{S}$ | <u>84</u>) | | | = -1.250 | | |
| For 30 ≤ X < 36: | 16 (X X -) | 5) | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x}{s}\right)$ | <u> </u> | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X-12}{S} + \frac{X}{S}$ | $\left(\frac{-18}{s}\right)$ | | | | = -0.250 | | |
| Three Lanes = | $-\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{s} + \frac{X-30}{s}$ | | | = -2.625 | | |
| For 36 ≤ X < 42: One Lane = | $\frac{16}{22}\left(\frac{X}{2} + \frac{X-1}{2}\right)$ | <u>e</u>] | | | | | = 0.625 | | |
| | 32(5 5 16(V V | × 10 × | -103 | | | | | | |
| Two Lanes = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-s}{s}\right)$ | $\frac{x+x-1}{s}$ + $\frac{x}{s}$ | s) | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{x-18}{S} + \frac{x-2}{S}$ | $\frac{4}{3} + \frac{X - 30}{S}$ | | | = -2.625 | | |
| Four Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{5} + \frac{X-12}{S} + \frac{X}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{x^4}{s} + \frac{x - 30}{s} + x - 3$ | $\left(\frac{X-36}{S}\right)$ | | = -4.375 | | |
| For 42 ≤ X ≤ 48: One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | <u>6</u>) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{5} + \frac{X - 12}{5} + \frac{X}{5}$ | $\left(\frac{-18}{s}\right)$ | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{5} + \frac{X - 12}{5} + \frac{X}{5}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\left(\frac{4}{s}+\frac{X-30}{s}\right)$ | | | = -2.625 | | |
| Four Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{6}{5} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{94}{5} + \frac{x-30}{5} + \frac{1}{5}$ | $\frac{X-36}{S} + \frac{X}{S}$ | $\left(\frac{-42}{s}\right)$ | = -6.500 | | |
| INTERIOR | _ | | | EXTER | IOR | | | | |
| One Lane Loaded | 1 | = 0.625 | | One La | ne Loade | d | | 0.625 | |
| Two Lanes Loade | d | = 0.875 | | Two La | nes Load | ed | = | 0.625 | |
| Three Lanes Load | ded | = 0.875 | | Three L | anes Loa | ded | - | 0.625 | |
| Four Lanes Load | ad | - 0.875 | | | | | | 0.005 | |

4.3.15.4.2 Span 2



| | County: | ANT ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LHFD Spe |
|---------|-----------|--------------------------|---|------------------------------|---------------|--------------|--------------|----------------|--------------|------------|
| VISION | C-S-J: | ITBC Design Exa | ID #: mole 2. Span 2 | XXXX | Ck Dsn: | Ex2 Sn | Date: | tion factors x | Rev. 10/18 - | (No Interi |
| INTER | IOR BE | | inple at opart a | | 11107 | Tene op | | | Onder | 2010 |
| Choorl | L Dietrib | ution Parl and / | Table 1622 | 20.11 | | | | | | |
| Shear L | C DISUID | ulion Fer Lane (| Table 4.0.2.2. | .od-1/. | | | | | | |
| | One La | he Loaded | Table 0.5 1 | 1.01 | | | | | | |
| | | Lever Hule | (Table 3.6.) | 0.750 | | | | | | |
| | | mg = 0.6 | 25 " 1.2 = | 0.750 | | | | | | |
| | | Modify to | or Skew: | | 1.005 | | | | | |
| | | | skew correc | | 1.095 | | | | | |
| | | | mg = 0.750 | 1.095 = | 0.821 | | | | | |
| | | Equation | (5) | | | | | | | |
| | | g = 0.30 | $p^{+}(\frac{1}{25})$ | | | | | | | |
| | | a = 0.36 | + (8 / 25) = | 0.680 | | | | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correc | ction = | 1.095 | | | | | |
| | | | q = 0.680 * | 1.095 = | 0.745 | | | | | |
| | | Range of App | licability (ROA | A) Checks | - | | | | | |
| | | Check S | 3.5'≤8.0'≤ | ≤ 16.0' | OK | | | | | |
| | | Check t. | : 4.5"≤8.0" | ≤ 12.0" | OK | | | | | |
| | | Check L | 20' ≤ 106.8 | ' ≤ 240' | OK | | | | | |
| | | Check N | 624 | | OK | | | | | |
| | | Lico Equation | from Table 4 | 62220.18 | acouso all c | initoria id | OK | | | |
| | | nV | 0.745 | Vicielod I v | Accause and | sitteria i | s one | | | |
| | | 9 * int1 = | 0.740 | | | | | | | |
| | Two or | More Lanes Lo | aded | | | | | | | |
| | | Lever Hule | (Table 3.6.1 | 1.1.2) | | | 0.005 | | | |
| | | mg = Ma | x(0.875 - 1.0, | 0.875 - 0.8 | 5, 0.875 - 0. | .65) = | 0.875 | | | |
| | | Modify fo | or Skew: | | 1 205 | | | | | |
| | | | skew correc | ction = | 1.095 | | | | | |
| | | Carlos and a | mg = 0.875 | * 1.095 = | 0.958 | | | | | |
| | | Equation | (s) (s | 2.0 | | | | | | |
| | | g = 0.2 | $+\left(\frac{1}{12}\right) - \left(\frac{1}{3}\right)$ | 5 | | | | | | |
| | | q = 0.2 + | (8/12) - (8/ | 35)^2.0 = | 0.814 | | | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correc | ction = | 1.095 | | | | | |
| | | | g = 0.814 * | 1.095 = | 0.891 | | | | | |
| | | Bange of App | licability (BOA | Checks | (same as f | or one l | ane loade | (be | | |
| | | Lisa Equation | from Table 4 | 62232-11 | le equene | vitoria i | - OK | | | |
| | | aV.m | 0.801 | 0.6.6.00-1.0 | ecause and | aniterita is | 5 O.A. | | | |
| | | 9 * int2+ - | 0.001 | Can be | | | | | | |
| | TXDOT | Policy states gv | Interior must be | ≥ m·NL÷Nb | - | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85*3/6 | = | 0.425 | | | | | |
| | ls W≥2 | 20ft? Yes | | | | | | | | |
| | TXDOT | Policy states the | at if $W < 20$ ft, | gVintenar is th | ne Maximum | of: gV | iti and m- | NL+Nb | | |
| >> | TXDOT | Policy states the | at if $W \ge 20$ ft, | gV _{Inletior} is th | ne Maximum | of: gVi | 111. gVint2+ | m·NL÷No. | | |
| | | | | | | | | | | |

| INTERI Moment | C-S-J: Descrip: OR BEA | ITBC Design Exa | ID #: mple 2, Span 2 | XXXX | Ck Dsn: | | Date: | 12 | Rev. 10/18 - | (No Interin |
|------------------|------------------------------|------------------------|---|--|--------------------------|------------|---------------|-----------------|--------------|-------------|
| INTERI Moment | OR BEA | M. | the at spect a | | LEIIA: | Ex2 So | an2 distribu | ution factors.x | Sheet: | 3 0 8 |
| <u>Moment</u> | LL Dietri | | | | T. HOL | | | | i onoral | |
| | LL DISIII | bution Per Lane | e (Table 4.6.2.) | 2.2b-1): | | | | | | |
| | One Lar | e Loaded | | | | | | | | |
| | | Lever Rule | (Table 3.6.1. | 1.2) | | | | | | |
| | | ma = 0.6 | 25 * 1.2 = | 0.750 | | | | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correct | tion = | 0.964 | | | | | |
| | | | mg = 0.750 * | 0.964 = | 0.723 | | | | | |
| | | Equation | 6 - 504 6 - | ×0.37 m | 1.07 | | | | | |
| | | g = 0.00 | $6 + \left(\frac{S}{14}\right) \left(\frac{S}{14}\right)$ | $\left(\frac{\mathbf{A}_{s}}{12Lt}\right)$ | 3 | | | | | |
| | | g = 0.06 | + (8/14)^0.4 * | (8/106.8)^0.3 | 3 * (1,271, | 611/(12 | 106.8*8 | 3))^0.1 = | 0.453 | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correct | tion = | 0.964 | | | | | |
| | | | g = 0.453 * 0 | .964 = | 0.437 | | | | | |
| | | Range of App | licability (ROA) | Checks | | | | | | |
| | | Check S | : 3.5' ≤ 8.0' ≤ | 16.0' | | OK | | | | |
| | | Check ts | : 4.5" ≤ 8.0" ≤ | \$ 12.0" | | OK | | | | |
| | | Check L | : 20' ≤ 106.8' | ≤ 240' | | OK | | | | |
| | | Check N | b: 6≥4 | | | OK | | | | |
| | | Check K | g: 10,000 ≤ 1,3 | 271,611≤7,0 | 000,000 | OK | | | | |
| | | Use Equation | from Table 4.6 | i.2.2.2b-1 be | cause all o | criteria i | s OK. | | | |
| | | gM _{int1} = | 0.437 | | | | | | | |
| | Two or | More Lanes Lo | aded | | | | | | | |
| | | Lever Rule | (Table 3.6.1. | 1.2) | | | | | | |
| | | mg = Ma | ax(0.875 * 1.0, | 0.875 * 0.85 | 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correct | tion = | 0.964 | | | | | |
| | | | mg = 0.875 | 0.964 = | 0.844 | | | | | |
| | | Equation a 0.07 | $75 + (S)^{0.6}$ | $S^{0.2}$ K | g)0.1 | | | | | |
| | | g = 0.01 | (9.5) | L) (121 | $\left(t_{3}^{3}\right)$ | | | | | |
| | | g = 0.075 Modify fo | 5 + (8/9.5)^0.6 or Skew: | * (8/106.8)^(| 0.2 * (1,27 | 1,611/(1 | 2*106.8* | 8^3))^0.1 = | 0.649 | |
| | | widding it | skew correct | tion = | 0.964 | | | | | |
| | | | a = 0.649 * 0 | 964 = | 0.626 | | | | | |
| | | Bange of App | licability (BOA) | Checks | (same as f | for one l | ane loade | (be | | |
| | | Lise Equation | from Table 4.6 | 2.2.2h-1 he | | oritoria i | e OK | | | |
| | | aMara = | 0.626 | | cause and | cinterna i | a one | | | |
| | TUDOT | Dellawatetee - | A mount he | S - N - M | | | | | | |
| | 1x0011 | m.N. : N | Anterior must be | < III.INF + INP | 0.405 | | | | | |
| | 10 11/20 | | 0.05 3/6= | | 0.420 | | | | | |
| | TXDOT I | Policy states the | at if W = 200 o | Muser is the | Maximun | n of aM | and m | NI =N | | |
| - | TXDOT | Policy states the | at if W ≥ 20H o | Murana is the | Maximun | n ol: aM | aM. | m.NN. | | |
| F | aM. | - 0 coc | | minitation is the | - manningh | an givi | ARI + REARING | 41 to tal and | | |
| XDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spee |
|---------|-----------|------------------------------------|-------------------------------------|------------------------------|------------------------------|-------------|------------|--|---------------------|-----------|
| VISION | C-S-J: | ITBC Design Ex | ID #: | XXXX | Ck Dsn: | Ex2 Soa | Date: | ition factors x | Rev. 10/18 | 4 of 8 |
| XTER | BIOR BE | AM. | Inple L, Opur L | | It no. | Los ope | | | Under. | 4010 |
| hoorl | I Dietrib | ution Par Lana | Table 16.2 | 2 2h 11 | | | | | | |
| snear L | C DISTID | ution Per Lane | (Table 4.6.2.) | 2.30-11: | | | | | | |
| | One La | ne Loaded | Table 0.0 | 1.1.01 | | | | | | |
| | | Lever Rule | (1 able 3.6 | .1.1.2) | TROT | | | and the last | | |
| | | mg = U. | 625 ° 1.0 ≃ | 0.625 | IxDOT us | es a mul | tiple pres | sence factor | of 1,0 for a | ine |
| | | NOOITY I | or Skew: | ation | 1 005 | a on me | GATOHOL | beam | | |
| | | | SKew Corre | E * 1 00E | 0.090 | | | | | |
| | | The Louise De | my = 0.02 | 0 1.090 = | 0.004 | o ob d | | | | |
| | | Use Lever Hi | ne. as per AA | SHIULAFI | J 18018 4.6 | 2.2.30-1. | | | | |
| | | gv _{ext1} = | 0.684 | | | | | | | |
| | Two or | More Lanes L | oaded | | | | | | | |
| | | Lever Rule | (Table 3.6 | .1.1.2) | | | | | | |
| | | mg = M | ax(0.625 * 1.0 | 0, 0.625 * 0.8 | 85, 0.625 * 0 | .65) = | 0.625 | | | |
| | | Modify I | or Skew: | | | | | | | |
| | | | skew corre | ection = | 1.095 | | | | | |
| | | | mg = 0.62 | 5 * 1.095 = | 0.684 | | | | | |
| | | Equation | | | | | | | | |
| | | d _e = dis | t. b/w CL web | to curb | | | | | | |
| | | $d_e = OH$ | - Rail Width | | | | | | | |
| | | d _e = | 3ft - 1ft = | 2.01 | t. | | | | | |
| | | a = 0.6 | $+\left(\frac{d_{e}}{d_{e}}\right)$ | | | | | | | |
| | | 6 = 0.0 | (10) | | | | | | | |
| | | e = 0.6 | + (2.0/10) = | 0.800 | | | | | | |
| | | g = e*g | Vint2+Eq | | | | | | | |
| | | g = 0.80 | 0 * 0.891 = | 0.713 | | | | | | |
| | | Skew C | orrection is in | cluded in gV | (interior). | | | | | |
| | | Range of App | blicability (RC | A) Checks | Interior | ROA is i | mplicitly | applied to th | ne exterior b | beam. |
| | | Check I | nterior Beam | ROA: | OK | | | | | |
| | | Check of | d _e : -1.0' ≤ 2.0 | '≤5.5' | OK | | | | | |
| | | Check I | N _b : 6≠3 | | OK | | | | | |
| | | Use Equation | from Table 4 | .6.2.2.3b-11 | because all o | criteria is | OK. | | | |
| | | $gV_{ext2+} =$ | 0.713 | | | | | | | |
| | TYDOT | Policy states o | V- musth | vo s av | | | | | | |
| | TADOI | aV= | 0 891 | - g v interior | | | | | | |
| | TYDOT | Policy states of | Vmust h | -NN. | | | | | | |
| | in son | m·N ₁ ÷N ₂ = | 0.85*3/6 | S = | 0 425 | | | | | |
| | Is OH < | SI2 2 Ves | 0.00 011 | - | Vitteo | | | | | |
| | Is W ≥2 | 20ft? Yes | | | | | | | | |
| >> | TXDOT | Policy states th | at if OH ≤ S/2 | 2, gV _{Exterior} is | gVintenior. | | | | | |
| | TXDOT | Policy states th | at if OH > S/a | 2 and W < 20 | It, gV _{Exterior} | s the Ma | ximum o | f: gV _{ext1} , gV | interior, and | |
| | | m·NL÷Nn. | | | w waterie | | | and an | and the strength | |
| | TXDOT | Policy states th | at if OH > S/2 | 2 ans W ≥ 20 | ft, gV _{Exterior} i | s the Ma | ximum o | ft gV _{ext1} , gV. | exi2+, gVinteria | or i |
| | | and m·Ni +Ni | | | Sec. Participa | | | C. Built Q. I | and the or infigure | |
| | | wine = 0.891 | | | | | | | | |

```
TXDOT
BRIDGE
                     ANY
           County:
                                       Highway
                                                     Any
XXXX
                                                                     Design:
                                                                                         Date
                                                                                                                     2017 LRFD Spel
                     XXX-XX-XXXX
                                                                                                                    10/18 - (No Inte
                                                                     Ck Dsn:
                                      ID #
                                                                                         Date
                    ITBC Design Exa
DIVISION
                                                                                                                             5 of 8
 EXTERIOR BEAM:
Moment LL Distribution Per Lane (Table 4.6.2.2.2d-1):
          One Lane Loaded
                     Lever Rule
                           mg = 0.625 * 1.0 =
                                                    0.625
                                                                  TxDOT uses a multiple presence factor of 1,0 for one
                                                                  lane loaded on the exterior beam.
                           Modify for Skew:
                                      skew correction =
                                                                    0.964
                                      mg = 0.625 * 0.964 =
                                                                    0.603
                     Use Lever Rule as per AASHTO LRFD Table 4.6.2.2.2d-1.
                     gMext1 =
                                       0.603
          Two or More Lanes Loaded
                    Lever Rule
                                       (Table 3.6.1.1.2)
                           mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) =
                                                                                         0.625
                           Modify for Skew:
                                      skew correction =
                                                                    0.964
                                      mg = 0.625 * 0.964 =
                                                                     0.603
                     Equation
                          \mathbf{e} = 0.77 + \left(\frac{d_e}{9.1}\right)
                          e = 0.77 + (2.0/9.1) =
                                                                  0.990
                          g = e^*gM_{int2+Eq}
                           g = 0.99 * 0.626 =
                                                     0.620
                           Skew Correction included in gM(interior).
                     Range of Applicability (ROA) Checks
                                                                     Interior ROA is implicitly applied to the exterior beam.
                          Check Interior Beam ROA:
                                                                  OK
                           Check d_e: -1.0' \leq 2.0' \leq 5.5'
                                                                OK
                           Check N<sub>b</sub>: 6 ≠ 3
                                                                  OK
                     Use Equation from Table 4.6.2.2.2d-1 because all criteria is OK.
                     gM_{ext2+} =
                                      0.620
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ gM<sub>interior</sub>
                     gMinterior =
                                     0.626
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ m·N<sub>L</sub>÷N<sub>b</sub>
                     m \cdot N_L \div N_b = 0.85 * 3 / 6 =
                                                                    0.425
          Is OH ≤ S/2 ? Yes
          Is W ≥ 20ft ? Yes
      >> TxDOT Policy states that if OH ≤ S/2, gMExterior is gMinterior.
          TxDOT Policy states that if OH > S/2 and W < 20ft, gM<sub>Exterior</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>interior</sub>, and
                     m·NI ÷Nn
          TxDOT Policy states that if OH > S/2 ans W \ge 20ft, gM<sub>Extensi</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>ext2+1</sub> gM<sub>mienor</sub>
                     and m·NL+NE
           gM<sub>exterior</sub> = 0.626
```



| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|--------------------------------|---|----------------------------------|-------------------------------|--|-------------------|------------|--------------------------|-----------------------------------|--------------------------------------|
| DIVISION Descrip: | ITBC Design Exar | nple 2, Span 2 | 10000 | File: | Ex2 Span | 2_distribu | ution factors.xl | Sheet: | 7 of 8 |
| LEVER RULE | S | = 8.0 ft | | | | | | | |
| INTERIOR (con't) | | | | | | | | | |
| For 18 ≤ S < 22: One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right.$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{s-4}{s} + \frac{s-10}{s}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{.s}$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{s-12}{s}+\frac{s}{s}$ | $\frac{-18}{S} + \frac{S-16}{S}$ | | | = 0.625 | | |
| For 22 ≤ S ≤ 24; One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{-18}{s}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{s-12}{s}+\frac{s}{s}$ | $\frac{-18}{S} + \frac{S-16}{S}$ | $+\frac{S-22}{S}$ | | = -1.500 | | |
| | | | | + 4 II - 4 II - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 | | | Rail Width X = S+OH-F | S = OH = = RW = RW-2ft = | 8.0 ft 3.0 ft 1.0 ft 8.0 ft |
| For X < 6: One Lane = | $\frac{16}{32}\left(\frac{X}{5}\right)$ | - s | ł | | | | = 0.500 | | |
| For 6 ≤ X < 12; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-C}{S}\right)$ |) | | | | | = 0.625 | | |
| For 12 ≤ X < 18; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ |) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $+\frac{X-12}{S}$ | | | | | = 0.375 | | |

| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|-------------------------|---|----------------------------------|---------------------------------|---|------------|------------|----------------|--------|-----------|
| IVISION Descrip: | ITBC Design Exan | nple 2, Span 2 | 17777 | File: | Ex2 Span | 2_distrib | ution_factors. | Sheet: | 8 of 8 |
| Contra Anna | | | | | | | | | |
| LEVER RULE | | | | | | | | | |
| EXTERIOR (con't | S = | 8.0 ft | | OH = | 3.0 ft | | | | |
| | RW = | 1.0 ft | X = S+C | H-RW-2ft = | 8.0 ft | | | | |
| For 18 ≤ X < 24: | 1000 00 00 00 | | | | | | | | |
| One Lane = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x-6}{s}\right)$ |) | | | | | = 0.625 | | |
| ÷ | 16 (X , X -6 | X -12 X | -18) | | | | 0.050 | | |
| Two Lanes = | 32 8 5 | S | S) | | | | = -0.250 | | |
| For 24 ≤ X < 30: | 16 (X X-6 | 1 | | | | | 0.005 | | |
| One Lane = | 32 5 5 |) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{22}\left(\frac{X}{5}+\frac{X-6}{5}\right)$ | $+\frac{X-12}{c}+\frac{X}{c}$ | -18 | | | | = -0.250 | | |
| | 32(5 5 16/V V-6 | a V = 12 V | -18 V-7 | an. | | | | | |
| Three Lanes = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-0}{s}\right)$ | $+\frac{x-12}{S}+\frac{x}{S}$ | $\frac{-13}{S} + \frac{x-z}{S}$ | <u>-</u>) | | | = -1.250 | | |
| For 30 ≤ X < 36: | 15/ X X - 6 | 1 | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-0}{s}\right)$ |) | | | | | = 0.625 | | |
| Two Lanes - | $\frac{16}{X} + \frac{X-6}{X}$ | $+\frac{X-12}{+}$ | -18 | | | | - 0 250 | | |
| Two canes = | 32 \ S S | S | s) | 1.10 | | | - 0.200 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x-6}{s}\right)$ | $+\frac{X-12}{S}+\frac{X}{S}$ | $\frac{-18}{S} + \frac{X-2}{S}$ | $\frac{4}{s} + \frac{X - 30}{S}$ | | | = -2.625 | | |
| For $36 \le X < 42$: | 12/2 2 2 | x | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-0}{s}\right)$ |) | | | | | = 0.625 | | |
| Two Lange - | $\frac{16}{X} + \frac{X}{X} = 6$ | $+ \frac{X-12}{4} + \frac{X}{4}$ | -18 | | | | - 0.250 | | |
| Two Lanes = | 32 8 8 | \$ | S) | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{5} + \frac{X-6}{5}\right)$ | $+\frac{X-12}{S}+\frac{X}{S}$ | $\frac{-18}{s} + \frac{x-2}{s}$ | $\frac{4}{4} + \frac{X-30}{S}$ | | | = -2.625 | | |
| | 16(X X-6 | X-12 X | -18 X-2 | 4 X - 30 | 8 - 36) | | | | |
| Four Lanes = | $\frac{1}{32}\left(\frac{1}{s} + \frac{1}{s}\right)$ | + - + - + | s + <u>s</u> | ++ | s) | | = -4.375 | | |
| For $42 \le X \le 48$: | 16/X X-6 | 1 | | | | | | | |
| One Lane = | $\frac{11}{32}\left(\frac{1}{s} + \frac{1}{s}\right)$ | J | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{16}\left(\frac{X}{x}+\frac{X-6}{6}\right)$ | $+ \frac{X - 12}{+} \frac{X}{+}$ | -18 | | | | = -0.250 | | |
| A TOP (Heavily State) | 32 8 8 | S IN IN | S J | | | | | | |
| Three Lanes = | $\frac{10}{32}\left(\frac{x}{s}+\frac{x-6}{s}\right)$ | $+\frac{X-12}{S}+\frac{X}{S}$ | $\frac{-18}{S} + \frac{X-2}{S}$ | $+\frac{x-30}{s}$ | | | = -2.625 | | |
| Four Lange - | $\frac{16}{X + X - 6}$ | $+\frac{X-12}{X}$ | -18 + x - 2 | $4 + \frac{x - 30}{x - 30} + \frac{x - 30}{x - 30}$ | x - 36 + x | -42) | 6 500 | | |
| rour canes = | 32 5 5 | S | 5 5 | S | S | <i>s</i>) | - 0.000 | | _ |
| INTERIOR | _ | | | EXTER | IOR | | | | |
| One Lane Loaded | | 0.625 | | One La | ne Loaded | ł | 1.1 | 0.625 | |
| Two Lanes Loade | d = | 0.875 | | Two La | nes Loade | d | | 0.625 | |
| Three Lanes Load | led = | 0.875 | | Three L | anes Load | ded | 1.5 | 0.625 | |
| Four Lanes Loade | d | 0.875 | | Fourts | nes Load | he | | 0.625 | |

| | C-S-J: | xxxxxx | | | Design: | BRG C | k Dsn: | BRG | |
|---|---------------|-----------|-------------|--------------|----------|-------------|------------|-----------|---------|
| Department of Transportation | Bridge I | Division | R | ev: 09/26/08 | | | Date: | Aug-20 | |
| ONCRETE SECTION SHE | AR CAPA | CITY BY A | ASHTO L | RFD BRID | GE DESIG | N SPECIFIC | ATIONS, FO | URTH EDIT | ON, 200 |
| esistance Factors: | | i | Units: | US | 1 | | 1.0 | - | 1.00 |
| / = | 0.9 | | | | | | | | |
| - | 0.9 | | | | | | | | |
| 4 = | 0.75 | | | | | | | | |
| oncrete: | - | 1 | Mild Steel: | | 1 | Prestressed | Steel: | | |
| fc =[| 5 | ksi | fy = | 60 | ksi | fpu = | 270 k | si | |
| Ec = | 4070 | ksi | Es = | 29000 | ksi | Ep = | 28500 k | si | |
| | | L | | 3 | SECTIONS | | | | |
| | Units | 8 | 12 | 32 | 36 | 56 | 60 | 80 | 84 |
| nput Data | | | | | | | | | |
| Bending moment, Mu | kip-ft | 499.7 | 718.4 | 592.8 | 394.2 | 394,2 | 592.8 | 718.4 | 50 |
| Shear force, Vu | kip | 237.2 | 243.5 | 133.6 | 452.1 | 234.9 | 251.6 | 137.6 | 422. |
| Axial force, Nu (+ if tensile) | kip | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Web width, bv | in | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 | 39.00 | 39.0 |
| Shear depth, dv | in | 80.53 | 80.53 | 80,53 | 80.53 | 80.53 | 80.53 | 80.53 | 80.5 |
| Mild steel reinf. area, As | in^2 | 10.92 | 10.92 | 10.92 | 10.92 | 10.92 | 10.92 | 10.92 | 10.9 |
| onc area on tension side, Ac | in^2 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657.5 | 1657. |
| Area of stirrups, Av | in^2 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.7 |
| Stirrup spacing, s | in | 7.4 | 7.4 | 7.4 | 7.4 | 7.4 | 7.4 | 7.4 | 7, |
| Prestressed steel area. Aps | in^2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Prestress shear, Vp | kip | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Average prestress, fps | ksi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Torsional moment, Tu | kip-ft | 706 | 353 | 353 | 706 | 706 | 353 | 353 | 70 |
| Shear flow area, Ao | in^2 | 2971.6 | 2971.6 | 2971.6 | 2971.6 | 2971.6 | 2971.6 | 2971.6 | 2971. |
| Area of one leg of stimup, At | in^2 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.4 |
| Perimeter of stirrup, Ph | in | 324 | 324 | 324 | 324 | 324 | 324 | 324 | 32 |
| alculated Values | - | | | | | | | | _ |
| Vc | kip | 543.7 | 541.5 | 605.8 | 494.9 | 543.7 | 537.0 | 601.4 | 494. |
| Vs | kip | 1669.4 | 1719.4 | 2009.4 | 1431.2 | 1669.4 | 1699.1 | 2000.9 | 1431. |
| φVn | kip | 1992 | 2035 | 2354 | 1733 | 1992 | 2013 | 2342 | 173 |
| E _x | 1221 | 6.67E-04 | 6.83E-04 | 4.01E-04 | 1.00E-03 | 6.61E-04 | 7.02E-04 | 4.12E-04 | 1.00E-0 |
| θ | deg | 32.60 | 32.80 | 29.00 | 36.40 | 32.60 | 33.10 | 29.10 | 36.4 |
| β | 12.1 | 2.450 | 2.440 | 2.730 | 2.230 | 2.450 | 2.420 | 2.710 | 2.23 |
| Req'd Shear reinf. Av/S | in^2/in | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.00 |
| Req'd Torsion reint. At/S aximum stirrup spacing. Smax | in^2/in in | 0.017 | 0.009 | 0.007 | 0.019 | 0.017 | 0.009 | 0.007 | 0.01 |
| onclusion | | 2.00 | 2.10 | 2,10 | | | | - 110 | a fait |
| Shear Re | inforcing | OK | OK | OK | OK | OK | OK | OK | OK |
| | | OK | OK | OK | OK | OK | OK | OK | OK |

4.3.15.5 Concrete Section Shear Capacity Spreadsheet

4.3.15.6 Bent Cap Details





4.4 INVERTED-T BENT CAP DESIGN EXAMPLE 3 (45° SKEW ANGLE)

Design example is in accordance with the AASHTO LRFD Bridge Design Specifications, 8th Ed. (2017) as prescribed by TxDOT Bridge Manual - LRFD (January 2020).

4.4.1 Design Parameters



Figure 4.53 Spans of the Bridge with 45 Degrees Skewed ITBC

Span 1

54' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 11.31' along the axis of bent with 3' overhangs

2" Haunch

<u>Span 2</u>

112' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 11.31' along the axis of bent with 3' overhangs

3.75" Haunch

<u>Span 3</u>

54' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 11.31' along the axis of bent with 3' overhangs

2" Haunch

All Spans

Deck is 46 ft wide

Type T551 Rail (0.382 k/ft)

8" Thick Slab (0.100 ksf)

Assume 2" Overlay @ 140 pcf (0.023 ksf)

Use Class "C" Concrete

 $f'_c = 5 \text{ ksi}$

 $w_c = 150 \text{ pcf (for weight)}$

"AASHTO LRFD" refers to the ASSHTO LRFD Bridge Design Specification, 8th Ed. (2017)..

"BDM-LRFD" refers to the TxDOT Bridge Design Manual -LRFD (January 2020).

"TxSP" refers to TxDOT guidance, recommendations, and standard practice.

"Furlong & Mirza" refers to "Strength and Serviceability of Inverted T-Beam Bent Caps Subject to Combined Flexure, Shear, and Torsion", Center for Highway Research Research Report No. 153-1F, The University of Texas at Austin, August 1974.

The basic bridge geometry can be found on the Bridge Layout located in the Appendices.

(TxSP)

(BDM-LRFD, Ch. 4, Sect. 5, Materials)

 $w_c = 145 \text{ pcf}$ (for Modulus of Elasticity calculation)

Grade 60 Reinforcing

 $f_v = 60 \text{ ksi}$

Bents

Use 36" Diameter Columns (Typical for Type TX54 Girders)

Define Variables

| <u>Back Span</u> | <u>Forward Span</u> | | |
|---|----------------------|--------------------------------|---|
| Span1 = 54ft | Span2 = 112ft | | Span Length |
| GdrSpa1 = 8ft | GdrSpa2 = 8ft | | Girder Spacing (Normalized values) |
| GdrNo1 = 6 | GdrNo2 = 6 | | Number of Girders in Span |
| GdrWt1 = 0.851klf | GdrWt2 = 0.851k | klf | Weight of Girder |
| Haunch1 = 2in | Haunch $2 = 3.75$ in | n | Size of Haunch |
| <u>Bridge</u> | | | |
| Skew = 45deg | | | Skew of Bents |
| BridgeW = 46ft | | | Width of Bridge Deck |
| RdwyW = 44ft | | | Width of Roadway |
| GirderD = 54in | | | Depth of Type TX54 Girder |
| BrgSeat = 1.5in | | | Bearing Seat Buildup |
| BrgPad = 2.75in | | | Bearing Pad Thickness |
| SlabThk = $8in$ | | | Thickness of Bridge Slab |
| OverlayThk = 2in | | | Thickness of Overlay |
| RailWt = 0.372 klf | | | Weight of Rail |
| $w_{a} = 0.150 \text{kcf}$ | | | Unit Weight of Concrete for Loads |
| $w_{Olay} = 0.140$ kcf | | | Unit Weigh of Overlay |
| Bents | | | |
| f _c = 5ksi | | | Concrete Strength |
| $w_{cE} = 0.145 kcf$ | | | Unit Weight of Concrete for E_c |
| $E_{c} = 33000 \cdot w_{cE}^{1.5} \cdot \sqrt{f}$ | E E C | $_{\rm c} = 4074 \; {\rm ksi}$ | Modulus of Elasticity of Concrete (AASHTO LRFD Eq. C5.4.2.4-2) |
| $f_y = 60$ ksi | | | Yield Strength of Reinforcement |
| $E_s = 29000$ ksi | | | Modulus of Elasticity of Steel |
| D _{column} = 36in | | | Diameter of Columns |

(BDM-LRFD, Ch. 4, Sect. 5, Materials)

Other Variables

Dynamic Load Allowance (AASHTO LRFD Table 3.6.2.1-1)





Figure 4.54Top View of the 45 Degrees Skewed ITBC with Spans and Girders

4.4.2 Determine Cap Dimensions



Figure 4.55 Section View of 45 Degrees Skewed ITBC

 $b_{stem} = 42$ in

4.4.2.1 Stem Width

```
b_{stem} = at least D_{column} + 3in
```

Use:

4.4.2.2 Stem Height

Distance from Top of Slab to Top of Ledge:

 $D_{Slab to Ledge} = SlabThk + Haunch2 + GirderD + BrgPa$

 $D_{Slab to Ledge} = 70.00 in$

StemHaunch = 3.75 in

The top of the stem must be 2.5" below the bottom of the slab. (BDM-LRFD, Ch. 4, Sect. 5, Geometric Constraints)

(TxSP)

The stem is typically at least 3"

wider than the Diameter of the

Column (36") to allow for the extension of the column

reinforcement into the Cap.

Haunch2 is the larger of the two

Accounting for the 1/2" of bituminous fiber, the top of the stem must have at least 2" of haunch on it, but the haunch should not be less than either of the haunches of the adjacent spans. $d_{stem} = D_{Slab_to_Ledge} - SlabThk - StemHaunch - 0.5in$

$$d_{stem} = 57.75$$
 in

Use: $d_{stem} = 57$ in

4.4.2.3 Ledge Width



The stem must accommodate \frac{1}{2}" of bituminous fiber.

Round the Stem Height down to the nearest 1". (TxSP)

The Ledge Width must be adequate for Bar M to develop fully.

"L_{dh,prov}" must be greater than or equal to "L_{dh,req}" for Bar M.

"cover" is measured from the center of the transverse bars.

"L" is the length of the Bearing Pad along the girder. A typical type TX54 bearing pad is $9" \times$ 21" for 45° skewed beents, as shown in the IGEB standard.

(AASHTO LRFD Eq.

(AASHTO LRFD 5.10.8.2.4b)

5.10.8.2.4a-2)

cover = 2.5 in

L = 9 in

Determine the Required Development Length of Bar M:

Try # 7 Bar for Bar M.

$$d_{bar_M} = 0.875 \text{ in}$$

 $A_{bar M} = 0.60 \text{ in}^2$

Basic Development Length

$$L_{dh} = \frac{38.0 \cdot d_{bar_M}}{60} \cdot \left(\frac{f_y}{\sqrt{f_c}}\right)$$

Modification Factors for L_{dh}:

Is Top Cover greater than or equal to 2.5", and Side Cover greater than or equal to 2"?

 $L_{dh} = 14.87$ in

SideCover = cover
$$-\frac{d_{bar,M}}{2} = 2.06$$
 in
TopCover = cover $-\frac{d_{bar,M}}{2} = 2.06$ in"Side Cover" and "Top Cover"
are the clear cover on the side
and top of the hook respectively.
The dimension "cover" is
measured from the center of Bar
M.No. Reinforcement Confinement Factor, $\lambda_{rc} = 1.0$
Coating Factor, $\lambda_{cw} = 1.0$ "Side Cover" and "Top Cover"
are the clear cover on the side
and top of the hook respectively.
The dimension "cover" is
measured from the center of Bar
M.Coating Factor, $\lambda_{cw} = 1.0$
Concrete Density Modification Factor, $\lambda = 1.0$ (AASHTO LRFD 5.4.2.8)The Required Development Length:
 $L_{dh,req} = \max(L_{dh} \cdot \left(\frac{\lambda_{rc} \lambda_{cw} \cdot \lambda_{er}}{\lambda}\right), 8 \cdot d_{bar,M}, 6in.)$ (AASHTO LRFD 5.10.8.2.4a)Ldh_req = 14.87 in
bledge_min = L_{dh,req} + cover + 12in $-\frac{L}{2}$
 $b_{ledge_min} = 24.87$ in
 $b_{ledge} = 25$ inThe distance from the face of
the stem to the center of
bearing is 12" for TxGirders
(IGEB).Width of Bottom Flange:
 $b_f = 2 \cdot b_{ledge} + b_{stem}$ $b_f = 92$ in4.4.2.4Ledge DepthAs a general rule of thumb,
Ledge Depth is greater than or

equal to 2'-3". This is the depth at which a bent from a typical

bridge will pass the punching

shear check.

Use a Ledge Depth of 28".

 $d_{ledge} = 28 \text{ in}$

Total Depth of Cap:

 $h_{cap} = d_{stem} + d_{ledge}$ $h_{cap} = 85$ in

4.4.2.5 <u>Summary of Cross Sectional Dimensions</u>

$$b_{stem} = 42$$
 in
 $d_{stem} = 57$ in
 $b_{ledge} = 25$ in
 $d_{ledge} = 28$ in
 $h_{cap} = 85$ in

4.4.2.6 Length of Cap

First define Girder Spacing and End Distance:



Figure 4.57 Elevation View of 45 Degrees Skewed ITBC

$$\begin{split} S &= 8 \ \text{ft} & Girder \ Spacing \\ c &= 2 \ \text{ft} & ``c`` is \ the \ distance \ from \ the \ Center \\ Line \ of \ the \ Exterior \ Girder \ to \ the \\ Edge \ of \ the \ Cap \ measured \ along \\ the \ Cap. \\ \\ L_{Cap} &= S \cdot (\text{GdrNo1} - 1) + 2c & L_{Cap} &= 44 \ \text{ft} & Length \ of \ Cap \end{split}$$

TxDOT policy is as follows, "The edge distance between the exterior bearing pad and the end of the inverted T-beam shall not be less than 12in." (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria) replacing the statement in AASHTO LRFD 5.13.2.5.5 stating it shall not be less than d_f . Preferably, the stem should extend at least 3" beyond the edge of the bearing seat.

| Bearing Pad Dimensions: | (IGEB standard) |
|-------------------------|-----------------------|
| L = 9 in | Length of Bearing Pad |
| W = 21 in | Width of Bearing Pad |

4.4.3 Cross Sectional Properties of Cap

$$\begin{split} A_{g} &= d_{ledge} \cdot b_{f} + d_{stem} \cdot b_{stem} & A_{g} &= 4970 \text{ in}^{2} \\ ybar &= \frac{d_{ledge} \cdot b_{f} \left(\frac{1}{2}d_{ledge}\right) + d_{stem} \cdot b_{stem} \cdot \left(d_{ledge} + \frac{1}{2}d_{stem}\right)}{A_{g}} & ybar &= 34.5 \text{ in} \quad \begin{array}{l} Distance \ from \ bottom \ of \ the \ cap \ to \ the \ center \ of \ gravity \ of \ the \ cap \ I_{g} &= \frac{b_{f} \cdot d_{ledge}^{3}}{12} + b_{f} \cdot d_{ledge} \cdot \left(ybar - \frac{1}{2}d_{ledge}\right)^{2} + \frac{b_{stem} \cdot d_{stem}}{12} + \cdots \\ b_{stem} \cdot d_{stem} \cdot \left[ybar - \left(d_{ledge} + \frac{1}{2}d_{stem}\right)\right]^{2} & I_{g} &= 3.06 \times 10^{6} \text{ in}^{4} \end{split}$$

4.4.4 Cap Analysis

4.4.4.1 Cap Model

Assume:

4 Columns Spaced @ 12'-0"

The cap will be modeled as a continuous beam with simple supports using TxDOT's CAP18 program.



Figure 4.58 Continuous Beam Model for 45 Degrees Skewed ITBC

TxDOT does not consider frame action for typical multi-column bents (BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis).



Figure 4.59 Cap 18 Model of 45 Degrees Skewed ITBC

The circled numbers in Figure 4.59 are the stations that will be used in the CAP 18 input file. One station is 0.5 ft in the direction perpendicular to the pgl, not parallel to the bent.

station = 0.5 ft

Station increment for CAP 18

Recall:

$$\begin{split} E_c &= 4074 \, \text{ksi} & I_g = 3.06 \times 10^6 \, \text{in}^4 \\ E_c I_g &= 1.25 \times 10^{10} \, \text{kip} \cdot \text{in}^2 / \, \left(12 \frac{\text{in}}{\text{ft}} \right)^2 \, E_c I_g = 8.66 \times 10^7 \text{kip} \cdot \text{ft}^2 \end{split}$$

SPAN 1

 $Rail1 = \frac{2 \cdot RailWt \cdot \frac{Span1}{2}}{\min(GdrNo1,6)}$

$$Slab1 = w_c \cdot GdrSpa1 \cdot SlabThk \cdot \frac{Span1}{2} \cdot 1.10$$

 $Girder1 = GdrWt1 \cdot \frac{Span1}{2}$

$$DLRxn1 = (Rail1 + Slab1 + Girder1)$$

$$Overlay1 = w_{Olay} \cdot GdrSpa1 \cdot OverlayThk \cdot \frac{Span1}{2}$$

SPAN 2

 $Rail2 = \frac{2 \cdot RailWt \cdot \frac{Span2}{2}}{\min(GdrNo2,6)}$

Slab2 =
$$w_c \cdot GdrSpa2 \cdot SlabThk \cdot \frac{Span2}{2} \cdot 1.10$$

Girder2 = GdrWt1
$$\cdot \frac{\text{Span2}}{2}$$
 Girder2 = 47.66 $\frac{\text{kip}}{\text{girder}}$

$$DLRxn2 = (Rail2 + Slab2 + Girder2)$$
 $DLRxn2 = 104.07 \frac{kip}{girder}$

Values used in the following equations can be found on "4.4.1 Design Parameters"

Rail Weight is distributed

thickened slab ends.

Slab1 = $23.76 \frac{\text{kip}}{\text{girder}}$ Increase slab DL by 10% to account for haunch and

evenly among stringers, up to 3 stringers per rail (TxSP).

Overlay is calculated

separetely, because it has different load factor than the rest of the dead loads.

Design for future overlay.

 $Rail1 = 3.44 \frac{kip}{girder}$

Girder1 = $22.98 \frac{\text{kip}}{\text{girder}}$

 $DLRxn1 = 50.17 \frac{kip}{girder}$

 $Overlay1 = 5.04 \frac{kip}{girder}$

Rail2 = $7.13 \frac{\text{kip}}{\text{girder}}$

Slab2 = $49.28 \frac{\text{kip}}{\text{girder}}$

$$Overlay2 = w_{Olay} \cdot GdrSpa2 \cdot OverlayThk \cdot \frac{Span2}{2} \qquad Overlay2 = 10.45 \frac{kip}{girder}$$

CAP

$$Cap = w_{c} \cdot A_{g} = 5.177 \frac{kip}{ft} \cdot \frac{0.5ft}{station} \qquad Cap = 2.589 \frac{kip}{station}$$

AASHTO LRFD 3.6.1.2.2 and 3.6.1.2.4)





LongSpan = max(Span1, Span2)
ShortSpan = min(Span1, Span2)

$$IM = 0.33$$

Long = 0 (Ablf (LongSpan+ShortSpan)

...

. .

2

Lane = 0.64klf $\cdot \left(\frac{\text{LongSpan+ShortSpan}}{2}\right)$

Lane =
$$53.12 \frac{\text{kip}}{\text{lane}}$$

$$Truck = 32kip + 32kip \cdot \left(\frac{LongSpan - 14ft}{LongSpan}\right) + 8kip \cdot \left(\frac{LongSpan - 28ft}{LongSpan}\right)$$

$$Truck = 66.00 \frac{ki}{lane}$$

LLRxn = Lane + Truck
$$\cdot$$
 (1 + IM)
LLRxn = 140.90 $\frac{\text{kip}}{\text{lane}}$

LongSpan = 112 ft

ShortSpan = 54 ft

Use HL-93 Live Load. For maximum reaction at interior bents, "Design Truck" will always govern over "Design Tandem". For the maximum reaction when the long span is more than twice as long as the short span, place the rear (32 kip) axle over the support and the middle (32 kip) and front (8 kip) axles on the long span. For the maximum reaction when the long span is less than twice as long as the short span, place the middle (32 kip) axle over the support, the front (8 kip) axle on the short span and the rear (32 kip) axle on the long span.

Combine "Design Truck" and "Design Lane" loadings (AASHTO LRFD 3.6.1.3). Dynamic load allowance, IM, does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4)



2 fi 6 20)

Figure 4.61 Live Load Model of 45 **Degrees Skewed ITBC for CAP18**

(AASHTO LRFD Table 3.6.1.1.2-1)

The Live Load is applied to the slab by two 16 kip wheel loads increased by the dynamic load allowance with the reminder of the live load distributed over a 10 ft (AASHTO LRFD 3.6.1.2.1) design lane width. (TxSP)

The Live Load applied to the slab is distributed to the beams assuming the slab is hinged at each beam except the outside beam. (BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis)

Input "Multiple Presence Factors" into CAP18 as "Load Reduction Factors".

> The cap design need only consider Strength I, Service I,

| No. of Lanes | Factor "m" |
|--------------|------------|
| 1 | 1.20 |
| 2 | 1.00 |
| 3 | 0.85 |
| >3 | 0.65 |

Limit States (AASHTO LRFD 3.4.1)

4.4.4.1.3 Cap 18 Data Input

Multiple Presence Factors, m

Strength I

| | Live Load and Dynamic Load Allowance | LL+IM = 1.75 | and Service I with DL (TxSP). |
|------------------|--------------------------------------|----------------|---|
| | Dead Load Components | DC = 1.25 | TrDOT allows the Quarlay |
| | Dead Load Wearing Surface (Overlay) | DW = 1.50 | Factor to be reduced to 1.25 |
| <u>Service</u>] | <u>e I</u> | | (TxSP), since overlay is typically used in design only to |
| | Live Load and Dynamic Load Allowance | LL+IM = 1.00 | increase the safety factor, but |
| | Dead Load and Wearing Surface | DC & DW = 1.00 | in this example we will use $DW=1.50$. |

Dead Load

TxDOT considers Service level Dead Load only with a limit reinforcement stress of 22 ksi to minimize cracking. (BDM-LRFD, Chapter 4, Section 5, Design Criteria)

4.4.4.1.4 Cap 18 Output

| | <u>Max +M</u> | <u>Max -M</u> |
|----------------|---|--|
| Dead Load: | $M_{posDL} = 379.0 \text{ kip} \cdot \text{ft}$ | $M_{negDL} = -563.1 \text{ kip} \cdot \text{ft}$ |
| Service Load: | $M_{posServ} = 721.8 \text{ kip} \cdot \text{ft}$ | $M_{negServ} = -862.2 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{posUlt} = 1080.5 \text{ kip} \cdot \text{ft}$ | $M_{negUlt} = -1238.4 \text{ kip} \cdot \text{ft}$ |

4.4.4.2 Girder Reactions on Ledge





 $DLSpan1 = 50.17 \frac{kip}{girder}$

 $DLSpan2 = 104.07 \frac{kip}{girder}$

Dead Load

DLSpan1 = Rail1 + Slab1 + Girder1 $Overlay1 = 5.04 \frac{kip}{girder}$

DLSpan2 = Rail2 + Slab2 + Girder2

 $0verlay2 = 10.45 \ \frac{kip}{girder}$

Live Load

Loads per Lane:



Use HL-93 Live Load. For maximum reaction at interior bents, "Design Truck" will always govern over "Design Tandem" for Spans greater than 26ft. For the maximum reaction, place the back (32 kips) axle over the support.

Figure 4.63 Live Load Model of 45 Degrees Skewed ITBC

for Girder Reactions on Ledge

LaneSpan1 = 0.64klf
$$\cdot \left(\frac{\text{Span1}}{2}\right)$$
LaneSpan1 = 17.28 $\frac{\text{kip}}{\text{lane}}$ LaneSpan2 = 0.64klf $\cdot \left(\frac{\text{Span2}}{2}\right)$ LaneSpan2 = 35.84 $\frac{\text{kip}}{\text{lane}}$

$$TruckSpan1 = 32kip + 32kip \cdot \left(\frac{Span1 - 14ft}{Span1}\right) + 8kip \cdot \left(\frac{Span1 - 28ft}{Span1}\right)$$
$$TruckSpan1 = 59.56 \frac{kip}{lane}$$
$$TruckSpan2 = 32kip + 32kip \cdot \left(\frac{Span2 - 14ft}{Span2}\right) + 8kip \cdot \left(\frac{Span2 - 28ft}{Span2}\right)$$
$$TruckSpan2 = 66.00 \frac{kip}{lane}$$

IM = 0.33 $LLRxnSpan1 = LaneSpan1 + TruckSpan1 \cdot (1 + IM)$ $LLRxnSpan1 = 96.49 \frac{kip}{lane}$ $LLRxnSpan2 = LaneSpan2 + TruckSpan2 \cdot (1 + IM)$ $LLRxnSpan2 = LaneSpan2 + TruckSpan2 \cdot (1 + IM)$

LLRxnSpan2 = $123.62 \frac{\text{kip}}{\text{girder}}$

 $gV_{Span1_Int} = 0.921$ $gV_{Span1_Ext} = 0.921$ $gV_{Span2_Int} = 0.947$ $gV_{Span2_Ext} = 0.947$

Combine "Design Truck" and "Design Lane" loadings (AASHTO LRFD 3.6.1.3).

Dynamic load allowance, IM, does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4).

The Live Load Reactions are assumed to be the Shear Live Load Distribution Factor multiplied by the Live Load Reaction per Lane. The Shear Live Load Distribution Factor is calculated using the "LRFD Live Load Distribution Factors" Spreadsheet found in the Appendices.

The Exterior Girders must have a Live Load Distribution Factor equal to or greater than the Interior Girders. This is to accommodate a possible future bridge widening. Widening the bridge would cause the exterior girders to become interior girders

| $LLSpan1Int = gV_{Span1_Int} \cdot LLRxnSpan1$ | LLSpan1Int = $88.87 \frac{\text{kip}}{\text{girder}}$ |
|---|--|
| $LLSpan1Ext = gV_{Span1_Ext} \cdot LLRxnSpan1$ | LLSpan1Ext = $88.87 \frac{\text{kip}}{\text{girder}}$ |
| $LLSpan2Int = gV_{Span2_Int} \cdot LLRxnSpan2$ | LLSpan2Int = $117.07 \frac{\text{kip}}{\text{girder}}$ |
| $LLSpan2Ext = gV_{Span2_Ext} \cdot LLRxnSpan2$ | LLSpan2Ext = $117.07 \frac{\text{kip}}{\text{girder}}$ |
| Snan 1 | |

Interior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1) $V_{s_Span1Int} = DLSpan1 + Overlay1 + LLSpan1Int$ $V_{s_Span1Int} = 144 \text{ kip}$ Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1) $V_{u_Span1Int} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1 + 1.75 \cdot LLSpan1Int$ $V_{u_Span1Int} = 226 \text{ kip}$ Exterior Girder Service Load (Service I Limit State, AASHTO LRFD 3.4.1) $V_{s_Span1Ext} = DLSpan1 + Overlay1 + LLSpan1Ext$ $V_{s_Span1Ext} = 144 \text{ kip}$ Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1) $V_{u_Span1Ext} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1 + 1.75 \cdot LLSpan1Ext$ $V_{u_Span1Ext} = 226 \text{ kip}$

Span 2

Interior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1) $V_{s_Span2Int} = DLSpan2 + Overlay2 + LLSpan2Int$ $V_{s_Span2Int} = 232 \text{ kip}$ Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1) $V_{u_Span2Int} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot LLSpan2Int$ $V_{u_Span2Int} = 351 \text{ kip}$ Exterior Girder Service Load (Service I Limit State, AASHTO LRFD 3.4.1) $V_{s_Span2Ext} = DLSpan2 + Overlay2 + LLSpan2Ext$ $V_{s_Span2Ext} = 232 \text{ kip}$

Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1)

 $V_{u_Span2Ext} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot LLSpan2Ext$

 $V_{u_{\text{Span2Ext}}} = 351 \text{ kip}$

4.4.4.3 Torsional Loads



To maximize the torsion, the live load only acts on the longer span.

Figure 4.64 Live Load Model of 45 Degrees Skewed ITBC for Torsional Loads





 $a_v = 12$ in

" a_v " is the value for the distance from the face of the stem to the center of bearing for the girders. 12" is the typical values for TxGirders on ITBC (IGEB). The lever arm is the distance from the center line of bearing to the centerline of the cap.

 $b_{stem} = 42$ in

LeverArm = $a_v + \frac{1}{2}b_{stem}$

Interior Girders

Girder Reactions

$$R_{u_{Span1}} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$$

 $R_{u \text{ Span1}} = 70 \text{ kip}$

LeverArm = 33 in

$$\begin{split} R_{u_Span2} &= 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot gV_{Span2_Int} \\ &\cdot [LaneSpan2 + TruckSapn2 \cdot (1 + IM)] \end{split}$$

 $R_{u_Span2} = 351 \, \text{kip}$

Torsional Load

$$T_{u_Int} = |R_{u_Span1} - R_{u_Span2}| \cdot \text{LeverArm}$$
$$T_{u_Int} = 773 \text{ kip} \cdot \text{ft}$$

Exterior Girders

Girder Reactions

$$R_{u_{Span1}} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$$

 $R_{u_{Span1}} = 70 \text{ kip}$

$$R_{u_{Span2}} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot gV_{Span2_{Ext}}$$
$$\cdot [LaneSpan2 + TruckSapn2 \cdot (1 + IM)]$$

 $R_{u_Span2} = 351 \, kip$

Torsional Load

$$\Gamma_{u_Ext} = |R_{u_Span1} - R_{u_Span2}| \cdot LeverArm$$

$$T_{u Ext} = 773 \text{ kip} \cdot \text{ft}$$

Torsion on Cap



Figure 4.66 Elevation View of 45 Degrees Skewed ITBC with Torsion Loads



Figure 4.67 Torsion Diagram of 45 Degrees Skewed ITBC

Analyzed assuming Bents are torsionally rigid at Effective Face of Columns.

$T_u = 773 \ \text{kip} \cdot \text{ft}$

Maximum Torsion on Cap

4.4.4.4 Load Summary

Ledge Loads

| Interior Girder | |
|---|-----------------------------------|
| Service Load | |
| $V_{s_{Int}} = max(V_{s_{Span1Int}}, V_{s_{Span2Int}})$ | $V_{s_Int} = 231.60 \text{ kip}$ |
| Factored Load | |
| $V_{u_{Int}} = max(V_{u_{Span1Int}}, V_{u_{Span2Int}})$ | $V_{u_Int} = 350.64 \text{ kip}$ |
| Exterior Girder | |
| Service Load | |
| $V_{s_Ext} = max(V_{s_Span1Ext}, V_{s_Span2Ext})$ | $V_{s_Ext} = 231.60 \text{ kip}$ |
| Factored Load | |
| $V_{u_Ext} = max(V_{u_Span1Ext}, V_{u_Span2Ext})$ | $V_{u_Ext} = 350.64 \text{ kip}$ |

Cap Loads

Positive Moment (From CAP18)

| Dead Load: | $M_{posDL} = 379.0 \text{ kip} \cdot \text{ft}$ |
|----------------|---|
| Service Load: | $M_{posServ} = 721.8 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{posUlt} = 1080.5 \text{ kip} \cdot \text{ft}$ |

Negative Moment (From CAP18)

| Dead Load: | $M_{negDL} = -563.1 \text{ kip} \cdot \text{ft}$ |
|----------------|--|
| Service Load: | $M_{negServ} = -862.2 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{negUlt} = -1238.4 \text{ kip} \cdot \text{ft}$ |

Maximum Torsion and Concurrent Shear and Moment (Strength I)

| and Forbion and Concartence Shear and Fremene (Strength I) | |
|--|---|
| $T_u = 773 \text{ kip} \cdot \text{ft}$ | Located two stations away from centerline of column |
| $V_u = 462.8 \text{ kip}$ | V. and M. values are from |
| $M_u = 504.8 \text{ kip} \cdot \text{ft}$ | CAP18 |

4.4.5 Locate and Describe Reinforcing



Figure 4.68 Section View of 45 Degrees Skewed ITBC

Recall:

$$b_{stem} = 42 \text{ in}$$

$$d_{stem} = 57 \text{ in}$$

$$b_{ledge} = 25 \text{ in}$$

$$d_{ledge} = 28 \text{ in}$$

$$b_{f} = 92 \text{ in}$$

$$h_{cap} = 85 \text{ in}$$

$$cover = 2.5 \text{ in}$$

4.4.5.1 Describe Reinforcing Bars

| Use # 11 bars for Bar A | | |
|----------------------------------|-------------------------|--|
| $A_{bar_A} = 1.56 \text{ in}^2$ | $d_{bar_A} = 1.410$ in | |
| Use # 11 bars for Bar B | | |
| $A_{bar_B} = 1.56 \text{ in}^2$ | $d_{bar_B} = 1.410$ in | |
| Use # 7 bars for Bar M | | In the calculation of b_{ledge} , # 7 |
| $A_{bar_M} = 0.60 \text{ in}^2$ | $d_{bar_M} = 0.875 in$ | Bar M was considered. Bar M |
| Use # 7 bars for Bar N | | must be # 7 or smaller to allow it fullv develop. |
| $A_{bar_N} = 0.60 \text{ in}^2$ | $d_{bar_N} = 0.875$ in | To prevent confusion, use the |
| Use # 6 bars for Bar S | | same bar size for Bar N as Bar |
| $A_{bar_S} = 0.44 \text{ in}^2$ | $d_{bar_S} = 0.75$ in | М. |
| Use # 6 bars for Bar T | | |
| $A_{bar_T} = 0.44 \text{ in}^2$ | $d_{bar_T} = 0.75$ in | |

4.4.5.2 <u>Calculate Dimensions</u>

| $d_{s_neg} = h_{cap} - cover - \frac{1}{2}d_{bar_S} - \frac{1}{2}d_{bar_A}$ | $d_{s_neg} = 81.42$ in |
|---|------------------------|
| $d_{s_pos} = h_{cap} - cover - \frac{1}{2}max(d_{bar_s}, d_{bar_M}) - \frac{1}{2}d_{bar_B}$ | $d_{s_pos} = 81.36$ in |
| $a_v = 12$ in | |
| $a_f = a_v + cover$ | $a_{\rm f}=14.50$ in |
| $d_e = d_{ledge} - cover$ | $d_e = 25.50$ in |
| $d_{f} = d_{ledge} - cover - \frac{1}{2}d_{bar_{-}M} - \frac{1}{2}d_{bar_{-}B}$ | $d_f=24.36 \text{ in}$ |
| $h = d_{ledge} + BrgSeat$ | h = 29.50 in |



Figure 4.69 Plan View of 45 Degrees Skewed ITBC

$$\alpha = 45 \deg$$

Recall:

L = 9 in

W = 21 in

4.4.6 **Check Bearing**

The load on the bearing pad propagates along a truncated pyramid whose top has the area A₁ and whose base has the area A_2 . A_1 is the loaded area (the bearing pad area: $L \times W$). A₂ is the area of the lowest rectangle contained wholly within the support (the Inverted Tee Cap). A₂ must not overlap the truncated pyramid of another load in either direction, nor can it extend beyond the edges of the cap in any direction.



horizontal)

Angle of Bars S (Angle from the

Dimension of Bearing Pad

Figure 4.70 Bearing Check for 45 Degrees Skew Angle

Resistance Factor (
$$\phi$$
) = 0.7

 $A_1 = L \cdot W$

Interior Girders

B = 8.5 in.

$$B = \min\left[\left(b_{\text{ledge}} - a_v\right) - \frac{1}{2}L, \left(a_v + \frac{1}{2}b_{\text{stem}}\right) - \frac{1}{2}L, 2d_{\text{ledge}}, \frac{1}{2}S - \frac{1}{2}W\right]$$

$$L_2 = L + 2 \cdot B$$
 $L_2 = 26.0$
 $W_2 = W + 2 \cdot B$
 $W_2 = 38.0$
 $A_2 = L_2 \cdot W_2$
 $A_2 = 988$

"B" is the distance from perimeter of A_1 to the perimeter of A_2 as seen *in the above figure*

(AASHTO LRFD 5.5.4.2)

Area under Bearing Pad

$$L_2 = 26.00 \text{ in}$$

 $W_2 = 38.00 \text{ in}$
 $A_2 = 988 \text{ in}^2$

 $A_1 = 189 \text{ in}^2$

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Modification factor

$$m = \min(\sqrt{\frac{A_2}{A_1}}, 2) = 2.29 \text{ and } 2$$
 $m = 2$
 AASHTO LRFD Eq. 5.6.5-3

 $\phi V_n = \phi$
 $0.85 f_c$
 A_1
 m
 $\phi V_n = 350.64 < \phi V_n$
 $\phi V_n = 1124.55 \text{ kips}$
 AASHTO LRFD Eqs. 5.6.5-1

 $V_{u_int} = 350.64 < \phi V_n$
 BearingChk = "OK!"
 $V_{u_int} from "4.4.4.4 \text{ Load Summary ".$

Exterior Girders

$$B = \min\left[\left(b_{\text{ledge}} - a_v\right) - \frac{1}{2}L, \left(a_v + \frac{1}{2}b_{\text{stem}}\right) - \frac{1}{2}L, 2d_{\text{ledge}}, \frac{1}{2}S - \frac{1}{2}W, c - \frac{1}{2}W\right]$$

| | $B=8.5 \text{ in.} \begin{array}{l} "B" \text{ is the distance from} \\ perimeter of A_1 \text{ to the} \\ perimeter of A_2 \text{ as seen} \\ \text{in the above figure} \end{array}$ |
|-----------------|--|
| $L_2 = L + 2 B$ | $L_2 = 26.00 \text{ in}$ |
| $W_2 = W + 2 B$ | $W_2 = 38.00$ in |
| $A_2 = L_2 W_2$ | $A_2 = 988 \text{ in}^2$ |

Modification factor

$$m = min\left(\sqrt{\frac{A_2}{A_1}}, 2\right) = 2.29 \text{ and } 2 \quad m = 2$$
 AASHTO LRFD Eq. 5.6.5-3

| $\phi V_n = \phi 0.85 f_c A_1 m$ | $\phi V_n = 1124.55 \text{ kips}$ | AASHTO LRFD Eqs. 5.6.5-1 and 5.6.5-2: |
|---|-----------------------------------|---|
| $V_{u_ext} = 350.64 \text{ kips} < \Phi V_n$ | BearingChk= "OK!" | V _{u_ext} from " <i>4.4.4.4</i> Load Summary ". |

4.4.7 Check Punching Shear



AASHTO LRFD **5.8.4.3.4**, the truncated pyramids assumed as failure surfaces for punching shear shall not overlap.

AASHTO LRFD 5.5.4.2.

Figure 4.71 Punching Shear Check for 45 Degrees Skew Angle

Resistance Factor (ϕ) = 0.90

Determine if the Shear Cones Intersect

Is
$$\frac{1}{2}S - \frac{1}{2}W \ge d_f$$
?Yes. Therefore, shear cones do not intersect in the
longitudinal direction of the cap. $\frac{1}{2}S - \frac{1}{2}W = 37.5$ in $TxDOT$ uses "df" instead of "de" for Punching
Shear (BDM-LRFD, Ch. 4, Sect. 5, Design
Criteria). This is because "df" has traditionally
been used for inverted tee bents and was sed in
the Inverted Tee Research (Furiong % Mirza pg.
58).

Is
$$\frac{1}{2}b_{stem} + a_v - \frac{1}{2}L \ge d_f$$
?
Yes. Therefore, shear cones do not intersect in the transverse direction of the cap.

 $\frac{1}{2}b_{stem} + a_v - \frac{1}{2}L = 28.5$ in d_f = 24.36 in

Interior Girders

| $V_n = 0.125 \boxtimes \lambda \sqrt{f_c'} \ b_o \ d_f$ | $V_{\rm n} = 597.27 {\rm kips}$ | AASHTO LRFD 5.8.4.3.4-3 |
|---|----------------------------------|---|
| $b_o = W + 2L + 2d_f$ | $b_0 = 87.72$ in | AASHTO LRFD 5.8.4.3.4-4 |
| $\phi V_n = 537.54 \text{ kips}$ | | |
| $V_{u_Int} = 350.64 \text{ kips} < \varphi V_n$ | PunchingShearChk= "OK!" | V_{u_int} from "4.4.4.4 Load Summary". |

| Exterior Girders | | | |
|--|-----------------------------|---|--|
| $V_{n} = \min[(0.125 \cdot \sqrt{f_{c}} \cdot \left(\frac{1}{2}W + L + d_{f} + c\right) * d_{f}, 0.125 \cdot \sqrt{f_{c}} \cdot (W + 2L + 2d_{f}) * d_{f})]$ | $V_n = 462.04 \text{ kips}$ | AASHTO LRFD 5.8.4.3.4-3 and 5.8.4.3.4-5 | |
| $\phi V_n = 415.84 \text{ kips}$ | | | |

| $V_{u_ext} = 350.64 \text{ kips} < \varphi V_n$ | PunchingShearChk= "OK!" | V _{u_ext} from "4.4.4.4 |
|--|-------------------------|----------------------------------|
| | | Load Summary". |

4.4.8 Check Shear Friction

| Resistance Factor (ϕ) =0.90 | AASHTO LRFD 5.5.4.2 |
|------------------------------------|---------------------|
|------------------------------------|---------------------|

Determine the Distribution Width

Interior Girders $b_{s_{s}Int} = min(W + 4a_v, S)$ "S" is the girder spacing.= min (69 in, 96 in) $b_{s_{s}Int} = 69 in$ $A_{cv} = b_{s_{s}Int} \cdot d_{e}$ $A_{cv} = 1759.5 in2$ Exterior Girders $b_{s_{s}Ext} = min(W + 4a_v, S, 2c)$ "S" is the girder spacing.= min [69, 96, 48]

$$A_{cv} = b_{s_ext} \cdot d_e \qquad \qquad A_{cv} = 1224 \text{ in } 2$$

Interior Girders

= 48 in

 $V_{n} = \min(0.2 \cdot f_{c} \cdot A_{cv}, 0.8 \cdot A_{cv}) \quad V_{n} = 1408 \text{ kips}$ $= \min(1759.5, 1408)$ $\phi V_{n} = 1267 \text{ kips}$ $V_{u_{int}} = 350.64 \text{ kips} < \phi V_{n}$ ShearFrictionChk="OK!" $V_{u_{int}} from "4.4.4.4 \text{ Load}$ Summary".

Exterior Girders

4.4.9 Flexural Reinforcement for Negative Bending (Bars A)

| $M_{dl} = M_{negDL} $ | $M_{dl} = 563.1 \text{ kip} \cdot \text{ft}$ |
|------------------------|--|
| $M_s = M_{negServ} $ | $M_s = 862.2 \text{ kip} \cdot \text{ft}$ |
| $M_u = M_{negUlt} $ | $M_u = 1238.4 \text{ kip} \cdot \text{ft}$ |

4.4.9.1 Minimum Flexural Reinforcement

Factored Flexural Resistance, M_r , must be greater than or equal to the lesser of $1.2M_{cr}$ (Cracking Moment) or $1.33M_u$ (Ultimate Moment).

| $I_g = 3.06 \times 10^6 \text{ in}^4$ | | Gross Moment of Inertia |
|--|---|---|
| $h_{cap} = 85$ in | | Depth of Cap |
| ybar = 34.5 in | | Distance to the Center of Gravity of the Cap from the bottom of the Cap |
| $f_r = 0.24\sqrt{f_c}$ | $f_r = 0.537$ ksi | Modulus of Rupture (BDM- LRFD, Ch. 4, Sect. 5, Design Criteria) |
| $y_t = n_{cap} - y_{bar}$ | $y_t = 50.50 \text{ in}$ | Distance from Center of Gravity to extreme tension fiber |
| $S = \frac{I_g}{y_t}$ | $S = 6.06 \times 10^4 \text{ in}^3$ | Section Modulus for the extreme tension fiber |
| $M_{cr} = S \cdot f_r \cdot \frac{1ft}{12in}$ | $M_{cr} = 2711.8 \text{ kip} \cdot \text{ft}$ | Cracking Moment (AASHTO LRFD Eq. 5.6.3.3-1) |
| M _f = minimum of: | | Design the lesser of $1.2M_{\odot}$ or |
| $1.2M_{cr} = 3254.2 \text{ kip} \cdot \text{ft}$ | | $1.33M_u$ when determining |
| $1.33M_u = 1647.1 \text{ kip} \cdot \text{ft}$ | | mininum area of steel required. |
| | | |

Thus, M_r must be greater than $M_f = 1647.1 \ \text{kip} \cdot \text{ft}$

4.4.9.2 Moment Capacity Design

Try, 7 ~ #11's Top Number of bars in tension BarANo = 7Diameter of main reinforcing $d_{bar A} = 1.410$ in bars $A_{\text{bar A}} = 1.56 \text{ in}^2$ Area of main reinforcing bars $A_{s} = 10.92 \text{ in}^{2}$ Area of steel in tension $A_s = BarANo \cdot A_{bar A}$ Diameter of shear reinforcing $d_{stirrup} = 0.75$ in $d_{stirrup} = d_{bar S}$ bars $d = d_{s neg}$ d = 81.42 in $b = b_f$ b = 92 in Compressive Strength of Concrete $f_c = 5.0 \text{ ksi}$ Yield Strength of Rebar $f_v = 60 \text{ ksi}$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.85 - 0.05(f_c - 4ksi)$ Bounded by: $0.65 \le \beta_1 \le 0.85$ $\beta_1 = 0.80$ Depth of Cross Section under $c=\frac{A_sf_y}{0.85f_c\beta_1b}$ c = 2.09 in Compression under Ultimate Load This "c" is the distance from the extreme compression fiber to the

neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.

$$a = c \cdot \beta_1$$
 $a = 1.67$ in

Note: "a" is less than "d_{ledge}". Therefore the equivalent stress block acts over a rectangular area. If "a" was greater than "dledge", it would act over a Tee shaped area.

$$\begin{split} M_n &= A_s f_y \left(d - \frac{a}{2} \right) \cdot \frac{1 f t}{12 i n} & M_n &= 4400 \text{ kip} \cdot f t \\ \epsilon_s &= 0.003 \cdot \frac{d - c}{c} & \epsilon_s &= 0.114 \end{split}$$

 $\epsilon_{s} > 0.005$

FlexureBehavior = "Tension Controlled"

$$\begin{split} \Phi_{M} &= 0.90 \\ M_{r} &= \Phi_{M}M_{n} \\ M_{f} &= 1647.1 \text{ kip} \cdot \text{ft} < M_{r} \\ M_{u} &= 1238.4 \text{ kip} \cdot \text{ft} < M_{r} \\ \end{split}$$

(AASHTO LRFD Eq. 5.6.3.1.2-4)

Depth of Equivalent Stress Block (AASHTO LRFD 5.6.2.2)

Nominal Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.2-1)

Strain in Reinforcing at Ultimate

(AASHTO LRFD 5.6.2.1)

(AASHTO LRFD 5.5.4.2)

Factored Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.1-1)

4.4.9.3 Check Serviceability

To find s_{max}:

Modular Ratio:

$$n = \frac{E_s}{E_c} \qquad \qquad n = 7.12$$

Tension Reinforcement Ratio:

$$\begin{split} \rho &= \frac{A_s}{b \cdot d} & \rho = 0.00146 \\ k &= \sqrt{(2\rho n) + (\rho n)^2} - (\rho n) & k = 0.134 \\ d \cdot k &= 10.91 \text{ in } < d_{\text{ledge}} = 28 \text{ in} \end{split}$$

Therefore, the compression force acts over a rectangular

$$j = 1 - \frac{k}{3}$$
 $j = 0.955$

$$\begin{split} f_{ss} &= \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12 \text{in}}{1 \text{ft}} & f_{ss} &= 12.2 \text{ ksi} \\ f_a &= 0.6 f_y & f_a &= 36.00 \text{ ksi} \\ f_{ss} &< f_a & \text{ServiceStress} = ``OK!`` \\ d_c &= \text{cover} + \frac{1}{2} d_{\text{stirrup}} + \frac{1}{2} d_{\text{bar}_A} & d_c &= 3.58 \text{ in} \end{split}$$

Exposure Condition Factor:

$$\begin{split} \gamma_e &= 1.00 \\ \beta_s &= 1 + \frac{d_c}{0.7(h_{cap} - d_c)} & \beta_s &= 1.06 \\ s_{max} &= \min\left(\frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c, 12in.\right) & s_{max} &= 12 \text{ in} \\ s_{Actual} &= \frac{b_{stem} - 2d_c}{BarANo - 1} & s_{Actual} &= 5.81 \text{ in} \end{split}$$

Check allowable M_{dl} : $f_{dl} = 22 \text{ ksi}$

$$M_{a} = A_{s} \cdot d \cdot j \cdot f_{dl} \cdot \frac{1 f t}{12 i n} \qquad M_{a} = 1556.7 \text{ kip} \cdot f t$$
$$M_{dl} = 563.1 \text{ kip} \cdot f t < M_{a} \qquad \text{DeadLoadMom} = \text{``OK!''}$$

For service loads, the stress on the cross-section is located as shown in Figure 4.72.



Figure 4.72 Stresses on the Cross Section for Service Loads of 45 Degrees Skewed ITBC

If the compression force does not act over rectangular area, j will be different.

Service Load Bending Stress in outer layer of the reinforcing.

Allowable Bending Stress (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

For Class 1 Exposure Conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e = 0.75$). (BDM-LRFD Ch. 4, Sect. 5, Design Criteria) (AASHTO LRFD Eq. 5.6.7-1)

A good practice is to place a bar every 12 in along each surface of the bent. (TxSP)

TxDOT limits dead load stress to 22 ksi, which is set to limit observed cracking under dead load.

Allowable Dead Load Moment

ServiceabilityCheck = "OK

4.4.10 Flexural Reinforcement for Positive Bending (Bars B)

$$\begin{split} M_{dl} &= M_{posDL} & M_{dl} &= 379.0 \text{ kip} \cdot \text{ft} \\ M_s &= M_{posServ} & M_s &= 721.8 \text{ kip} \cdot \text{ft} \\ M_u &= M_{posUlt} & M_u &= 1080.5 \text{ kip} \cdot \text{ft} \end{split}$$

4.4.10.1 Minimum Flexural Reinforcement

Factored Flexural Resistance, M_r , must be greater than or equal to the lesser of $1.2M_{cr}$ (Cracking Moment) or $1.33M_u$ (Ultimate Moment).

| $I_g = 3.06 \times 10^6 \text{ in}^4$ | | Gross Moment of Inertia |
|--|---|--|
| $y_t = ybar$ | y _t = 34.5 in | Distance to the Center of Gravity of the Cap from the top of the Cap |
| $f_r = 0.24\sqrt{f_c}$ | $f_r = 0.537$ ksi | Modulus of Rupture (BDM- LRFD, Ch. 4, Sect. 5, Design |
| $S = \frac{I_g}{y_t}$ | $S = 8.87 \times 10^4 \text{ in}^3$ | <i>Criteria)</i> Section Modulus for the extreme tension fiber |
| $M_{cr} = S \cdot f_r \cdot \frac{1ft}{12in}$ | $M_{cr} = 3969.3 \text{ kip} \cdot \text{ft}$ | Cracking Moment (AASHTO LRFD Eq. 5.6.3.3-1) |
| $M_f = minimum of:$ | | Design the lesser of $1.2M_{cr}$ or |
| $1.2M_{cr} = 4763.2 \text{ kip} \cdot \text{ft}$ | | $1.33M_u$ when determining mininum area of steel required. |
| $1.33M_u = 1437.1 \text{ kip} \cdot \text{ft}$ | | |

Thus, M_r must be greater than $M_f = 1437.1 \; \text{kip} \cdot \text{ft}$
4.4.10.2 Moment Capacity Design

а

Try, $11 \sim #11$'s Bottom Number of bars in tension BarBNo = 11Diameter of main reinforcing $d_{\text{bar B}} = 1.41$ in bars $A_{\text{bar B}} = 1.56 \text{ in}^2$ Area of main reinforcing bars Area of steel in tension $A_s = BarBNo \cdot A_{bar B}$ $A_s = 17.16 \text{ in}^2$ d = 81.36 in $d = d_{s pos}$ $b = b_{stem}$ b = 42 inCompressive Strength of Concrete $f_{c} = 5.0 \text{ ksi}$ Yield Strength of Rebar $f_v = 60 \text{ ksi}$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.85 - 0.05(f_c - 4ksi)$ Bounded by: $0.65 \le \beta_1 \le 0.85$ $\beta_1 = 0.80$ Depth of Cross Section under $c=\frac{A_sf_y}{0.85f_c\beta_1b}$ c = 7.21 in

This "c" is the distance from the extreme compression fiber to the neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.

$$= \mathbf{c} \cdot \boldsymbol{\beta}_1$$
 $\mathbf{a} = 5.77$ in

4 CL

Note: "a" is less than "dstem". Therefore the equivalent stress block acts over a rectangular area. If "a" was greater than "dstem", it would act over a Tee shaped area.

$$\begin{split} M_n &= A_s f_y \left(d - \frac{a}{2} \right) \cdot \frac{111}{12 \text{ in}} & M_n &= 6733.2 \text{ kip} \cdot \text{ft} & \text{Nominal Flexural (AASHTO LRFD in the second secon$$

$$M_r = \Phi_M \cdot M_n$$
 $M_r = 6059.9 \text{ kip} \cdot ft$

 $M_{f} = 1437.1 \text{ kip} \cdot \text{ft} < M_{r}$ MinReinfChk = "OK!" $M_u = 1080.5 \text{ kip} \cdot \text{ft} < M_r$ UltimateMom = "OK!" Compression under Ultimate Load (AASHTO LRFD Eq. 5.6.3.1.2-4)

Depth of Equivalent Stress Block (AASHTO LRFD 5.6.2.2)

h T · 1 [] l Resistance Eq. 5.6.3.2.2-1) ing at Ultimate

5.6.2.1)

5.5.4.2)

Factored Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.1-1) 4.4.10.3 Check Serviceability

To find s_{max}:

Modular Ratio:

$$n = \frac{E_s}{E_c} \qquad \qquad n = 7.12$$

Tension Reinforcement Ratio:

$$\rho = \frac{A_s}{b \cdot d} \qquad \rho = 0.005$$

$$\sqrt{(2\rho n) + (\rho n)^2} - (\rho n) \qquad k = 0.234$$

$$k = \sqrt{(2\rho n) + (\rho n)^2} - (\rho n)$$
 $k = 0.2$

 $d \cdot k = 19.04$ in $< d_{stem} = 57.00$ in

Therefore, the compression force acts over a rectangular

$$j = 1 - \frac{k}{3}$$
 $j = 0.922$

$$f_{ss} = \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12in}{1ft}$$

$$f_{ss} = 6.73 \text{ ksi}$$

$$f_a = 0.6f_y$$

$$f_a = 36.00 \text{ ksi}$$

$$f_{ss} < f_a$$

$$g_c = cover + \frac{1}{2}d_{stirrup} + \frac{1}{2}d_{har B}$$

$$d_c = 3.64 \text{ in}$$

$$d_c = cover + \frac{1}{2}d_{stirrup} + \frac{1}{2}d_{bar_B} \qquad d_c =$$

Exposure Condition Factor:

$$\begin{split} \gamma_e &= 1.00 \\ \beta_s &= 1 + \frac{d_c}{_{0.7(h_{cap} - d_c)}} \qquad \qquad \beta_s = 1.06 \end{split}$$

$$s_{max} = min\left(\frac{700\gamma_e}{\beta_s f_{ss}} - 2d_c, 12in.\right)$$
 $s_{max} = 12 in$

Bars Inside Stirrup Bar S

Try: BarBInsideSNo = 5

$$s_{Actual} = \frac{b_{stem} - 2\left(cover \ \frac{1}{2}d_{bar_s} + \frac{1}{2}d_{bar_B}\right)}{BarBInsideSNo -}$$

.

 $s_{actual} < s_{max}$

For service loads, the stress on the cross-section is located as shown in Figure 4.73.



Figure 4.73 Stresses on the Cross Section for Bars B for Service Loads of 45 Degrees Skewed ITBC

> If the compression force does not act over rectangular area, j will be different.

Service Load Bending Stress in outer layer of the reinforcing.

Allowable Bending Stress (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

For Class 1 Exposure Conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e = 0.75$). (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

(AASHTO LRFD Eq. 5.6.7-1)

A good practice is to place a bar every 12 in along each surface of the bent. (TxSP)

Number of Bars B that are inside Stirrup Bar S.

 $s_{Actual} = 8.71$ in

ServiceabilityCheck = "OK!"

Bars Outside Stirrup Bar S

BarBOutsideSNo = 11 - BarBInsideSNoNumber of Bars B that are inside
Stirrup Bar S.BarBOutsideSNo = 6 $s_{Actual} = \frac{2b_{ledge} + 2(cover \frac{1}{2}d_{bar_S} + \frac{1}{2}d_{bar_B} - cover \frac{1}{2}d_{bar_M} - \frac{1}{2}d_{bar_B})}{BarBOutsideSNo}$ $s_{actual} = 8.31 \text{ in } < s_{max}$ ServiceabilityCheck = "OK!"

4.4.10.4 Check Dead Load

Check allowable M_{dl} : $f_{dl} = 22 \text{ ksi}$

TxDOT limits dead load stress to 22 ksi. This is due to observed cracking under dead load.

 $M_{a} = A_{s} \cdot d \cdot j \cdot f_{dl} \cdot \frac{1 \text{ft}}{12 \text{in}} \qquad M_{a} = 2360 \text{ kip} \cdot \text{ft}$ $M_{dl} = 379.0 \text{ kip} \cdot \text{ft} < M_{a} \qquad \text{DeadLoadMom} = \text{``OK!''}$

Allowable Dead Load Moment

Flexural Steel Summary:

Use 7 ~ # 11 Bars on Top & 11 ~ # 11 Bars on Bottom

4.4.11 Ledge Reinforcement (Bars M & N)

Try Bars M and Bars N at a 6.20" spacing.

$$s_{bar_M} = 6.20 \text{ in}$$

 $s_{bar_N} = 6.20 \text{ in}$

Use trial and error to determine the spacing needed for the ledge reinforcing.

It is typical for Bars M & N to be paired together

4.4.11.1 Determine Distribution Widths

These distribution widths will be used on the following pages to determine the required ledge reinforcement per foot of cap.

Distribution Width for Shear (AASHTO LRFD 5.8.4.3.2)Note: These are the same
distribution widths used for the
Shear Friction check. $b_{s_Int} = min(W + 4a_v, S)$ "S" is the girder spacing. $b_{s_Int} = 69.00$ in"S" is the distance from the center
of bearing of the outside beam to
the end of the ledge.Distribution Width for Bending and Axial Loads (AASHTO LRFD 5.8.4.3.3)Distribution S.8.4.3.3

Interior Girders

 $b_{m_{Int}} = min(W + 5a_f, S)$ $b_{m_{Int}} = 93.50 in$

Exterior Girders

 $b_{m_{Ext}} = \min(W + 5a_f, 2c, S)$ $b_{m_{Ex}} = 48.00 \text{ in}$

4.4.11.2 Reinforcing Required for Shear Friction

d_e = 25.50 in

 $a_{vf_min} = \frac{0.05 k si \cdot d_e}{f_v}$

| $\Phi = 0.90$ | | |
|---------------|---------------|--------------------------|
| $\mu = 1.4$ | $c_1 = 0$ ksi | $P_c = 0 \ \mathrm{kip}$ |

Recall:

Minimum Reinforcing (AASHTO LRFD Eq. 5.7.4.2-1)

 $\begin{aligned} A_{vf_min} &= \frac{0.05 \text{ ksi} \cdot A_{cv}}{f_y} \\ A_{cv} &= d_e \cdot b_s \quad \text{and} \qquad a_{vf} = \frac{A_{vf}}{b_s} \end{aligned}$

(AASHTO LRFD 5.5.4)

"µ" is 1.4 for monolithically placed concrete. (AASHTO LRFD 5.7.4.4)

For clarity, the cohesion factor is labeled " c_1 ". This is to prevent confusion with "c", the distance from the last girder to the edge of the cap. c_1 is 0ksi for corbels and ledges. (AASHTO LRFD 5.7.4.4)

" P_c " is zero as there is no axial compression.

 $a_{vf_min} = 0.26 \frac{in^2}{ft}$ Minimum Reinforcing required for Shear Friction

- Interior Girders
 - $A_{cv} = 1759 \text{ in}^2$ $A_{cv} = d_e \cdot b_{s \text{ Int}}$ $V_{u \text{ Int}} = 350.6 \text{ kip}$ From "4.4.4.4 Load Summarv". $V_n = c_1 A_{cv} + \mu (A_{vf} f_v + P_c)$ (AASHTO LRFD Eq. 5.7.4.3-3) (AASHTO LRFD Eq. 5.7.4.3-1 & $\Phi V_n \ge V_n$ AASHTO LRFD Eq. 5.7.4.3-2) $\Phi \cdot \left[c_1 A_{cv} + \mu (A_{vf} f_v + P_c) \right] \ge V_{u}$ $A_{vf} = \frac{\frac{V_{u_{\perp}Int}}{\Phi} - c_1 A_{cv}}{\mu} - P_c}{f}$ $A_{vf} = 4.64 \text{ in}^2$ Required Reinforcing for Shear Friction $a_{vf_{Int}} = 0.81 \frac{in^2}{ft}$ Required Reinforcing for Shear $a_{vf_{Int}} = \frac{A_{vf}}{b_{s_{Int}}}$ Friction per foot length of cap

AASHTO LRFD 5.7.4.1

 $a_{vf_Ext} = \frac{A_{vf}}{b_{s Ext}}$

 $A_{cv} = d_e \cdot b_s E_{xt}$

Exterior Girders

 $V_{n} = c_{1}A_{cv} + \mu(A_{vf}f_{y} + P_{c})$ $\Phi V_{n} \ge V_{u}$

$$\Phi \cdot [c, A + \mu(A, f + P)] > V$$

$$\Phi \cdot [c_1 A_{cv} + \mu (A_{vf} I_y + P_c)] \ge V_u$$

$$A_{\rm vf} = \frac{\frac{\frac{\Psi_{\rm u} Ext}{\Phi} - c_1 A_{\rm cv}}{\Phi} - P_{\rm c}}{\frac{\mu}{f_{\rm y}}}$$

Recall: h = 29.50 in $d_e = 25.50$ in $a_v = 12$ in

 $A_{cv} = 1224 \text{ in}^2$

From "4.4.4.4 Load Summary". (AASHTO LRFD Eq. 5.7.4.3-3) (AASHTO LRFD Eq. 5.7.4.3-1 & AASHTO LRFD Eq. 5.7.4.3-2)

 $A_{vf} = 4.64 \text{ in}^2$ Required Reinforcing for Shear Friction

 $a_{vf_Ext} = 1.16 \frac{in^2}{ft}$ Required Reinforcing for Shear Friction per foot length of cap

4.4.11.3 Reinforcing Required for Flexure AASHTO LRFD 5.8.4.2.1

From "4.4.5.2 Calculate Dimensions"

Interior Girders

| $V_{u_Int} = 350.6 \text{ kip}$ | From "4.4.4.4 Load Summary". | |
|---|--|-------------------------------|
| $N_{uc_{Int}} = 0.2 \cdot V_{u_{Int}}$ | $N_{uc_Int} = 70.1 \ kip$ | (AASHTO LRFD 5.8.4.2.1) |
| $M_{u_{Int}} = V_{u_{Int}} \cdot a_v + N_{uc_{Int}}(h - d_e)$ | $M_{u_Int} = 374 \text{ kip} \cdot \text{ft}$ | (AASHTO LRFD Eq. 5.8.4.2.1-1) |

Use the following equations to solve for A_f:

| | $\Phi M_n \ge M_{u_Int}$ | | (AASHTO LRFD Eq. 1.3.2.1-1) |
|----------------------|--|--|---|
| | $M_{n} = A_{f}f_{y}\left(d_{e} - \frac{a}{2}\right)$ | | (AASHTO LRFD Eq.5.6.3.2.2-1) |
| | $c = \frac{A_f f_y}{\alpha_1 f_c \beta_1 b_{m_Int}}$ | | (AASHTO LRFD Eq. 5.6.3.1.2-4) |
| | $\alpha_1 = 0.85$ | | |
| | $\beta_1 = 0.80$ | | (AASHTO LRFD 5.6.2.2) |
| | $a = c\beta_1$ | | |
| | $0.75 \le \Phi = 0.65 + 0.15 \left(\frac{d_e}{c} - \right.$ | $1 \le 0.90$ | AASHTO LRFD 5.5.4.2 |
| Solve for | or A _f : | $A_{\rm f}=3.29\text{in}^2$ | Required Reinforcing for Flexure |
| a _{f_Int} = | $= \frac{A_f}{b_{m_Int}}$ | $a_{f_Int}=0.42\frac{\mathrm{in^2}}{\mathrm{ft}}$ | Required Reinforcing for Flexure per foot length of cap |

Exterior Girders

| $V_{u_Ext} = 350.6 \text{ kip}$ | | | From "4.4.4.4 Load Summary". |
|--|---|-----------------|---|
| $N_{uc_Ext} = 0.2 \cdot V_{u_Ext}$ | $N_{uc_Ext} = 70.1 \ \text{kip}$ | | (AASHTO LRFD 5.8.4.2.1) |
| $M_{u_Ext} = V_{u_Ext} \cdot a_v + N_{uc_Ext}(h - d_e)$ | $M_{u_{\text{Ext}}} = 374 \text{ kip} \cdot$ | ft | (AASHTO LRFD Eq. 5.8.4.2.1-1) |
| Use the following equations to solve for | A _f : | | |
| $\Phi M_n \ge M_{u_Ext}$ | | (AAS | HTO LRFD Eq. 1.3.2.1-1) |
| $M_{n} = A_{f}f_{y}\left(d_{e} - \frac{a}{2}\right)$ | | (AAS | HTO LRFD Eq.5.6.3.2.2-1) |
| $c = \frac{A_f f_y}{\alpha_1 f_c \beta_1 b_{m_Ext}}$ | | (AAS | HTO LRFD Eq. 5.6.3.1.2-4) |
| $\alpha_1 = 0.85$ $\beta_1 = 0.80$ | | (AAS | HTO LRFD 5.6.2.2) |
| $a = c\beta_1$ $0.75 \le \Phi = 0.65 + 0.15 \left(\frac{d_e}{c} - \frac{d_e}{c}\right)$ | $1) \le 0.90$ | AASE | ITO LRFD 5.5.4.2 |
| Solve for A _f : | $A_{\rm f} = 3.32 \text{ in}^2$ | Requ | ired Reinforcing for Flexure |
| $a_{f_{-}Ext} = \frac{A_f}{b_{m_{-}Ext}}$ | $a_{f_Ext} = 0.83 \frac{\mathrm{in^2}}{\mathrm{ft}}$ | Requi per fo | ired Reinforcing for Flexure pot length of cap |

4.4.11.4 Reinforcing Required for Axial Tension

 $\Phi = 0.90$

Interior Girders:

$$\begin{split} N_{uc_Int} &= 0.2 V_{u_Int} & N_{uc_Int} & \\ A_n &= \frac{N_{uc_Int}}{\Phi f_y} & A_n &= 1.3 \\ a_{n_Int} &= \frac{A_n}{b_{m_Int}} & a_{n_Int} & \\ \end{split}$$

Exterior Girders:

$$\begin{split} N_{uc_Ext} &= 0.2 V_{u_Int} \\ A_n &= \frac{N_{uc_Ext}}{\Phi f_y} \\ a_{n_Ext} &= \frac{A_n}{b_{m_Ext}} \end{split}$$

(AASHTO LRFD 5.8.4.2.2)

AASHTO LRFD 5.5.4.2

 $N_{uc Int} = 70.1 \text{ kip}$

| $A_n = 1.30 \text{ in}^2$ | Required Reinforcing for Axial Tension |
|-------------------------------------|--|
| $a_{n_Int} = 0.17 \frac{in^2}{ft}$ | Required Reinforcing for Axial Tension per foot length of cap |

 $N_{uc_Ext} = 70.1 \ \text{kip}$

| $A_n = 1.29 \text{ in}^2$ | Required Reinforcing for Axial Tension |
|-----------------------------------|---|
| $a_{n Ext} = 0.32 \frac{in^2}{c}$ | Required Reinforcing for Axial |

4.4.11.5 Minimum Reinforcing

$$a_{s_min} = 0.04 \frac{f_c}{f_y} d_e$$

4.4.11.6 Check Required Reinforcing

Actual Reinforcing:

$$a_{s} = \frac{A_{bar_{M}}}{s_{bar_{M}}}$$

$$a_{s} = 1.16 \frac{in^{2}}{ft}$$

$$Primary Ledge Reinforcing Provided$$

$$a_{h} = \frac{A_{bar_{N}}}{s_{bar_{N}}}$$

$$a_{h} = 1.16 \frac{in^{2}}{ft}$$

$$Auxiliary Ledge Reinforcing Provided$$

<u>Checks:</u> $A_s \ge A_{s_min}$

$$A_{s} \ge A_{f} + A_{n}$$
$$A_{s} \ge \frac{2A_{vf}}{3} + A_{n}$$

$$A_{\rm h} \ge 0.5(A_{\rm s} - A_{\rm n})$$

Check Interior Girders:

Bar M:

Check if:

 $a_s = 1.16 \frac{in^2}{ft}$

 $a_{s} \ge a_{f_Int} + a_{n_Int}$ $a_{s} \ge \frac{2a_{vf_Int}}{3} + a_{n_Int}$

 $a_s \ge a_{s \min}$

$$a_{f_Int} + a_{n_Int} = 0.59 \frac{in^2}{ft} < a_s$$
$$\frac{2a_{vf_Int}}{3} + a_{n_Int} = 0.71 \frac{in^2}{ft} < a_s$$

 $a_{s_min} = 1.02 \frac{in^2}{ft} < a_s$

BarMCheck = "OK!"

Bar N:

$$a_{h} \ge 0.5 \cdot (a_{s} - a_{n_Int})$$
$$a_{s} = The maximum of:$$
$$a_{f_Int} + a_{n_Int}$$
$$^{2a_{vf}Int} + a_{r}$$

$$\frac{2a_{vf_Int}}{3} + a_{n_Int}$$

 $a_s = 0.71 \frac{in^2}{ft}$

Check if:

(AASHTO LRFD Eq. 5.8.4.2.2-6)

" a_s " in this equation is the steel required for Bar M, based on the requirements for Bar M in AASHTO LRFD 5.8.4.2.2. This is derived from the suggestion that Ah should not be less than $A_{f}/2$ nor less than $A_{vf}/3$ (Furlong & Mirza pg. 73 & 74)

(AASHTO LRFD 5.8.4.2.1) $a_{s_min} = 1.02 \frac{in^2}{ft} \quad Minimum \ Required \ Reinforcing$

(AASHTO LRFD 5.8.4.2.1)

(AASHTO LRFD 5.8.4.2.2)

(AASHTO LRFD 5.8.4.2.1)

(AASHTO LRFD Eq. 5.8.4.2.2-5)

(AASHTO LRFD Eq. 5.8.4.2.2-6)

$$0.5 \cdot (a_s - a_{n_Int}) = 0.28 \frac{in^2}{ft} < a_h$$

BarNCheck = "OK!"

Check Exterior Girders:

Bar M:

Check if:

$$a_{s} \ge a_{s_min}$$

$$a_{s} \ge a_{f_Ext} + a_{n_Ext}$$

$$a_{s} \ge \frac{2a_{vf_Ext}}{3} + a_{n_Ext}$$

$$a_{s} = 1.16\frac{in^{2}}{ft}$$

 $a_{s_min} = 1.02 \frac{in^2}{ft} < a_s$

 $a_{f_Ext} + a_{n_Ext} = 1.15 \frac{in^2}{ft} ~<~ a_s$

 $\frac{2a_{vf_{.}Ext}}{3} + a_{n_{.}Ext} = 1.09 \frac{in^2}{ft} < a_s$

BarMCheck = "OK!"

Bar N:

Check if:

$$a_{h} \ge 0.5 \cdot (a_{s} - a_{n_Ext})$$
 (AASHTO LRFD Eq. 5.8.4.2.2-6)
 $a_{s} =$ The maximum of:
 $a_{f_Ext} + a_{n_Ex}$
 $\frac{2a_{vf_Ext}}{3} + a_{n_Ext}$ (arrow and bound on the suggestion that Ah
 $a_{s} = 1.15 \frac{in^{2}}{ft}$ (Furlong & Mirza pg. 73 & 74)
 $0.5 \cdot (a_{s} - a_{n_Ext}) = 0.42 \frac{in^{2}}{ft} < a_{h}$
BarNCheck = "OK!"

Ledge Reinforcement Summary:

Use # 7 primary ledge reinforcing @ 6.20" maximum spacing & # 7 auxiliary ledge reinforcing @ 6.20" maximum spacing

4.4.12 Hanger Reinforcement (Bars S)

Try Double # 6 Stirrups at a 7.20" spacing.

 $s_{bar S} = 7.20$ in

Use trial and error to determine the spacing needed for the hanger reinforcing.

| $A_{hr} = 2 stirrups \cdot A_{bar_S}$ | $A_{\rm hr}=0.88{\rm in^2}$ |
|---------------------------------------|-----------------------------|
| $A_v = 2 legs \cdot A_{hr}$ | $A_v = 1.76 \text{ in}^2$ |

4.4.12.1 Check Minimum Transverse Reinforcement

| $b_v = b_{stem}$ | $b_v = 42$ in | |
|--|---------------|-----------------------------|
| $A_{v_min} = 0.0316\lambda \sqrt{f_c} \frac{b_v \cdot s_{bar_S}}{f_y}$ | | (AASHTO LRFD Eq. 5.7.2.5-1) |
| | | (AASHTO LRFD 5.4.2.8) |

 $\lambda = 1.0$ for normal weight concrete

 $A_{v min} = 0.36 in^2$

MinimumSteelCheck = "OK!"

4.4.12.2 Check Service Limit State

AASHTO LRFD 5.8.4.3.5 with notifications from BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

Interior Girders

 $A_v > A_{v \min}$

$$V_{all} = minimum of:$$

Abr: $(\frac{2}{f_{tr}})$

$$\frac{A_{hr} \cdot \left(\frac{z}{3}f_{y}\right)}{s_{bar} \cdot s} \cdot (W + 3a_{v}) = 235 \text{ kip}$$

TxDOT uses "2/3 f_y " from the original research (Furlong & Mirza Eq. 5.4) instead of "0.5 f_y " from AASHTO LRFD Eq. 5.8.4.3.5-1. (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)

Bounded by: $(W + 3a_v) \le \min(S, 2c)$

$$\frac{A_{hr} \cdot \left(\frac{2}{3} f_{y}\right)}{s_{bar_S}} \cdot S = 469 \text{ kip}$$

 $V_{all} = 235 \text{ kip}$ $V_{s \text{ Int}} = 231.6 \text{ kip} < V_{all}$

(2)

(BDM-LRFD, Cn. 4, Sect. 5, Design Criteria) S, 2c) (BDM-LRFD Ch.4, Sect. 5, Design Criteria

(BDM-LKFD Ch.4, Seci. 5, Design Criteria modified to limit the distribution width to the girder spacing. This will prevent distribution widths from overlapping)

ServiceCheck = "OK!"

Exterior Girders

 $V_{all} = minimum of:$

V_{all} for the Interior Girder

$$\frac{A_{hr}\left(\frac{2}{3}f_{y}\right)}{s_{bar_{s}}} \cdot \left(\frac{W+3a_{v}}{2}+c\right) = 235 \text{ kip}$$

Bounded by: $(W + 3a_v) \le \min(S, 2c)$

$$\frac{A_{hr} \cdot \left(\frac{2}{3} f_{y}\right)}{s_{bar_{s}} \cdot \left(\frac{s}{2} + c\right)} = 352 \text{ kip}$$

$$V_{all} = 235 \text{ kip}$$

 $V_{s_Ext} = 231.6 \text{ kip} < V_{all}$

 $\Phi = 0.90$

Interior Girders:

TxDOT uses "2/3 f_y " from the original research (Furlong & Mirza Eq. 5.4) instead of "0.5 f_y " from AASHTO LRFD Eq. 5.8.4.3.5-1. (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)

(BDM-LRFD Ch.4, Sect. 5, Design Criteria Modified to limit the distribution width to half the girder spacing and the distance to the edge of the cap. This will prevent distribution widths from overlapping or extending over the edge of the cap.)

ServiceCheck = "OK!"

(AASHTO LRFD 5.8.4.3.5)

 $\frac{A_{hr} \cdot f_y}{s_{bar_s}} \cdot S = 704 \text{ kip} \qquad (AASHTO LRFD Eq. 5.8.4.3.5-2)$ $(0.063\sqrt{f_c} \cdot b_f \cdot d_f) + \frac{A_{hr} \cdot f_y}{s_{bar_s}} (W + 2d_f) = 827 \text{ kip} \qquad (AASHTO LRFD Eq. 5.8.4.3.5-3)$ $V_n = 704 \text{ kip}$

 $\Phi V_n = 634 \text{ kip}$ $V_{u \text{ Int}} = 350.6 \text{ kip} < \Phi V_n$ UltimateCheck = "OK!"

Exterior Girders:

 $V_n = minimum of:$

 $V_n = minimum of:$

 $V_{n} \text{ for the Interior Girder}$ $\frac{A_{hr} \cdot f_{y}}{s_{bar_{-}S}} \cdot \left(\frac{S}{2} + c\right) = 528 \text{ kip}$ (AASHTO LRFD Eq. 5.8.4.3.5-2) $(0.063\sqrt{f_{c}} \cdot b_{f} \cdot d_{f}) + \frac{A_{hr} \cdot f_{y}}{s_{bar_{-}S}} \left(\frac{W+2d_{f}}{2} + c\right) = 747 \text{ kip}$ (AASHTO LRFD Eq. 5.8.4.3.5-3) (These equations are modified to limit the distribution width to the edge of the cap) $V_{n} = 475 \text{ kip}$ $V_{n} \text{ Ext} = 350.6 \text{ kip} < \Phi V_{n}$ UltimateCheck = "OK!"

4.4.12.4 Check Combined Shear and Torsion

 $d_v = 80.59$ in

The following calculations are for Station 36. All critical locations must be checked. See the Concrete Section Shear Capacity spreadsheet in the appendices for calculations at other locations. Shear and Moment were calculated using the CAP 18 program.

 $M_u = 504.8 \text{ kip} \cdot \text{ft}$ $V_u = 462.8 \text{ kip}$ $N_u = 0 \text{ kip}$ $T_u = 773 \text{ kip} \cdot \text{ft}$ Recall: $\beta_1 = 0.80$ $f_v = 60 \text{ ksi}$ $f_c = 5.0 \text{ ksi}$ $E_{s} = 29000 \text{ ksi}$ $h_{cap} = 85$ in $b_{stem} = 42$ in $b_f = 92$ in h = 29.50 in $b_{v} = 42$ in $b_v = b_{stem}$ Find d_v: (AASHTO LRFD 5.7.2.8) $A_s = 10.92 \text{ in}^2$ $A_s = A_{\text{bar }A} \cdot \text{BarANo}$ Shears are maximum near the $c = \frac{A_s f_y}{0.85 f_c \beta_1 b_f}$ column faces. In these regions the c = 2.10 in cap is in negative bending with tension in the top of the cap. $a = c \cdot \beta_1$ a = 1.68 in Therefore, the calculations are $d_s = d_{s neg}$ $d_s = 81.42$ in based on the steel in the top of the bent cap. $M_n = A_s f_v \left(d_s - \frac{a}{2} \right)$ $M_n = 4400 \text{ kip} \cdot f$ $A_{ns} = 0 \text{ in}^2$ $d_e = \frac{A_{ps}f_{ps}d_p + A_sf_yd_s}{A_{ps}f_{ps} + A_sf_y}$ $d_e = 81.42$ in (AASHTO LRFD Eq. 5.7.2.8-2) $d_v = maximum of:$ $\frac{M_n}{A_s f_v + A_{ns} f_{ns}} = 80.59 \text{ in}$ $0.9d_e = 73.28$ in 0.72h = 21.24 in

The method for calculating θ and β used in this design example are from AASHTO LRFD Appendix B5. The method from AASHTO LRFD 5.7.3.4.2 may be used instead. The method from 5.7.3.4.2 is based on the method from Appendix B5; however, it is less accurate and more conservative (often excessively conservative). The method from Appendix B5 is preferred because it is more accurate, but it requires iterating to a solution.

Determine θ and β :

$$\Phi_{V} = 0.90$$

$$v_{u} = \frac{|V_{u} - (\Phi_{V} \cdot V_{p})|}{\Phi_{V} \cdot b_{v} \cdot d_{v}}$$

$$v_{u} = 0.15 \text{ ksi}$$

$$\frac{v_{u}}{f_{c}} = 0.03$$

Using Table B5.2-1 with $\frac{v_u}{f_c} = 0.03$ and $\varepsilon_x = 0.001$ $\theta = 36.4 \text{ deg}$ and $\beta = 2.23$

$$\epsilon_{x} = \frac{\frac{|M_{u}|}{d_{v}} + 0.5N_{u} + 0.5|V_{u} - V_{p}|cot\theta - A_{ps}f_{po}}{2(E_{s}A_{s} + E_{p}A_{ps})}$$

where $|M_u| = 504.8 \text{ kip} \cdot \text{ft}$ must be $> |V_u - V_p| d_v = 3108 \text{ kip} \cdot \text{ft}$

$$\varepsilon_{\rm x} = 1.23 \times 10^{-3} > 1.00 \times 10^{-3}$$

use $\varepsilon_{\rm x} = 1.00 \times 10^{-3}$.

 $V_p = 0 \text{ kip}$

 $A_{c} = b_{stem} \cdot \frac{h_{cap}}{2}$ $s = s_{bar S}$

(AASHTO LRFD Eq. 5.5.4.2)

Shear Stress on the Concrete (AASHTO LRFD Eq. 5.7.2.8-1)

Determining θ and β is an iterative process, therefore, assume initial shear strain value ε_x of 0.001 per LRFD B5.2 and then verify that the assumption was valid.

Strain halfway between the compressive and tensile resultants (AASHTO LRFD Eq. B5.2-3) If $\varepsilon_x < 0$, then use equation B5.2-5 and re-solve for ε_x .

For values of ε_x greater than 0.001, the tensile strain in the reinforcing, ε_t is greater than 0.002. ($\varepsilon_t = 2\varepsilon_x - \varepsilon_c$, where ε_c is < 0) Grade 60 steel yields at a strain of 60 ksi / 29,000 ksi = 0.002. By limiting the tensile strain in the steel to the yield strain and using the Modulus of Elasticity of the steel prior to yield, this limits the tensile stress of the steel to the yield stress. ε_x has not changed from the assumed value, therefore no iterations are required.

"V_p" is zero as there is no prestressing.

 $A_{c} = 1785 \text{ in}^{2}$ $A_{c} = 1785 \text{ in}^{2}$

Eq. B5.2-3 is negative.



The transverse reinforcement, " A_v ", is double closed stirrups. The failure surface intersects four stirrup legs, therefore the area of the shear steel is four times the stirrup bar's area (0.44in2). See the sketch of the failure plane to the left.

Figure 4.74 Failure Surface of 45 Degrees Skewed ITBC for Combined Shear and Torsion

$$\begin{split} A_v &= 2 \text{legs} \cdot 2 \text{stirrups} \cdot A_{\text{bar}_S} & A_v &= 1.76 \text{ in}^2 \\ A_t &= 1 \text{leg} \cdot A_{\text{bar}_S} & A_t &= 0.44 \text{ in}^2 \\ A_{\text{oh}} &= (d_{\text{stem}}) \cdot (b_{\text{stem}} - 2 \text{cover}) + (d_{\text{ledge}} - 2 \text{cover}) \cdot (b_f - 2 \text{cover}) \\ & A_{\text{oh}} &= 4110 \text{ in}^2 \\ A_0 &= 0.85A_{\text{oh}} & A_0 &= 3493.5\text{in}^2 \\ p_h &= (b_{\text{stem}} - 2 \text{cover}) + 2(b_{\text{ledge}}) + (b_f - 2 \text{cover}) + 2(h_{\text{cap}} - 2 \text{cover}) \\ & p_h &= 334 \text{ in} \end{split}$$

Equivalent Shear Force

$$V_{u_{Eq}} = \sqrt{V_{u}^{2} + \left(\frac{0.9p_{h}T_{u}}{2A_{0}}\right)^{2}} \qquad V_{u_{Eq}} = 611.1 \text{ kip } (AASHTO LRFD Eq. B.5.2-1)$$

Shear Steel Required

 V_n = the lesser of:

$$V_c + V_s + V_p$$
(AASHTO LRFD Eq. 5.7.3.3-1) $0.25 \cdot f_c \cdot b_v \cdot d_v + V_p$ (AASHTO LRFD Eq. 5.7.3.3-2)

Check maximum ΦV_n for section:

 $\Phi V_{n_max} = \Phi \cdot \left(0.25 \cdot f_{c} \cdot b_{v} \cdot d_{v} + V_{p} \right)$

$$\Phi V_{n_{max}} = 3808 \text{ kip}$$

$$V_u = 462.8 \text{ kip } < \Phi V_{n_max}$$
 MaxShearCheck = "OK!"

Calculate required shear steel:

$$V_{u} < \Phi V_{n}$$

$$V_{c} = 0.0316 \cdot \beta \cdot \sqrt{f_{c}} \cdot b_{v} \cdot d_{v}$$

$$V_{u} < \Phi_{V} \cdot (V_{c} + V_{s} + V_{p})$$

$$V_{s} = \frac{A_{v} \cdot f_{y} \cdot d_{v} \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha}{s_{req}}$$

$$a_{v_{r}req} = \frac{\frac{V_{u}}{\Phi_{V}} - V_{c} - V_{p}}{f_{v} \cdot d_{v} \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha}$$

(AASHTO LRFD Eq. 1.3.2.1-1) V_c = 533 kip (AASHTO LRFD Eq. 5.7.3.3-3)

$$a_{v_req} = 0.00 \frac{in^2}{ft}$$

(AASHTO LRFD 5.5.4.2) (AASHTO LRFD Eq. 1.3.2.1-1) (AASHTO LRFD Eq. 5.7.3.6.2-1)

The transverse reinforcement is

$$a_{t_req} = 0.22 \frac{in^2}{ft}$$

Total Required Transverse Steel

 $T_n = \frac{2A_oA_tf_y cot\theta}{s_{bar_S}}$

 $a_{t_req} = \frac{T_u}{\Phi_T 2 A_o f_y cot \theta}$

Torsional Steel Required

 $\Phi_{\rm T} = 0.9$

 $T_u \leq \Phi_T T_n$

$$a_{req} = a_{v_req} + 2sides \cdot a_{t_req} \qquad a_{req} = 0.44 \frac{in^2}{ft} \qquad designed for the side of the section a_{prov} = \frac{A_v}{s_{bar_s}} \qquad a_{prov} = 2.93 \frac{in^2}{ft} \qquad are additive. (AASHTO LRFD C5.7.3.6.1) a_{prov} > a_{req} \qquad TransverseSteelCheck = "OK!"$$

Longitudinal Reinforcement

$$\begin{split} A_{ps}f_{ps} + A_{s}f_{y} &\geq \frac{|M_{u}|}{\Phi d_{v}} + \frac{0.5N_{u}}{\Phi} + \cdots \\ & cot\Theta\sqrt{\left(\left|\frac{V_{u}}{\Phi} - V_{p}\right| - 0.5V_{s}\right)^{2} + \left(\frac{0.45p_{h}T_{u}}{2A_{0}\Phi}\right)^{2}} \\ V_{s} &= a_{t_req} \cdot f_{y} \cdot d_{v} \cdot (cot\Theta + cot\alpha) \cdot sin\alpha \end{split} \qquad (AASHTO LRFD Eq. 5.7.3.3-4)$$

Bounded By:
$$V_s < \frac{V_u}{\Phi_V}$$
 $V_s = 514.2 \text{ kip}$ (AASHTO LRFD Eq. 5.7.3.5-1)

$$\frac{|\mathsf{M}_{u}|}{\Phi_{f}d_{v}} + \frac{0.5\mathsf{N}_{u}}{\Phi_{c}} + \cot\theta \sqrt{\left(\left|\frac{\mathsf{V}_{u}}{\Phi_{V}} - \mathsf{V}_{p}\right| - 0.5\mathsf{V}_{s}\right)^{2} + \left(\frac{0.45p_{h}\mathsf{T}_{u}}{2\mathsf{A}_{0}\Phi_{T}}\right)^{2}} = 544 \text{ kip}$$

Provided Force:

$$A_s f_y = 655.2 \text{ kip} > 544 \text{ kip}$$
 LongitudinalReinfChk = "OK!"

| 4.4.12.5 Maximum Spacing of Transverse Reinford | (AASHTO LRFD 5.7.2.6) | |
|---|----------------------------|-----------------------------|
| Shear Stress | | |
| $v_u = \frac{ v_u - \Phi_V v_p }{\Phi_V b_v d_v}$ | $v_{\rm u}=0.15~{ m ksi}$ | (AASHTO LRFD Eq. 5.7.2.8-1) |
| $0.125 \cdot f_c = 0.625 \text{ ksi}$ | | |
| If $v_u < 0.125 \cdot f_c$ | | (AASHTO LRFD Eq. 5.7.2.6-1) |
| $s_{max} = min(0.8d_v, 24in)$ | | |
| If $v_u \ge 0.125 \cdot f_c$ | | (AASHTO LRFD Eq. 5.7.2.6-2) |
| $s_{max} = min(0.4d_v, 12in)$ | | |
| Since $v_u < 0.125 \cdot f_c$ | $s_{max} = 24.00$ in | |
| TxDOT limits the maximum transverse reinforcement sp | (BDM-LRFD, Ch. 4, Sect. 5, | |
| $s_{max} = 12.00$ in | | Detailing) |
| $s_{\text{bar}_S} = 7.20 \text{ in } < s_{\text{max}}$ | SpacingCheck= "C | <mark>K!"</mark> |

Hanger Reinforcement Summary:

Use double # 6 stirrups @ 7.20" maximum spacing

4.4.13 End Reinforcements (Bars U1, U2, U3, and G)

Extra vertical, horizontal, and diagonal reinforcing at the end surfaces is provided to reduce the maximum crack widths. According to the parametric analysis, it is recommended to place #6 U1 Bars, U2 Bars, and U3 Bars at the end faces and #7 G Bars at approximately 6in. spacing at the first 30" to 35" of the end of bent cap. U1 Bars are the vertical end reinforcements, U2 Bars and U3 Bars are the horizontal end reinforcements at the stem and the ledge, respectively. G Bars are the diagonal end reinforcement.



Figure 4.75 End Face Section View of 45 Degrees Skewed ITBC



Figure 4.76 End Face Elevation View of 45 Degrees Skewed ITBC

4.4.14 Skin Reinforcement (Bars T)

Try 7 ~ # 6 bars in Stem and 3 ~ # 6 bars in Ledge on each side



 A_{sk} need not be greater than one quarter of the main reinforcing ($A_s/4$)per side face within d/2 of the main reinforcing. (AASHTO LRFD 5.6.7)

"d" is the distance from the extreme compression fiber to the centroid of the extreme tension steel element. In this example design, $d = d_{s_pos} = 81.36$ in.

$$A_{sk_max} = max \left(\frac{\frac{A_{bar_A} \cdot BarANo}{4}}{\frac{d_{s_neg}}{2}}, \frac{\frac{A_{bar_B} \cdot BarBNo}{4}}{\frac{d_{s_pos}}{2}}\right)$$
$$A_{sk_max} = 1.27 \frac{in^2}{ft}$$
$$A_{skReq} = min(A_{sk_Req}, A_{sk_max})$$
$$A_{skReq} = 0.62 \frac{in^2}{ft}$$

4.4.14.2 Required Spacing of Skin Reinforcement

(AASHTO LRFD 5.6.7)

 $s_{req} = minimum of:$

$$\frac{A_{bar_T}}{A_{skReq}} = 8.52 \text{ in}$$
$$\frac{d_{s_neg}}{6} = 13.57 \text{ in}$$
$$\frac{d_{s_pos}}{6} = 13.56 \text{ in}$$

& 12 in

 $s_{req} = 8.52$ in

4.4.14.3 Actual Spacing of Skin Reinforcement

Check T Bars spacing in Stem:

$$\begin{split} h_{top} &= d_{stem} - \left(cover + \frac{d_{bar_S}}{2} + \frac{d_{bar_A}}{2} \right) + \left(cover + \frac{d_{bar_M}}{2} + \frac{d_{bar_T}}{2} \right) \\ h_{top} &= 56.73 \text{ in} \end{split}$$

 $s_{skStem} = \frac{h_{top}}{NoTBarsStem+1}$

 $s_{skStem} = 7.09$ in

 $s_{skStem} < s_{req}$

SkinSpacing = "OK!"

Check T Bars spacing in Ledge:

$$h_{bot} = d_{ledge} - \left(cover + \frac{d_{bar_M}}{2} + \frac{d_{bar_T}}{2}\right) - \left(cover + \frac{d_{bar_S}}{2} + \frac{d_{bar_B}}{2}\right)$$
$$h_{bot} = 21.11 \text{ in}$$

 $S_{skLedge} = \frac{h_{bot} - a}{NoTBarsLedge}$

| $s_{skLedge} = 7.56$ in |
|-------------------------|
| SkinSpacing = "OK! |

Check if "a" is less than s_{req}

 $s_{skLedge} < s_{req}$

$$a = 6 \text{ in } < s_{req}$$

SkinSpacing = "OK!"

Skin Reinforcement Summary:

Use $7 \sim #6$ bars in Stem and $3 \sim #6$ bars in Ledge on each side

4.4.15 Design Details and Drawings

4.4.15.1 Bridge layout



4.4.15.2 CAP 18 Input File

User Date (Today CSJ Init if Blank) Comment SFile Proj \$Header Card 2 -----CAP18 Version 6.00 ITBC Design Example 3, Skew = 45.00 SProblem Card -----1 E 0 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay) \$TABLE 1 - CONTROL DATA ------Enter 1 to keep: Ŝ Number cards Options: \$ Env Tab2 Tab3 Tab4 on Table 4 Envelope Print Skew Angle XX X XX 16 х х х х XXXXXXXXXXX Ś 45.0 \$TABLE 2 - CONSTANTS ------Anly Opt (1=Working, ŝ TABLE 2a |-Movable Load Data--| 2=Load Factor,3=Both) Num Increment |Num Start Stop Step|Anly| Load Factors: Ś Ś |Inc Sta Sta Size| Opt| Dead Live XXX XXX XXX X X X XXXXXXXX XXXXXXXX 20 2 70 1 3 1.25 1.75 Ś Inc Length Ŝ XX XXXXXXXXX 0.5 92 Ś TABLE 2b Max # |-----Live Load Reduction Factors-----------Ŝ Overlav Load Factor Lanes | 1 lane 2 lanes 3 lanes 4 lanes 5 lanes Ś XXXXX X XXXX XXXX XXXX XXXX XXXX 1.50 3 1.2 1.0 0.85 0.65 0.65 \$ STABLE 3 - LIST OF STATIONS ------Number of input values for Lane Str Sup MCP VCP XX XX XX XX XX XX VCP - Shear Control Points Ś Ś XX XX XX XX XX 3 6 4 11 8 \$ VCP - Shear Control Points (Num Inputs) Left Lane Boundary Stations Ś \$ Right Lane Boundary Stations Ś \$ (Lane Right) 32 60 90 Ś Station of Stringers (two rows max, may be at tenths of stations, XX.X) \$ (Stringers) 6 22 38 54 70 86 Station of Supports (two rows max) Ś Ś Moment Control Point Stations (two rows max) Ś Ŝ (Mom CP) (Mom CP) 86 Ś Shear Control Point Stations (two rows max) Ś (Shear CP) \$TABLE 4 - STIFFNESS AND LOAD DATA -----Bending Sidewalk, Cap & Station 1 if Stiffness Slab Stringer Moving From To Cont'd of Cap Loads Loads Loads S Ś Overlay From To Cont'd of Cap Loads SComments Loads, DW \$XXXXXXXXXXXXXXX XXX 2 8.66E+07 (CAP EI & DL) 90 -2.589(DL Span1, Bm1) 6 6 -50.17-5.04 -50.17 (DL Span1, Bm2) 22 -5.04 22 (DL Span1, Bm3) 38 38 -50.17 -5.04 (DL Span1, Bm4) (DL Span1, Bm5) 54 54 -50.17-5.04 70 70 -50.17-5.04 (DL Span1, Bm6) (DL Span2, Bm1) 86 86 -50.17-5.04 6 6 -104.1 -10.5 (DL Span2, Bm2) 22 22 -104.1 -10.5 (DL Span2, Bm3) (DL Span2, Bm4) 38 38 -104.1-10.5 54 54 -104.1 -10.5 (DL Span2, Bm5) 70 -104.1 -10.5 70 (DL Span2, Bm6) 86 86 -104.1 -10.5 (Dist. Lane Ld) -4.92 0 20 (Conc. Lane Ld) 4 4 -21.3 (Conc. Lane Ld) 16 16 -21.3

4.4.15.3 CAP 18 Output File

AUG 11, 2020 TEXAS DEPARTMENT OF TRANSPORTATION (TxDOT) PAGE 1 CAP18 BENT CAP ANALYSIS Ver. 6.2 (Jul, 2011) HIGHWAY PD- CONTROL- CODED PSF COUNTY NO IPE SECTION-JOB BY DATE NO 00001 ___County____ Highwy Pro# 0000-00-000 BRG AUG 11, 2020 Comment CAP18 Version 6.00 ITBC Design Example 3, Skew = 45.00 PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay ENGLISH SYSTEM UNITS TABLE 1. CONTROL DATA OPTION TO PRINT TABLE SRS (1=YES) 0 ENVELOPES TABLE NUMBER OF MAXIMUMS 2 3 4 KEEP FROM PRECEDING PROBLEM (1=YES) 0 0 0 0 CARDS INPUT THIS PROBLEM 16 OPTION TO CLEAR ENVELOPES BEFORE LANE LOADINGS (1=YES) 0 OPTION TO OMIT PRINT FOR TABLES (TABLE DESIGNATIONS IN PARENTHESES) -1(4A), -2(5) -3(4A,5), -4(4A,5,6), -5(4A,5,6,7): 0 SKEW ANGLE, DEGREES 45.000 TABLE 2. CONSTANTS NUMBER OF INCREMENTS FOR SLAB AND CAP 92 INCREMENT LENGTH, FT 0.500 NUMBER OF INCREMENTS FOR MOVABLE LOAD 20 START POSITION OF MOVABLE-LOAD STA ZERO 2 STOP POSITION OF MOVABLE-LOAD STA ZERO 70 NUMBER OF INCREMENTS BETWEEN EACH POSITION OF MOVABLE LOAD 1 ANALYSIS OPTION (1=WORKING STRESS, 2=LOAD FACTOR, 3=BOTH) 3 LOAD FACTOR FOR DEAD LOAD 1.25 LOAD FACTOR FOR OVERLAY LOAD 1.50 LOAD FACTOR FOR LIVE LOAD 1.75 MAXIMUM NUMBER OF LANES TO BE LOADED SIMULTANEOUSLY 3 LIST OF LOAD COEFFICIENTS CORRESPONDING TO NUMBER OF LANES LOADED 4 5 1 2 3 1.000 0.850 1.200

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 3. LISTS OF STATIONS

NUM OF
LANESNUM OF
STRINGERSNUM OF
SUPPORTSNUM MOM
CONTR PTSNUM SHEAR
CONTR PTSLANE LEFT23260-LANE RIGHT326090-STRINGERS6.022.038.054.070.0STRINGERS6.022.038.054.070.0SUPPORTS10345882MOM CONTR610223438SHEAR CONTR81232365660

TABLE 4. STIFFNESS AND LOAD DATA

| FIXED-OR-MOVABLE FIXED-POSITION DATA MOVABLE- |
|--|
| STA STA CONTD CAP BENDING SIDEWALK, STRINGER, OVERLAY POSITION |
| FROM TO IF=1 STIFFNESS SLAB LOADS CAP LOADS LOADS SLAB LOADS |
| (K-FT*FT) (K) (K) (K) |
| |
| 2 90 0 86600000.000 0.000 -2.589 0.000 0.000 |
| 6 6 0 0.000 0.000 -50.170 -5.040 0.000 |
| 22 22 0 0.000 0.000 -50.170 -5.040 0.000 |
| 38 38 0 0.000 0.000 -50.170 -5.040 0.000 |
| 54 54 0 0.000 0.000 -50.170 -5.040 0.000 |
| 70 70 0 0.000 0.000 -50.170 -5.040 0.000 |
| 86 86 0 0.000 0.000 -50.170 -5.040 0.000 |
| 6 6 0 0.000 0.000 -104.100 -10.500 0.000 |
| 22 22 0 0.000 0.000 -104.100 -10.500 0.000 |
| 38 38 0 0.000 0.000 -104.100 -10.500 0.000 |
| 54 54 0 0.000 0.000 -104.100 -10.500 0.000 |
| 70 70 0 0.000 0.000 -104.100 -10.500 0.000 |
| 86 86 0 0.000 0.000 -104.100 -10.500 0.000 |
| 0 20 0 0.000 0.000 0.000 0.000 -4.920 |
| 4 4 0 0.000 0.000 0.000 0.000 -21.300 |
| 16 16 0 0.000 0.000 0.000 0.000 -21.300 |
| |

TABLE 4A. DEAD LOAD RESULTS (WORKING STRESS)

| STA | DIST X (FT) | DEFLECTIO | N (FT) | MOMENT (K-FT) | SHEAR (K) |
|-----|-------------|------------|--------|---------------|-----------|
| -1 | -0.71 | 0.000000 | 0.0 | 0.0 | |
| 0 | 0.00 | 0.000000 | 0.0 | 0.0 | |
| 1 | 0.71 | -0.000087 | 0.0 | 0.0 | |
| 2 | 1.41 | -0.000076 | 0.0 | -0.9 | |
| 3 | 2.12 | -0.000065 | -1.3 | -3.7 | |
| 4 | 2.83 | -0.000055 | -5.2 | -7.3 | |
| 5 | 3.54 | -0.000044 | -11./ | -11.0 | |
| 6 | 4.24 | -0.000033 | -20.7 | -99.6 | |
| 6 | 4.95 | -0.000023 | -152.4 | + -188.1 | |
| 0 | 5.00 | -0.000015 | -200. | 7 - 191.0 | |
| 10 | 7.07 | 0.000003 | -425. | 1 22.0 | |
| 11 | 7.07 | 0.000000 | -303. | 1 -55.0 | |
| 12 | 8/9 | 0.000002 | -380 | 2 125.5 | |
| 13 | 919 | -0.000002 | -292 | 7 122.0 | |
| 14 | 9.90 | -0.000005 | -207 | 7 118.4 | |
| 15 | 10.61 | -0.000011 | -125 | 3 114.7 | |
| 16 | 11.31 | -0.000017 | -45 | 5 111.0 | |
| 17 | 12.02 | -0.000024 | 31. | 8 107.4 | |
| 18 | 12.73 | -0.000030 | 106 | .4 103.7 | |
| 19 | 13.44 | -0.000036 | 178 | .4 100.0 | |
| 20 | 14.14 | -0.000041 | 247 | .9 96.4 | |
| 21 | 14.85 | -0.000044 | 314 | .7 92.7 | |
| 22 | 15.56 | -0.000046 | 379 | .0 4.2 | |
| 23 | 16.26 | -0.000045 | 320 | .6 -84.4 | |
| 24 | 16.97 | -0.000042 | 259 | .6 -88.1 | |
| 25 | 17.68 | -0.000038 | 196 | .1 -91.7 | |
| 26 | 18.38 | -0.000033 | 129 | .9 -95.4 | |
| 27 | 19.09 | -0.000027 | 61. | 2 -99.1 | |
| 28 | 19.80 | -0.000021 | -10. | 2 -102.7 | |
| 29 | 20.51 | -0.000015 | -84. | 1 -106.4 | |
| 30 | 21.21 | -0.000009 | -160 | 1.6 -110.0 | |
| 31 | 21.92 | -0.000004 | -235 | 4 1174 | |
| 22 | 22.05 | -0.000001 | -521 | .4 -117.4 | |
| 34 | 23.33 | 0.000001 | -403 | 5 115 | |
| 35 | 24.04 | -0.0000004 | -342 | 7 210.1 | |
| 36 | 25.46 | -0.000009 | -195 | 4 206.4 | |
| 37 | 26.16 | -0.000016 | -50 | 8 202.8 | |
| 38 | 26.87 | -0.000023 | 91. | 3 114.2 | |
| 39 | 27.58 | -0.000029 | 110 | .7 25.6 | |
| 40 | 28.28 | -0.000035 | 127 | .6 22.0 | |
| 41 | 28.99 | -0.000040 | 141 | .8 18.3 | |
| 42 | 29.70 | -0.000045 | 153 | .4 14.6 | |
| 43 | 30.41 | -0.000048 | 162 | .5 11.0 | |

TABLE 4A. DEAD LOAD RESULTS (WORKING STRESS)

| STA | DIST X (FT) | DEFLECTIO | N (FT) M | OMENT (K-FT) | SHEAR (K) |
|-----|-------------|-----------|----------|--------------|-----------|
| 44 | 31.11 | -0.000051 | 169.0 | 7.3 | |
| 45 | 31.82 | -0.000052 | 172.9 | 3.7 | |
| 46 | 32.53 | -0.000053 | 174.2 | 0.0 | |
| 47 | 33.23 | -0.000052 | 172.9 | -3.7 | |
| 48 | 33.94 | -0.000051 | 169.0 | -7.3 | |
| 49 | 34.65 | -0.000048 | 162.5 | -11.0 | |
| 50 | 35.36 | -0.000045 | 153.4 | -14.6 | |
| 51 | 36.06 | -0.000040 | 141.8 | -18.3 | |
| 52 | 36.77 | -0.000035 | 127.6 | -22.0 | |
| 53 | 37.48 | -0.000029 | 110.7 | -25.6 | |
| 54 | 38.18 | -0.000023 | 91.3 | -114.2 | |
| 55 | 38.89 | -0.000016 | -50.8 | -202.8 | |
| 56 | 39.60 | -0.000009 | -195.4 | -206.4 | |
| 57 | 40.31 | -0.000004 | -342.7 | -210.1 | |
| 58 | 41.01 | 0.000000 | -492.5 | -44.5 | |
| 59 | 41.72 | 0.000001 | -405.7 | 121.0 | |
| 60 | 42.43 | -0.000001 | -321.4 | 117.4 | |
| 61 | 43.13 | -0.000004 | -239.7 | 113.7 | |
| 62 | 43.84 | -0.000009 | -160.6 | 110.0 | |
| 63 | 44.55 | -0.000015 | -84.1 | 106.4 | |
| 64 | 45.25 | -0.000021 | -10.2 | 102.7 | |
| 65 | 45.96 | -0.000027 | 61.2 | 99.1 | |
| 66 | 46.67 | -0.000033 | 129.9 | 95.4 | |
| 67 | 47.38 | -0.000038 | 196.1 | 91.7 | |
| 68 | 48.08 | -0.000042 | 259.6 | 88.1 | |
| 69 | 48.79 | -0.000045 | 320.6 | 84.4 | |
| 70 | 49.50 | -0.000046 | 379.0 | -4.2 | |
| 71 | 50.20 | -0.000044 | 314.7 | -92.7 | |
| 72 | 50.91 | -0.000041 | 247.9 | -96.4 | |
| 73 | 51.62 | -0.000036 | 178.4 | -100.0 | |
| 74 | 52.33 | -0.000030 | 106.4 | -103.7 | |
| 75 | 53.03 | -0.000024 | 31.8 | -107.4 | |
| 76 | 53.74 | -0.000017 | -45.5 | -111.0 | |
| 77 | 54.45 | -0.000011 | -125.3 | -114.7 | |
| 78 | 55.15 | -0.000005 | -207.7 | -118.4 | |
| 79 | 55.86 | -0.000001 | -292.7 | -122.0 | |
| 80 | 56.57 | 0.000002 | -380.2 | -125.7 | |
| 81 | 57.28 | 0.000002 | -470.4 | -129.3 | |
| 82 | 57.98 | 0.000000 | -563.1 | 33.0 | |
| 83 | 58.69 | -0.000005 | -423.7 | 195.4 | |
| 84 | 59.40 | -0.000013 | -286.7 | 191.8 | |
| 85 | 60.10 | -0.000023 | -152.4 | 188.1 | |
| 86 | 60.81 | -0.000033 | -20.7 | 99.6 | |
| 87 | 61.52 | -0.000044 | -11.7 | 11.0 | |
| 88 | 62.23 | -0.000055 | -5.2 | 7.3 | |
| 89 | 62.93 | -0.000065 | -1.3 | 3.7 | |
| 90 | 63.64 | -0.000076 | 0.0 | 0.9 | |

| 91 | 64.35 | -0.000087 | 0.0 | 0.0 |
|----|-------|-----------|-----|-----|
| 92 | 65.05 | 0.000000 | 0.0 | 0.0 |
| 93 | 65.76 | 0.000000 | 0.0 | 0.0 |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 5. MULTI-LANE LOADING SUMMARY (WORKING STRESS) (*--CRITICAL NUMBER OF LANE LOADS)

MOMENT (FT-K)

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIV | E LC | DAD A | T : ST | LA | NE OR | NEC DER | MAX | e lo Imun | AD A 1 L | AT ANE : | STA |
|-----------|----------------------------------|-------------------------------|---------------------------------|-----------------------------|----------------------------|-----------|------------------|----------|------------|-----|--------------|-------------|-------------|-----|
| 6 | -20.7 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | 0. 0. 0. 0. | 0 0 0 0 | | | | | | | | | |
| 10 | -563.1 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | -249 -249 0. 0. | 9.3 9.3 0 0 | 1 1 | 2 2 | | | | | | | |
| 22 | 379.0 0 1 2 3 0* | 285.7 284.5 13.2 0.0 | 0 13 1 12 3 62 3 0* | 0 1 2 0. | -47.2 -47.2 0.0 0 | | 2 2 | 36 36 | | | | | | |
| 34 | -492.5 0 1 2 3 0* | 26.4 26.4 0.0 0.0 | 3 62 3 62 2 3 2* | 0 - 1 - -119 0. | 192.8 164.8 9.8 0 | 2 | 0 1 32 | 18 12 | | | | | | |
| 38 | 91.3 0 1 2 3 0* | 118.2 118.2 4.5 0.0 | 2 32 2 32 3 62 3 0* | 0 1 2 0. | -83.2 -83.2 0.0 0 | | 1 1 | 9 9 | | | | | | |
| 46 | 174.2 0 1 2 3 0* | 98.1 98.1 0.0 0.0 | 2 36 2 36 2 3 2* | 0 1 -39 0.0 | -39.3 -39.3 0.3 0 | 3 | 1 1 63 | 9 9 | | | | | | |
| 54 | 91.3 0 1 2 3 0* | 118.2 118.2 4.5 0.0 | 2 40 2 40 1 10 3 0* | 0 1 2 0.0 | -83.2 -83.2 0.0 0 | | 3 3 | 63 63 | | | | | | |
| 58 | -492.5 0 1 2 3 0* | 26.4 26.4 0.0 0.0 | 1 9 1 9 2 3 2* | 0 -1 1 -1 -119 0.0 | 92.8 64.8 9.8 0 | 2 | 0 9 3 (40 | 54 50 | | | | | | |

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MOMENT (FT-K)

| AT STA | DEAD LD EFFECT | ORDER | POSITI MAXIN | VE LO MUM | DAD A LANI | T E S | LA TA | NE OR | NEGATIV DER MAX | E LOA IMUM | D AT LANE STA |
|-----------|-------------------|-------|-----------------|--------------|---------------|----------|----------|----------|--------------------|---------------|------------------|
| 70 | 379.0 0 | 285.7 | 0 59 | 0 | -47.2 | , | 2 | 36 | | | |
| | 1 | 284.5 | 3 60 | 1 | -47.2 | 2 | 2 | 36 | | | |
| | 2 | 13.2 | 19 | 2 | 0.0 | | | | | | |
| | 3 0* | 0.0 | 3 0* | , , | .0 | | | | | | |
| 82 | -563.1 | | | | | | | | | | |
| | 0 | 0.0 | 0 | -24 | 9.3 | 3 | 70 |) | | | |
| | 1 | 0.0 | 1 | -24 | 9.3 | 3 | 70 |) | | | |
| | 2 | 0.0 | 2 | 0 | .0 | | | | | | |
| | 3 | 0.0 | 3 | 0 | .0 | | | | | | |
| | 0* | | 0* | | | | | | | | |
| 86 | -20.7 | | | | | | | | | | |
| | 0 | 0.0 | 0 | 0 | .0 | | | | | | |
| | 1 | 0.0 | 1 | 0 | .0 | | | | | | |
| | 2 | 0.0 | 2 | 0 | .0 | | | | | | |
| | 3 | 0.0 | 3 | 0 | .0 | | | | | | |
| | 0* | | 0* | r | | | | | | | |

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SHEAR (K)

| AT STA | DEAD LD EFFECT | LANE POSITIVE LOAD AT LANE NEGATIVE LOAD ORDER MAXIMUM LANE STA ORDER MAXIMUM |) AT LANE STA |
|-----------|----------------------------------|---|------------------|
| 8 | -191.8 0 1 2 3 0* | 0.0 0 -88.1 1 2 0.0 1 -88.1 1 2 0.0 2 0.0 0.0 3 0.0 0* | |
| 12 | 125.7 0 1 2 3 0* | 44.8 1 6 0 -5.6 2 36 44.8 1 6 1 -5.6 2 36 1.6 3 62 2 0.0 0.0 3 0.0 0* | |
| 32 | -117.4 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 36 | 206.4 0 1 2 3 2* | 87.6 0 28 0 -7.8 3 63 84.1 2 32 1 -7.8 3 63 30.7 1 12 2 0.0 0.0 3 0.0 0* | |
| 56 | -206.4 0 1 2 3 0* | 7.8 1 9 0 -87.6 0 44 7.8 1 9 1 -84.1 2 40 0.0 2 -30.7 3 60 0.0 3 0.0 2* | |
| 60 | 117.4 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 80 | -125.7 0 1 2 3 0* | 5.6 2 36 0 -44.8 3 66 5.6 2 36 1 -44.8 3 66 0.0 2 -1.6 1 9 0.0 3 0.0 0* | |
| 84 | 191.8 0 1 2 3 0* | 88.1 3 70 0 0.0 88.1 3 70 1 0.0 0.0 2 0.0 0.0 3 0.0 0.* | |

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REACTION (K)

| AT | DEAD L | D LANE | POSITIVE | LOAD A | T LANE NE | EGATIVE LOA | D AT |
|-----|---------|--------|------------------|--------|-----------|-------------|----------|
| STA | EFFECT | ORDE | R MAXIMU | M LANE | STA ORDE | r maximum | LANE STA |
| | | | | | | | |
| 10 | 222.1 | | | | | | |
| 10 | 352.1 | 177 0 | 1 2 0 | -5.6 | 2 36 | | |
| | 1 | 127.9 | 1 2 1 | -5.6 | 2 36 | | |
| | 2 | 1.6 | 3 62 2 | 0.0 | 2 50 | | |
| | 3 | 0.0 | 3 | 0.0 | | | |
| | 0* | | 0* | | | | |
| | | | | | | | |
| 34 | 338.4 | | | | 2 62 | | |
| | 0 | 117.1 | 0 22 0 | -9.3 | 3 63 | | |
| | 2 | 95.3 | 2 32 I 1 12 2 | -9.3 | 3 63 | | |
| | 2 | 0.0 | 3 | 0.0 | | | |
| | 2* | 0.0 | 0* | 0.0 | | | |
| | | | | | | | |
| 58 | 338.4 | | | | | | |
| | 0 | 117.1 | 0 50 0 | -9.3 | 19 | | |
| | 1 | 95.3 | 2 40 1 | -9.3 | 19 | | |
| | 2 | 83.6 | 3 60 2 | 0.0 | | | |
| | 3 2* | 0.0 | 3 | 0.0 | | | |
| | 2 | | 0 | | | | |
| 82 | 332.1 | | | | | | |
| | 0 | 127.9 | 3 70 0 | -5.6 | 2 36 | | |
| | 1 | 127.9 | 3 70 1 | -5.6 | 2 36 | | |
| | 2 | 1.6 | 192 | 0.0 | | | |
| | 3 | 0.0 | 3 | 0.0 | | | |
| | 0* | | 0* | | | | |

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TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | DIST X | MAX + | мом м | AX - MOM | MAX + SHEAF | MAX - SHEAR |
|-----|--------|--------|----------|----------|-------------|-------------|
| | (FT) | (FT-K) | (FT-K) | (K) (| К) | |
| -1 | -0.71 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 1 | 0.71 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 2 | 1.41 | 0.0 | 0.0 | -0.9 | -0.9 | |
| 3 | 2.12 | -1.3 | -1.3 | -3.7 | -3.7 | |
| 4 | 2.83 | -5.2 | -5.2 | -7.3 | -7.3 | |
| 5 | 3.54 | -11.7 | -11.7 | -11.0 | -11.0 | |
| 6 | 4.24 | -20.7 | -20.7 | -99.6 | -152.4 | |
| 7 | 4.95 | -152.4 | -227.2 | -188.1 | -293.9 | |
| 8 | 5.66 | -286.7 | -436.3 | -191.8 | -297.5 | |
| 9 | 6.36 | -423.7 | -648.0 | -195.4 | -301.2 | |
| 10 | 7.07 | -563.1 | -862.2 | -16.1 | -62.1 | |
| 11 | 7.78 | -451.8 | -735.8 | 183.1 | 122.7 | |
| 12 | 8.49 | -336.6 | -611.9 | 179.5 | 119.0 | |
| 13 | 9.19 | -223.0 | -490.6 | 175.8 | 115.3 | |
| 14 | 9.90 | -112.0 | -371.9 | 172.1 | 111.7 | |
| 15 | 10.61 | -3.1 | -255.7 | 168.5 | 108.0 | |
| 16 | 11.31 | 104.9 | -142.2 | 164.8 | 104.4 | |
| 1/ | 12.02 | 211.8 | -31.3 | 161.2 | 100.7 | |
| 18 | 12.73 | 317.6 | 68.6 | 157.5 | 97.0 | |
| 19 | 13.44 | 421.4 | 136.0 | 153.8 | 93.4 | |
| 20 | 14.14 | 523.6 | 200.7 | 150.2 | 89.7 | |
| 21 | 14.85 | 623.6 | 262.8 | 146.5 | 86.1 | |
| 22 | 16.26 | /21.8 | 322.4 | 20.1 | -9.0 | |
| 23 | 16.20 | 511.7 | 200.0 | -02.5 | -150.0 | |
| 24 | 17.69 | 402.7 | 192.4 | -00.2 | -155.0 | |
| 25 | 19 29 | 201.9 | 50.8 | -09.9 | -157.5 | |
| 20 | 10.00 | 179.5 | -24.5 | -95.5 | -164.6 | |
| 27 | 19.09 | 73.6 | -102.4 | -100.8 | -168 3 | |
| 29 | 20.51 | -32.8 | -182.4 | -104.5 | -171 9 | |
| 30 | 21 21 | -134.2 | -266.5 | -108.2 | -175.6 | |
| 31 | 21.21 | -212.0 | -388.3 | -111.8 | -179.3 | |
| 32 | 22.63 | -292.3 | -515.3 | -115.5 | -182.9 | |
| 33 | 23.33 | -375.3 | -645.0 | -119.2 | -186.6 | |
| 34 | 24.04 | -460.8 | -777.2 | 88.3 | 27.0 | |
| 35 | 24.75 | -317.6 | -546.1 | 324.9 | 200.8 | |
| 36 | 25.46 | -176.9 | -342.7 | 321.2 | 197.1 | |
| 37 | 26.16 | 20.9 | -171.0 | 317.6 | 193.5 | |
| 38 | 26.87 | 233.2 | -8.5 | 172.6 | 104.9 | |
| 39 | 27.58 | 248.4 | 17.5 | 34.9 | 16.3 | |
| 40 | 28.28 | 261.4 | 40.9 | 31.3 | 12.7 | |
| 41 | 28.99 | 272.3 | 61.7 | 27.6 | 9.0 | |
| 42 | 29.70 | 281.0 | 74.8 | 23.9 | 5.3 | |

TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | DIST X | MAX + N | лом мл | AX - MOM | MAX + SHEAR | MAX - SHEAR |
|-----|--------|----------|--------|----------|-------------|-------------|
| | (FT) | (FT-K) (| FT-K) | (K) (I | <) | |
| | | | | | | |
| 43 | 30.41 | 287.1 | 83.8 | 20.3 | 1.7 | |
| 44 | 31.11 | 290.6 | 90.3 | 16.6 | -2.0 | |
| 45 | 31.82 | 291.5 | 94.2 | 13.0 | -5.6 | |
| 46 | 32.53 | 291.9 | 95.5 | 9.3 | -9.3 | |
| 47 | 33.23 | 291.5 | 94.2 | 5.6 | -13.0 | |
| 48 | 33.94 | 290.6 | 90.3 | 2.0 | -16.6 | |
| 49 | 34.65 | 287.1 | 83.8 | -1.7 | -20.3 | |
| 50 | 35.36 | 281.0 | 74.8 | -5.3 | -23.9 | |
| 51 | 36.06 | 272.3 | 61.7 | -9.0 | -27.6 | |
| 52 | 36.77 | 261.4 | 40.9 | -12.7 | -31.3 | |
| 53 | 37.48 | 248.4 | 17.5 | -16.3 | -34.9 | |
| 54 | 38.18 | 233.2 | -8.5 | -104.9 | -172.6 | |
| 55 | 38.89 | 20.9 | -171.0 | -193.5 | -317.6 | |
| 56 | 39.60 | -176.9 | -342.7 | -197.1 | -321.2 | |
| 57 | 40.31 | -317.6 | -546.1 | -200.8 | -324.9 | |
| 58 | 41.01 | -460.8 | -777.2 | -27.0 | -88.3 | |
| 59 | 41.72 | -375.3 | -645.0 | 186.6 | 119.2 | |
| 60 | 42.43 | -292.3 | -515.3 | 182.9 | 115.5 | |
| 61 | 43.13 | -212.0 | -388.3 | 179.3 | 111.8 | |
| 62 | 43.84 | -134.2 | -266.5 | 175.6 | 108.2 | |
| 63 | 44.55 | -32.8 | -182.8 | 171.9 | 104.5 | |
| 64 | 45.25 | 73.6 | -102.4 | 168.3 | 100.8 | |
| 65 | 45.96 | 179.5 | -24.5 | 164.6 | 97.2 | |
| 66 | 46.67 | 291.8 | 50.8 | 160.9 | 93.5 | |
| 67 | 47.38 | 402.7 | 123.0 | 157.3 | 89.9 | |
| 68 | 48.08 | 511.2 | 192.4 | 153.6 | 86.2 | |
| 69 | 48.79 | 617.7 | 258.8 | 150.0 | 82.5 | |
| 70 | 49.50 | 721.8 | 322.4 | 9.0 | -20.1 | |
| 71 | 50.20 | 623.6 | 262.8 | -86.1 | -146.5 | |
| 72 | 50.91 | 523.6 | 200.7 | -89.7 | -150.2 | |
| 73 | 51.62 | 421.4 | 136.0 | -93.4 | -153.8 | |
| 74 | 52.33 | 317.6 | 68.6 | -97.0 | -157.5 | |
| 75 | 53.03 | 211.8 | -31.3 | -100.7 | -161.2 | |
| 76 | 53.74 | 104.9 | -142.2 | -104.4 | -164.8 | |
| 77 | 54.45 | -3.1 | -255.7 | -108.0 | -168.5 | |
| 78 | 55.15 | -112.0 | -371.9 | -111.7 | -172.1 | |
| 79 | 55.86 | -223.0 | -490.6 | -115.3 | -175.8 | |
| 80 | 56.57 | -336.6 | -611.9 | -119.0 | -179.5 | |
| 81 | 57.28 | -451.8 | -735.8 | -122.7 | -183.1 | |
| 82 | 57.98 | -563.1 | -862.2 | 62.1 | 16.1 | |
| 83 | 58.69 | -423.7 | -648.0 | 301.2 | 195.4 | |
| 84 | 59.40 | -286.7 | -436.3 | 297.5 | 191.8 | |
| 85 | 60.10 | -152.4 | -227.2 | 293.9 | 188.1 | |
| 86 | 60.81 | -20.7 | -20.7 | 152.4 | 99.6 | |

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TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| стл | | MAY | | | | | |
|-----|-------|--------|--------|------|------|------|-------------|
| SIP | | | | | | HEAR | WAA - SHEAR |
| | (FI) | (FI-K) | (FI-K) | (K) | (K) | | |
| | | | | | | | |
| 87 | 61.52 | -11.7 | -11.7 | 11.0 | 11.0 | | |
| 88 | 62.23 | -5.2 | -5.2 | 7.3 | 7.3 | | |
| 89 | 62.93 | -1.3 | -1.3 | 3.7 | 3.7 | | |
| 90 | 63.64 | 0.0 | 0.0 | 0.9 | 0.9 | | |
| 91 | 64.35 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 92 | 65.05 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 93 | 65.76 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| | | | | | | | |

TABLE 7. MAXIMUM SUPPORT REACTIONS (WORKING STRESS)

| | | | | - |
|-----|--------|-------|-------|-------------|
| STA | DIST X | MAX + | REACT | MAX - REACT |
| (| FT) | (K) | (K) | |
| | | | | |
| 10 | 7.07 | 485.6 | 325. | .4 |
| 34 | 24.04 | 517.3 | 327 | .3 |
| 58 | 41.01 | 517.3 | 327 | .3 |
| 82 | 57.98 | 485.6 | 325 | .4 |

TABLE 5. MULTI-LANE LOADING SUMMARY (LOAD FACTOR) (*--CRITICAL NUMBER OF LANE LOADS)

MOMENT (FT-K)

| AT STA | DEAD LD EFFECT | LANE ORDER | POSITIV MAXIM | e load Um la | D AT | LA TA | NE ORI | NEG. DER | ATIVE MAXI | E LOA MUM | D AT LAN | E STA |
|-----------|----------------------------------|-------------------------------|-----------------------------------|-----------------------------------|-------------------|--------------|---------------|-------------|---------------|--------------|-------------|-------|
| 6 | -25.9 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | | | | | | | | |
| 10 | -714.9 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 1 2 3 0* | -436.2 -436.2 0.0 0.0 | 1 1 | 2 2 | | | | | | |
| 22 | 480.6 0 1 2 3 0* | 499.9 497.9 23.1 0.0 | 0 13 1 12 3 62 3 0* | 0 -82 1 -82 2 0. 0.0 | 2.6 2.6 0 | 2 2 | 36 36 | | | | | |
| 34 | -623.9 0 1 2 3 0* | 46.2 46.2 0.0 0.0 | 3 62 3 62 2 3 2* | 0 -33 1 -28 -209.6 0.0 | 7.3 8.5 2 | 0 1 32 | 18 12 | | | | | |
| 38 | 116.9 0 1 2 3 0* | 206.9 206.9 8.0 0.0 | 2 32 2 32 3 62 2 3 0* | 0 -14 1 -14 2 0.0 0.0 | 5.6 5.6) | 1 1 | 9 9 | | | | | |
| 46 | 220.4 0 1 2 3 0* | 171.6 171.6 0.0 0.0 | 2 36 2 36 2 3 2* | 0 -68 1 -68 -68.9 0.0 | 8.9 8.9 3 | 1 1 63 | 9 9 | | | | | |
| 54 | 116.9 0 1 2 3 0* | 206.9 206.9 8.0 0.0 | 2 40 2 40 1 10 3 0* | 0 -14 1 -14 2 0.0 0.0 | 45.6 45.6 0 | 3 | 63 63 | | | | | |
| 58 | -623.9 0 1 2 3 0* | 46.2 46.2 0.0 0.0 | 19 19 2 3 2* | 0 -337 1 -288 -209.6 0.0 | 7.3 3.5 5 2 | 0 3 4(| 54 60) | | | | | |

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MOMENT (FT-K)

| AT | DEAD LD | LANE | POSIT | IVE | LOAD | AT | LA | NE | NEG | GATI | VE L | OA | D AT | |
|-----|---------|-------|-------|---------|-------|------|----|----|-----|------|------|----|------|-----|
| STA | EFFECT | ORDER | MAXI | MUN | 1 LAI | NE S | ΤA | OR | DER | MA | XIMU | JM | LAN | STA |
| | | | | | | | | | | | | | | |
| 70 | 480.6 | | | | | | | | | | | | | |
| | 0 | 499.9 | 0 59 | 0 | -82 | .6 | 2 | 36 | | | | | | |
| | 1 | 497.9 | 3 60 | 1 | -82 | .6 | 2 | 36 | | | | | | |
| | 2 | 23.1 | 1 9 | 2 | 0.0 | | | | | | | | | |
| | 3 | 0.0 | 3 | 3 | 0.0 | | | | | | | | | |
| | 0* | | 0 | * | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| 82 | -714.9 | | | | | | | | | | | | | |
| | 0 | 0.0 | (|) - | 436.2 | 3 | 70 |) | | | | | | |
| | 1 | 0.0 | | | 436.2 | 3 | 70 |) | | | | | | |
| | 2 | 0.0 | | 2 | 0.0 | | | | | | | | | |
| | 3 | 0.0 | - | 3 | 0.0 | | | | | | | | | |
| | 0* | | 0 | * | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| 86 | -25.9 | 0.0 | | | ~ ~ | | | | | | | | | |
| | 0 | 0.0 | (|) | 0.0 | | | | | | | | | |
| | 1 | 0.0 | | | 0.0 | | | | | | | | | |
| | 2 | 0.0 | - | <u></u> | 0.0 | | | | | | | | | |
| | 3 | 0.0 | | * | 0.0 | | | | | | | | | |
| | 0. | | 0 | | | | | | | | | | | |

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SHEAR (K)

| AT STA | DEAD LD EFFECT | LANE POSITIVE LOAD AT LANE NEGATIVE LOAD AT ORDER MAXIMUM LANE STA ORDER MAXIMUM LANE STA |
|-----------|----------------------------------|--|
| 8 | -243.6 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 12 | 159.2 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 32 | -148.5 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 36 | 261.9 0 1 2 3 2* | 153.2 0 28 0 -13.6 3 63 147.2 2 32 1 -13.6 3 63 53.7 1 12 2 0.0 0.0 3 0.0 0* |
| 56 | -261.9 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 60 | 148.5 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 80 | -159.2 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 84 | 243.6 0 1 2 3 0* | 154.2 3 70 0 0.0 154.2 3 70 1 0.0 0.0 2 0.0 0.0 3 0.0 0* |
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|--------------|-----------------------|-----------------------|---------|
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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

REACTION (K)

| AT STA | DEAD LE EFFECT | D LANE | POSITIV R MAXIM | /E LOA IUM L/ | D AT L ANE STA | ANE OR | NEGATIVE LC | OAD AT 1 LANE STA |
|-----------|---------------------------------|--------------------------------|----------------------------------|------------------------------|-----------------------|-----------|-------------|----------------------|
| 10 | 421.1 | | | | | | | |
| | 0 1 2 3 0* | 223.8 223.8 2.7 0.0 | 1 2 1 2 3 62 3 0* | 0 -9 1 -9 2 0. 0.0 | 0.7 2 0.7 2 0 | 36 36 | | |
| 34 | 428.7 0 1 2 3 2* | 205.0 166.8 146.3 0.0 | 0 22 2 32 1 12 3 0* | 0 -1 1 -1 2 (0.0 | 6.3 3 6.3 3 0.0 | 63 63 | | |
| 58 | 428.7 0 1 2 3 2* | 205.0 166.8 146.3 0.0 | 0 50 2 40 3 60 3 0* | 0 -1 1 -1 2 (0.0 | 6.3 1 6.3 1 0.0 | 9 9 | | |
| 82 | 421.1 0 1 2 3 0* | 223.8 223.8 2.7 0.0 | 3 70 3 70 1 9 2 3 0* | 0 -9 1 -9 2 0.0 0.0 | 9.7 2 9.7 2) | 36 36 | | |

PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA | DIST | K MAX + | MOM N | MAX - MO | MC | MAX + SH | EAR | MAX - S | HEAR |
|-----|-------|---------|---------|----------|------|----------|-----|---------|------|
| | (FT) | (FT-K) | (FT-K) | (K) | (K) |) | | | |
| | | | | , | | | | | |
| -1 | -0.71 | 0.0 | 0.0 | 0.0 | 0. | 0 | | | |
| 0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | | | |
| 1 | 0.71 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | | | |
| 2 | 1.41 | 0.0 | 0.0 | -1.1 | -1. | 1 | | | |
| 3 | 2.12 | -1.6 | -1.6 | -4.6 | -4 | 6 | | | |
| 4 | 2.83 | -6.5 | -6.5 | -9.2 | -9 | 2 | | | |
| 5 | 3.54 | -14.6 | -14.6 | -13.7 | _ | 13.7 | | | |
| 6 | 4.24 | -25.9 | -25.9 | -126.4 | - 1 | 218.9 | | | |
| 7 | 4.95 | -193.3 | -324.2 | -239 | .0 | -424.1 | | | |
| 8 | 5.66 | -363.9 | -625.6 | -243 | .6 | -428.7 | | | |
| 9 | 6.36 | -537.8 | -930.4 | -248 | .2 | -433.2 | | | |
| 10 | 7.07 | -714.9 | -1238.4 | 1 -12 | 2.6 | -93.0 | | | |
| 11 | 7 78 | -565.0 | -1061 9 | 25 | 79 | 152.1 | | | |
| 12 | 8.49 | -406.9 | -888.7 | 253 | 3.3 | 147.5 | | | |
| 13 | 9.19 | -250.4 | -718.7 | 248 | 3.8 | 142.9 | | | |
| 14 | 9.90 | -97.2 | -552.0 | 244 | 2 | 138.4 | | | |
| 15 | 10.61 | 53.6 | -388.5 | 239 | .6 | 133.8 | | | |
| 16 | 11.31 | 204.3 | -228.2 | 23 | 5.0 | 129.2 | | | |
| 17 | 12.02 | 354.3 | -71.1 | 230 | .5 | 124.6 | | | |
| 18 | 12.73 | 503.5 | 67.8 | 225 | .9 | 120.1 | | | |
| 19 | 13.44 | 650.7 | 151.1 | 22 | 1.3 | 115.5 | | | |
| 20 | 14.14 | 796.2 | 231.2 | 210 | 5.7 | 110.9 | | | |
| 21 | 14.85 | 939.3 | 308.0 | 212 | 2.1 | 106.3 | | | |
| 22 | 15.56 | 1080.5 | 381.5 | 5 33 | 3.3 | -17.6 | | | |
| 23 | 16.26 | 926.2 | 298.1 | -10- | 4.0 | -222.0 | | | |
| 24 | 16.97 | 769.1 | 211.2 | -10 | 8.6 | -226.6 | | | |
| 25 | 17.68 | 609.7 | 120.3 | -11 | 3.2 | -231.2 | | | |
| 26 | 18.38 | 447.6 | 25.7 | -117 | .7 | -235.7 | | | |
| 27 | 19.09 | 284.0 | -72.9 | -122 | 2.3 | -240.3 | | | |
| 28 | 19.80 | 133.3 | -174.7 | -12 | 6.9 | -244.9 | | | |
| 29 | 20.51 | -17.3 | -279.8 | -131 | .5 | -249.5 | | | |
| 30 | 21.21 | -157.7 | -389.2 | -13 | 6.1 | -254.0 | | | |
| 31 | 21.92 | -255.5 | -564.2 | -14 | 0.6 | -258.6 | | | |
| 32 | 22.63 | -356.6 | -746.9 | -14 | 5.2 | -263.2 | | | |
| 33 | 23.33 | -460.9 | -932.8 | -14 | 9.8 | -267.8 | | | |
| 34 | 24.04 | -568.4 | -1122. | 0 13 | 33.4 | 26.0 | | | |
| 35 | 24.75 | -389.9 | -789.9 | 46 | 7.4 | 250.2 | | | |
| 36 | 25.46 | -214.5 | -504.8 | 3 46 | 2.8 | 245.6 | | | |
| 37 | 26.16 | 62.0 | -273.8 | 458 | .2 | 241.1 | | | |
| 38 | 26.87 | 365.1 | -57.8 | 247 | .0 | 128.4 | | | |
| 39 | 27.58 | 382.0 | -22.0 | 48. | 3 | 15.8 | | | |
| 40 | 28.28 | 396.5 | 10.5 | 43. | 7 | 11.2 | | | |
| 41 | 28.99 | 408.3 | 39.8 | 39. | 2 | 6.6 | | | |
| 42 | 29.70 | 417.7 | 56.8 | 34. | 6 | 2.0 | | | |
| 43 | 30.41 | 423.9 | 68.2 | 30. | 0 | -2.5 | | | |
| 44 | 31.11 | 426.8 | 76.3 | 25. | 4 | -7.1 | | | |

| 45 | 31.82 | 426.5 | 81.1 | 20.9 | -11.7 | |
|--------|--------|-----------|---------|---------|-------------------|------------|
| 46 | 32.53 | 426.4 | 82.7 | 16.3 | -16.3 | |
| 47 | 33.23 | 426.5 | 81.1 | 11.7 | -20.9 | |
| 48 | 33.94 | 426.8 | 76.3 | 7.1 | -25.4 | |
| | | | | | | |
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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA | DIST X | MAX + N | IOM MA | X - MOM | MAX + SHEAR | MAX - SHEAR |
|-----|--------|----------|-----------------|---------|-------------|-------------|
| (| FT) (| FT-K) (F | -Т-К) (| K) (I | <) | |
| 49 | 34.65 | 423.9 | 68.2 | 2.5 | -30.0 | |
| 50 | 35.36 | 417.7 | 56.8 | -2.0 | -34.6 | |
| 51 | 36.06 | 408.3 | 39.8 | -6.6 | -39.2 | |
| 52 | 36.77 | 396.5 | 10.5 | -11.2 | -43.7 | |
| 53 | 37.48 | 382.0 | -22.0 | -15.8 | -48.3 | |
| 54 | 38.18 | 365.1 | -57.8 | -128.4 | -247.0 | |
| 55 | 38.89 | 62.0 | -273.8 | -241.1 | -458.2 | |
| 56 | 39.60 | -214.5 | -504.8 | -245.6 | -462.8 | |
| 57 | 40.31 | -389.9 | -789.9 | -250.2 | -467.4 | |
| 58 | 41.01 | -568.4 | -1122.0 | -26.0 | -133.4 | |
| 59 | 41.72 | -460.9 | -932.8 | 267.8 | 149.8 | |
| 60 | 42.43 | -356.6 | -746.9 | 263.2 | 145.2 | |
| 61 | 43.13 | -255.5 | -564.2 | 258.6 | 140.6 | |
| 62 | 43.84 | -157.7 | -389.2 | 254.0 | 136.1 | |
| 63 | 44.55 | -17.3 | -279.8 | 249.5 | 131.5 | |
| 64 | 45.25 | 133.3 | -174.7 | 244.9 | 126.9 | |
| 65 | 45.96 | 284.0 | -72.9 | 240.3 | 122.3 | |
| 66 | 46.67 | 447.6 | 25.7 | 235.7 | 117.7 | |
| 67 | 47.38 | 609.7 | 120.3 | 231.2 | 113.2 | |
| 68 | 48.08 | 769.1 | 211.2 | 226.6 | 108.6 | |
| 69 | 48.79 | 926.2 | 298.1 | 222.0 | 104.0 | |
| 70 | 49.50 | 1080.5 | 381.5 | 17.6 | -33.3 | |
| 71 | 50.20 | 939.3 | 308.0 | -106.3 | -212.1 | |
| 72 | 50.91 | 796.2 | 231.2 | -110.9 | -216.7 | |
| 73 | 51.62 | 650.7 | 151.1 | -115.5 | -221.3 | |
| 74 | 52.33 | 503.5 | 57.8 | -120.1 | -225.9 | |
| 75 | 53.03 | 354.3 | -/1.1 | -124.6 | -230.5 | |
| 70 | 55.74 | 204.5 | -220.2 200 E | 122.2 | -235.0 | |
| 79 | 55 15 | 97.2 | -500.5 | -133.0 | -239.0 | |
| 70 | 55.86 | -97.2 | -552.0 | -130.4 | -244.2 | |
| 80 | 56.57 | -406.9 | -888.7 | -147 5 | -253.3 | |
| 81 | 57.28 | -565.0 | -1061.9 | -152.1 | -257.9 | |
| 82 | 57.98 | -714.9 | -1238.4 | 93.0 | 12.6 | |
| 83 | 58.69 | -537.8 | -930.4 | 433.2 | 248.2 | |
| 84 | 59.40 | -363.9 | -625.6 | 428.7 | 243.6 | |
| 85 | 60.10 | -193.3 | -324.2 | 424.1 | 239.0 | |
| 86 | 60.81 | -25.9 | -25.9 | 218.9 | 126.4 | |
| 87 | 61.52 | -14.6 | -14.6 | 13.7 | 13.7 | |
| 88 | 62.23 | -6.5 | -6.5 | 9.2 | 9.2 | |
| 89 | 62.93 | -1.6 | -1.6 | 4.6 | 4.6 | |

| 90 | 63.64 | 0.0 | 0.0 | 1.1 | 1.1 | |
|----|-------|-----|-----|-----|-----|--|
| 91 | 64.35 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 92 | 65.05 | 0.0 | 0.0 | 0.0 | 0.0 | |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA (| DIST X FT) (| MAX + FT-K) | MOM (FT-K) | MAX - MO (K) | М МАХ + SHI (К) | EAR MAX - SHEAR |
|----------|------------------|-----------------|---------------|-------------------|--------------------------|-----------------|
| 93 | 65.76 | 0.0 | 0.0 | 0.0 | 0.0 | |

PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 7. MAXIMUM SUPPORT REACTIONS (LOAD FACTOR)

| | | | - |
|------------|-------|-------|-------------|
| STA DIST X | MAX + | REACT | MAX - REACT |
| (FT) | (K) | (K) | |
| | | | - |
| 10 7.07 | 689.7 | 409 | .4 |
| 34 24.04 | 741.8 | 409 | 9.2 |
| 58 41.01 | 741.8 | 409 | 9.2 |
| 82 57.98 | 689.7 | 409 | 9.4 |

4.4.15.4 Live Load Distribution Factor Spreadsheet

4.4.15.4.1 Spans 1 & 3



| NDGE | County: | ANY XXX.XX XXXX | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spe |
|--------|-----------|--------------------------|--|----------------------------|--------------|-----------------------|-------------|-----------------|--------|----------|
| ISION | Descrip: | ITBC Design Exa | mple 3, Span 1 & | 3 | File: | Ex3 Sp | an1_distrib | ution_factors.x | Sheet: | 2 of 8 |
| ITER | IOR BE | AM: | | | | | | | | |
| near L | L Distrib | ution Per Lane (| Table 4.6.2.2. | 3a-1): | | | | | | |
| | One La | ne Loaded | | | | | | | | |
| | | Lever Rule | (Table 3.6.1 | .1.2) | | | | | | |
| | | mg = 0.6 | 25 * 1.2 = | 0.750 | | | | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correc | tion = | 1.131 | | | | | |
| | | | mg = 0.750 | * 1.131 = | 0.848 | | | | | |
| | | Equation | 1 X | | | | | | | |
| | | g = 0.36 | $5 \pm \left(\frac{S}{25}\right)$ | | | | | | | |
| | | g = 0.36 | + (8 / 25) = | 0.680 | | | | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correc | tion = | 1.131 | | | | | |
| | | | g = 0.680 * | 1.131 = | 0.769 | | | | | |
| | | Range of App | licability (ROA |) Checks | | | | | | |
| | | Check S | : 3.5'≤8.0'≤ | 16.0' | OK | | | | | |
| | | Check ts | : 4.5" ≤ 8.0" : | ≤ 12.0" | OK | | | | | |
| | | Check L | 20' ≤ 50.3' ≤ | s 240' | OK | | | | | |
| | | Check N | b; 6≥4 | | OK | | | | | |
| | | Use Equation | from Table 4.6 | 5.2.2.3a-1 b | ecause all | criteria is | SOK. | | | |
| | | gV _{int1} = | 0.769 | | | | | | | |
| | Two or | More Lanes Lo | aded | | | | | | | |
| | | Lever Rule | (Table 3.6.1 | .1.2) | | | | | | |
| | | mg = Ma | x(0.875 * 1.0. | 0.875 * 0.8 | 5. 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correc | tion = | 1.131 | | | | | |
| | | | mg = 0.875 | * 1.131 = | 0.990 | | | | | |
| | | Equation | | > 2.0 | | | | | | |
| | | a = 0.2 | $+\left(\frac{s}{s}\right) - \left(\frac{s}{s}\right)$ | _) | | | | | | |
| | | 5 | (12) (35 | 5) | | | | | | |
| | | g = 0.2 + | - (8 / 12) - (8 / 3 | 35)^2.0 = | 0,814 | | | | | |
| | | Modify to | or Skew: | | | | | | | |
| | | | skew correc | tion = | 1,131 | | | | | |
| | | Section and | g = 0.814 " | 1.131 = | 0.921 | | | | | |
| | | Range of App | licability (ROA |) Checks | (same as I | or one la | ane load | ed) | | |
| | | Use Equation | from Table 4.6 | 5.2.2.3a-1 b | ecause all | criteria is | SOK. | | | |
| | | $gV_{int2+} =$ | 0.921 | | | | | | | |
| | TXDOT | Policy states gV | Interior must be | $\ge m \cdot N_L \div N_b$ | | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85 * 3 / 6 = | - | 0.425 | | | | | |
| | ls W ≥ 2 | 20ft ? Yes | | | | | | | | |
| | TXDOT | Policy states the | at if W < 20ft, g | Vinteniar is th | ie Maximun | n of: gV _m | iti and m | NL+Nb. | | |
| | TXDOT | Policy states that | at if W ≥ 20ft, c | Vinletior is th | e Maximun | of: gV | 11. gVint2. | m-NL÷Nn. | | |
| >> | - | | | | | | the second | | | |

| DDIDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spe |
|-----------|--------------------|--------------------------|---------------------------------------|--|--|-------------|-------------------|----------------|------------|----------|
| IVISION | C-S-J: Descrip: | ITBC Design Exa | mple 3. Span 1 8 | 3 | Elle: | Ex3 So | Date: | ution factors. | Sheet | 3 of 8 |
| INTER | IOR BE | AM: | | | To not | | | | d. Grieval | |
| Momen | t LL Distr | ribution Per Lan | e (Table 4.6.2 | 2.2b-1): | | | | | | |
| internet. | One La | ne Loaded | o Tradio Hole | and the | | | | | | |
| | | Lever Bule | (Table 3.6.) | 1.1.2) | | | | | | |
| | | ma = 0.0 | 525 * 1.2 = | 0.750 | | | | | | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corre | ction = | 0.858 | | | | | |
| | | | mg = 0.750 | * 0.858 = | 0.644 | | | | | |
| | | Equation | | | × 0.1 | | | | | |
| | | g = 0.0 | $6 + \left(\frac{S}{14}\right)^{0.4}$ | $\left(\frac{S}{L}\right)^{0.3} \left(\frac{K_s}{12Lt}\right)^{0.3}$ | <u>.</u> | | | | | |
| | | g = 0.06 | + (8/14)^0.4 | (8/50.3)^0.3 | 1 (1,271,6 | 11/(12*5 | 50.3*8^3) |)^0.1 = | 0.591 | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corre | ction = | 0.858 | | | | | |
| | | | g = 0.591 * | 0.858 = | 0.507 | | | | | |
| | | Range of App | licability (ROA | A) Checks | | | | | | |
| | | Check S | 3: 3.5' ≤ 8.0' : | ≤ 16.0' | | OK | | | | |
| | | Check t | : 4.5" ≤ 8.0" | ≲ 12.0″ | | OK | | | | |
| | | Check L | .: 20' ≤ 50.3' | ≤ 240' | | OK | | | | |
| | | Check N | l _b : 6≥4 | | | OK | | | | |
| | | Check H | Kg: 10,000 ≤ 1 | ,271,611≤7 | ,000,000 | OK | | | | |
| | | Use Equation | from Table 4 | 6.2.2.2b-1 b | ecause all | criteria is | s OK. | | | |
| | | gM _{int1} = | 0.507 | | | | | | | |
| | Two or | More Lanes Lo | baded | | | | | | | |
| | | Lever Rule | (Table 3.6.) | 1.1.2) | | | | | | |
| | | mg = Ma | ax(0.875 * 1.0 | 0.875 * 0.85 | 5, 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corre | ction = | 0.858 | | | | | |
| | | | mg = 0.875 | * 0.858 = | 0.751 | | | | | |
| | | Equation | (c)00 | (c)02() | 20.1 | | | | | |
| | | g = 0.0 | $75 + \left(\frac{3}{9.5}\right)$ | $\left(\frac{3}{L}\right) \left(\frac{1}{12}\right)$ | $\left(\frac{Lt_{g}^{3}}{Lt_{g}^{3}}\right)$ | | | | | |
| | | g = 0.07 Modify f | 5 + (8/9.5)^0.0 or Skew: | 3 * (8/50.3)^0 |).2 * (1,271 | ,611/(12 | 2*50.3*8^: | 3))^0.1 = | 0.795 | |
| | | | skew corre | ction = | 0.858 | | | | | |
| | | | g = 0.795 * | 0.858 = | 0.682 | | | | | |
| | | Range of App | licability (ROA | A) Checks | (same as l | for one I | ane loade | ed) | | |
| | | Use Equation | from Table 4. | 6.2.2.2b-1 be | ecause all | criteria i | s OK. | | | |
| | | gM _{int2+} = | 0.682 | | | | | | | |
| | TXDOT | Policy states of | Mutanor must be | $a \ge m N_1 \pm N_2$ | | | | | | |
| | | $m \cdot N_1 \div N_h =$ | 0.85 * 3/6 | = | 0.425 | | | | | |
| | ls W≥3 | 20ft ? Yes | 5.00 570 | | and the second | | | | | |
| | TXDOT | Policy states th | at if W < 20ft. | gMinterne is th | e Maximur | n of: gM | int and m | NI +NI- | | |
| >> | TXDOT | Policy states th | at if W ≥ 20ft. | gMinterior is th | e Maximun | n ol: gM | gMinio | m-NL=Nn | | |
| - | aM | anor = 0.682 | | an (Constitution of the | | CUDE | and a second lies | | | |

| TXDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Specs |
|---------|--------------------|--------------------------------------|----------------------------------|------------------------------|-------------------------------|------------|-------------|-----------------------------|------------------|--------------|
| BRIDGE | C-S-J: | ITBC Design Ex | ID #: | XXXX & 3 | Ck Dsn: | Ex3 So | Date: | ution factors x | Rev. 10/18 | (No Interim) |
| EXTER | RIOR BE | AM: | | | It ind. | Line op | | | Under. | 4010 |
| Shear L | L Distrib | ution Per Lane | (Table 4.6.2.2 | 2.3b-1): | | | | | | |
| | One La | ne Loaded | | | | | | | | |
| | | Lever Rule | (Table 3.6 | 1.1.2) | | | | | | 10 C |
| | | mg = 0. | 625 * 1.0 = | 0.625 | TxDOT us | es a mu | Itiple pres | sence factor | of 1,0 for a | ne |
| | | Modify f | or Skew: | | lane loade | d on the | e exterior | beam. | | |
| | | | skew corre | ection = | 1.131 | | | | | |
| | | | mg = 0.62 | 5 * 1.131 = | 0.707 | | | | | |
| | | Use Lever Ru | Ile, as per AA | SHTO LRFL | Table 4.6.2 | 2.2.3b-1 | 22 C | | | |
| | | gV _{ext1} = | 0.707 | | | | | | | |
| | Two or | More Lanes L | oaded | | | | | | | |
| | | Lever Rule | (Table 3.6 | .1.1.2) | | | | | | |
| | | mg = M | ax(0.625 * 1.0 | 0, 0.625 * 0.8 | 85, 0.625 * 0 | .65) = | 0.625 | | | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corre | ection = | 1.131 | | | | | |
| | | | mg = 0.623 | 5 * 1.131 = | 0.707 | | | | | |
| | | Equation | | 10.00 | | | | | | |
| | | | t. b/w GL web | to curb | | | | | | |
| | | d _e = OH | - Hall Width | 2.04 | i. | | | | | |
| | | u _e = | 311 - 111 = | 2.01 | 1 | | | | | |
| | | e = 0.6 | $+\left(\frac{a_{e}}{10}\right)$ | | | | | | | |
| | | 0-06 | (10) | 0.000 | | | | | | |
| | | 6 = 0.0 | + (2.0/10) = | 0.000 | | | | | | |
| | | g = e ⁻ g | Vint2+Eq | 0.707 | | | | | | |
| | | g = 0.80 | 0 0.921 = | oluded in al | lintorior | | | | | |
| | | Banga of Apr | disability (PO | A) Chocks | Interior). | POA in | implicitly | applied to th | | oom. |
| | | Check I | nterior Beam | ROA. | OK | NUMIS | implicitiy | applied to ti | ne exterior i | Jean. |
| | | Check c | d.: -1.0'≤2.0 | '≤5.5' | OK | | | | | |
| | | Check M | N _h : 6≠3 | - 0.0 | OK | | | | | |
| | | Use Equation | from Table 4 | .6.2.2.3b-1 | because all o | criteria i | s OK. | | | |
| | | gV _{ext2+} = | 0.737 | | | | | | | |
| | TXDOT | Policy states of | Ver. must b | e ≥ aV | | | | | | |
| | 1.45.51 | qVistoriar = | 0.921 | a - 3 · menor | | | | | | |
| | TXDOT | Policy states g | VExterior must b | $e \ge m \cdot N_1 \div N_1$ | h | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85*3/6 | 6 = | 0.425 | | | | | |
| | ls OH ≤ | S/2 ? Yes | | | | | | | | |
| | ls W ≥ 2 | 20ft? Yes | | | | | | | | |
| >> | TXDOT | Policy states th | at if OH ≤ S/2 | 2, gV _{Exterior} is | gV _{intenior} . | | | | | |
| | TXDOT | Policy states th | at if OH > S/a | 2 and W < 20 | off, gV _{Exterior} | is the Ma | aximum o | of: gV _{ext1} , gV | interior, and | |
| | | m·N _L ÷N _b . | | (mailes | á in - | | | NAME OF | | |
| | TXDOT | Policy states th | at if OH > S/2 | $2 \text{ ans } W \ge 20$ | off, gV _{Exterior} i | s the Ma | aximum c | ft gV _{ext1} , gV | ext2+, gVinteric | ci. |
| | | and m N _L +N _b | - | | | | | | | |
| | gV _{exte} | erior = 0.921 | | | | | | | | |

| TXDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|---------|-------------------|---|------------------------------------|---------------------------|------------------|-------------|------------|-----------------------------|---------------|-----------------------|
| IVISION | C-S-J: Descrip | ITBC Design Exa | ID #: mole 3. Span 1 & | 3 | Ck Dsn: File: | Ex3 Sor | Date: | ution factors x | Rev. 10/18 | (No Interin 5 of 8 |
| EXTER | NOR BE | AM: | | | T. ildi | Jana ope | | | Ondota | 0 01 0 |
| Momen | t I I Dist | ribution Per Lan | e (Table 4.6.2 | 2 2d-1) | | | | | | |
| Monteri | Onela | ne Loaded | o Tradic T.o.e | | | | | | | |
| | one Lu | Lever Bule | | | | | | | | |
| | | ma = 0.0 | 525 * 1.0 = | 0.625 | TXDOT US | es a mul | tiole ore: | sence factor | of 1.0 for a | ñe. |
| | | Modify f | or Skew: | | lane loade | d on the | exterior | beam. | er na isra | (IFC |
| | | | skew correc | ction = | 0.858 | | | | | |
| | | | mg = 0.625 | * 0.858 = | 0.536 | | | | | |
| | | Use Lever Ru | le as per AAS | HTO LRFD |) Table 4.6.2 | 2.2d-1. | | | | |
| | | gM _{ext1} = | 0.536 | | | | | | | |
| | Two or | More Lanes Lo | baded | | | | | | | |
| | C. C. T. C. | Lever Rule | (Table 3.6.1 | .1.2) | | | | | | |
| | | mg = Ma | ax(0.625 * 1.0, | 0.625 * 0.1 | 85, 0.625 * 0 | .65) = | 0.625 | | | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew correc | ction = | 0.858 | | | | | |
| | | | mg = 0.625 | * 0.858 = | 0.536 | | | | | |
| | | Equation | | | | | | | | |
| | | a = 0.7 | $7 + \left(\frac{d_e}{d_e}\right)$ | | | | | | | |
| | | 0 = 0.7 | (9.1) | | | | | | | |
| | | e = 0.77 | + (2.0/9.1) = | | 0.990 | | | | | |
| | | g = e*gN | Mint2+Eq | | | | | | | |
| | | g = 0.99 | * 0.682 = | 0.675 | | | | | | |
| | | Skew G | orrection inclu | ded in gM(i | interior). | | | | | |
| | | Range of App | licability (ROA |) Checks | Interior | ROA is i | mplicitly | applied to the | he exterior b | beam. |
| | | Check I | nterior Beam F | ROA: | OK | | | | | |
| | | Check d | l _e : -1.0' ≤ 2.0' | ≤ 5.5' | OK | | | | | |
| | | Check N | N _b : 6≠3 | | OK | | - | | | |
| | | Use Equation | from Table 4. | 6.2.2.2d-1 | because all o | criteria is | OK | | | |
| | | gM _{ext2+} = | 0.675 | | | | | | | |
| | TXDOT | Policy states gl | M _{Exterior} must be | e ≥ gM _{interio} | r | | | | | |
| | 1.2.2.2 | gM _{interior} = | 0.682 | | | | | | | |
| | TXDOT | Policy states gf | M _{Exterior} must be | e ≥ m·N _L ÷N | b | | | | | |
| | | $\mathbf{m} \cdot \mathbf{N}_{\mathbf{L}} \div \mathbf{N}_{\mathbf{b}} =$ | 0.85 * 3 / 6 | - | 0.425 | | | | | |
| | Is OH ≤ | S/2 ? Yes | | | | | | | | |
| ~ | TXDOT | Policy states th | at if OH \$ S/2 | aMenan is | Mulan | | | | | |
| | TXDOT | Policy states th | at if $OH > S/2$ | and $W < 2$ | Oft. aMexterior | is the Ma | aximum | of: aMaur. aM | Antonior, and | |
| | | m·Ni ÷Nn | | | erre Brucertenn) | | | an american a | - Unterior + | |
| | TXDOT | Policy states th | at if OH > S/2 | ans W ≥ 20 | Oft, gMexterior | s the Ma | aximum o | of: gM _{ext1} , gN | Aest2++ gMmte | norr- |
| | | and m·NL+Nb | | | and a second | | | | | |
| | gMext | erior = 0.682 | | | | | | | | |
| | <u> </u> | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |



| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|--------------------------------|---|----------------------------------|-------------------------------|-----------------------------------|-------------------|------------|------------------|-----------------------|------------------|
| DIVISION Descrip: | ITBC Design Exa | nple 3, Span 1 & | 3 | File: | Ex3 Span | 1_distribu | ution factors.xl | Sheet: | 7 of 8 |
| LEVER RULE | S | = 8.0 ft | | | | | | | |
| INTERIOR (con't) | | | | | | | | | |
| For 18 ≤ S < 22: One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S}$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S-16}{S}$ | | | = 0.625 | | |
| For 22 ≤ S ≤ 24; One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{-18}{s}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{5-18}{S} + \frac{S-16}{S}$ | $+\frac{S-22}{S}$ | | = -1.500 | | |
| | | | | ed hinge | | | Raji Width | S = OH = = BW - | 8.0 ft 3.0 ft |
| Ļ | он — — — | - s | 4 | | | | X = S+OH-I | RW-2ft = | 8.0 R |
| For X < 6: One Lane = | $\frac{16}{32}\left(\frac{X}{S}\right)$ | | | | | | = 0.500 | | |
| For 6 ≤ X < 12: One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-C}{S}\right)$ | ·) | | | | | = 0.625 | | |
| For 12 ≤ X < 18; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | ²) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $+\frac{X-12}{S}$ | | | | | = 0.375 | | |

| RIDGE County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 LRFD Spe |
|--------------------------------|---|--|----------------------------------|--|--------------------------------|------------------------------|-----------------|---------------|
| IVISION Descrip: | ITBC Design Exa | mple 3, Span 1 | & 3 | File: | Ex3 Span | 1_distrib | ution_factors.x | Sheet: 8 of 8 |
| 10.120 Z.110 | | | | | | | | |
| LEVER RULE | | | | | | | | |
| EXTERIOR (con't |) S - | = 8.0 ft | Ê | OH = | 3.0 ft | | | |
| | RW = | = 1.0 f | X = S + C | OH-RW-2ft = | 8.0 ft | | | |
| For 18 ≤ X < 24: | 16/V V- | 63 | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s}\pm\frac{x-s}{s}\right)$ | <u>-</u>) | | | | | = 0.625 | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{5} + \frac{X-12}{5} + \frac{X}{5}$ | $\left(\frac{18}{S}\right)$ | | | | = -0.250 | |
| For 24 ≤ X < 30: | 167 V V- | 5) | | | | | | |
| One Lane = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x-c}{s}\right)$ | <u> </u> | | | | | = 0.625 | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X-12}{S} + \frac{X}{S}$ | $\left(\frac{t-18}{s}\right)$ | | | | = -0.250 | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-1}{S}\right)$ | $\frac{6}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{x-18}{S} + \frac{x-2}{S}$ | <u>*</u>) | | | = -1.250 | |
| For 30 ≤ X < 36: | 16 (X X -) | 5) | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x}{s}\right)$ | j | | | | | = 0.625 | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X-12}{S} + \frac{X}{S}$ | $\left(\frac{-18}{s}\right)$ | | | | = -0.250 | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X-12}{S} + \frac{X}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\left(\frac{4}{s}+\frac{X-30}{s}\right)$ | | | = -2.625 | |
| For 36 ≤ X < 42: One Lane = | $\frac{16}{22}\left(\frac{X}{2} + \frac{X-1}{2}\right)$ | <u>e</u>] | | | | | = 0.625 | |
| | 32(3 S | × 10 x | -10 | | | | | |
| Two Lanes = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-c}{s}\right)$ | $\frac{1}{s} + \frac{x - 12}{s} + \frac{x}{s}$ | $\left(\frac{1}{S}\right)$ | | | | = -0.250 | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{9} + \frac{X-30}{S}$ | | | = -2.625 | |
| Four Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{6}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{S} + \frac{X-30}{S} + \frac{1}{S}$ | $\left(\frac{x-36}{s}\right)$ | | = -4.375 | |
| For 42 ≤ X ≤ 48: One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | <u>6</u>) | | | | | = 0.625 | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X-12}{S} + \frac{X}{S}$ | $\left(\frac{18}{s}\right)$ | | | | = -0.250 | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{s} + \frac{X-12}{s} + \frac{X}{s}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{s} + \frac{X-30}{S}$ | | | = -2.625 | |
| Four Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-C}{S}\right)$ | $\frac{6}{S} + \frac{X-12}{S} + \frac{X}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{5} + \frac{X - 30}{S} + $ | $\frac{x-36}{s} + \frac{x}{s}$ | $\left(\frac{-42}{s}\right)$ | = -6.500 | |
| INTERIOR | _ | | | EXTER | IOR | | | |
| One Lane Loaded | | = 0.625 | | One La | ne Loaded | d | i e | 0.625 |
| Two Lanes Loade | d | = 0.875 | | Two La | nes Loade | ed | - | 0.625 |
| Three Lanes Load | led | - 0.875 | | Three L | anes Loa | ded | - | 0.625 |
| Four Lange Lande | and a | 0.975 | | - | | 80° - | | The state |

4.4.15.4.2 Span 2



| XDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spe |
|--------|-----------|-------------------|-------------------------|--------------------|------------------|-------------------|-----------------|------------------|--------------|------------|
| VISION | C-S-J: | ITBC Design Exa | ID #: mole 3. Span 2 | XXXX | Ck Dsn: | Ex3 So | Date: | tion factors x | Rev. 10/18 - | (No Interi |
| NTER | IOR BE | AM. | inple of open a | | Trinds | Line op | | | Onder | 2010 |
| Choorl | L Dietrik | ution Dar Lano | Table 1622 | 20.11 | | | | | | |
| Snear | Orala | and reded | Table 4.0.2.2 | . <u>Jd-1).</u> | | | | | | |
| | One La | he Loaded | (Table 0.C. | 1 1 01 | | | | | | |
| | | Lever Hule | (Table 3.6. | 0.750 | | | | | | |
| | | mg = 0.6 | 25 1.2 = | 0.750 | | | | | | |
| | | Modify to | or Skew: | | | | | | | |
| | | | skew correc | | 1,164 | | | | | |
| | | | mg = 0.750 | 1.104 = | 0.073 | | | | | |
| | | Equation | (5) | | | | | | | |
| | | g = 0.30 | $2^{+}(\overline{25})$ | | | | | | | |
| | | q = 0.36 | + (8 / 25) = | 0.680 | | | | | | |
| | | Modify for | or Skew: | | | | | | | |
| | | | skew correc | ction = | 1.164 | | | | | |
| | | | g = 0.680 * | 1.164 = | 0.792 | | | | | |
| | | Range of App | licability (ROA | A) Checks | - | | | | | |
| | | Check S | : 3.5' ≤ 8.0' : | ≤ 16.0' | OK | | | | | |
| | | Check t | : 4.5" ≤ 8.0" | ≤ 12.0" | OK | | | | | |
| | | Check L | 20'≤ 106.5 | 5' ≤ 240' | OK | | | | | |
| | | Check N | l _b ; 6≥4 | | OK | | | | | |
| | | Use Equation | from Table 4 | 62238-11 | ecause all o | viteria is | SOK | | | |
| | | aVieta = | 0.792 | COLUMN AND A | and and an other | - () - () - () | | | | |
| | T.u | Maralanaala | a dad | | | | | | | |
| | Two or | More Lanes Lo | /Table 2.6 | 1.1.01 | | | | | | |
| | | Lever Hule | (1 able 3.0. | 0.975 * 0.9 | 5 0 975 * 0 | CEV - | 0.975 | | | |
| | | Modify f | n Skow | , 0.075 0.0 | 5, 0.875 0. | .00) = | 0.075 | | | |
| | | NOUTY I | skow.corror | ction - | 1 164 | | | | | |
| | | | ma - 0.875 | * 1 164 - | 1.019 | | | | | |
| | | Fairefier | my = 0.075 | 1.104 = | 1.015 | | | | | |
| | | Equation | (S) (S | $(5)^{2.0}$ | | | | | | |
| | | g = 0.2 | $+(12)^{-}(3)$ | 5) | | | | | | |
| | | g = 0.2 + | + (8 / 12) - (8 / | 35)^2.0 = | 0,814 | | | | | |
| | | Modify for | or Skew: | | | | | | | |
| | | | skew correct | ction = | 1,164 | | | | | |
| | | | g = 0.814 * | 1.164 = | 0.947 | | | | | |
| | | Range of App | licability (ROA | A) Checks | (same as f | or one l | ane loade | ed) | | |
| | | Use Equation | from Table 4. | 6.2.2.3a-11 | ecause all o | criteria is | s OK. | | | |
| | | $gV_{int2+} =$ | 0.947 | | | | | | | |
| | TYDOT | Policy states al | must he | > m.NN. | | | | | | |
| | TADOT | m·N· ÷N· = | 0.85 * 3 / 6 | - un talfanap | 0.425 | | | | | |
| | In MAN | 20ft 2 Voc | 0.00 0/0 | - | V.423 | | | | | |
| | TXDOT | Policy states Ih | at if W < 20th | oVie ti | ne Maximum | Vo to | and m. | NN. | | |
| | TYDOT | Policy states the | at if $W > 200$ | aV. interior is th | ne Maximum | of aV | in and m | m-NN. | | |
| 22 | C aV | - 0.047 | | a . Interior ia it | in maannuun | 91.9×K | 1111 A + 1015+1 | the nali an alle | | |
| | 9 v inte | arior = 0.947 | | | | | | | | |

| TXDOT | County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spe |
|---------|-------------------|--------------------------|---------------------------------------|---|--|------------|------------------|---------------|---------------------|----------|
| IVISION | C-S-J: Descrip | ITBC Design Ex | ID #: ample 3. Span 2 | XXXX | Ck Dsn: | Ex3 So | Date: | ution factors | Rev. 10/18 Sheet | 3 of 8 |
| INTER | IOR BE | AM: | | | D. HOL | Land Op | | | ender. | 0010 |
| Momer | t I I Dist | ribution Per Lan | e (Table 4.6 | 2 2 2h-1): | | | | | | |
| Montal | Onela | ne Loaded | o (ruoic +.o | | | | | | | |
| | One Lu | Lever Bule | (Table 3 F | 5112) | | | | | | |
| | | ma = 0 | 625 * 1.2 = | 0.750 | | | | | | |
| | | Modify f | or Skew: | 0.000 | | | | | | |
| | | incomy i | skew corr | ection = | 0.919 | | | | | |
| | | | ma = 0.75 | 0 * 0.919 = | 0.689 | | | | | |
| | | Equation | | | 2.0.1 | | | | | |
| | | g = 0.0 | $6 + \left(\frac{S}{14}\right)^{0.4}$ | $\left(\frac{S}{L}\right)^{0.5} \left(\frac{K_s}{12L}\right)^{0.5}$ | | | | | | |
| | | g = 0.06 | 6 + (8/14)^0.4 | * (8/106.5)^0 | 3* (1,271, | 611/(12 | *106.5*8 | ^3))^0.1 = | 0.453 | |
| | | Modify f | or Skew: | 0.0 | 2. A.S | | | | | |
| | | 1.1774 | skew corr | ection = | 0.919 | | | | | |
| | | | g = 0.453 | * 0.919 = | 0.416 | | | | | |
| | | Range of App | licability (RC | DA) Checks | | | | | | |
| | | Check S | 3: 3.5'≤8.0 | '≤ 16.0' | | OK | | | | |
| | | Check t | ; 4.5" ≤ 8.0 |)" ≤ 12.0" | | OK | | | | |
| | | Check L | .: 20'≤ 106 | .5' ≤ 240' | | OK | | | | |
| | | Check M | N _b : 6≥4 | | | OK | | | | |
| | | Check H | Kg: 10,000 ≤ | 1,271,611 ≤ 7 | ,000,000 | OK | | | | |
| | | Use Equation | from Table | 4.6.2.2.2b-1 b | ecause all | criteria i | s OK | | | |
| | | gM _{int1} = | 0.416 | | | | | | | |
| | Two or | More Lanes L | oaded | | | | | | | |
| | | Lever Rule | (Table 3.6 | 5.1.1.2) | | | | | | |
| | | mg = M | ax(0.875 * 1. | 0, 0.875 * 0.8 | 5, 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corr | ection = | 0.919 | | | | | |
| | | | mg = 0.87 | /5 * 0.919 = | 0.804 | | | | | |
| | | Equation | (-) | 0.6 (=> 0.2 (| 10.1 | | | | | |
| | | g = 0.0 | $75 + \left(\frac{s}{9.5}\right)$ | $\left(\frac{S}{L}\right)\left(\frac{1}{12}\right)$ | $\left(\frac{\Delta_g}{Lt_s^3}\right)$ | | | | | |
| | | g = 0.07 Modify f | 75 + (8/9.5)^(for Skew: |).6 * (8/106.5) [,] | 0.2 * (1,27 | 1,611/(1 | 12*106.5* | 8^3))^0.1 = | 0.649 | |
| | | | skew corr | ection = | 0.919 | | | | | |
| | | | g = 0.649 | * 0.919 = | 0.596 | | | | | |
| | | Range of App | blicability (RC | DA) Checks | (same as I | for one l | ane load | ed) | | |
| | | Use Equation | from Table | 4.6.2.2.2b-1 b | ecause all | criteria i | s OK. | | | |
| | | gM _{int2+} = | 0.596 | | | | | | | |
| | TXDOT | Policy states of | Mustanor must | be≥m·N,÷N, | | | | | | |
| | | $m \cdot N_1 \div N_h =$ | 0.85 * 3 / | 6 = | 0.425 | | | | | |
| | ls W≥ | 20ft ? Yes | | | Salaria a | | | | | |
| | TXDOT | Policy states th | at if W < 201 | t. gMintern is th | e Maximur | n of: aM | and m | NI +NI | | |
| >> | TXDOT | Policy states th | at if W ≥ 20F | L gMinterior is U | e Maximun | Mpilan | Ima gMint | m·Ni=Na | | |
| | aM. | = 0.596 | | and the second second second | | C. M. S. | TO PERFORMENTING | | | |
| | givinte | nor - 0.590 | _ | | | | | | | |

| XDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spe |
|--------|-------------------|-----------------------|-------------------------------------|------------------|-----------------------|-------------|------------|-----------------|---------------------|----------------------|
| VISION | C-S-J: Descrip | ITBC Design Ex | ID #: ample 3. Span 2 | XXXX | Ck Dsn: File: | Ex3 Soa | Date: | ution factors x | Rev. 10/18 - | (No Interi 4 of 8 |
| TEE | NOR BE | AM. | | | It no. | Line opt | | | Onder | 4010 |
| Choorl | I Dietrik | ution Parl and | Table 16 2 | 0.06 11. | | | | | | |
| SnearL | C DISTING | ution Per Lane | (12018 4.0.2.) | 2.30-1]: | | | | | | |
| | One La | ne Loaded | | 1.1.00 | | | | | | |
| | | Lever Hule | (Table 3,6 | .1.1.2) | - | | | | | |
| | | mg = 0. | 625 * 1.0 = | 0.625 | TxDOT us | es a mul | tiple pres | sence factor | of 1,0 for a | ne |
| | | Modify | for Skew: | ~ | lane loade | a on me | exterior | Deam. | | |
| | | | skew corre | ection = | 1,164 | | | | | |
| | | | mg = 0.62 | 5 * 1.164 = | 0.728 | | | | | |
| | | Use Lever Ri | ule. as per AA | ASHTO LRFL | D Table 4.6.2 | 2.2.3b-1. | | | | |
| | | gV _{ext1} = | 0.728 | | | | | | | |
| | Two or | More Lanes L | oaded | | | | | | | |
| | | Lever Rule | (Table 3.6 | .1.1.2) | | | | | | |
| | | mg = M | ax(0.625 * 1.0 | 0, 0.625 * 0.8 | 35, 0.625 * 0 | .65) = | 0.625 | | | |
| | | Modify | for Skew: | | | | | | | |
| | | | skew corre | ection = | 1.164 | | | | | |
| | | | ma = 0.62 | 5 * 1.164 = | 0.728 | | | | | |
| | | Equation | | | 1.111 | | | | | |
| | | d. = dis | t. b/w CL web | to curb | | | | | | |
| | | $d_a = OH$ | - Rail Width | | | | | | | |
| | | d. = | 3ft - 1ft = | 20 | ti. | | | | | |
| | | 08 | (1) | | | | | | | |
| | | e = 0.6 | $i + \left \frac{a_x}{10} \right $ | | | | | | | |
| | | - 00 | (10) | 0.000 | | | | | | |
| | | e = 0.6 | +(2.0/10) = | 0.800 | | | | | | |
| | | $g = e^*g$ | Vint2+Eq | | | | | | | |
| | | g = 0.80 | 00 * 0.947 = | 0.758 | | | | | | |
| | | Skew C | orrection is in | icluded in gV | /(interior). | | | | | |
| | | Range of Ap | olicability (RC | A) Checks | Interior | ROA is i | implicitly | applied to the | he exterior b | eam. |
| | | Check I | nterior Beam | ROA: | OK | | | | | |
| | | Check of | d _e : -1.0' ≤ 2.0 |)' ≤ 5.5' | OK | | | | | |
| | | Check I | N _b : 6≠3 | | OK | | | | | |
| | | Use Equation | from Table 4 | 4.6.2.2.3b-1 | because all o | criteria is | OK. | | | |
| | | gV _{ext2+} = | 0.758 | | | | | | | |
| | TYDOT | Policy states o | V- must h | ne > dV | | | | | | |
| | Two C . | aVistadas = | 0.947 | - 3 · menor | | | | | | |
| | TXDOT | Policy states d | Vran must t | ne > m·NN | | | | | | |
| | THE OT | m·N, ÷N, = | 0.85*3/6 | 8 - | 0 425 | | | | | |
| | IS OH S | 6/2.2 Voc | 0.00 071 | 5 - | 0.460 | | | | | |
| | Is W > | 20ft 2 Ves | | | | | | | | |
| >> | TXDOT | Policy states th | at if OH ≤ S/2 | 2. aVestation is | aVinterior | | | | | |
| | TXDOT | Policy states th | at if OH > S/ | 2 and W < 20 | off. aVenuera | is the Ma | aximum c | of aV aV | and | |
| | 1,001 | m·N·-N | | | Strain B + Exterior 1 | (e)C | entrent e | a stexin 94 | midfiorr curice | |
| | TYDOT | Policy states th | at if OH > SI | 2 ans W > 20 | off aV- | s the Ma | vimum o | f aV aV | aV. | |
| | 14001 | and m.N. +N | at in girt - off | Lung 11 - 20 | 9 Y Exterior | 0 110 1410 | annun u | A A extl. A A | ext2+> 9 * interior | 0 |
| | | and third #14 | | | | | | | | |
| | gv _{ext} | erior = 0.947 | | | | | | | | |

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TXDOT
BRIDGE
                     ANY
           County:
                                       Highway
                                                      Any
XXXX
                                                                      Design:
                                                                                          Date
                                                                                                                       2017 LRFD Spel
                     XXX-XX-XXXX
                                                                                                                      10/18 - (No Inte
                                                                      Ck Dsn:
                                       ID #
                                                                                          Date
                     ITBC Design Exa
DIVISION
                                                                                                                               5 of 8
 EXTERIOR BEAM:
Moment LL Distribution Per Lane (Table 4.6.2.2.2d-1):
          One Lane Loaded
                     Lever Rule
                           mg = 0.625 * 1.0 =
                                                     0.625
                                                                  TxDOT uses a multiple presence factor of 1,0 for one
                                                                  lane loaded on the exterior beam.
                           Modify for Skew:
                                       skew correction =
                                                                     0.919
                                       mg = 0.625 * 0.919 =
                                                                      0.574
                     Use Lever Rule as per AASHTO LRFD Table 4.6.2.2.2d-1.
                     gMext1 =
                                       0.574
          Two or More Lanes Loaded
                     Lever Rule
                                       (Table 3.6.1.1.2)
                           mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) =
                                                                                          0.625
                           Modify for Skew:
                                       skew correction =
                                                                     0.919
                                       mg = 0.625 * 0.919 =
                                                                      0.574
                     Equation
                           e = 0.77 + \left(\frac{d_e}{9.1}\right)
                           e = 0.77 + (2.0/9.1) =
                                                                  0.990
                           g = e^{*}gM_{int2+Eq}
                           g = 0.99 * 0.596 =
                                                      0.590
                           Skew Correction included in gM(interior).
                     Range of Applicability (ROA) Checks
                                                                      Interior ROA is implicitly applied to the exterior beam.
                           Check Interior Beam ROA:
                                                                  OK
                           Check d_e: -1.0' \leq 2.0' \leq 5.5'
                                                                 OK
                           Check N<sub>b</sub>: 6 ≠ 3
                                                                  OK
                     Use Equation from Table 4.6.2.2.2d-1 because all criteria is OK.
                     gM<sub>ext2+</sub> =
                                       0.590
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ gM<sub>interior</sub>
                     gMinterior =
                                     0.596
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ m·N<sub>L</sub>÷N<sub>b</sub>
                     m \cdot N_L \div N_b = 0.85 * 3 / 6 =
                                                                     0.425
          Is OH ≤ S/2 ? Yes
          Is W ≥ 20ft ? Yes
      >> TxDOT Policy states that if OH ≤ S/2, gM<sub>Exterior</sub> is gM<sub>interior</sub>.
          TxDOT Policy states that if OH > S/2 and W < 20ft, gM<sub>Exterior</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>interior</sub>, and
                     m·NI ÷Nn
          TxDOT Policy states that if OH > S/2 ans W \ge 20ft, gM_{\text{Extension}} is the Maximum of: gM_{\text{ext1}}, gM_{\text{ext2+r}} gM_{\text{milenorm}}
                     and m·NL+NE
            gM<sub>exterior</sub> = 0.596
```



| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|--------------------------------|---|----------------------------------|-------------------------------|----------------------------------|-------------------|------------|--------------------------|--------------------|------------------|
| DIVISION Descrip: | ITBC Design Exa | mple 3, Span 2 | 10000 | File: | Ex3_Span | 2_distribu | ution factors.xl | Sheet: | 7 of 8 |
| LEVER RULE | S | = 8.0 ft | | | | | | | |
| INTERIOR (con't) | | | | | | | | | |
| For 18 ≤ S < 22: One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{s}$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S-16}{S}$ | | | = 0.625 | | |
| For 22 ≤ S ≤ 24; One Lane = | $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{-18}{s}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S-16}{S}$ | $+\frac{S-22}{S}$ | | = -1.500 | | |
| | | | | | | | | S = | 8.0 ft |
| L. | он — — — — — — — — — — — — — — — — — — — | — s —— | i Cassume | ed hinge | | | Rail Width X = S+OH-I | = RW = RW-2ft = | 1.0 ft 8.0 ft |
| For X < 6: One Lane = | $\frac{16}{32}\left(\frac{X}{S}\right)$ | | | | | | = 0.500 | | |
| :For 6 ≤ X < 12; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | 5) | | | | | = 0.625 | | |
| For 12 ≤ X < 18; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | <u>s</u>) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\left(\frac{X-12}{S}\right)$ | | | | | = 0.375 | | |

| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|-------------------------------|---|-------------------------------|----------------------------------|----------------------------------|-------------------------------|-----------|----------------|--------|-----------|
| IVISION Descrip: | ITBC Design Exar | nple 3, Span 2 | 17777 | File: | Ex3 Span | 2 distrib | ution_factors. | Sheet: | 8 of 8 |
| 16.121 Z.112 | | | | | | | | | |
| LEVER RULE | | | | | | | | | |
| EXTERIOR (con't |) S = | 8.0 ft | É. | OH = | 3.0 ft | | | | |
| | RW = | 1.0 ft | X = S+C | H-RW-2ft = | 8.0 ft | | | | |
| For 18 ≤ X < 24: | | | | | | | | | |
| One Lane = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x-6}{s}\right)$ |) | | | | | = 0.625 | | |
| ÷ | 16 (X . X -6 | X -12 X | (-18) | | | | | | |
| Two Lanes = | 32 8 8 | S | S) | | | | = -0.250 | | |
| For 24 ≤ X < 30: | 16 (X X - 6 | 1 | | | | | | | |
| One Lane = | $32 \left(\frac{s}{s} \right)^+ \frac{s}{s}$ |) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{22}\left(\frac{X}{2}+\frac{X-6}{2}\right)$ | $+\frac{X-12}{2}+\frac{X}{2}$ | -18 | | | | = -0.250 | | |
| | 32(5 5 | 5 | 5 / | | | | | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{x}{S} + \frac{x-6}{S}\right)$ | $+\frac{X-12}{S}+\frac{X}{S}$ | $\frac{x-18}{S} + \frac{x-2}{S}$ | ") | | | = -1.250 | | |
| For 30 ≤ X < 36: | 10/10 10 1 | | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{S} + \frac{x-0}{S}\right)$ | | | | | | = 0.625 | | |
| Two Longs | 16(X + X - 6) | X -12X | -18) | | | | 0.050 | | |
| Two Lanes = | 32 (s' s) | S | \$) | | | | = -0.200 | | |
| Three Lanes = | $-\frac{16}{32}\left(\frac{X}{S}+\frac{X-6}{S}\right)$ | $+\frac{X-12}{S}+\frac{X}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{5} + \frac{X - 30}{S}$ | | | = -2.625 | | |
| For $36 \le X \le 42^{\circ}$ | | | 2 8 | | | | | | |
| One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ |) | | | | | = 0.625 | | |
| 4 | 16(X, X - 6) | X -12 X | -18) | | | | | | |
| Two Lanes = | 32 8 8 | s | S) | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{22}\left(\frac{X}{c} + \frac{X-6}{c}\right)$ | $+\frac{X-12}{c}+\frac{X}{c}$ | $\frac{x-18}{c} + \frac{x-2}{c}$ | $\frac{4}{4} + \frac{X-30}{c}$ | | | = -2.625 | | |
| | 32(5 5 16(V V-6 | S V 12 V | 5 5 -18 V-7 | 5 / | Y - 36) | | | | |
| Four Lanes = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-0}{s}\right)$ | $+\frac{x-12}{S}+\frac{x}{S}$ | $\frac{1}{S} + \frac{x-2}{S}$ | $+\frac{x-30}{s}+$ | $\left(\frac{x-30}{s}\right)$ | | = -4.375 | | |
| For $42 \le X \le 48$: | ICAN N. C | | | | | | | | |
| One Lane = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x-6}{s}\right)$ |) | | | | | = 0.625 | | |
| Two Longs | 16(X - 6) | X -12 X | (-18) | | | | 0.250 | | |
| Two Lanes = | 32 8 5 | S | S) | | | | = -0.200 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{5} + \frac{X-6}{5}\right)$ | $+\frac{X-12}{8}+\frac{X}{8}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{5} + \frac{X-30}{5}$ | | | = -2.625 | | |
| | 16(X - X = 6 | X -12 X | -18 X-2 | 4 X = 30 | x - 36 x | -42) | | | |
| Four Lanes = | $\frac{1}{32}\left(\frac{1}{s} + \frac{1}{s}\right)$ | + | s + <u>s</u> | -+ <u>-</u> + | 5 + 1 | S) | = -6.500 | | |
| INTERIOR | _ | | | EXTER | IOB | | | | |
| One Lane Loaded | | = 0.625 | | One La | ne Loaded | 1 | | 0.625 | |
| Two Lanes Loade | d | 0.875 | | Two La | nes Loade | d | - | 0.625 | |
| Three Lanes Load | led - | 0.875 | | Three L | anes Load | ded | | 0.625 | |
| Four Lanes Loade | rd . | 0.875 | | Faurta | 24.1 4 1.2.4 | S | | 0.005 | |

| | Highway: | ANY | | | 1 | | | | |
|---------------------------------|-----------|-----------|-------------|--------------|----------|-------------|------------|-----------|----------|
| Tavas | C-S-J: | XXXXXXX | | | Design: | BRG C | k Dsn: | BRG | |
| Department of Transportation | Bridge I | Division | R | ev: 09/26/08 | | | Date: | Aug-20 | |
| CONCRETE SECTION SHEA | AR CAPA | CITY BY A | ASHTO L | RFD BRID | GE DESIG | N SPECIFIC | ATIONS, FO | URTH EDIT | ON, 2007 |
| Resistance Factors: | | 7 | Units: | US | | _ | - | | |
| ¢v = | 0.9 | | | | | | | | |
| φ _M = | 0.9 | | | | | | | | |
| φ _N = | 0.75 | | | | | | | | |
| Concrete: | - | - | Mild Steel: | | | Prestressed | Steel: | | |
| fc =[| 5 | ksi | fy = | 60 | ksi | fpu = | 270 k | si | |
| Ec = | 4070 | ksi | Es = | 29000 | ksi | Ep = | 28500 k | si | |
| | | - | | | SECTIONS | | | | |
| | Units | 8 | 12 | 32 | 36 | 56 | 60 | 80 | 84 |
| Input Data | | | | | | | | | |
| Bending moment, Mu | kip-ft | 625.6 | 888.7 | 746.9 | 504.8 | 504.8 | 746.9 | 888.7 | 62 |
| Shear force, Vu | kip | 243.6 | 253.3 | 145.2 | 462.8 | 245.6 | 263.2 | 147.5 | 428. |
| Axial force, Nu (+ if tensile) | kip | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Web width, bv | in | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.0 |
| Shear depth, dv | in | 80.59 | 80.59 | 80.59 | 80.59 | 80.59 | 80.59 | 80.59 | 80.5 |
| Mild steel reinf. area, As | in^2 | 10.92 | 10.92 | 10.92 | 10.92 | 10.92 | 10.92 | 10.92 | 10.9 |
| Conc area on tension side, Ac | in^2 | 1785 | 1785 | 1785 | 1785 | 1785 | 1785 | 1785 | 178 |
| Area of stirrups, Av | in^2 | 1.76 | 1.76 | 1,76 | 1.76 | 1.76 | 1.76 | 1.76 | 1.7 |
| Stirrup spacing, s | in | 7,2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 | 7, |
| Prestressed steel area, Aps | in^2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Prestress shear, Vp | kip | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - |
| Average prestress, tps | ksi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Torsional moment, Tu | kip-ft | 773 | 387 | 387 | 773 | 773 | 387 | 387 | 77. |
| Shear flow area, Ao | in^2 | 3493.5 | 3493.5 | 3493.5 | 3493.5 | 3493.5 | 3493.5 | 3493.5 | 3493. |
| Area of one leg of stirrup. At | in^2 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.4 |
| Perimeter of stirrup, Ph | in | 334 | 334 | 334 | 334 | 334 | 334 | 334 | 33 |
| Calculated Values | | | | | | | | | |
| Vc | kip | 583.6 | 578.8 | 641.0 | 533.3 | 581.2 | 574.0 | 641.0 | 533. |
| Vs | kip | 1715.2 | 1753.6 | 2037.8 | 1484.3 | 1708.2 | 1731.8 | 2029.6 | 1484. |
| φVn | kip | 2069 | 2099 | 2411 | 1816 | 2060 | 2075 | 2404 | 181 |
| E _X | 1.22 | 6.83E-04 | 7.07E-04 | 4.33E-04 | 1.00E-03 | 6.88E-04 | 7.31E-04 | 4.39E-04 | 1.00E-0 |
| θ | deg | 32.80 | 33.10 | 29.40 | 36.40 | 32.90 | 33.42 | 29.50 | 36.4 |
| Peo'd Shear reinf Au/S | 1040.60 | 2.990 | 2.920 | 2.680 | 2.230 | 2.930 | 2.900 | 2.680 | 2.23 |
| Reg'd Torsion reinf At/S | in/2/m | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.00 |
| Maximum stirrup spacing, Smax | in | 74 0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24 |
| Construction of the state | | 21.0 | 2 | 2 1.0 | 210 | 21.0 | 21.0 | 2.110 | £.1. |
| Conclusion | | 011 | OK | OK | OK | OK | OK | OK | OK |
| Conclusion Shear Be | inforcing | OK I | Un I | | | | | | |

4.4.15.5 Concrete Section Shear Capacity Spreadsheet

If torsion is not being considered, leave last five rows of input data blank.

4.4.15.6 Bent Cap Details



4.5 INVERTED-T BENT CAP DESIGN EXAMPLE 4 (60° SKEW ANGLE)

Design example is in accordance with the AASHTO LRFD Bridge Design Specifications, 8th Ed. (2017) as prescribed by TxDOT Bridge Manual - LRFD (January 2020).

4.5.1 Design Parameters



Figure 4.78 Spans of the Bridge with 60 Degrees Skewed ITBC

<u>Span 1</u>

54' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 16' along the axis of bent with 3' overhangs

2" Haunch

Span 2

112' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 16' along the axis of bent with 3' overhangs

3.75" Haunch

<u>Span 3</u>

54' Type TX54 Girders (0.851 k/ft)

6 Girders Spaced @ 16' along the axis of bent with 3' overhangs

2" Haunch

<u>All Spans</u>

Deck is 46 ft wide

Type T551 Rail (0.382 k/ft)

8" Thick Slab (0.100 ksf)

Assume 2" Overlay @ 140 pcf (0.023 ksf)

Use Class "C" Concrete

$$\begin{split} f_c^{'} &= 5 \text{ ksi} \\ w_c &= 150 \text{ pcf (for weight)} \\ w_c &= 145 \text{ pcf (for Modulus of Elasticity calculation)} \end{split}$$

"AASHTO LRFD" refers to the ASSHTO LRFD Bridge Design Specification, 8th Ed. (2017)..

"BDM-LRFD" refers to the TxDOT Bridge Design Manual -LRFD (January 2020).

"TxSP" refers to TxDOT guidance, recommendations, and standard practice.

"Furlong & Mirza" refers to "Strength and Serviceability of Inverted T-Beam Bent Caps Subject to Combined Flexure, Shear, and Torsion", Center for Highway Research Research Report No. 153-1F, The University of Texas at Austin, August 1974.

The basic bridge geometry can be found on the Bridge Layout located in the Appendices.

(TxSP)

(BDM-LRFD, Ch. 4, Sect. 5, Materials)

Grade 60 Reinforcing

 $f_y = 60 \text{ ksi}$

Bents

Use 36" Diameter Columns (Typical for Type TX54 Girders)

Define Variables

| <u>Back Span</u> | <u>Forward Span</u> | |
|---|-----------------------------------|---|
| Span1 = 54ft | Span2 = 112ft | Span Length |
| GdrSpa1 = 8ft | GdrSpa2 = 8ft | Girder Spacing (Normalized values) |
| GdrNo1 = 6 | GdrNo2 = 6 | Number of Girders in Span |
| GdrWt1 = 0.851klf | GdrWt2 = 0.851klf | Weight of Girder |
| Haunch1 = 2in | Haunch $2 = 3.75$ in | Size of Haunch |
| Bridge | | |
| Skew $= 60$ deg | | Skew of Bents |
| BridgeW = 46ft | | Width of Bridge Deck |
| RdwyW = 44ft | | Width of Roadway |
| GirderD = 54in | | Depth of Type TX54 Girder |
| BrgSeat = 1.5in | | Bearing Seat Buildup |
| BrgPad = 2.75in | | Bearing Pad Thickness |
| SlabThk = 8in | | Thickness of Bridge Slab |
| OverlayThk = 2in | | Thickness of Overlay |
| RailWt = 0.372klf | | Weight of Rail |
| $w_{c} = 0.150 kcf$ | | Unit Weight of Concrete for Loads |
| $w_{Olav} = 0.140$ kcf | | Unit Weigh of Overlay |
| Bents | | |
| $f_c = 5$ ksi | | Concrete Strength |
| $w_{eF} = 0.145 \text{kcf}$ | | Unit Weight of Concrete for E_c |
| $E_c = 33000 \cdot w_{cE}^{1.5} \cdot $ | $\overline{f_c}$ $E_c = 4074$ ksi | Modulus of Elasticity of Concrete (AASHTO LRFD Eq. C5.4.2.4-2) |
| $f_y = 60$ ksi | | Yield Strength of Reinforcement |
| $E_s = 29000 ksi$ | | Modulus of Elasticity of Steel |
| | | |

 $D_{column} = 36in$

Diameter of Columns

Other Variables

IM = 33%



Figure 4.79 Top View of the 60 Degrees Skewed ITBC with Spans and Girders

4.5.2 Determine Cap Dimensions



Figure 4.80 Section View of 60 Degrees Skewed ITBC

 $b_{stem} = 42$ in

4.5.2.1 Stem Width

```
b_{stem} = at least D_{column} + 3in
```

Use:

4.5.2.2 Stem Height

Distance from Top of Slab to Top of Ledge:

 $D_{Slab_{to_{Ledge}}} = SlabThk + Haunch2 + GirderD + BrgPa$

 $D_{Slab to Ledge} = 70.00 in$

StemHaunch = 3.75 in

wider than the Diameter of the Column (36") to allow for the extension of the column reinforcement into the Cap. (TxSP) Haunch2 is the larger of the two haunches.

The stem is typically at least 3"

The top of the stem must be 2.5" below the bottom of the slab. (BDM-LRFD, Ch. 4, Sect. 5, Geometric Constraints)

Accounting for the 1/2" of bituminous fiber, the top of the stem must have at least 2" of haunch on it, but the haunch should not be less than either of the haunches of the adjacent spans. $d_{stem} = D_{Slab_to_Ledge} - SlabThk - StemHaunch - 0.5in$

$$d_{stem} = 57.75$$
 in

Use: $d_{stem} = 57$ in

4.5.2.3 Ledge Width



The stem must accommodate ¹/₂" of bituminous fiber.

Round the Stem Height down to the nearest 1". (TxSP)

The Ledge Width must be adequate for Bar M to develop fully.

 $L_{dh,prov}$ " must be greater than or equal to $L_{dh,req}$ " for Bar M.

"cover" is measured from the center of the transverse bars.

"L" is the length of the Bearing Pad along the girder. A typical type TX54 bearing pad is circular 15" Dia. for 60° skewed beents, as shown in the IGEB standard.

(AASHTO LRFD Eq.

(AASHTO LRFD 5.10.8.2.4b)

5.10.8.2.4a-2)

cover = 2.5 in

L = 15 in

Determine the Required Development Length of Bar M:

Try # 7 Bar for Bar M.

$$d_{bar_M} = 0.875$$
 in
 $A_{bar_M} = 0.60$ in²

Basic Development Length

$$L_{dh} = \frac{38.0 \cdot d_{bar_M}}{60} \cdot \left(\frac{f_y}{\sqrt{f_c}}\right)$$

Modification Factors for L_{dh} :

Is Top Cover greater than or equal to 2.5", and Side Cover greater than or equal to 2"?

 $L_{dh} = 14.87$ in

SideCover = cover
$$-\frac{d_{bar,M}}{2} = 2.06$$
 in
TopCover = cover $-\frac{d_{bar,M}}{2} = 2.06$ in
TopCover = cover $-\frac{d_{bar,M}}{2} = 2.06$ in
No. Reinforcement Confinement Factor, $\lambda_{rc} = 1.0$
Coating Factor, $\lambda_{cw} = 1.0$
Excess Reinforcement Factor, $\lambda_{er} = 1.0$
Concrete Density Modification Factor, $\lambda = 1.0$
Concrete Density Modification Factor, $\lambda = 1.0$
 $L_{dh,req} = max(L_{dh} \cdot (\frac{\lambda rc \lambda_{cw} \lambda er}{\lambda}), 8 \cdot d_{bar,M}, 6in.)$ "Side Cover" and "Top Cover"
are the clear cover on the side
and top of the hook respectively.
The dimension "cover" is
measured from the center of Bar
M.Development Length:
 $L_{dh,req} = max(L_{dh} \cdot (\frac{\lambda rc \lambda_{cw} \lambda er}{\lambda}), 8 \cdot d_{bar,M}, 6in.)$ (AASHTO LRFD 5.10.8.2.4a)
the stem to the center of
bearing is 12" for TxGirders
(IGEB).Development Length:
 $L_{db_req} = 25$ in $D_{ledge,min} = 21.87$ in
 $D_{ledge} = 25$ inThe distance from the face of
the stem to the center of
bearing is 12" for TxGirders
(IGEB).Width of Bottom Flange:
 $b_f = 2 \cdot b_{ledge} + b_{stem}$ $b_f = 92$ inAs a general rule of thumb,
Ledge Depth is greater than or

equal to 2'-3". This is the depth at which a bent from a typical

bridge will pass the punching

shear check.

Use a Ledge Depth of 28".

 $d_{ledge} = 28 \text{ in}$

Total Depth of Cap:

 $h_{cap} = d_{stem} + d_{ledge} \qquad \qquad h_{cap} = 85 \text{ in}$

4.5.2.5 <u>Summary of Cross Sectional Dimensions</u>

$$b_{stem} = 42$$
 in
 $d_{stem} = 57$ in
 $b_{ledge} = 25$ in
 $d_{ledge} = 28$ in
 $h_{cap} = 85$ in

4.5.2.6 Length of Cap

First define Girder Spacing and End Distance:



Figure 4.82 Elevation View of 60 Degrees Skewed ITBC

$$\begin{split} S &= 8 \ \text{ft} & Girder \ Spacing \\ c &= 2 \ \text{ft} & ``c`` is \ the \ distance \ from \ the \ Center \\ Line \ of \ the \ Exterior \ Girder \ to \ the \\ Edge \ of \ the \ Cap \ measured \ along \\ the \ Cap. \\ L_{Cap} &= S \cdot (\text{GdrNo1} - 1) + 2c & L_{Cap} &= 44 \ \text{ft} & Length \ of \ Cap \end{split}$$

TxDOT policy is as follows, "The edge distance between the exterior bearing pad and the end of the inverted T-beam shall not be less than 12in." (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria) replacing the statement in AASHTO LRFD 5.13.2.5.5 stating it shall not be less than d_f . Preferably, the stem should extend at least 3" beyond the edge of the bearing seat.

Bearing Pad Dimensions:

Bearing Pad Dimensions:(IGEB standard)L = 15 inLength of Bearing PadW = 15 inWidth of Bearing Pad

4.5.3 Cross Sectional Properties of Cap

$$\begin{split} A_{g} &= d_{ledge} \cdot b_{f} + d_{stem} \cdot b_{stem} & A_{g} &= 4970 \text{ in}^{2} \\ ybar &= \frac{d_{ledge} \cdot b_{f} \cdot \left(\frac{1}{2}d_{ledge}\right) + d_{stem} \cdot b_{stem} \cdot \left(d_{ledge} + \frac{1}{2}d_{stem}\right)}{A_{g}} & ybar &= 34.5 \text{ in} \quad \begin{array}{l} Distance \text{ from bottom of the cap to} \\ the center of \text{ gravity of the cap} \end{array} \\ I_{g} &= \frac{b_{f} \cdot d_{ledge}^{3}}{12} + b_{f} \cdot d_{ledge} \cdot \left(ybar - \frac{1}{2}d_{ledge}\right)^{2} + \frac{b_{stem} \cdot d_{stem}}{12} + \cdots \\ b_{stem} \cdot d_{stem} \cdot \left[ybar - \left(d_{ledge} + \frac{1}{2}d_{stem}\right)\right]^{2} & I_{g} &= 3.06 \times 10^{6} \text{ in}^{4} \end{split}$$

4.5.4 Cap Analysis

4.5.4.1 Cap Model

Assume:

4 Columns Spaced @ 12'-0"

The cap will be modeled as a continuous beam with simple supports using TxDOT's CAP18 program.



Figure 4.83 Continuous Beam Model for 60 Degrees Skewed ITBC

TxDOT does not consider frame action for typical multi-column bents (BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis).



Figure 4.84 Cap 18 Model of 60 Degrees Skewed ITBC

The circled numbers in Figure 4.84 are the stations that will be used in the CAP 18 input file. One station is 0.5 ft in the direction perpendicular to the pgl, not parallel to the bent.

station = 0.5 ft

Station increment for CAP 18

Recall:

$$\begin{split} E_c &= 4074 \text{ ksi} & I_g = 3.06 \times 10^6 \text{ in}^4 \\ E_c I_g &= 1.25 \times 10^{10} \text{ kip} \cdot \text{in}^2 / \left(12 \frac{\text{in}}{\text{ft}} \right)^2 \text{ } E_c I_g = 8.66 \times 10^7 \text{kip} \cdot \text{ft}^2 \end{split}$$

SPAN 1

 $Rail1 = \frac{2 \cdot RailWt \cdot \frac{Span1}{2}}{\min(GdrNo1,6)}$

$$Slab1 = w_c \cdot GdrSpa1 \cdot SlabThk \cdot \frac{Span1}{2} \cdot 1.10$$

 $Girder1 = GdrWt1 \cdot \frac{Span1}{2}$

$$DLRxn1 = (Rail1 + Slab1 + Girder1)$$

$$Overlay1 = w_{Olay} \cdot GdrSpa1 \cdot OverlayThk \cdot \frac{Span1}{2}$$

SPAN 2

 $Rail2 = \frac{2 \cdot RailWt \cdot \frac{Span2}{2}}{\min(GdrNo2,6)}$

Slab2 =
$$w_c \cdot GdrSpa2 \cdot SlabThk \cdot \frac{Span2}{2} \cdot 1.10$$

Girder2 = GdrWt1
$$\cdot \frac{\text{Span2}}{2}$$
 Girder2 = 47.66 $\frac{\text{kip}}{\text{girder}}$

$$DLRxn2 = (Rail2 + Slab2 + Girder2)$$
 $DLRxn2 = 104.07 \frac{kip}{girder}$

Values used in the following equations can be found on "4.5.1 Design Parameters"

Rail Weight is distributed

thickened slab ends.

Slab1 = $23.76 \frac{\text{kip}}{\text{girder}}$ Increase slab DL by 10% to account for haunch and

evenly among stringers, up to 3 stringers per rail (TxSP).

Overlay is calculated

separetely, because it has different load factor than the rest of the dead loads.

Design for future overlay.

 $Rail1 = 3.44 \frac{kip}{girder}$

Girder1 = $22.98 \frac{\text{kip}}{\text{girder}}$

 $DLRxn1 = 50.17 \frac{kip}{girder}$

 $Overlay1 = 5.04 \frac{kip}{girder}$

Rail2 = $7.13 \frac{\text{kip}}{\text{girder}}$

 $Slab2 = 49.28 \frac{kip}{girder}$

$$Overlay2 = w_{Olay} \cdot GdrSpa2 \cdot OverlayThk \cdot \frac{Span2}{2} \qquad Overlay2 = 10.45 \frac{kip}{girder}$$

CAP

$$Cap = w_c \cdot A_g = 5.177 \frac{kip}{ft} \cdot \frac{0.5ft}{station} \qquad Cap = 2.589 \frac{kip}{station}$$

AASHTO LRFD 3.6.1.2.2 and 3.6.1.2.4)





ShortSpan = min(Span1, Span2)
IM = 0.33
Lane =
$$0.64$$
klf $\cdot \left(\frac{\text{LongSpan+ShortSpan}}{2}\right)$
Lane = $53.12 \frac{\text{kip}}{\text{lane}}$

LongSpan = max(Span1, Span2)

 $Truck = 32kip + 32kip \cdot \left(\frac{LongSpan - 14ft}{LongSpan}\right) + 8kip \cdot \left(\frac{LongSpan - 28ft}{LongSpan}\right)$

$$Truck = 66.00 \frac{kip}{lane}$$

LLRxn = Lane + Truck
$$\cdot$$
 (1 + IM)
LLRxn = 140.90 $\frac{\text{kip}}{\text{lane}}$

ShortSpan = 54 ft Use HL-93 Live Load. For maximum reaction at interior bents, "Design

LongSpan = 112 ft

reaction at interior bents, "Design Truck" will always govern over "Design Tandem". For the maximum reaction when the long span is more than twice as long as the short span, place the rear (32 kip) axle over the support and the middle (32 kip) and front (8 kip) axles on the long span. For the maximum reaction when the long span is less than twice as long as the short span, place the middle (32 kip) axle over the support, the front (8 kip) axle on the short span and the rear (32 kip) axle on the long span.

Combine "Design Truck" and "Design Lane" loadings (AASHTO LRFD 3.6.1.3). Dynamic load allowance, IM, does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4)



Figure 4.86 Live Load Model of 60 Degrees Skewed ITBC for CAP18

(AASHTO LRFD Table 3.6.1.1.2-1)

2 fi

20)

The Live Load is applied to the slab by two 16 kip wheel loads increased by the dynamic load allowance with the reminder of the live load distributed over a 10 ft (AASHTO LRFD 3.6.1.2.1) design lane width. (TxSP)

The Live Load applied to the slab is distributed to the beams assuming the slab is hinged at each beam except the outside beam. (BDM-LRFD, Ch. 4, Sect. 5, Structural Analysis)

Input "Multiple Presence Factors" into CAP18 as "Load Reduction Factors".

The cap design need only consider Strength I, Service I,

| No. of I | Lanes Factor "m' |
|----------|------------------|
| 1 | 1.20 |
| 2 | 1.00 |
| 3 | 0.85 |

>3 0.65 Limit States (AASHTO LRFD 3.4.1)

4.5.4.1.3 Cap 18 Data Input

Multiple Presence Factors, m

Strength I

| | Live Load and Dynamic Load Allowance | LL+IM = 1.75 | and Service I with DL (TxSP). |
|---------|--------------------------------------|----------------|---|
| | Dead Load Components | DC = 1.25 | TrDOT allows the Overlay |
| | Dead Load Wearing Surface (Overlay) | DW = 1.50 | Factor to be reduced to 1.25 |
| Service | <u>e I</u> | | (TxSP), since overlay is typically used in design only to |
| | Live Load and Dynamic Load Allowance | LL+IM = 1.00 | increase the safety factor, but |
| | Dead Load and Wearing Surface | DC & DW = 1.00 | in this example we will use <i>DW</i> =1.50. |

Dead Load

TxDOT considers Service level Dead Load only with a limit reinforcement stress of 22 ksi to minimize cracking. (BDM-LRFD, Chapter 4, Section 5, Design Criteria)

4.5.4.1.4 Cap 18 Output

| | Max +M | <u>Max -M</u> |
|----------------|--|---|
| Dead Load: | $M_{posDL} = 582.2 \text{ kip} \cdot \text{ft}$ | $M_{negDL} = -844.9 \text{ kip} \cdot \text{ft}$ |
| Service Load: | $M_{posServ} = 1067.0 \text{ kip} \cdot \text{ft}$ | $M_{negServ} = -1267.9 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{posUlt} = 1585.8 \text{ kip} \cdot \text{ft}$ | $M_{negUlt} = -1812.0 \text{ kip} \cdot \text{ft}$ |

4.5.4.2 Girder Reactions on Ledge





 $DLSpan1 = 50.17 \frac{kip}{girder}$

 $DLSpan2 = 104.07 \frac{kip}{girder}$

Dead Load

DLSpan1 = Rail1 + Slab1 + Girder1 Overlay1 = $5.04 \frac{\text{kip}}{\text{girder}}$

DLSpan2 = Rail2 + Slab2 + Girder2

 $0verlay2 = 10.45 \ \frac{kip}{girder}$

Live Load

Loads per Lane:



Use HL-93 Live Load. For maximum reaction at interior bents, "Design Truck" will always govern over "Design Tandem" for Spans greater than 26ft. For the maximum reaction, place the back (32 kips) axle over the support.

Figure 4.88 Live Load Model of 60 Degrees Skewed ITBC

for Girder Reactions on Ledge

LaneSpan1 = 0.64klf
$$\cdot \left(\frac{\text{Span1}}{2}\right)$$
LaneSpan1 = 17.28 $\frac{\text{kip}}{\text{lane}}$ LaneSpan2 = 0.64klf $\cdot \left(\frac{\text{Span2}}{2}\right)$ LaneSpan2 = 35.84 $\frac{\text{kip}}{\text{lane}}$
$$TruckSpan1 = 32kip + 32kip \cdot \left(\frac{Span1 - 14ft}{Span1}\right) + 8kip \cdot \left(\frac{Span1 - 28ft}{Span1}\right)$$
$$TruckSpan1 = 59.56 \frac{kip}{lane}$$
$$TruckSpan2 = 32kip + 32kip \cdot \left(\frac{Span2 - 14ft}{Span2}\right) + 8kip \cdot \left(\frac{Span2 - 28ft}{Span2}\right)$$
$$TruckSpan2 = 66.00 \frac{kip}{lane}$$

IM = 0.33

LLRxnSpan1 = LaneSpan1 + TruckSpan1
$$\cdot$$
 (1 + IM)
LLRxnSpan1 = 96.49 $\frac{\text{kip}}{\text{lane}}$

LLRxnSpan2 = LaneSpan2 + TruckSpan2 \cdot (1 + IM) LLRxnSpan2 = 123.62 $\frac{\text{kip}}{\text{girder}}$

 $gV_{Span1_Int} = 0.999$ $gV_{Span1_Ext} = 0.999$ $gV_{Span2_Int} = 1.045$ $gV_{Span2_Ext} = 1.045$

Combine "Design Truck" and "Design Lane" loadings (AASHTO LRFD 3.6.1.3).

Dynamic load allowance, IM, does not apply to "Design Lane." (AASHTO LRFD 3.6.1.2.4).

The Live Load Reactions are assumed to be the Shear Live Load Distribution Factor multiplied by the Live Load Reaction per Lane. The Shear Live Load Distribution Factor is calculated using the "LRFD Live Load Distribution Factors" Spreadsheet found in the Appendices.

The Exterior Girders must have a Live Load Distribution Factor equal to or greater than the Interior Girders. This is to accommodate a possible future bridge widening. Widening the bridge would cause the exterior girders to become interior girders

| $LLSpan1Int = gV_{Span1_Int} \cdot LLRxnSpan1$ | LLSpan1Int = $96.40 \frac{\text{kip}}{\text{girder}}$ |
|---|--|
| $LLSpan1Ext = gV_{Span1_Ext} \cdot LLRxnSpan1$ | LLSpan1Ext = $96.40 \frac{\text{kip}}{\text{girder}}$ |
| $LLSpan2Int = gV_{Span2_Int} \cdot LLRxnSpan2$ | LLSpan2Int = $129.18 \frac{\text{kip}}{\text{girder}}$ |
| $LLSpan2Ext = gV_{Span2_Ext} \cdot LLRxnSpan2$ | LLSpan2Ext = $129.18 \frac{\text{kip}}{\text{girder}}$ |
| <u>Span 1</u> | |

Interior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1) $V_{s_Span1Int} = DLSpan1 + Overlay1 + LLSpan1Int$ $V_{s_Span1Int} = 152 \text{ kip}$ Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1) $V_{u_Span1Int} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1 + 1.75 \cdot LLSpan1Int$ $V_{u_Span1Int} = 239 \text{ kip}$ Exterior Girder Service Load (Service I Limit State, AASHTO LRFD 3.4.1) $V_{s_Span1Ext} = DLSpan1 + Overlay1 + LLSpan1Ext$ $V_{s_Span1Ext} = 152 \text{ kip}$ Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1) $V_{u_Span1Ext} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1 + 1.75 \cdot LLSpan1Ext$ $V_{u_Span1Ext} = 239 \text{ kip}$

<u>Span 2</u>

Interior Girder

Service Load (Service I Limit State, AASHTO LRFD 3.4.1) $V_{s_Span2Int} = DLSpan2 + Overlay2 + LLSpan2Int$ $V_{s_Span2Int} = 244 \text{ kip}$ Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1) $V_{u_Span2Int} = 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot LLSpan2Int$ $V_{u_Span2Int} = 372 \text{ kip}$ Exterior Girder Service Load (Service I Limit State, AASHTO LRFD 3.4.1) $V_{s_Span2Ext} = DLSpan2 + Overlay2 + LLSpan2Ext$

 $V_{s \text{ Span}2\text{Ext}} = 244 \text{ kip}$

Factored Load (Strength I Limit State, AASHTO LRFD 3.4.1)

 $V_{u \text{ Span2Ext}} = 1.25 \cdot \text{DLSpan2} + 1.5 \cdot \text{Overlay2} + 1.75 \cdot \text{LLSpan2Ext}$

 $V_{u_{Span2Ext}} = 372 \text{ kip}$

4.5.4.3 Torsional Loads



To maximize the torsion, the live load only acts on the longer span.

Figure 4.89 Live Load Model of 60 Degrees Skewed ITBC for Torsional Loads



Figure 4.90 Loads on the Ledge of 60 Degrees Skewed ITBC for Torsion

 $a_v = 12$ in

" a_v " is the value for the distance from the face of the stem to the center of bearing for the girders. 12" is the typical values for TxGirders on ITBC (IGEB). The lever arm is the distance from the center line of bearing to the centerline of the cap.

 $b_{stem} = 42$ in

LeverArm = $a_v + \frac{1}{2}b_{stem}$

LeverArm = 33 in

Interior Girders

Girder Reactions

 $R_{u_Span1} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$

 $R_{u \text{ Span1}} = 70 \text{ kip}$

$$\begin{split} R_{u_Span2} &= 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot gV_{Span2_Int} \\ &\cdot [LaneSpan2 + TruckSapn2 \cdot (1 + IM)] \end{split}$$

 $R_{u_{Span2}} = 372 \text{ kip}$

Torsional Load

$$T_{u_{Int}} = |R_{u_{Span1}} - R_{u_{Span2}}| \cdot \text{LeverArm}$$

 $T_{u_Int} = 830 \; kip \cdot ft$

Exterior Girders

Girder Reactions

$$R_{u \text{ Span1}} = 1.25 \cdot DLSpan1 + 1.5 \cdot Overlay1$$

$$\begin{split} R_{u_Span2} &= 1.25 \cdot DLSpan2 + 1.5 \cdot Overlay2 + 1.75 \cdot gV_{Span2_Ext} \\ &\cdot [LaneSpan2 + TruckSapn2 \cdot (1 + IM)] \end{split}$$

$$R_{u_{Span2}} = 372 \text{ kip}$$

Torsional Load

$$T_{u_Ext} = |R_{u_Span1} - R_{u_Span2}| \cdot LeverArm$$

$$T_{u Ext} = 830 \text{ kip} \cdot \text{ft}$$

Torsion on Cap



Figure 4.91 Elevation View of 60 Degrees Skewed ITBC with Torsion Loads



Figure 4.92 Torsion Diagram of 60 Degrees Skewed ITBC

Analyzed assuming Bents are torsionally rigid at Effective Face of Columns.

 $T_u = 830 \; kip \cdot ft$

Maximum Torsion on Cap

4.5.4.4 Load Summary

Ledge Loads

Interior Girder

Service Load

$$V_{s_{Int}} = max(V_{s_{Span1Int}}, V_{s_{Span2Int}})$$
 $V_{s_{Int}} = 243.7 \text{ kip}$

Factored Load

$$V_{u_{Int}} = max(V_{u_{Span1Int}}, V_{u_{Span2Int}}) \qquad V_{u_{Int}} = 371.8 \text{ kip}$$

Exterior Girder

Service Load

$$V_{s_Ext} = max(V_{s_Span1Ext}, V_{s_Span2Ext}) \qquad V_{s_Ext} = 243.7 \text{ kip}$$

Factored Load
$$V_{u_Ext} = max(V_{u_Span1Ext}, V_{u_Span2Ext}) \qquad V_{u_Ext} = 371.8 \text{ kip}$$

Cap Loads

Positive Moment (From CAP18)

| Dead Load: | $M_{posDL} = 582.2 \text{ kip} \cdot \text{ft}$ |
|----------------|---|
| Service Load: | $M_{posServ} = 1067.0 \; kip \cdot ft$ |
| Factored Load: | $M_{posUlt} = 1585.8 \text{ kip} \cdot \text{ft}$ |

Negative Moment (From CAP18)

| Dead Load: | $M_{negDL} = -844.9 \text{ kip} \cdot \text{ft}$ |
|----------------|---|
| Service Load: | $M_{negServ} = -1267.9 \text{ kip} \cdot \text{ft}$ |
| Factored Load: | $M_{negUlt} = -1812.0 \text{ kip} \cdot \text{ft}$ |

Maximum Torsion and Concurrent Shear and Moment (Strength I)

| | (| 0) | |
|---|---|-----|---|
| $T_u = 830 \text{ kip} \cdot \text{ft}$ | | | Located two stations away from centerline of column |
| $V_u = 481.8 	ext{ kip}$ | | | V. and M. values are from |
| $M_u = 769.1 \text{ kip} \cdot \text{ft}$ | | | CAP18 |

4.5.5 Locate and Describe Reinforcing



Figure 4.93 Section View of 60 Degrees Skewed ITBC

Recall:

$$b_{stem} = 42 \text{ in}$$

$$d_{stem} = 57 \text{ in}$$

$$b_{ledge} = 25 \text{ in}$$

$$d_{ledge} = 28 \text{ in}$$

$$b_{f} = 92 \text{ in}$$

$$h_{cap} = 85 \text{ in}$$

cover = 2.5 in

4.5.5.1 Describe Reinforcing Bars

| Use # 11 bars for Bar A | | |
|----------------------------------|------------------------|--|
| $A_{bar_A} = 1.56 \text{ in}^2$ | $d_{bar_A} = 1.410$ in | |
| Use # 11 bars for Bar B | | |
| $A_{bar_B} = 1.56 \text{ in}^2$ | $d_{bar_B} = 1.410$ in | |
| Use # 7 bars for Bar M | | In the calculation of b _{ledge} , #7 |
| $A_{bar_M} = 0.60 \text{ in}^2$ | $d_{bar_M} = 0.875 in$ | Bar M was considered. Bar M |
| Use # 7 bars for Bar N | | must be # 7 or smaller to allow it fullv develon. |
| $A_{bar_N} = 0.60 \text{ in}^2$ | $d_{bar_N}=0.875~in$ | To prevent confusion, use the |
| Use # 6 bars for Bar S | | same bar size for Bar N as Bar |
| $A_{bar_S} = 0.44 \text{ in}^2$ | $d_{bar_S} = 0.75$ in | М. |
| Use # 6 bars for Bar T | | |
| $A_{bar_T} = 0.44 \text{ in}^2$ | $d_{bar_T} = 0.75$ in | |

4.5.5.2 <u>Calculate Dimensions</u>

| $d_{s_neg} = h_{cap} - cover - \frac{1}{2}d_{bar_s} - \frac{1}{2}d_{bar_A}$ | $d_{s_neg} = 81.42$ in |
|--|----------------------------|
| $d_{s_pos} = h_{cap} - cover - \frac{1}{2}max(d_{ba_s}, d_{bar_M}) - \frac{1}{2}d_{bar_B}$ | $d_{s_pos} = 81.36$ in |
| $a_v = 12$ in | |
| $a_f = a_v + cover$ | $a_{\rm f}=14.50$ in |
| $d_e = d_{ledge} - cover$ | $d_{e} = 25.50 \text{ in}$ |
| $d_{f} = d_{ledge} - cover - \frac{1}{2}d_{bar_{-}M} - \frac{1}{2}d_{bar_{-}B}$ | $d_{\mathrm{f}}=24.36$ in |
| $h = d_{ledge} + BrgSeat$ | h = 29.50 in |



Figure 4.94 Plan View of 60 Degrees Skewed ITBC

$$\alpha = 30 \text{ deg}$$

Recall:

L = 15 in

W = 15 in

4.5.6 Check Bearing

The load on the bearing pad propagates along a truncated pyramid whose top has the area A_1 and whose base has the area A_2 . A_1 is the loaded area (the bearing pad area: LxW). A_2 is the area of the lowest rectangle contained wholly within the support (the Inverted Tee Cap). A_2 must not overlap the truncated pyramid of another load in either direction, nor can it extend beyond the edges of the cap in any direction.



horizontal)

Angle of Bars S (Angle from the

Dimension of Bearing Pad (15"

Dia. Circular Bearing Pad)

Plan View

"B" is the distance from perimeter of A_1 to the perimeter of A_2 as seen

Figure 4.95 Bearing Check for 60 Degrees Skew Angle

in the above figure

Elevation View

Resistance Factor (
$$\phi$$
) = 0.7(AASHTO LRFD 5.5.4.2) $A_1 = \frac{\pi}{4} d_1^2$ $d_1 = 15in, A_1 = 176.71 in^2$ Area under Bearing Pade

Interior Girders

$$B = \min\left[\left(b_{\text{ledge}} - a_{\text{v}}\right) - \frac{1}{2}L, \left(a_{\text{v}} + \frac{1}{2}b_{\text{stem}}\right) - \frac{1}{2}L, 2d_{\text{ledge}}, \frac{1}{2}S - \frac{1}{2}W\right]$$

B = 5.5 in.

Diameter of truncated area, $d_2 = d_1 + 2 \cdot B$ Base of the truncated pyramid, $A_2 = \frac{\pi}{4} d_2^2$ $A_2 = 530.93 in^2$

Modification factor

$$m = min\left(\sqrt{\frac{A_2}{A_1}}, 2\right) = 1.73 \text{ and } 2 \quad m = 1.73$$

$$\phi V_n = \phi \quad 0.85 \quad f_c \quad A_1 \quad m \qquad \phi V_n = 909.48 \text{ kips} \qquad AASHTO \ LRFD \ Eqs. 5.6.5-1 \\ and 5.6.5-2. \\ V_{u_Int} = 371.8 < \phi V_n \qquad BearingChk = "OK!" \qquad V_{u_int} \ from "4.5.4.4 \ Load \\ Summary".$$

Exterior Girders

$$B = \min\left[\left(b_{\text{ledge}} - a_{v}\right) - \frac{1}{2}L, \left(a_{v} + \frac{1}{2}b_{\text{stem}}\right) - \frac{1}{2}L, 2d_{\text{ledge}}, \frac{1}{2}S - \frac{1}{2}W, c - \frac{1}{2}W\right]$$

 $B=5.5 \text{ in.} \qquad \begin{array}{l} "B" \text{ is the distance from} \\ perimeter of A_1 \text{ to the} \\ perimeter of A_2 \text{ as seen} \\ \text{ in the above figure} \end{array}$

 $d_2 = 26$ in $A_2 = 530.93 in^2$

Diameter of truncated area, $d_2 = d_1 + 2 \cdot B$ Base of the truncated pyramid, $A_2 = \frac{\pi}{4} d_2^2$

Modification factor

$$m = min\left(\sqrt{\frac{A_2}{A_1}}, 2\right) = 1.73 \text{ and } 2 \quad m = 1.73$$
 AASHTO LRFD Eq. 5.6.5-3

| $\varphi V_n = \varphi \ 0.85 \ f_c \ A_1 \ m$ | $\phi V_n = 909.48 \text{ kips}$ | AASHTO LRFD Eqs. 5.6.5-1 and 5.6.5-2: |
|--|----------------------------------|--|
| $V_{u_ext} = 371.8 \text{ kips} < \Phi V_n$ | BearingChk= "OK!" | V _{u_ext} from "4.5.4.4 Load Summary". |

4.5.7 Check Punching Shear



AASHTO LRFD **5.8.4.3.4**, the truncated pyramids assumed as failure surfaces for punching shear shall not overlap.

Figure 4.96 Punching Shear Check for 60 Degrees Skew Angle

Resistance Factor (ϕ) = 0.90

Determine if the Shear Cones Intersect

Is
$$\frac{1}{2}S - \frac{1}{2}W \ge d_f$$
?
 $\frac{1}{2}S - \frac{1}{2}W = 40.5$ in
 $d_f = 24.36$ in

$$\operatorname{Is} \frac{1}{2} \mathbf{b}_{\text{stem}} + \mathbf{a}_{\text{v}} - \frac{1}{2} \mathbf{L} \ge \mathbf{d}_{\text{f}}?$$

$$\frac{1}{2}b_{stem} + a_v - \frac{1}{2}L = 25.5$$
 in
d_f = 24.36 in

Interior Girders

| $V_n = 0.125 \boxtimes \lambda \sqrt{f_c'} \ b_o \ d_f$ | $V_n = 581.39 \text{ kips}$ | AASHTO LRFD 5.8.4.3.4-3 |
|---|-----------------------------|---|
| $b_o = \frac{\pi}{2} * \left(D + d_f \right) + D$ | $b_o = 76.82 in$ | AASHTO LRFD 5.8.4.3.4-4 |
| $\phi V_n = 523.25 \text{ kips}$ | | |
| $V_{u_Int} = 371.25 \text{ kips} < \varphi V_n$ | PunchingShearChk= "OK!" | V _{u_int} from "4.5.4.4 Load Summary". |

Yes. Therefore, shear cones do not intersect in the longitudinal direction of the cap.

AASHTO LRFD 5.5.4.2.

TxDOT uses "df" instead of "de" for Punching Shear (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria). This is because "df" has traditionally been used for inverted tee bents and was sed in the Inverted Tee Research (Furiong % Mirza pg. 58).

Yes. Therefore, shear cones do not intersect in the transverse direction of the cap.

Exterior Girders

$$\begin{split} V_{n} &= \min[0.125 \cdot \sqrt{f_{c}} & V_{n} &= 424.96 \text{ kips} & AASHTO LRFD \\ & \cdot \left(\frac{\pi}{4} \cdot (D+d_{f}) + \frac{D}{2} + c\right) & 5.8.4.3.4-3 \text{ and} \\ & \cdot \left(\frac{\pi}{4} \cdot (D+d_{f}) + \frac{D}{2} + c\right) & 5.8.4.3.4-5 \\ & \cdot d_{f}, 0.125 \cdot \sqrt{f_{c}} \cdot \frac{\pi}{2} \cdot (D+d_{f}) \\ & + D \end{bmatrix} \\ \varphi V_{n} &= 382.46 \text{ kips} \\ V_{u_ext} &= 371.8 \text{ kips} < \varphi V_{n} & PunchingShearChk="OK!" V_{u_ext} from "4.5.4.4 \\ Load Summary". \end{split}$$

4.5.8 Check Shear Friction

Resistance Factor (
$$\phi$$
) =0.90 AASHTO LRFD 5.5.4.2

Determine the Distribution Width

| $\frac{\text{Interior Girders}}{b_{s_{\text{Int}}} = \min(W + 4a_{v}, S)}$ | "S" is the girder spacing. |
|--|-------------------------------|
| = min (63 in, 96 in) | |
| $b_{s_{Int}} = 63 \text{ in}$ | |
| $A_{cv} = b_{s_{Int}} \cdot d_{e}$ | $A_{cv} = 1606.5 in^2$ |
| $\frac{\text{Exterior Girders}}{b_{s_{\text{Ext}}}} = \min(W + 4a_v, S, 2c)$ | "S" is the girder spacing. |
| = min [69, 96, 48] | |
| = 48 in | |
| $A_{cv} = b_{s_ext} \cdot d_e$ | $A_{cv} = 1224 \text{ in } 2$ |

Interior Girders

| $V_n = \min(0.2 \cdot f_c \cdot A_{cv}, 0.8 \cdot A_{cv})$ | $V_n = 1285.2 \text{ kips}$ | AASHTO LRFD 5.8.4.2.2-1 and |
|--|-----------------------------|---|
| = min (1606.5, 1285.2) | | 5.8.4.2.2-2 |
| $\phi V_n = 1156.68 \text{ kips}$ | | |
| $V_{u_Int} = 371.68 \text{ kips} < \varphi V_n$ | ShearFrictionChk= "OK!" | V _{u_int} from "4.5.4.4 Load Summary" |

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Exterior Girders

 $V_{n} = \min(0.2 \cdot f_{c} \cdot A_{cv}, 0.8 \cdot A_{cv}) \qquad V_{n} = 979.2 \text{ kips} \qquad AASHTO LRFD 5.8.4.2.2-1 and 5.8.4.2.2-2 \\ \varphi V_{n} = 881 \text{ kips} \qquad V_{u_{ext}} = 371.81 \text{ kips} < \varphi V_{n} \qquad ShearFrictionChk="OK!" \qquad V_{u_{ext}} from "4.5.4.4 Load Summary".$

4.5.9 Flexural Reinforcement for Negative Bending (Bars A)

| $M_{dl} = M_{negDL} $ | $M_{dl} = 844.9 \text{ kip} \cdot \text{ft}$ |
|------------------------|--|
| $M_s = M_{negServ} $ | $M_s = 1267.9 \text{ kip} \cdot \text{ft}$ |
| $M_{u} = M_{negUlt} $ | $M_u = 1812.0 \; \text{kip} \cdot \text{ft}$ |

4.5.9.1 Minimum Flexural Reinforcement

Factored Flexural Resistance, M_r , must be greater than or equal to the lesser of $1.2M_{cr}$ (Cracking Moment) or $1.33M_u$ (Ultimate Moment).

| | Gross Moment of Inertia |
|---|--|
| | Depth of Cap |
| | Distance to the Center of Gravity of the Cap from the bottom of the Cap |
| $f_{\rm r} = 0.537 \rm ksi$ | Modulus of Rupture (BDM- LRFD, Ch. 4, Sect. 5, Design Criteria) |
| $y_t = 50.50 \text{ in}$ | <i>Distance from Center of Gravity</i> <i>to extreme tension fiber</i> |
| $S = 6.06 \times 10^4 \text{ in}^3$ | Section Modulus for the extreme tension fiber |
| $M_{cr} = 2711.8 \text{ kip} \cdot \text{ft}$ | Cracking Moment (AASHTO LRFD Eq. 5.6.3.3-1) |
| | Design the lesser of $1.2M_{cr}$ or |
| | $1.33M_u$ when determining |
| | mininum area of steel required. |
| | $f_r = 0.537 \text{ ksi}$ $y_t = 50.50 \text{ in}$ $S = 6.06 \times 10^4 \text{ in}^3$ $M_{cr} = 2711.8 \text{ kip} \cdot \text{ft}$ |

Thus, M_r must be greater than $M_f = 2410 \ \text{kip} \cdot \text{ft}$

4.5.9.2 Moment Capacity Design

Try, 7 ~ #11's Top Number of bars in tension BarANo = 7Diameter of main reinforcing $d_{bar A} = 1.410$ in bars $A_{\text{bar A}} = 1.56 \text{ in}^2$ Area of main reinforcing bars $A_s = 10.92 \text{ in}^2$ Area of steel in tension $A_s = BarANo \cdot A_{bar A}$ Diameter of shear reinforcing $d_{stirrup} = 0.75$ in $d_{stirrup} = d_{bar S}$ bars $d = d_{s neg}$ d = 81.42 in $b = b_f$ b = 92 in Compressive Strength of Concrete $f_c = 5.0 \text{ ksi}$ Yield Strength of Rebar $f_v = 60 \text{ ksi}$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.85 - 0.05(f_c - 4ksi)$ Bounded by: $0.65 \le \beta_1 \le 0.85$ $\beta_1 = 0.80$ Depth of Cross Section under $c = \frac{A_s f_y}{0.85 \ _c \beta_1 b}$ c = 2.09 in Compression under Ultimate Load This "c" is the distance from the extreme compression fiber to the (AASHTO LRFD Eq. 5.6.3.1.2-4)

neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.

$$a = c \cdot \beta_1$$
 $a = 1.67$ in

Note: "a" is less than "d_{ledge}". Therefore the equivalent stress block acts over a rectangular area. If "a" was greater than "dledge", it would act over a Tee shaped area.

$$\begin{split} M_n &= A_s f_y \left(d - \frac{a}{2} \right) \cdot \frac{1 f t}{12 i n} & M_n &= 4400 \text{ kip} \cdot f t \\ \epsilon_s &= 0.003 \cdot \frac{d - c}{c} & \epsilon_s &= 0.114 \end{split}$$

 $\epsilon_{s} > 0.005$

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FlexureBehavior = "Tension Controlled"

$$\begin{split} \Phi_{M} &= 0.90 \\ M_{r} &= \Phi_{M}M_{n} \\ M_{f} &= 2410 \text{ kip} \cdot \text{ft} < M_{r} \\ M_{u} &= 1812 \text{ kip} \cdot \text{ft} < M_{r} \\ \end{split} \qquad \begin{aligned} \text{MinReinfChk} &= \text{``OK!''} \\ \text{UltimateMom} &= \text{``OK!''} \end{aligned}$$

Depth of Equivalent Stress Block (AASHTO LRFD 5.6.2.2)

Nominal Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.2-1)

Strain in Reinforcing at Ultimate

(AASHTO LRFD 5.6.2.1)

(AASHTO LRFD 5.5.4.2)

Factored Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.1-1)

4.5.9.3 Check Serviceability

To find s_{max}:

Modular Ratio:

$$n = \frac{E_s}{E_c} \qquad \qquad n = 7.12$$

Tension Reinforcement Ratio:

$$\begin{split} \rho &= \frac{A_{s}}{b \cdot d} & \rho = 0.0014 \\ k &= \sqrt{(2\rho n) + (\rho n)^{2}} - (\rho n) & k = 0.134 \\ d \cdot k &= 10.91 \text{ in } < d_{ledge} = 28 \text{ in} \end{split}$$

Therefore, the compression force acts over a rectangular

$$j = 1 - \frac{k}{3}$$
 $j = 0.955$

$$\begin{split} f_{ss} &= \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12 \text{in}}{1 \text{ ft}} & f_{ss} &= 17.92 \text{ ksi} \\ f_a &= 0.6 f_y & f_a &= 36.00 \text{ ksi} \\ f_{ss} &< f_a & \text{ServiceStress} = ``OK!`` \\ d_c &= \text{cover} + \frac{1}{2} d_{\text{stirrup}} + \frac{1}{2} d_{\text{bar}_A} & d_c &= 3.58 \text{ in} \end{split}$$

Exposure Condition Factor:

$$\begin{split} \gamma_{e} &= 1.00 \\ \beta_{s} &= 1 + \frac{d_{c}}{0.7(h_{cap} - d_{c})} \\ s_{max} &= \min\left(\frac{700\gamma_{e}}{\beta_{s}f_{ss}} - 2d_{c}, 12in.\right) \\ s_{Actual} &= \frac{b_{stem} - 2d_{c}}{BarANo-} \\ s_{actual} &< s_{max} \\ \end{split}$$

4.5.9.4 Check Dead Load

Check allowable M_{dl} : $f_{dl} = 22 \text{ ksi}$

$$M_{a} = A_{s} \cdot d \cdot j \cdot f_{dl} \cdot \frac{1 \text{ft}}{12 \text{in}} \qquad M_{a} = 1556.7 \text{ kip} \cdot \text{ft}$$
$$M_{dl} = 844.9 \text{ kip} \cdot \text{ft} < M_{a} \qquad \text{DeadLoadMom} = \text{``OK!''}$$

For service loads, the stress on the cross-section is located as shown in Figure 4.97.



Figure 4.97 Stresses on the Cross Section for Service Loads of 60 Degrees Skewed ITBC

> If the compression force does not act over rectangular area, j will be different.

Service Load Bending Stress in outer layer of the reinforcing.

Allowable Bending Stress (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

For Class 1 Exposure Conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e = 0.75$). (BDM-LRFD Ch. 4, Sect. 5, Design Criteria) (AASHTO LRFD Eq. 5.6.7-1)

A good practice is to place a bar every 12 in along each surface of the bent. (TxSP)

ck = "OK

TxDOT limits dead load stress to 22 ksi, which is set to limit observed cracking under dead load.

Allowable Dead Load Moment

4.5.10 Flexural Reinforcement for Positive Bending (Bars B)

| $M_{dl} = M_{posDL}$ | $M_{dl} = 582.2 \text{ kip} \cdot \text{ft}$ |
|----------------------|--|
| $M_s = M_{posServ}$ | $M_s = 1067.0 \text{ kip} \cdot \text{ft}$ |
| $M_u = M_{posUlt}$ | $M_u = 1585.8 \: \text{kip} \cdot \text{ft}$ |

4.5.10.1 Minimum Flexural Reinforcement

Factored Flexural Resistance, M_r , must be greater than or equal to the lesser of $1.2M_{cr}$ (Cracking Moment) or $1.33M_u$ (Ultimate Moment).

| $I_g = 3.06 \times 10^6 \text{ in}^4$ | | Gross Moment of Inertia |
|--|---|---|
| $y_t = ybar$ | y _t = 34.5 in | Distance to the Center of Gravity of the Cap from the top of the Cap |
| $f_r = 0.24 \sqrt{f_c}$ | $f_r = 0.537$ ksi | Modulus of Rupture (BDM- LRFD, Ch. 4, Sect. 5, Design Criteria) |
| $S = \frac{I_g}{y_t}$ | $S = 8.87 \times 10^4 \text{ in}^3$ | Section Modulus for the extreme tension fiber |
| $M_{cr} = S \cdot f_r \cdot \frac{1ft}{12in}$ | $M_{cr} = 3969.3 \text{ kip} \cdot \text{ft}$ | Cracking Moment (AASHTO LRFD Eq. 5.6.3.3-1) |
| M _f = minimum of: | | Design the lesser of $1.2M_{cr}$ or |
| $1.2M_{cr} = 4763.2 \text{ kip} \cdot \text{ft}$ | | $1.33M_u$ when determining |
| $1.33M_u = 2109.1 \text{ kip} \cdot \text{ft}$ | | mininum area of steel required. |

Thus, M_r must be greater than $M_f = 2109.1 \ \text{kip} \cdot \text{ft}$

4.5.10.2 Moment Capacity Design

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Try, $11 \sim #11$'s Bottom Number of bars in tension BarBNo = 11Diameter of main reinforcing $d_{\text{bar B}} = 1.41$ in bars $A_{\text{bar B}} = 1.56 \text{ in}^2$ Area of main reinforcing bars Area of steel in tension $A_s = BarBNo \cdot A_{bar B}$ $A_s = 17.16 \text{ in}^2$ d = 81.36 in $d = d_{s pos}$ $b = b_{stem}$ b = 42 inCompressive Strength of Concrete $f_{c} = 5.0 \text{ ksi}$ Yield Strength of Rebar $f_v = 60 \text{ ksi}$ (AASHTO LRFD 5.6.2.2) $\beta_1 = 0.85 - 0.05(f_c - 4ksi)$ Bounded by: $0.65 \le \beta_1 \le 0.85$ $\beta_1 = 0.80$ Depth of Cross Section under $c = \frac{A_s f_y}{0.85\ _c\beta_1 b}$ c = 7.21 in Compression under Ultimate Load

This "c" is the distance from the extreme compression fiber to the neutral axis, not the distance from the center of bearing of the last girder to the end of the cap.

$$= \mathbf{c} \cdot \boldsymbol{\beta}_1$$
 $\mathbf{a} = 5.77$ in

Note: "a" is less than "dstem". Therefore the equivalent stress block acts over a rectangular area. If "a" was greater than "dstem", it would act over a Tee shaped area. 4 6

$$\begin{split} M_n &= A_s f_y \left(d - \frac{a}{2} \right) \cdot \frac{1 \pi t}{12 \text{ in}} & M_n &= 6733.2 \text{ kip} \cdot \text{ft} & \text{Nominal Flexure} \\ \epsilon_s &= 0.003 \cdot \frac{d - c}{c} & \epsilon_s &= 0.031 & \text{Strain in Reinfor} \\ \epsilon_s &> 0.005 & \text{FlexureBehavior} = "Tension Controlled"} & (AASHTO LRFL) \\ \Phi_M &= 0.90 & (AASHTO LRFL) \\ \end{split}$$

$$M_r = \Phi_M \cdot M_n \qquad \qquad M_r = 6059.9 \text{ kip} \cdot \text{ft}$$

 $M_{f} = 2109.1 \text{ kip} \cdot \text{ft} < M_{r}$ MinReinfChk = "OK!" $M_u = 1585.8 \text{ kip} \cdot \text{ft} < M_r$ UltimateMom = "OK!" 1 [1] al Resistance D Eq. 5.6.3.2.2-1)

(AASHTO LRFD Eq. 5.6.3.1.2-4)

Depth of Equivalent Stress Block

(AASHTO LRFD 5.6.2.2)

rcing at Ultimate

D 5.6.2.1)

D 5.5.4.2)

Factored Flexural Resistance (AASHTO LRFD Eq. 5.6.3.2.1-1) 4.5.10.3 Check Serviceability

To find s_{max}:

Modular Ratio:

$$n = \frac{E_s}{E_c} \qquad \qquad n = 7.12$$

Tension Reinforcement Ratio:

$$\rho = \frac{A_s}{b \cdot d} \qquad \rho = 0.005$$

$$\sqrt{(2on) + (on)^2} = (on) \qquad k = 0.234$$

$$k = \sqrt{(2\rho n) + (\rho n)^2 - (\rho n)}$$
 $k = 0.23$

 $d \cdot k = 19.04$ in $< d_{stem} = 57.00$ in Therefore, the compression force acts over a rectangular area.

$$j = 1 - \frac{k}{3}$$
 $j = 0.922$

$$f_{ss} = \frac{M_s}{A_s \cdot j \cdot d} \cdot \frac{12in}{1ft}$$

$$f_{ss} = 9.95 \text{ ksi}$$

$$f_a = 0.6f_y$$

$$f_a = 36.00 \text{ ksi}$$

$$f_{ss} < f_a$$

$$grviceStress = "OK!"$$

$$d_c = cover + \frac{1}{2}d_{stirrup} + \frac{1}{2}d_{har B}$$

$$d_c = 3.64 \text{ in}$$

$$\begin{split} \gamma_e &= 1.00 \\ \beta_s &= 1 + \frac{d_c}{0.7(h_{cap} - d_c)} \end{split} \qquad \qquad \beta_s = 1.06 \end{split}$$

$$s_{max} = \min\left(\frac{_{700\gamma_e}}{_{\beta_s f_{ss}}} - 2d_c, 12in.\right) \qquad s_{max} = 12 \text{ in}$$

Bars Inside Stirrup Bar S

Try: BarBInsideSNo = 5 $\frac{2(2)}{2} \left(\frac{1}{2} + \frac{1}{2$

$$s_{Actual} = \frac{b_{stem} - 2\left(cover + \frac{1}{2}d_{bar_S} + \frac{1}{2}d_{bar_B}\right)}{BarBInsideSNo-}$$

 $s_{actual} < s_{max}$

For service loads, the stress on the cross-section is located as shown in Figure 4.98.



Figure 4.98 Stresses on the Cross Section for Bars B for Service Loads of 60 Degrees Skewed ITBC

If the compression force does not act over rectangular area, j will be different.

Service Load Bending Stress in outer layer of the reinforcing.

Allowable Bending Stress (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

For Class 1 Exposure Conditions. For areas where deicing chenicals are frequently used, design for Class 2 Exposure ($\gamma_e = 0.75$). (BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

(AASHTO LRFD Eq. 5.6.7-1)

A good practice is to place a bar every 12 in along each surface of the bent. (TxSP)

Number of Bars B that are inside Stirrup Bar S.

 $s_{Actual} = 8.71$ in

ServiceabilityCheck = "OK

Bars Outside Stirrup Bar S

BarBOutsideSNo = 11 - BarBInsideSNoNumber of Bars B that are inside
Stirrup Bar S.BarBOutsideSNo = 6 $s_{Actual} = \frac{2b_{ledge} + 2(cover \frac{1}{2}d_{bar_S} + \frac{1}{2}d_{bar_B} - cove \frac{1}{2}d_{bar_M} - \frac{1}{2}d_{bar_B})}{BarBOutsideSNo}$ $s_{Actual} = \frac{2b_{ledge} + 2(cover \frac{1}{2}d_{bar_S} + \frac{1}{2}d_{bar_B} - cove \frac{1}{2}d_{bar_M} - \frac{1}{2}d_{bar_B})}{BarBOutsideSNo}$ $s_{actual} = 8.31 \text{ in } < s_{max}$ ServiceabilityCheck = "OK

4.5.10.4 Check Dead Load

Check allowable M_{dl} : $f_{dl} = 22 \text{ ksi}$

TxDOT limits dead load stress to 22 ksi. This is due to observed cracking under dead load.

$$\begin{split} M_{a} &= A_{s} \cdot d \cdot j \cdot f_{dl} \cdot \frac{1 f t}{12 i n} & M_{a} &= 2360 \text{ kip} \cdot f t \\ M_{dl} &= 582.2 \text{ kip} \cdot f t < M_{a} & \text{DeadLoadMom} = "OK!" \end{split}$$

Allowable Dead Load Moment

Flexural Steel Summary:

Use 7 ~ # 11 Bars on Top & 11 ~ # 11 Bars on Bottom

4.5.11 Ledge Reinforcement (Bars M & N)

Try Bars M and Bars N at a 5.80" spacing.

 $s_{bar_M} = 5.80$ in $s_{bar_N} = 5.80$ in Use trial and error to determine the spacing needed for the ledge reinforcing.

It is typical for Bars M & N to be paired together

4.5.11.1 Determine Distribution Widths

These distribution widths will be used on the following pages to determine the required ledge reinforcement per foot of cap.

Distribution Width for Shear (AASHTO LRFD 5.8.4.3.2)Note: These are the same
distribution widths used for the
Shear Friction check. $b_{s_Int} = min(W + 4a_v, S)$
 $b_{s_Int} = 63.00 in$ "S" is the girder spacing.Exterior Girders
 $b_{s_Ext} = min(W + 4a_v, 2c, S)$
 $b_{s_Ext} = 48.00 in$ "c" is the distance from the center
of bearing of the outside beam to
the end of the ledge.Distribution Width for Bending and Axial Loads (AASHTO LRFD 5.8.4.3.3)Distribution S.8.4.3.3)

Interior Girders

 $b_{m_{Int}} = min(W + 5a_f, S)$ $b_{m Int} = 87.50 in$

Exterior Girders

 $b_{m_Ext} = min(W + 5a_f, 2c, S)$ $b_{m_Ext} = 48.00 in$

4.5.11.2 Reinforcing Required for Shear Friction

| $\Phi = 0.90$ | |
|---------------|--|
|---------------|--|

| $\mu = 1.4$ | $c_1 = 0$ ksi | $P_{c}=0\;\mathrm{kip}$ |
|-------------|----------------------------|-------------------------|
| Recall: | $d_{e} = 25.50 \text{ in}$ | |

Minimum Reinforcing (AASHTO LRFD Eq. 5.7.4.2-1)

$$\begin{split} A_{vf_min} &= \frac{0.05 \text{ ksi} \cdot A_{cv}}{f_y} \\ A_{cv} &= d_e \cdot b_s \quad \text{and} \qquad a_{vf} = \frac{A_{vf}}{b_s} \end{split}$$

 $a_{vf_min} = \frac{0.05 k s i \cdot d_e}{f_v}$

AASHTO LRFD 5.7.4.1

"µ" is 1.4 for monolithically placed concrete. (AASHTO LRFD 5.7.4.4)

For clarity, the cohesion factor is labeled " c_1 ". This is to prevent confusion with "c", the distance from the last girder to the edge of the cap. c_1 is 0ksi for corbels and ledges. (AASHTO LRFD 5.7.4.4)

" P_c " is zero as there is no axial compression.

 $a_{vf_min} = 0.26 \frac{in^2}{ft}$ Minimum Reinforcing required for Shear Friction

- Interior Girders
 - $A_{cv} = 1606.5 \text{ in}^2$ $A_{cv} = d_e \cdot b_{s \text{ Int}}$ $V_{u \text{ Int}} = 371.8 \text{ kip}$ From "4.5.4.4 Load Summarv". $V_n = c_1 A_{cv} + \mu (A_{vf} f_v + P_c)$ (AASHTO LRFD Eq. 5.7.4.3-3) (AASHTO LRFD Eq. 5.7.4.3-1 & $\Phi V_n \ge V_n$ AASHTO LRFD Eq. 5.7.4.3-2) $\Phi \cdot \left[c_1 A_{cv} + \mu (A_{vf} f_v + P_c) \right] \ge V_{u}$ $A_{vf} = \frac{\frac{V_{u_Int}}{\Phi} - c_1 A_{cv}}{\frac{\mu}{f}} - P_c}{f}$ $A_{vf} = 4.92 \text{ in}^2$ Required Reinforcing for Shear Friction $a_{vf_{Int}} = 0.94 \frac{in^2}{ft}$ Required Reinforcing for Shear $a_{vf_{Int}} = \frac{A_{vf}}{b_{s_{Int}}}$ Friction per foot length of cap

Exterior Girders

$$\begin{aligned} A_{cv} = d_{e} \cdot b_{s,Ext} & A_{cv} = 1224 \text{ in}^{2} \\ V_{u,Ext} = 371.8 \text{ kip} & From ``4.5.4.4 \text{ Load Summary}''. \\ V_{n} = c_{1}A_{cv} + \mu(A_{vf}f_{y} + P_{c}) & (AASHTO LRFD Eq. 5.7.4.3-3) \\ \Phi V_{n} \geq V_{u} & (AASHTO LRFD Eq. 5.7.4.3-1) \& \\ A_{vf} \geq \frac{V_{u} \text{ Ext}}{\Phi} \cdot [c_{1}A_{cv} + \mu(A_{vf}f_{y} + P_{c})] \geq V_{u} & AASHTO LRFD Eq. 5.7.4.3-2) \\ A_{vf} = \frac{\frac{V_{u} \text{ Ext}}{\Phi} \cdot c_{1}A_{cv}}{\frac{\mu}{f_{y}}} & A_{vf} = 4.92 \text{ in}^{2} & Required Reinforcing for Shear} \\ Friction & a_{vf,Ext} = \frac{A_{vf}}{b_{s,Ext}} & a_{vf,Ext} = 1.23 \frac{\text{in}^{2}}{\text{ft}} & Required Reinforcing for Shear} \\ Friction per foot length of cap \\ \hline 4.5.11.3 & Reinforcing Required for Flexure & AASHTO LRFD 5.8.4.2.1 \\ \text{Recall: } h = 29.50 \text{ in} \quad d_{e} = 25.50 \text{ in} \quad a_{v} = 12 \text{ in} \\ Interior Girders & V_{u,Int} = 371.8 \text{ kip} & From ``4.5.4.4 \text{ Load Summary'}. \\ N_{uc,Int} = 0.2 \cdot V_{u,Int} & N_{uc,Int} = 74.4 \text{ kip} & (AASHTO LRFD 5.8.4.2.1) \\ M_{u,Int} = V_{u,Int} \cdot a_{v} + N_{uc,Int}(h - d_{e}) & M_{u,Int} = 397 \text{ kip} \cdot \text{ft} & (AASHTO LRFD Eq. 5.8.4.2.1-1) \\ Use the following equations to solve for A_{f}: \\ \Phi M_{n} \geq M_{u,Int} & (AASHTO LRFD Eq. 5.6.3.2.2-1) \\ c = \frac{A_{vfy}}{\alpha_{v}(\theta_{0}} \frac{a^{2}}{2}) & (AASHTO LRFD Eq. 5.6.3.1.2-4) \\ a_{t} = 0.85 \\ \hline \end{cases}$$

 $0.75 \le \Phi = 0.65 + 0.15 \left(\frac{d_e}{c} - 1\right) \le 0.90$ AASHTO LRFD 5.5.4.2

Solve for A_f : $A_f = 3.50 \text{ in}^2$ Required Reinforcing for Flexure $a_{f_Int} = \frac{A_f}{b_{m_Int}}$ $a_{f_Int} = 0.48 \frac{\text{in}^2}{\text{ft}}$ Required Reinforcing for Flexure
per foot length of cap

 $\beta_1 = 0.80$

 $a=c\beta_1$

Exterior Girders

| Vu | _{L_Ext} = 371.8 kip | | | From "4.5.4.4 Load Summary". |
|----------------|--|---|---------------|---|
| N | $uc_{Ext} = 0.2 \cdot V_{u_{Ext}}$ | $N_{uc_Ext} = 74.4 \text{ ki}$ | р | (AASHTO LRFD 5.8.4.2.1) |
| Μ | $u_{\text{Ext}} = V_{u_{\text{Ext}}} \cdot a_v + N_{uc_{\text{Ext}}}(h - d_e)$ |) $M_{u_{Ext}} = 397 \text{ kip}$ | • ft | (AASHTO LRFD Eq. 5.8.4.2.1-1) |
| U | se the following equations to solve for | or A _f : | | |
| | $\Phi M_n \ge M_{u_Ext}$ | | (AA) | SHTO LRFD Eq. 1.3.2.1-1) |
| | $M_n = A_f f_y \left(d_e - \frac{a}{2} \right)$ | | (AA) | SHTO LRFD Eq.5.6.3.2.2-1) |
| | $c = \frac{A_f f_y}{\alpha_1 f_c \beta_1 b_{m_Ext}}$ | | (AA) | SHTO LRFD Eq. 5.6.3.1.2-4) |
| | $\alpha_1 = 0.85$ $\beta_1 = 0.80$ | | (AA) | SHTO LRFD 5.6.2.2) |
| | $a = c\beta_1$ | | | |
| | $0.75 \le \Phi = 0.65 + 0.15 \left(\frac{d_e}{c}\right)$ | $(-1) \le 0.90$ | AAS | "HTO LRFD 5.5.4.2 |
| So | olve for A _f : | $A_{\rm f}=3.53~{\rm in^2}$ | Req | uired Reinforcing for Flexure |
| a _f | $_{\text{Ext}} = \frac{A_{\text{f}}}{b_{\text{m}}_{\text{Ext}}}$ | $a_{f_Ext} = 0.88 \frac{\text{in}^2}{\text{ft}}$ | Requ per j | uired Reinforcing for Flexure foot length of cap |

4.5.11.4 Reinforcing Required for Axial Tension

 $\Phi = 0.90$

Interior Girders:

$$\begin{split} N_{uc_Int} &= 0.2V_{u_Int} & N_{uc_Int} & = 74.4 \text{ kip} \\ A_n &= \frac{N_{uc_Int}}{\Phi f_y} & A_n &= 1.38 \text{ in}^2 \\ a_{n_Int} &= \frac{A_n}{b_{m_Int}} & a_{n_Int} &= 0.19 \frac{\text{in}^2}{\text{ft}} \end{split}$$

Exterior Girders:

$$\begin{split} N_{uc_Ext} &= 0.2 V_{u_Int} \\ A_n &= \frac{N_{uc_Ext}}{\Phi f_y} \\ a_{n_Ext} &= \frac{A_n}{b_{m_Ext}} \end{split}$$

(AASHTO LRFD 5.8.4.2.2)

AASHTO LRFD 5.5.4.2

| $A_n = 1.38 \text{ in}^2$ | Required Reinforcing for Axial Tension |
|-------------------------------------|--|
| $a_{n_Int} = 0.19 \frac{in^2}{ft}$ | Required Reinforcing for Axial Tension per foot length of cap |

 $N_{uc_Ext} = 74.4 \text{ kip}$

| $A_n = 1.38 \text{ in}^2$ | Required Reinforcing for Axial Tension |
|--|--|
| $a_{n_Ext}=0.35\frac{\mathrm{i}n^2}{\mathrm{ft}}$ | Required Reinforcing for Axial Tension per foot length of cap |

4.5.11.5 Minimum Reinforcing

$$a_{s_min} = 0.04 \frac{f_c}{f_y} d_e$$

4.5.11.6 Check Required Reinforcing

Actual Reinforcing:

$$a_{s} = \frac{A_{bar}M}{s_{bar}M}$$

$$a_{s} = 1.24 \frac{in^{2}}{ft}$$

$$Primary Ledge Reinford Provided$$

$$a_{h} = \frac{A_{bar}N}{s_{bar}N}$$

$$a_{h} = 1.24 \frac{in^{2}}{ft}$$

$$Auxiliary Ledge Reinford Provided$$

<u>Checks:</u> $A_s \ge A_{s_min}$

$$A_{s} \ge A_{f} + A_{n}$$
$$A_{s} \ge \frac{2A_{vf}}{3} + A_{n}$$

$$A_h \ge 0.5(A_s - A_n)$$

Check if:

Check Interior Girders:

Bar M:

 $a_{s} \ge a_{s_min}$ $a_{s} \ge a_{f_Int} + a_{n_Int}$ $a_{s} \ge \frac{2a_{vf_Int}}{3} + a_{n_Int}$

$$a_{s} = 1.24 \frac{in^{2}}{ft}$$

$$a_{s_min} = 1.02 \frac{in^{2}}{ft} < a_{s}$$

$$a_{f_Int} + a_{n_Int} = 0.67 \frac{in^{2}}{ft} < a_{s}$$

$$\frac{2a_{vf_Int}}{3} + a_{n_Int} = 0.82 \frac{in^{2}}{ft} < a_{s}$$

BarMCheck = "OK!"

Bar N:

$$a_{h} \ge 0.5 \cdot (a_{s} - a_{n_Int})$$
$$a_{s} = The \text{ maximum of:}$$
$$a_{f_Int} + a_{n_Int}$$
$$\frac{2a_{vf_Int}}{3} + a_{n_Int}$$

$$a_{\rm s} = 0.82 \frac{\rm in^2}{\rm ft}$$

Check if:

(AASHTO LRFD 5.8.4.2.1)
$$a_{s_min} = 1.02 \frac{in^2}{ft} \quad Minimum \ Required \ Reinforcing$$

| $1.24 \frac{\text{in}^2}{\text{ft}}$ | Primary Ledge Reinforcing Provided |
|--------------------------------------|--|
| $1.24 \frac{\text{in}^2}{\text{ft}}$ | Auxiliary Ledge Reinforcing Provided (AASHTO LRFD 5.8.4.2.1) |
| | (AASHTO LRFD 5.8.4.2.2) |
| | (AASHTO LRFD Eq. 5.8.4.2.2-5) |
| | (AASHTO LRFD Eq. 5.8.4.2.2-6) |

| (AASHTO LRFD 5.8.4.2.1) |
|-------------------------------|
| (AASHTO LRFD 5.8.4.2.2) |
| (AASHTO LRFD Eq. 5.8.4.2.2-5) |

(AASHTO LRFD Eq. 5.8.4.2.2-6)

" a_s " in this equation is the steel required for Bar M, based on the requirements for Bar M in AASHTO LRFD 5.8.4.2.2. This is derived from the suggestion that Ah should not be less than $A_{f}/2$ nor less than $A_{vf}/3$ (Furlong & Mirza pg. 73 & 74)

$$0.5 \cdot (a_s - a_{n_Int}) = 0.32 \frac{in^2}{ft} < a_h$$

BarNCheck = "OK!"

Check Exterior Girders:

Bar M:

Check if:

$$a_{s} \ge a_{s_min}$$

$$a_{s} \ge a_{f_Ext} + a_{n_Ext}$$

$$a_{s} \ge \frac{2a_{vf_Ext}}{3} + a_{n_Ext}$$

$$a_{s} = 1.24 \frac{in^{2}}{ft}$$

 $a_{s_min} = 1.02 \frac{in^2}{ft} < a_s$

 $a_{f_Ext} + a_{n_Ext} = 1.23 \frac{in^2}{ft} ~<~ a_s$

 $\frac{2a_{vf_{.}Ext}}{3} + a_{n_{.}Ext} = 1.17 \frac{in^2}{ft} < a_s$

BarMCheck = "OK!"

Bar N:

Check if:

$$a_{h} \ge 0.5 \cdot (a_{s} - a_{n_Ext})$$
 (AASHTO LRFD Eq. 5.8.4.2.2-6)
 $a_{s} =$ The maximum of:
 $a_{f_Ext} + a_{n_Ex}$
 $\frac{2a_{vf_Ext}}{3} + a_{n_Ext}$ (arrow and bound on the suggestion that Ah
 $a_{s} = 1.15 \frac{in^{2}}{ft}$ (Furlong & Mirza pg. 73 & 74)
 $0.5 \cdot (a_{s} - a_{n_Ext}) = 0.42 \frac{in^{2}}{ft} < a_{h}$
BarNCheck = "OK!"

Ledge Reinforcement Summary:

Use # 7 primary ledge reinforcing @ 5.80" maximum spacing & # 7 auxiliary ledge reinforcing @ 5.80" maximum spacing

4.5.12 Hanger Reinforcement (Bars S)

Try Double # 6 Stirrups at a 6.80" spacing.

 $s_{bar S} = 6.80 in$

Use trial and error to determine the spacing needed for the hanger reinforcing.

| $A_{hr} = 2stirrups \cdot A_{bar_S}$ | $A_{hr} = 0.88 \text{ in}^2$ |
|--------------------------------------|------------------------------|
| $A_v = 2 legs \cdot A_{hr}$ | $A_v = 1.76 \text{ in}^2$ |

4.5.12.1 Check Minimum Transverse Reinforcement

| $b_v = b_{stem}$ | $b_v = 42$ in | |
|--|---------------|-----------------------------|
| $A_{v_{min}} = 0.0316\lambda \sqrt{f_c} \frac{b_v \cdot s_{bar_s}}{f_v}$ | | (AASHTO LRFD Eq. 5.7.2.5-1) |

 $\lambda = 1.0$ for normal weight concrete

(AASHTO LRFD 5.4.2.8)

 $A_{v_min} = 0.34 \text{ in}^2$

MinimumSteelCheck = "OK!"

4.5.12.2 Check Service Limit State

AASHTO LRFD 5.8.4.3.5 with notifications from BDM-LRFD Ch. 4, Sect. 5, Design Criteria)

Interior Girders

 $A_v > A_{v \min}$

$$V_{all} = \text{minimum of:}$$
$$\frac{A_{hr} \cdot \left(\frac{2}{3} f_y\right)}{s_{bar,S}} \cdot (W + 3a_v) = 249 \text{ kip}$$

TxDOT uses "2/3 f_y " from the original research (Furlong & Mirza Eq. 5.4) instead of "0.5 f_y " from AASHTO LRFD Eq. 5.8.4.3.5-1. (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)

Bounded by: $(W + 3a_v) \le \min(S, 2c)$

$$\frac{A_{hr} \cdot \left(\frac{2}{3}f_{y}\right)}{s_{bar_{s}}} \cdot S = 497 \text{ kip}$$

$$V_{all} = 249 \text{ kip}$$

 $V_{s \text{ Int}} = 243.7 \text{ kip} < V_{all}$

*(***0**))

(BDM-LRFD, Ch. 4, Sect. 5, Design Criteria, (S, 2c)

(BDM-LRFD Ch.4, Sect. 5, Design Criteria modified to limit the distribution width to the girder spacing. This will prevent distribution widths from overlapping)

ServiceCheck = "OK!"

Exterior Girders

 $V_{all} = minimum of:$

V_{all} for the Interior Girder

$$\frac{A_{hr}\left(\frac{2}{3}f_{y}\right)}{s_{bar_{s}}} \cdot \left(\frac{W+3a_{v}}{2}+c\right) = 249 \text{ kip}$$

Bounded by: $(W + 3a_v) \le \min(S, 2c)$

$$\frac{A_{hr} \cdot \left(\frac{2}{3} f_{y}\right)}{s_{bar_{-}S}} \cdot \left(\frac{S}{2} + c\right) = 373 \text{ kip}$$

$$V_{all} = 249 \text{ kip}$$

 $V_{s \text{ Ext}} = 243.7 \text{ kip} < V_{all}$

 $\Phi = 0.90$

Interior Girders:

TxDOT uses "2/3 f_y " from the original research (Furlong & Mirza Eq. 5.4) instead of "0.5 f_y " from AASHTO LRFD Eq. 5.8.4.3.5-1. (BDM-LRFD, Ch. 4, Sect. 5, Design Criteria)

 $(W + 3a_v) \leq \min(3, 2c)$ (BDM-LRFD Ch

(BDM-LRFD Ch.4, Sect. 5, Design Criteria Modified to limit the distribution width to half the girder spacing and the distance to the edge of the cap. This will prevent distribution widths from overlapping or extending over the edge of the cap.)

ServiceCheck = "OK!"

(AASHTO LRFD 5.8.4.3.5)

 $\frac{A_{hr} \cdot f_y}{s_{bar_s}} \cdot S = 745 \text{ kip} \qquad (AASHTO LRFD Eq. 5.8.4.3.5-2)$ $(0.063\sqrt{f_c} \cdot b_f \cdot d_f) + \frac{A_{hr} \cdot f_y}{s_{bar_s}} (W + 2d_f) = 810 \text{ kip} \qquad (AASHTO LRFD Eq. 5.8.4.3.5-3)$ $V_n = 745 \text{ kip}$

T T1. *

 $V_{u_{Int}} = 371.8 \text{ kip } < \Phi V_n$ UltimateCheck = "OK!"

Exterior Girders:

 $V_n = minimum of:$

 $\Phi V_n = 670 \text{ kip}$

 $V_n = minimum of:$

 $V_{n} \text{ for the Interior Girder}$ $\frac{A_{hr} \cdot f_{y}}{s_{bar_{-}S}} \cdot \left(\frac{S}{2} + c\right) = 560 \text{ kip}$ (AASHTO LRFD Eq. 5.8.4.3.5-2) $(0.063\sqrt{f_{c}} \cdot b_{f} \cdot d_{f}) + \frac{A_{hr} \cdot f_{y}}{s_{bar_{-}S}} \left(\frac{W+2d_{f}}{2} + c\right) = 808 \text{ kip}$ (AASHTO LRFD Eq. 5.8.4.3.5-3) (These equations are modified to limit the distribution width to the edge of the cap) $V_{n} = 504 \text{ kip}$ $V_{n} \text{ Ext} = 371.8 \text{ kip} < \Phi V_{n}$ UltimateCheck = "OK!"

4.5.12.4 Check Combined Shear and Torsion

The following calculations are for Station 36. All critical locations must be checked. See the Concrete Section Shear Capacity spreadsheet in the appendices for calculations at other locations. Shear and Moment were calculated using the CAP 18 program.

 $M_u = 769.1 \text{ kip} \cdot \text{ft}$ $V_u = 481.8 \text{ kip}$ $N_u = 0 \text{ kip}$ $T_u = 830 \text{ kip} \cdot \text{ft}$ Recall: $\beta_1 = 0.80$ $f_v = 60 \text{ ksi}$ $f_c = 5.0 \text{ ksi}$ $E_{s} = 29000 \text{ ksi}$ $h_{cap} = 85$ in $b_{ste} = 42 in$ $b_f = 92$ in h = 29.50 in $b_{v} = 42$ in $b_v = b_{stem}$ Find d_v: (AASHTO LRFD 5.7.2.8) $A_s = 10.92 \text{ in}^2$ $A_s = A_{\text{bar }A} \cdot \text{BarANo}$ Shears are maximum near the $c = \frac{A_s f_y}{0.85 \ c \beta_1 b_f}$ column faces. In these regions the c = 2.10 in cap is in negative bending with tension in the top of the cap. $a = c \cdot \beta_1$ a = 1.68 in Therefore, the calculations are based $d_s = d_{s neg}$ $d_s = 81.42$ in on the steel in the top of the bent cap. $M_n = A_s f_v \left(d_s - \frac{a}{2} \right)$ $M_n = 4400 \text{ kip} \cdot \text{ft}$ $A_{ns} = 0$ in² $d_e = \frac{A_{ps}f_{ps}d_p + A_sf_yd_s}{A_{ps}f_{ps} + A_sf_y}$ $d_e = 81.42$ in (AASHTO LRFD Eq. 5.7.2.8-2) $d_v = maximum of:$ $\frac{M_n}{A_s f_v + A_{ns} f_{ns}} = 80.59 \text{ in}$ $0.9d_e = 73.28$ in 0.72h = 21.24 in $d_v = 80.59$ in

The method for calculating θ and β used in this design example are from AASHTO LRFD Appendix B5. The method from AASHTO LRFD 5.7.3.4.2 may be used instead. The method from 5.7.3.4.2 is based on the method from Appendix B5; however, it is less accurate and more conservative (often excessively conservative). The method from Appendix B5 is preferred because it is more accurate, but it requires iterating to a solution.

Determine θ and β :

$$\Phi_{V} = 0.90$$

$$v_{u} = \frac{|v_{u} - (\Phi_{V} \cdot v_{p})|}{\Phi_{V} \cdot b_{v} \cdot d_{v}}$$

$$v_{u} = 0.16 \text{ ksi}$$

$$\frac{v_{u}}{f_{c}} = 0.03$$

Using Table B5.2-1 with $\frac{v_u}{f_c} = 0.03$ and $\varepsilon_x = 0.001$ $\theta = 36.4 \text{ deg}$ and $\beta = 2.23$

$$\begin{split} \epsilon_{x} &= \frac{\frac{|M_{u}|}{d_{v}} + 0.5 N_{u} + 0.5 |V_{u} - V_{p}| \cot \theta - A_{ps} f_{po}}{2(E_{s}A_{s} + E_{p}A_{ps})} \\ \text{where } |M_{u}| &= 769.1 \text{ kip} \cdot \text{ft must be} > |V_{u} - V_{p}| d_{v} = 3236 \text{ kip} \cdot \text{ft} \\ \epsilon_{x} &= 1.23 \times 10^{-3} > 1.00 \times 10^{-3} \\ \text{use } \epsilon_{x} &= 1.00 \times 10^{-3}. \end{split}$$

 $V_p = 0 \text{ kip}$

$$A_c = b_{stem} \cdot \frac{h_{cap}}{2}$$

 $s = s_{bar_s}$

(AASHTO LRFD Eq. 5.5.4.2)

Shear Stress on the Concrete (AASHTO LRFD Eq. 5.7.2.8-1)

Determining θ and β is an iterative process, therefore, assume initial shear strain value ε_x of 0.001 per LRFD B5.2 and then verify that the assumption was valid.

Strain halfway between the compressive and tensile resultants (AASHTO LRFD Eq. B5.2-3) If $\varepsilon_x < 0$, then use equation B5.2-5 and re-solve for ε_x .

For values of ε_x greater than 0.001, the tensile strain in the reinforcing, ε_t is greater than 0.002. ($\varepsilon_t = 2\varepsilon_x - \varepsilon_c$, where ε_c is < 0) Grade 60 steel yields at a strain of 60 ksi / 29,000 ksi = 0.002. By limiting the tensile strain in the steel to the yield strain and using the Modulus of Elasticity of the steel prior to yield, this limits the tensile stress of the steel to the yield stress. ε_x has not changed from the assumed

"V_p" is zero as there is no prestressing.

 $A_{c} = 1785 \text{ in}^{2}$ $(AASHTO LRFD B5.2) "A_{c}" \text{ is the}$ area of concrete on the flexural s = 6.80 in tension side of the cap, from the extreme tension fiber to one half the cap depth. "A " is needed if AASHTO LRED

"A_c" is needed if AASHTO LRFD Eq. B5.2-3 is negative.



The transverse reinforcement, " A_v ", is double closed stirrups. The failure surface intersects four stirrup legs, therefore the area of the shear steel is four times the stirrup bar's area (0.44in2). See the sketch of the failure plane to the left.

Figure 4.99 Failure Surface of 60 Degrees Skewed ITBC for Combined Shear and Torsion

$$\begin{split} A_v &= 2 \text{legs} \cdot 2 \text{stirrups} \cdot A_{\text{bar}_S} & A_v &= 1.76 \text{ in}^2 \\ A_t &= 1 \text{leg} \cdot A_{\text{bar}_S} & A_t &= 0.44 \text{ in}^2 \\ A_{\text{oh}} &= (d_{\text{stem}}) \cdot (b_{\text{stem}} - 2 \text{cover}) + (d_{\text{ledge}} - 2 \text{cover}) \cdot (b_f - 2 \text{cover}) \\ & A_{\text{oh}} &= 4110 \text{ in}^2 \\ A_0 &= 0.85A_{\text{oh}} & A_0 &= 3493.5 \text{in}^2 \\ p_h &= (b_{\text{stem}} - 2 \text{cover}) + 2(b_{\text{ledge}}) + (b_f - 2 \text{cover}) + 2(h_{\text{cap}} - 2 \text{cover}) \\ & p_h &= 334 \text{ in} \end{split}$$

Equivalent Shear Force

$$V_{u_{Eq}} = \sqrt{V_{u}^{2} + \left(\frac{0.9p_{h}T_{u}}{2A_{0}}\right)^{2}} \qquad V_{u_{Eq}} = 624.3 \text{ kip } (AASHTO LRFD Eq. B.5.2-1)$$

Shear Steel Required

 V_n = the lesser of:

$$V_c + V_s + V_p$$
(AASHTO LRFD Eq. 5.7.3.3-1) $0.25 \cdot f_c \cdot b_v \cdot d_v + V_p$ (AASHTO LRFD Eq. 5.7.3.3-2)

Check maximum ΦV_n for section:

 $\Phi V_{n_{max}} = \Phi \cdot \left(0.25 \cdot f_{c} \cdot b_{v} \cdot d_{v} + V_{p} \right)$

$$\Phi V_{n_{max}} = 3808 \text{ kip}$$

$$V_u = 481.8 \text{ kip } < \Phi V_{n_max}$$
 MaxShearCheck = "OK!"

Calculate required shear steel:

$$\begin{split} V_{u} &< \Phi V_{n} \\ V_{c} &= 0.0316 \cdot \beta \cdot \sqrt{f_{c}} \cdot b_{v} \cdot d_{v} \\ V_{u} &< \Phi_{V} \cdot \left(V_{c} + V_{s} + V_{p}\right) \\ V_{s} &= \frac{A_{v} \cdot f_{y} \cdot d_{v} \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha}{s_{req}} \\ a_{v_req} &= \frac{\frac{V_{u}}{\Phi_{V}} - V_{c} - V_{p}}{f_{v} \cdot d_{v} \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha} \end{split}$$

(AASHTO LRFD Eq. 1.3.2.1-1) V_c = 533 kip (AASHTO LRFD Eq. 5.7.3.3-3)

$$a_{v_req} = 0.004 \frac{\mathrm{in^2}}{\mathrm{ft}}$$

The transverse reinforcement is

$$a_{t_req} = 0.23 \frac{in^2}{ft}$$

Total Required Transverse Steel

 $T_n = \frac{2A_oA_tf_y \cot\theta}{s_{bar_S}}$

 $a_{t_req} = \frac{T_u}{\Phi_T 2 A_o f_y cot \theta}$

Torsional Steel Required

 $\Phi_{\rm T} = 0.9$

 $T_u \leq \Phi_T T_n$

$$\begin{array}{ll} a_{req} = a_{v_req} + 2sides \cdot a_{t_req} & a_{req} = 0.46 \ \frac{in^2}{ft} & designed for the side of the section \\ a_{prov} = \frac{A_v}{s_{bar_S}} & a_{prov} = 3.10 \ \frac{in^2}{ft} & c5.7.3.6.1 \end{array}$$

Longitudinal Reinforcement

$$\begin{split} A_{ps}f_{ps} + A_{s}f_{y} &\geq \frac{|M_{u}|}{\Phi d_{v}} + \frac{0.5N_{u}}{\Phi} + \cdots \\ & cot\Theta \sqrt{\left(\left|\frac{V_{u}}{\Phi} - V_{p}\right| - 0.5V_{s}\right)^{2} + \left(\frac{0.45p_{h}T_{u}}{2A_{0}\Phi}\right)^{2}} \\ V_{s} &= a_{t_{r}req} \cdot f_{y} \cdot d_{v} \cdot (cot\Theta + cot\alpha) \cdot sin\alpha \end{split}$$
(AASHTO LRFD Eq. 5.7.3.3-4)

Bounded By:
$$V_s < \frac{V_u}{\Phi_V}$$
 $V_s = 535.3 \text{ kip}$ (

$$\frac{|M_u|}{\Phi_f d_v} + \frac{0.5N_u}{\Phi_c} + \cot\theta \sqrt{\left(\left|\frac{V_u}{\Phi_V} - V_p\right| - 0.5V_s\right)^2 + \left(\frac{0.45 \text{ }_h T_u}{2A_0 \Phi_T}\right)^2} = 614 \text{ kip}$$

Provided Force:

$$A_s f_y = 655.2 \text{ kip} > 614 \text{ kip}$$
 LongitudinalReinfChk = "OK!"

| 4.5.12.5 Maximum Spacing of Transverse Reinforcement | | (AASHTO LRFD 5.7.2.6) |
|---|------------------------------|-----------------------------|
| Shear Stress | | |
| $v_u = \frac{ v_u - \Phi_V v_p }{\Phi_V b_v d_v}$ | $v_u = 0.16$ ksi | (AASHTO LRFD Eq. 5.7.2.8-1) |
| $0.125 \cdot f_c = 0.625 \text{ ksi}$ | | |
| If $v_u < 0.125 \cdot f_c$ | | (AASHTO LRFD Eq. 5.7.2.6-1) |
| $s_{max} = min(0.8d_v, 24in)$ | | |
| If $v_u \ge 0.125 \cdot f_c$ | | (AASHTO LRFD Eq. 5.7.2.6-2) |
| $s_{max} = min(0.4d_v, 12in)$ | | |
| Since $v_u < 0.125 \cdot f_c$ | $s_{max} = 24.00 \text{ in}$ | |
| TxDOT limits the maximum transverse reinforcement spacing to 12". | | (BDM-LRFD, Ch. 4, Sect. 5, |
| $s_{max} = 12.00$ in | | Detailing) |
| $s_{\text{bar}_S} = 6.80 \text{ in } < s_{\text{max}}$ | SpacingCheck= "C | <mark>)K!"</mark> |

Hanger Reinforcement Summary:

Use double # 6 stirrups @ 6.80" maximum spacing

4.5.13 End Reinforcements (Bars U1, U2, U3, and G)

Extra vertical, horizontal, and diagonal reinforcing at the end surfaces is provided to reduce the maximum crack widths. According to the parametric analysis, it is recommended to place #6 U1 Bars, U2 Bars, and U3 Bars at the end faces and #7 G Bars at approximately 6in. spacing at the first 30" to 35" of the end of bent cap. U1 Bars are the vertical end reinforcements, U2 Bars and U3 Bars are the horizontal end reinforcements at the stem and the ledge, respectively. G Bars are the diagonal end reinforcement.



Figure 4.100 End Face Section View of 60 Degrees ITBC



Figure 4.101 End Face Elevation View of 60 Degrees ITBC

4.5.14 Skin Reinforcement (Bars T)

Try 7 ~ # 6 bars in Stem and 3 ~ # 6 bars in Ledge on each side



 A_{sk} need not be greater than one quarter of the main reinforcing ($A_s/4$)per side face within d/2 of the main reinforcing. (AASHTO LRFD 5.6.7)

"d" is the distance from the extreme compression fiber to the centroid of the extreme tension steel element. In this example design, $d = d_{s_pos} = 81.36$ in.

$$\begin{split} A_{sk_max} &= max \left(\frac{\frac{A_{bar_A} \cdot BarANo}{4}}{\frac{d_{s_neg}}{2}}, \frac{\frac{A_{bar_B} \cdot BarBNo}{4}}{\frac{d_{s_pos}}{2}} \right) \\ A_{sk_max} &= 1.27 \frac{in^2}{ft} \\ A_{skReq} &= min(A_{sk_Req}, A_{sk_max}) \\ A_{skReq} &= 0.62 \frac{in^2}{ft} \end{split}$$

(AASHTO LRFD 5.6.7)

 $s_{req} = minimum of:$

$$\frac{A_{\text{bar}_T}}{A_{\text{skReq}}} = 8.52 \text{ in}$$
$$\frac{d_{s.neg}}{6} = 13.57 \text{ in}$$

$$\frac{d_{s_pos}}{6} = 13.56$$
 in & 12 in

 $s_{req} = 8.52$ in

4.5.14.3 Actual Spacing of Skin Reinforcement

Check T Bars spacing in Stem:

$$h_{top} = d_{stem} - \left(cover + \frac{d_{bar_S}}{2} + \frac{d_{bar_A}}{2}\right) + \left(cover + \frac{d_{bar_M}}{2} + \frac{d_{bar_T}}{2}\right)$$
$$h_{top} = 56.73 \text{ in}$$

 $s_{skStem} = \frac{h_{top}}{NoTBarsStem +}$

 $s_{skStem} < s_{req}$

 $s_{skStem} = 7.09$ in

SkinSpacing = "OK!"

Check T Bars spacing in Ledge:

$$h_{bot} = d_{ledge} - \left(cover + \frac{d_{bar_M}}{2} + \frac{d_{bar_T}}{2}\right) - \left(cover + \frac{d_{bar_S}}{2} + \frac{d_{bar_B}}{2}\right)$$
$$h_{bot} = 21.11 \text{ in}$$

 $S_{skLedge} = \frac{n_{bot} - a}{NoTBarsLedge}$

$$s_{skLedge} = 7.56$$
 in

$$S_{skLedge} < S_{req}$$
 SkinSpacing = "OK!"

Check if "a" is less than s_{req}

$$a = 6 \text{ in } < s_{req}$$
 SkinSpacing = "OK!

Skin Reinforcement Summary:

Use $7 \sim \# 6$ bars in Stem and $3 \sim \# 6$ bars in Ledge on each side

4.5.15 Design Details and Drawings

4.5.15.1 Bridge Layout


4.5.15.2 AP 18 Input File

CAP18 Version 6.00 ITBC Design Example 4, Skew = 60.00 \$Problem Card -----1 E 0 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay) \$TABLE 1 - CONTROL DATA -----_____ Enter 1 to keep: Ŝ Number cards Options: Ś Env Tab2 Tab3 Tab4 on Table 4 Envelope Print Skew Angle XX X XX XXXXXXXXX 16 60.0 Ŝ х х х х XXXXXXXXXXX STABLE 2 - CONSTANTS ------Anly Opt (1=Working, \$ TABLE 2a |-Movable Load Data--| 2=Load Factor,3=Both) Num Increment |Num Start Stop Step|Anly| Load Factors: Ś Ŝ |Inc Sta Sta Size| Opt| Dead Live xxx xxx xxx x x x xxxxxxx xxx xxx 20 2 70 1 3 1.25 1.75 Inc Length Ś Ś XX XXXXXXXXX 0.5 92 Ś TABLE 2b Max # |-----Live Load Reduction Factors-----------Overlay Ŝ
 Load Factor
 Lanes
 1 lane
 2 lanes
 3 lanes
 4 lanes
 5 lanes

 XXXXX
 X
 XXXX
 XXXX
 XXXX
 XXXX
 XXXX

 1.50
 3
 1.2
 1.0
 0.85
 0.65
 0.65
 S \$ STABLE 3 - LIST OF STATIONS -----Number of input values for Lane Str Sup MCP VCP XX XX XX XX XX XX VCP - Shear Control Points Ś Ś XX XX XX XX XX (Num Inputs) 3 6 4 11 8 VCP - Shear Control Points \$ Left Lane Boundary Stations Ś \$ Ŝ \$ Ś Station of Stringers (two rows max, may be at tenths of stations, XX.X) \$ (Stringers) 6 22 38 54 70 86 Ś Station of Supports (two rows max) (Supports) 10 34 58 82 Ś Ś Moment Control Point Stations (two rows max) \$ (Mom CP) (Mom CP) 86 Ś Shear Control Point Stations (two rows max) Ś (Shear CP) STABLE 4 - STIFFNESS AND LOAD DATA -----_____ Bending Sidewalk, Cap & Station 1 if Stiffness Slab Stringer Moving From To Cont'd of Cap Loads Loads Loads Ś Ś Overlay From To Cont'd of Cap Loads \$Comments Loads, DW (CAP EI & DL) 2 90 8.66E+07 -2.589-5.04 (DL Span1, Bml) 6 6 -50.17(DL Span1, Bm2) 22 22 -50.17-5.04 (DL Span1, Bm3) -50.17 -5.04 38 38 (DL Span1, Bm4) (DL Span1, Bm5) 54 -50.17 -5.04 54 70 70 -50.17-5.04 (DL Span1, Bm6) (DL Span2, Bm1) 86 86 -50.17-5.04 -104.1 -10.5 6 6 (DL Span2, Bm2) 22 22 -104.1 -10.5 (DL Span2, Bm3) (DL Span2, Bm4) 38 -104.138 -10.5 54 54 -104.1-10.5 (DL Span2, Bm5) (DL Span2, Bm6) 70 70 -104.1 -10.5 86 86 -104.1 -10.50 -4.92 (Dist. Lane Ld) 20 (Conc. Lane Ld) 4 4 -21.3(Conc. Lane Ld) 16 16 -21.3

4.5.15.3 CAP 18 Output File

TEXAS DEPARTMENT OF TRANSPORTATION (TxDOT) AUG 12, 2020 PAGE 1 CAP18 BENT CAP ANALYSIS Ver. 6.2 (Jul, 2011) PSF HIGHWAY PD- CONTROL- CODED COUNTY NO IPE SECTION-JOB BY DATE NO 00001 ___County____ Highwy Pro# 0000-00-000 BRG AUG 12, 2020 Comment CAP18 Version 6.00 ITBC Design Example 4, Skew = 60.00 PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay ENGLISH SYSTEM UNITS TABLE 1. CONTROL DATA OPTION TO PRINT TABLE SRS (1=YES) 0 ENVELOPES TABLE NUMBER OF MAXIMUMS 2 3 4 KEEP FROM PRECEDING PROBLEM (1=YES) 0 0 0 0 CARDS INPUT THIS PROBLEM 16 OPTION TO CLEAR ENVELOPES BEFORE LANE LOADINGS (1=YES) 0 OPTION TO OMIT PRINT FOR TABLES (TABLE DESIGNATIONS IN PARENTHESES) -1(4A), -2(5) -3(4A,5), -4(4A,5,6), -5(4A,5,6,7): 0 SKEW ANGLE, DEGREES 60.000 TABLE 2. CONSTANTS NUMBER OF INCREMENTS FOR SLAB AND CAP 92 INCREMENT LENGTH, FT 0.500 NUMBER OF INCREMENTS FOR MOVABLE LOAD 20 START POSITION OF MOVABLE-LOAD STA ZERO 2 STOP POSITION OF MOVABLE-LOAD STA ZERO 70 NUMBER OF INCREMENTS BETWEEN EACH POSITION OF MOVABLE LOAD 1 ANALYSIS OPTION (1=WORKING STRESS, 2=LOAD FACTOR, 3=BOTH) 3 LOAD FACTOR FOR DEAD LOAD 1.25 LOAD FACTOR FOR OVERLAY LOAD 1.50 LOAD FACTOR FOR LIVE LOAD 1.75 MAXIMUM NUMBER OF LANES TO BE LOADED SIMULTANEOUSLY 3 LIST OF LOAD COEFFICIENTS CORRESPONDING TO NUMBER OF LANES LOADED 1 4 5

1 2 3 4 1.200 1.000 0.850 AUG 12, 2020 TEXAS DEPARTMENT OF TRANSPORTATION (TxDOT) PAGE 2 CAP18 BENT CAP ANALYSIS Ver. 6.2 (Jul, 2011)

PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 3. LISTS OF STATIONS

 NUM OF LANES
 NUM OF STRINGERS
 NUM OF SUPPORTS
 NUM MOM CONTR PTS
 NUM SHEAR CONTR PTS

 LANE LEFT
 2
 32
 60
 11
 8
 8

 LANE RIGHT
 32
 60
 90
 5
 5
 5
 6
 4
 11
 8
 10
 10
 10
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TABLE 4. STIFFNESS AND LOAD DATA

| | | | | | | | - | | | |
|-------------|-----------|------------|------------|---------|----------|---------|---------|-----|----------|----|
| FIXE STA | D-O ST | R-N A C | ONTD CAP | BENDING | SIDEWA | ION DAT | A | MO | VABLE- | ON |
| FRUI | VI | 10 | IF-I SHFF | NE22 21 | AD LUADS | CAPIL | ADS LU | AUS | SLAD LUA | US |
| | | (k | (-FT*FT) (| K) (K |) (K) | (K) | | | | |
| 2 | 90 | 0 | 86600000. | 000 0. | 000 -2.5 | 89 0.0 | 0.0 0.0 | 00 | | |
| 6 | 6 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 22 | 22 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 38 | 38 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 54 | 54 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 70 | 70 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 86 | 86 | 0 | 0.000 | 0.000 | -50.170 | -5.040 | 0.000 | | | |
| 6 | 6 | 0 | 0.000 | 0.000 | -104.100 | -10.500 | 0.000 | | | |
| 22 | 22 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0.000 |) | | |
| 38 | 38 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0.000 |) | | |
| 54 | 54 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0.000 |) | | |
| 70 | 70 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0 0.000 |) | | |
| 86 | 86 | 0 | 0.000 | 0.000 | -104.100 | -10.50 | 0.000 |) | | |
| 0 | 20 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -4.920 | | | |
| 4 | 4 | 0 | 0.000 | 0.000 | 0.000 | 0.000 - | 21.300 | | | |
| 16 | 16 | 0 | 0.000 | 0.000 | 0.000 | 0.000 | -21.300 | | | |

TABLE 4A. DEAD LOAD RESULTS (WORKING STRESS)

| STA | DIST X (FT) | DEFLECTIO | N (FT) | MOMENT (K-FT) | SHEAR (K) |
|------------|-------------|-----------|--------|-----------------------|-----------|
| -1 | -1.00 | 0.000000 | 0.0 | 0.0 | |
| 0 | 0.00 | 0.000000 | 0.0 | 0.0 | |
| 1 | 1.00 | -0.000237 | 0.0 | 0.0 | |
| 2 | 2.00 | -0.000208 | 0.0 | -1.3 | |
| 3 | 3.00 | -0.000178 | -2.6 | -5.2 | |
| 4 | 4.00 | -0.000148 | -10.4 | -10.4 | |
| 5 | 5.00 | -0.000119 | -23.3 | -15.5 | |
| 6 | 6.00 | -0.000090 | -41.4 | -105.6 | |
| 6 | 7.00 | -0.000061 | -234. | 5 -195.7 | |
| 0 | 8.00 | -0.000035 | -452. | o -200.9 | |
| 9 | 9.00 | -0.000014 | -030. | 5 -200.1 | |
| 11 | 11.00 | 0.000000 | -044 | 1/1/9 -50.0 | |
| 12 | 12.00 | 0.000004 | -097 | 3 139.6 | |
| 12 | 13.00 | -0.000000 | -355 | 23 134.5 | |
| 14 | 14.00 | -0.000011 | -286 | 5.4 129.3 | |
| 15 | 15.00 | -0.000045 | -150 | 7 124.1 | |
| 16 | 16.00 | -0.000065 | -38 | 2 118.9 | |
| 17 | 17.00 | -0.000086 | 78 | .2 113.7 | |
| 18 | 18.00 | -0.000106 | 189 | 0.3 108.6 | |
| 19 | 19.00 | -0.000124 | 295 | .3 103.4 | |
| 20 | 20.00 | -0.000138 | 396 | 5.1 98.2 | |
| 21 | 21.00 | -0.000148 | 491 | .7 93.0 | |
| 22 | 22.00 | -0.000152 | 582 | 2.2 3.0 | |
| 23 | 23.00 | -0.000150 | 497 | 7.6 -87.1 | |
| 24 | 24.00 | -0.000141 | 407 | ⁷ .9 -92.3 | |
| 25 | 25.00 | -0.000128 | 313 | 3.0 -97.5 | |
| 26 | 26.00 | -0.000112 | 213 | 3.0 -102.7 | |
| 27 | 27.00 | -0.000093 | 107 | 7.7 -107.8 | |
| 28 | 28.00 | -0.000072 | -2. | 7 -113.0 | |
| 29 | 29.00 | -0.000052 | -118 | 3.3 -118.2 | |
| 30 | 30.00 | -0.000033 | -239 | 9.1 -123.4 | |
| 31 | 31.00 | -0.000017 | -365 | 5.1 -128.6 | |
| 32 | 32.00 | -0.000005 | -496 | 5.2 -133.7 | |
| 33 | 33.00 | 0.000001 | -632 | 2.6 -138.9 | |
| 34 | 34.00 | 0.000000 | -//4 | 43.9 | |
| 35 | 35.00 | -0.000010 | -544 | 4./ ZZ6.8 | |
| 30 | 36.00 | -0.000026 | -520 | 221.0 | |
| 3/ | 37.00 | -0.000046 | -101 | 1.5 210.4 | |
| 20 | 30.00 | -0.000008 | 1 5 1 | 1 26.2 | |
| <u> 10</u> | 40.00 | -0.000087 | 19/ | 1 20.2 | |
| 40 | 41.00 | -0.000100 | 213 | 23 250 | |
| 42 | 42.00 | -0.000122 | 213 | 6 20.7 | |
| 43 | 43.00 | -0.000146 | 254 | .7 15.5 | |
| | | | | | |

TABLE 4A. DEAD LOAD RESULTS (WORKING STRESS)

| STA | DIST X (FT) | DEFLECTION | l (FT) | MOMENT (K-FT) | SHEAR (K) |
|-----|-------------|------------|--------|---------------|-----------|
| 44 | 44.00 | -0.000154 | 267 | .6 10.4 | |
| 45 | 45.00 | -0.000159 | 275 | .4 5.2 | |
| 46 | 46.00 | -0.000160 | 278 | .0 0.0 | |
| 47 | 47.00 | -0.000159 | 275 | .4 -5.2 | |
| 48 | 48.00 | -0.000154 | 267 | .6 -10.4 | |
| 49 | 49.00 | -0.000146 | 254 | .7 -15.5 | |
| 50 | 50.00 | -0.000135 | 236 | .6 -20.7 | |
| 51 | 51.00 | -0.000122 | 213 | .3 -25.9 | |
| 52 | 52.00 | -0.000106 | 184 | .8 -31.1 | |
| 53 | 53.00 | -0.000087 | 151 | .1 -36.2 | |
| 54 | 54.00 | -0.000068 | 112 | .3 -126.3 | |
| 55 | 55.00 | -0.000046 | -101 | .5 -216.4 | |
| 56 | 56.00 | -0.000026 | -320 | .5 -221.6 | |
| 57 | 57.00 | -0.000010 | -544 | .7 -226.8 | |
| 58 | 58.00 | 0.000000 | -774 | .1 -43.9 | |
| 59 | 59.00 | 0.000001 | -632 | .6 138.9 | |
| 60 | 60.00 | -0.000005 | -496 | .2 133.7 | |
| 61 | 61.00 | -0.000017 | -365 | .1 128.6 | |
| 62 | 62.00 | -0.000033 | -239 | .1 123.4 | |
| 63 | 63.00 | -0.000052 | -118 | .3 118.2 | |
| 64 | 64.00 | -0.000072 | -2.7 | 7 113.0 | |
| 65 | 65.00 | -0.000093 | 107 | .7 107.8 | |
| 66 | 66.00 | -0.000112 | 213 | .0 102.7 | |
| 67 | 67.00 | -0.000128 | 313 | .0 97.5 | |
| 68 | 68.00 | -0.000141 | 407 | .9 92.3 | |
| 69 | 69.00 | -0.000150 | 497 | .6 87.1 | |
| 70 | 70.00 | -0.000152 | 582 | .2 -3.0 | |
| 71 | 71.00 | -0.000148 | 491 | .7 -93.0 | |
| 72 | 72.00 | -0.000138 | 396 | .1 -98.2 | |
| 73 | 73.00 | -0.000124 | 295 | .3 -103.4 | |
| 74 | 74.00 | -0.000106 | 189 | .3 -108.6 | |
| 75 | 75.00 | -0.000086 | 78. | 2 -113.7 | |
| 76 | 76.00 | -0.000065 | -38. | 2 -118.9 | |
| 77 | 77.00 | -0.000045 | -159 | .7 -124.1 | |
| 78 | 78.00 | -0.000026 | -286 | .4 -129.3 | |
| 79 | 79.00 | -0.000011 | -418 | .3 -134.5 | |
| 80 | 80.00 | 0.000000 | -555 | .3 -139.6 | |
| 81 | 81.00 | 0.000004 | -697 | .5 -144.8 | |
| 82 | 82.00 | 0.000000 | -844 | .9 30.6 | |
| 83 | 83.00 | -0.000014 | -636 | .3 206.1 | |
| 84 | 84.00 | -0.000035 | -432 | .8 200.9 | |
| 85 | 85.00 | -0.000061 | -234 | .5 195.7 | |
| 86 | 86.00 | -0.000090 | -41. | 4 105.6 | |
| 87 | 87.00 | -0.000119 | -23. | 3 15.5 | |
| 88 | 88.00 | -0.000148 | -10. | 4 10.4 | |
| 89 | 89.00 | -0.000178 | -2.6 | 5 5.2 | |
| 90 | 90.00 | -0.000208 | 0.0 |) 1.3 | |

| 91 | 91.00 | -0.000237 | 0.0 | 0.0 |
|----|-------|-----------|-----|-----|
| 92 | 92.00 | 0.000000 | 0.0 | 0.0 |
| 93 | 93.00 | 0.000000 | 0.0 | 0.0 |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 5. MULTI-LANE LOADING SUMMARY (WORKING STRESS) (*--CRITICAL NUMBER OF LANE LOADS)

MOMENT (FT-K)

| AT STA | DEAD LD EFFECT | LANE POSITIVE LOAD AT L ORDER MAXIMUM LANE STA | ANE NEGATIVE LOAD AT A ORDER MAXIMUM LANE STA |
|-----------|----------------------------------|---|--|
| 6 | -41.4 0 1 2 3 0* | 0.0 0 0.0 0.0 1 0.0 0.0 2 0.0 0.0 3 0.0 0* | |
| 10 | -844.9 0 1 2 3 0* | 0.0 0 -352.5 1 0.0 1 -352.5 1 0.0 2 0.0 0.0 3 0.0 0* | 2 2 |
| 22 | 582.2 0 1 2 3 0* | 404.0 0 13 0 -66.7 2 402.4 1 12 1 -66.7 2 18.7 3 62 2 0.0 0.0 3 0.0 0* | 2 36 2 36 |
| 34 | -774.1 0 1 2 3 0* | 37.4 3 62 0 -272.6 0 37.4 3 62 1 -233.1 1 0.0 2 -169.4 2 3 0.0 3 0.0 2* |) 18 12 32 |
| 38 | 112.3 0 1 2 3 0* | 67.2 2 32 0 -117.6 67.2 2 32 1 -117.6 6.4 3 62 2 0.0 0.0 3 0.0 0* | 1 9 1 9 |
| 46 | 278.0 0 1 2 3 0* | 138.7 2 36 0 -55.6 1 138.7 2 36 1 -55.6 1 0.0 2 -55.6 3 6 0.0 3 0.0 2* | 9 9 3 |
| 54 | 112.3 0 1 2 3 0* | 67.2 2 40 0 -117.6 3 67.2 2 40 1 -117.6 3 6.4 1 10 2 0.0 0.0 3 0.0 0* | 3 63 3 63 |
| 58 | -774.1 0 1 2 3 0* | 37.4 1 9 0 -272.6 0 37.4 1 9 1 -233.1 3 0.0 2 -169.4 2 4 0.0 3 0.0 2* | 54 60 0 |

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MOMENT (FT-K)

| AT | DEAD LD |) LANE | POSITI | VE L | OAD A | T | LA | NE | NEGATIVE L | OAD | AT | |
|-----|----------------|--------|--------|------|-------|----|----|----|------------|-----|-------|-----|
| SIA | EFFECT | ORDER | MAXIN | /IUM | LAN | ES | IA | OR | DER MAXIMU | IVI | LANES | AIG |
| | | | | | | | | | | | | |
| 70 | 502.2 | | | | | | | | | | | |
| /0 | 582.2 | | | | | | | | | | | |
| | 0 | 404.0 | 0 59 | 0 | -66.7 | / | 2 | 36 | | | | |
| | 1 | 402.4 | 3 60 | 1 | -66.7 | 7 | 2 | 36 | | | | |
| | 2 | 18.7 | 1 9 | 2 | 0.0 | | | | | | | |
| | 3 | 0.0 | 3 | C | .0 | | | | | | | |
| | 0* | | 0* | | | | | | | | | |
| | 0 | | 0 | | | | | | | | | |
| 82 | -844.9 | | | | | | | | | | | |
| | 0 | 0.0 | 0 | -34 | 52.5 | 3 | 70 |) | | | | |
| | 1 | 0.0 | 1 | -30 | 2.5 | 3 | 70 | Ś | | | | |
| | 2 | 0.0 | 2 | -5. | 2.5 | 5 | 10 | , | | | | |
| | 2 | 0.0 | 2 | 0 | .0 | | | | | | | |
| | 3 | 0.0 | 3 | U | .0 | | | | | | | |
| | 0* | | 0* | | | | | | | | | |
| | | | | | | | | | | | | |
| 86 | -41.4 | | | | | | | | | | | |
| | 0 | 0.0 | 0 | C | .0 | | | | | | | |
| | 1 | 0.0 | 1 | C | 0.0 | | | | | | | |
| | 2 | 0.0 | 2 | C | 0 | | | | | | | |
| | 2 | 0.0 | 2 | 0 | 0 | | | | | | | |
| | 0 + | 0.0 | 0+ | | .0 | | | | | | | |
| | 0^ | | 0^ | | | | | | | | | |

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SHEAR (K)

| AT STA | DEAD LD EFFECT | LANE POSITIVE LOAD AT LANE NEGATIVE LOAD AT ORDER MAXIMUM LANE STA ORDER MAXIMUM LANE ST | A |
|-----------|----------------------------------|---|---|
| 8 | -200.9 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 12 | 139.6 0 1 2 3 0* | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ | |
| 32 | -133.7 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 36 | 221.6 0 1 2 3 2* | 87.6 0 28 0 -7.8 3 63 84.1 2 32 1 -7.8 3 63 30.7 1 12 2 0.0 0.0 3 0.0 0* | |
| 56 | -221.6 0 1 2 3 0* | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ | |
| 60 | 133.7 0 1 2 3 0* | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ | |
| 80 | -139.6 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 84 | 200.9 0 1 2 3 0* | 88.1 3 70 0 0.0 88.1 3 70 1 0.0 0.0 2 0.0 0.0 3 0.0 0* | |

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REACTION (K)

| AT STA | DEAD LD EFFECT | LANE ORDEF | POSITIVE MAXIMUN | LOAD AT /I LANE S | LANE TA OR | NEGATIVE LOA DER MAXIMUM | D AT LANE STA |
|-----------|---------------------------------|------------------------------|---------------------------------------|----------------------------|---------------|-----------------------------|------------------|
| 10 | 361.2 0 1 2 3 0* | 127.9 127.9 1.6 0.0 | 1 2 0 1 2 1 3 62 2 3 0* | -5.6 -5.6 0.0 0.0 | 2 36 2 36 | | |
| 34 | 376.0 0 1 2 3 2* | 117.1 95.3 83.6 0.0 | 0 22 0 2 32 1 1 12 2 3 0* | -9.3 -9.3 0.0 0.0 | 3 63 3 63 | | |
| 58 | 376.0 0 1 2 3 2* | 117.1 95.3 83.6 0.0 | 0 50 0 2 40 1 3 60 2 3 0* | -9.3 -9.3 0.0 0.0 | 19 19 | | |
| 82 | 361.2 0 1 2 3 0* | 127.9 127.9 1.6 0.0 | 3 70 0 3 70 1 1 9 2 3 0* | -5.6 -5.6 0.0 0.0 | 2 36 2 36 | | |

TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | DIST) | K MAX + I | MOM M | AX - MOM | MAX + SH | EAR | MAX - SHEAR |
|-----|--------|-----------|---------|----------|----------|-----|-------------|
| (| (FT) | (FT-K) (| FT-K) | (K) | (K) | | |
| | | | | | | | |
| -1 | -1.00 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 1 | 1.00 | 0.0 | 0.0 | 0.0 | 0.0 | | |
| 2 | 2.00 | 0.0 | 0.0 | -1.3 | -1.3 | | |
| 3 | 3.00 | -2.6 | -2.6 | -5.2 | -5.2 | | |
| 4 | 4.00 | -10.4 | -10.4 | -10.4 | -10.4 | | |
| 5 | 5.00 | -23.3 | -23.3 | -15.5 | -15.5 | | |
| 6 | 6.00 | -41.4 | -41.4 | -105.6 | -158.5 | | |
| 7 | 7.00 | -234.5 | -340.3 | -195.7 | -301.4 | | |
| 8 | 8.00 | -432.8 | -644.3 | -200.9 | -306.6 | | |
| 9 | 9.00 | -636.3 | -953.5 | -206.1 | -311.8 | | |
| 10 | 10.00 | -844.9 | -1267.9 | -13.1 | 7 -59.6 | | |
| 11 | 11.00 | -671.3 | -1072.8 | 198. | 6 138.1 | | |
| 12 | 12.00 | -493.5 | -882.9 | 193.4 | 133.0 | | |
| 13 | 13.00 | -319.7 | -698.2 | 188.3 | 3 127.8 | | |
| 14 | 14.00 | -151.1 | -518.6 | 183.1 | 122.6 | | |
| 15 | 15.00 | 13.0 | -344.2 | 177.9 | 117.4 | | |
| 16 | 16.00 | 174.5 | -175.0 | 172.7 | 112.3 | | |
| 17 | 17.00 | 332.8 | -10.9 | 167.5 | 107.1 | | |
| 18 | 18.00 | 488.0 | 135.9 | 162.4 | 101.9 | | |
| 19 | 19.00 | 638.9 | 235.3 | 157.2 | 96.7 | | |
| 20 | 20.00 | 786.0 | 329.4 | 152.0 | 91.5 | | |
| 21 | 21.00 | 928.5 | 418.3 | 146.8 | 86.4 | | |
| 22 | 22.00 | 1067.0 | 502.1 | 18.9 | -10.2 | | |
| 23 | 23.00 | 917.7 | 410.2 | -85.3 | -152.7 | | |
| 24 | 24.00 | 763.7 | 312.8 | -90.4 | -157.9 | | |
| 25 | 25.00 | 605.2 | 209.7 | -95.6 | -163.0 | | |
| 26 | 26.00 | 441.9 | 101.0 | -100.8 | -168.2 | | |
| 27 | 27.00 | 275.0 | -13.5 | -106.0 | -173.4 | | |
| 28 | 28.00 | 115.8 | -133.1 | -111.2 | -178.6 | | |
| 29 | 29.00 | -45.8 | -257.9 | -116.3 | -183.8 | | |
| 30 | 30.00 | -201.8 | -388.8 | -121.5 | -188.9 | | |
| 31 | 31.00 | -325.9 | -575.3 | -126.7 | 7 -194.1 | | |
| 32 | 32.00 | -455.1 | -770.5 | -131.9 | -199.3 | | |
| 33 | 33.00 | -589.6 | -970.9 | -137.0 | -204.5 | | |
| 34 | 34.00 | -729.2 | -1176.6 | 87.7 | 26.4 | | |
| 35 | 35.00 | -509.1 | -832.4 | 341.6 | 5 217.5 | | |
| 36 | 36.00 | -294.2 | -528.8 | 336.4 | 212.3 | | |
| 37 | 37.00 | -0.1 | -271.5 | 331.2 | 207.1 | | |
| 38 | 38.00 | 312.9 | -28.9 | 184.8 | 117.0 | | |
| 39 | 39.00 | 345.8 | 19.3 | 45.5 | 26.9 | | |
| 40 | 40.00 | 374.1 | 62.2 | 40.4 | 21.8 | | |
| 41 | 41.00 | 397.8 | 100.0 | 35.2 | 16.6 | | |
| 42 | 42.00 | 416.9 | 125.3 | 30.0 | 11.4 | | |

TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | DIST X | MAX + N | IOM MA | X - MOM | MAX + SHEAR | MAX - SHEAR |
|-----|--------|---------|---------|---------|-------------|-------------|
| | (FT) (| FT-K) (| FT-K) (| K) (F | () | |
| | | | | | | |
| 43 | 43.00 | 430.9 | 143.4 | 24.8 | 6.2 | |
| 44 | 44.00 | 439.6 | 156.4 | 19.7 | 1.1 | |
| 45 | 45.00 | 443.3 | 164.1 | 14.5 | -4.1 | |
| 46 | 46.00 | 444.5 | 166.7 | 9.3 | -9.3 | |
| 47 | 47.00 | 443.3 | 164.1 | 4.1 | -14.5 | |
| 48 | 48.00 | 439.6 | 156.4 | -1.1 | -19.7 | |
| 49 | 49.00 | 430.9 | 143.4 | -6.2 | -24.8 | |
| 50 | 50.00 | 416.9 | 125.3 | -11.4 | -30.0 | |
| 51 | 51.00 | 397.8 | 100.0 | -16.6 | -35.2 | |
| 52 | 52.00 | 374.1 | 62.2 | -21.8 | -40.4 | |
| 53 | 53.00 | 345.8 | 19.3 | -26.9 | -45.5 | |
| 54 | 54.00 | 312.9 | -28.9 | -117.0 | -184.8 | |
| 55 | 55.00 | -0.1 | -271.5 | -207.1 | -331.2 | |
| 56 | 56.00 | -294.2 | -528.8 | -212.3 | -336.4 | |
| 57 | 57.00 | -509.1 | -832.4 | -217.5 | -341.6 | |
| 58 | 58.00 | -729.2 | -1176.6 | -26.4 | -87.7 | |
| 59 | 59.00 | -589.6 | -970.9 | 204.5 | 137.0 | |
| 60 | 60.00 | -455.1 | -770.5 | 199.3 | 131.9 | |
| 61 | 61.00 | -325.9 | -575.3 | 194.1 | 126.7 | |
| 62 | 62.00 | -201.8 | -388.8 | 188.9 | 121.5 | |
| 63 | 63.00 | -45.8 | -257.9 | 183.8 | 116.3 | |
| 64 | 64.00 | 115.8 | -133.1 | 178.6 | 111.2 | |
| 65 | 65.00 | 275.0 | -13.5 | 173.4 | 106.0 | |
| 66 | 66.00 | 441.9 | 101.0 | 168.2 | 100.8 | |
| 67 | 67.00 | 605.2 | 209.7 | 163.0 | 95.6 | |
| 68 | 68.00 | 763.7 | 312.8 | 157.9 | 90.4 | |
| 69 | 69.00 | 917.7 | 410.2 | 152.7 | 85.3 | |
| 70 | 70.00 | 1067.0 | 502.1 | 10.2 | -18.9 | |
| 71 | 71.00 | 928.5 | 418.3 | -86.4 | -146.8 | |
| 72 | 72.00 | 786.0 | 329.4 | -91.5 | -152.0 | |
| 73 | 73.00 | 638.9 | 235.3 | -96.7 | -157.2 | |
| 74 | 74.00 | 488.0 | 135.9 | -101.9 | -162.4 | |
| 75 | 75.00 | 332.8 | -10.9 | -107.1 | -167.5 | |
| 76 | 76.00 | 174.5 | -175.0 | -112.3 | -172.7 | |
| 77 | 77.00 | 13.0 | -344.2 | -117.4 | -177.9 | |
| 78 | 78.00 | -151.1 | -518.6 | -122.6 | -183.1 | |
| 79 | 79.00 | -319.7 | -698.2 | -127.8 | -188.3 | |
| 80 | 80.00 | -493.5 | -882.9 | -133.0 | -193.4 | |
| 81 | 81.00 | -671.3 | -1072.8 | -138.1 | -198.6 | |
| 82 | 82.00 | -844.9 | -1267.9 | 59.6 | 13.7 | |
| 83 | 83.00 | -636.3 | -953.5 | 311.8 | 206.1 | |
| 84 | 84.00 | -432.8 | -644.3 | 306.6 | 200.9 | |
| 85 | 85.00 | -234.5 | -340.3 | 301.4 | 195.7 | |
| 86 | 86.00 | -41.4 | -41.4 | 158.5 | 105.6 | |

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TABLE 6. ENVELOPES OF MAXIMUM VALUES (WORKING STRESS)

| STA | DIST X (FT) | MAX + (FT-K) (| MOM N FT-K) | /IAX - MON (K) | 1 MAX + SF (K) | IEAR MAX - SHEAR |
|-----|------------------|---------------------|----------------|---------------------|-----------------------------|------------------|
| 87 | 87.00 | -23.3 | -23.3 | 15.5 | 15.5 | |
| 88 | 88.00 | -10.4 | -10.4 | 10.4 | 10.4 | |
| 89 | 89.00 | -2.6 | -2.6 | 5.2 | 5.2 | |
| 90 | 90.00 | 0.0 | 0.0 | 1.3 | 1.3 | |
| 91 | 91.00 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 92 | 92.00 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 93 | 93.00 | 0.0 | 0.0 | 0.0 | 0.0 | |

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TABLE 7. MAXIMUM SUPPORT REACTIONS (WORKING STRESS)

| STA | DIST X | MAX + | REACT | MAX - REACT |
|-----|--------|-------|-------|-------------|
| (| FT) | (K) | (K) | |
| | | | | - |
| 10 | 10.00 | 514.7 | 354 | .6 |
| 34 | 34.00 | 554.9 | 364 | .9 |
| 58 | 58.00 | 554.9 | 364 | .9 |
| 82 | 82.00 | 514.7 | 354 | .6 |

TABLE 5. MULTI-LANE LOADING SUMMARY (LOAD FACTOR) (*--CRITICAL NUMBER OF LANE LOADS)

MOMENT (FT-K)

| AT STA | DEAD LD EFFECT | ORDE | POSITIVE LOAD AT LANE NEGATIVE LOAD A R MAXIMUM LANE STA ORDER MAXIMUM LA | T NE STA |
|-----------|-----------------------------------|-------------------------------|--|-------------|
| 6 | -51.8 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 0.0 1 0.0 2 0.0 3 0.0 0* | |
| 10 | -1071.7 0 1 2 3 0* | 0.0 0.0 0.0 0.0 | 0 -616.9 1 2 1 -616.9 1 2 2 0.0 3 0.0 0* | |
| 22 | 737.4 0 1 2 3 0* | 707.0 704.1 32.7 0.0 | 0 13 0 -116.8 2 36 1 12 1 -116.8 2 36 3 62 2 0.0 3 0.0 0* | |
| 34 | -979.2 0 1 2 3 0* | 65.4 65.4 0.0 0.0 | 3 62 0 -477.1 0 18 3 62 1 -408.0 1 12 2 -296.4 2 32 3 0.0 2* | |
| 38 | 144.3 0 1 2 3 0* | 292.6 292.6 11.2 0.0 | 2 32 0 -205.9 1 9 2 32 1 -205.9 1 9 3 62 2 0.0 3 0.0 0* | |
| 46 | 351.4 0 1 2 3 0* | 242.7 242.7 0.0 0.0 | 2 36 0 -97.4 1 9 2 36 1 -97.4 1 9 2 -97.4 3 63 3 0.0 2* | |
| 54 | 144.3 0 1 2 3 0* | 292.6 292.6 11.2 0.0 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| 58 | -979.2 0 1 2 3 0* | 65.4 65.4 0.0 0.0 | 1 9 0 -477.1 0 54 1 9 1 -408.0 3 60 2 -296.4 2 40 3 0.0 2* | |

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MOMENT (FT-K)

| AT | DEAD LD | LANE | POSITI | VE LO | DAD A | AT . | LA | NE | NEG | ATIVE | LOA | DAT | |
|-----|---------|-------|--------|----------|-------|------|----|----|-----|-------|-----|------|-----|
| SIA | FFFFCI | ORDER | MAXIN | /UM | LAN | ΕS | IA | OR | DER | MAXI | MUM | LANE | SIA |
| | | | | | | | | | | | | | |
| 70 | 737 4 | | | | | | | | | | | | |
| /0 | 0 | 707.0 | 0 59 | 0 | -116 | 8 | 2 | 36 | | | | | |
| | 1 | 704.1 | 3 60 | 1 | -116 | 8 | 2 | 36 | | | | | |
| | 2 | 32.7 | 1 9 | 2 | 0.0 | 0 | 2 | 50 | | | | | |
| | 2 | 0.0 | 2 | <u>د</u> | 0.0 | | | | | | | | |
| | 0* | 0.0 | 0* | 0 | .0 | | | | | | | | |
| | 0 | | 0 | | | | | | | | | | |
| 82 | -1071.7 | | | | | | | | | | | | |
| | 0 | 0.0 | 0 | -61 | 6.9 | 3 | 70 | | | | | | |
| | 1 | 0.0 | 1 | -61 | 6.9 | 3 | 70 | | | | | | |
| | 2 | 0.0 | 2 | 0 | .0 | - | | | | | | | |
| | 3 | 0.0 | 3 | 0 | 0 | | | | | | | | |
| | 0* | 0.0 | 0* | | .0 | | | | | | | | |
| | 0 | | 0 | | | | | | | | | | |
| 86 | -51.8 | | | | | | | | | | | | |
| | 0 | 0.0 | 0 | 0 | 0 | | | | | | | | |
| | 1 | 0.0 | 1 | 0 | 0 | | | | | | | | |
| | 2 | 0.0 | 2 | 0 | 0 | | | | | | | | |
| | 3 | 0.0 | 3 | 0 | 0 | | | | | | | | |
| | 0* | 0.0 | 0* | | .0 | | | | | | | | |
| | | | 5 | | | | | | | | | | |

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|--------------|-----------------------|-----------------------|---------|
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.....

SHEAR (K)

| AT STA | DEAD LD EFFECT | LANE POSITIVE LOAD AT LANE NEGATIVE LOAD AT ORDER MAXIMUM LANE STA ORDER MAXIMUM LANE STA |
|-----------|----------------------------------|--|
| 8 | -255.0 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 12 | 176.7 0 1 2 3 0* | 78.4 1 6 0 -9.7 2 36 78.4 1 6 1 -9.7 2 36 2.7 3 62 2 0.0 0.0 3 0.0 0* |
| 32 | -168.9 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 36 | 280.9 0 1 2 3 2* | 153.2 0 28 0 -13.6 3 63 147.2 2 32 1 -13.6 3 63 53.7 1 12 2 0.0 0.0 3 0.0 0* |
| 56 | -280.9 0 1 2 3 0* | $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ |
| 60 | 168.9 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 80 | -176.7 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 84 | 255.0 0 1 2 3 0* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |

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|--------------|-----------------------|-----------------------|---------|
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REACTION (K)

| AT STA | DEAD LE | O LANE | R MAXIMU | LOAD A | T LANE STA OR | NEGATIVE LOA | D AT LANE STA |
|-----------|---------------------------------|--------------------------------|-------------------------------------|------------------------------------|------------------|--------------|------------------|
| | | | | | | | |
| 10 | 457.5 0 1 2 3 0* | 223.8 223.8 2.7 0.0 | 1 2 0 1 2 1 3 62 2 3 0* | -9.7 -9.7 0.0 0.0 | 2 36 2 36 | | |
| 34 | 475.7 0 1 2 3 2* | 205.0 166.8 146.3 0.0 | 0 22 2 32 1 12 3 0* | 0 -16.3 1 -16.3 2 0.0 0.0 | 3 63 3 63 | | |
| 58 | 475.7 0 1 2 3 2* | 205.0 166.8 146.3 0.0 | 0 50 2 40 3 60 3 0* | 0 -16.3 1 -16.3 2 0.0 0.0 | 19 19 | | |
| 82 | 457.5 0 1 2 3 0* | 223.8 223.8 2.7 0.0 | 3 70 3 70 1 9 2 3 0* | 0 -9.7 1 -9.7 0.0 0.0 | 2 36 2 36 | | |

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|--------------|-----------------------|-----------------------|---------|
| CAP18 | BENT CAP ANALYSIS | Ver. 6.2 (Jul, 2011) | |

TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA | DIST > | (MAX + | MOM N | IAX - MON | MAX + SHEA | R MAX - SHEAR |
|-----|--------|----------|---------|-----------------|------------|---------------|
| | (FT) | (FT-K) (| FT-K) | (K) (| (K) | |
| | | | | | | |
| -1 | -1.00 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 1 | 1.00 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 2 | 2.00 | 0.0 | 0.0 | -1.6 | -1.6 | |
| 3 | 3.00 | -3.2 | -3.2 | -6.5 | -6.5 | |
| 4 | 4.00 | -12.9 | -12.9 | -12.9 | -12.9 | |
| 5 | 5.00 | -29.1 | -29.1 | -19.4 | -19.4 | |
| 07 | 7.00 | -51.8 | -51.8 | -134.0 249 E | -220.5 | |
| 6 | 2.00 | -297.1 | -462.1 | -246.5 | -435.0 | |
| 0 | 0.00 | -546.6 | 1262.2 | -255.0 | -440.0 | |
| 10 | 10.00 | -007.0 | -1912 | -201.5 | -440.5 | |
| 11 | 11.00 | -839.4 | -15/2.1 | 277 | 3 171 / | |
| 12 | 12.00 | -597.4 | -1278.9 | 277. | 8 165.0 | |
| 13 | 12.00 | -359.6 | -1270.0 | 264 | 3 158 5 | |
| 14 | 14.00 | -128.3 | -771 5 | 257.8 | 152.0 | |
| 15 | 15.00 | 97.6 | -527.5 | 251.0 | 145.6 | |
| 16 | 16.00 | 321.6 | -290.0 | 244 9 | 139.1 | |
| 17 | 17.00 | 542.6 | -59.0 | 238.4 | 132.6 | |
| 18 | 18.00 | 760.7 | 144.5 | 232.0 | 126.1 | |
| 19 | 19.00 | 973.9 | 267.4 | 225.5 | 119.7 | |
| 20 | 20.00 | 1183.0 | 383.9 | 219.0 |) 113.2 | |
| 21 | 21.00 | 1386.6 | 493.8 | 212.5 | 5 106.7 | |
| 22 | 22.00 | 1585.8 | 597.3 | 31.8 | -19.1 | |
| 23 | 23.00 | 1365.1 | 476.9 | -107.4 | 4 -225.4 | |
| 24 | 24.00 | 1138.6 | 349.5 | -113.9 | 9 -231.9 | |
| 25 | 25.00 | 907.0 | 214.8 | -120.4 | -238.4 | |
| 26 | 26.00 | 669.5 | 72.9 | -126.8 | -244.8 | |
| 27 | 27.00 | 428.2 | -76.6 | -133.3 | -251.3 | |
| 28 | 28.00 | 203.0 | -232.5 | -139.8 | -257.8 | |
| 29 | 29.00 | -23.8 | -394.9 | -146.3 | -264.2 | |
| 30 | 30.00 | -238.0 | -565.4 | -152.7 | -270.7 | |
| 31 | 31.00 | -394.0 | -830.5 | -159.2 | -277.2 | |
| 32 | 32.00 | -556.5 | -1108.4 | -165. | 7 -283.7 | |
| 33 | 33.00 | -725.4 | -1392.8 | -172. | 1 -290.1 | |
| 34 | 34.00 | -900.8 | -1683.6 | 132. | 6 25.2 | |
| 35 | 35.00 | -626.4 | -1192.1 | 488. | 2 271.1 | |
| 36 | 36.00 | -358.5 | -769.1 | 481.8 | 264.6 | |
| 37 | 37.00 | 50.5 | -424.3 | 475.3 | 258.1 | |
| 38 | 38.00 | 495.4 | -102.8 | 262.1 | 143.6 | |
| 39 | 39.00 | 533.5 | -38.0 | 61.6 | 29.0 | |
| 40 | 40.00 | 566.2 | 20.4 | 55.1 | 22.6 | |
| 41 | 41.00 | 593.4 | /2.3 | 48.6 | 16.1 | |
| 42 | 42.00 | 615.2 | 104.9 | 42.2 | 9.6 | |
| 43 | 43.00 | 630.6 | 127.5 | 35.7 | 3.1 | |
| 44 | 44.00 | 639.4 | 143.7 | 29.2 | -3.3 | |

| 45 | 45.00 | 641.9 | 153.4 | 22.7 | -9.8 |
|----|-------|-------|-------|------|-------|
| 46 | 46.00 | 642.7 | 156.6 | 16.3 | -16.3 |
| 47 | 47.00 | 641.9 | 153.4 | 9.8 | -22.7 |
| 48 | 48.00 | 639.4 | 143.7 | 3.3 | -29.2 |
| | | | | | |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA | DIST X | MAX + N | 10M MA | X - MOM | MAX + SHEAR | MAX - SHEAR |
|-----|--------|----------|---------|---------|-------------|-------------|
| (| (FT) (| FT-K) (F | -T-K) (| K) (K | () | |
| | | | | | | |
| 49 | 49.00 | 630.6 | 127.5 | -3.1 | -35.7 | |
| 50 | 50.00 | 615.2 | 104.9 | -9.6 | -42.2 | |
| 51 | 51.00 | 593.4 | 72.3 | -16.1 | -48.6 | |
| 52 | 52.00 | 566.2 | 20.4 | -22.6 | -55.1 | |
| 53 | 53.00 | 533.5 | -38.0 | -29.0 | -61.6 | |
| 54 | 54.00 | 495.4 | -102.8 | -143.6 | -262.1 | |
| 55 | 55.00 | 50.5 | -424.3 | -258.1 | -475.3 | |
| 56 | 56.00 | -358.5 | -769.1 | -264.6 | -481.8 | |
| 57 | 57.00 | -626.4 | -1192.1 | -271.1 | -488.2 | |
| 58 | 58.00 | -900.8 | -1683.6 | -25.2 | -132.6 | |
| 59 | 59.00 | -725.4 | -1392.8 | 290.1 | 172.1 | |
| 60 | 60.00 | -556.5 | -1108.4 | 283.7 | 165.7 | |
| 61 | 61.00 | -394.0 | -830.5 | 277.2 | 159.2 | |
| 62 | 62.00 | -238.0 | -565.4 | 270.7 | 152.7 | |
| 63 | 63.00 | -23.8 | -394.9 | 264.2 | 146.3 | |
| 64 | 64.00 | 203.0 | -232.5 | 257.8 | 139.8 | |
| 65 | 65.00 | 428.2 | -76.6 | 251.3 | 133.3 | |
| 66 | 66.00 | 669.5 | 72.9 | 244.8 | 126.8 | |
| 67 | 67.00 | 907.0 | 214.8 | 238.4 | 120.4 | |
| 68 | 68.00 | 1138.6 | 349.5 | 231.9 | 113.9 | |
| 69 | 69.00 | 1365.1 | 476.9 | 225.4 | 107.4 | |
| 70 | 70.00 | 1585.8 | 597.3 | 19.1 | -31.8 | |
| 71 | 71.00 | 1386.6 | 493.8 | -106.7 | -212.5 | |
| 72 | 72.00 | 1183.0 | 383.9 | -113.2 | -219.0 | |
| 73 | 73.00 | 973.9 | 267.4 | -119.7 | -225.5 | |
| 74 | 74.00 | 760.7 | 144.5 | -126.1 | -232.0 | |
| 75 | 75.00 | 542.6 | -59.0 | -132.6 | -238.4 | |
| 76 | 76.00 | 321.6 | -290.0 | -139.1 | -244.9 | |
| 77 | 77.00 | 97.6 | -527.5 | -145.6 | -251.4 | |
| 78 | 78.00 | -128.3 | -771.5 | -152.0 | -257.8 | |
| 79 | 79.00 | -359.6 | -1021.9 | -158.5 | -264.3 | |
| 80 | 80.00 | -597.4 | -1278.8 | -165.0 | -270.8 | |
| 81 | 81.00 | -839.4 | -1542.1 | -171.4 | -277.3 | |
| 82 | 82.00 | -1071.7 | -1812.0 | 90.0 | 9.6 | |
| 83 | 83.00 | -807.0 | -1362.2 | 446.5 | 261.5 | |
| 84 | 84.00 | -548.8 | -918.9 | 440.0 | 255.0 | |
| 85 | 85.00 | -297.1 | -482.1 | 433.6 | 248.5 | |
| 86 | 86.00 | -51.8 | -51.8 | 226.5 | 134.0 | |
| 87 | 87.00 | -29.1 | -29.1 | 19.4 | 19.4 | |
| 88 | 88.00 | -12.9 | -12.9 | 12.9 | 12.9 | |
| 89 | 89.00 | -3.2 | -3.2 | 6.5 | 6.5 | |

| 90 | 90.00 | 0.0 | 0.0 | 1.6 | 1.6 | |
|----|-------|-----|-----|-----|-----|--|
| 91 | 91.00 | 0.0 | 0.0 | 0.0 | 0.0 | |
| 92 | 92.00 | 0.0 | 0.0 | 0.0 | 0.0 | |

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PROB 1 (Spans L=54'-112'-54', Type TX54 Girder @ 8.0', 8" Slab, 2" O'lay (CONTINUED)

TABLE 6. ENVELOPES OF MAXIMUM VALUES (LOAD FACTOR)

| STA (| DIST X FT) | (MAX (FT-K) | + MOM (FT-K) | MAX - MC (K) | OM MAX (K) | + SHEAR | MAX - SHEAR |
|----------|----------------|------------------|-------------------|-------------------|---------------|---------|-------------|
| 93 | 93.00 | 0.0 | 0.0 | 0.0 | 0.0 | | |

TABLE 7. MAXIMUM SUPPORT REACTIONS (LOAD FACTOR)

| STA | DIST X | MAX + | REACT | MAX - REACT |
|-----|--------|-------|-------|-------------|
| (| FT) | (K) | (K) | |
| | | | | - |
| 10 | 10.00 | 726.1 | 445 | 5.8 |
| 34 | 34.00 | 788.8 | 456 | 5.2 |
| 58 | 58.00 | 788.8 | 456 | 5.2 |
| 82 | 82.00 | 726.1 | 445 | 5.8 |

4.5.15.4 Live Load Distribution Factor Spreadsheet

4.5.15.4.1 Spans 1 & 3



| DDIDOF | County: | AIVI | Highway: | Any | Design: | BRG | Date: | 0/10/20 | 2017 | LHFU Spe |
|--------------|--------------------|--------------------------|--|------------------------------------|--------------|------------------------|---------------------------|------------------|--------------|-----------------------|
| IVISION | C-S-J: Descrip: | ITBC Design Exar | nole 4. Span 1 & | 3 | Eile: | Ex4 Sp | Date: an1 distribution | ution factors.xl | Rev. 10/18 - | (No Interin 2 of 8 |
| INTER | IOR BE | AM: | | | 1 mar | | | | Griddell | |
| Shear I | L Distrib | ution Per Lane (| Table 4.6.2.2 | 3a-1): | | | | | | |
| <u>onear</u> | Onela | ne Loaded | | <u></u> | | | | | | |
| | one Eu | Lever Bule | (Table 3.6.1 | 12) | | | | | | |
| | | ma - 0.6 | 25 * 1 2 - | 0.750 | | | | | | |
| | | Modify fo | r Skew | 0.750 | | | | | | |
| | | inicenty to | skew correc | tion = | 1.227 | | | | | |
| | | | ma = 0.750 | * 1.227 = | 0.920 | | | | | |
| | | Equation | ing unou | | | | | | | |
| | | g = 0.36 | $i + \left(\frac{S}{25}\right)$ | | | | | | | |
| | | q = 0.36 | + (8 / 25) = | 0.680 | | | | | | |
| | | Modify to | r Skew: | | | | | | | |
| | | | skew correc | tion = | 1.227 | | | | | |
| | | | g = 0.680 * | 1.227 = | 0.834 | | | | | |
| | | Range of Appl | icability (ROA |) Checks | THE P | | | | | |
| | | Check S: | 3.5' ≤ 8.0' ≤ | 16.0' | OK | | | | | |
| | | Check te: | 4.5" ≤ 8.0" | ≤ 12.0" | OK | | | | | |
| | | Check L: | 20' ≤ 50.3' : | \$ 240' | OK | | | | | |
| | | Check N | . 6≥4 | | OK | | | | | |
| | | Use Equation | from Table 4.6 | 52238-11 | ecause all | oriteria is | SOK | | | |
| | | gV _{int1} = | 0.834 | | | - 1 const. (de) (| | | | |
| | Two or | More Lanes Lo | aded | | | | | | | |
| | | Lever Rule | (Table 3.6.1 | .1.2) | | | | | | |
| | | mg = Ma: Modify fo | x(0.875 * 1.0, or Skew: | 0.875 * 0.8 | 5, 0.875 * 0 | .65) = | 0.875 | | | |
| | | | skew correc | tion = | 1.227 | | | | | |
| | | | mg = 0.875 | * 1.227 = | 1.074 | | | | | |
| | | Equation | 1 - 2 - 1 - | > 2.0 | | | | | | |
| | | q = 0.2 - | $+\left(\frac{s}{s}\right)-\left(\frac{s}{s}\right)$ | | | | | | | |
| | | | (12) (35 | 5) | | | | | | |
| | | g = 0.2 + | (8 / 12) - (8 / | 35)^2.0 = | 0,814 | | | | | |
| | | Modify to | r Skew: | | 1 007 | | | | | |
| | | | skew correc | | 1.22/ | | | | | |
| | | | g = 0.814 " | 1.227 = | 0.999 | | | | | |
| | | Range of Appl | icability (ROA |) Checks | (same as t | or one l | ane loade | ed) | | |
| | | Use Equation | from Table 4.6 | 5.2.2.3a-1 b | ecause all | criteria is | S OK. | | | |
| | | $gV_{int2+} =$ | 0.999 | | | | | | | |
| | TXDOT | Policy states gV | Interior must be | ≥ m·N _L ÷N _b | | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85*3/6 | | 0.425 | | | | | |
| | ls W≥2 | 20ft ? Yes | | | | | | | | |
| | TXDOT | Policy states that | t if $W < 20$ ft, g | Vinterior is th | e Maximun | n of: gV _e | iii and m | NL+Nb. | | |
| >> | TXDOT | Policy states that | t if W≥20ft, g | Vinletior is th | e Maximun | n of: gV _{in} | n11, gVint2+ | m·NL÷No. | | |
| | 1 | | | | | | | | | |

| TXDOT | County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|----------|-------------------|--------------------------|--|---|--|------------|-----------|----------------|------------|-----------|
| DIVISION | C-S-J: Descrip | ITBC Design Exa | ID #: | 8 3 | Ck Dsn: | Ex4 So | Date: | ution factors. | Rev. 10/18 | 3 of 8 |
| INTER | IOR BE | ΔM· | | | D. HOL | | | | ondot. | 0010 |
| Momen | t I I Distr | ibution Per Lan | e (Table 4.6 | 2.2.2h-1)- | | | | | | |
| Momen | Onela | ne Loaded | 6 (Tubic 4.0. | L.L.LU (). | | | | | | |
| | One Eu | Lever Bule | (Table 3.6 | 112) | | | | | | |
| | | ma = 0 f | 125 * 1 2 - | 0.750 | | | | | | |
| | | Modify f | or Skew: | 0.700 | | | | | | |
| | | (noon) i | skew corr | ection = | 0.676 | | | | | |
| | | | ma = 0.75 | 0 * 0.676 = | 0.507 | | | | | |
| | | Equation | | | ~ 0.1 | | | | | |
| | | g = 0.0 | $6 + \left(\frac{S}{14}\right)^{6\pi}$ | $\left(\frac{S}{L}\right)^{0.3} \left(\frac{K_s}{12L}\right)^{0.3}$ | r (1) | | | | | |
| | | g = 0.06 | + (8/14)^0.4 | * (8/50.3)^0.3 | 3* (1,271,6 | 11/(12* | 50.3*8^3) |)^0.1 = | 0.591 | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corre | ection = | 0.676 | | | | | |
| | | | g = 0.591 | * 0.676 = | 0.400 | | | | | |
| | | Range of App | licability (RC | A) Checks | | | | | | |
| | | Check S | 3: 3.5' ≤ 8.0 | '≤ 16.0' | | OK | | | | |
| | | Gheck t | : 4.5" ≤ 8.0 | " ≤ 12.0" | | OK | | | | |
| | | Check L | : 20'≤50.3 | l' ≤ 240' | | OK | | | | |
| | | Check N | l _b : 6≥4 | | | OK | | | | |
| | | Check K | kg: 10,000 ≤ | 1,271,611 ≤ 7 | ,000,000 | OK | | | | |
| | | Use Equation | from Table : | 4.6.2.2.2b-1 b | ecause all | criteria i | s OK | | | |
| | | gM _{int1} = | 0.400 | | | | | | | |
| | Two or | More Lanes Lo | baded | | | | | | | |
| | | Lever Rule | (Table 3.6 | .1.1.2) | | | | | | |
| | | mg = Ma | ax(0.875 * 1.0 | 0, 0.875 * 0.8 | 5, 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corre | ection = | 0.676 | | | | | |
| | | | mg = 0.87 | 5 * 0.676 = | 0.592 | | | | | |
| | | Equation | (5)0 | 6 (c) 0.2 (| K)0.1 | | | | | |
| | | g = 0.0 | $75 + \left(\frac{3}{9.5}\right)$ | $\left(\frac{3}{L}\right)\left(\frac{1}{12}\right)$ | $\left(\frac{Lt_{g}^{3}}{Lt_{g}^{3}}\right)$ | | | | | |
| | | g = 0.07 Modify f | 5 + (8/9.5)^0 or Skew: | .6 * (8/50.3)^(|).2 * (1,271 | ,611/(12 | 2*50.3*8^ | 3))^0.1 = | 0.795 | |
| | | | skew corre | ection = | 0.676 | | | | | |
| | | | g = 0.795 | * 0.676 = | 0.537 | | | | | |
| | | Range of App | licability (RC | A) Checks | (same as | for one I | ane load | ed) | | |
| | | Use Equation | from Table 4 | 4.6.2.2.2b-1 b | ecause all | oriteria i | s OK. | | | |
| | | gM _{int2+} = | 0.537 | | | | | | | |
| | TXDOT | Policy states gl | Anterior must b | be≥m·NL÷Nb | | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85 * 3 / 6 | 6 = | 0.425 | | | | | |
| | ls W≥2 | 20ft ? Yes | | | | | | | | |
| | TXDOT | Policy states th | at if W < 2011 | , gM _{Internar} is th | ne Maximur | n of: gM | int and m | NL+NL+ND- | | |
| >> | TXDOT | Policy states th | at if W ≥ 20ft | gMinitation is U | e Maximun | n ol: gM | gMmie | m·NL÷No | x | |
| | gMinte | erior = 0.537 | | | | | | | | |

| TXDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 LRFD Spec |
|---------|--------------------|--------------------------|-------------------------------------|------------------------------|-------------------------------|-------------|------------|----------------------------|---|
| IVISION | C-S-J: | ITBC Design Exa | ID #: | xxxx & 3 | Ck Dsn: | Ex4 So: | Date: | ition factors x | Rev. 10/18 - (No Interit Sheet! 4 of 8 |
| EXTER | NOR BE | EAM. | | | Ti na. | Last opt | | | Shoel 4010 |
| Shoarl | I Dietrib | ution Per Lane | Table 4.6.2 S | 2 3h-11. | | | | | |
| onear L | Onela | ne Loaded | 114016 4.0.2.4 | | | | | | |
| | One La | Lever Bule | (Table 3.6 | 112) | | | | | |
| | | ma - 01 | 625 * 1 0 - | 0.625 | TYDOTUS | | Vela area | ance Factor | of 1 D for age |
| | | Modify f | or Skow | 0.02.0 | lane loade | d on the | exterior | beam. | or no for one |
| | | Nicolity I | skew corre | ection - | 1 227 | | | | |
| | | | ma = 0.62 | 5*1 227 = | 0.767 | | | | |
| | | Lise Lover B | ile as por AA | SHTO I BEI | Table 4 6 S | 2.2h.1 | | | |
| | | aV = | 0 767 | on o chi i | 1 auto 4.0/2 | | | | |
| | S | 9 • exti | 0.701 | | | | | | |
| | Two or | More Lanes L | oaded | | | | | | |
| | | Lever Rule | (Table 3.6 | .1.1.2) | | | | | |
| | | mg = Ma | ax(0.625 * 1.0 | 0, 0.625 * 0.8 | 35, 0.625 * 0. | .65) = | 0.625 | | |
| | | Modify t | or Skew: | | | | | | |
| | | | skew corre | ection = | 1,227 | | | | |
| | | 6.110 | mg = 0.623 | 5 * 1.227 = | 0.767 | | | | |
| | | Equation | | Sec. Sec. | | | | | |
| | | | t. b/w GL web | to curb | | | | | |
| | | d _e = OH | - Hall Width | | | | | | |
| | | 0 ₈ = | 311 - 111 = | 2.01 | n. | | | | |
| | | e = 0.6 | $+\left(\frac{d_{e}}{d_{e}}\right)$ | | | | | | |
| | | | (10) | 0.000 | | | | | |
| | | e = 0.6 | + (2.0/10) = | 0.800 | | | | | |
| | | g = e*g\ | Vint2+Eq | | | | | | |
| | | g = 0.80 | = 999.0 * 0 | 0.799 | | | | | |
| | | Skew C | orrection is in | cluded in gV | (interior). | | | | |
| | | Range of App | blicability (RO | A) Checks | Interior | ROA is | implicitly | applied to the | he exterior beam. |
| | | Check I | nterior Beam | ROA: | OK | | | | |
| | | Check c | d _e : -1.0' ≤ 2.0 | ' ≤ 5.5' | OK | | | | |
| | | Check N | N _b : 6 ≠ 3 | | OK | | | | |
| | | Use Equation | from Table 4 | .6.2.2.3b-1 | because all o | criteria is | OK. | | |
| | | $gV_{ext2+} =$ | 0.799 | | | | | | |
| | TXDOT | Policy states g | VExtenar must b | e ≥ gV _{interior} | | | | | |
| | | gV _{interior} = | 0.999 | | | | | | |
| | TXDOT | Policy states g | VExterior must b | $e \ge m \cdot N_L \div N_L$ | b | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85*3/6 | 3 = | 0.425 | | | | |
| | ls OH ≤ | S/2 ? Yes | | | | | | | |
| | ls W ≥ 2 | 20ft? Yes | | | | | | | |
| >> | TXDOT | Policy states th | at if OH ≤ S/2 | 2, gV _{Exterior} is | gV _{intenor} . | | | | |
| | TXDOT | Policy states th | at if OH > S/a | 2 and W < 20 | off, gV _{Exterior} i | s the Ma | aximum o | f; gV _{ext1} , gV | interior, and |
| | | $m \cdot N_L \div N_b.$ | | | | | | | |
| | TXDOT | Policy states th | at if OH > S/2 | 2 ans W ≥ 20 | oft, gV _{Exterior} i | s the Ma | iximum o | ft gV _{ext1} , gV | ext2+, gVinterior |
| | | and m·NL+Nb | - | | | | | | |
| | gV _{exte} | erior = 0.999 | 10 | | | | | | |

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TXDOT
BRIDGE
                     ANY
           County:
                                      Highway
                                                     Any
XXXX
                                                                     Design:
                                                                                        Date
                                                                                                                     2017 LRFD Spel
                     XXX-XX-XXXX
                                                                                                                    10/18 - (No Inte
                                                                     Ck Dsn:
                                      ID #
                                                                                        Date
                                     mple 4, Span 1 &
                    ITBC Design Exa
DIVISION
                                                                                                                            5 of 8
 EXTERIOR BEAM:
Moment LL Distribution Per Lane (Table 4.6.2.2.2d-1):
          One Lane Loaded
                     Lever Rule
                           mg = 0.625 * 1.0 =
                                                    0.625
                                                                 TxDOT uses a multiple presence factor of 1,0 for one
                                                                 lane loaded on the exterior beam.
                           Modify for Skew:
                                      skew correction =
                                                                    0.676
                                      mg = 0.625 * 0.676 =
                                                                    0.423
                     Use Lever Rule as per AASHTO LRFD Table 4.6.2.2.2d-1.
                     gMext1 =
                                      0.423
          Two or More Lanes Loaded
                    Lever Rule
                                      (Table 3.6.1.1.2)
                           mg = Max(0.625 * 1.0, 0.625 * 0.85, 0.625 * 0.65) =
                                                                                        0.625
                           Modify for Skew:
                                      skew correction =
                                                                    0.676
                                      mg = 0.625 * 0.676 =
                                                                     0.423
                     Equation
                          e = 0.77 + \left(\frac{d_e}{9.1}\right)
                          e = 0.77 + (2.0/9.1) =
                                                                 0.990
                          g = e^*gM_{int2+Eq}
                           g = 0.99 * 0.537 =
                                                     0.532
                           Skew Correction included in gM(interior).
                     Range of Applicability (ROA) Checks
                                                                     Interior ROA is implicitly applied to the exterior beam.
                          Check Interior Beam ROA:
                                                                 OK
                           Check d_e: -1.0' \leq 2.0' \leq 5.5'
                                                                OK
                           Check N<sub>b</sub>: 6 ≠ 3
                                                                 OK
                     Use Equation from Table 4.6.2.2.2d-1 because all criteria is OK.
                     gM_{ext2+} =
                                      0.532
          TxDOT Policy states gM<sub>Exterior</sub> must be ≥ gM<sub>interior</sub>
                     gMinterior =
                                     0.537
          TxDOT Policy states gM_{Exterior} must be \ge m \cdot N_L \div N_b
                     m \cdot N_L \div N_b = 0.85 * 3 / 6 =
                                                                    0.425
          Is OH ≤ S/2 ? Yes
          Is W ≥ 20ft ? Yes
      >> TxDOT Policy states that if OH ≤ S/2, gM<sub>Exterior</sub> is gM<sub>interior</sub>.
          TxDOT Policy states that if OH > S/2 and W < 20ft, gM<sub>Exterior</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>interior</sub>, and
                     m·NI ÷Nn
          TxDOT Policy states that if OH > S/2 ans W \ge 20ft, gM<sub>Extensi</sub> is the Maximum of: gM<sub>ext1</sub>, gM<sub>ext2+</sub>, gM<sub>mienor</sub>
                     and m·NL+NE
           gM<sub>exterior</sub> = 0.537
```



| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|--------------------------------|---|----------------------------------|-------------------------------|---|-------------------|------------|------------------|-----------------------|------------------|
| DIVISION Descrip: | ITBC Design Exa | nple 4, Span 1 & | 3 | File: | Ex4 Span | 1_distribu | ution factors.xl | Sheet: | 7 01 8 |
| LEVER RULE | S | = 8.0 ft | | | | | | | |
| INTERIOR (con't) | | | | | | | | | |
| For 18 ≤ S < 22: One Lane = | $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S}$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{s-4}{s} + \frac{s-10}{s}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S-16}{S}$ | | | = 0.625 | | |
| For 22 ≤ S ≤ 24: One Lane = | $\frac{16}{32}\left(1+\frac{S-6}{S}\right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{-18}{s}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S-16}{S}$ | $+\frac{S-22}{S}$ | | = -1.500 | | |
| | | | | P T T T T T T T T T T T T T T T T T T T | | | Bail Width | S = OH = - BW - | 8.0 ft 3.0 ft |
| Ļ | он — — — — | - s | | | | | X = S+OH-F | = HW = RW-2ft = | 8.0 R |
| For X < 6: One Lane = | $\frac{16}{32} \left(\frac{X}{S} \right)$ | | | | | | = 0.500 | | |
| For 6 ≤ X < 12: One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-C}{S}\right)$ | •) | | | | | = 0.625 | | |
| For 12 ≤ X < 18; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ |) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $+\frac{X-12}{S}$ | | | | | = 0.375 | | |

| RIDGE County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 LRFD Spe |
|--------------------------------|---|--|----------------------------------|--|--------------------------------|------------------------------|-----------------|---------------|
| IVISION Descrip: | ITBC Design Exa | mple 4, Span 1 | & 3 | File: | Ex4 Span | Date: | ution_factors.x | Sheet: 8 of 8 |
| 10.120 Z.110 | | | | | | | | |
| LEVER RULE | | | | | | | | |
| EXTERIOR (con't |) S: | = 8.0 f | Ê | OH = | 3.0 ft | 0 | | |
| | RW | = 1.0 f | X = S + C | OH-RW-2ft = | 8.0 ft | | | |
| For 18 ≤ X < 24: | 16/V V- | 63 | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} \pm \frac{x-s}{s}\right)$ | <u> </u> | | | | | = 0.625 | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\left(\frac{18}{S}\right)$ | | | | = =0.250 | |
| For 24 ≤ X < 30: | 167 Y Y - | 5) | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-s}{s}\right)$ | <u> </u> | | | | | = 0.625 | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X-12}{S} + \frac{X}{S}$ | $\left(\frac{t-18}{s}\right)$ | | | | = -0.250 | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-1}{S}\right)$ | $\frac{6}{S} + \frac{X - 12}{S} + \frac{3}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | <u>14</u>) | | | = -1.250 | |
| For 30 ≤ X < 36: | 16 (X X -) | 6) | | | | | | |
| One Lane = | $\frac{13}{32}\left(\frac{\pi}{s} + \frac{\pi}{s}\right)$ | 5 | | | | | = 0.625 | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{s} + \frac{x-12}{s} + \frac{x}{s}$ | $\left(\frac{-18}{s}\right)$ | | | | = -0.250 | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-1}{S}\right)$ | $\frac{6}{S} + \frac{X - 12}{S} + \frac{S}{S}$ | $\frac{C-18}{S} + \frac{X-2}{S}$ | $\frac{4}{s} + \frac{X-30}{S}$ | | | = -2.625 | |
| For 36 ≤ X < 42: One Lane = | $\frac{16}{22}\left(\frac{X}{c}+\frac{X-c}{c}\right)$ | <u>e</u>) | | | | | = 0.625 | |
| | 16/X X = 0 | 5 X - 12 X | (-18) | | | | | |
| Two Lanes = | $\frac{1}{32}\left(\frac{1}{s} + \frac{1}{s}\right)$ | \$ | S) | | | | = -0.250 | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-S}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{C-18}{S} + \frac{X-2}{S}$ | $\frac{4}{4} + \frac{X-30}{S} \bigg)$ | | | = -2.625 | |
| Four Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{6}{5} + \frac{X-12}{S} + \frac{3}{5}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{S} + \frac{X-30}{S} + \frac{1}{S}$ | $\left(\frac{x-36}{s}\right)$ | | = -4.375 | |
| For 42 ≤ X ≤ 48: One Lane = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x}{s}\right)$ | <u>6</u>) | | | | | = 0.625 | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\left(\frac{18}{5}\right)$ | | | | = -0.250 | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{s} + \frac{\dot{X} - 30}{s} \bigg)$ | | | = -2.625 | |
| Four Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-S}{S}\right)$ | $\frac{6}{5} + \frac{X-12}{S} + \frac{2}{S}$ | $\frac{x-18}{s} + \frac{x-2}{s}$ | $\frac{4}{S} + \frac{X - 30}{S} + \frac{1}{S}$ | $\frac{X-36}{S} + \frac{X}{S}$ | $\left(\frac{-42}{s}\right)$ | = -6.500 | |
| INTERIOR | | - | | EXTER | IOR | | | |
| One Lane Loaded | | = 0.625 | | One La | ne Loade | d | i e | 0.625 |
| Two Lanes Loade | d | = 0.875 | | Two La | nes Load | ed | | 0.625 |
| Three Lanes Load | led | - 0.875 | | Three L | anes Loa | ded | | 0.625 |
| Four Lanes Loads | h | - 0.875 | | Fourts | nee Load | bol | 1.12 | A COE |

4.5.15.4.2 Span 2



| DIDOC | County. | ANY OU DOUD | Highway: | Алу | Design: | BRG | Date: | 0/10/20 | 2017 | LHFD Spe |
|--------------|--------------------|--------------------------|--|------------------------------|------------------|------------------------|---------------------------|------------------|--------------|----------|
| IVISION | C-S-J: Descrip: | ITBC Design Exa | ID #: mple 4. Span 2 | XXXX | Ck Dsn: File: | Ex4 Sp | Date: an2 distribution | ution factors.xl | Rev. 10/18 - | 2 of 8 |
| INTER | IOR BE | AM: | | | L. Her | | | | Grident | |
| Shear I | L Distrib | ution Per Lane (| Table 4622 | 3a-1): | | | | | | |
| <u>onour</u> | Onela | ne Loaded | 10010 110.0.0. | <u>ou 17.</u> | | | | | | |
| | one Eu | Lever Bule | (Table 3.6.1 | 12) | | | | | | |
| | | ma = 0.6 | 25 * 1.2 = | 0.750 | | | | | | |
| | | Modify fo | r Skew: | | | | | | | |
| | | | skew correc | tion = | 1.284 | | | | | |
| | | | ma = 0.750 | * 1.284 = | 0.963 | | | | | |
| | | Equation | | | | | | | | |
| | | g = 0.36 | $5 + \left(\frac{S}{25}\right)$ | | | | | | | |
| | | g = 0.36 | + (8 / 25) = | 0.680 | | | | | | |
| | | Modify fo | or Skew: | | | | | | | |
| | | | skew correc | tion = | 1.284 | | | | | |
| | | | g = 0.680 * | 1.284 = | 0.873 | | | | | |
| | | Range of App | licability (ROA |) Checks | | | | | | |
| | | Check S | 3.5' ≤ 8.0' ≤ | 16.0' | OK | | | | | |
| | | Check ts | 4.5" ≤ 8.0" | ≤ 12.0" | OK | | | | | |
| | | Check L | 20' ≤ 106.5 | ' ≤ 240' | OK | | | | | |
| | | Check N | 5 6≥4 | | OK | | | | | |
| | | Use Equation | from Table 4. | 6.2.2.3a-1 k | ecause all | criteria is | S OK | | | |
| | | gV _{int1} = | 0.873 | | | | | | | |
| | Two or | More Lanes Lo | aded | | | | | | | |
| | | Lever Rule | (Table 3.6.1 | .1.2) | | | | | | |
| | | mg = Ma Modify fo | x(0.875 * 1.0, or Skew: | 0.875 * 0.8 | 5, 0.875 * 0 | .65) = | 0.875 | | | |
| | | | skew correc | tion = | 1,284 | | | | | |
| | | | mg = 0.875 | * 1.284 = | 1.124 | | | | | |
| | | Equation | 102 10 | > 2.0 | | | | | | |
| | | q = 0.2 | $+\left(\frac{s}{12}\right) - \left(\frac{s}{21}\right)$ | - | | | | | | |
| | | - 00 | (12) (35 | | 0.014 | | | | | |
| | | g = 0.2 + | (8/12) - (8/ | 35)~2.0 = | 0,814 | | | | | |
| | | would be | skew.correc | tion - | 1 284 | | | | | |
| | | | a = 0.814 * | 1 284 - | 1.045 | | | | | |
| | | Bange of App | licability (BOA | Chocks | /samo as 1 | or one l | ane load | (be | | |
| | | Hange or App | from Toble // | 2 0 0 0 0 1 | (Same as i | or one i | | suj | | |
| | | gV _{int2+} = | 1.045 | 0.2.2.98-11 | euduse all | unteria i: | S UN. | | | |
| | TXDOT | Policy states gV | Interior must be | ≥ m·NL÷Nb | | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85*3/6 | - | 0.425 | | | | | |
| | ls W≥2 | 20ft ? Yes | | | | | | | | |
| | TXDOT | Policy states the | at if $W < 20$ ft, g | gV _{interior} is th | ne Maximun | n of: gV _e | in and m | NL+Nb. | | |
| >> | TXDOT | Policy states that | at if $W \ge 20$ ft, g | gV _{Interior} is th | ne Maximun | n of: gV _{in} | n11, gVint2+ | m-NL÷No. | | |
| | -1/ | 1 0 4 5 | | | | | | | | |

| TXDOT | County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|----------|-------------------|--------------------------|---------------------------------------|---|---|------------|------------|---------------|------------|-------------------------|
| DIVISION | C-S-J: Descrip | ITBC Design Exa | ID #: mole 4. Span 2 | XXXX | Ck Dsn: | Ex4 So | Date: | ution factors | Rev. 10/18 | - (No Interin 3 of 8 |
| INTER | IOR BE | AM· | | | D. HOL | | | | in ondou | 0010 |
| Momen | t I I Dist | ribution Per Lan | e (Table 4.6 | 2.2.2h-1): | | | | | | |
| Momen | Onela | ne Loaded | C [140/C 4.0. | 2.2.20 1). | | | | | | |
| | One Eu | Lever Bule | (Table 3 F | 112) | | | | | | |
| | | ma = 0 f | 125 * 1 2 - | 0.750 | | | | | | |
| | | Modify f | or Skew: | 0.750 | | | | | | |
| | | thoury i | skew corr | ection = | 0.815 | | | | | |
| | | | ma = 0.75 | 0 * 0.815 = | 0.611 | | | | | |
| | | Equation | | | ~ 0.1 | | | | | |
| | | g = 0.0 | $6 + \left(\frac{S}{14}\right)^{0.4}$ | $\left(\frac{S}{L}\right)^{0.5} \left(\frac{K_s}{12L_s}\right)^{0.5}$ | <u>r</u> | | | | | |
| | | g = 0.06 | + (8/14)^0.4 | * (8/106.5)^0 | .3 * (1,271, | 611/(12 | 106.5*8 | ^3))^0.1 = | 0.453 | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corr | ection = | 0.815 | | | | | |
| | | | g = 0.453 | * 0.815 = | 0.369 | | | | | |
| | | Range of App | licability (RC | A) Checks | | | | | | |
| | | Check S | 3: 3.5' ≤ 8.0 | '≤ 16.0' | | OK | | | | |
| | | Gheck t | : 4.5" ≤ 8.0 |)" ≤ 12.0" | | OK | | | | |
| | | Check L | : 20'≤106 | .5' ≤ 240' | | OK | | | | |
| | | Check N | l _b : 6≥4 | | | OK | | | | |
| | | Check K | _g : 10,000 ≤ | 1,271,611 ≤ 7 | ,000,000 | OK | | | | |
| | | Use Equation | from Table | 4.6.2.2.2b-1 b | ecause all | criteria i | s OK | | | |
| | | gM _{int1} = | 0.369 | | | | | | | |
| | Two or | More Lanes Lo | baded | | | | | | | |
| | | Lever Rule | (Table 3.6 | 5.1.1.2) | | | | | | |
| | | mg = Ma | ax(0.875 * 1. | 0, 0.875 * 0.8 | 5, 0.875 * 0 | .65) = | 0.875 | | | |
| | | Modify f | or Skew: | | | | | | | |
| | | | skew corr | ection = | 0.815 | | | | | |
| | | | mg = 0.87 | 5 * 0.815 = | 0.713 | | | | | |
| | | Equation | (5) | 1.6 (s) 0.2 (| K)0.1 | | | | | |
| | | g = 0.0 | $75 + \left(\frac{5}{9.5}\right)$ | $\left(\frac{3}{L}\right)\left(\frac{1}{12}\right)$ | $\left(\frac{l_{g}}{Lt_{s}^{3}}\right)$ | | | | | |
| | | g = 0.07 Modify f | 5 + (8/9.5)^0 or Skew: | 0.6 * (8/106.5) | 0.2 * (1,27 | 1,611/(1 | 2*106.5* | 8^3))^0.1 = | 0.649 | |
| | | | skew corr | ection = | 0.815 | | | | | |
| | | | g = 0.649 | * 0.815 = | 0.529 | | | | | |
| | | Range of App | licability (RC | DA) Checks | (same as | for one I | ane load | ed) | | |
| | | Use Equation | from Table | 4.6.2.2.2b-1 b | ecause all | criteria i | s OK. | | | |
| | | gM _{int2+} = | 0.529 | | | | | | | |
| | TXDOT | Policy states gl | Ainterior must I | be≥m·NL÷Nb | | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85 * 3 / | 6 = | 0.425 | | | | | |
| | ls W ≥ 2 | 20ft ? Yes | | | | | | | | |
| | TXDOT | Policy states th | at if W < 201 | t, gM _{interior} is th | ne Maximur | n of: gM | Inti and m | NL+NL+Nb- | | |
| >> | TXDOT | Policy states th | at if W ≥ 20F | l, gM _{interior} is ll | e Maximun | n oli gM | man gMinte | ++ m·NL÷Nb | | |
| | gMinte | arior = 0.529 | | | | | | | | |

| XDOT | County: | ANY | Highway: | Алу | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|---------|-----------------------|------------------|---------------------------------------|-----------------|---------------------------|-------------|------------|------------------|--------------------|-----------|
| IVISION | C-S-J: Descrip | ITBC Design Fig | ID #: ample 4, Span 2 | XXXX | Ck Dsn: | Ex4 So | Date: | ution factors vi | Rev. 10/18 - | 4 of 8 |
| EXTER | IOR BE | AM. | | | Trings | Last opt | | | Ondot. | 4010 |
| Shear I | Distrib | ution Per Lane | (Table 4.6.2.5 | 3h-11 | | | | | | |
| oncar c | Onela | ne Loaded | 11000 4.0.2.2 | | | | | | | |
| | One Eu | Lever Bule | (Table 3.6 | 1.1.2) | | | | | | |
| | | ma = 0.0 | 625 * 1.0 = | 0.625 | TYDOTUS | es a mul | tinle pres | ence factor | of 1 0 for a | de. |
| | | Modify f | or Skew: | 0.040 | lane loade | d on the | exterior | beam. | ur na iar a | (IP) |
| | | | skew corre | ection = | 1.284 | | | | | |
| | | | ma = 0.625 | 5*1.284 = | 0.803 | | | | | |
| | | Use Lever Bi | ile as per AA | SHTOLBED | Table 4.6.2 | 2.3b-1 | | | | |
| | | aVert = | 0.803 | 2002 2000 | | | | | | |
| | | Maria Lamas L. | and a d | | | | | | | |
| | I WO OF | More Lanes Lo | VTeble 2.C | 1101 | | | | | | |
| | | Lever Hule | (Table 3.6. | 1.1.2) | E 0 005 * 0 | CEL | O PDE | | | |
| | | Modify f | ax (0.025 1.0 | , 0.025 0.0 | 5, 0.025 0. | .03) = | 0.020 | | | |
| | | NOUTY 1 | skow corre | ection - | 1 284 | | | | | |
| | | | mn - 0.62 | 5 1 284 - | 0.803 | | | | | |
| | | Equation | mg = 0.02. | 1.204- | 0.000 | | | | | |
| | | d - dist | h/w CI web | to curb | | | | | | |
| | | $d_e = OH$ | - Bail Width | to ourb | | | | | | |
| | | d. = | 3ft - 1ft = | 201 | i. | | | | | |
| | | -6 | (d) | | | | | | | |
| | | e = 0.6 | $+\left[\frac{\alpha_{e}}{10}\right]$ | | | | | | | |
| | | e-06. | + (2 0/10) - | 0.800 | | | | | | |
| | | 0 = 0.0 | / | 0.000 | | | | | | |
| | | g = e gv | int2+Eq | 0.000 | | | | | | |
| | | g = 0.80 | 0 1.045 = | 0.836 | linteries) | | | | | |
| | | Skew C | orrection is in | | (intenor). | DOAL | | | and the second | |
| | | Range of App | ntorior Poom | A) Checks | Interior | HUAIS | implicitiy | applied to th | te exterior t | beam. |
| | | Check | | 1 < 5 5' | OK | | | | | |
| | | Check N | $h_{e^{-1.0} \le 2.0}$ | 2 0.0 | OK | | | | | |
| | | Lise Equation | from Table / | 6223h11 | acquea all r | vritorio is | OK | | | |
| | | aV | 0.836 | .0.2.2.00-11 | lecause and | anena is | OR. | | | |
| | T-DOT | g • ext2+ - | 0.000 | | | | | | | |
| | IXDOT | Policy states g | VEdenar must b | e 2 gV interior | | | | | | |
| | TUDOT | gvinterior = | 1.045 | A. M. M. | | | | | | |
| | TXDOT | m N :N - | COF to / C | e ≤ m·w[÷w[| 0.405 | | | | | |
| | - | | 0.85 376 |) = | 0.420 | | | | | |
| | Is W > 1 | 20ft ? Yes | | | | | | | | |
| >> | TXDOT | Policy states th | at if OH ≤ S/2 | QVENTATION IS | gV _{interior} | | | | | |
| | TXDOT | Policy states th | at if OH > S/2 | and W < 20 | It, gV Existing I | s the Ma | aximum o | f: gVavia aV | interior, and | |
| | Conce do | m·Ni÷Nn. | | | Chighter - | | | - W WIT DI | Contract Local | |
| | TXDOT | Policy states th | at if OH > S/2 | ans W≥20 | ft, qV _{Externe} | s the Ma | ximum o | ft gVexti, gV | exiza, qVinterio | |
| | and the second second | and m N +N | | 100.000 0.00 | Ser Paterini, | E NOT OUT | | 9 . BALL 3 . | enter er - milling | |
| | | SHU HINN TINE | | | | | | | | |

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|---------|-------------------|--------------------------|-------------------------------|-------------------------------|-------------------|-------------|------------|------------------|-----------------|-----------------------|
| IVISION | C-S-J: Descrip | ITBC Design Exa | ID #: mole 4. Span 2 | XXXX | Ck Dsn: | Ex4 So | Date: | ition factors x | Rev. 10/18 - | (No Interin 5 of 8 |
| EXTER | NOR BE | AM: | aniple if opentia | | D. no. | | | | Ondota | 0 01 0 |
| Momen | t I I Dist | ribution Per Lan | e (Table 4.6.2 | 2 2d-1): | | | | | | |
| moment | Onela | ne Loaded | 0 11000 4.0. | inches (). | | | | | | |
| | Unit Lu | Lever Bule | | | | | | | | |
| | | mg = 0.0 | 525 * 1.0 = | 0.625 | TXDOT US | es a mul | tiple pres | sence factor | of 1.0 for a | ñe. |
| | | Modify f | or Skew: | | lane loade | d on the | exterior | beam. | er ne ler e | (IEC |
| | | | skew corre | ction = | 0.815 | | | | | |
| | | | mg = 0.625 | 5 * 0.815 = | 0.509 | | | | | |
| | | Use Lever Ru | le as per AAS | SHTO LRFD | Table 4.6.2 | 2.2d-1. | | | | |
| | | gM _{ext1} = | 0.509 | | | | | | | |
| | Two or | More Lanes L | naded | | | | | | | |
| | | Lever Rule | (Table 3.6. | 1.1.2) | | | | | | |
| | | mg = Ma | ax(0.625 * 1.0 | . 0.625 * 0.8 | 35, 0.625 * 0 | .65) = | 0.625 | | | |
| | | Modify f | or Skew: | | | and the | | | | |
| | | | skew corre | ction = | 0.815 | | | | | |
| | | | mg = 0.625 | 5 * 0.815 = | 0.509 | | | | | |
| | | Equation | | | | | | | | |
| | | 0.7 | $\frac{d}{d_e}$ | | | | | | | |
| | | e = 0.7 | (+(9.1) | | | | | | | |
| | | e = 0.77 | + (2.0/9.1) = | | 0.990 | | | | | |
| | | g = e*gN | Aint2+Eq | | | | | | | |
| | | g = 0.99 | * 0.529 = | 0.524 | | | | | | |
| | | Skew G | orrection inclu | ided in gM(i | nterior). | | | | | |
| | | Range of App | licability (RO | A) Checks | Interior | ROA is | implicitly | applied to th | ne exterior b | beam. |
| | | Check I | nterior Beam | ROA: | OK | | | | | |
| | | Check d | l _e : -1.0' ≤ 2.0' | '≤ 5.5' | OK | | | | | |
| | | Check N | l _b : 6 ≠ 3 | | OK | | | | | |
| | | Use Equation | from Table 4 | 6.2.2.2d-1 | because all o | criteria is | OK | | | |
| | | gM _{ext2+} = | 0.524 | | | | | | | |
| | TxDOT | Policy states gl | M _{Exterior} must b | $e \ge gM_{interior}$ | | | | | | |
| | | gM _{interior} = | 0.529 | | | | | | | |
| | TXDOT | Policy states gf | M _{Exterior} must b | e≥m·N _L ÷N | ь | | | | | |
| | | $m \cdot N_L \div N_b =$ | 0.85 * 3 / 6 | = | 0.425 | | | | | |
| | ls OH ≤ | S/2 ? Yes | | | | | | | | |
| | ls W ≥ 2 | 20ft? Yes | | | | | | | | |
| >> | TXDOT | Policy states th | at if $OH \leq S/2$ | , givi _{Exterior} is | gMinterior: | the M | automore a | ti al la al | A and | |
| | TXDOT | m M . M | at 11 OFI > 5/2 | | Jit, giviExterior | is the Ma | aximumic | or: giviexit, gi | Minterior, and | |
| | TYDOT | Policy states th | at if OH > SP | anc W > 20 | H all | r the M | avimum c | t all al | 4 | |
| | TAUGT | and m.N. ±N. | unii 011- 012 | | And And Extension | | annunn u | Simexiii Si | rext2++ 9141mle | norr |
| | oM. | 0.520 | | | | | | | | |
| | giviext | erior = 0.529 | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |



| TXDOT County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 | LRFD Spec |
|--------------------------------|--|----------------------------------|-------------------------------|------------------------------------|-------------------|------------|--------------------------|--------------------|------------------|
| DIVISION Descrip: | ITBC Design Exar | nple 4, Span 2 | 10000 | File: | Ex4_Span | 2_distribu | ution factors.xl | Sheet: | 7 of 8 |
| LEVER RULE | S | = 8.0 ft | | | | | | | |
| INTERIOR (con't) | | | | | | | | | |
| For 18 ≤ S < 22: One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right.$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{s-4}{s} + \frac{s-10}{s}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{-18}{s}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{s} + \frac{s-16}{s}$ | | | = 0.625 | | |
| For 22 ≤ S ≤ 24; One Lane = | $\frac{16}{32} \left(1 + \frac{S-6}{S} \right)$ | | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ |) | | | | = 0.750 | | |
| Three Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\left(\frac{-18}{s}\right)$ | | | = -0.125 | | |
| Four Lanes = | $\frac{16}{32}\left(1+\frac{S-6}{S}+\right)$ | $\frac{S-4}{S} + \frac{S-10}{S}$ | $+\frac{S-12}{S}+\frac{S}{S}$ | $\frac{-18}{S} + \frac{S - 16}{S}$ | $+\frac{S-22}{S}$ | | = -1.500 | | |
| | | | | | | | | S = OH = | 8.0 ft 3.0 ft |
| L | он — — — — — | s | | . milja | | | Rail Width X = S+OH-F | = RW = RW-2ft = | 1.0 ft 8.0 ft |
| For X < 6: One Lane = | $\frac{16}{32}\left(\frac{X}{S}\right)$ | | | | | | = 0.500 | | |
| For 6 ≤ X < 12; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-\ell}{S}\right)$ | ·) | | | | | ≈ 0.625 | | |
| For 12 ≤ X < 18; One Lane = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ |) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $+\frac{X-12}{S}$ | | | | | = 0.375 | | |
| County: | ANY | Highway: | Any | Design: | BRG | Date: | 8/15/20 | 2017 LRFD S | Spece |
|--------------------------------|---|--|---------------------------------|--|--------------------------------|------------------------------|------------------|-------------|-------|
| IVISION Descrip: | ITBC Design Exa | mple 4, Span 2 | 14444 | File: | Ex4 Spana | 2_distrib | ution_factors.xl | Sheet: 8 of | 8 |
| 10.120 Z.110 | | | | | | | | | |
| LEVER RULE | | | | | | | | | |
| EXTERIOR (con't |) S = | = 8.0 ft | | OH = | 3.0 ft | | | | |
| | RW = | = 1.0 ft | X = S + C | H-RW-2ft = | 8.0 ft | | | | |
| For 18 ≤ X < 24: | K/V V | 63 | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} \pm \frac{x-s}{s}\right)$ | <u>*)</u> | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{5} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{-18}{S}$ | | | | = -0.250 | | |
| For 24 ≤ X < 30: | 167 X X-1 | 5) | | | | | | | |
| One Lane = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-s}{s}\right)$ | 2) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{-18}{S}$ | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-1}{S}\right)$ | $\frac{6}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{-18}{S} + \frac{X-2}{S}$ | $\frac{4}{2}$ | | | = -1.250 | | |
| For 30 ≤ X < 36: | 16 (X X -) | 5) | | | | | | | |
| One Lane = | $\frac{13}{32}\left(\frac{\pi}{s} + \frac{\pi}{s}\right)$ | -) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X-12}{S} + \frac{X}{S}$ | $\frac{-18}{s}$ | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{-18}{S} + \frac{X-2}{S}$ | $\frac{4}{s} + \frac{X-30}{S}$ | | | = -2.625 | | |
| For 36 ≤ X < 42: One Lane = | $\frac{16}{22}\left(\frac{X}{c} + \frac{X-c}{c}\right)$ | 2) | | | | | = 0.625 | | |
| | $\frac{16}{x} = \frac{16}{x}$ | x =12 x | -18) | | | | | | |
| Two Lanes = | $\frac{10}{32}\left(\frac{x}{s} + \frac{x-s}{s}\right)$ | $\frac{1}{s} + \frac{x - 12}{s} + \frac{x}{s}$ | s) | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{-18}{S} + \frac{X-2}{S}$ | $\frac{4}{9} \div \frac{X-30}{S}$ | | | = -2.625 | | |
| Four Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{-18}{S} + \frac{X-2}{S}$ | $\frac{4}{S} + \frac{X-30}{S} + \frac{1}{S}$ | $\left(\frac{X-36}{S}\right)$ | | = -4.375 | | |
| For 42 ≤ X ≤ 48: One Lane = | $\frac{16}{32}\left(\frac{x}{s} + \frac{x-s}{s}\right)$ | <u>6</u>) | | | | | = 0.625 | | |
| Two Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{-18}{S}$ | | | | = -0.250 | | |
| Three Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{5}{S} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{-18}{S} + \frac{X-2}{S}$ | $\frac{4}{s} + \frac{\dot{X} - 30}{s}$ | | | = -2.625 | | |
| Four Lanes = | $\frac{16}{32}\left(\frac{X}{S} + \frac{X-6}{S}\right)$ | $\frac{6}{5} + \frac{X - 12}{S} + \frac{X}{S}$ | $\frac{-18}{s} + \frac{x-2}{s}$ | $\frac{4}{S} + \frac{X - 30}{S} + \frac{1}{S}$ | $\frac{X-36}{S} + \frac{X}{S}$ | $\left(\frac{-42}{s}\right)$ | = -6.500 | | |
| INTERIOR | | - | | EXTER | IOR | | | | |
| One Lane Loaded | | = 0.625 | | One La | ne Loaded | ł | | 0.625 | |
| Two Lanes Loade | d | = 0.875 | | Two La | nes Loade | d | = | 0.625 | |
| Three Lanes Load | led | - 0.875 | | Three L | anes Load | ded | | 0.625 | |
| Four Lanes Loade | d | = 0.875 | | Fourla | nes Loade | be | | 0.625 | |

| <u> </u> | Highway: | ANY | | | Dealart | ppc lo | h Deer | PDC | |
|--------------------------------|-----------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|----------------|
| Texas | C-S-J: | ****** | | | Design: | BRG | k Dsn: | BHG | |
| of Transportation | Bridge | Division | B | ev: 09/26/08 | B Date: Aug-20 | | | Aug-20 | |
| CONCRETE SECTION SHEA | AR CAP | ACITY BY A | ASHTO L | RFD BRID | GE DESIG | N SPECIFIC | ATIONS, FO | URTH EDIT | ION, 200 |
| Resistance Factors: | | | Units: | US | | | | | |
| 4v = | 0.9 | | | | | | | | |
| φ _M = | 0.9 | 0 | | | | | | | |
| φ _N = | 0.75 | | | | | | | | |
| Concrete: | _ | | Mild Steel: | | | Prestressed | Steel: | - | |
| fc= | 5 | ksi | fy = | 60 | ksi | fpu = | 270 k | si | |
| Ec = | 4070 | ksi | Es = | 29000 | ksi | Ep = | 28500 k | si | |
| | _ | | | | SECTIONS | | | | |
| | Units | 8 | 12 | 32 | 36 | 56 | 60 | 80 | 84 |
| Input Data | _ | | | _ | | | _ | | |
| Bending moment, Mu | kip-ft | 918.9 | 1278.8 | 1108.4 | 769.1 | 769.1 | 1108.4 | 1278.8 | 91 |
| Shear force, Vu | kip | 255 | 270.8 | 165.7 | 481.8 | 264.6 | 283.7 | 165 | 44 |
| Axial force, Nu (+ if tensile) | kip | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Web width, bv | in | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.00 | 42.0 |
| Shear depth, dv | in | 80.59 | 80.59 | 80.59 | 80.59 | 80.59 | 80.59 | 80.59 | 80.5 |
| Mild steel reinf. area, As | in^2 | 10.92 | 10.92 | 10.92 | 10.92 | 10.92 | 10.92 | 10.92 | 10.9 |
| Conc area on tension side, Ac | in^2 | 1785 | 1785 | 1785 | 1785 | 1785 | 1785 | 1785 | 178 |
| Area of stirrups, Av | in^2 | 1.76 | 1,76 | 1.76 | 1.76 | 1.76 | 1,76 | 1.76 | 1.7 |
| Stirrup spacing, s | in | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6. |
| Prestressed steel area, Aps | in^2 | 0 | 0 | .0 | 0 | 0 | 0 | 0 | |
| Prestress shear, Vp | kip | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Average prestress, fps | ksi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Torsional moment, Tu | kip-ft | 830 | 415 | 415 | 830 | 830 | 415 | 415 | 83 |
| Shear flow area, Ao | in^2 | 3493.5 | 3493.5 | 3493.5 | 3493.5 | 3493.5 | 3493.5 | 3493.5 | 3493. |
| Area of one leg of stirrup, At | in^2 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.4 |
| Perimeter of stirrup, Ph | în | 334 | 334 | 334 | 334 | 334 | 334 | 334 | 33 |
| Calculated Values | _ | | | | | | | | |
| Vc | kip | 576.4 | 569.2 | 624.2 | 533.3 | 571.6 | 564.4 | 614.7 | 533. |
| Vs | kip | 1784.9 | 1812.7 | 2077.9 | 1569.9 | 1763.2 | 1791.6 | 2039,4 | 1569. |
| ¢Vn € _v | kip | 2125 7.10E-04 | 2144 7.48E-04 | 2432 4.86E-04 | 1893 1.00E-03 | 2101 7.33E-04 | 2120 7.80E-04 | 2389 5.20E-04 | 189 1.00E-0 |
| 0 | den | 33.20 | 33.70 | 30.30 | 36.40 | 33.50 | 34.00 | 30.75 | 36.4 |
| 8 | oog | 2,410 | 2,380 | 2,610 | 2,230 | 2,390 | 2,360 | 2.570 | 2.23 |
| Reg'd Shear reinf. Av/S | in^2/in | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.00 |
| Req'd Torsion reinf. At/S | in^2/in | 0.017 | 0.009 | 0.008 | 0.019 | 0.017 | 0.009 | 0.008 | 0.01 |
| Maximum stirrup spacing, Smax | in | 24.0 | 24.0 | 24.0 | 22.5 | 24.0 | 24.0 | 24.0 | 22. |
| Conclusion | | | | | | | - | _ | |
| Shear Re | inforcing | OK | OK |
| Longitudinal Reinforcing | | OK | OK | OK | OK | OK | OK | OF | OK |

4.5.15.5 Concrete Section Shear Capacity Spreadsheet

4.5.15.6 Bent Cap Details





CHAPTER 5: SUMMARY AND CONCLUSIONS

5.1 SUMMARY OF THE RESEARCH WORK

The summary of the test and analytical results on inverted-T bent cap specimens under the scope of this project work is presented below.

- Bent 2, Bent 6, and Bent 7 of a seven-span bridge, which are under construction on Donigan Road over IH 10 near Brookshire in Waller County, are selected. These bent caps have skew angles of 43°, 33°, and 33°, respectively.
- 2. The preliminary finite element (FE) analysis of the selected skew ITBCs is performed using ABAQUS to better understand the overall structural behavior of skew reinforcement in actual ITBCs and to determine critical loading patterns during the load tests and crucial strain gauge locations.
- 3. Stresses in skew transverse reinforcement at the service load and at the ultimate state are obtained according to the finite element results. The displacement and principal tensile strains of the bent caps are studied to understand the structural behavior of actual ITBCs designed with skew transverse reinforcement.
- 4. To investigate the structural performance of skew ITBCs with traditional transverse reinforcement and with skew transverse reinforcement, a total of ninety-six large-scale specimens are modeled in ABAQUS.
- 5. Design parameters are the skew angle (43° or 33°), detailing of transverse reinforcements (skew transverse reinforcement or traditional transverse reinforcement), end bars (with or without U1 Bars, U2 Bars, U3 Bars, and G Bars), size of S Bars (minimum, current design, 20% more or 40% more than current design), size of G Bars (No. 3 to No. 7 bars), and concrete strength (5 or 7 ksi). Based on these parameters, the displacement and the stiffness at the service load, the principal tensile strain of concrete and crack widths at the service load, and the ultimate capacities of the bent caps are investigated.
- 6. Cost-benefit analyses of ninety-six specimens are conducted considering the design and construction costs of ITBCs.
- 7. According to the parametric analysis results, a set of design recommendations for skew ITBCs is presented.
- Following AASHTO LRFD Bridge Design Specifications, 8th Ed. (2017) and TxDOT Bridge Manual - LRFD (January 2020), four ITBC design examples with different skew angles (0°, 30°, 45°, and 60°) are presented with the step by step procedures.

5.2 CONCLUSIONS

After performing the FE analysis on the actual ITBC structures, the conclusions are presented below.

1. For the selected skew ITBCs in this research, it is observed that the critical locations to paste the strain gauges and attach LVDTs are the cantilever end faces of the bent caps.

- 2. It is also observed that all the bent caps with skew transverse reinforcing are safe under service and ultimate state loading.
- 3. According to the cost-benefit analysis results, the skew transverse reinforcement (Case 1) provides better structural performance, reduced number of cracks and reduced crack width compared to the traditional transverse reinforcement (Case 2 and Case 3) with notably reduced construction cost. Therefore, the skew transverse reinforcement can well be used for the design of skewed ITBCs.
- 4. The increase of the S Bar area notably enhances the stiffness and ultimate strength. In addition, the increase of the S Bar area also reduces the crack width. The increase of the S Bar area will contribute notably to the construction cost. Based on the parametric simulation results, the current design of the S bar area is adequate for structural safety and crack resistance.
- 5. Having end bars (U1 Bars, U2 Bars, U3 Bars, and G Bars) significantly decreases the crack width on skew ITBCs.
- 6. The increase of the G Bar area notably reduces the maximum crack width with a negligible influence on the stiffness, ultimate strength, and construction cost. The current design of the G Bar (No. 7 Bars) is adequate for crack control.
- 7. When the concrete strength increases from 5 ksi to 7 ksi, the ultimate strength and the stiffness of ITBCs increase with reduced crack width. In addition, the influence of concrete strength on the construction cost is negligible.
- 8. Based on the research results, the RT completed four design examples of skewed ITBCs with various skew angles $(0^{\circ}, 30^{\circ}, 45^{\circ}, \text{ and } 60^{\circ})$.

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APPENDIX 1

Updates from AASHTO LRFD 2010 to AASHTO LRFD 2017

This document shows the revisions from AASHTO LRFD Bridge Design Specifications, 5th Ed. (2010) to AASHTO LRFD Bridge Design Specifications, 8th Ed. (2017) for the sections, equations, and tables that are used in the design of the inverted Tee bent cap. "NR" denotes no revision.

| | AASHTO LRFD 2010 | AASHTO LRFD 2017 | | | |
|--|--|-------------------|---|--|--|
| Section Number | Title or Content | Section Number | Title or Content | | |
| Eq. 1.3.2.1-1 | $\sum \eta_i \gamma_i Q_i \le \Phi R_n = R_r$ | NR | NR | | |
| 3.4.1 | Load Factors and Combinations | NR | NR | | |
| 3.6.1.1.2 | Multiple Presence of Live Load | NR | | | |
| Table 3.6.1.1.2-1 | Multiple Presence Factors, m | NR | NR | | |
| 3.6.1.2.1 | Design Vehicular Live Load - General | NR | NR | | |
| 3.6.1.2.2 | Design Vehicular Live Load - Design Truck | NR | NR | | |
| 3.6.1.2.4 | Design Vehicular Live Load - Design Lane Load | NR | NR | | |
| 3.6.1.3 | Design Vehicular Live Load - Application of Design Vehicular Live Loads | NR | NR | | |
| Table 3.6.2.1-1 | Dynamic Load Allowance, IM | NR | NR | | |
| Table 4.6.2.2.1-1 | Common Deck Superstructures | NR | NR | | |
| Eq. 4.6.2.2.1-1 | $K_g = n\big(I + Ae_g^2\big)$ | NR | NR | | |
| <u>Table</u> <u>4.6.2.2.2e-</u> <u>1</u> | Reduction of Load Distribution Factors for Moment in Longitudinal Beams on Skewed Supports | NR | NR | | |
| Table 4.6.2.2.3a- 1 | Distribution of Live Load for Shear in Interior Beams | NR | NR | | |
| Table 4.6.2.2.3b- 1 | Distribution of Live Load for Shear in Exterior Beams | NR | NR | | |
| $\frac{\underline{\text{Table}}}{\underline{4.6.2.2.3c-}}$ | Correction Factors for Load Distribution Factors for Support Shear of the Obtuse Corner | NR | NR | | |
| Eq. 5.4.2.4-1 | $E_c = 33000 K_1 w_c^{1.5} \sqrt{f_c}$ | NR | $E_c = 120000 K_1 w_c^{2.0} f_c^{0.33}$ | | |

Table A1.1 Comparison between AASHTO (2010) and AASHTO (2017)

| | AASHTO LRFD 2010 | AASHTO LRFD 2017 | | | |
|--------------------|---|--------------------|---|--|--|
| Section Number | Title or Content | Section Number | Title or Content | | |
| 5.5.4.2.1 | Resistance Factors | 5.5.4.2 | Some revisons for lightweight concrete | | |
| 5.7.2.1 | Assumptions for Strength and Extreme Event Limit States - General | 5.6.2.1 | NR | | |
| 5.7.2.2 | Assumptions for Strength and Extreme Event Limit States – Rectangular Stress Distribution | 5.6.2.2 | α_1 to the description of the compression zone | | |
| Eq. 5.7.3.1.2-3 | $c = \frac{A_{ps}f_{ps} + A_sf_s - A'_sf'_s - 0.85f_c(b - b_w)h_f}{0.85f_c\beta_1 b_w}$ | Eq. 5.6.3.1.2-3 | $C = \frac{A_{ps}f_{ps} + A_sf_s - A_sf_s - \alpha_1f_c(b - b_w)h_f}{\alpha_1f_c\beta_1b_w}$ | | |
| Eq. 5.7.3.1.2-4 | $c = \frac{A_{ps}f_{ps} + A_{s}f_{s} - A'_{s}f'_{s}}{0.85f_{c}\beta_{1}b}$ | Eq. 5.6.3.1.2-4 | $C = \frac{A_{ps}f_{ps} + A_{s}f_{s} - A'_{s}f'_{s}}{\alpha_{1}f_{c}\beta_{1}b}$ | | |
| Eq. 5.7.3.2.1-1 | $M_r = \Phi M_n$ | Eq. 5.6.3.2.1-1 | NR | | |
| Eq. 5.7.3.2.2-1 | $M_{n} = A_{ps}f_{ps}\left(d_{p} - \frac{a}{2}\right) + A_{s}f_{s}\left(d_{s} - \frac{a}{2}\right) - A'_{s}f'_{s}\left(d'_{s} - \frac{a}{2}\right) + 0.85f_{c}(b - b_{w})h_{f}\left(\frac{a}{2} - \frac{h_{f}}{2}\right)$ | Eq. 5.6.3.2.2-1 | $M_n = A_{ps} f_{ps} \left(d_p - \frac{a}{2} \right) + A_s f_s \left(d_s - \frac{a}{2} \right) - A'_s f'_s \left(d'_s - \frac{a}{2} \right) + \alpha_1 f_c (b - b_w) h_f \left(\frac{a}{2} - \frac{h_f}{2} \right)$ | | |
| Eq. 5.7.3.3.2-1 | $M_{cr} = \gamma_3 \left[\left(\gamma_1 f_r + \gamma_2 f_{cpe} \right) S_c - M_{dnc} \left(\frac{S_c}{S_{nc}} - 1 \right) \right]$ | Eq. 5.6.3.3- 1 | NR | | |
| 5.7.3.4 | Control of Cracking by Distribution of Reinforcement | 5.6.7 | NR | | |
| Eq. 5.7.3.4-1 | $s \le \frac{700\gamma_e}{\beta_{s}f_{ss}} - 2d_c$ | Eq. 5.6.7-1 | NR | | |
| Eq. 5.7.3.4-2 | $A_{sk} \ge 0.012(d_l - 30) \le \frac{A_s + A_{ps}}{4}$ | Eq. 5.6.7-3 | NR | | |
| 5.7.5 | Bearing | 5.6.5 | NR | | |
| Eq. 5.7.5-1 | $P_r = \Phi P_n$ | Eq. 5.6.5-1 | NR | | |
| Eq. 5.7.5-2 | $P_n = 0.85 f_c A_1 m$ | Eq. 5.6.5-2 | NR | | |
| Eq. 5.7.5-3 | $m = \sqrt{\frac{A_2}{A_1}} \le 2.0$ | Eq. 5.6.5-3 | NR | | |
| 5.8.2.1 | Shear and Torsion – General Requirements – General | 5.7.2.1 | NR | | |
| Eq. 5.8.2.1-6 | $V_{u_{eq}} = \sqrt{V_{u}^{2} + \left(\frac{0.9p_{h}T_{u}}{2A_{o}}\right)^{2}}$ | Eq. B5.2-1 | "Equivalent factored shear force" is placed into Appendix B5 as "effective shear force" with no revision in the equations | | |
| 5.8.2.5 | Shear and Torsion – Minimum Transverse Reinforcement | 5.7.2.5 | NR | | |

| | AASHTO LRFD 2010 | AASHTO LRFD 2017 | | |
|--------------------|--|--------------------|--|--|
| Section Number | Title or Content | Section Number | Title or Content | |
| Eq. 5.8.2.5-1 | $A_v \ge 0.0316\sqrt{f_c} \frac{b_v s}{f_y}$ | Eq. 5.7.2.5- 1 | $A_v \ge 0.0316\lambda\sqrt{f_c}\frac{b_v s}{f_y}$ | |
| 5.8.2.7 | Shear and Torsion – Minimum Spacing of Transverse Reinforcement | 5.7.2.6 | NR | |
| Eq. 5.8.2.7-1 | $s_{max} = 0.8d_{\nu} \le 24.0in$ | Eq. 5.7.2.6- 1 | NR | |
| Eq. 5.8.2.7-2 | $s_{max} = 0.4d_{\nu} \le 12.0in$ | Eq. 5.7.2.6- 2 | NR | |
| 5.8.2.9 | Shear and Torsion – Shear Stress on Concrete | 5.7.2.8 | NR | |
| Eq. 5.8.2.9-2 | $d_e = \frac{A_{ps}f_{ps}d_p + A_sf_y d_s}{A_{ps}f_{ps} + A_sf_y}$ | Eq. 5.7.2.8- 2 | NR | |
| Eq. 5.8.3.3-1 | $V_n = V_c + V_s + V_p$ | Eq. 5.7.3.3- 1 | NR | |
| Eq. 5.8.3.3-2 | $V_n = 0.25 f_c b_v d_v + V_p$ | Eq. 5.7.3.3- 2 | NR | |
| Eq. 5.8.3.3-3 | $V_c = 0.0316\beta \sqrt{f_c} b_v d_v$ | Eq. 5.7.3.3- 3 | $V_c = 0.0316\beta\lambda\sqrt{f_c}b_v d_v$ | |
| Eq. 5.8.3.3-4 | $V_{s} = \frac{A_{v}f_{y}d_{v}(\cot\theta + \cot\alpha)sin\alpha}{s}$ | Eq. 5.7.3.3- 4 | NR | |
| 5.8.3.4.2 | Shear and Torsion – Procedures for Determining Shear Resistance – General Procedure | 5.7.3.4.2 | Procedures for Determining Shear Resistance Parameter β and Θ - General Procedure | |
| Eq. 5.8.3.4.2-1 | $\beta = \frac{4.8}{(1+750\varepsilon_s)}$ | Eq. 5.7.3.4.2-1 | NR | |
| Eq. 5.8.3.4.2-3 | $\theta = 29 + 3500\varepsilon_s$ | Eq. 5.7.3.4.2-3 | NR | |
| Eq. 5.8.3.4.2-4 | $\varepsilon_s = \frac{\frac{ M_u }{d_v} + 0.5N_u + V_u - V_p - A_{ps}f_{po}}{E_s A_s + E_p A_{ps}}$ | Eq. 5.7.3.4.2-4 | NR | |
| Eq. 5.8.3.6.2-1 | $T_n = \frac{2A_0 A_t f_y \cot\theta}{s}$ | Eq. 5.7.3.6.2-1 | NR | |
| 5.8.4.1 | Interface Shear Transfer – Shear Friction - General | 5.7.4.1 | NR | |
| Eq. 5.8.4.1-1 | $V_{ri} = \Phi V_{ni}$ | Eq. 5.7.4.3- 1 | NR | |
| Eq. 5.8.4.1-2 | $V_{ri} \ge \Phi V_{ul}$ | Eq. 5.7.4.3- 2 | NR | |
| Eq. 5.8.4.1-3 | $V_{ni} = cA_v + \mu (A_{vf}f_y + P_c)$ | Eq. 5.7.4.3- 3 | NR | |
| 5.8.4.3 | Cohesion and Friction Factors | 5.7.4.4 | NR | |

| | AASHTO LRFD 2010 | AASHTO LRFD 2017 | | |
|-------------------------|---|--------------------------|---|--|
| Section Number | Title or Content | Section Number | Title or Content | |
| Eq. 5.8.4.4-1 | $A_{vf} \ge \frac{0.05A_{cv}}{f_y}$ | Eq. 5.7.4.2- 1 | NR | |
| 5.11.2.4.2 | Standard Hooks in Tension – Modification Factors | 5.10.8.2.4b | NR | |
| Eq. 5.11.2.4.1 | $l_{hb} = \frac{38.0d_b}{\sqrt{f_c}}$ | Eq. 5.10.8.2.4a- 2 | $l_{hb} = \frac{38.0d_b}{60.0} \left(\frac{f_y}{\sqrt{f_c}}\right)$ | |
| 5.11.2.4.2 | Standard Hooks in Tension – Modification Factors | 5.10.8.2.4b | NR | |
| 5.13.2.4 | Brackets and Corbels | 5.8.4.2 | NR | |
| 5.13.2.4.1 | Brackets and Corbels – General | 5.8.4.2.1 | NR | |
| Eq. 5.13.2.4.1- 1 | $M_u = V_u a_v + N_{uc}(h-d)$ | Eq. 5.8.4.2.1-1 | NR | |
| 5.13.2.4.2 | Brackets and Corbels – Alternative to Strut- and-Tie Model | 5.8.4.2.2 | NR | |
| Eq. 5.13.2.4.2- 1 | $V_n = 0.2 f_c b_w d_e$ | Eq. 5.8.4.2.2-1 | NR | |
| Eq. 5.13.2.4.2- 2 | $V_n = 0.8b_w d_e$ | Eq. 5.8.4.2.2-2 | NR | |
| Eq. 5.13.2.4.2- 5 | $A_s \ge \frac{2A_{vf}}{3} + A_n$ | Eq. 5.8.4.2.2-5 | NR | |
| Eq. 5.13.2.4.2- 6 | $A_h \ge 0.5(A_s - A_n)$ | Eq. 5.8.4.2.2-6 | NR | |
| 5.13.2.5.2 | Beam Ledges – Design for Shear | 5.8.4.3.2 | NR | |
| 5.13.2.5.3 | Beam Ledges – Design for Flexure and Horizontal Force | 5.8.4.3.3 | NR | |

| | AASHTO LRFD 2010 | AASHTO LRFD 2017 | | | |
|-------------------------|---|--------------------|--|--|--|
| Section Number | Title or Content | Section Number | Title or Content | | |
| 5.13.2.5.4 | Beam Ledges – Design for Punching Shear $\Phi V_n = \Phi 0.125 \sqrt{f_c} (W + 2L + 2d_f) * d_f$ | 5.8.4.3.4 | | | |
| | $\Phi V_n = \Phi \min(0.125\sqrt{f_c}\left(\frac{1}{2}W + L + d_f + c\right)d_f, 0.125\sqrt{f_c}\left(W + 2L + 2d_f\right) \cdot d_f)$ | | $\Phi V_n = \Phi \cdot \lambda \cdot 0.125 \cdot \sqrt{f_c} \cdot (W + 2L + 2d_f) \cdot d_f$ | | |
| | | | $\Phi V_n = \Phi \cdot \lambda \cdot \min(0.125 \cdot \sqrt{f_c}) \\ \cdot \left(\frac{1}{2}W + L\right)$ | | |
| | | | $+ d_f + c$ | | |
| | | | $ \begin{array}{c} \cdot d_f, 0.125 \cdot \sqrt{f_c} \\ \cdot (W + 2L \\ + 2d_f) \cdot d_f) \end{array} $ | | |
| 5.13.2.5.5 | Beam Ledges – Design of Hanger Reinforcement | 5.8.4.3.5 | NR | | |
| Eq. 5.13.2.5.5- 1 | $V_n = \frac{A_{hr}(0.5f_y)}{s}(W + 3a_v)$ | Eq. 5.8.4.3.5-1 | The equation has not changed. However, there is a limitation which | | |
| | | | $(W+3a_v) < \min(S, 2c)$ | | |
| Eq. 5.13.2.5.5- 2 | $V_n = \frac{A_{hr} f_y}{s} S$ | Eq. 5.8.4.3.5-2 | The equation has not changed. However, there is a limitation which | | |
| | | | S < 2c | | |
| Eq. 5.13.2.5.5- 3 | $V_n = \left(0.063\sqrt{f_c}b_f d_f\right) + \frac{A_{hrfy}}{s}\left(W + 2d_f\right)$ | Eq. 5.8.4.3.5-3 | $\frac{V_n = (0.063\lambda\sqrt{f_c}b_f d_f) + \frac{A_{hrfy}}{s}(W + 2d_f)$ | | |
| Appendix B5 | General Procedure for Shear Design with Tables | NR | NR | | |
| Eq. B5.2-1 | $\varepsilon_{\chi} = \frac{\frac{ M_{u} }{d_{v}} + 0.5N_{u} + 0.5 V_{u} - V_{p} cot\theta - A_{ps}f_{po}}{2(E_{s}A_{s} + E_{p}A_{ps})}$ | Eq. B5.2-3 | NR | | |
| Eq. B5.2-3 | $\varepsilon_{\chi} = \frac{\frac{ M_{u} }{d_{v}} + 0.5N_{u} + 0.5 V_{u} - V_{p} cot\theta - A_{ps}f_{po}}{2(E_{c}A_{c} + E_{s}A_{s} + E_{p}A_{ps})}$ | Eq. B5.2-5 | NR | | |
| Table B5.2-1 | Values of Θ and β for Sections with Transverse Reinforcement | NR | NR | | |
| - | This section is not included in AASHTO LRFD 2010 | 5.4.2.8 | Concrete Density Modification Factor | | |
| - | The equation for the elastic modulus of concrete in AASHTO LRFD 2010 is placed into commentary | Eq. C5.4.2.4-2 | $E_c = 33000K_1 w_c^{1.5} \sqrt{f_c}$ | | |

| | AASHTO LRFD 2010 | AASHTO LRFD 2017 | | |
|-------------------|--|-------------------|------------------------|--|
| Section Number | Title or Content | Section Number | Title or Content | |
| - | The equation for the elastic modulus of concrete in AASHTO LRFD 2010 is placed into commentary | Eq. C5.4.2.4-3 | $E_c = 1820\sqrt{f_c}$ | |