Technical Report Documentation Page

1. Report No. FHWA/TX-15/0-6652-2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Behavior of the Splice Regions of Spliced I-Girder Bridges		5. Report Date February 2015; Published March 2015 6. Performing Organization Code
7. Author(s) Chris Williams, Andrew Moore, Dhiaa Al-Tarafany, Josh Massey, Oguzhan Bayrak, James Jirsa, and Wassim Ghannoum		8. Performing Organization Report No. 0-6652-2
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 1616 Guadalupe Street, Suite 4.202 Austin, TX 78701		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-6652
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Technical Report 09/01/2010-01/31/2015 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

16. Abstract

Spliced girder bridge technology continues to attract attention due to its versatility over traditional prestressed concrete highway bridge construction. Relatively limited data is available in the literature, however, for large-scale tests of spliced girders, and few studies have examined the behavior of the cast-in-place (CIP) splice regions of spliced girder bridges. In addition to limited knowledge on CIP splice region behavior, a wide variety of splice region details (e.g., mild reinforcement details, shear interface details, overall geometry, etc.) continue to be used in the field.

In response to these issues, the research program described in this report was developed to (i) study the strength and serviceability behavior of the CIP splice regions of spliced I-girders, (ii) identify design and detailing practices that have been successfully implemented in CIP splice regions, and (iii) develop design recommendations based on the structural performance of spliced I-girder test specimens.

To accomplish these tasks, an industry survey was first conducted to identify the best practices that have been implemented within the splice regions of existing bridges. Splice region details were then selected to be included within large-scale post-tensioned spliced I-girder test specimens. Two tests were conducted to study splice region behavior and evaluate the performance of the chosen details. Consistent with their design, the failure mechanisms of both test girders were characterized by a shear-compression failure of the web concrete with primary crushing occurring in the vicinity of the top post-tensioning duct. Most significantly, the girders acted essentially as monolithic members in shear at failure. The web crushing extended across much of the test span and was not localized within the splice regions. Based on the results of the tests, design recommendations were developed, including recommended CIP splice region details.

17. Key Words Spliced Girder, Splice Region, Post-Tensioning, Shear, Prestressed I-Girder	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161; www.ntis.gov.

19. Security Classif. (of report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	266	

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THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

Behavior of the Splice Regions of Spliced I-Girder Bridges

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CTR Technical Report:	0-6652-2
Report Date:	February 2015; Published March 2015
Project:	0-6652
Project Title:	Spliced Tx Girder Bridges
Sponsoring Agency:	Texas Department of Transportation
Performing Agency:	Center for Transportation Research at The University of Texas at Austin

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

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Acknowledgments

The authors are grateful to the Texas Department of Transportation (TxDOT) for providing the funds to conduct this research study. The contributions of the project manager Darrin Jensen and members of the Project Monitoring Committee, including Greg Turco, Alanna Bettis, Leon Flournoy, and Michael Hyzak, are deeply appreciated. A special thanks is also offered to the numerous students and staff members at Ferguson Structural Engineering Laboratory for ensuring the successful completion of the spliced girder experimental program.

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Chapter 1. Introduction

1.1 Overview

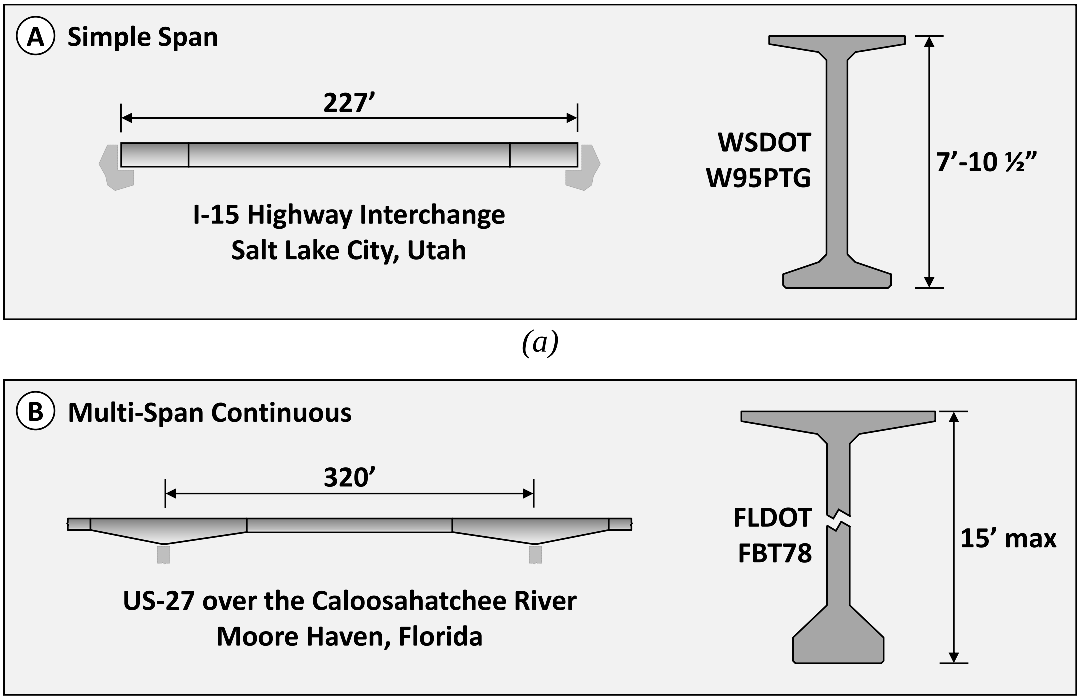
Spliced girder bridge technology has recently attracted attention due to its versatility over traditional prestressed concrete highway bridge construction. By joining multiple precast concrete girders together using post-tensioning, spliced girder technology effectively extends the application of low-cost precast construction to uncharacteristic span lengths. Relatively limited data is available in the literature, however, for large-scale shear tests of post-tensioned I-girders, and only a few studies have examined the behavior of the cast-in-place (CIP) splice regions of spliced girder bridges. The goal of the current research program is to evaluate the strength and performance of spliced girders. Phase I of the program, described in Moore et al. (2015), focused on the effect of the presence of a post-tensioning duct in the web of an I-girder on the overall shear performance. The purpose of Phase II is to study the behavior of the CIP splice regions where two precast girders are joined. The details of Phase II of the spliced girder research program are described within this report.

1.2 Overview of Spliced Girder Technology

Modern spliced girder bridges typically consist of multiple precast pretensioned girders joined at short splice regions cast at the bridge site. The geometry of the precast segments and resulting locations of the girder splices are generally tailored to each project. The versatility of spliced girder technology coupled with the span lengths that can be achieved results in a cost-effective alternative to other bridge types (e.g., steel plate girder and concrete segmental construction) within the moderate-span market.

1.2.1 Typical Applications

Spliced girder technology can be applied to both simple-span and multi-span continuous bridge construction, as illustrated in Figure 1.1. Both applications lead to significantly longer span ranges than would be possible with traditional precast girder construction. Simple-span bridges, often limited to 160 ft or less due to transportation restrictions, can be extended to 200 ft or more (Shutt, 1999), as indicated in Figure 1.1(a). When the benefits of structural continuity are coupled with the appropriate details, the application of spliced girder technology to multi-span continuous bridges is allowing precast concrete girder construction to approach its full potential with spans in excess of 300 ft (Figure 1.1.(b)). The splice region experimental program described within this report was tailored to provide results that are applicable to various possible bridge configurations.



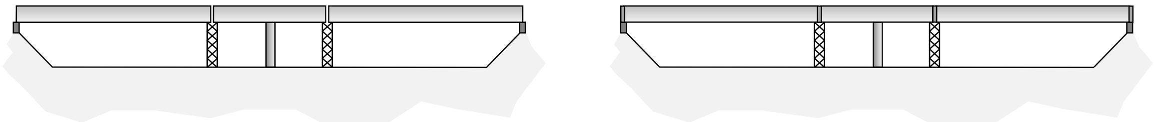
(a)

(b)

Figure 1.1: Typical spliced girder bridge configurations and representative spans – (a) simple span; (b) multi-span continuous

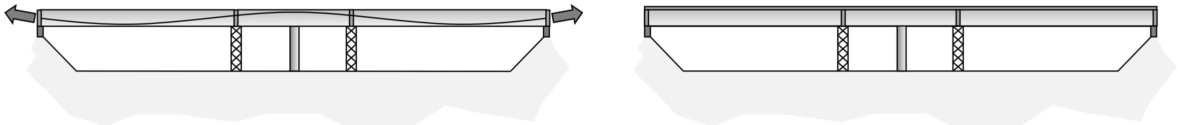
1.2.2 Typical Construction Sequence

The application of spliced girder bridge technology introduces challenges that are not typically encountered in traditional precast girder design and construction. One of these challenges can arise from the construction sequence that must be carefully considered when designing a spliced girder bridge. Critical aspects of the construction sequence include casting schedules, use of temporary shoring or strong-backs, post-tensioning, and tendon grouting. A simplified version of a typical construction sequence for a spliced girder bridge is presented in Figure 1.2.



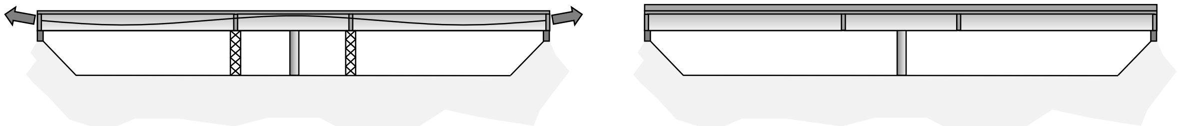
1: Erect Precast Segments

2: Cast Splices and Diaphragms



3: Perform First Stage Post-Tensioning

4: Cast Deck



5: Perform Second Stage Post-Tensioning

6: Remove Temporary Supports and Place Railings

Figure 1.2: Typical construction sequence (adapted from Abdel-Karim and Tadros, 1992)

Within Figure 1.2, the post-tensioning operation is conducted in two stages: one prior to and one after the placement of the deck. An alternative to this sequence is to fully stress the post-tensioning tendons before the deck is placed. This approach simplifies a complete deck removal and replacement in the future (Castrodale and White, 2004). Furthermore, some construction scenarios may allow the girder splicing to be conducted on the ground prior to lifting the post-tensioned girders into their final positions.

1.3 Project Objectives and Scope

The primary objectives of Phase II of the spliced girder research program were:

(i) Study the strength and serviceability behavior of the CIP splice regions of spliced I-girders.

(ii) Identify design and detailing practices that have been successfully implemented in CIP splice regions located within the span lengths of existing spliced I-girder bridges.

(iii) Develop design recommendations based on the structural performance of spliced girder test specimens that include selected candidate details within the CIP splice regions.

Considering the limited data available in the literature for the performance of CIP splice regions, the tests performed as part of the Phase II experimental program provide significant insights into the strength and behavior of spliced girders. The test specimens were designed to exhibit a shear-compression failure. This failure mode was selected as the most critical failure mode that is likely to be influenced by the presence of post-tensioning ducts and duct couplers. The test setup for the experimental program, however, was configured in a manner that ensured the splice regions would experience both high shear and flexural demands as the ultimate load was approached, providing a critical loading scenario.

A wide variety of splice region details (e.g., splice region length, mild reinforcement details, cross-sectional geometry, etc.) have been used in the field due to the absence of uniform design standards. To identify the best practices that have been successfully implemented within the splice regions of existing bridges, an industry survey was conducted. After analyzing the survey responses and supplementary material offered by the survey participants, candidate splice region details to be proof tested in the laboratory were developed. Input offered by the Texas Department of Transportation (TxDOT) Project Monitoring Committee (PMC) and a project advisory panel were invaluable resources during the selection of the details. The project advisory panel consisted of practitioners with first-hand experience in spliced girder technology.

Two proof tests were conducted in the laboratory on large-scale spliced girder specimens to evaluate the performance of the selected splice details. The effect of the longitudinal interface reinforcement extending from the precast segments into the splice region was of particular interest. To study the influence of the bars on the behavior of the test girders, the interface reinforcement was varied between the two specimens. Each of the test girders were loaded monotonically until the specimen exhibited a shear-compression failure of the web concrete. Based on the results of the experimental program, design and detailing recommendations for the splice regions of spliced I-girder bridges were developed.

1.4 Organization

A general background of spliced girder technology is provided in Chapter 2, including a literature review focusing on studies of splice region/joint performance. In Chapter 3, the responses received from the industry survey are summarized, and a description of the survey results as they relate to the design and detailing of splice regions is presented. The Phase II spliced girder experimental program, including the specimen design and fabrication, is discussed in Chapter 4. The selection of the splice region details of the test girders is described along with the specimen instrumentation, loading configuration, and test procedure. In Chapter 5, the analysis of experimental results and observations are presented. The strength and serviceability behavior of the girders is evaluated, and the influence of longitudinal interface reinforcement is examined. Design recommendations based on the results of the spliced girder research program are provided in Chapter 6, including considerations for splice region detailing and strength calculations. Lastly, the overall findings and conclusions of the research program are summarized in Chapter 7.

Chapter 2. Background of Spliced Girder Technology

2.1 Introduction

A background of spliced girder technology is presented in this chapter to place the Phase II program into perspective with the current state of spliced girder construction and research. To accomplish this task, a brief history of spliced girder technology is presented. Then, a review of experimental programs examining the behavior of the splice regions/joints of internally prestressed spliced girders is provided. The overview of spliced girder technology in this chapter reveals the need for the study evaluating the behavior of cast-in-place (CIP) splice regions that is described within the remainder of this report.

2.2 Historical Perspective

The development of more efficient bridge girders by various state Departments of Transportation (DOTs) has historically sparked concerted efforts to implement spliced girder technology. In the early 1980s, the state of Florida evaluated the performance of a new bulb-tee cross-section, commonly referred to as the Florida Bulb-Tee or FBT. Following vetted use in a number of continuous span-by-span bridges, the FBT was selected for a 200-ft spliced girder span over the Choctawhatchee Bay (Garcia, 1993). The Florida DOT quickly recognized the value of the technology; over thirty spliced girder bridges (with main span lengths up to 320 ft) were constructed along the Florida coast from 1988 to 2004 (Castrodale and White, 2004). Florida is now considered to be one of the leaders in the design and construction of spliced girder bridges. Similar histories can be written in regards to the use of the New England Bulb-Tee, Washington Wide-Flange (a variant of Nebraska's NU I-girder), and the California Wide-Flange girders.

The growing popularity of spliced girder construction is evidenced by the availability of design aids that include spliced girder example problems (Castrodale and White, 2004; *PCI Bridge Design Manual*, 2014). However, experimental research within the literature relating to modern-day spliced girder bridges with CIP splice regions is limited. In fact, no tests studying the shear failure mechanism of post-tensioned spliced girders containing in-span CIP splice regions have been identified. Spliced girder designs are therefore based on a combination of concepts adopted from both segmental and conventional precast prestressed girder construction. Research programs examining the behavior of spliced girder bridges and CIP splice regions can lead to refinements to the current design procedures and detailing practices and therefore provide the tools necessary for spliced girder technology to better reach its full potential.

2.3 Past Experimental Studies

Considering the documents available within the literature related to spliced girder technology, primary interest was placed on experimental studies conducted to examine the behavior of the splice regions/joints of spliced girder bridges. A limited number of studies relevant to the performance of spliced, internally prestressed precast girders have been identified. The research findings of such studies related to the behavior of the splice regions/joints are described within this section.

A number of documents describing the design and construction of existing spliced girder bridges are also available within the literature. Although details of the splice region geometry and mild reinforcement are included within some of these sources, the behavior of the splice region is generally not a major focus. Splice region details that have been successfully implemented in the field are examined in Chapter 3.

2.3.1 Garcia (1993)

Garcia (1993) describes the implementation of a continuous post-tensioned bulb-tee girder system in Florida. The testing of a full-scale prototype girder line is highlighted. The test was conducted prior to the full production of the bulb-tee girder system for the Eau Gallie Bridge near Melbourne, Florida. The specimen consisted of two 145-ft long girders spliced together at an intermediate support (see Figure 2.1). Failure of the specimen was governed by flexure at the intermediate support. The specimen exhibited highly ductile behavior of the post-tensioned bulb-tee girder system and a capacity significantly greater than the design loads. At failure, the factored applied shear force was reported to be 1.13 times greater than the design shear force calculated according to the 1977 AASHTO *Standard Specifications for Highway Bridges*.

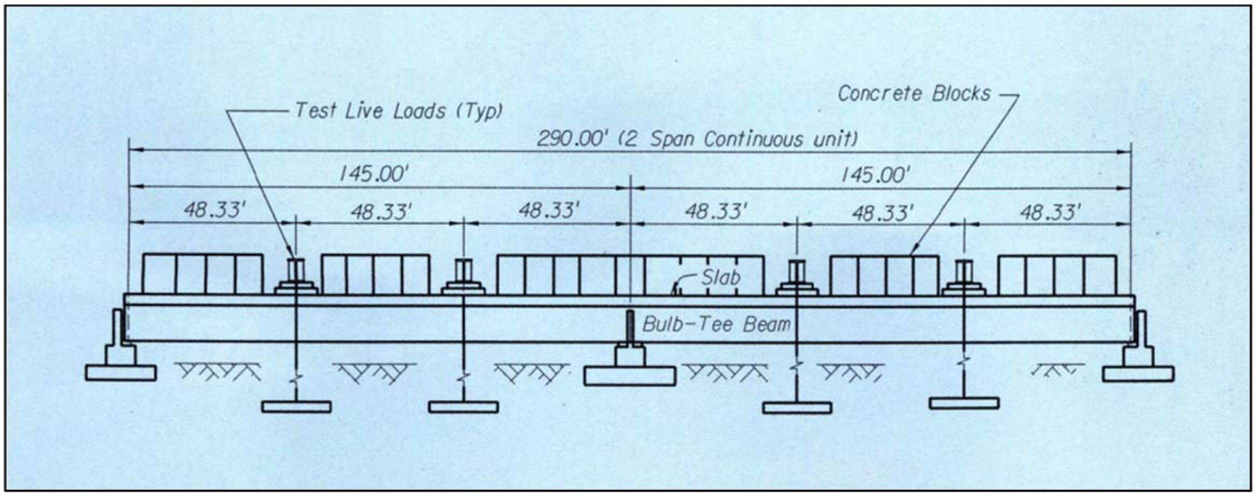


Figure 2.1: Elevation view of prototype girder line (from Garcia, 1993)

2.3.2 Tadros et al. (1993)

Tadros et al. (1993) introduced a splicing method that relies on continuity provided by coupled pretensioned strands extending for the ends of precast girder segments. The proposed method is illustrated in Figure 2.2. The precast pretensioned segments are first fabricated. The ends of the segments are coped to accommodate strand splicing. The strand extensions from adjacent girders are then spliced using mechanical connectors. Next, hydraulic rams are installed and used to push outward on the girder segments (see Figure 2.2(c)), imposing tensile forces on the coupled strand extensions. Following the jacking procedure, a closure pour is performed within the splice region. After the concrete reaches its required strength, the jacking force is released, introducing compression to the splice concrete. The proposed method is intended to be implemented at interior supports to provide continuity between adjacent bridge spans without the use of continuous post-tensioning.

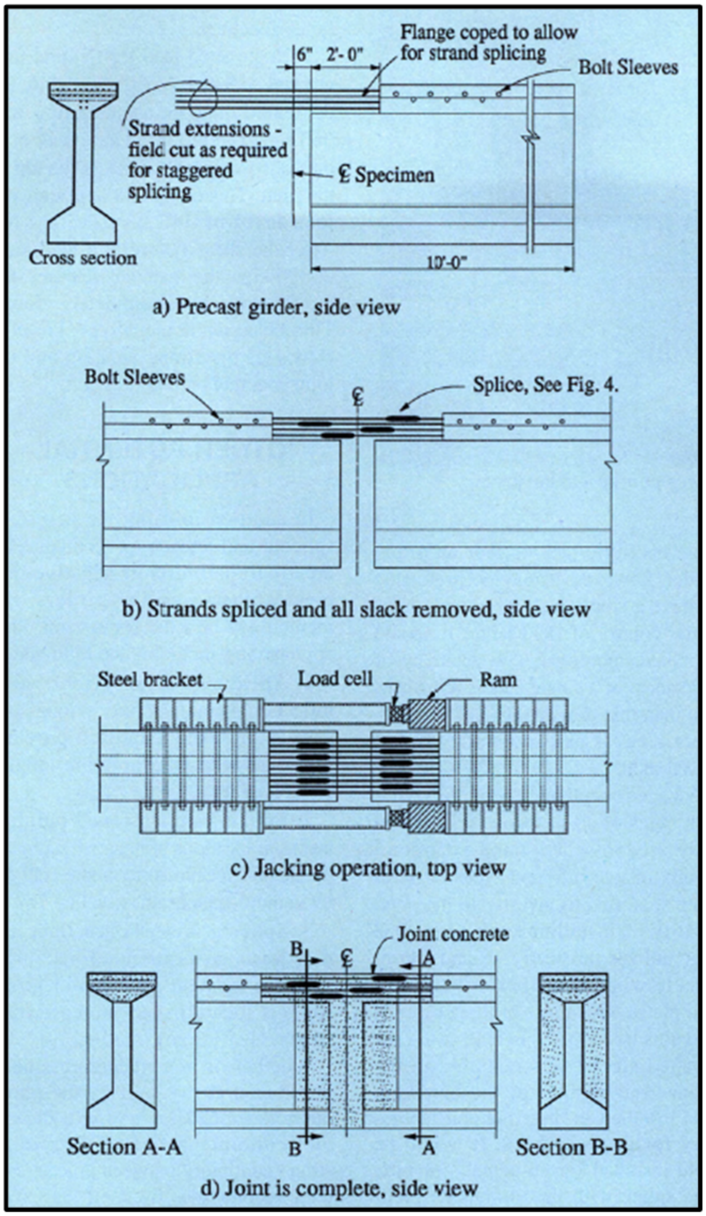


Figure 2.2: Splicing operation of test specimen (from Tadros et al., 1993)

A load test was conducted on a specimen consisting of two 10-ft long precast I-girders spliced together using the proposed detail. The 20-ft long spliced girder was simply supported, and load was applied at the location of the splice region (i.e., at the midspan). The specimen exhibited a shear failure, as shown in Figure 2.3. The failure occurred at an applied load of 390 kips, while the estimated shear capacity was 360 kips. The authors report that the single flexural crack that formed during testing completely closed upon release of the applied load. They state that the "behavior demonstrates the efficiency of the strand splicing and the joint concrete precompression" (Tadros et al., 1993).

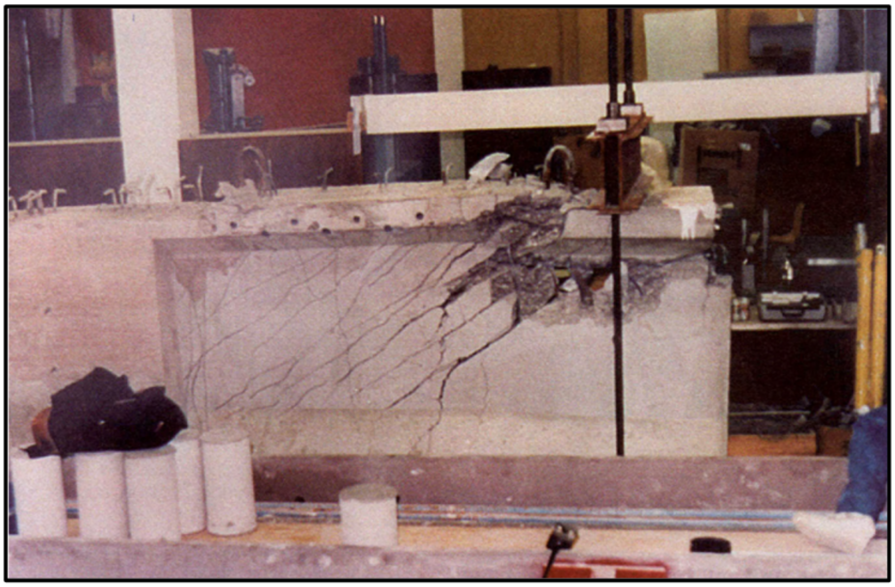


Figure 2.3: Test specimen after failure (from Tadros et al., 1993)

2.3.3 Holombo, Priestley, and Seible (2000)

Holombo, Priestley, and Seible (2000) studied the performance of precast prestressed spliced girders with superstructure-column continuity. Primary focus was placed on the design and behavior of the connection between the girders and the bent cap under seismic loads. Two model bridge structures were tested to evaluate the structural performance. The test setups for the 40-percent scale specimens are shown in Figure 2.4. One of the models incorporated post-tensioned bulb-tee girders that included girder segments that passed continuously through the bent cap. The other model used bathtub girders that were discontinuous at the face of the bent cap. The girders were therefore spliced with continuous post-tensioning at the supporting bent. Both specimens were subjected to simulated seismic forces and displacements imposed by the horizontal actuators illustrated in Figure 2.4.

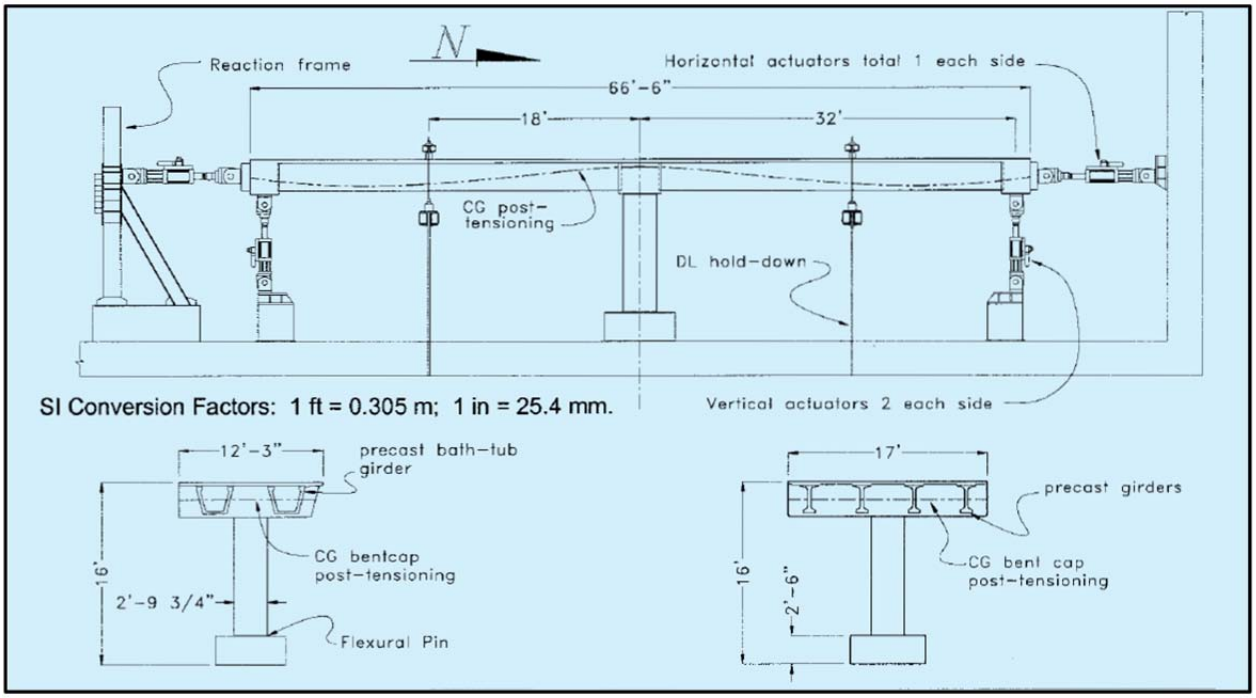


Figure 2.4: Test setup for model bridge specimens (from Holombo, Priestley, and Seible, 2000)

Both model bridge specimens exhibited satisfactory ductile behavior under forces and displacements exceeding seismic design requirements, demonstrating the potential of the integral superstructure-column connection. The bent cap and superstructure displayed an essentially elastic response throughout the tests with the development of only minor cracks. An additional superstructure capacity test was later performed on each specimen using a different test setup designed to apply vertical excitation (Holombo, Priestley, and Seible, 1997). The superstructures also exhibited ductile behavior under these simulated seismic demands.

2.3.4 Kim, Chung, and Kim (2008)

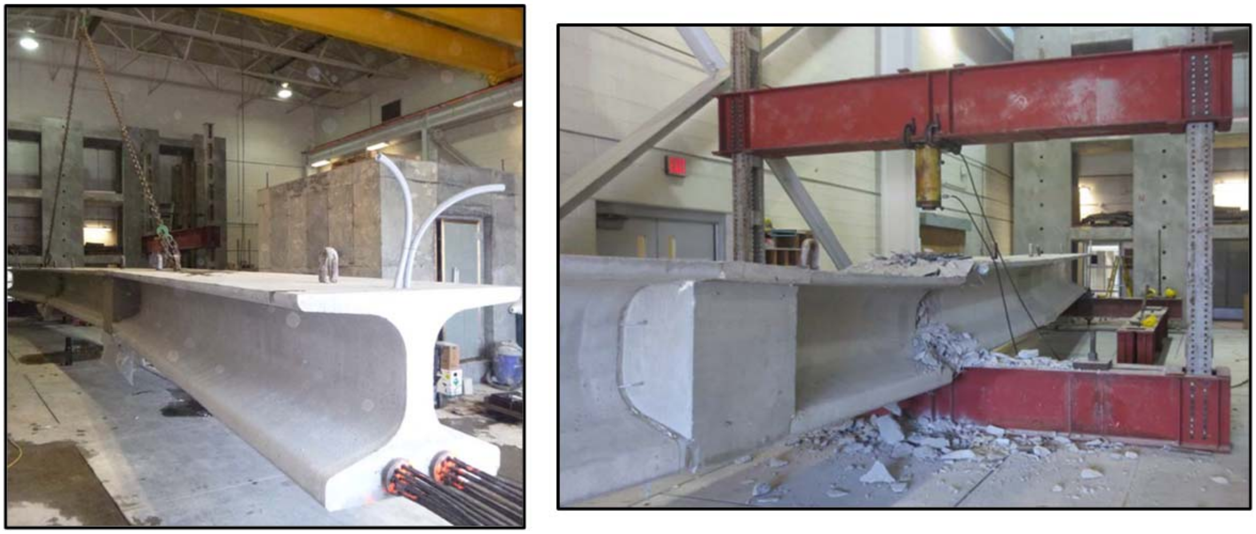
Kim, Chung, and Kim (2008) performed load tests on two precast post-tensioned box girder specimens, one cast monolithically and the other consisting of three spliced girder segments. The precast segments of the spliced girder were match-cast. Multiple mechanical shear connectors, shown in Figure 2.5, were installed in the ends of adjacent segments to aid in shear transfer at the match-cast joints. Epoxy resin was also applied to the joint surfaces. Continuity between the precast segments was provided by continuous post-tensioning. During the load tests, both the monolithic and spliced girders were simply supported with a span of 65 ft. The applied loads were centered on the span to evaluate and compare the flexural performance of the two specimens. The maximum load applied to the specimens was governed by the capabilities of the laboratory equipment, not the ultimate strength of the girders.

Figure 2.5: Mechanical shear connector used at match-cast joints (from Kim, Chung, and Kim, 2008)

During the tests, both specimens exhibited similar behavior under service loads and within the elastic range. The spliced girder experienced a reduced flexural stiffness compared to the monolithic girder at higher loads. Failure of the joints of the spliced girder was not observed, and the measured relative vertical displacements between adjacent precast segments were negligible up to the maximum applied load. Chung and Kim (2011) evaluated the dynamic properties of the same two specimens both before and after the flexural load tests were performed. The findings revealed that the spliced and monolithic girders exhibited similar dynamic characteristics in both the undamaged and the cracked states.

2.3.5 Alawneh (2013)

Alawneh (2013) proposed a system to be used as an alternative to traditional curved bridge superstructures. The system consists of relatively short straight-line precast concrete girder segments that are post-tensioned together at kinked joints (i.e., splice regions) to mimic the shape of truly curved girders. As part of the research program, two specimens were fabricated and tested. Each specimen was constructed from three precast girder segments that were joined together at splice regions. The precast segments were not pretensioned. Instead, the primary longitudinal reinforcement consisted of two post-tensioning tendons there were contained within the bottom flanges of the specimens. The straight-line segments were oriented in a manner to mimic a curve with a radius of 200 ft. One of the specimens was comprised of three tub-girder segments, while the other specimen consisted of I-girder segments, as shown in Figure 2.6(a). The two splice regions within the I-girder specimen were of different shapes. One matched the cross-section of the adjacent segments, while the other extended out to at least the bottom flange of the girders.



(a) *(b)*

Figure 2.6: I-girder test specimen with two splice regions – (a) during lifting; (b) after failure (from Alawneh, 2013)

Each of the post-tensioned girders had a test span of 600 ft with a single point load applied at midspan. Failure did not occur at the splice regions of either specimen. The flexural failure under the load point of the I-girder specimen is presented in Figure 2.6(b). From the results of the research program, the author states that shear friction theory can be used to design the joints between the girder segments if stresses from both shear and torsional effects are considered.

2.3.6 Brenkus and Hamilton (2013)

Brenkus and Hamilton (2013) evaluated the performance of a girder splicing procedure with similar concepts to the method introduced in Tadros et al. (1993). A total of nine specimens with an AASHTO Type II cross-section were tested. Three of the specimens were cast monolithically, while the remaining six each consisted of two precast segments joined at a cast-in-place splice region (see Figure 2.7). Continuity was provided between the precast girder segments through the coupling of prestressing strands extending from the bottom flanges. Tensile forces were applied to the strands by hydraulic rams attached to each side of the girder webs. For each pair of precast segments, one contained five fully bonded pretensioned strands. The other segment contained only one bonded pretensioned strand. Another five strands, unbonded along the segment length, were coupled with the strands extending from the first segment during the splicing operation. The full-scale application of the splicing procedure was intended for a simply-supported span length greater than 200 ft.

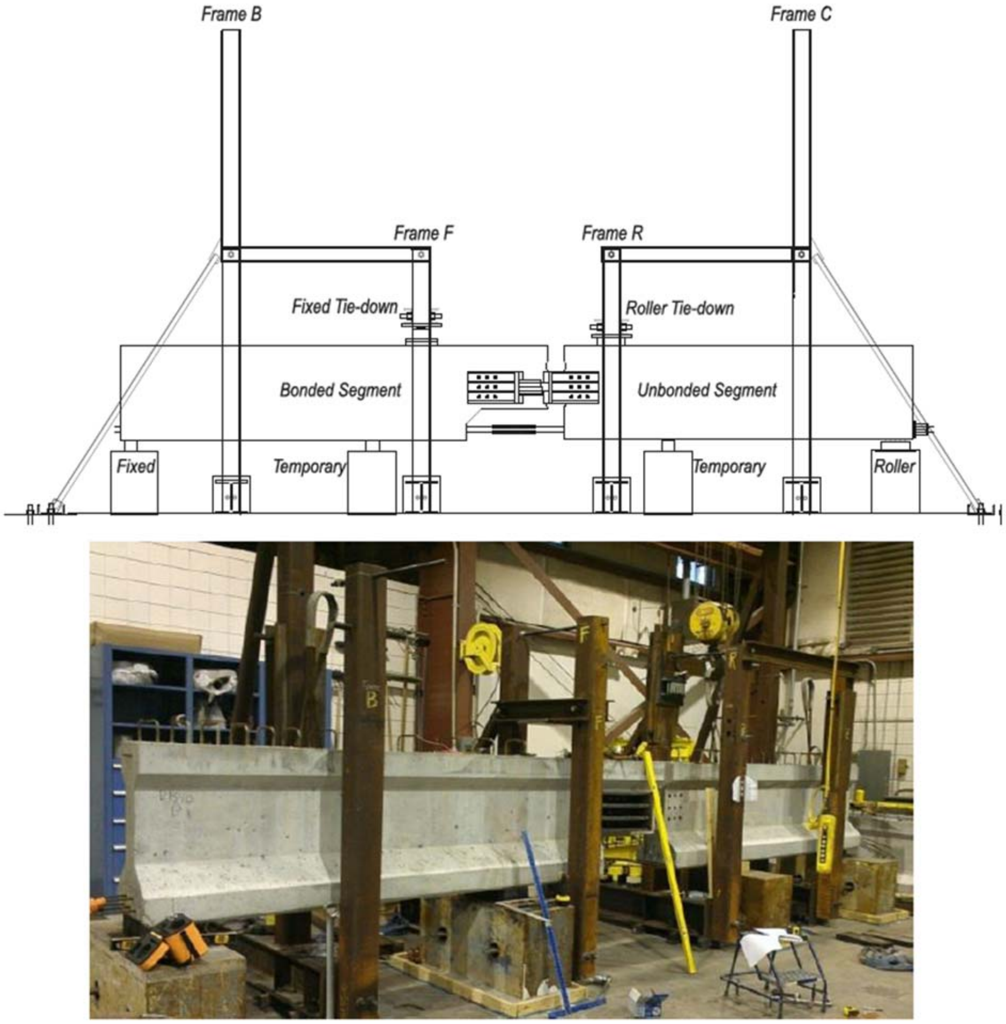


Figure 2.7: Girder segments in splice assembly frame (from Brenkus and Hamilton, 2013)

The testing program examined the flexural, shear, and fatigue performance of the spliced and monolithic (i.e., control) girder specimens. The flexural tests demonstrated that the failure loads of the spliced specimens exceeded the calculated capacity according to AASHTO LRFD (2007) by 15 percent if bonded strands were assumed and by 24 percent assuming unbonded strands. Although a different test setup was configured to study the shear behavior of the girders, only one of the specimens exhibited a shear failure. The failure was characterized by slip at the vertical interface between the splice region and the segment containing unbonded strands. The ratio of the applied ultimate shear force to the shear capacity predicted by Section 5.8.3.4.2 of AASHTO LRFD (i.e., general shear procedure) was reported to be 1.03.

During the testing program, the researchers also observed that the application of epoxy on the ends of the precast segments prior to the closure pour resulted in a noticeable improvement to the bond between the cast-in-place concrete and the precast girder segments. Furthermore, the authors noted the importance of adequate vibration to properly consolidate the concrete within the congested splice regions, even with the use of a self-consolidating mixture.

2.4 Summary

The span lengths achieved by spliced girder bridges have caused the technology to gain increasing attention, and several state DOTs have shown interest in its widespread implementation. Although limited research focusing on spliced girder behavior has been conducted, experimental programs that included tests on spliced girders with internal prestressing were identified, and relevant findings from such studies were presented in the previous sections. Despite the value of past spliced girder research, many questions concerning the behavior of CIP splice regions remain unanswered.

In the following chapter, an overview of the industry survey conducted as part of the spliced girder research is presented. The experimental program is then introduced and detailed in Chapter 4.

Chapter 3. Industry Survey

3.1 Overview and Objective

An industry survey was conducted to identify design and detailing practices that have been successfully implemented in cast-in-place (CIP) splice regions located within the span lengths of existing spliced I-girder bridges. The survey participants were given the opportunity to provide information regarding standard detailing practices as well as their overall experiences with the implementation of spliced girder technology. The information from the survey responses were used to develop the candidate splice region details for the splice region proof testing program, as described in Chapter 4.

The survey was distributed in the spring of 2013 to every state department of transportation (DOT) in the country outside of Texas. Responses from 24 states and the District of Columbia were received. Narrowly focused questions on the survey led to the gathering of valuable information concerning the details of CIP splice regions. Among the state DOTs that have experience with the design and construction of spliced I-girder bridges, the survey revealed that the details of splice regions vary significantly. From the in-depth responses and supplementary material provided by the survey participants, however, successful practices for the design and construction of splice regions could be identified. The responses from the survey participants are provided in Appendix A.

3.2 Experience with Spliced Girder Technology

The first section of the industry survey was used to identify each state DOT's experience in the design and construction of spliced girder bridges. Out of the 25 responses, 12 state DOTs have had experience with the technology. The experience of these states DOTs in the design and/or construction of spliced U-girder or box girder bridges and of spliced I-girder bridges is summarized in Figure 3.1. Although the Minnesota Department of Transportation (MnDOT) has had experience with spliced I-girder bridges, the experience was not current. MnDOT did not therefore respond to the survey questions that followed. The states where the most number of spliced I-girder bridges had been constructed were California, Florida, and Washington, each with over 20 bridges. For the remainder of the survey, the participants with experience in spliced I-girder bridge construction were asked to focus on the design and construction details for this specific bridge type.

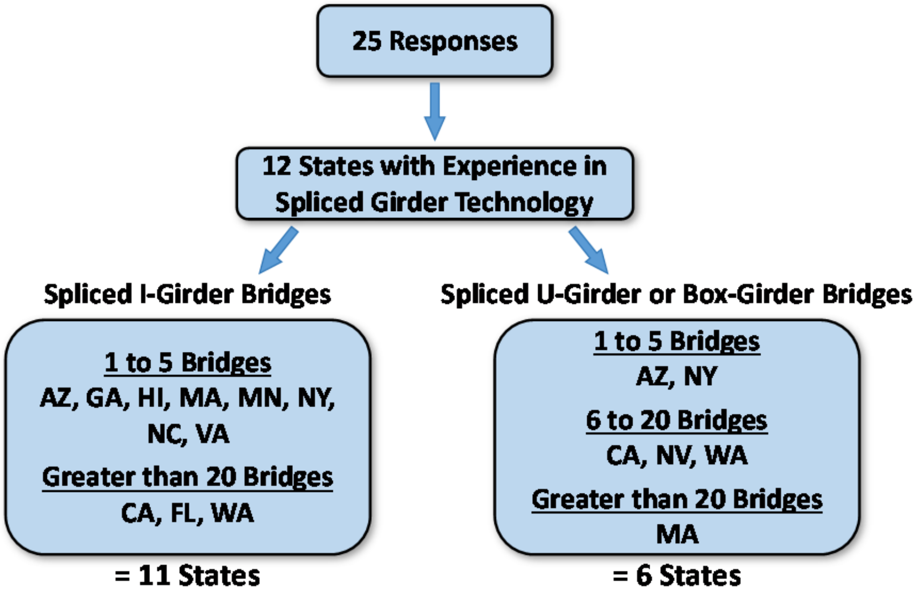


Figure 3.1: State DOT experience with spliced girder technology

3.3 Design and Construction Practices of Spliced I-Girder Bridges

The main body of the industry survey focused on the design and construction practices of spliced I-girder bridges, with specific attention given to CIP splice regions. For each detail examined through the survey, the key observations gathered from the responses are provided in the following sections. The 10 state DOTs that have had recent experience with spliced I-girder bridge design and/or construction receive primary focus.

3.3.1 Duct Material

The post-tensioning tendons of spliced girder bridges are generally contained within either galvanized steel ducts or plastic ducts. The survey participants were asked to provide the percentage of spliced girder bridge projects in their state/district for which each type of duct material had been specified. If one material was preferred over the other, the participants were also asked to explain why. They were then asked to describe any problems that may have been encountered due to the duct material that was chosen for a particular project. Considering the usage of each duct material along with the accompanying comments, it can be inferred that 7 state DOTs prefer steel post-tensioning ducts, while only 3 DOTs prefer plastic ducts. The reasons given by the survey participants for preferring a particular duct material are summarize in Table 3.1.

Table 3.1: Reasons for preferring steel or plastic ducts

Steel Ducts	Plastic Ducts
• Require less support to prevent misalignment and displacement during casting (reference was made to Castrodale and White, 2004) • Offer ease of placement • Fit better within the web width because of ducts' exterior dimensions	• Less prone to corrosion • Provide better durability • Can be sealed better • Have a smaller chance of being damaged during construction

3.3.2 Consideration of a Reduction in Shear Strength due to Presence of Ducts

The following question on the survey inquired whether the states/districts consider a reduction in shear strength due to the presence of post-tensioning ducts within girder webs. The responses revealed that only 4 of the state DOTs with experience in spliced I-girder technology reduce the shear strength to account for the effect of the ducts. The other 6 DOTs do not consider the strength reduction.

3.3.3 Grouted versus Ungrouted Ducts

The survey participants were asked if their state/district has ever used ungrouted ducts in spliced I-girder construction. The responses indicated that none of the state DOTs have used ungrouted ducts within spliced I-girders.

3.3.4 Shear Interface Detail

Drawings of existing spliced I-girder bridges reveal that various concrete surface details have been specified at the interface between the precast concrete segments and the CIP splice regions. The primary purpose of the surface details are to aid in transferring shear between the precast concrete and the splice region concrete. The most common shear interface details identified in the drawings of existing bridges are presented in Figure 3.2.

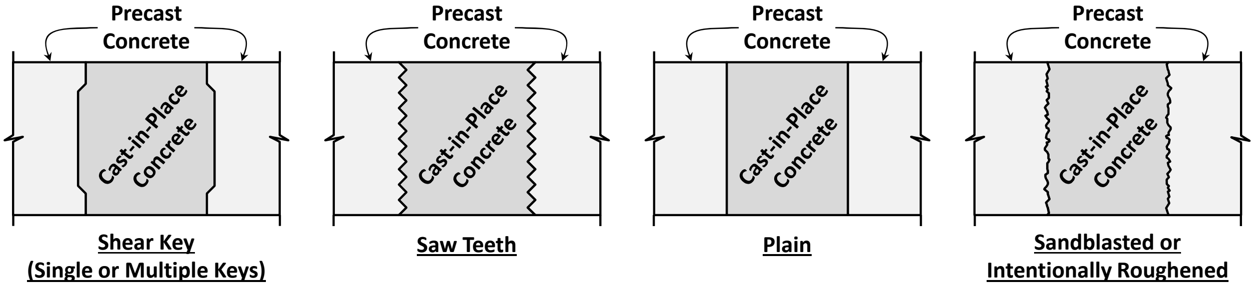


Figure 3.2: Common shear interface details

The survey participants were asked what shear interface details have been used for spliced I-girder bridges in their state/district and for what percent of projects each type of detail has been specified. The responses to these questions are summarized in Figure 3.3. For this figure, the number of spliced I-girder bridges in each state was estimated using the survey responses along with the listing of spliced girder bridge projects provided in NCHRP Report 517 (Castrodale and White, 2004). The percent of projects with each interface type as indicated by the survey responses was then used to calculate the number of bridges that are represented in

Figure 3.3. As shown in the figure, shear keys are the most common shear interface detail, used in over half of the total estimated number of spliced I-girder bridges.

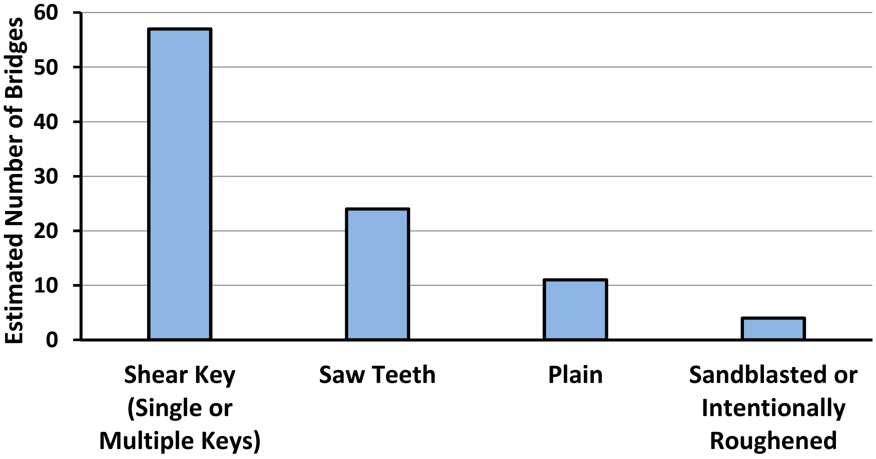


Figure 3.3: Use of the various shear interface details

The survey also provided the opportunity for the participants to explain the factors that affect the type of shear interface detail this is chosen. Only two of the responses referred to structural behavior or constructability related to the interface detail. The New York State DOT stated that that they "believe a shear key provided the best shear transfer mechanism." The North Carolina DOT explained that shear keys are a "[s]imple detail that is easy to fabricate and control during fabrication."

3.3.5 Longitudinal Interface Reinforcement

The detailing of the mild longitudinal interface reinforcement that extends from the precast concrete segments into the CIP splice regions vary significantly among existing spliced I-girder bridges. In general, this longitudinal reinforcement is provided to satisfy stress limits for the splice region at the service limit state as well as to meet shear strength requirements at the splice (Castrodale and White, 2004). Possible bar details for the interface reinforcement are presented in Figure 3.4.

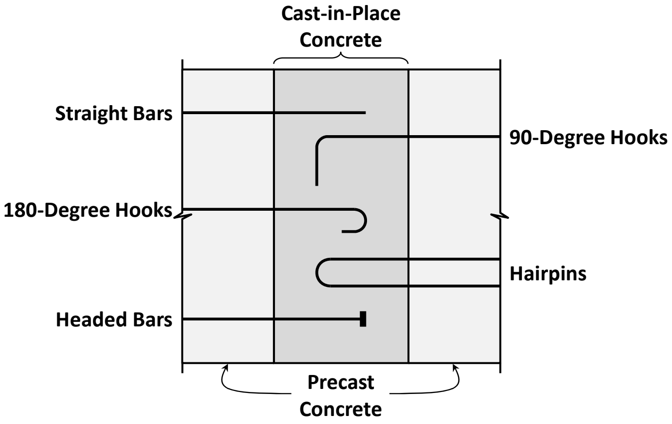


Figure 3.4: Possible bar details for longitudinal interface reinforcement

To determine the most common interface reinforcement details specified for spliced I-girder bridges, the survey participants were asked to identify how the bars are typically detailed in their state/district. More than one answer could be selected. The responses to the survey question are summarized in Table 3.2. The California, Florida, and Washington State DOTs had the most experience in spliced I-girder technology among the survey participants, and these states are thus emphasized within the table. The responses reveal that there is no consensus as to what interface reinforcement detail is most suitable. The implications of the interface reinforcement provided within the splice region is further examined within the Phase II experimental program in the following chapters.

Table 3.2: Use of various details for longitudinal interface reinforcement

Straight Bars	90-Degree Hooks	180-Degree Hooks	Hairpins	Headed Bars
HI, VA, **WA**	**CA**, GA, NY, NC	**FL**, GA, NC	AZ, **FL**, GA, MA, NY, NC, VA	None

3.3.6 Duct Diameter to Web Width Ratio

The industry survey provided the opportunity to determine the combinations of girder web width, b_w, and duct diameter that have been specified for existing spliced I-girder bridges. The combinations of web width and duct diameter specified within each state along with the estimated percent of projects using each combination, according to the survey responses, are presented in Table 3.3. The duct diameter to web width ratios are also presented and are seen to range from 0.31 to 0.56. Article 5.4.6.2 of AASHTO LRFD (2014) limits the duct diameter to web width ratio to a value of 0.4. The data in Table 3.3 reveals that this limit has been surpassed in all 10 states where the DOT has recent experience with spliced I-girder technology.

Table 3.3: Combinations of web width, b_w, and duct diameter

State	Web Width, b_w (in.)	Duct Diameter (in.)	$\frac{\text{Duct Diameter}}{b_w}$	Percent of Projects	Note
Arizona	8	4	0.5	100	---
California	8	4	0.5	30	---
	8	3½	0.44	50	---
	8	3	0.38	20	---
Florida	8 (+/-)	4	0.5 (+/-)	Not Provided	Steel Ducts
	8½	4	0.47		PP* Ducts
	9	4	0.44		PP* Ducts
	7	2⅜	0.34		PE** Oval Ducts
Georgia	9	3.82	0.42	50	---
	12	2 (in pairs)	---	50	---
Hawaii	7⅞	4⅜	0.56	33	---
	8½	4⅝	0.54	33	---
	14	4⅜	0.31	33	---
Massachusetts	7	3	0.43	100	---
New York	8	4	0.5	50	---
	7	3	0.43	50	---
North Carolina	8	3.42	0.43	33	---
	9	3.82	0.42	67	---
Virginia	9	3.7	0.41	50	---
	8	3¼	0.41	50	---
Washington	8	4¼	0.53	100	---

*PP = Polypropylene
**PE = Polyethylene

3.3.7 Location of Splice Regions Relative to Transverse Diaphragms

The next question on the industry survey asked whether the states/districts prefer to locate transverse diaphragms at the same location as the CIP splice regions or if they typically place splice regions away from the diaphragms (refer to Figure 3.5). Locating a transverse diaphragm at the splice region provide benefits such as improved consolidation of concrete due to the extra space within the diaphragm formwork, additional stability during construction, and improved concrete confinement (Castrodale and White, 2004). According to the survey responses, out of the 10 state DOTs having recent experience with spliced I-girder bridges, 7 prefer to locate splice regions at transverse diaphragms. California, Georgia, and Washington, however, prefer to place them away from transverse diaphragms.

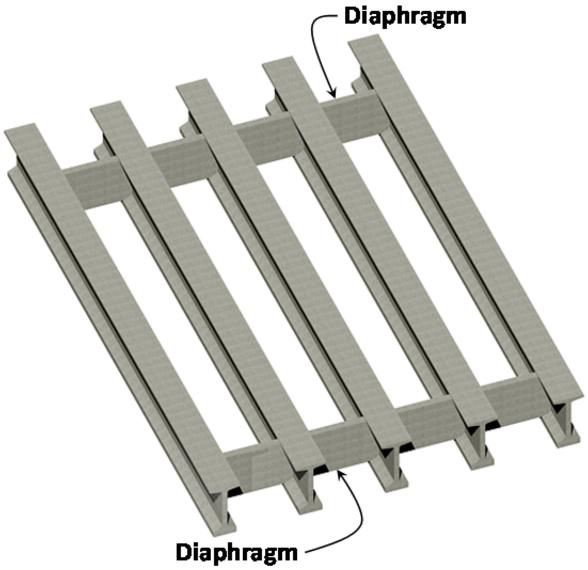


Figure 3.5: Transverse diaphragms

3.3.8 Transverse Width of Splice Region

One of the most critical components for the detailing of spliced I-girders is the geometry of the splice regions. The range of possible splice region geometries were considered by examining both the transverse widths and the longitudinal lengths of splices within existing bridges.

The transverse width of CIP splice regions (i.e., the member cross-section at the splice) is often chosen to match one of the options illustrated in Figure 3.6. Considering the extra space transverse diaphragms may provide, the cases in which the splice regions are located away from transverse diaphragms were the primary focus when examining the typical transverse width of the splice according to the industry survey results. The detailing practices in California, Georgia, and Washington were therefore considered.

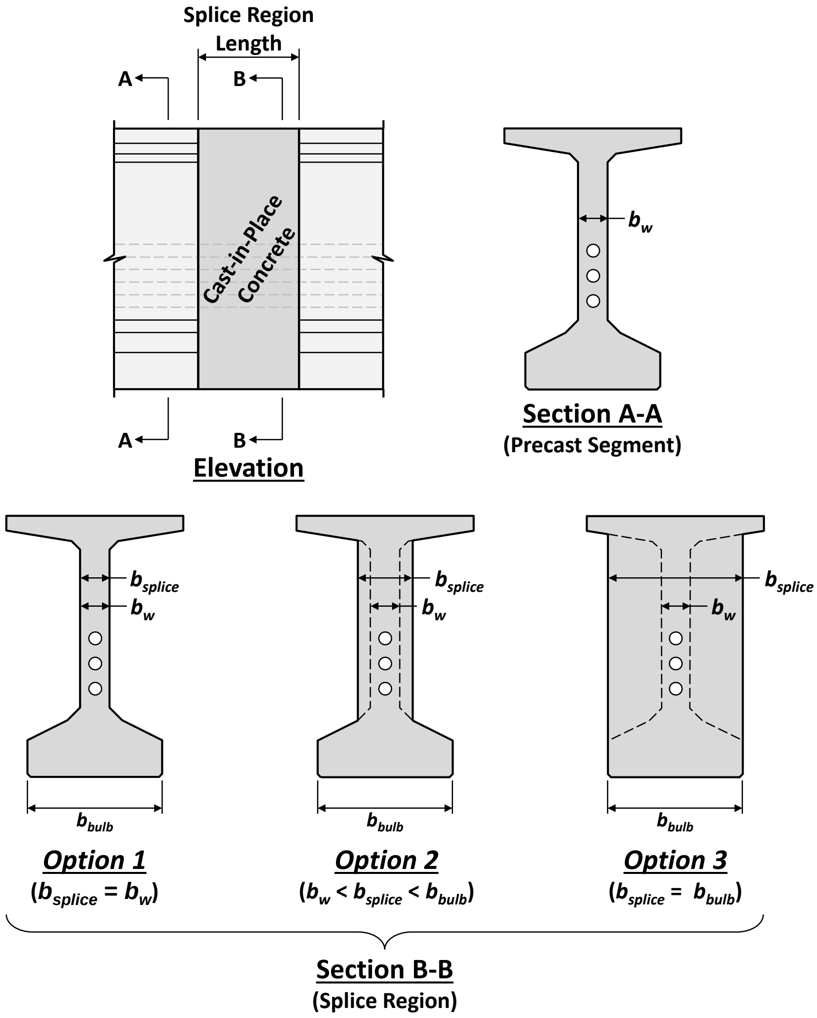


Figure 3.6: Possible options for the transverse width of splice regions

According to the survey responses, the width of the web at the splice region is typically widened to match the width of the bottom flange in California. The width is selected to allow ease of forming the splice section and to provide enough space for reinforcement and concrete placement. In contrast, the Washington State DOT has typically maintained a constant section through the splice region in the past. In other words, the splice regions match the shape of the adjacent precast I-girders. The survey responses indicate that the Georgia DOT has only been involved in the design/construction of two spliced girder bridges. One of these bridges, constructed in the early 1990s, contains an atypical splice with a stepped support. The other bridge, constructed more recently, includes splice regions with a cross-section matching that of the adjacent girders.

3.3.9 Length of Splice Region

The survey participants were asked to provide the values for the lengths of the splice regions specified for existing spliced I-girder bridges. The responses are summarized in Table 3.4. Considering the range of the splice region lengths, the minimum length that has been specified is 10 in., while the maximum length is 48 in. Considering the typical lengths for each state, the most common value is 24 in.

Table 3.4: Length of Splice Region

State	Minimum Length (in.)	Maximum Length (in.)	Typical Length (in.)
Arizona	---	---	24
California	24	48	24
Florida	18 (+/-)	20 (+/-)	N/A
Georgia	4	30	N/A
Hawaii	24	36	24
Massachusetts	12	14	12
New York	---	---	10
North Carolina	24	Dependent Upon Skew	24
Virginia	---	---	12
Washington	24	Special Cases	24

The primary factors affecting the selected splice region length according to the survey responses include the need for adequate space to place shear reinforcement, splice the post-tensioning ducts, and properly place concrete. Some state DOTs mentioned that the splice region length must allow for the development and lap splicing of longitudinal reinforcement.

3.3.10 Serviceability and Aesthetic Issues

Near the end of the industry survey, the participants were given the opportunity to describe any specific problems they have encountered related to the splice regions of existing bridges. When asked if any serviceability or aesthetic issues have arisen (e.g., cracking, discolored concrete, etc.), the New York State DOT answered that the color of the concrete within the splice region generally does not match the color of the precast girders. All other survey participants answered that no serviceability or aesthetic issues have been observed.

3.3.11 Constructability Issues

Several of the survey responses indicated that constructability issues related to splice regions have been encountered in the field. Most of the problems were associated with either the placement of concrete within the splice regions or the use of temporary supports. Three of the responses (California, New York, and Washington) mentioned concrete consolidation issues at the splice regions, highlighting the importance of proper mixture designs and adequate vibration of the concrete. Three other DOTs (Florida, North Carolina, and Virginia) noted issues with temporary shoring or strong-backs. For example, the Virginia DOT observed cracking at splice regions due to shoring that allowed the pier segments to rotate slightly. Such issues underscore the need for the careful review of construction sequences, falsework submittals, and any documentation related to temporary supports.

3.4 Supplementary Material

The industry survey participants were also given the opportunity to submit relevant supplementary material with their responses. Several state DOTs provided drawings of existing spliced girder bridges. Some participants also gave access to design guidelines and/or other design-related documents. The supplementary material was reviewed during the development of the splice region details of the test specimens and provided a deeper insight into design and construction procedures that have been successfully implemented.

3.5 Summary

The evaluation of the responses from the industry survey resulted in an increased awareness of typical spliced girder design and detailing practices within various states across the country. Out of the 25 responses received from DOTs, 10 indicated recent experience in spliced I-girder technology. Survey participants put forth special efforts to provide useful information for the spliced girder research, particularly in regards to CIP splice region details. As described in Chapter 4, the survey responses helped to guide the development of the splice details that were constructed and proof tested for the Phase II experimental program.

Chapter 4. Experimental Program

4.1 Overview

The experimental program described in this chapter was conducted to better understand the behavior of spliced I-girders. More specifically, the primary objective was to evaluate the structural performance of the cast-in-place (CIP) splice regions with the chosen candidate details. These structural details were selected based on the industry survey and related supplementary material described in Chapter 3 as well as from input offered by the TxDOT Project Monitoring Committee and a project advisory panel. Proof tests were performed on two large-scale girder specimens as part of the experimental program. The tests provide significant insights into the strength and behavior of spliced girders that are otherwise unavailable within the literature. The design, details, fabrication, and testing of the specimens are described in the following sections.

4.2 Project Advisory Panel

Consultation with knowledgeable professionals with first-hand experience in spliced girder technology is essential to understanding the intricacies involved in the design and construction of spliced I-girder bridges. A project advisory panel was selected to fulfill this need and offer insights and suggestions related to the experimental program. The advisory panel consisted of the followed practitioners:

- Bijan Khaleghi of the Washington State Department of Transportation
- Steve Seguirant of Concrete Technology Corporation in Tacoma, Washington
- Christopher White of Michael Baker Jr., Inc. in Houston, Texas

4.3 Section Geometry

The section geometry of the specimens tested as part of the splice region experimental program is illustrated in Figure 4.1. The section followed the geometry of a Tx62 girder except that all horizontal (i.e., transverse) dimensions were increased by 2 in. The specimens therefore had a web width of 9 in., unlike the standard 7-in. web of TX girders, to accommodate ducts with a 4-in. diameter. The end regions of the spliced girder specimens had thickened end blocks for proper anchorage of the post-tensioning tendons. Please refer to Section 4.7 for the details of the end blocks.

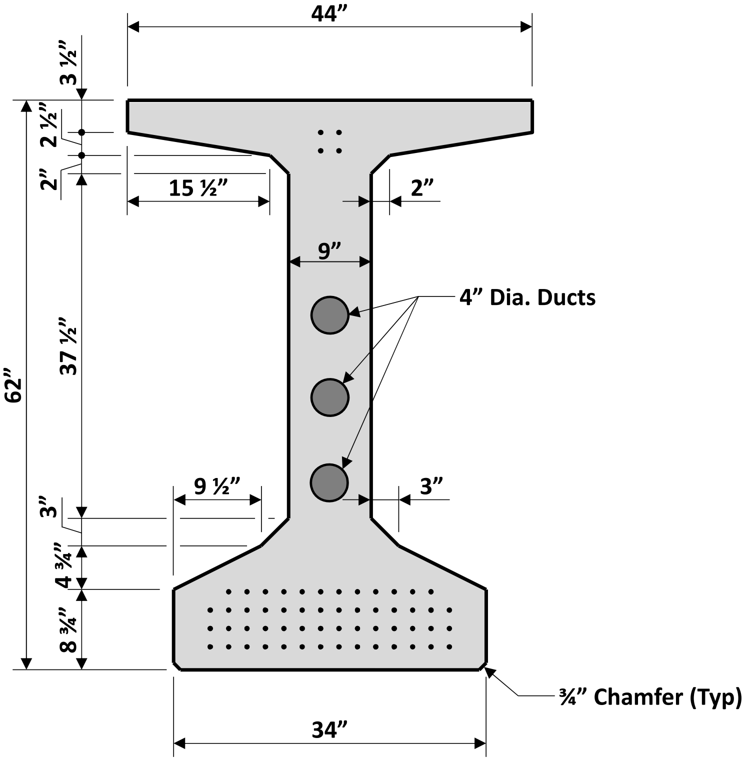


Figure 4.1: Section geometry of spliced girder test specimens

A deck with a thickness of 8 in. was placed on the girder specimens prior to testing. The deck geometry is described in Section 4.13.6.

4.4 Specimen Configuration

The spliced girder test specimens each consisted of two precast girder segments that were joined at a cast-in-place splice region, as illustrated in Figure 4.2. The short precast segment had a length of 14 ft while the long segment had a length of 34 ft. The CIP splice region was 2-ft long, giving a total specimen length of 50 ft. The geometry of the splice region is further discussed in Sections 4.9.1 and 4.9.2.

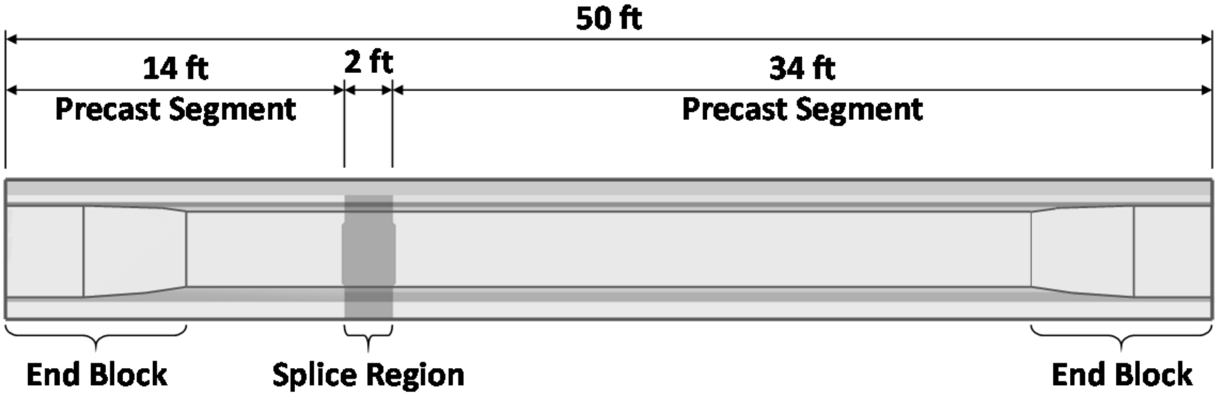


Figure 4.2: Spliced girder specimen configuration

4.5 Pretensioning Strand Layout

The precast segments of the spliced girder test specimens were pretensioned with 0.5-in. diameter low-relaxation 7-wire prestressing strands with a specified tensile strength, f_{pu}, of 270 ksi (ASTM A416). An identical strand pattern, illustrated in Figure 4.3, was used for all four precast segments fabricated for the testing program. Within the bottom flange, 54 strands were placed in four horizontal rows. The top flange contained 4 strands distributed in two rows. No strands were debonded along the lengths of the precast segments. Each strand was individually stressed to a value of $0.75f_{pu}$, or 202.5 ksi, within a tolerance of ±5 percent. The stresses in the extreme fibers of the girder cross-section at prestress transfer were calculated using gross sectional properties. A concrete compressive release strength, f'_{ci}, of 6.0 ksi was specified to satisfy the required stress limits of TxDOT's *Bridge Design Manual – LRFD* (2013).

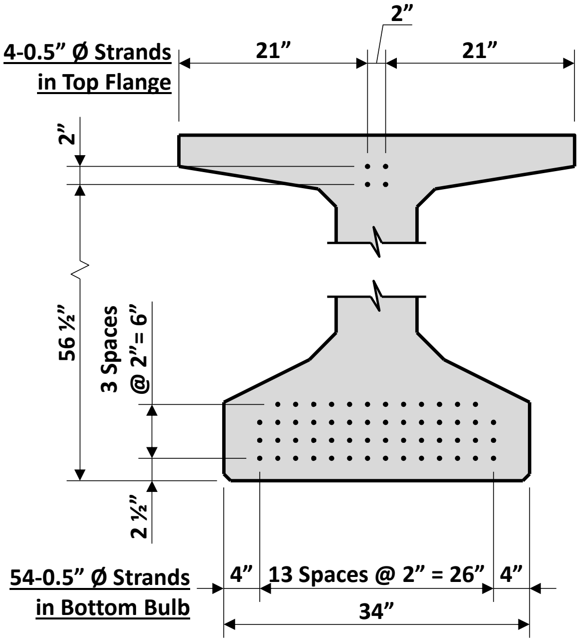
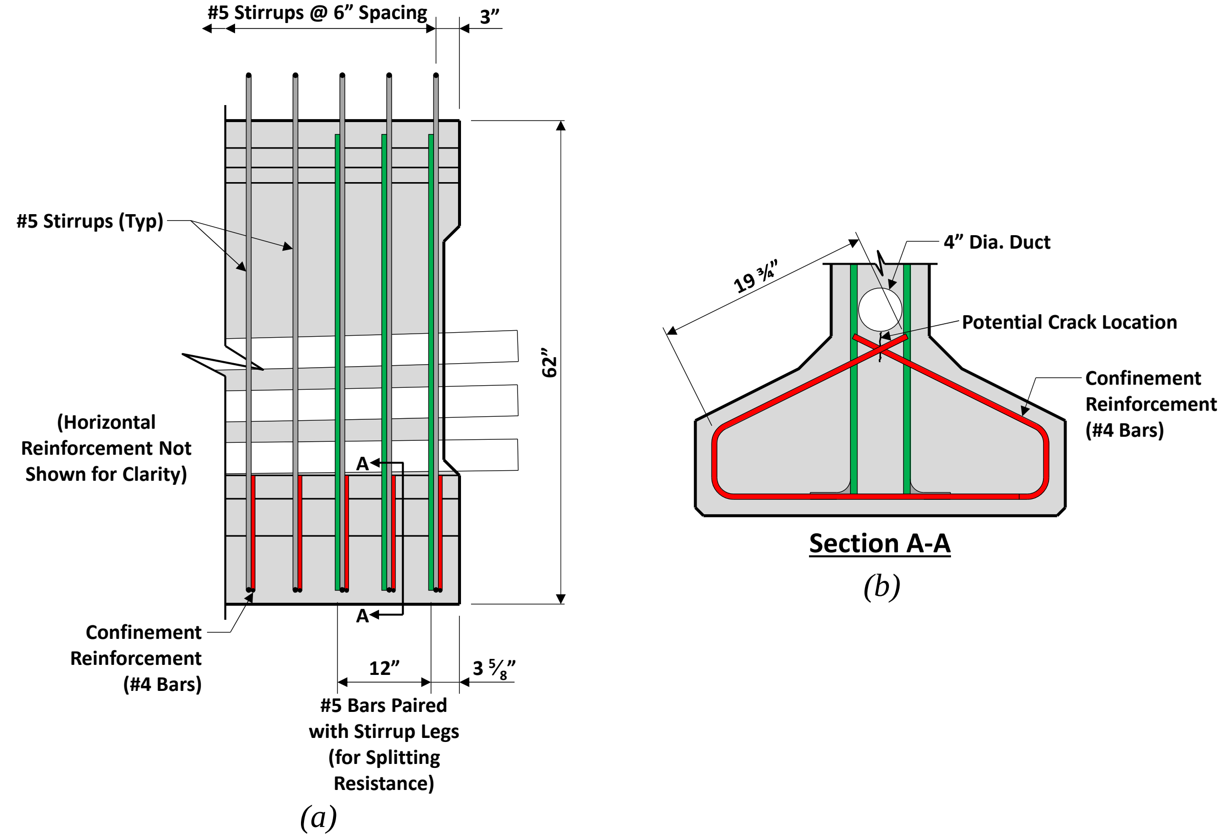


Figure 4.3: Pretensioning strand layout

4.6 End Region Reinforcement (Near Splice Region)

Supplementary vertical reinforcement was placed within the non-thickened end regions of the precast girder segments (i.e., girder ends near the splice region) to provide splitting resistance. The specified reinforcement was selected to be the minimum allowed by Article 5.10.10.1 of AASHTO LRFD (2014) in order to ensure that additional bars contributed little to the shear strength of the girders. The supplementary reinforcement consisted of straight No. 5 bars paired with the legs of the first three stirrups near the ends of the girder segments, as indicated in Figure 4.4(a). The contribution of these straight bars to the shear strength of the girders was neglected in strength calculations. Confinement reinforcement was also provided in the bottom flange within the girder end regions to satisfy Article 5.10.10.2 of AASHTO LRFD (2014). The details of the confinement reinforcement were slightly different from the bars typically used in standard TX girders. The diagonal extensions of the reinforcement were made longer to control any vertical cracks that may develop under the bottom post-tensioning duct, as illustrated in Figure 4.4(b).



(a)

(b)

Figure 4.4: End region reinforcement – (a) vertical reinforcement; (b) confinement reinforcement

4.7 End Block Design and Details

The Tx62 girder segments were modified to include thickened end blocks to accommodate the post-tensioning anchorages located at the two ends of the 50-ft long test girders (refer to Figure 4.2). The design and details of the end blocks are outlined in Sections 3.2.5 through 3.2.9 of Moore et al. (2015).

4.8 Post-Tensioning

4.8.1 Duct Material and Tendon Layout

Three post-tensioning ducts were contained within the web of the test girders and extended the full length of the specimens. The ducts had a diameter of 4 in. Plastic ducts were selected, as opposed to steel ducts, primarily due to the size of the couplers used to join the duct segments together. The relative size of the coupler for a plastic duct with a given nominal diameter is typically larger than the coupler for a steel duct with that same diameter. The use of plastic ducts allowed any localized effects due to the relatively large duct couplers to be identified during testing. Additional information of the specific duct coupler installed within the test girders is provided in Section 4.9.7.

Each of the post-tensioning ducts contained 12 0.6-in. diameter low-relaxation 7-wire prestressing strands with a specified tensile strength, f_{pu}, of 270 ksi (ASTM A416). The tendons were draped to provide the necessary flexural strength within the test region to ensure the girders exhibited a shear-compression failure. The tendon layout is presented in Figure 4.5. The elevation of each duct (measured from the bottom of the girder) is provided in the figure at 2-ft increments along the length of the test specimens.

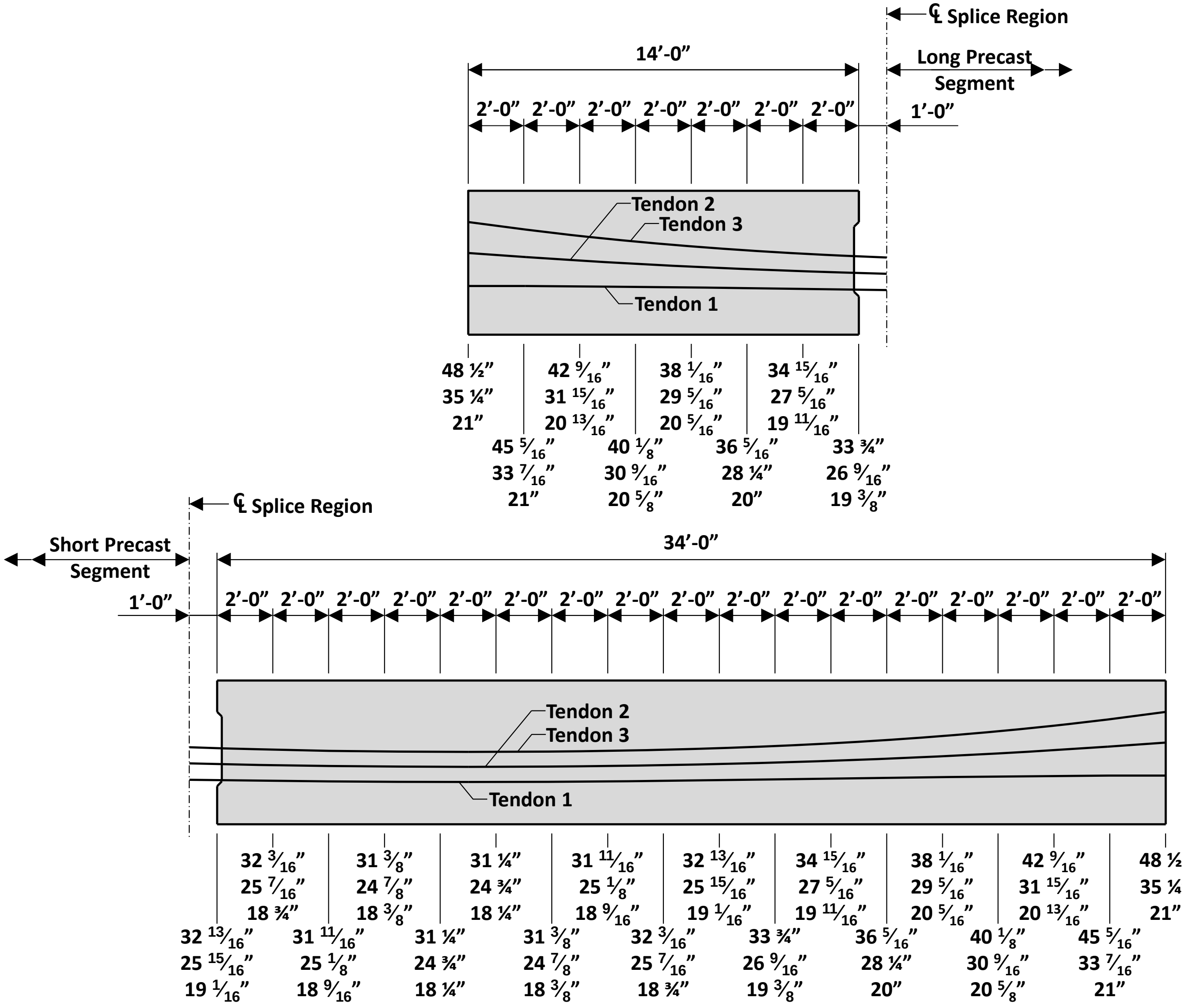


Figure 4.5: Post-tensioning tendon layout

4.8.2 Anchorage

Each end of the post-tensioning tendons were anchored by a multi-plane cast iron bearing trumplate and a steel anchor head, as shown in Figure 4.6. Information regarding the local zone reinforcement required to be used with the anchorage devices is provided in Section 3.2.8 of Moore et al. (2015).

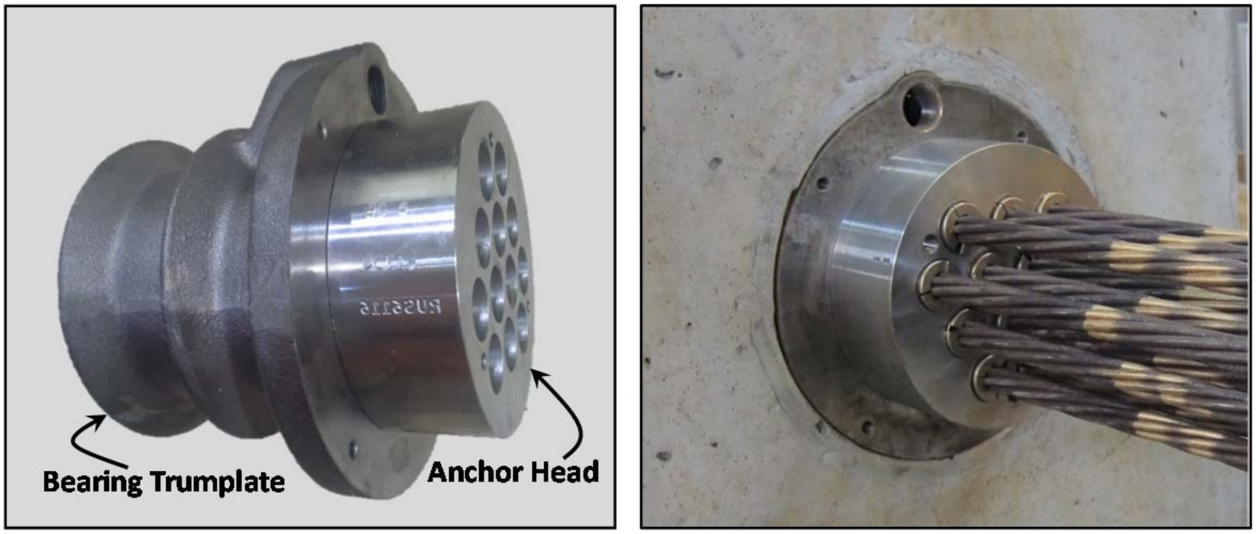


Figure 4.6: Post-tensioning anchorage

4.9 Splice Region Details

The splice region details of the two test specimens were selected to conduct proof tests that would provide valuable information that could then be directly applied to the design and detailing of actual field structures. The industry survey results as well as input from the project advisory panel and the TxDOT Project Monitoring Committee were all invaluable resources in the development of the details. While designing the splice regions, one of the primary considerations of the details were their simplicity in application. Furthermore, the details were selected to create test specimens representative of existing spliced girder bridges while also considering critical design and construction scenarios.

4.9.1 Length of Splice Region

The length of the splice region measured along the longitudinal axis of the girder was chosen to be 24 in. for both test specimens. This value was primarily based upon the industry survey results, which showed that 24 in. is the most typical splice region length, and discussions with the project advisory panel. A length of 24 in. provides the space needed to place stirrups, splice the post-tensioning ducts, and properly cast concrete. The chosen length also offers the space necessary to accommodate any minor duct misalignment issues within the splice region.

4.9.2 Transverse Width of Splice Region

The transverse width of the splice regions of the testing program (i.e., the member cross-section at the splice) was selected to match the shape of the adjacent precast girder segments. Maintaining a constant cross-section through the splice region gives a worst-case scenario in terms of constructability (e.g., concrete placement). Moreover, it provides the opportunity to study the behavior of a splice region with a restricted cross-sectional area. The findings from the proof tests can then be applied to spliced girder bridge designs in which a constant cross-section along the span length is desired for aesthetic reasons. An illustration of the selected splice region geometry is presented in Figure 4.7.

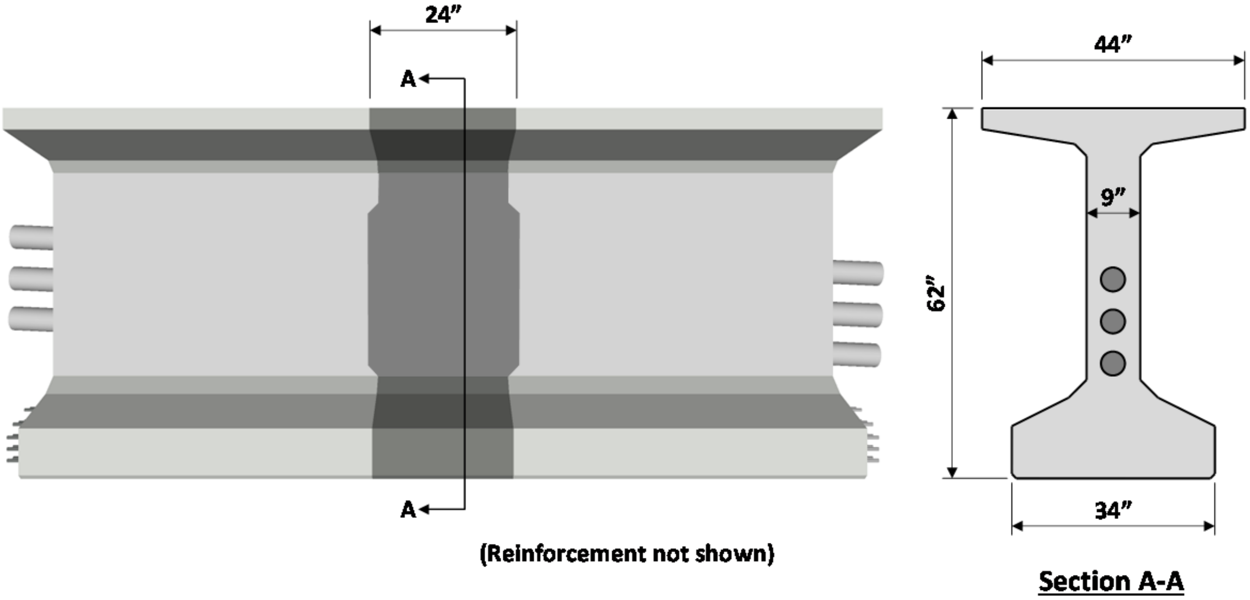
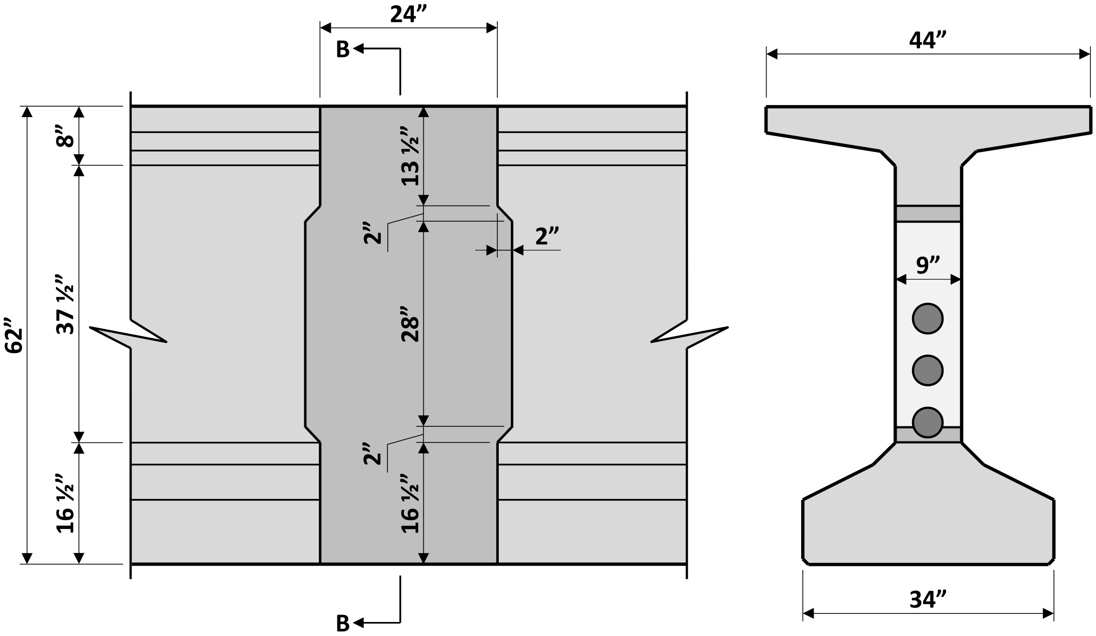


Figure 4.7: Geometry of splice region

4.9.3 Shear Interface Detail

Spliced girders are typically designed with an interface detail at the transitions between the precast segments and the cast-in-place splice regions to aid in shear transfer. A single shear key was chosen as the interface detail for the spliced girder test specimens, as illustrated in Figure 4.8. The shear key had a 2-in. inset and was contained within the web of the girder. The selection of a single shear key was based on its successful application in existing spliced girder bridges as indicated by the industry survey (refer to Section 3.3.4). Moreover, the detail is simple and the required formwork is relatively easy to fabricate.



(Reinforcement not shown)

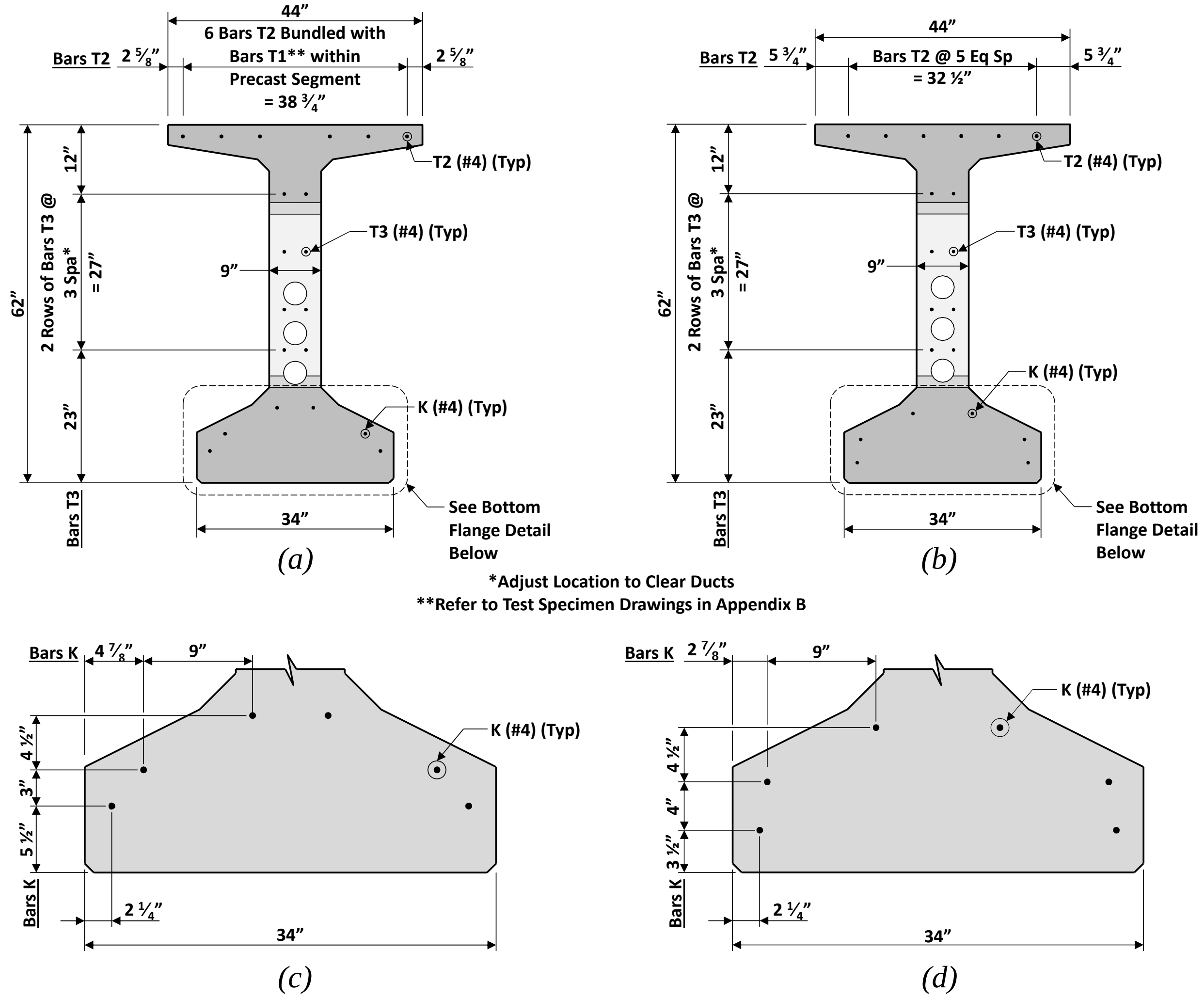
Section B-B

Figure 4.8: Shear key detail

4.9.4 Longitudinal Interface Reinforcement

The effect of the mild longitudinal reinforcement crossing the interface between the precast girder segments and the splice region was one of the primary interests of the testing program. Straight bars were selected to provide a simple detail that would lead to reduced congestion in the splice region as compared to some other possible bar detailing options.

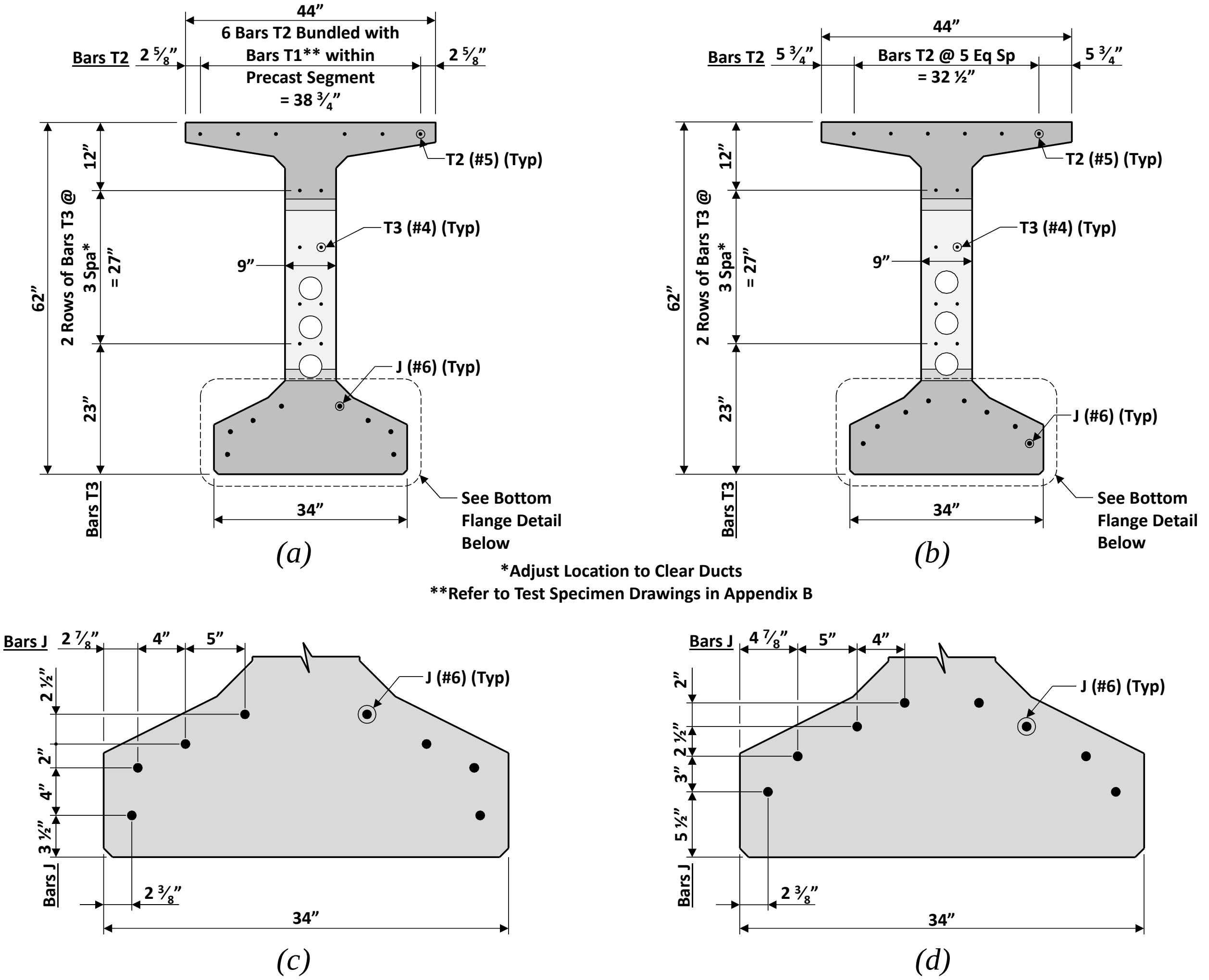
The interface reinforcement details of the two test specimens are illustrated in Figures 4.9 and 4.10. The amount of interface reinforcement was varied between the two specimens to determine the effect of the bars on the behavior of the splice region. Within the bottom flanges of the test girders, 6 No. 4 bars (A_s = 1.2 in.^{2}) extended from each precast segment into the splice region of the first specimen, while 8 No. 6 bars (A_s = 3.52 in.^{2}) extended into the splice region of the second specimen. The second test girder therefore contained approximately 3 times the area of interface reinforcement within its bottom flange compared to the first girder. Both test specimens contained No. 4 interface bars along the height of the web, as shown in Figures 4.9 and 4.10. Within the top flange, 6 No. 4 bars extended from each precast girder segment of the first test specimen, and 6 No. 5 bars extended from each precast segment of the second specimen. All of the interface reinforcement was embedded 24 in. into the precast segments, and each bar extended 21 in. into the splice region.



*Adjust Location to Clear Ducts

**Refer to Test Specimen Drawings in Appendix B

Figure 4.9: Longitudinal interface reinforcement of Test Girder 1 – (a) end of long precast segment; (b) end of short precast segment; (c) flange detail of long precast segment; (d) flange detail of short precast segment



(a)

(b)

*Adjust Location to Clear Ducts

**Refer to Test Specimen Drawings in Appendix B

(c)

(d)

Figure 4.10: Longitudinal interface reinforcement of Test Girder 2– (a) end of long precast segment; (b) end of short precast segment; (c) flange detail of long precast segment; (d) flange detail of short precast segment

All four precast girder segments (i.e., two precast segments for each of the test specimens) were fabricated during the same period due to scheduling restrictions with the concrete precaster. To provide flexibility with the interface reinforcement details of the two test specimens, each precast segment was fabricated with both the No. 4 and No. 6 bars extending from the bottom flanges. The unwanted interface bars were later cut at the surface of the precast segments. For example, the No. 4 bars extending from the bottom flange of the girder segments for the second test specimen were cut off to only include the effect of the No. 6 bars crossing into the splice region.

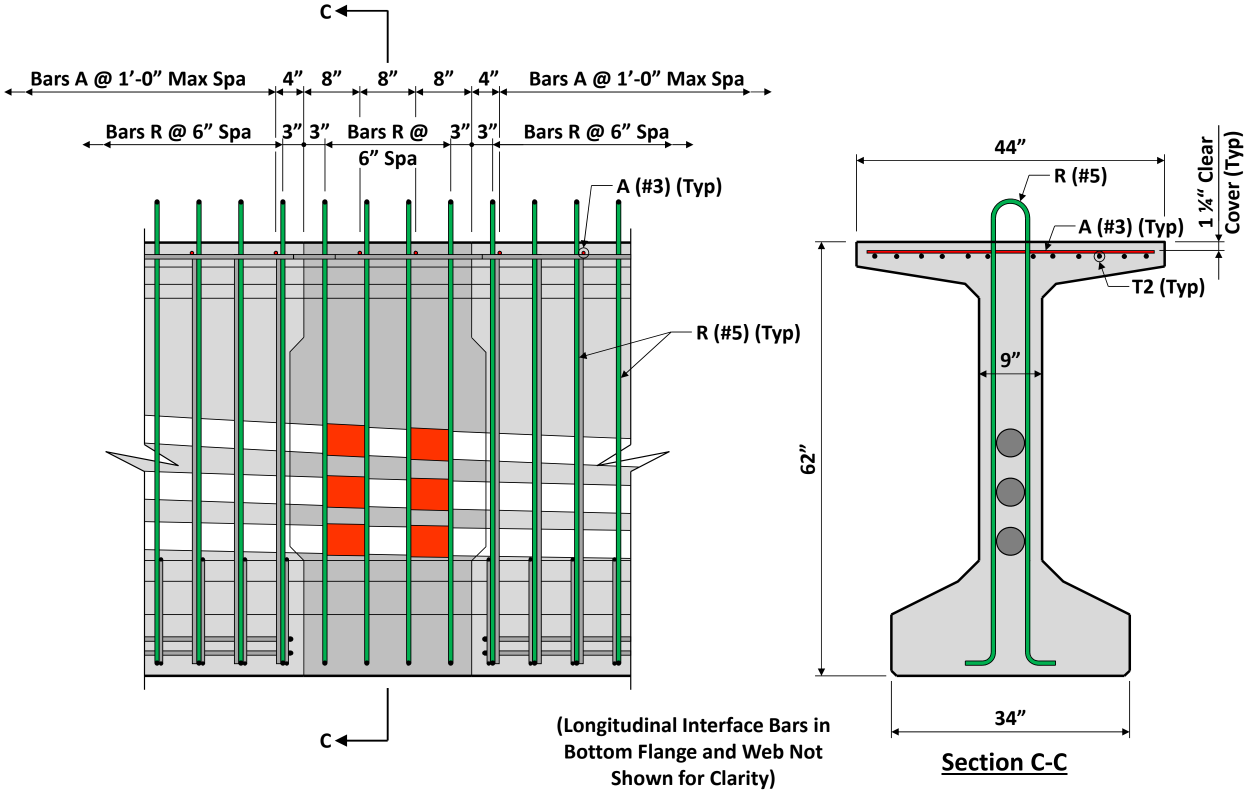
After fabrication of the precast girder segments, the pretensioned strands extended from both the top and bottom flanges at the beam ends. To avoid additional congestion within the splice region, the pretensioned strands were cut within 3 in. of the surface of the girder segments. Although allowing the strands to extend farther into the splice region would have provided additional steel that may have had a beneficial effect on the performance of the test girders, the risk of concrete consolidation issues due to the added congestion of the strands was determined to outweigh any possible benefits (refer to the mock-up cast in Section 4.11.2).

4.9.5 Duct Diameter to Web Width Ratio

Ducts with a 4-in. diameter were contained within the 9-in. webs of the test specimens, giving a duct diameter to web width ratio of 0.44. Considering the results of the industry survey presented in Section 3.3.6, a value of 0.44 is within the range of typical duct diameter to web width ratios of existing spliced girder bridges. Furthermore, the ratio is slightly greater than the AASHTO LRFD (2014) limit of 0.4, a value often exceeded in the field.

4.9.6 Shear and Transverse Reinforcement within the Splice Region

The shear and transverse reinforcement within the splice region of the test specimens was essentially a continuation of the reinforcement provided within the adjacent precast segments, as illustrated in Figure 4.11. The 6-in. spacing of No. 5 stirrups (Bars R) within the girder segments was continued through the splice region. The No. 3 bars (Bars A) that were provided as transverse reinforcement within the top flange of the precast segments were also included in the splice region as shown in Figure 4.11.

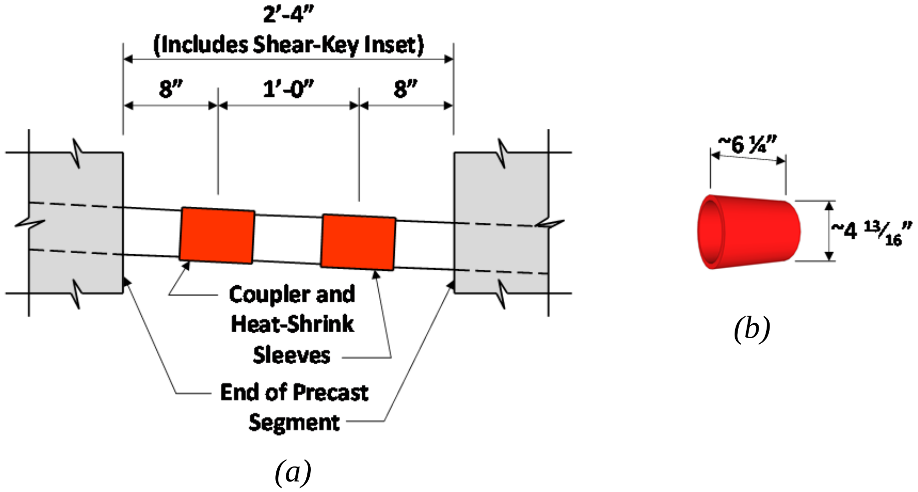


(Longitudinal Interface Bars in Bottom Flange and Web Not Shown for Clarity)

Figure 4.11: Shear reinforcement (Bars R) and transverse reinforcement (Bars A) within the splice region

4.9.7 Duct Coupling Detail

The manner in which the post-tensioning ducts are coupled together within the splice region is typically included within the detailed drawings of spliced girder bridges. The ducts are generally coupled using either a single coupler at the center of the splice region or by using two couplers with a short duct segment in the middle. Strength and constructability were both major factors when specifying the duct coupling detail within the splice regions of the test specimens. Considering these two factors, the detail presented in Figure 4.12(a) was developed. If the relatively large plastic duct couplers have a detrimental effect on the shear behavior of the specimens (refer to Section 4.8.1), the chosen detail with two couplers may result in a more critical (i.e., worst-case) scenario than the use of only one coupler. Furthermore, the detail with two couplers better accommodates potential misalignment of the ducts extending from the precast segments, simplifying construction.



(a)

(b)

Figure 4.12: Duct coupling – (a) construction detail; (b) coupler dimensions

The duct couplers used within the test girders are slip-on couplers, as opposed to snap-on couplers. The approximate dimensions of the couplers are provided in Figure 4.12(b). Heat-shrink sleeves were used to seal the ends of each duct coupler (refer to Figure 4.18(d)).

4.10 Precast Concrete Mixture

The four precast segments of the testing program were all fabricated at a single precast concrete yard. The standard mixture used at the precasting plant to cast TX girders was also used to cast the girder segments. The concrete was a self-consolidating concrete (SCC) mixture with ½-in. (TxDOT Grade 6) river gravel as the coarse aggregate. The concrete mixture design used for the precast segments is provided in Table 4.1.

Table 4.1: Precast Concrete Mixture Design

Material	Details	Design Quantity	Units
Cementitious Material	Type III Cement	663	lb/yd^3 concrete
	Class F Fly Ash	271	
Coarse Aggregate	River Gravel (1/2" Nominal)	1,555	
Fine Aggregate	Sand (F.M. = 2.7)	1,222	
Water	---	269	
Admixtures	High-Range Water Reducer	5.50	oz/cwt
	Water Reducer/Retarder	2.50	
	Corrosion Inhibiter	41.15	
	Viscosity Modifier	2.78	

4.11 Splice Region Concrete

4.11.1 Mixture Design

The mixture for the splice region concrete was designed to meet requirements for both strength and workability. Any undesired effects caused by two drastically different strengths between the precast concrete and the cast-in-place splice region concrete should be prevented. Given the high strength of the concrete used for the precast segments (refer to Section 4.17), the concrete compressive strength achieved within the splice region of the test specimens should also be relatively high. At the same time, the splice region concrete was ensured to be a mixture that would be readily available in the field from a local ready-mix supplier.

In addition to the concrete strength, the workability of the mixture had to be suitable to allow the concrete to flow into the relatively congested splice region without resulting in any consolidation problems. A mock-up cast, described in Section 4.11.2 below, was conducted to ensure the proper workability of the chosen mixture.

The mixture design presented in Table 4.2 was selected after making certain that the desired strength could be achieved and that concrete consolidation issues would be avoided. The chosen mixture has 700 lbs of cementitious material per cubic yard of concrete and contains 1-in. (TxDOT Grade 4) river gravel as the coarse aggregate. The target slump of the mixture is 8.0 in.

Table 4.2: Splice Region Concrete Mixture Design

Material	Details	Design Quantity	Units
Cementitious Material	Type I/II Cement	525	lb/yd^3 concrete
	Class F Fly Ash	175	
Coarse Aggregate	River Gravel (1" Nominal)	1,880	
Fine Aggregate	Sand	1,221	
Water	---	233	
Admixtures	High-Range Water Reducer	5.5	oz/cwt
	Water Reducer/Retarder	2.0 to 3.0	

4.11.2 Mock-Up Cast: Findings and Solutions

The casting of a splice region mock-up was considered to be essential to ensuring that the proper concrete strength would be reached within the splice region of the test specimens and that no consolidation issues would arise. For the mock-up cast, formwork was constructed in the shape of the 2-ft long splice region, as shown in Figure 4.13. Transparent polycarbonate sheets were used to form the I-shaped cross-section to allow the concrete placement to be observed during casting. A single internal vibrator with a ¾-in. diameter head was used to consolidate the concrete. From his location, the operator of the internal vibrator was unable to observe the concrete through the polycarbonate sheeting, similar to actual field conditions.

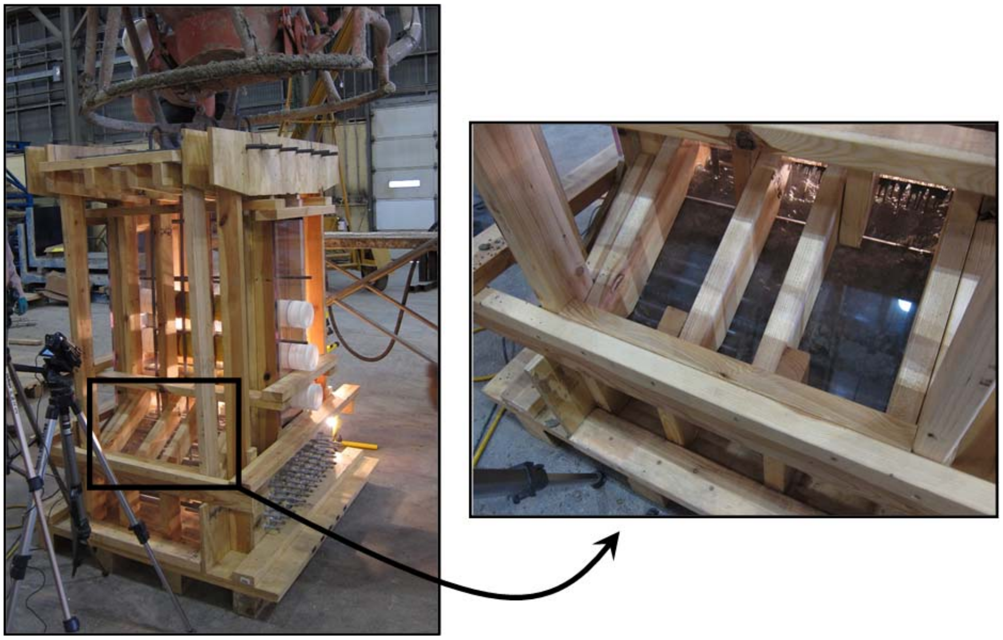


Figure 4.13: Formwork for splice region mock-up cast

After allowing the concrete to cure for several days, the forms were removed. Consolidation issues were observed within the bottom flange of the mock-up specimen as shown in Figure 4.14. No other problems, however, were noted along the height of the specimen. Based on these observations, three measures were taken to ensure that similar consolidation issues did not reoccur when casting the splice regions of the test girders. First, the pretensioned strands extending from the precast segments into the splice region were cut within 3 in. of the surface of the girder segments, as described in Section 4.9.4. The mock-up specimen simulated the strands extending 10 in. into the splice region. Second, external form vibrators were used to ensure the concrete consolidated properly within the bottom flange of the splice region (refer to Section 4.13.3). Lastly, small air holes ($^{5}/_{64}$-in. diameter) were provided along the bottom of the formwork for the splice regions of the test specimens to allow any trapped air to escape from the bottom flange. The details of the longitudinal interface reinforcement were also updated after the mock-up cast. This change in the details, however, is believed to have had a small effect, if any, on the consolidation of the concrete within the splice region.

The concrete mixture used for the mock-up cast achieved a compressive strength adequate for the splice regions of the test girders. A similar mixture was therefore used for the two splice region casts (refer to Section 4.11.1).

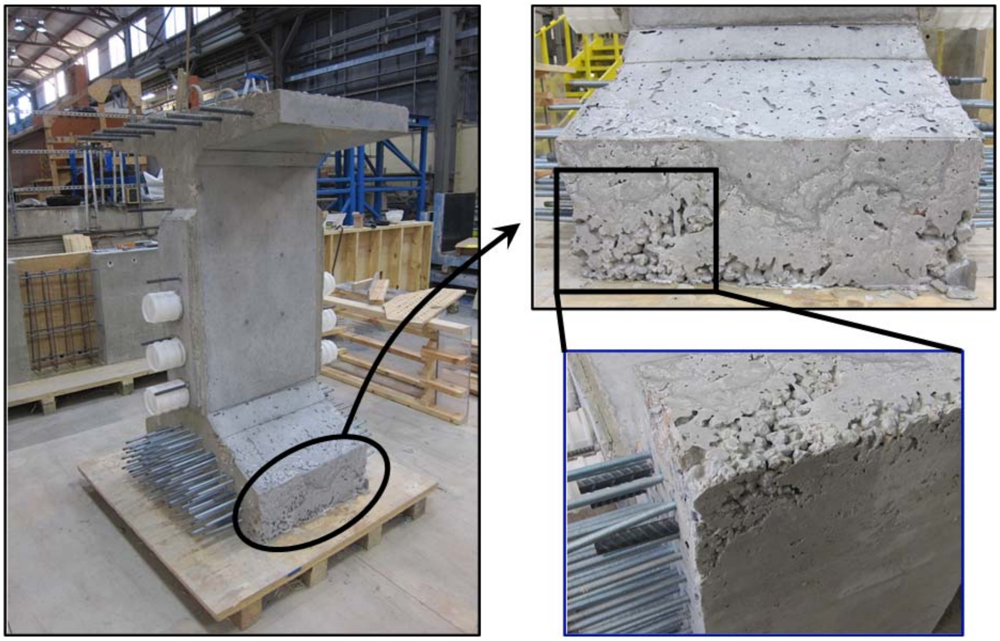


Figure 4.14: Consolidation issues of splice region mock-up cast

4.12 Deck Concrete Mixture

The concrete mixture design used for the 8-in. thick deck placed on the first test girder specimen is provided in Table 4.3. The mixture has a water-cement ratio of 0.30 and contains $^3/_8$-in. (TxDOT Grade 7) crushed limestone as the coarse aggregate. A different mixture was used for the deck of the second girder specimen, as presented in Table 4.4, to expedite the experimental program by ensuring adequate strength was reached at an early age. The water-cement ratio was decreased compared to the previous mixture and a hydration controlling admixture was added to enhance the strength gain within the 2 weeks between casting the deck and testing the girder specimen.

Table 4.3: Deck Concrete Mixture Design – Test Girder 1

Material	Details	Design Quantity	Units
Cementitious Material	Type I/II Cement	592	lb/yd^3 concrete
	Class F Fly Ash	200	
Coarse Aggregate	Crushed Limestone (3/8" Nominal)	1,720	
Fine Aggregate	Sand	1,358	
Water	---	238	
Admixtures	High-Range Water Reducer	6.0	oz/cwt
	Water Reducer/Retarder	1.0	

Table 4.4: Deck Concrete Mixture Design – Test Girder 2

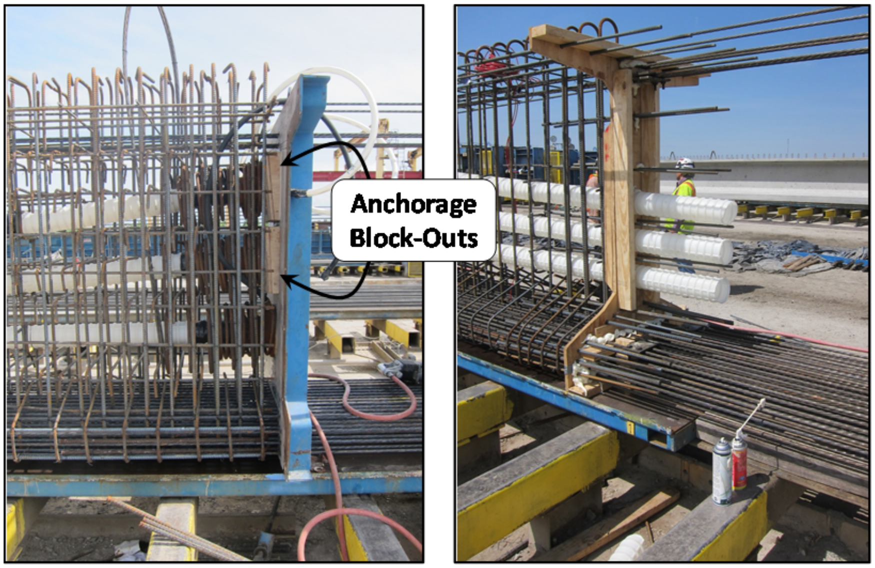
Material	Details	Design Quantity	Units
Cementitious Material	Type I/II Cement	658	lb/yd^3 concrete
	Class F Fly Ash	282	
Coarse Aggregate	Crushed Limestone (3/8" Nominal)	1,750	
Fine Aggregate	Sand	1,168	
Water	---	250	
Admixtures	High-Range Water Reducer	6.5	oz/cwt
	Hydration Stabilizer	1.5	

4.13 Test Specimen Fabrication

4.13.1 Fabrication of Precast Segments

The precast segments of the two test girders were fabricated offsite at a precast/prestressed concrete yard. For each 50-ft long girder test specimen, both precast segments (i.e., the 34-ft long segment and the 14-ft long segment) were cast at the same time. The details of the fabrication of the girder segments are similar to that of the Phase I test specimens as described in Section 3.3 of Moore et al. (2015). Therefore, only notable distinctions between the fabrication of the Phase I and Phase II precast girders are discussed within this current section.

Each precast girder segment had a steel end form placed at the thickened end block. To accommodate the angle of the anchorages of the top two post-tensioning tendons, block-outs were installed with the anchorage hardware as shown in Figure 4.15(a). At the ends of the precast segments that were later to be spliced together, wooden end forms were installed (refer to Figure 4.15(b)). Holes were cut through the wooden end forms at the specified locations of the longitudinal interface reinforcement that was to extend into the splice region.



(a) (b)

Figure 4.15: Ends forms of precast girder segments – (a) at thickened end block; (b) at end to be spliced

Once much of the mild reinforcement was in place, the ducts for the three post-tensioning tendons were installed. The locations of the ducts were then adjusted to match the tendon profiles presented in Section 4.8.1. The ducts were supported at a maximum spacing of 2 ft in accordance with the *Specification for Grouting of Post-Tensioned Structures* (PTI M55.1-12) and the *AASHTO LRFD Bridge Construction Specifications* (2010). After the remaining mild reinforcement was placed, the positions of the ducts were once again verified before the side forms were installed. The completed reinforcing cages for a set of the precast girder segments are shown in Figure 4.16.

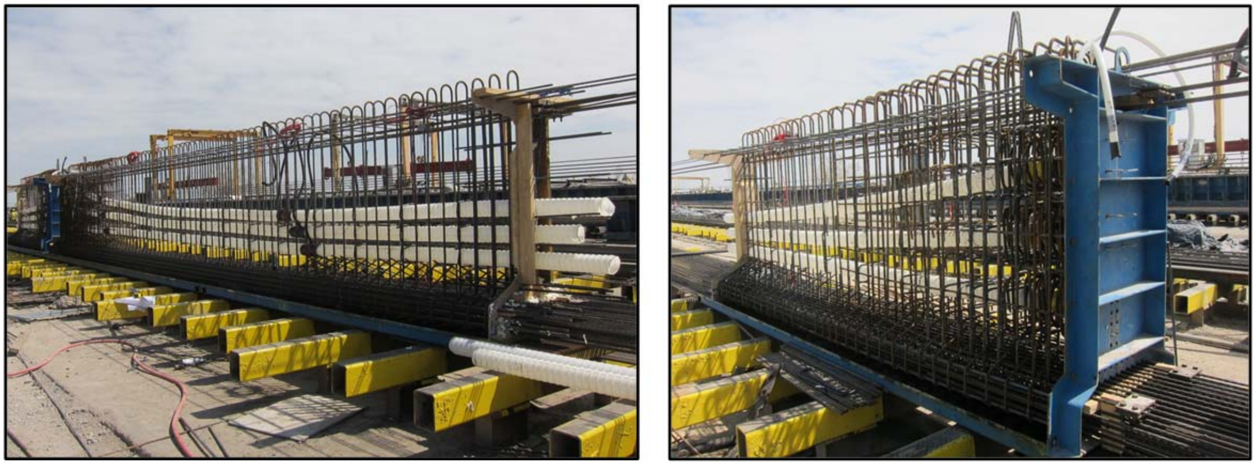

(a) *(b)*

Figure 4.16: Completed reinforcing cages of precast girder segments – (a) long precast segment; (b) short precast segment

After casting, the girder segments were allowed to cure with the side forms in place until the specified compressive release strength, f'_{ci}, of 6.0 ksi was reached. After the actual compressive strength of the concrete, f_{ci}, reached the specified release strength, the side forms were removed, the pretensioned strands were released, the strands were flame cut, and the girder segments were placed in storage until transported to the Phil M. Ferguson Structural Engineering Laboratory.

4.13.2 Preparation of Precast Segments

Prior to splicing the two precast segments of each test girder, preparatory work was performed on the girder ends located at the splice region. After the precast segments were transported to the laboratory (Figure 4.17(a)) and wooden end forms were removed, the following steps were completed to prepare for the splicing operation:

(i) Cut pretensioned strands:
The pretensioned strands extending from the top and bottom flanges of the precast segments were cut within 3 in. of the girder faces as described in Section 4.9.4 and shown in Figure 4.17(b).

(ii) Trim post-tensioning ducts:
The three post-tensioning ducts extending from each precast segment were trimmed at approximately 8 in. from the girder faces in accordance with the detail of Figure 4.12 (see Figure 4.17(c)).

(iii) Cut longitudinal interface reinforcement:
As described in Section 4.9.4, all four precast segments were fabricated with No. 4 and No. 6 longitudinal interface bars extending from the bottom flanges. The interface bars not included in the details of each test girder were therefore cut at the surface of the girder segments to match the reinforcement layouts presented in Figures 4.9 and 4.10.

(iv) Install strain gauges:
Prior to moving the girder segments into their final positions for the splicing operation, foil strain gauges were installed on the interface bars as described in Section 4.14.2 below.

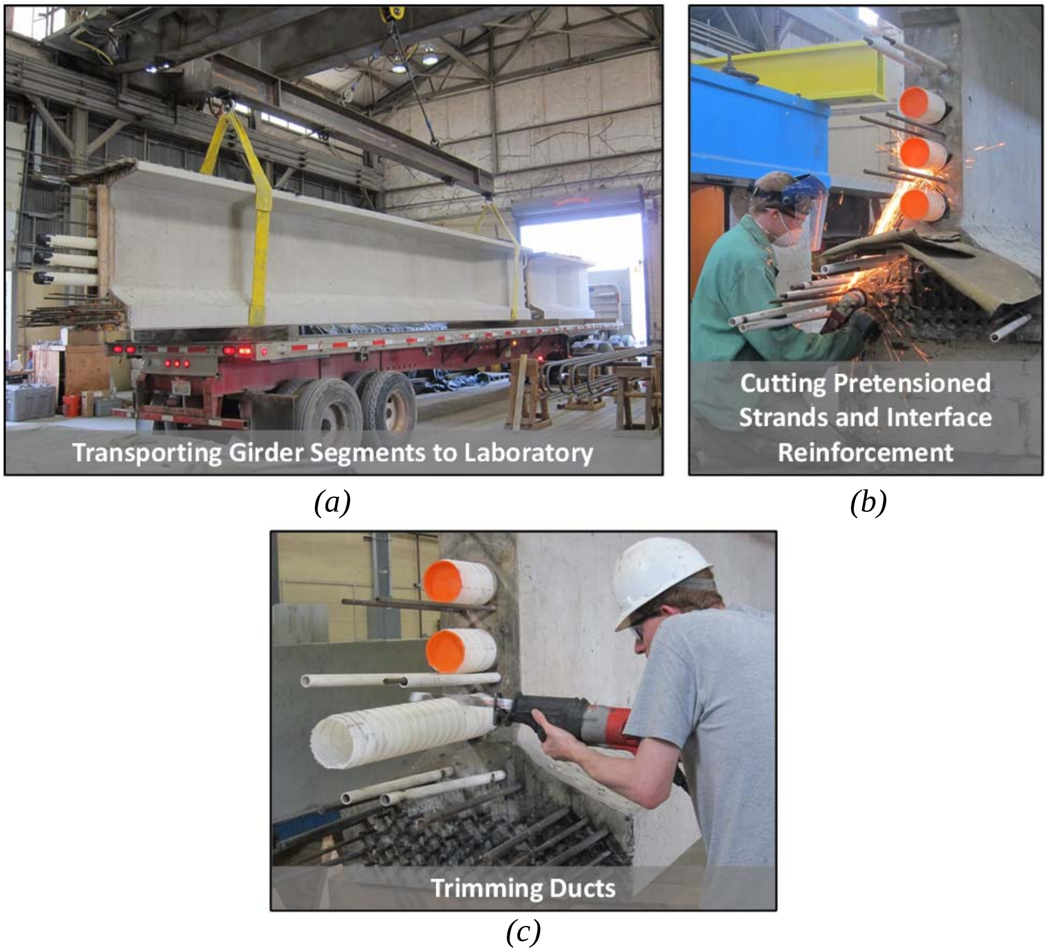


Figure 4.17: Preparing precast segments – (a) transporting girder segments to laboratory; (b) cutting pretensioned strands and interface reinforcement; (c) trimming ducts

4.13.3 Splicing Procedure

Several steps were required to splice the precast girder segments together, including placing the segments in their proper positions and preparing the splice region for casting. The splicing procedure is detailed below and each step is shown for the first test specimen in Figures 4.18 and 4.19.

(i) Place girder segments into position for splicing:
Three concrete pedestals, shown in Figure 4.18(a), were fabricated and moved into position to support the two girder segments of each test specimen. The girder segments were moved into position onto the pedestals and separated by a 2-ft long gap as shown in Figure 4.18(b). The ends of the segments to be spliced together were supported on the 5-ft long center pedestal. The splice region was later cast directly on this center pedestal.

(ii) Verify proper alignment and placement of the girder segments:
Once the precast girder segments were positioned on the concrete pedestals, the placement of the segments was checked and the vertical and transverse alignment at the splice region was verified (see Figure 4.18(c)). If required, metal shims were used at the supports to aid in aligning the girder segments at the splice region.

(iii) Couple ducts:
After the girder segments were placed in their final positions, the ducts extending into the splice region were coupled as shown in Figure 4.18(d). After the duct couplers were moved into their proper positions as detailed in Figure 4.12(a), heat-shrink sleeves were used to seal the ends of each coupler.

(iv) Splice longitudinal interface reinforcement:
Contact lap splices were used to provide continuity to the longitudinal interface bars extending from the webs of the girder segments. These No. 4 bars were tied together as shown in Figure 4.18(e).

(v) Place shear and transverse reinforcement:
Four No. 5 stirrups (Bars R) spaced at 6 in. were placed within the splice region as detailed in Figure 4.11. The transverse reinforcement (Bars A) were then tied to the longitudinal interface bars extending into the top flange of the splice region (see Figure 4.18(f)).

(vi) Install side forms:
Side forms for casting the splice region were fabricated at the laboratory from hollow structural steel sections. Once all preparations of the splice region were completed as shown in Figure 4.19(a), the side forms were installed onto the girder segments (see Figure 4.19(b)). Threaded rods extended between each side-form piece to clamp the forms to the girder segments.

(vii) Cast the splice region:
The final step in the splicing procedure was casting the splice region, shown in Figure 4.19(c). In addition to the use of an internal vibrator with a ¾-in. diameter head, external

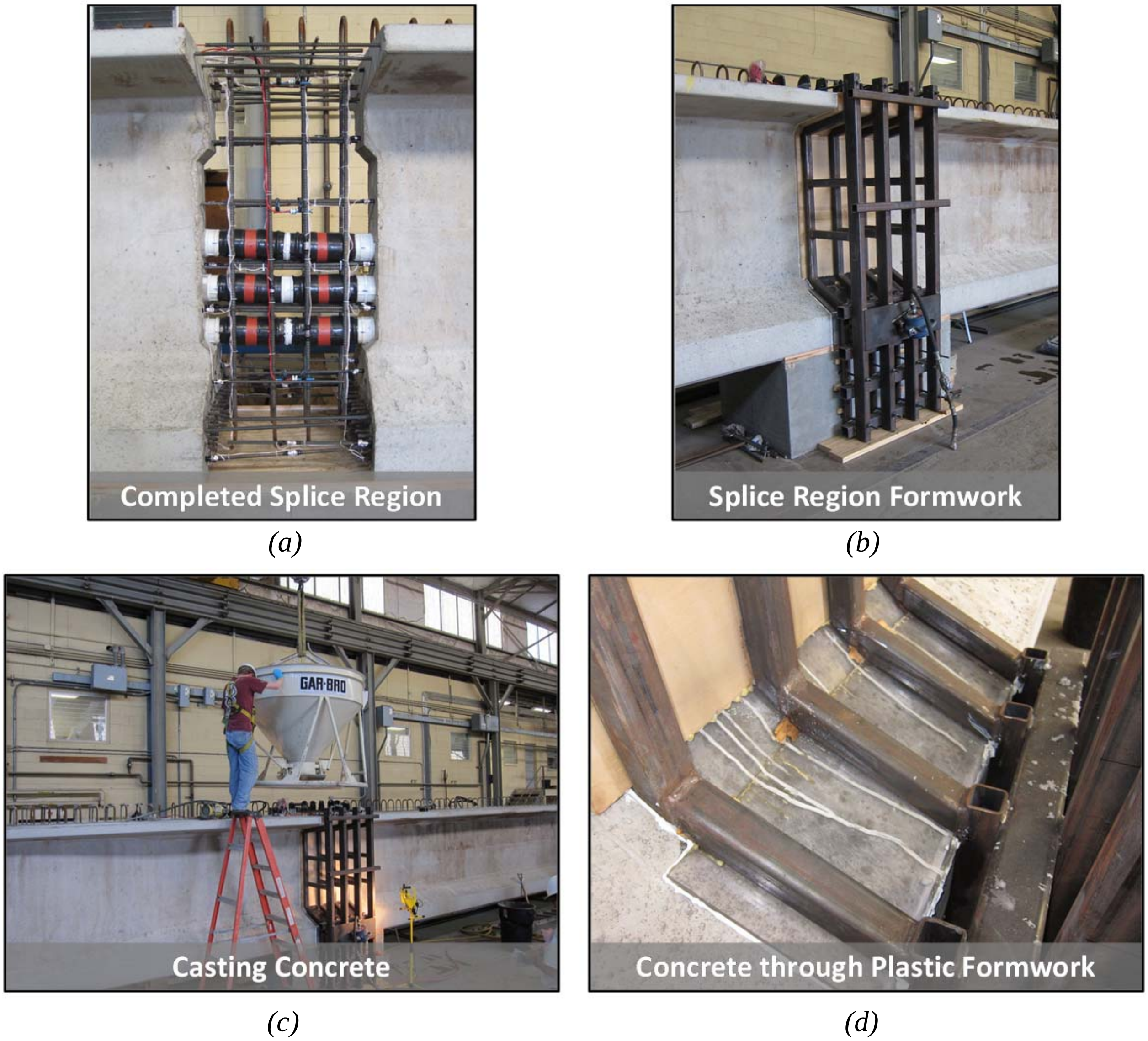
vibrators were installed on each side form to aid in consolidating the concrete. The bottom flange of the splice region was formed with transparent polycarbonate as shown in Figure 4.19(d) in order to ensure concrete was placed properly during the cast.

(a) *(b)*

(c) *(d)*

(e) *(f)*

Figure 4.18: Splicing procedure – (a) concrete pedestals; (b) placing girder segments; (c) verifying girder placement; (d) coupling ducts; (e) spliced interface reinforcement; (f) shear and transverse reinforcement



(a) (b)

(c) (d)

Figure 4.19: Casting the splice region – (a) completed splice region; (b) splice region formwork; (c) casting concrete; (d) concrete through plastic formwork

4.13.4 Post-Tensioning Procedure

After the splice region concrete reached the required strength, the three tendons could be post-tensioned. Considering the close spacing of the tendons along with their draped profile, the post-tensioning sequence was governed by the desire to prevent any risk of the break-through of one tendon into the duct located immediately above that tendon. To eliminate this risk, each tendon of the girder specimen was post-tensioned and then grouted before repeating the procedure for the next tendon. Furthermore, the top tendon was post-tensioned and grouted first, followed by the middle and then the bottom tendons.

A hydraulic cylinder with a hollow plunger (i.e., center hole) was used to apply force to the post-tensioning strands, as shown in Figure 4.20. A pressure transducer was installed in-line with the hydraulic system to monitor the applied force during the post-tensioning operations. The procedure outlined in Section 3.3.2 of Moore et al. (2015) was also followed for the Phase II spliced girder specimens and is therefore not repeated here for the sake of brevity.

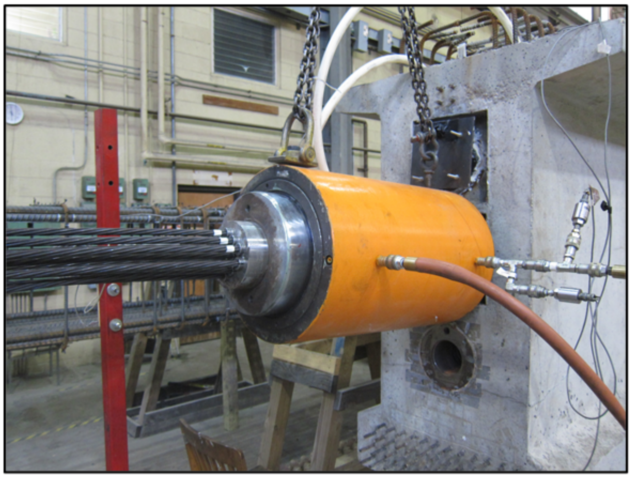


Figure 4.20: Hydraulic cylinder used for post-tensioning

4.13.5 Grouting Procedure

Following the post-tensioning procedure, each tendon was grouted with duct grout for prestressing strands. A grout plant, shown in Figure 4.21, was used to mix and pump the grout. Five grout vents were placed along the length of each tendon. Four of the vents were located at the ends of the 50-ft long test girder as described in Section 3.3.3 of Moore et al. (2015). The fifth vent was placed near the center of the girder at the low point of the tendon profile. One of the grout vents originating at the top of the bearing trumplate was typically used as the inlet for the grout to flow into the duct. Prior to the grouting procedure, the grout caps were installed at the ends of the girder and all vents were installed with positive shut-off valves. Pressure gauges were located at the inlet to the duct and between the grout plant and the girder. The following procedure (based on the requirements in PTI M55.1-12) describes the steps performed for each grouting operation:

(i) Batch water:
Water was first measured by weight in accordance with the dosage recommended by the grout manufacturer (1.8 to 2.1 gallons per 55-lb bag of grout). The grout plant contained a water batching tank that was used to store water until it was needed.

(ii) Mix grout in colloidal mixer:
After adding water to the colloidal mixing tank, the mixer was started and grout was added to the tank (see Figure 4.22(a)). Once mixed, the grout was transferred to the agitator tank where a paddle mixer ensured the grout remained in motion.

(iii) Test wet density and flow of grout:
Both the wet density and flow of the grout mixture was tested to verify its quality and pumpability. The modified flow cone test was performed in accordance with Section 4.4.5.2 of PTI M55.1-12 (see Figure 4.22(b)) to ensure the efflux time was between 5 and

15 seconds (a 5 to 30 second range is recommended in PTI M55.1-12). A mud balance was then used per Section 4.4.8 of PTI M55.1-12 to verify the wet density of the grout was greater than 1.95 g/cm^3 as recommended by the manufacturer (see Figure 4.22(c)). The flow and wet density of the grout was satisfactory for each grouting procedure conducted during the testing program.

(iv) Pump grout:

Once the wet density and flow of the grout was verified, samples were taken to cast 2-in. cubes according to ASTM C1107 for future compression testing. The grout was then pumped into the duct. Each of the grout vents were closed in succession after approximately 2 gallons of grout were emitted from the outlet, as shown in Figure 4.22(d). Immediately after the last outlet was closed, the valve at the inlet was also closed, and the pump was then powered down.

Figure 4.21: Grout plant

(a) *(b)*

(c) *(d)*

Figure 4.22: Grouting procedure – (a) adding grout to colloidal mixing tank; (b) flow cone test; (c) measuring wet density with mud balance; (d) grout emitted from outlets

4.13.6 Deck Placement

The girders were moved to their final location for testing after the post-tensioning and grouting procedures were completed. An 8-in. thick deck was then cast on top of the spliced girders to provide additional strength and simulate actual field conditions. The deck had a width of 42 in., 2 in. narrower than the top flange, to ease formwork construction (see Figure 4.23). The concrete used for the deck was sourced from a local ready-mix supplier. The concrete mixture design is provided in Section 4.12.

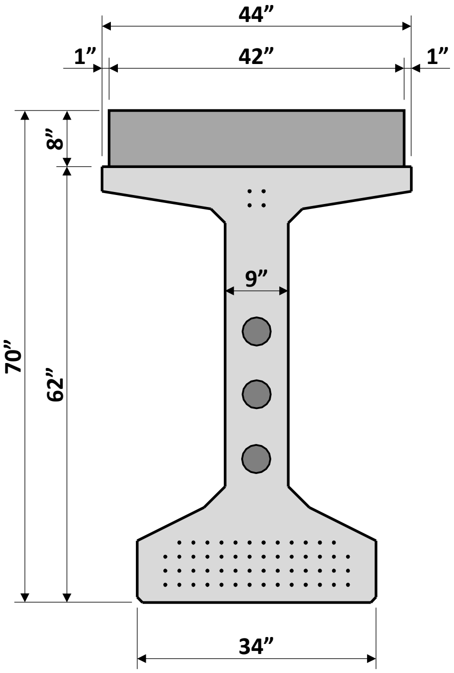


Figure 4.23: Test girder with deck dimensions

4.14 Instrumentation

Several sensor types were installed on the test girders or embedded within the concrete to aid in developing a more complete understanding of the behavior of the specimens. The manner in which sensors were used is detailed within this section. The sensor data most relevant to understanding the behavior of the test girders are described in Chapter 5.

4.14.1 Vibrating Wire Gauges

Vibrating wire gauges (VWGs) were embedded within the precast segments and the splice region to measure concrete strains at various phases of construction and during testing. A VWG attached to the longitudinal interface reinforcement within the web of the splice region of the first test girder is pictured in Figure 4.24. Each gauge was installed in the horizontal orientation as shown. As indicated in Figure 4.25(a), a total of 15 VWGs arranged at 5 different sections (labeled 1 through 5) were placed within each test girder. The approximate locations of the gauges within Sections 1, 2, and 4 are shown in Figure 4.25(b) as an example. After each VWG was installed, its exact location was measure and recorded to be used within post-processing computations.

Figure 4.24: Vibrating wire gauge within splice region

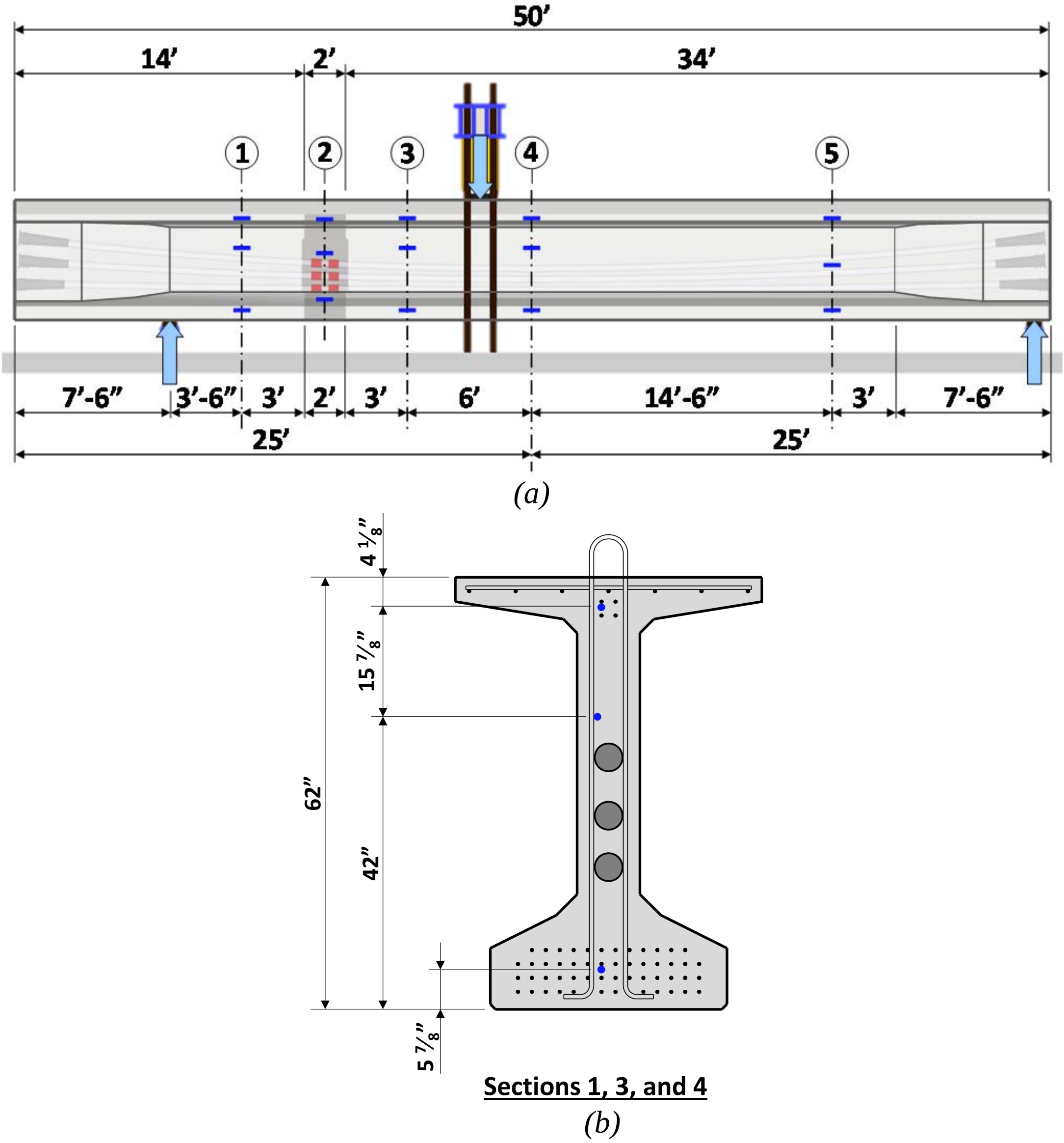


Figure 4.25: Vibrating wire gauge placement – (a) elevation view; (b) Sections 1, 2, and 4

As will be discussed in Section 5.2.2, the critical section of the test girders is located at the interface between the long precast segment and the splice region. Since the pretensioned strands are discontinuous at this location, the stress in the post-tensioning tendons governed the shear strength and was determined using data from the vibrating wire gauges. The VWGs can be used to calculate an applied post-tensioning force at each of the 5 cross-sections shown in Figure 4.25(a) by applying the computational method outlined in Section 3.3.5 of Moore et al. (2015). For each post-tensioning operation, the tendon force calculated from VWG data was compared to the force indicated by the pressure transducer to verify the final jacking stress. The VWG readings were then used to measure the losses experienced by each tendon when the anchorage was set. At the end of the post-tensioning operation for each tendon, the losses indicated by the VWGs at each of the 5 cross-sections were averaged. This value was subtracted from the final jacking stress indicated by the pressure transducer to obtain the stress in the tendon used in strength calculations. The VWGs did not present a clear trend of friction losses along the girder lengths. Therefore, any effect of these losses were conservatively neglected for comparisons of the calculated shear strengths of the girder specimens with their experimental capacities. The stress in each tendon of the two girder specimens at the end of each post-tensioning operation is provided in Section 4.17 below. Please see Section 5.4.4 for further discussion on post-tensioning losses.

The VWGs also have the capability to measure additional post-tensioning losses (i.e., creep and shrinkage losses) prior to testing the specimens as well as losses in the pretensioned strands from the time of prestress transfer.

4.14.2 Foil Strain Gauges

Foil strain gauges were installed on the mild reinforcement within the splice regions of the girder specimens to measure the change in strain of the steel during testing. They had a gauge length of 6 mm and a width of 2.6 mm. Their nominal resistance was 350 ohms (± 1.5 ohms).

To install a foil gauge, the surface of the rebar was first lightly ground and polished to remove the bar deformations and create a smooth surface. Extra care was taken to ensure that very little cross-sectional area of the bar was removed. Adhesive was then used to affix the gauge to the rebar. Although the strain gauges were pre-coated with a waterproof epoxy resin, the gauges were covered with a combination of electrical and foil tape to provide further protection. The strain gauge installation procedure is demonstrated in Figure 4.26.

Figure 4.26: Strain gauge installation procedure

A total of 30 foil strain gauges were installed within the splice region of each girder specimen. Due to interest in the effect of the longitudinal interface reinforcement on the behavior of the spliced girders, a majority of the gauges were placed on the interface bars and centered at ½ in. from the faces of the precast girder segments. Strain gauges installed on interface bars extending from the long segment of the second girder specimen are pictured in Figure 4.27(a). Other gauges were affixed to the legs of the middle two stirrups within the splice regions. They were placed to coincide with the location of the post-tensioning ducts, as shown in Figure 4.27(b). Two additional gauges were also installed on the stirrups above the ducts in the second test girder.

The strain gauges were continuously monitored during each post-tensioning operation and during testing. The resulting data that is most relevant to understanding the role of the interface and shear reinforcement on the behavior of the test girders are detailed in Chapter 5.

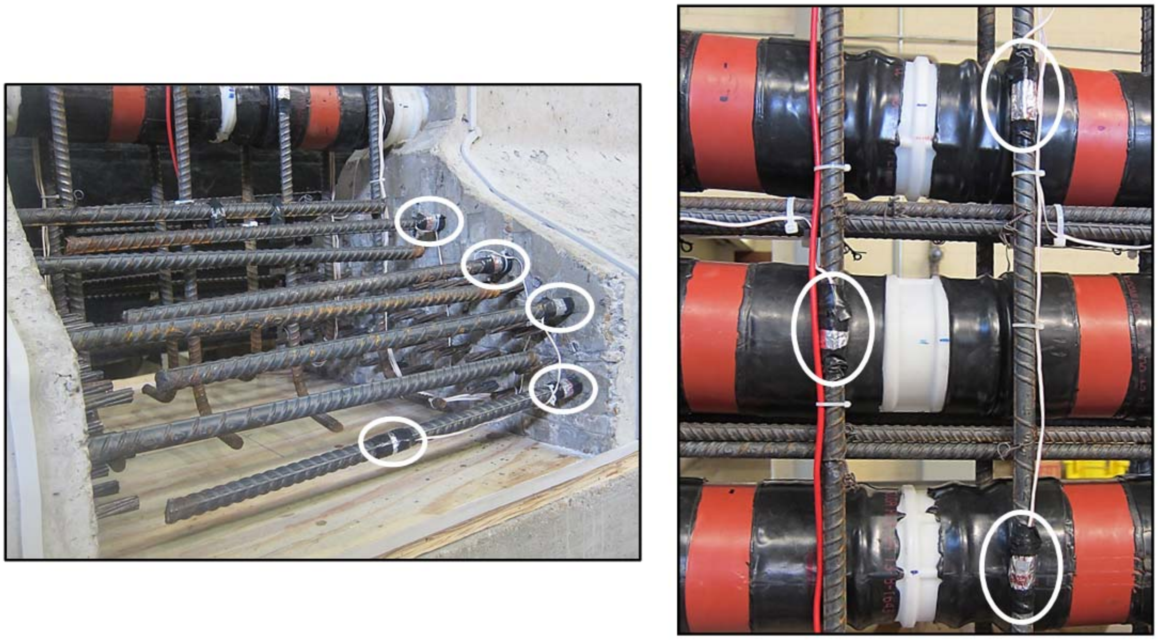

(a) *(b)*

Figure 4.27: Strain gauge placement in splice region – (a) longitudinal interface bars; (b) stirrup legs

4.14.3 Linear Potentiometers

The test specimens were instrumented with linear potentiometers to measure the vertical deflection of the girder as well as any relative displacements and flexural deformations at the splice region. The placement of linear potentiometers at the splice region is presented in Figure 4.28. Aluminum mounting brackets and plates were installed on the girder web to facilitate measurement of the relative vertical displacements between the precast segments and the splice region in addition to any vertical crack openings at the splice region interface (refer to parts (a) through (c) of Figure 4.29). Three linear potentiometers were also attached to the bottom surface of the girder, as shown in Figure 4.29(d), to measure the opening of flexural cracks at the splice region interface or within the splice region itself. Epoxy was used to affix all mounting brackets and plates to the concrete surface. Additional linear potentiometers were placed on floor stands to capture the vertical deflection of the girder within and immediately outside the splice region, as pictured in Figure 4.29(e), as well as the deflections at the load point and support bearings (see Figure 4.30).

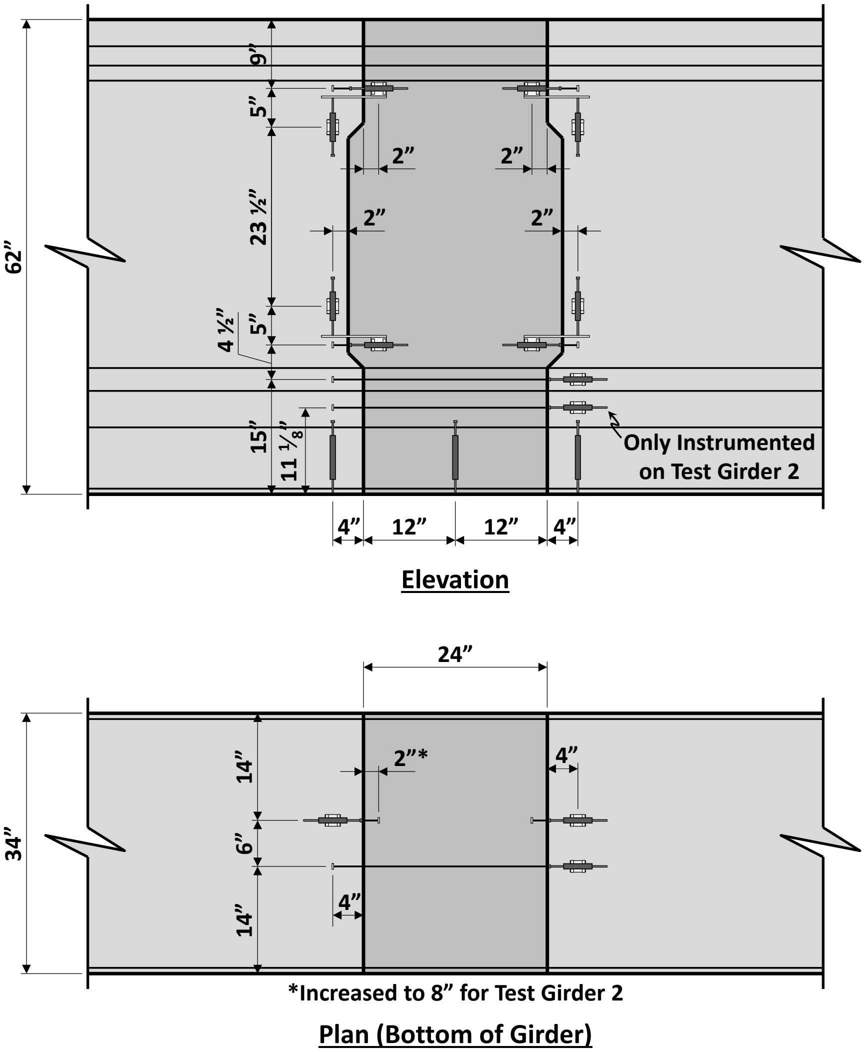
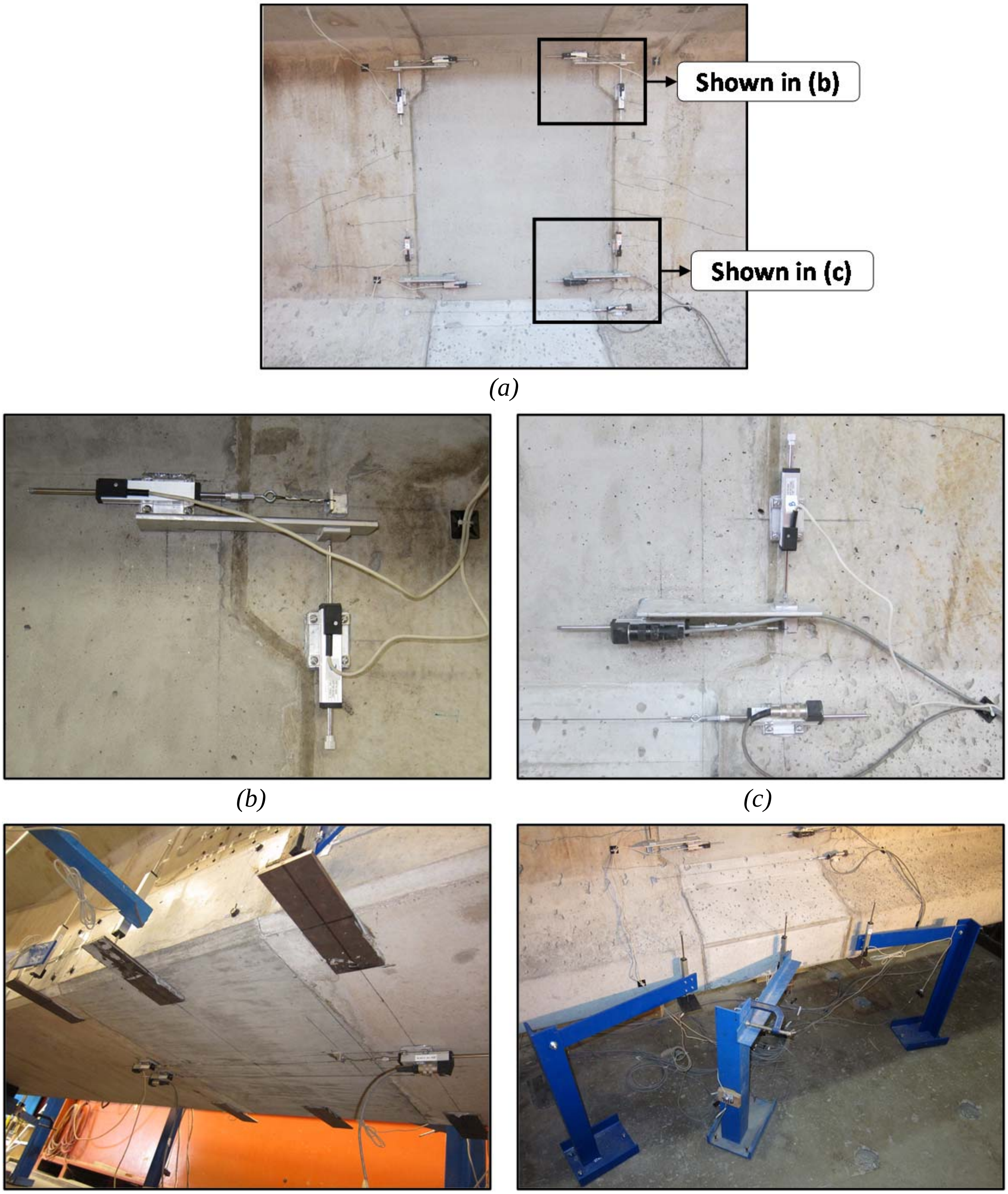


Figure 4.28: Linear potentiometer placement at splice region



(a)

(b)

(c)

(d)

(e)

Figure 4.29: Linear potentiometer instrumentation – (a) girder web; (b) near top of web; (c) near bottom of web; (d) bottom surface of girder; (e) measuring relative vertical displacement

4.14.4 Load Cells and Pressure Transducer

The reactions at each support location were measured with two 1000-kip capacity load cells, as shown in Figure 4.30. For each test specimen, load readings were captured at the time the girder was placed on the supports to determine its self-weight and the corresponding shear within the test span. Measurements were also taken after the load frame was installed to obtain the dead load shear it imposed on the girder. These values were added to the applied shear measured during testing to calculate the total shear force within the test span. To ensure accuracy, a pressure transducer was attached to the hydraulic cylinder to verify the applied load indicated by the four load cells, as noted in Figure 4.30.

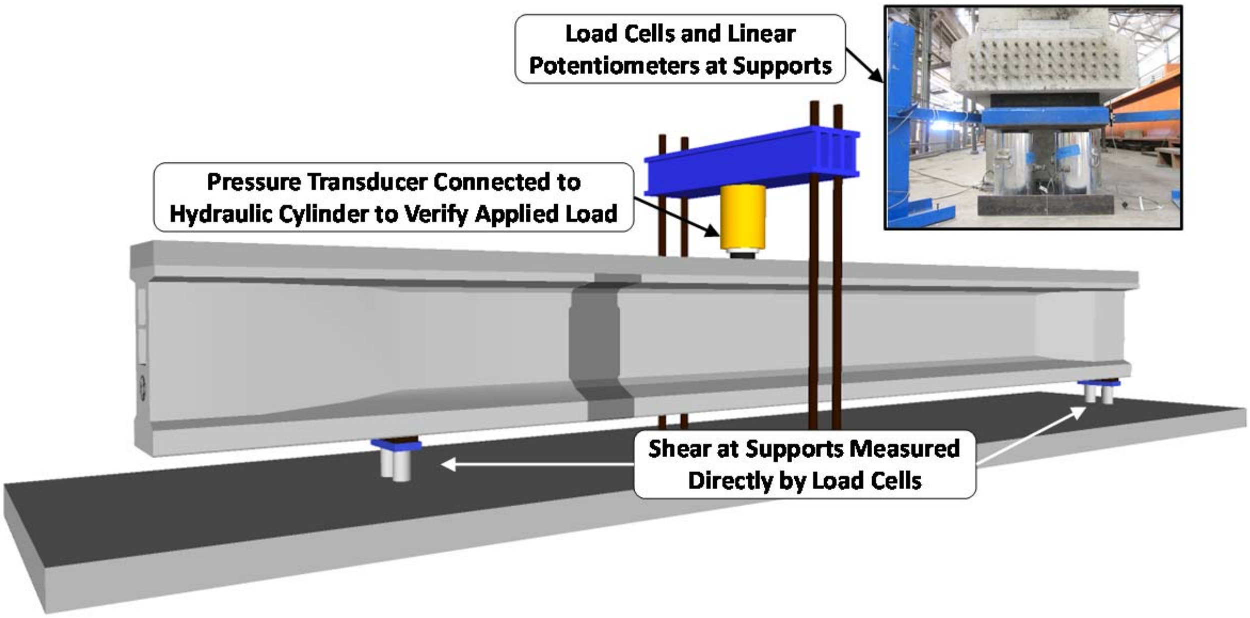


Figure 4.30: Load cell and pressure transducer instrumentation

4.15 Loading Configuration

The loading configuration for the spliced girder testing program is illustrated in Figure 4.31. The girders were simply supported, and a 2,000-kip capacity load frame was installed to apply load to the specimens. The test span was 15 ft in length with the 2-ft long splice region centered within the span. To eliminate any effects of the thickened web on the behavior of the girder, the end block was located outside the test span by allowing it to overhang the support (i.e., the support was placed 7 ft-6 in. from the girder end). The far support was located 9 in. from the opposite end of the test girder, giving a back span length of 26 ft-9 in. The test setup was configured to ensure the splice region would experience both high shear and flexural demands as the ultimate load was approached, providing a critical loading scenario. At the same time, the configuration was designed to cause the girders to exhibit a shear-compression failure. This failure mode was selected as the most critical failure mode that is likely to be influenced by the presence of post-tensioning ducts and duct couplers.

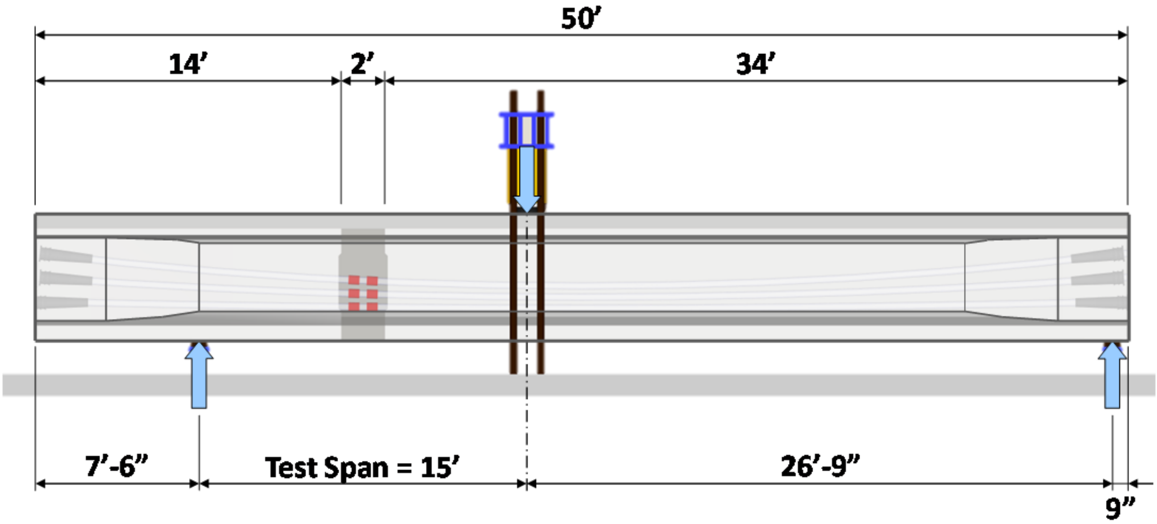


Figure 4.31: Loading configuration

4.16 Test Procedure

Each of the two test girders were loaded monotonically until the specimen exhibited a shear-compression failure of the web concrete. Load was applied in increments of 100 kips or less. After each load increment up to an applied load of 800 kips, the girders were visually inspected to detect the formation or growth of cracks, and cracks were marked with felt-tipped permanent markers (see Figure 4.32(a)). Furthermore, the widths of both shear and flexural cracks were monitored throughout the tests using a crack comparator card (see Figure 4.32(b)). For safety concerns as the specimens approached failure, cracks were not marked or measured after an applied load of 800 kips was reached. Photographs were taken throughout the testing procedure, and the failure of each test girder was video recorded.

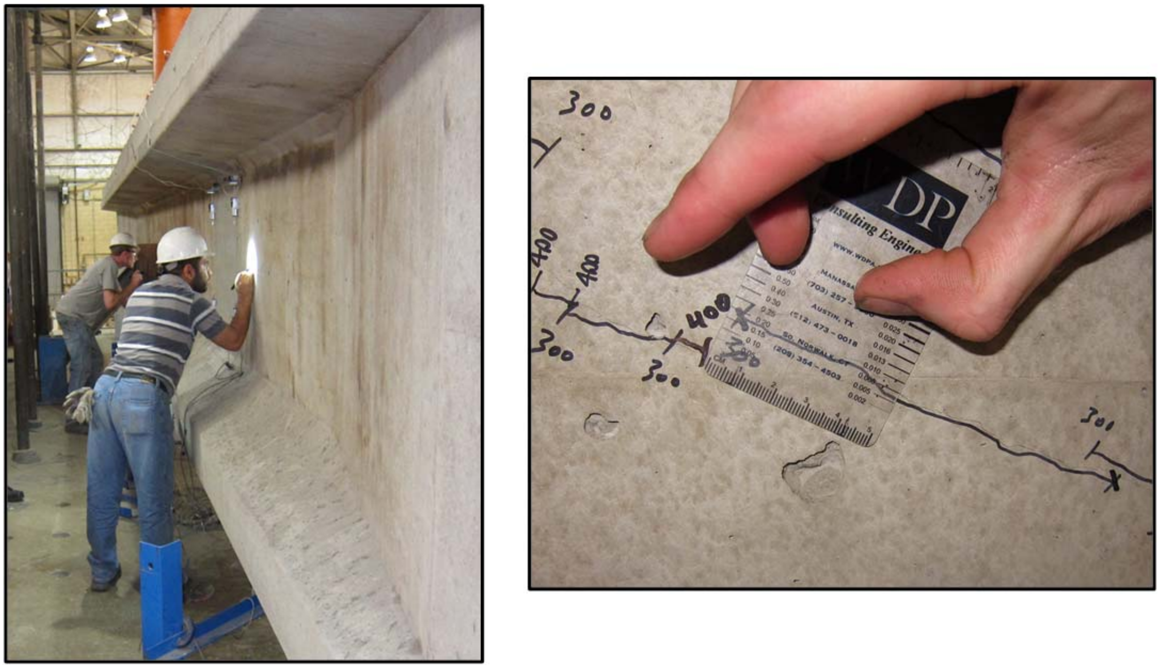

(a) (b)

Figure 4.32: Marking and measuring cracks during testing – (a) marking cracks with felt-tipped markers; (b) measuring crack widths

4.17 Quantitative Test Specimen Details

A summary of the quantitative test specimen details for the two girders described in this chapter are provided in Tables 4.5 and 4.6. The post-tensioning data presented in Table 4.6 correspond to the critical section described in Section 5.2.2. The variables used in the tables are defined as follows:

A_{ps} = Area of prestressing steel (in.^{2})
f'_c = Compressive strength of concrete or grout at the time of testing (ksi)
f'_t = Splitting tensile strength of concrete at the time of testing (ksi)
f_{vy} = Measured yield strength of vertical shear reinforcement (ksi)
Stress = Stress in post-tensioning tendon at the end of the post-tensioning operation, calculated as described in Section 4.14.1 (ksi)
y_p = Distance from the bottom of the girder to the centroid of the post-tensioning tendon at the critical section (in.)
ρ_v = Ratio of the area of vertical shear reinforcement to the gross concrete area of a horizontal section

Table 4.5: Summary of Test Specimen Details (Part 1 of 2)

Test Specimen	Transverse Reinforcement		Precast Segments		Splice Region		Deck
	ρ_v (%)	f_{vy} (ksi)	f'_c (ksi)	f'_t (ksi)	f'_c (ksi)	f'_t (ksi)	f'_c (ksi)
Girder 1	1.15	62.0	13.88	0.98	9.48	0.90	6.50
Girder 2	1.15	67.7	14.54	0.97	10.07	0.87	9.72

Table 4.6: Summary of Test Specimen Details (Part 2 of 2)

Test Specimen	Tendon	Grout	Post-Tensioning Strand			
		f'_c (ksi)	Force (kip)	Stress (ksi)	A_{ps} (in.^{2})	y_p* (in.)
Girder 1	Bottom (1)	8.71	492	189	2.604	20.1
	Middle (2)	9.40	495	190	2.604	26.9
	Top (3)	8.76	471	181	2.604	33.8
Girder 2	Bottom (1)	10.94	487	187	2.604	20.1
	Middle (2)	10.87	479	184	2.604	26.9
	Top (3)	10.59	482	185	2.604	33.8

*A 1-in. offset of the tendon from the center of the duct is assumed

4.18 Summary

The details of the experimental program conducted to study the behavior of spliced I-girders was described in this chapter. Two girder specimens were tested, each consisting of two precast segments joined at a cast-in-place splice region. Continuity was provided by three post-tensioning tendons that extended the full 50-ft length of each girder. The structural performance of the details within the splice regions were of primary interest, and the reasons for selecting each detail were discussed. The amount of longitudinal interface reinforcement within the bottom flanges of the test girders was varied between the two specimens to study the effect of the bars on the behavior of the splice regions.

Several steps were required to fabricate the precast segments and conduct the splicing operations. The girders were tested in a 2,000-kip capacity load frame until the specimens failed in shear. Several instruments, such as strain gauges, linear potentiometers, and load cells, were used to monitor the behavior of the girders during testing.

The analysis of experimental results and observations from the spliced girder test program are described in Chapter 5. The design recommendations based on the findings are then presented in Chapter 6.

Chapter 5. Analysis of Experimental Results and Observations

5.1 Introduction

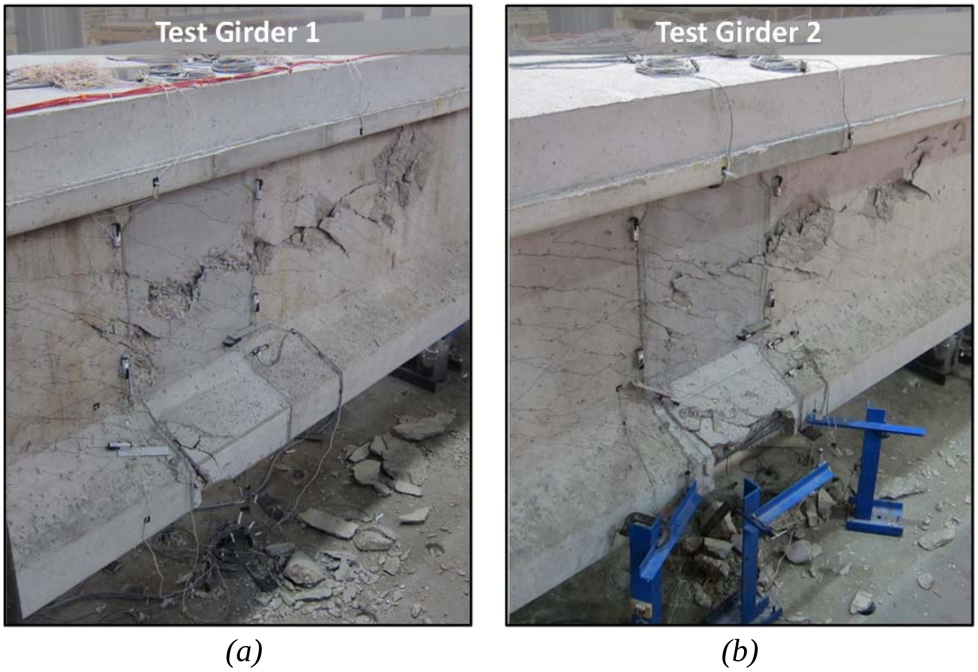
The experimental results of the Phase II load tests performed on the two spliced girder specimens are discussed in detail in this chapter. A basic overview of the test results is followed by a more in-depth description of the strength and serviceability behavior of the test girders. Primary emphasis is placed on the behavior of the cast-in-place (CIP) splice regions. Data from the various sensor types monitored during the load tests are presented and analyzed to gain a better understanding of the behavior of spliced girders. Furthermore, the effect of the longitudinal interface reinforcement extending from the precast segments into the splice regions is highlighted.

5.2 Overview of Experimental Results

The results of the spliced girder testing program provide significant insights into the strength and structural behavior of CIP splice regions. To provide an overview of the test results, the following section describes the observed failure mechanism of the girders. Load-deflection plots are then presented following an explanation of how the shear force acting at the critical section is determined.

5.2.1 Shear-Compression Failure Mechanism

In an effort to study the structural performance of cast-in-place splice regions, the test specimens were designed to exhibit a shear-compression failure. This failure mode was selected as the most critical failure mode that is likely to be influenced by the presence of post-tensioning ducts and duct couplers. Consistent with their design, the failure mechanisms of both test girders were characterized by a shear-compression failure of the web concrete. The primary crushing occurred in the vicinity of the top post-tensioning duct. The failure mechanism was consistent with the behavior of the Phase I test specimens which contained a single duct located at the mid-height of the girder webs. Photographs of the two Phase II test girders after failure are shown in Figure 5.1.



(a) (b)

Figure 5.1: Test girders after failure – (a) Test Girder 1; (b) Test Girder 2

The crack patterns after failure of the girders are provided in Figures 5.2 and 5.3. The two illustrations reveal that a majority of the concrete crushing was located near the top duct. The cracks shown in green within Figures 5.2 and 5.3, in addition to other crack maps within this chapter, were preexisting before the start of the load tests (refer to Section 5.3). The spalling of concrete from the bottom flange within the splice region at later stages of loading is discussed in Section 5.5.

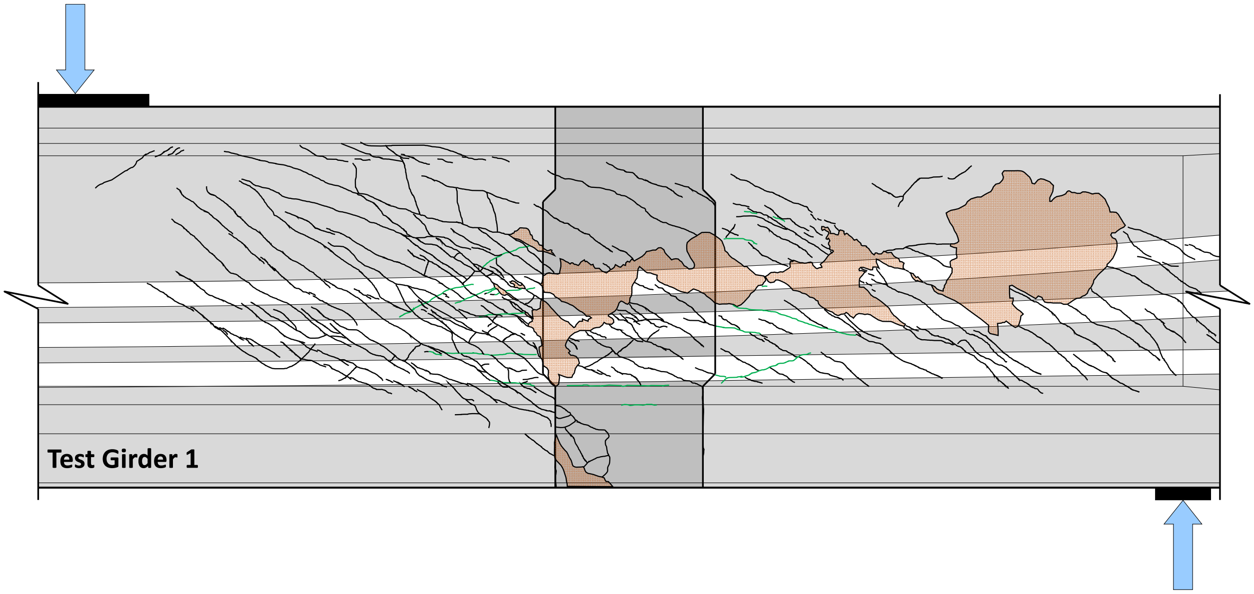


Figure 5.2: Crack pattern after failure – Test Girder 1

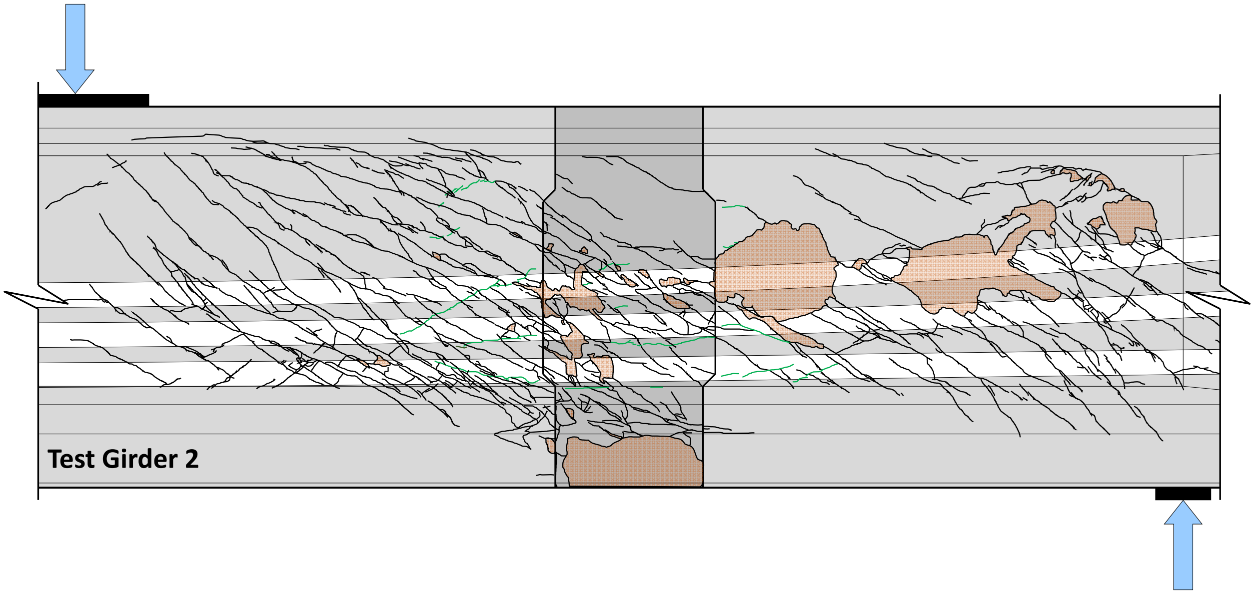


Figure 5.3: Crack pattern after failure – Test Girder 2

Based on the observed behavior of the specimens as indicated in Figures 5.1 through 5.3, the girders acted essentially as monolithic members in shear at failure. The web crushing extended across much of the test spans and was not localized within the splice regions. This seemingly simple observation is viewed to be the most significant experimental observation in view of the primary objectives of this research program.

5.2.2 Critical Section and Calculation of Shear Force

For purposes of evaluating the strength of the test girders, the critical section was taken as the location at the splice region with the lowest calculated shear strength according to the general shear procedure of Article 5.8.3.4.2 of AASHTO LRFD (2014). The critical section was determined to be located at the interface between the long precast segment and the splice region, as indicated in Figure 5.4.

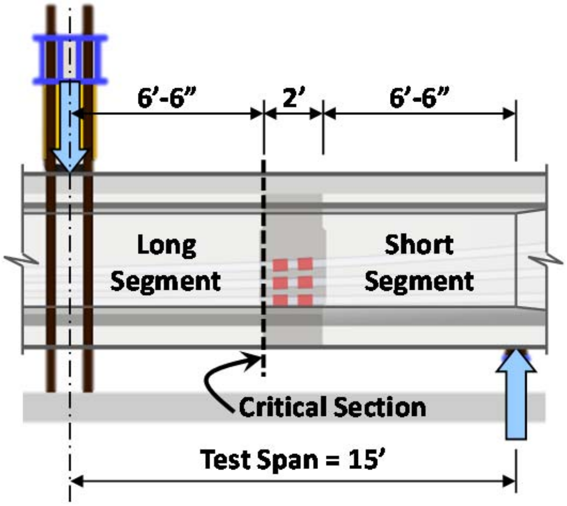
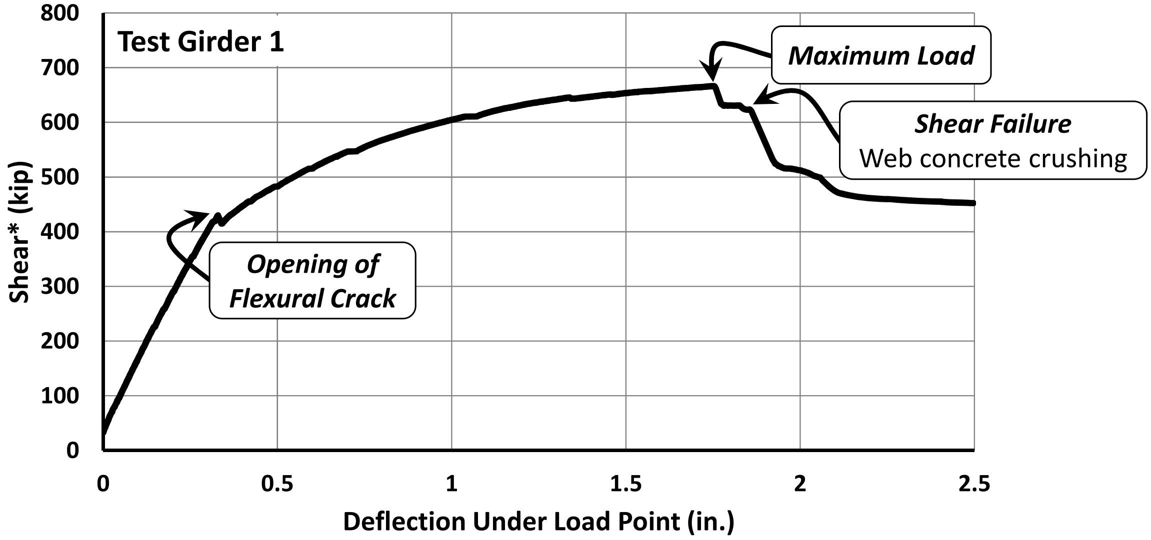


Figure 5.4: Location of critical section

The shear force acting at the critical section of the test specimens consisted of the effects of three components: self-weight of the girders, the weight of the load frame, and load applied by the hydraulic cylinder during testing. The ultimate shear force, V_{test}, was therefore calculated by summing the shear force at the critical section due to the self-weight of the girder, the shear from the weight of the load frame, and the *maximum* shear applied to the test region by the hydraulic cylinder. The weight of each girder as well as the shear force applied to the test region was measured by the load cells located at each support, as described in Section 4.14.4. A similar approach was followed for the Phase I experimental program and is further detailed in Section 4.3.3 of Moore et al. (2015). For consistency, much of the data presented in the current chapter are plotted versus the shear force acting at the critical section, including the effects of the girder self-weight and the weight of the load frame.

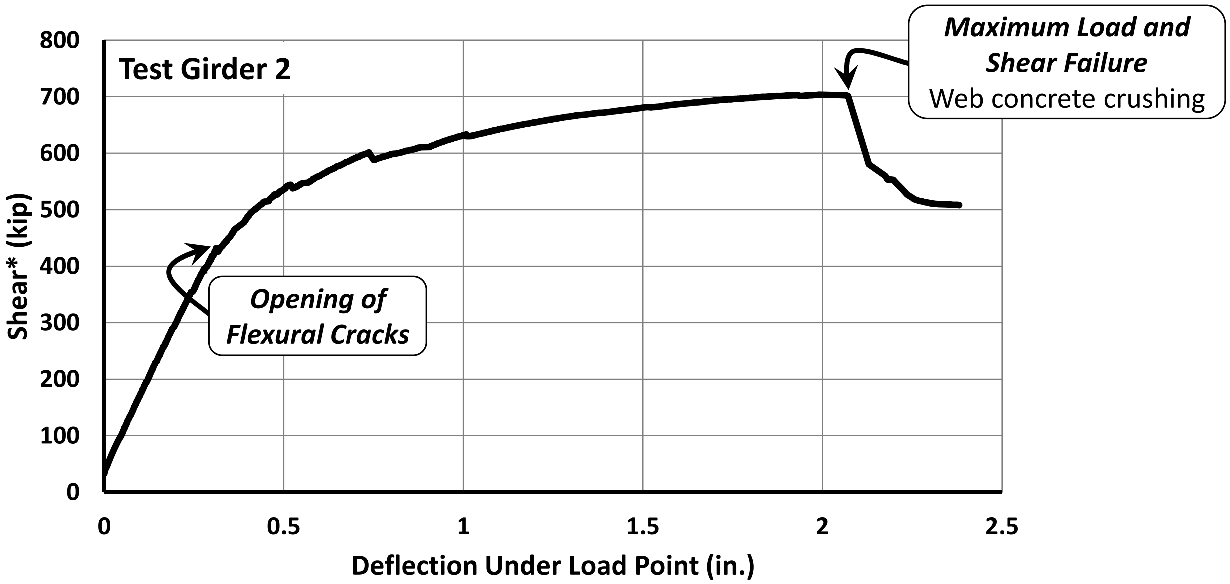
5.2.3 Load-Deflection Behavior

The overall behavior of the test girders can be described from their load-deflection plots provided in Figures 5.5 and 5.6. Within these figures, the shear force applied to the critical section located at the interface between the splice region and the precast segment, indicated in Figure 5.4, is plotted versus the deflection measured under the load point. Notable events during the loading of the test girders are labeled on the plots. The displacement measurements were obtained by averaging the output from two linear potentiometers located on opposite sides of the girders at the location of the load point.



*Includes shear from self-weight of girder and load frame (Refer to Section 5.2.2)

Figure 5.5:Load-deflection plot of Test Girder 1



*Includes shear from self-weight of girder and load frame (Refer to Section 5.2.2)

Figure 5.6: Load-deflection plot of Test Girder 2

Considering the load-deflection plots, the behavior of the girders was relatively linear until flexural cracking at the splice region resulted in a notable reduction in stiffness. Upon further loading, the stiffness continued to decrease until the maximum load was reached. The occurrence of shear failure was accompanied by a significant reduction in load-carrying capacity and indicated by crushing of the web concrete in the vicinity of the top post-tensioning duct.

5.3 Evaluation of Service-Level Shear Behavior

The behavior of the spliced girder specimens under service-level shear loads was evaluated during the experimental program. Within this section, the assessment of the service-level behavior includes shear cracking that occurred at shear forces between 28 and 73 percent of the maximum shear force, V_{test}, in an attempt to cover all relevant observations during the tests. Additional discussions regarding the flexural behavior as well as displacements at the splice region are presented within Section 5.4.

Prior to examining the behavior of the girders during the load tests, it is important to note the existence of cracks within the end regions of the precast girder segments that formed due to the transfer of the pre-tensioning force to the concrete. As an example, the cracks in the non-thickened end region (i.e., the end region to be spliced) of the short precast segment of the first test girder is shown in Figure 5.7. As described in Section 4.6, vertical reinforcement was provided within the non-thickened end regions to provide splitting resistance. The amount of reinforcement, however, was kept at a minimum to reduce its effect on the shear strength of the specimens. Additional reinforcement may have aided in controlling these end-region cracks.

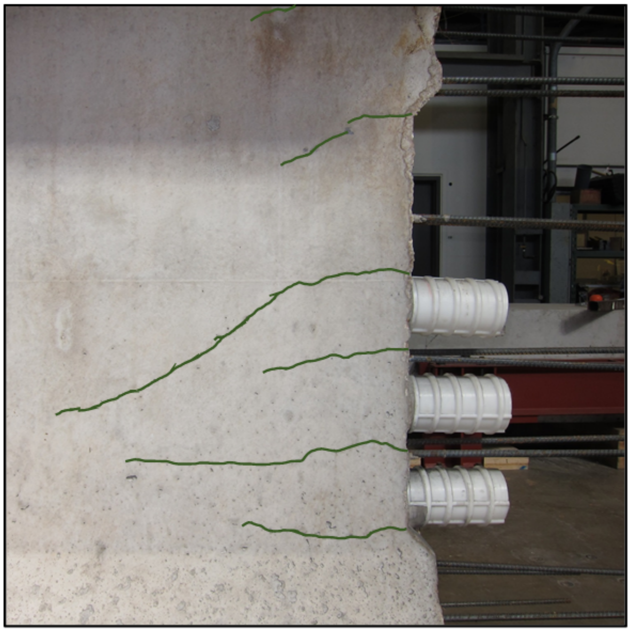
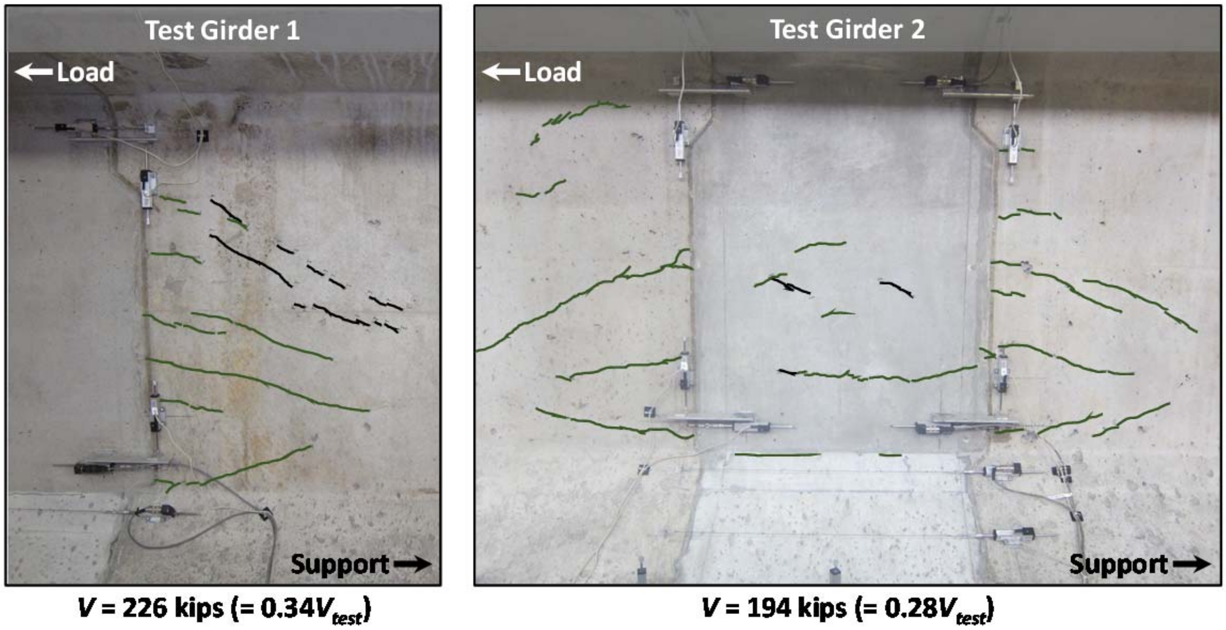


Figure 5.7: End-region cracking – short precast segment of Test Girder 1

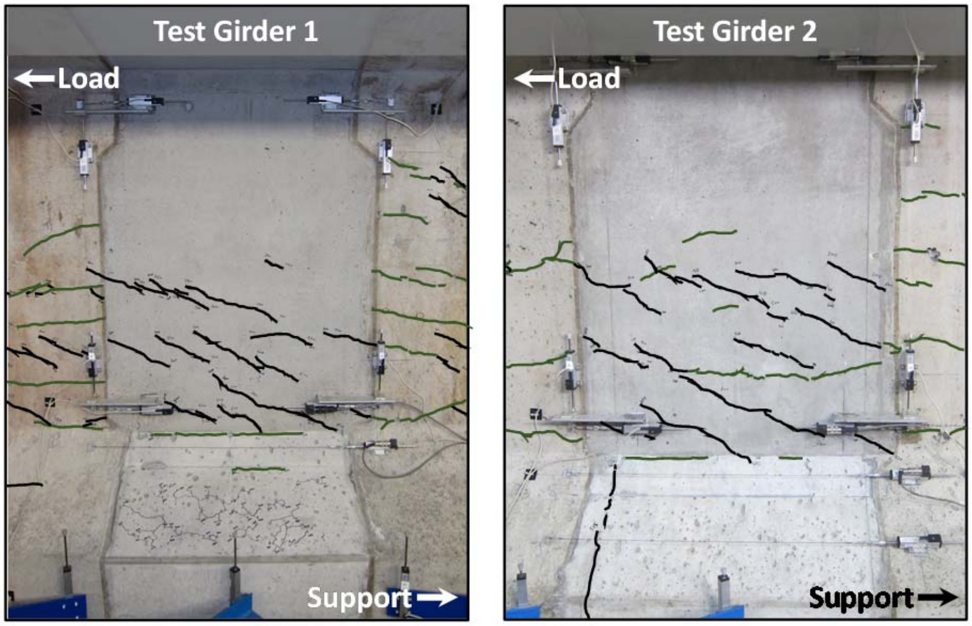
The first cracks that formed during the load tests of the spliced girders are presented in Figure 5.8. Both specimens exhibited the formation of localized diagonal hairline cracks. For Test Girder 1, the cracks were first noted at a total shear force of 226 kips, 34 percent of the maximum shear force, V_{test}. The cracks may have developed, however, at a somewhat lower load since the formation of cracks was not checked between a shear force of 162 kips and 226 kips. As shown in Figure 5.8(a), the cracks formed outside of the splice region, possibly due to existing strains in the concrete caused by the pre-tensioning force. The development of cracks during the load test of Test Girder 2 were first observed at a total shear force of 194 kips, 28 percent of V_{test}. Unlike the first test girder, however, the cracks were located within the splice region, primarily in the vicinity of the top post-tensioning duct, and may have been influenced by the location of the relatively large plastic duct couplers. It should be noted that they are consistent with the hairline cracks that formed along the post-tensioning ducts of the Phase I test girders (refer to Section 4.2 of Moore, et al. (2015)). The cracks marked green within the splice region of Figure 5.8(b), likely caused by shrinkage of the cast-in-place concrete, existed prior to the start of the load test.



(a) *(b)*

Figure 5.8: First cracks during load tests – (a) Test Girder 1; (b) Test Girder 2

Upon further loading of the girder specimens, the formation of localized cracks continued to distribute within the test region. The cracks tended to develop in the vicinities of the three post-tensioning ducts, as shown in Figure 5.9 at a total shear force of approximately 420 kips (63 percent and 59 percent of V_{test} for the first and second test girders, respectively).

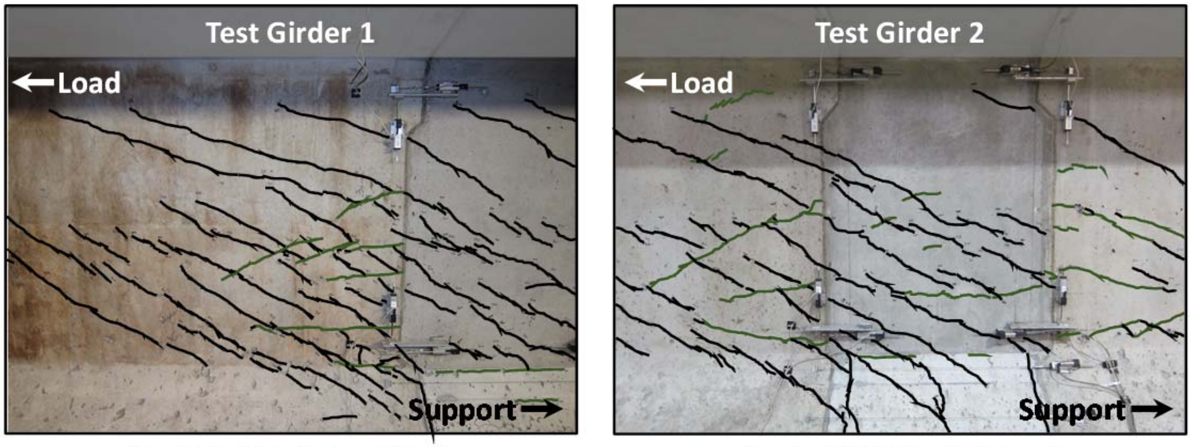


V = 419 kips (= $0.63V_{test}$) V = 418 kips (= $0.59V_{test}$)

(a) *(b)*

Figure 5.9: Distribution of cracks within the splice region – (a) Test Girder 1; (b) Test Girder 2

At a shear force of 483 kips, the formation of cracks that extended over much of the web depth was visually detected for both test girders, as presented in Figure 5.10. These cracks were consistent with the first shear cracks that develop during load tests of pretensioned girders without post-tensioning ducts (Avendaño and Bayrak, 2008). Similar behavior was also observed for the test girders of the Phase I experimental program (Moore et al., 2015).



V = 483 kips (= $0.73V_{test}$) V = 483 kips (= $0.69V_{test}$)

(a) *(b)*

Figure 5.10: Cracks extending through the web – (a) Test Girder 1; (b) Test Girder 2

5.4 Evaluation of Strength Behavior

The following sections describe the behavior of the test girders until the occurrence of shear failure. As described in Chapter 4, various sensor types were monitored during the tests to capture the behavior of the specimens. Localized displacements and deformations at the splice region were of particular interest during the spliced girder experimental program. Selected data are therefore presented to provide an overview of the splice region behavior. The maximum shear forces experienced by the girders are then compared to the calculated strengths according to sectional shear provisions.

5.4.1 Vertical Displacements at Splice Region

Relative displacements between the precast concrete segments and the CIP splice region of each girder were monitored during testing by the linear potentiometers installed within the test span. Three linear potentiometers mounted to floor stands were placed on each side of the girders at the splice region as shown in Figure 5.11. The displacements captured by the sensors are plotted versus the total shear force in Figures 5.12 and 5.13 for the two test specimens. The plots were created by averaging the displacements measured by each pair of potentiometers located on opposite sides of the girders. One of the linear potentiometers located at the center of the splice region, however, did not provide complete data during either of the load tests. The displacement at this location is therefore plotted for only one sensor. Furthermore, the deflection after the maximum force was reached was not accurately captured by this remaining potentiometer. Please note the placement of the sensors (north versus south) in relation to the load and support locations illustrated in Figure 5.11. It should also be mentioned that flexural deformations (e.g., bending) can contribute to differences in deflection in addition to vertical slip at the splice region.

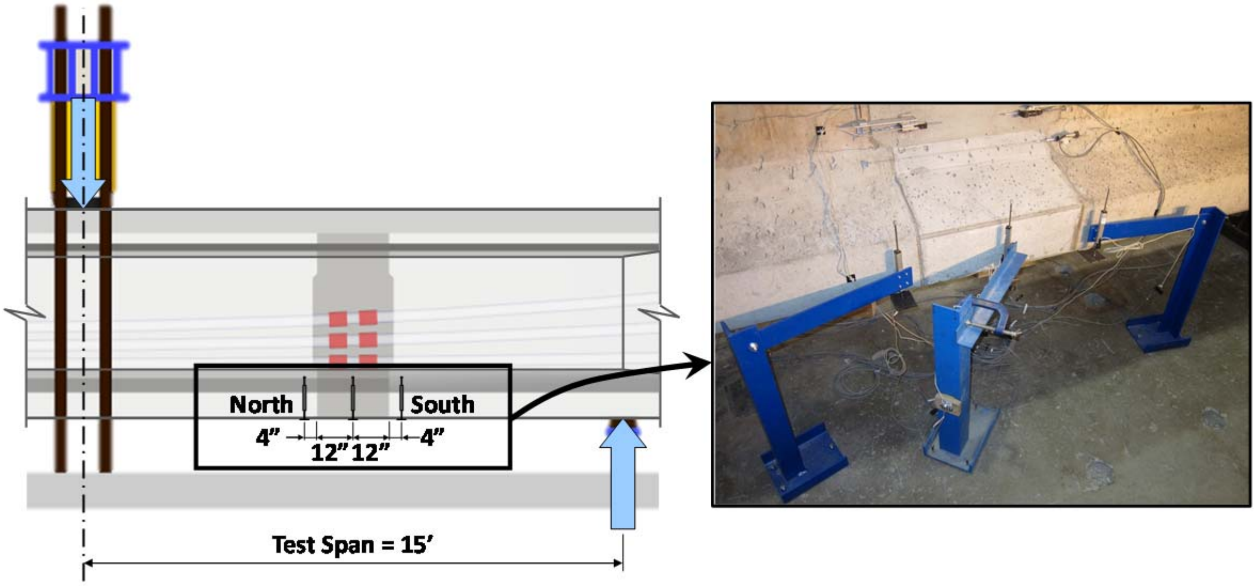
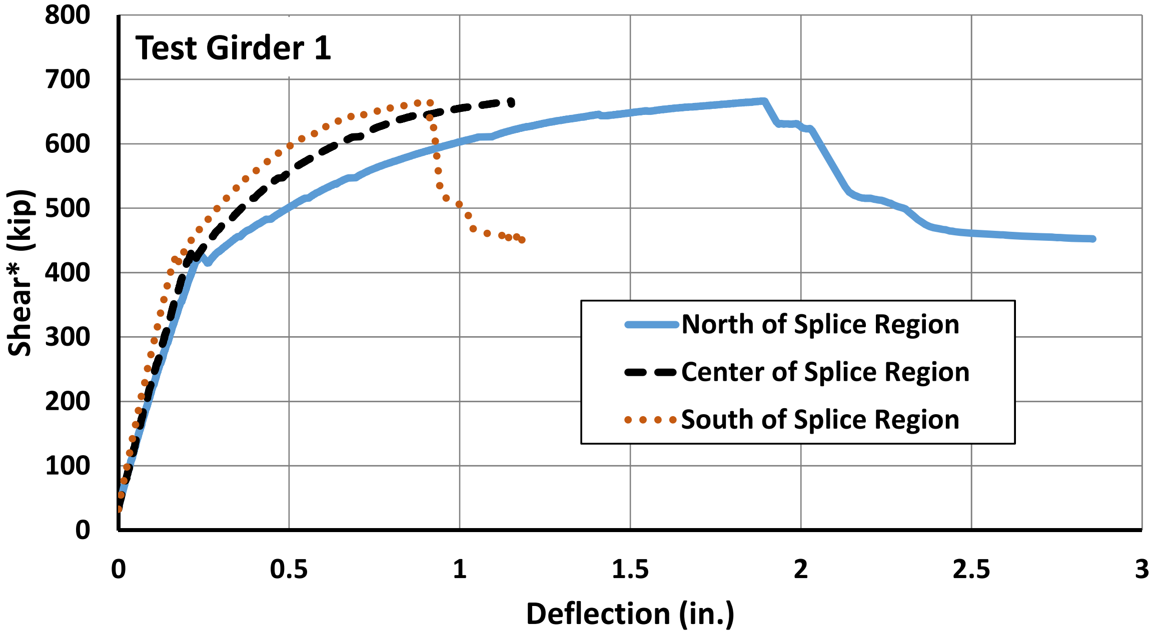
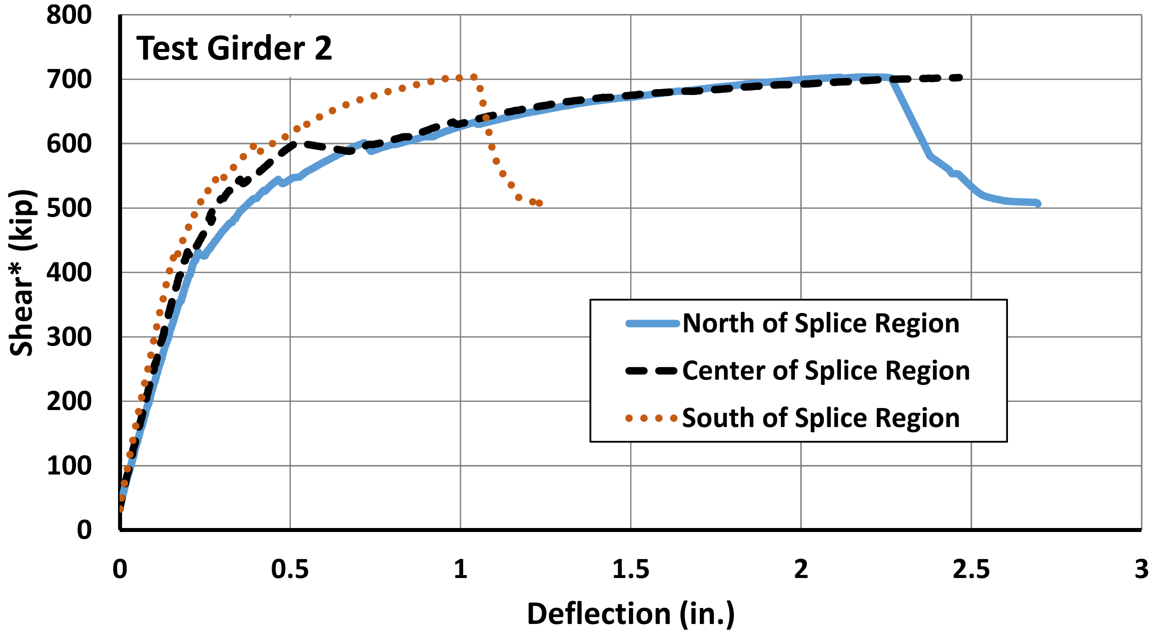


Figure 5.11: Linear potentiometers for measuring deflection at the splice region



*Includes shear from self-weight of girder and load frame (Refer to Section 5.2.2)

Figure 5.12: Girder deflections at splice region of Test Girder 1



*Includes shear from self-weight of girder and load frame (Refer to Section 5.2.2)

Figure 5.13: Girder deflections at splice region of Test Girder 2

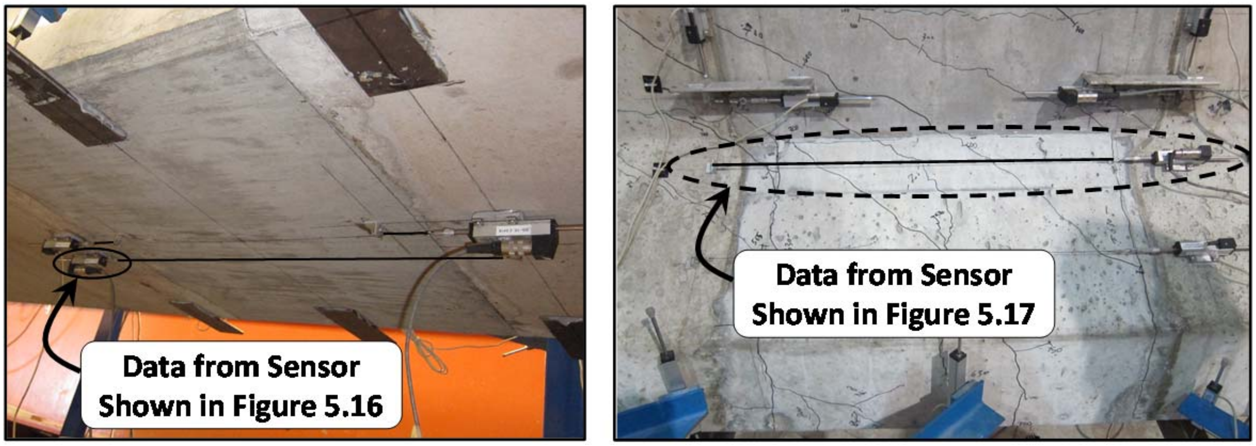
Differential displacements at the splice region is evidenced by the plots in Figures 5.12 and 5.13, particularly after the occurrence of flexural cracking (refer to Figures 5.5 and 5.6). Visual confirmation of the differential displacements near the north splice region interface is presented in Figure 5.14 for Test Girder 1 after reaching a total shear of 611 kips, 92 percent of V_{test}.

Figure 5.14: Differential displacement at the splice region of Test Girder 1

5.4.2 Flexural Behavior of Splice Region

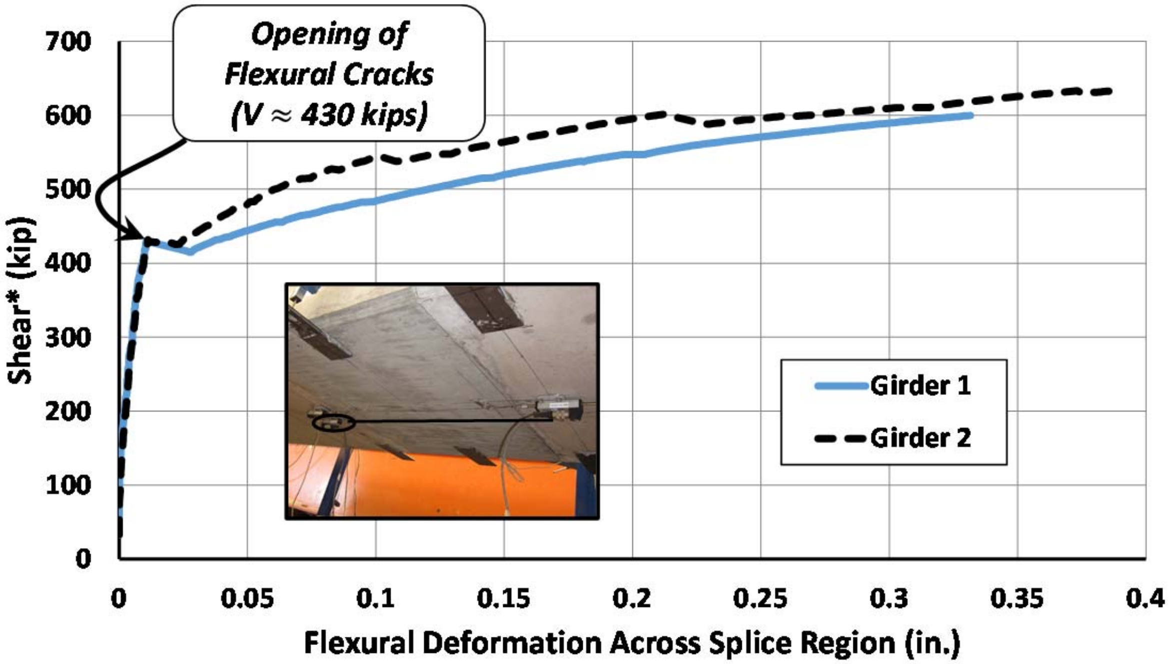
During the two load tests, flexural cracks formed at the splice region, as shown in Figure 5.14. For the first test girder, the opening of a flexural crack was accompanied by a slight drop in load and a loud popping sound at a shear force of 430 kips. The crack was located near the north interface between the long precast segment and the splice region (i.e., near the critical section). No flexural cracks were noted prior to this event. During the second load test, faint popping noises at a shear force of approximately 395 kips indicated the formation of a flexural crack near the critical section. Then, at a shear force of 432 kips, a slight drop in load accompanied additional flexural cracking at the splice region.

Linear potentiometers were installed to capture the opening of flexural cracks at the splice regions of the test girders, as shown in Figure 5.15. Strings mounted to the girder using small aluminum angle pieces were attached to the linear potentiometers shown in the figure to measure the flexural deformations of the member at the splice region. The displacement measured by the linear potentiometer installed on the bottom surface of the test girders and indicated in Figure 5.15(a) is plotted in Figure 5.16 for both test girders up to a shear force of 90 percent of V_{test}. Similarly, data from the potentiometer located near the top of the bottom flange of the girders, shown in Figure 5.15(b), are plotted in Figure 5.17 up to the occurrence of shear failure. Please note that the string attached to both sensors extended across the entire splice region.



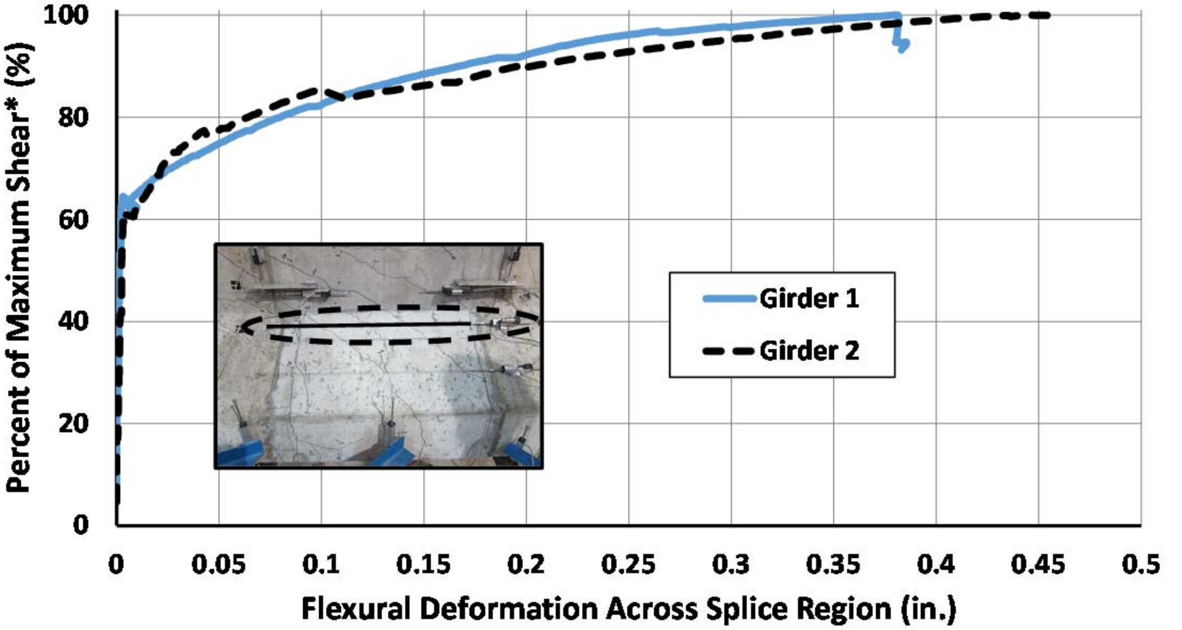
(a) *(b)*

Figure 5.15: Linear potentiometers measuring flexural deformations – (a) on the bottom surface; (b) at the bottom flange



*Includes shear from self-weight of girder and load frame (Refer to Section 5.2.2)

Figure 5.16: Flexural deformations across bottom of splice region (plotted to $0.9V_{test}$)

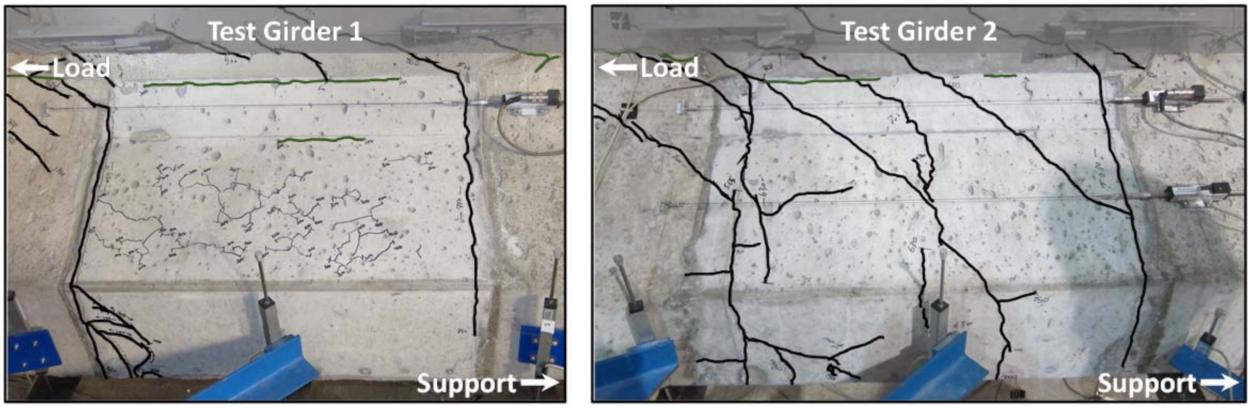


*Includes shear from self-weight of girder and load frame (Refer to Section 5.2.2)

Figure 5.17: Flexural deformations across splice region at top of bottom flange (plotted to shear failure)

In Figure 5.16, the plots of the data from the linear potentiometers attached to the bottom of the test specimens indicate a similar behavior between the two girders. In fact, an abrupt opening of flexural cracks occurred at nearly the same load for both specimens (i.e., at a shear of approximately 430 kips). Although relatively minor flexural cracking was noticed at a shear force of 395 kips for Test Girder 2, the primary flexural cracking began at nearly the same load for both specimens. The data shown in Figure 5.17, plotted versus the percent of the maximum shear force reached during the load tests, also reveals similarities between the behaviors of the test girders at the splice regions.

Although the overall flexural deformations across the splice regions were similar, the distribution of flexural cracks within the bottom flanges of the two test specimens were notably different. The longitudinal interface reinforcement extending from the precast segments into the splice regions had a significant impact on the cracking behavior of the test specimens (refer to Section 4.9.4). To provide a comparison, the bottom flange at the splice region of each girder is shown in Figure 5.18 at a shear force of approximately 515 kips. (Please note that the small cracks marked on the top surface of the bottom flange of Test Girder 1 in Figure 5.18(a) are shrinkage cracks that existed before the start of the test.) The flexural cracks in Test Girder 1 are concentrated at the interface between the splice region and the precast segments. Test Girder 2, however, displays flexural cracks that are distributed across the length of the splice region. The additional longitudinal reinforcement within the bottom flange of the second test girder prevented the cracking from concentrating at the splice region interfaces.

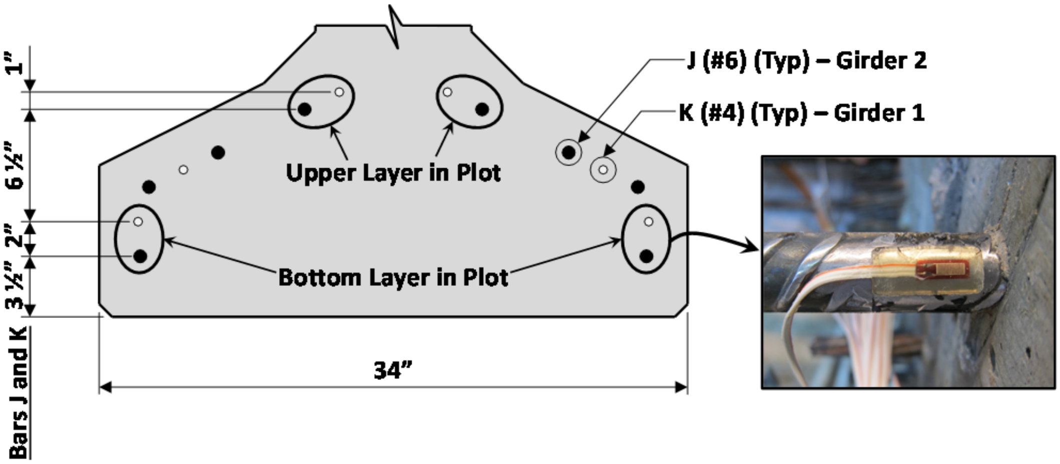


V = 515 kips (= 0.77V_{test})
(a)

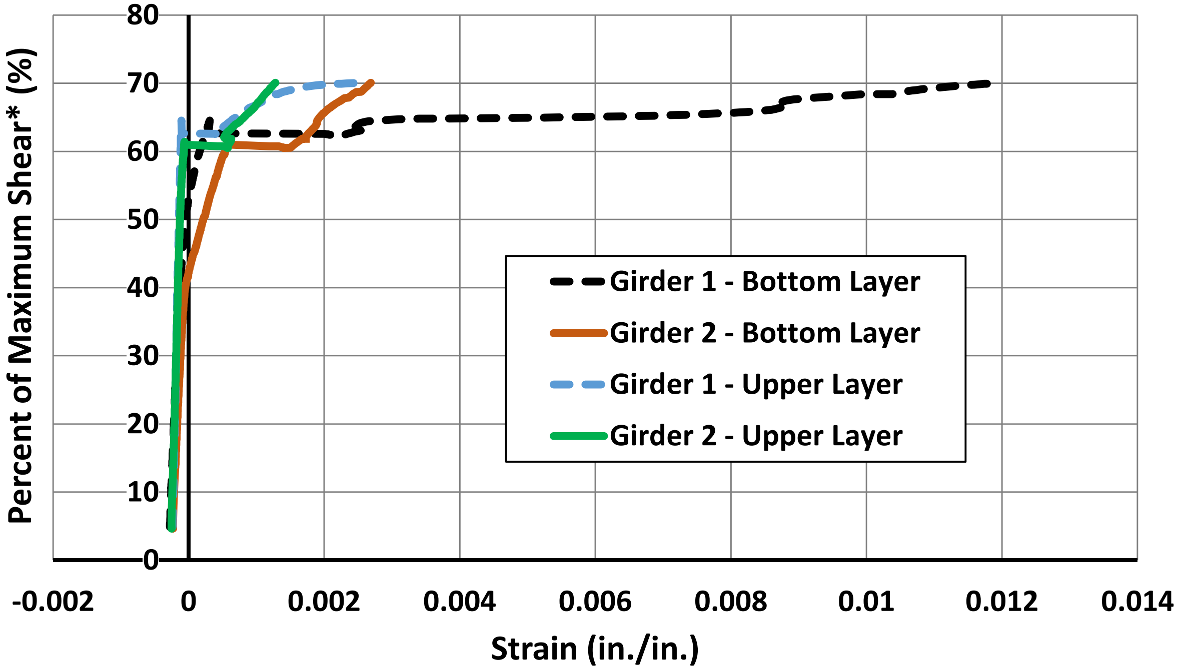
V = 514 kips (= 0.73V_{test})
(b)

Figure 5.18: Flexural cracking at the splice region – (a) Test Girder 1; (b) Test Girder 2

Evaluation of the strains in the longitudinal interface reinforcement extending into the splice regions of both girders also reveals a difference in the flexural behaviors of the specimens. Strains in the reinforcement indicated in Figure 5.19(a) are plotted in Figure 5.19(b) up to 70 percent of the maximum shear force for both girders. The data is gathered from strain gauges installed on the rebar near the splice region interface at the critical section. The bottom flange illustrated in Figure 5.19(a) includes the interface reinforcement of both girder specimens (i.e., Bars K of Test Girder 1 and Bars J of Test Girder 2). For each girder, data from a strain gauge installed on one of the bars within each layer labeled in the figure (i.e., "upper" or "lower" layer) is presented in Figure 5.19(b). Please note that an initial compressive strain in the reinforcement that was introduced and monitored during the post-tensioning operations is included within the plots.



(a)



*Includes shear from self-weight of girder and load frame (Refer to Section 5.2.2)

(b)

Figure 5.19: Strain in longitudinal interface reinforcement – (a) locations of strain gauges; (b) strains measured near the splice region interface

The strain data agrees with the observed flexural crack distribution within the bottom flanges of the two test girders. As the applied load increased, the reinforcement within the first test girder tended to experience higher strains near the splice region interface compared to the bars within Test Girder 2. This corresponds with a wider crack near the interface of Test Girder 1 and therefore less distribution of cracks through the length of the splice region.

Although the interface reinforcement did affect the splice region behavior after the initiation of flexural cracking within the bottom flange, the formation of flexural cracks at the splice region interface can be prevented by ensuring that the tensile stress in the extreme fiber of the girder due to applied loads does not overcome the compressive stress imposed by the post-tensioning force. As an example, using the gross cross-sectional properties and the stress in the post-tensioned strands at the completion of the post-tensioning operations (refer to Table 4.6), the compressive stress at the bottom fiber of Test Girder 1 at the critical section is calculated to be 1.56 ksi. Considering the gross cross-sectional properties of the composite girder (i.e., the girder plus the deck), the applied moment required to overcome this compressive stress is 35,466 kip-in. This moment corresponds with a shear force of 348 kips, 81 percent of the shear force when flexural cracks were noted (430 kips). This provides evidence that flexural cracking can easily be prevented under service-level design loads.

5.4.3 Strain in Stirrups

Strains in the stirrups (i.e., shear reinforcement) located within the splice regions were monitored during testing to identify any notable trends and to relate the strains to the cracking behavior of the girder webs. The placement of strain gauges on the shear reinforcement is illustrated in Figure 5.20. The two stirrups located at the center of the splice regions were instrumented. Three strain gauges were placed to correspond with the locations of the post-tensioning ducts. A fourth strain gauge was also installed within Test Girder 2 to monitor rebar strains above the ducts. The strains measured until the occurrence of shear failure by the four gauges installed on a stirrup within the splice region of Test Girder 2 are presented in Figure 5.21. Although some variations existed between the strains measured for each stirrup, the trends indicated in the figure were fairly typical.

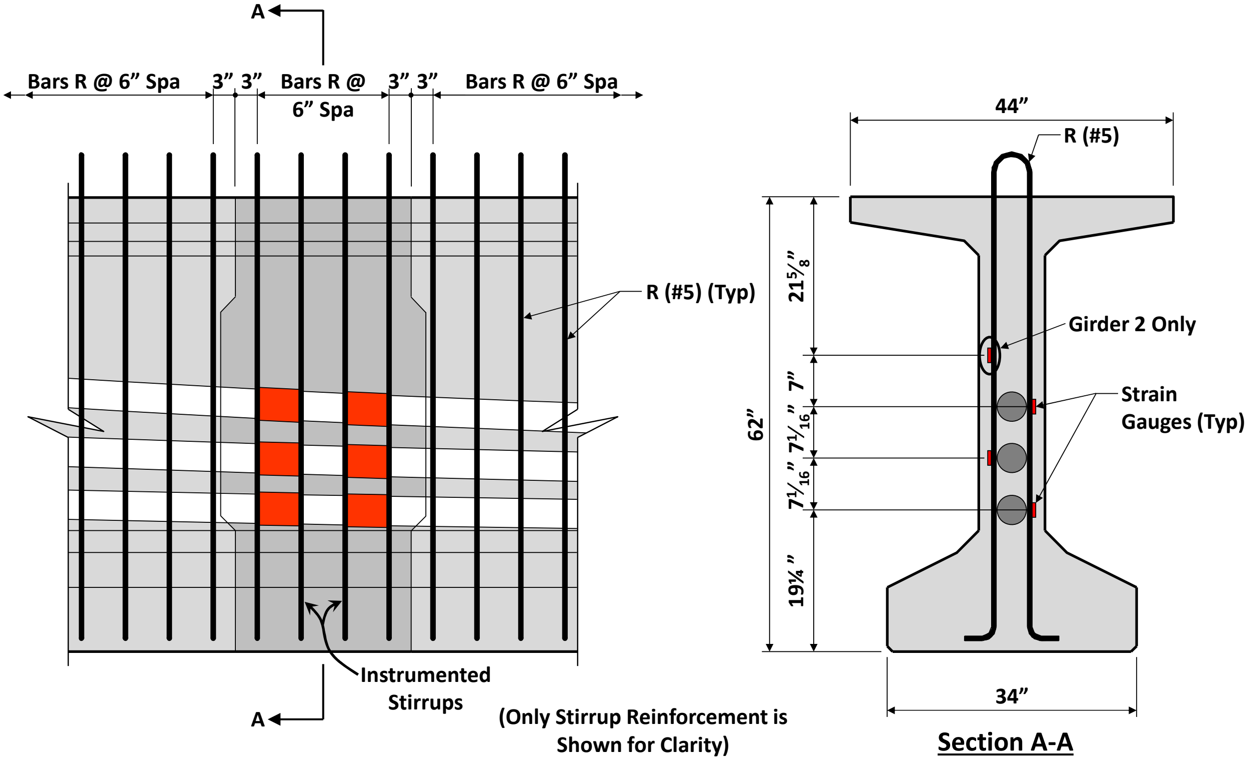
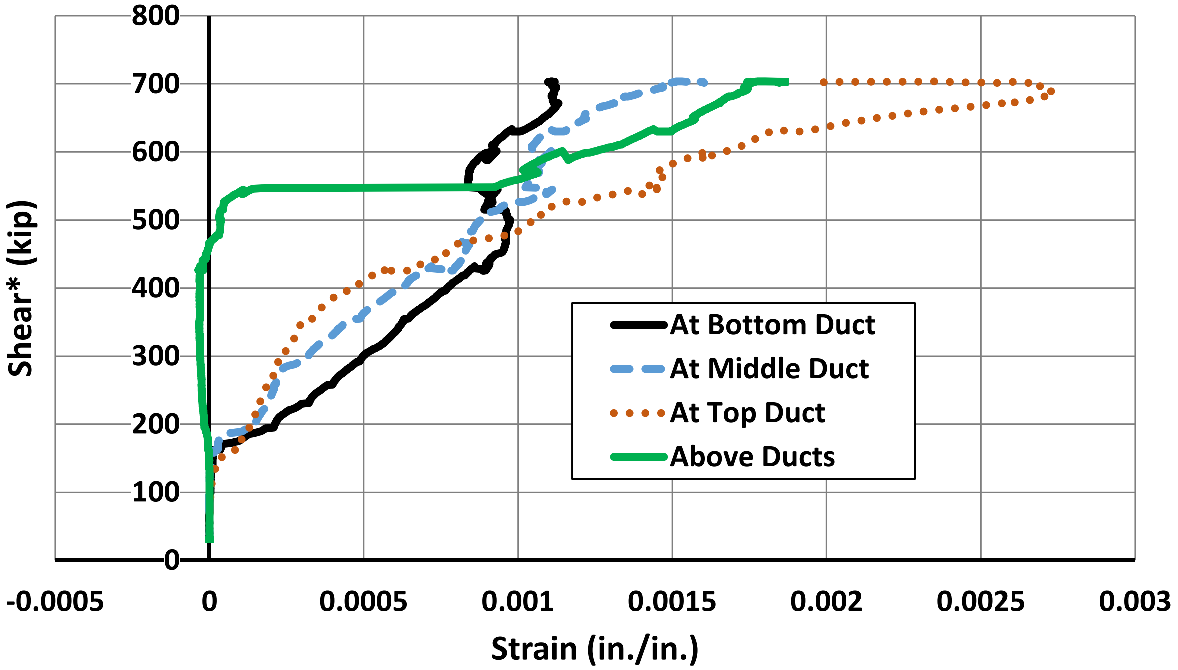


Figure 5.20: Strain gauges installed on stirrup reinforcement within the splice region



*Includes shear from self-weight of girder and load frame (Refer to Section 5.2.2)

Figure 5.21: Strains in stirrup reinforcement within the splice region (plotted to shear failure) – Test Girder 2

Analyzing the data plotted in Figure 5.21 results in a few interesting observations. First, the reinforcement experienced notable tensile strains at the locations of the ducts at a significantly lower shear force than at the strain gauge placed above the ducts. The development of tensile strains near the ducts corresponds with the observance of the first shear cracks within the web at a shear force of 194 kips (refer to Section 5.3). Furthermore, as the girder approached failure, the reinforcement was strained highest at the location of the top post-tensioning duct. This is expected based on the shear-compression failure mechanism characterized by concrete crushing in the vicinity of the top duct.

5.4.4 Comparison of Tested Capacities to Calculated Strengths

The experimental shear capacities of the two spliced girder test specimens were compared to the calculated strengths based on the general shear procedure of Article 5.8.3.4.2 of AASHTO LRFD (2014) and the proposed shear design procedure introduced in Moore et al. (2015). The location of the critical section for the evaluation of the shear strength calculation was provided in Section 5.2.2. The calculated shear strengths, V_n, and the experimental shear capacities, V_{test}, are summarized in Table 5.1.

Table 5.1: Summary of Experimental Capacities and Calculated Strengths

Test Specimen	V_{test} (kips)	AASHTO LRFD (2014) General *Article 5.8.3.4.2*		Proposed Procedure *Moore et al. (2015)*	
		V_n (kips)	V_{test}/V_n	V_n (kips)	V_{test}/V_n
Girder 1	666	638	1.04	563	1.18
Girder 2	703	656	1.07	573	1.23

To account for the discontinuity in girder webs due to the presence of post-tensioning ducts, the calculated strength based on the AASHTO LRFD (2014) general shear procedure considers a web width reduction of one-quarter the diameter of grouted ducts, as stated in Article 5.8.2.9 of the specifications. The shear design procedure presented in Section 6.5 of Moore at al. (2015) proposes that the gross web width, b_w, be used within the AASHTO LRFD general shear procedure and a quadratically decreasing strength reduction factor, λ_{duct}, be applied to the shear resistance provided by the transverse reinforcement, V_s. The proposed modifications to the AASHTO LRFD (2014) general shear procedure are provided in Appendix E.

To calculate the shear strength based on both the AASHTO LRFD (2014) general shear provisions and the proposed procedure, it was first necessary to define the values used within the design equations. Considering that the critical section is located at the interface between the precast girder segment and the CIP splice region, the concrete compressive strength, f'_c, used in the calculations was governed by the lower-strength splice region concrete. Furthermore, the value of f_{po} within Equation 5.8.3.4.2-4 of AASHTO LRFD (2014) was conservatively taken as the average tensile stress in the post-tensioning tendons after the anchorages were set (refer to Section 4.14.1). Alternatively, the value of f_{po} could have been taken as the stress in the tendons at the time of testing, as some past researchers have assumed. The additional prestressing losses between the completion of each post-tensioning operation and the load test were small and would result in only minor changes to the calculated shear strengths. The post-tensioning stress in each tendon and the concrete compressive strengths used for the shear calculations were presented in Tables 4.5 and 4.6.

Within the calculations, the mild longitudinal interface reinforcement is not considered to contribute to the strength of the girders. As explained in the following section (Section 5.5), the girder behavior provided evidence that the interface reinforcement is not fully effective at the ultimate state of the girder specimens. Therefore, it is recommended that the contribution of the mild interface reinforcement not be considered in flexural or sectional shear strength calculations, as was assumed for the calculated strengths presented in Table 5.1. The only steel considered effective within the splice region at the ultimate state is the post-tensioning tendons and the transverse shear reinforcement (i.e., stirrups).

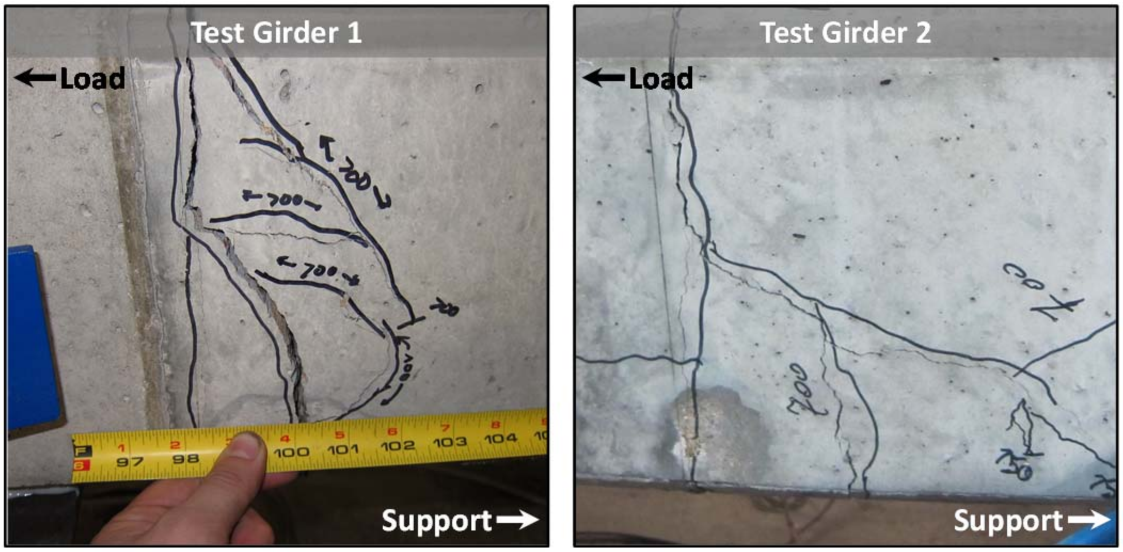
The shear strength ratios, V_{test}/V_n, presented in Table 5.1 indicate that both sectional shear procedures can be applied at the splice regions of the test specimens; the shear strength ratio is greater than unity in all cases. The proposed shear design procedure, however, provided added conservatism, with the lowest V_{test}/V_n ratio having a value of 1.18.

As noted in Section 4.8.1, any effects due to the relatively large size of the plastic duct couplers within the splice region was of particular interest. It should be noted that a duct diameter of 4 in. was assumed for all shear strength calculations presented in Table 5.1. Using the outer diameter of the coupler as opposed to the duct diameter would, of course, result in more conservative design calculations and higher shear strength ratios. For example, using a coupler diameter of 4 $^{13}/_{16}$ in. (refer to Figure 4.12 for coupler dimensions), the calculated shear strengths for Test Girder 1 using both the AASHTO LRFD (2014) general shear provisions and the proposed procedure result in V_{test}/V_n ratios of 1.05 and 1.25, respectively.

Lastly, it is important to note that the maximum shear stress limit of $0.25f'_c$ within Article 5.8.3.3 of AASHTO LRFD (2014) did not govern the calculated shear strength for either test girder. More detailed shear strength calculations for the specimens are provide in Appendix C.

5.5 Influence of Longitudinal Interface Reinforcement

The primary variable between the two spliced girder test specimens was the mild longitudinal interface reinforcement extending from the precast segments into the splice region (refer to Section 4.9.4). As previously discussed, the additional interface reinforcement provided in Test Girder 2 resulted in a more distributed flexural cracking pattern when compared to the behavior of the first test girder. The flexural cracks near the splice region interface that is located at the critical section are shown in Figure 5.22 for both test girders after reaching a shear force of 547 kips. The photographs further illustrate the concentration of flexural cracking near the splice region interface of Test Girder 1, resulting in a wider crack opening at this location compared to Test Girder 2. Therefore, additional interface reinforcement resulted in a notable difference in the girder's behavior after the formation of flexural cracks.

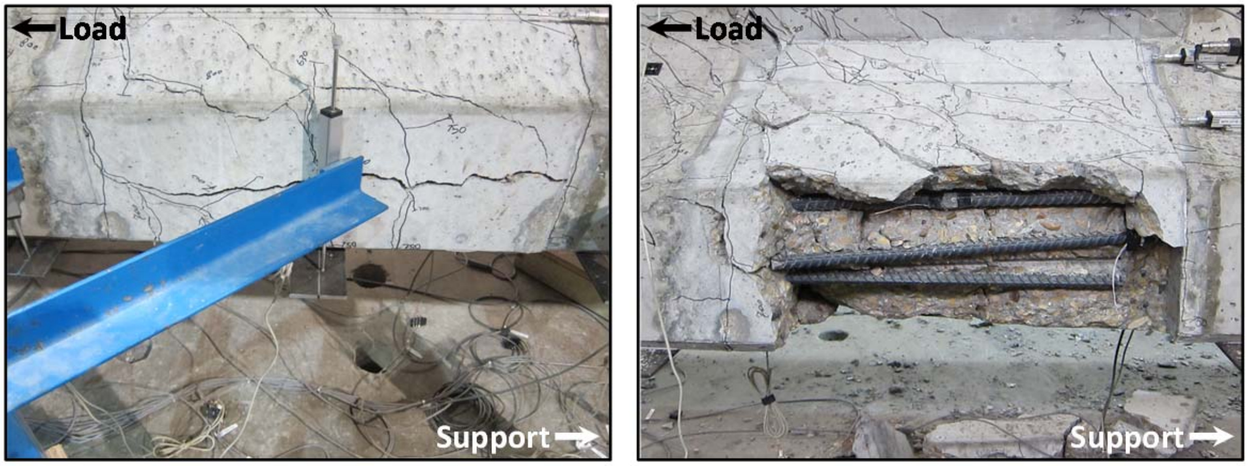


V = 547 kips (= $0.82V_{test}$)
(a)

V = 547 kips (= $0.78V_{test}$)
(b)

Figure 5.22: Flexural cracking near the splice region interface – (a) Test Girder 1; (b) Test Girder 2

The appearance of the bottom flange of the second test girder at both a shear force of $0.87V_{test}$ and after the occurrence of shear failure is presented in Figure 5.23. As the ultimate shear force was approached, horizontal cracks corresponding with the locations of longitudinal interface bars opened within the bottom flange (Figure 5.23(a)). Upon further loading, concrete within this region began to spall, as evidenced in Figure 5.23(b).



V = 610 kips (= 0.87V_{test}) **Post-Failure**

(a) *(b)*

Figure 5.23: Bottom flange at splice region of Test Girder 2 – (a) at a shear force of 0.87V_{test}; (b) post-failure

The behavior shown in Figure 5.23 provides evidence that longitudinal interface bars extending into the splice region should not be considered effective at the ultimate state. It is therefore recommended that the contribution of interface reinforcement be conservatively neglected in flexural and sectional shear strength calculations, as assumed for the values presented in Section 5.4.4.

5.6 Summary

In this chapter, the results and observations from the load tests conducted on the two spliced girder test specimens were presented with special focus placed on the behavior of the cast-in-place splice regions. Both test girders exhibited a shear-compression failure mechanism characterized by crushing of the web concrete in the vicinity of the top post-tensioning duct. The web crushing observed during failure of each specimen was not localized at the splice region but extended across much of the test span.

Both the strength and service-level shear behaviors were also detailed, including the cracking behavior and deformations within the splice regions. The effect of the longitudinal interface reinforcement on the girder behavior after the formation of flexural cracks was evaluated. Comparisons of the experimental shear capacities of the girders with calculated strengths revealed that the AASHTO LRFD (2014) general shear provisions and the proposed shear design procedure introduced in Moore et al. (2015) can both be applied at the splice regions of the test girders.

Design recommendations based on the results of the Phase II research program are presented in Chapter 6, followed by a summary of the research findings in Chapter 7.

Chapter 6. Design Recommendations

6.1 Introduction

Design recommendations for the cast-in-place (CIP) splice regions of spliced I-girder bridges were developed based on the results obtained in the experimental program described in the preceding chapters. The splice region details of the test girders were carefully selected, and technical input was provided by the TxDOT Project Monitoring Committee (PMC) and a project advisory panel during their development. Two proof tests were then conducted to evaluate the details and to gain insight into the behavior of the CIP splice regions. The testing configuration was selected such that the splice regions would experience both high shear and flexural demands in order to study various aspects of the girder behaviors. The results were then used to help develop a comprehensive set of design recommendations. The girders demonstrated satisfactory strength and exhibited a failure mechanism similar to that of monolithic post-tensioned girders.

Throughout the fabrication and testing of the specimens, observations were made and data was collected that led to the design recommendations presented in the following sections. The recommendations were developed to provide guidelines for satisfactory splice region performance and address issues that can arise during spliced girder construction.

6.2 Splice Region Details

Recommendations for the splice region details are presented in this section. Example splice region standard details based on the following recommendations are provided in Appendix D.

6.2.1 Longitudinal Interface Reinforcement

The primary variable between the two test girders was the longitudinal interface reinforcement. As discussed in Sections 5.4.2 and 5.5, the additional interface reinforcement included within the bottom flange of Test Girder 2 (approximately 3 times the interface reinforcement within the bottom flange of Test Girder 1) resulted in improved flexural behavior after the initiation of flexural cracking. Based on the performance of the two specimens, the additional area of reinforcement provided in the second test girder is recommended. The interface reinforcement details of Test Girder 2 are again provided in Figure 6.1 for easy reference. Please refer to Appendix D for detailed splice region drawings.

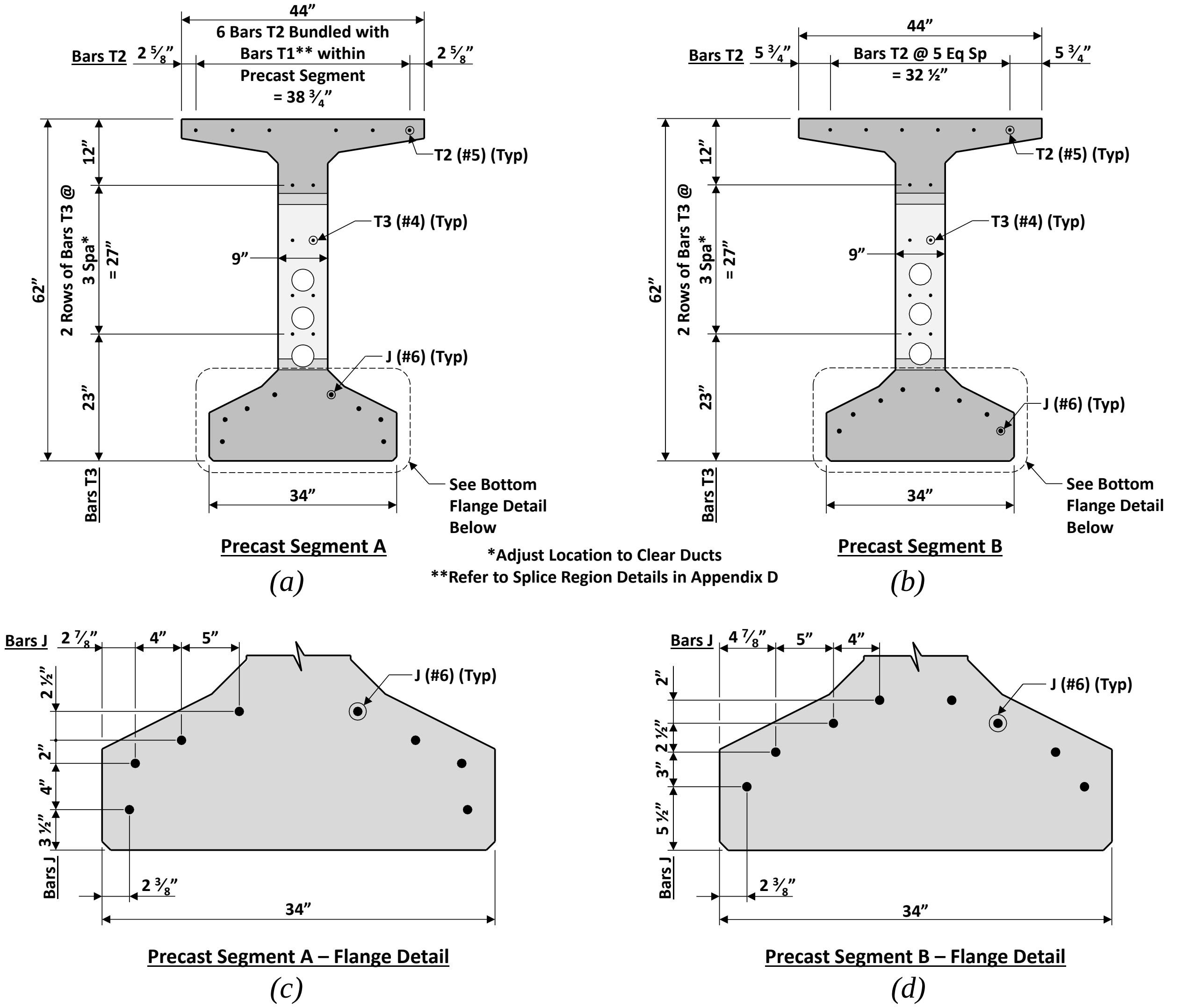


Figure 6.1: Recommended longitudinal interface reinforcement– (a) end of Precast Segment A; (b) end of Precast Segment B; (c) flange detail of Precast Segment A; (d) flange detail of Precast Segment B

As described in Section 5.4.2, flexural cracking can easily be prevented under service-level design loads. Should flexural cracks form, the recommended interface reinforcement was selected with the intent to better control cracking when compared to a lesser amount of reinforcement such as that of Test Girder 1.

To aid in the development of the longitudinal interface reinforcement within the splice region after the formation of cracks, various alternatives to the details presented in Figure 6.1 could be explored when designing spliced girders. For example, hairpin bar details, as presented in Section 3.3.5, could be specified. Lap splices designed in accordance with Article 5.11.5 of AASHTO LRFD (2014) can be used if continuity is needed to satisfy design requirements (e.g., stress limits as specified in AASHTO LRFD). The use of confinement reinforcement within the bottom flange of the splice region as illustrated in Figure 6.2 could also be considered in order to improve the development of the mild steel and better control the horizontal cracking behavior of the bottom flange observed during the testing program (see Section 5.5). With any detail that is specified, however, the designer should remain mindful of potential rebar congestion within the splice region. The design should allow for proper concrete consolidation, and special consideration should be given to concrete placement in the bottom flange.

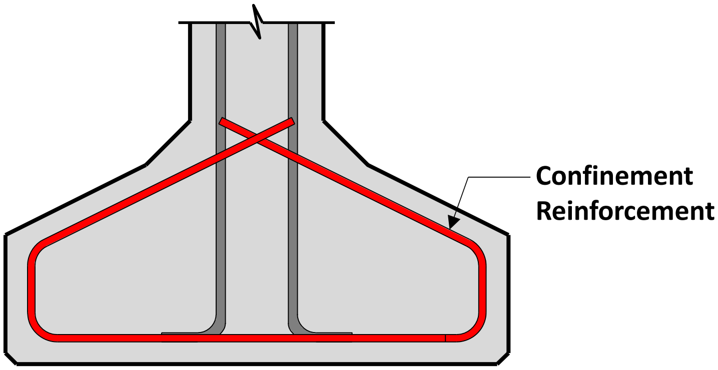


Figure 6.2: Potential confinement reinforcement within the splice region

Please recall that the pretensioned strands extending from the ends of the precast girder segments were cut within 3 in. of the girder faces to avoid additional congestion within the splice regions. A similar detail is recommended in the drawings provided in Appendix D.

6.2.2 Splice Region Geometry

The splice region geometry for the girder specimens was discussed in Sections 4.9.1 and 4.9.2. The length of the splice region measured along the longitudinal axis of the girders was chosen to be 24 in. From the first-hand experience of constructing the splice regions of the test specimens, a length of 24 in. is recommended from a constructability standpoint. The recommended length allowed the ducts to be coupled while accommodating any minor duct misalignment issues. Moreover, the 24-in. length was needed to ensure adequate space for reinforcing bar placement. The splice region fabrication would have been more difficult if a shorter length had been chosen. Please note that the splice region length should also accommodate the splicing of mild steel where continuity is needed to satisfy design considerations (see Article 5.14.1.3.2b of AASHTO LRFD (2014)).

The cross-section at the splice regions of the test specimens was selected to match the shape of the adjacent precast girder segments. Although this choice resulted in a restricted space for concrete placement, the splice region was successfully cast by ensuring adequate vibration of the concrete (see Section 4.13.3). Furthermore, the girders exhibited satisfactory strength when compared to calculated values and displayed a shear-compression failure mechanism consistent with monolithic post-tensioned girders (Moore et al., 2015). Based on these results, the recommended splice region details maintain a constant cross-section for the precast segments and the splice region. This recommended geometry may also be desirable for aesthetic reasons to provide a constant shape along the length of a fascia girder.

6.2.3 Other Splice Region Details

A shear key was included at the interface of the splice regions of the test specimens (refer to Section 4.9.3). The selected detail exhibited satisfactory strength and serviceability performance during both proof tests. The shear key detail is therefore included in the recommended splice region details in Appendix D.

The shear and transverse reinforcement placed in the splice regions of the test girders was essentially a continuation of reinforcement provided in the precast segments (refer to Section 4.9.6). Based on the strength of the test specimens, it is recommended that the shear reinforcement within the splice region be the larger of that provided in the adjacent precast girders, as is currently required in the AASHTO LRFD (2014) provisions (see Article 5.14.1.3.2b).

The duct coupling detail that was selected for the splice region consisted of two couplers with a short duct segment in the middle (refer to Section 4.9.7). From a constructability standpoint, the coupling detail accommodated any minor duct misalignment issues. As mentioned in Section 5.3, however, the formation of shear cracks during the testing program may have been influenced by the locations of the duct couplers. It is important to note that the various types of couplers available in the market may result in different cracking behaviors. The duct coupling detail (i.e., the use of one or two couplers for each duct) is therefore left to the discretion of the engineer.

Although the proof tests resulted in significant insights into splice region behavior and provided a means to study splice details, the evaluation of all the provisions relating to the design and detailing of spliced girders within the AASHTO LRFD (2014) specifications was beyond the scope of this research.

6.3 Strength Calculations

The test girders exhibited a shear-compression failure mechanism of the web concrete with crushing that extended across much of the test span. Comparison of the experimental capacities with calculated shear strengths revealed that sectional shear provisions can be applied at the splice regions. Based on these comparisons as well as the observed behaviors of the test girders, the following recommendations were developed for calculating the shear strength at the splice region:

- **Concrete Strength, f'_c:** The specified compressive strength of concrete, f'_c, used within sectional shear calculations at the splice region should be conservatively defined as the lesser of the specified strengths of the precast concrete and the cast-in-place splice region concrete. As discussed in Section 5.4.4, the governing lower-strength splice region concrete of the test girders was used when evaluating the sectional shear provisions.

- **Effect of Longitudinal Interface Reinforcement:** The splice region behavior observed during the testing program as the specimen capacity was approached provided evidence that longitudinal interface reinforcement extending from the precast segments into the splice region should not be considered effective at the ultimate state. It is therefore recommended that the contribution of all interface reinforcement be conservatively neglected in flexural and sectional shear strength calculations, as assumed for the evaluation of the shear strength provisions in Section 5.4.4.

- **Proposed Modifications to AASHTO LRFD (2014) General Shear Procedure:** Phase I of the spliced girder research program resulted in proposed modifications to

> the AASHTO LRFD (2014) general shear procedure based on a detailed analysis of the Evaluation Database for Post-Tensioned Girders (Moore et al., 2015). Details of the suggested modifications are provided in Appendix E. In Section 5.4.4, comparisons of the shear strength ratios, V_{test}/V_n, for both the current AASHTO LRFD (2014) general shear provisions and the proposed procedure were presented. The comparisons revealed that, although both design procedures result in V_{test}/V_n ratios with values greater than 1.0, the proposed modifications provide strength predictions that are slightly more conservative. Considering that the shear strength performance of post-tensioned spliced girders with CIP splice regions can only be evaluated with the two tests of the research program described in this report, it is recommended that the more conservative approach be followed.
>
> Nakamura, Avendaño, and Bayrak (2013) examined the conservatism of the AASHTO LRFD (2010) general shear procedure using a database of 171 tests on prestressed concrete beams representative of field members. The database evaluation revealed an average V_{test}/V_n ratio of 1.43 with a coefficient of variation (COV) of 0.18. The shear strength ratios for the spliced girder test specimens using the proposed shear design procedure are in better agreement with this average V_{test}/V_n value than are the shear strength ratios resulting from the current AASHTO LRFD provisions (refer to Table 5.1). Furthermore, the shear-compression failure mechanism exhibited by the spliced girder specimens is consistent with the mechanical model on which the proposed modifications are based (see Section 5.6 of Moore et al., 2015).
>
> For the reasons outlined above, the use of the proposed modifications to the AASHTO LRFD (2014) general shear procedure introduced in Moore et al. (2015) is recommended for calculating the nominal shear resistance, V_n, of spliced girders.

The interface shear strength at the splice region interface is also a limit state that should be considered when designing spliced girders. Designers should ensure that splice regions have adequate interface shear strength according to Article 5.8.4 of the AASHTO LRFD (2014) specifications. The spliced girder specimens of the test program were designed to evaluate sectional shear provisions and did not experience interface shear failures. The accuracy of interface shear strength calculations at CIP splice regions cannot therefore be assessed with the results of the two proof tests.

6.4 Summary

Design recommendations based on the results of the large-scale experimental program were presented in this chapter. The recommended splice region details were selected based on the performance observed during the proof tests while minimizing potential constructability issues. Guidelines for spliced girder shear strength calculations were also presented. The results of the experimental program reinforce the need to modify the AASHTO LRFD (2014) general shear procedure as outlined in Moore et al. (2015). The proposed modifications are based on a mechanical model consistent with the behavior of post-tensioned bridge girders, including the spliced girder specimens.

The two proof tests described in this report provided significant insights into the strength and serviceability behavior of spliced girders. The test results also led to recommendations that can be directly applied to the design and detailing of field structures. Nevertheless, additional testing and evaluation of spliced girder behavior could result in further refinements to the splice region details.

Chapter 7. Summary and Conclusions

7.1 Summary

Phase II of the spliced girder research program was developed to build upon the findings of Phase I, which focused on the shear performance of monolithic post-tensioned girders. In order to better understand the behavior of the cast-in-place (CIP) splice regions of spliced I-girder bridges, two tests were performed as part of the Phase II experimental program and provided invaluable information regarding splice region behavior that is otherwise unavailable in the literature. The primary objectives of the research conducted as part of Phase II were:

(iv) Study the strength and serviceability behavior of the CIP splice regions of spliced I-girders.

(v) Identify design and detailing practices that have been successfully implemented in CIP splice regions located within the span lengths of existing spliced I-girder bridges.

(vi) Develop design recommendations based on the structural performance of spliced girder test specimens that include selected candidate details within the CIP splice regions.

Considering the wide variety of splice region details that have been used in the field, the identification of best practices that have been successfully implemented for splice regions of existing bridges was needed. During this process, awareness of potential constructability issues relating to each detail was essential. An industry survey was therefore conducted to aid in the selection of splice details that would later be included in spliced girder specimens and proof tested. In addition to the survey, the TxDOT Project Monitoring Committee (PMC) and a project advisory panel offered invaluable input from first-hand experience with spliced girder technology. With these available resources, splice region details were developed and implemented in two I-girder test specimens.

Each test girder consisted of two precast pretensioned segments that were joined with a 2-ft long CIP splice region. The girders were made continuous by three post-tensioning tendons that extended the full length of the specimens. Due to the interest in studying the shear strength behavior of spliced girders, the specimens were designed to fail in shear. As the ultimate load was approached during the tests, the girders also experienced high flexural demands, providing the opportunity to study various aspects of the splice region behavior and enhancing the value of the proof tests. The amount of mild longitudinal interface reinforcement extending from the precast segments into the splice region was varied between the two specimens to identify the effect of the bars on the behavior of the girder after the formation of flexural cracks in the splice region.

The two proof tests were conducted successfully with the girders exhibiting shear-compression failure mechanisms similar to that of the monolithic post-tensioned girders of the Phase I experimental program. From the test results, design recommendations for splice region details and shear strength calculations were developed. The recommendations were outlined in Chapter 6.

7.2 Observations and Conclusions

The overall findings of the Phase II research program are outlined within this section. Key observations collected during the proof tests are included along with the conclusions developed from the analysis of the research results.

7.2.1 Behavior of the Splice Regions of Spliced I-Girder Bridges

- **Service-Level Behavior:** During the load tests, the development of localized shear cracks were observed in the vicinity of the post-tensioning ducts at service-level shear forces. The cracking continued to distribute within the vicinity of the ducts upon further loading. The formation of cracks that extended over much of the web depth were visually detected at shear forces of 73 percent and 69 percent of the maximum shear force, V_{test}, for the first and second test girders, respectively, consistent with behavior observed during the Phase I testing program.
  Considering the flexural behaviors of the girders, it was demonstrated that flexural cracking can be prevented under service-level design loads (refer to Section 5.4.2).
- **Shear Behavior at Failure:** Both girder specimens exhibited a shear-compression failure mechanism characterized by localized crushing that occurred primarily in the vicinity of the top post-tensioning duct. This behavior was consistent with the observed failures of monolithic post-tensioned I-girders tested during the Phase I program (Moore et al., 2015). The web crushing of the spliced girder specimens extended across much of the test span and was not localized within the splice regions.
- **Recommended Shear Strength Calculations:** Comparison of the experimental capacities with calculated shear strengths revealed that sectional shear provisions can be applied at the splice regions of the test specimens. Application of the sectional shear design procedure proposed by Moore et al. (2015) (see Appendix E) is recommended for spliced girder strength calculations. When calculating the shear resistance, the lesser of the specified strengths of the precast concrete and the cast-in-place concrete should be assumed as the value of f'_c at the splice region interface. Furthermore, any contribution of longitudinal interface reinforcement should be neglected.

7.2.2 Splice Region Details

- **Industry Survey Results:** The industry survey results provided insights into the design and construction of spliced girder bridges from the viewpoints of state departments of transportation (DOTs) with experience in spliced girder technology. The survey was designed to identify splice region details that are typically specified in the various states. Although the details vary significantly among the state DOTs, successful practices could be identified from the survey responses and supplementary material provided by the participants. In addition to the industry survey, input from the TxDOT Project Monitoring Committee and the project advisory panel were invaluable when developing the splice region details to be tested.

- **Large-Scale Splice Region Proof Tests:** The results of the load tests on the spliced girder specimens were analyzed to evaluate the performance of the candidate splice region details. Both test girders experienced shear forces at the critical section (i.e., splice region interface) that were greater than the calculated strengths based on sectional shear provisions. The selected splice region details also allowed both specimens to exhibit failure behaviors similar to that of monolithic girders (i.e., shear failure was not localized at the splice region).
- **Recommended Splice Region Details:** Splice region details were proposed based on the structural performance of the test girders and other relevant observations that were gathered during the research program. The recommended mild interface reinforcement was based on the cracking behavior of the two test girders. The second test girder with a larger area of interface reinforcement compared to Test Girder 1 exhibited better control of flexural cracking at high loads. Lessons learned during the construction of the splice regions also contributed to the recommendations. Drawings of the recommended splice region details are provided in Appendix D.

7.3 Concluding Remarks

It is the authors' belief that the spliced girder research program resulted in a significant contribution to the understanding of the shear behavior of spliced post-tensioned girders. During the Phase I experimental program (detailed in Moore et al. (2015)), eleven shear tests were performed on large-scale I-girder specimens. Ten of these tests were added to the Evaluation Database for Post-Tensioned Girders, which now contains a total of 44 tests. The specimens from the spliced girder research therefore comprise 23 percent of the database. A comprehensive analysis of the database resulted in proposed modifications to the AASHTO LRFD (2014) general shear procedure to better account for the presence of post-tensioning ducts in the webs of bridge girders. Phase II of the spliced girder research program (described in this report) included the only known tests in which a shear failure mechanism was developed in post-tensioned spliced girders containing in-span cast-in-place splice regions. The two spliced girder tests lead to a better understanding of CIP splice region behavior. The spliced girders failed at shear strengths exceeding calculated values. Furthermore, splice region details were recommended based on the results of the Phase II program. The spliced girder research findings are presented with the hope that their implementation will result in the tools needed for the precast concrete girder industry to better reach its full potential.

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Appendix A. Industry Survey Responses

Introduction

The responses to the industry survey conducted for Phase II of the spliced girder research program are provided in this appendix. A total of 25 responses were received. The survey participants who indicated that their state/district did not have past experience with the design and/or construction of spliced girder bridges were not required to proceed with the survey after the second page. In these cases, only the first two pages of the survey responses are included.

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

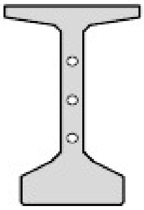
Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

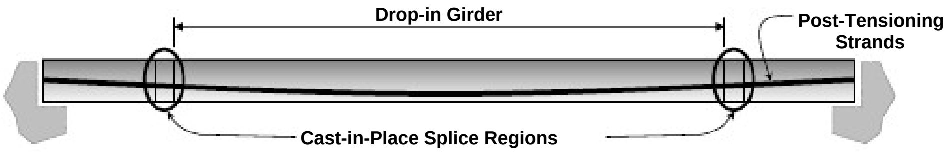
The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

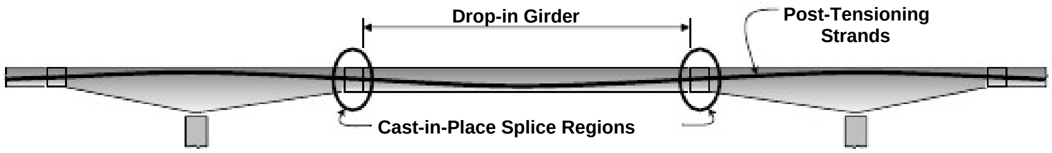
Please return this survey **by April 30** to: Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact: Greg Turco, PE **Address:** Bridge Division 125 East 11th St. Austin, TX 78701 **Phone:** 512-416-2580 **Email:** Greg.Turco@txdot.gov	**The University of Texas Research Team:** Dr. Oguzhan Bayrak: bayrak@mail.utexas.edu Dr. James Jirsa: jirsa@uts.cc.utexas.edu Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu Chris Williams: chrisw05@utexas.edu Andy Moore: ammoore@utexas.edu **Address:** Ferguson Structural Engineering Laboratory The University of Texas at Austin 10100 Burnet Rd., Building 177 Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Pe-Shen Yang

Title: Assistant State Bridge Engineer

State/District: Arizona

Organization/Unit: Arizona Department of Transportation

Address: 205 S. 17th Ave., MD631E, RM 269E
Phoenix, AZ 85007

Phone: 602-712-8606

Fax: 602-712-3056

Email: pyang@azdot.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ☒ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☒ Yes ☐ No

If *Yes,* please list the consultant(s).

AECOM, TyLin, URS

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 100 %
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☒ No

If *Yes,* please briefly describe the problem(s).

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☒ Yes ☐ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☒ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

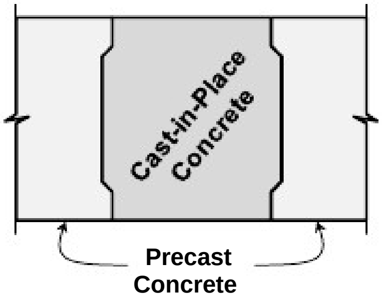
☐ Other; please specify: ______________________________

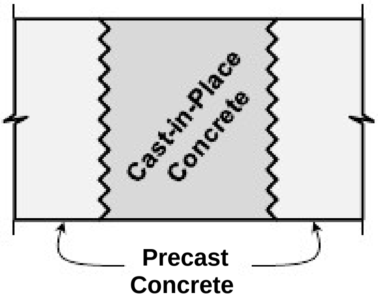
9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

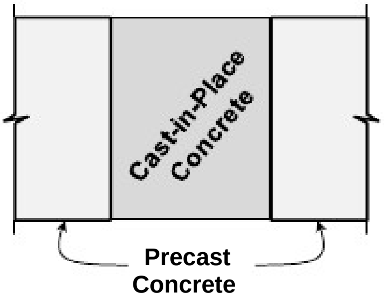
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

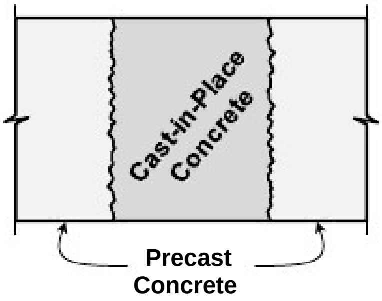
☐ Shear key: 80 % ☒ Saw teeth: 20 % ☐ Plain: ________%







☐ Sandblasting or intentional roughening: ________%



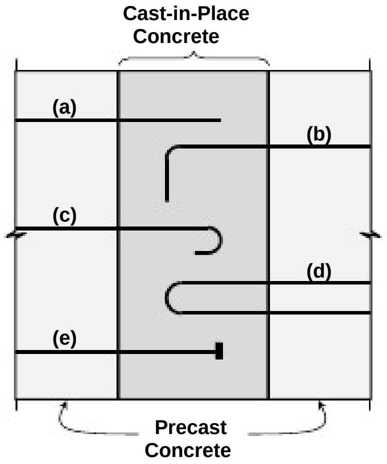
Please explain the factors that affect the type of interface that is chosen.

designer determines

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☐ (a) Straight bars ☐ (b) 90-degree hooks ☐ (c) 180-degree hooks ☒ (d) Hairpins

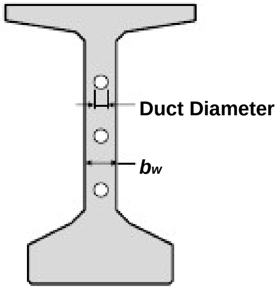
☐ (e) Headed bars ☐ Other; please describe: ____________________



Please elaborate on the detailing of the interface reinforcement if necessary.

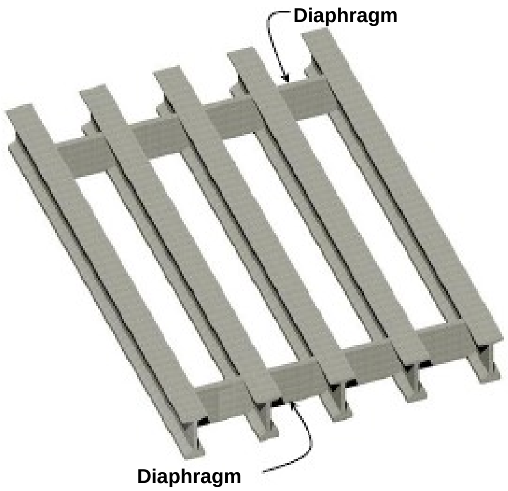
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
8	4"	100 %
		%
		%
		%
		%



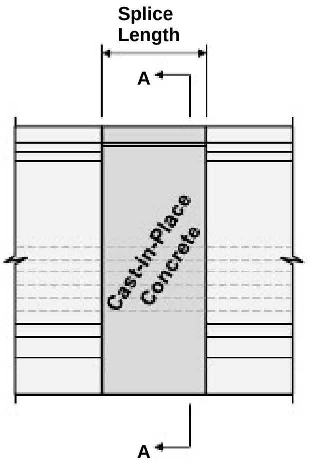
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☒ At the splice ☐ Away from the splice ☐ No preference

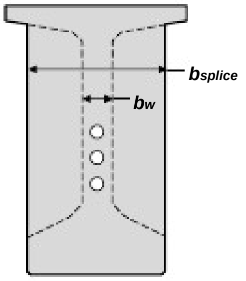


14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	Minimum	Maximum	Typical
Length	24"		24"
b_{splice} - b_w	16"		16"



Elevation



Section A-A

Please explain the factors that affect the **length** of the splice region?

the need to lap reinforcement

Please explain the factors that affect the **width** of the splice region?

Typical use the width of the bottom flange of the precast girder or width of the web of precast box girders

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

Two of the sliced AASHTO girder bridge (both two spans) have slight angle point at splice locations because roadway was on a slight curve.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here:

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

Please return this survey **by April 30** to: Greg Turco, TxDOT Bridge Division
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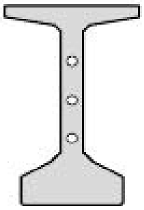
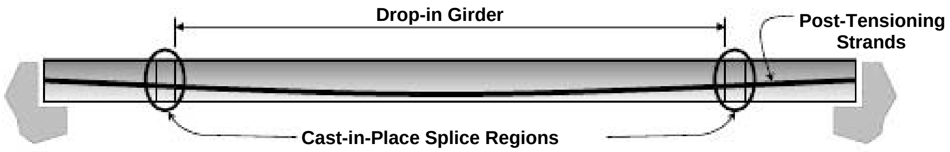
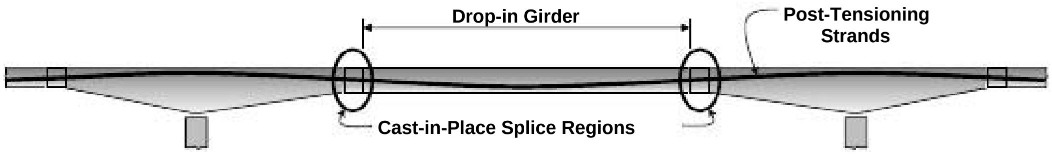
TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact: Greg Turco, PE **Address:** Bridge Division 125 East 11th St. Austin, TX 78701 **Phone:** 512-416-2580 **Email:** Greg.Turco@txdot.gov	**The University of Texas Research Team:** Dr. Oguzhan Bayrak: bayrak@mail.utexas.edu Dr. James Jirsa: jirsa@uts.cc.utexas.edu Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu Chris Williams: chrisw05@utexas.edu Andy Moore: ammoore@utexas.edu **Address:** Ferguson Structural Engineering Laboratory The University of Texas at Austin 10100 Burnet Rd., Building 177 Austin TX, 78758

Contact Information

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Phone: (501) 569-2362

Fax: (501) 569-2623

Email: carl.fuselier@arkansashighways.com

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☒ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

Arkansas does not have a concrete beam fabricator so a small percentage of the bridges utilize concrete beams.

Spliced girder technology has not been used due to our unfamiliarity with the process.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

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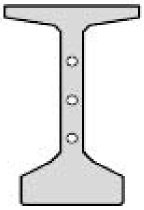
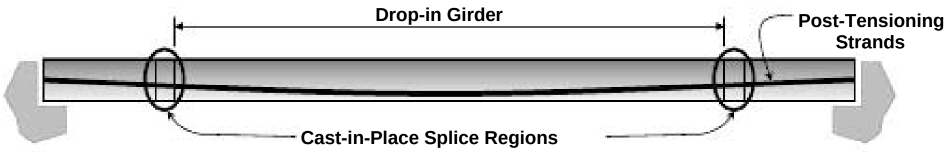
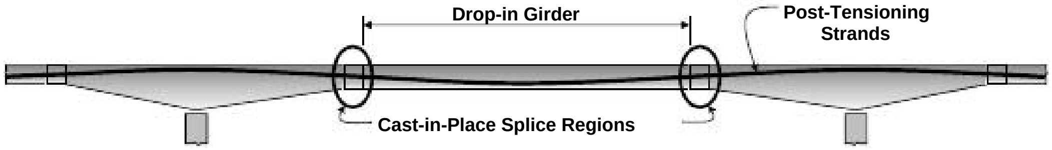
TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
Greg Turco, PE

Address:
Bridge Division
125 East 11th St.
Austin, TX 78701

Phone: 512-416-2580
Email: Greg.Turco@txdot.gov

The University of Texas Research Team:
Dr. Oguzhan Bayrak: bayrak@mail.utexas.edu
Dr. James Jirsa: jirsa@uts.cc.utexas.edu
Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu
Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
Ferguson Structural Engineering Laboratory
The University of Texas at Austin
10100 Burnet Rd., Building 177
Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Jim Ma

Title: Senior Bridge Engineer/Prestressed Concrete Specialist

State/District: California

Organization/Unit: California Department Of Transportation

Address: 1820 Alhambra Blvd, MS 9-1/5c FM2, SACRAMENTO, CA 95816

Phone: 916-227-8175

Fax:

Email: JIM_MA@DOT.CA.GOV

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☒ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☒ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ☒ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☒ Yes ☐ No

If *Yes,* please list the consultant(s).

URS, QUINCY ENGINEERING, HNTB, TYLIN, DOKKEN, ENGINEERING, RAJAPPAN & MEYER, ETC.

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 100 %
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

CALTRANS DOES NOT ALLOW PLASTIC DUCTS IN POST-TENSIONING SYSTEMS.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☒ No

If *Yes,* please briefly describe the problem(s).

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☒ Yes ☐ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☒ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

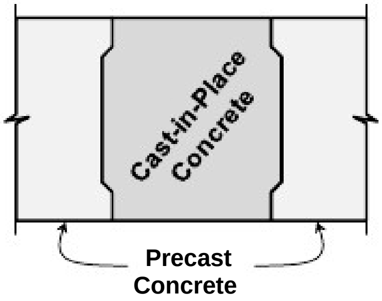
☐ Other; please specify: CALIFORNIA AMENDMENTS

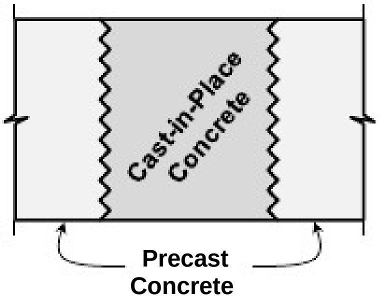
9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

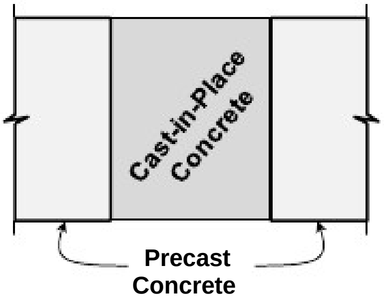
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

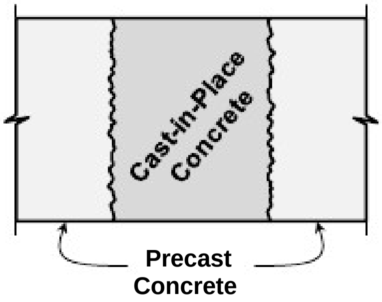
☐ Shear key: 30 % ☐ Saw teeth: ____% ☐ Plain: 50 %







☐ Sandblasting or intentional roughening: 20 % ________

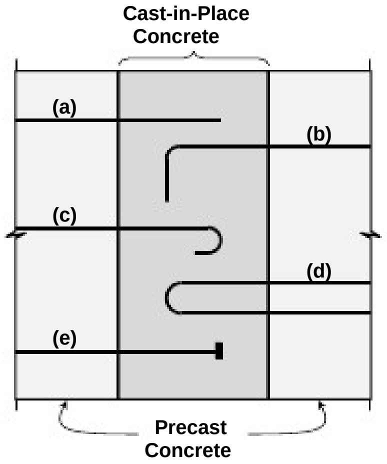


Please explain the factors that affect the type of interface that is chosen.

CALTRANS HAS MOVED FROM PLAIN INTERFACE DETAIL TO SHEAR KEY FACE AND ROUGH INTERFACE DETAILS.

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

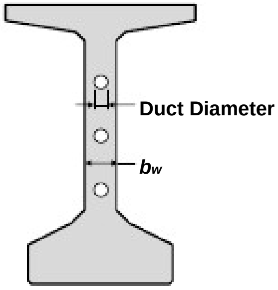
☐ (a) Straight bars
☒ (b) 90-degree hooks
☐ (c) 180-degree hooks
☐ (d) Hairpins
☐ (e) Headed bars
☐ Other; please describe:



Please elaborate on the detailing of the interface reinforcement if necessary.

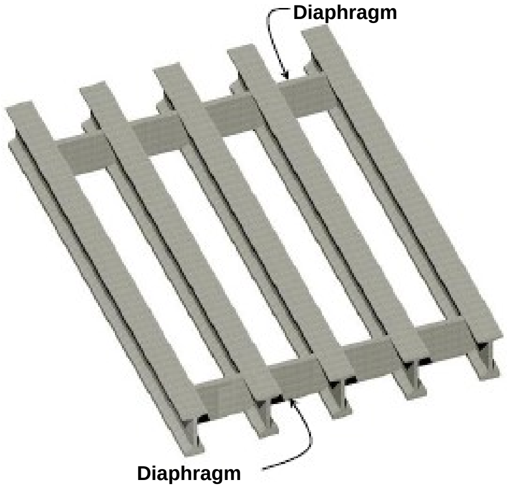
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	**Duct Diameter**	**Percent of Projects**
8"	4"	30 %
8"	3.5"	50 %
8"	3"	20 %
		%
		%



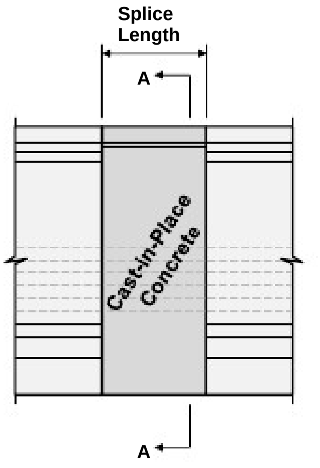
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☐ At the splice ☒ Away from the splice ☐ No preference

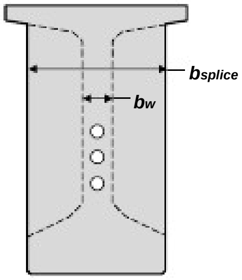


14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	Minimum	Maximum	Typical
Length	24"	48"	24"
$b_{splice} - b_w$	21.5"	38.5"	bsplice is the SAME WIDTH AS THE BULB



Elevation



Section A-A

Please explain the factors that affect the **length** of the splice region?

1. PT DUCT SPLICE LENGTH

2. DEVELOPMENT LENGTH OF THE EXTENDED STRANDS AND REBARS

3. SPACE FOR SHEAR REINFORCEMENT

4. ROOM FOR WORKING SPACE

Please explain the factors that affect the **width** of the splice region?

1. DOABLE SECTION OF PRECAST GIRDER FORM

2. ENOUGH SPACE FOR REBAR PLACEMENT

3. ENOUGH SPACE FOR CONCRETE POUR AND VIBRATION

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☒ Yes ☐ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

ISSUE: CONCRETE AIR POCKETS AND VOIDS AT SPLICE REGIONS

PROBLEM CAUSED: DIDN'T (AND HARD TO) VIBRATE CONCRETE ENOUGH FOR DEEP GIRDER BRIDGES

LESSONS LEARNED: IMPROVE VIBRATION METHOD AND REMOVE FORMWORK TO INSPECT THE SPLICE REGIONS BEFORE POST-TENSIONING

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

ONE OF THE NOTES FOR SPLICED GIRDER DESIGN REGARDING TO SPLICE REGIONS IS: Wet closure joints between girder segments are usually used instead of match-cast joints. The width of a closure joint shall not be less than 24 inches and shall allow for the splicing of post tensioning ducts and rebar. Web reinforcement (Av/s) within the joint should be the larger of that provided in the adjacent girders. The face of the precast segments at closure joints must be intentionally roughened or cast with shear keys in place.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here: WILL ATTACH DESIGN GUIDELINES AND UPLOAD SOME DESIGN PLANS

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

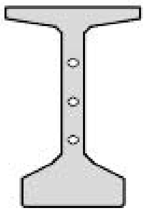
The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

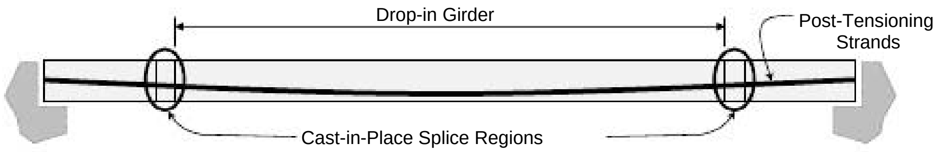
Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

Please return this survey **by April 30** to:

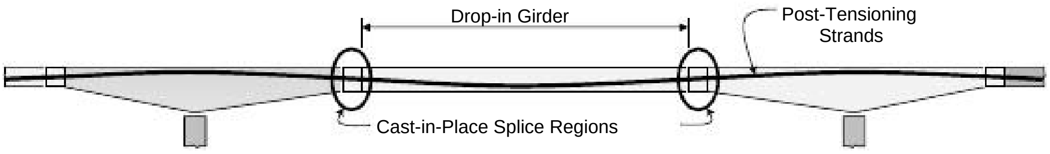
Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
Greg Turco, PE

Address:
Bridge Division
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Austin, TX 78701

Phone: 512-416-2580
Email: Greg.Turco@txdot.gov

The University of Texas Research Team:
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Address:
Ferguson Structural Engineering Laboratory
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Austin TX, 78758

Contact Information

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Organization/Unit: DC Department of Transportation

Address: 55 M St., S.E., 4th Floor, Washington, DC 20003

Phone: 202-671-4568

Fax: 202-671-4710

Email: konjit.eskender@dc.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☒ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

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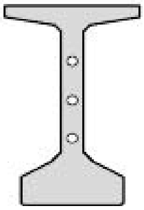
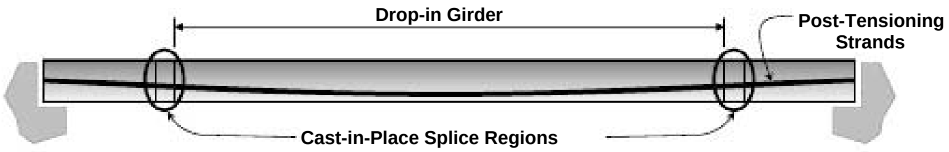
TYPICAL SPLICED-GIRDER LAYOUTS





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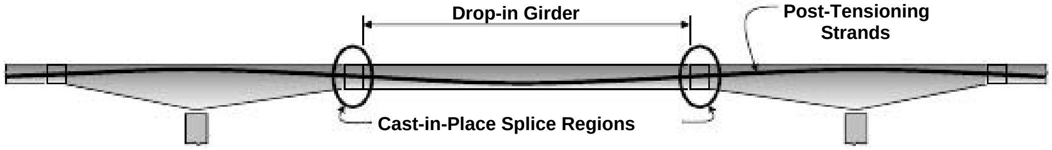

Multi-Span Continuous

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Contact Information

Name of Person Completing the Survey: Robert Robertson

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Organization/Unit: Structures Design Office

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Tallahassee, FL 32399

Phone: 850-414-4267

Fax:

Email: robert.robertson@dot.state.fl.us

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

   ☒ Yes ☐ No

   If *No,* has your state/district considered the use of spliced girder technology?

   ☐ Yes ☐ No

   If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

   If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

   ☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☒ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

   ☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ☒ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☒ Yes ☐ No

If *Yes,* please list the consultant(s).

There are currently 52 Consultant Firms qualified to design spliced I-girder bridges in the State of Florida. Spliced I-girders are covered under Work Group 4.2.1, Major Bridge Design - Concrete as defined in Rule 14-75. See the URL link below for qualifying firms and Rule 14-75.

http://www2.dot.state.fl.us/procurement/ProfessionalServices/lppc/prequal_listing.asp

http://www.dot.state.fl.us/procurement/Project%20Costing/pdf/Rule%2014-75.pdf

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 60 %
- Plastic (HDPE): 40 %

If one of the materials is preferred over the other, please explain why.

Corrugated steel duct was used on older structures. New FDOT policy is to use corrugated polypropylene (not HDPE) for internal tendons.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☒ No

If *Yes,* please briefly describe the problem(s).

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☐ Yes ☒ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☐ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

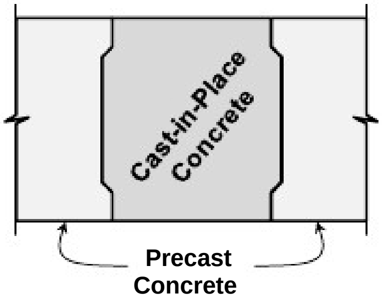
☐ Other; please specify: ________________

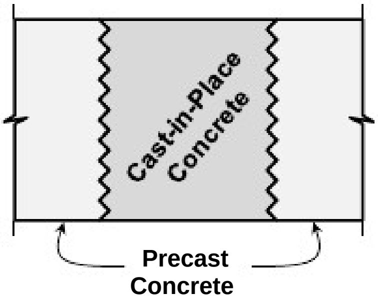
9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

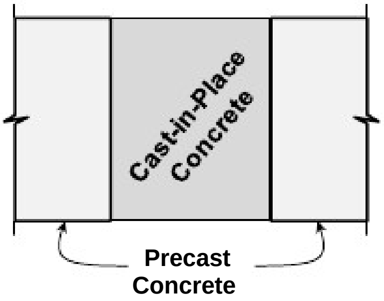
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

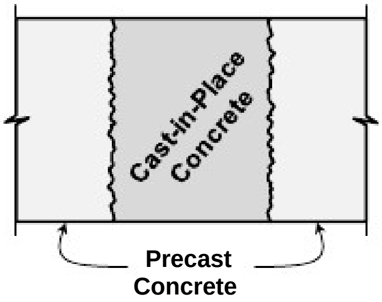
☒ Shear key: 100 % ☐ Saw teeth: ________% ☐ Plain: ________%







☐ Sandblasting or intentional roughening: ________%

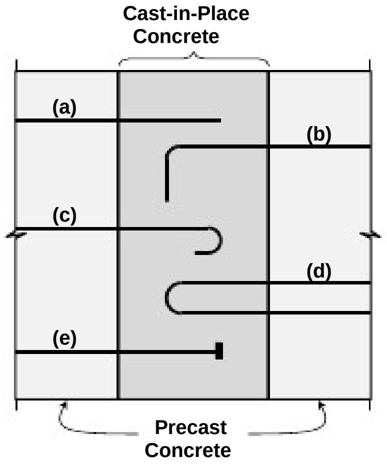


Please explain the factors that affect the type of interface that is chosen.

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☐ (a) Straight bars ☐ (b) 90-degree hooks ☒ (c) 180-degree hooks ☒ (d) Hairpins

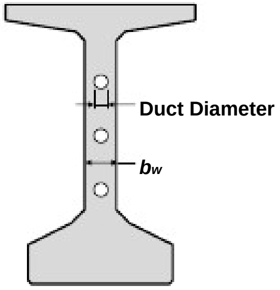
☐ (e) Headed bars ☐ Other; please describe: ______________________



Please elaborate on the detailing of the interface reinforcement if necessary.

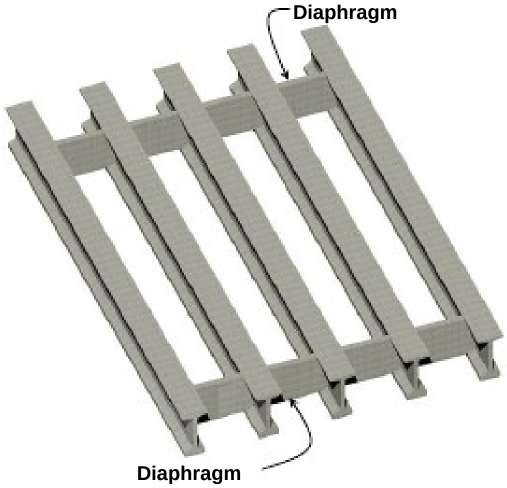
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
8" (+/-)	4" (Steel)	%
7"	2 3/8" x 5"(PE) (Oval)	%
8 1/2"	4" (PP)	%
9"	4" (PP)	%
		%



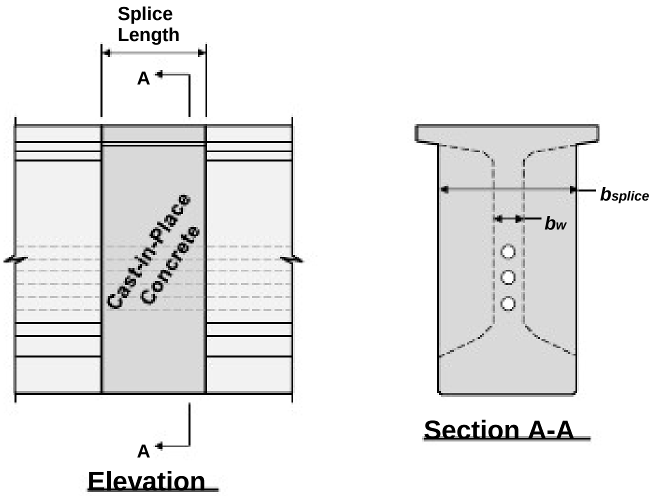
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☒ At the splice ☐ Away from the splice ☐ No preference



14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	**Minimum**	**Maximum**	**Typical**
Length	18" (+/-)	20" (+/-)	N/A
$b_{splice} - b_w$			



Please explain the factors that affect the **length** of the splice region?

Length to make duct connections

Reinforcing details

Please explain the factors that affect the **width** of the splice region?

Typically, diaphragms are used in the splice locations. Width of splice region is the same as the length of the diaphragm.

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

We have had only one instance when the drop in segment "walked off" the supports. This has been addressed in the SDG Detailing Manual Chapter 23.

(http://www.dot.state.fl.us/Structures/StructuresManual/CurrentRelease/Vol2_SDM.pdf)

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

-New Chapter in the Structures Manual for Spliced Girder Construction (see Chapter 23 in the Detailing Manual)

-Developed policy for sizing webs for spliced girders. See Table 4.5.6 of the Structures Design Guidelines in the Structures Manual. (http://www.dot.state.fl.us/Structures/StructuresManual/CurrentRelease/Vol1_SDG.pdf)

-Developed maximum duct dimensions to be used for detailing. See Table 4.5.12-1 of the Structures Design Guidelines in the Structures Manual.

-Curved U-Girder bridges are currently under design for expressway authorities.

A new design bulletin which outlines our policies for spliced curved U-beams will be issued by the end of May, 2013.

For a list of spliced I-girder bridges constructed in Florida prior to 2004, see NCHRP, Report 517, Appendix C2.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here:

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

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Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

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Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

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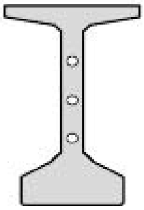
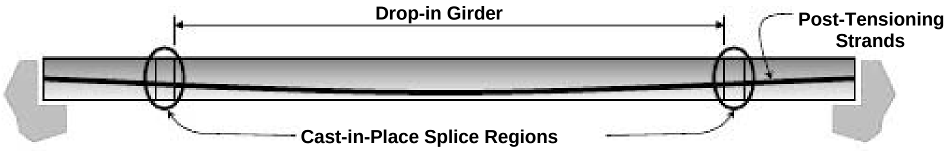
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





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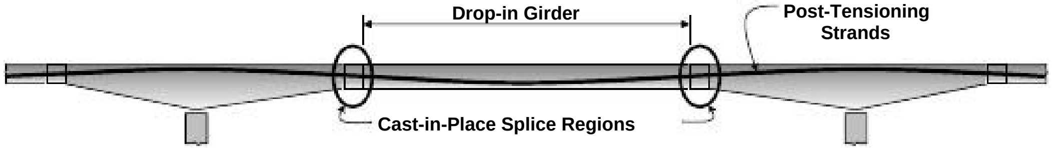

Multi-Span Continuous

Texas Department of Transportation Contact:
Greg Turco, PE

Address:
Bridge Division
125 East 11th St.
Austin, TX 78701

Phone: 512-416-2580
Email: Greg.Turco@txdot.gov

The University of Texas Research Team:
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Dr. James Jirsa: jirsa@uts.cc.utexas.edu
Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu
Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
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The University of Texas at Austin
10100 Burnet Rd., Building 177
Austin TX, 78758

Contact Information

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Title: Assistant Director of Engineering

State/District: Georgia

Organization/Unit: Georgia Department of Transportation

Address: 600 West Peachtree Street, 24th Floor
Atlanta, GA 30308

Phone: (404) 631-1882

Fax: (404) 631-1954

Email: (404) 631-1954

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ■ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

■ Yes ☐ No

If *Yes,* please list the consultant(s).

Parsons Brinkerhoff

The LPA Group

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 50 %
- Plastic (HDPE): 50 %

If one of the materials is preferred over the other, please explain why.

HDPE is less prone to corrosion and it is felt that the HDPE ducts can be sealed better.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

■ Yes ☐ No

If *Yes,* please briefly describe the problem(s).

We had leakage in the ducts for our metal duct spliced girder bridge.

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☐ Yes ☒ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☐ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

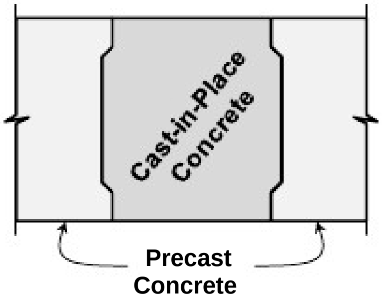
☐ Other; please specify: ______________________________________

9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

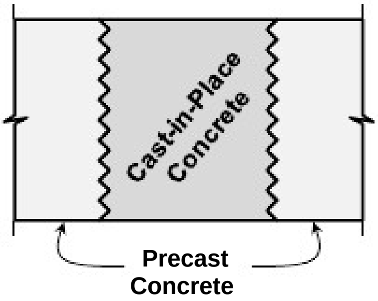
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

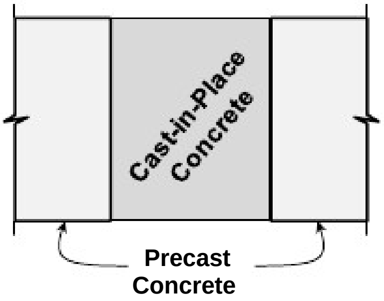
☒ Shear key: 100 %



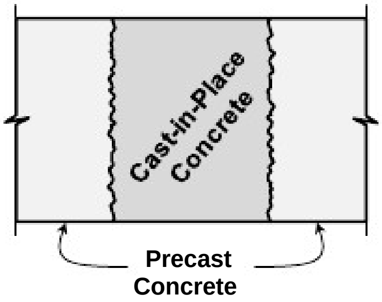
☐ Saw teeth: _______%



☐ Plain: _______%



☐ Sandblasting or intentional roughening: _______%



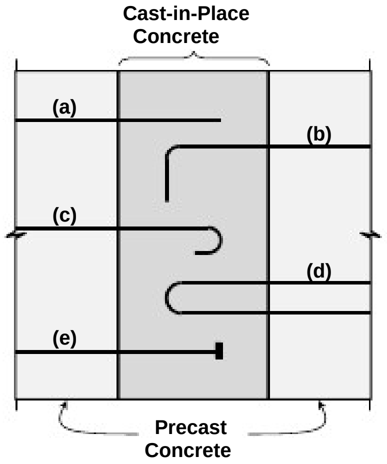
Please explain the factors that affect the type of interface that is chosen.

Shear keys are usually required in the design specs. The shape of the shear keys is usually the Designer's decision

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☐ (a) Straight bars ☒ (b) 90-degree hooks ☒ (c) 180-degree hooks ☒ (d) Hairpins

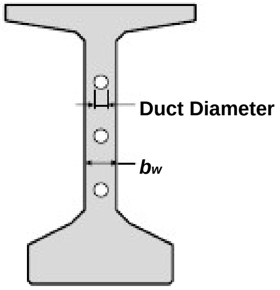
☐ (e) Headed bars ☒ Other; please describe: No reinforcement, uses a stepped joint



Please elaborate on the detailing of the interface reinforcement if necessary.

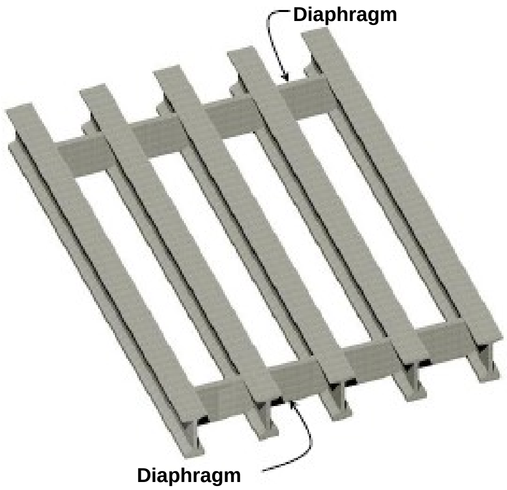
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
9"	3.82"	50 %
12"	2" duct pairs	50 %
		%
		%
		%



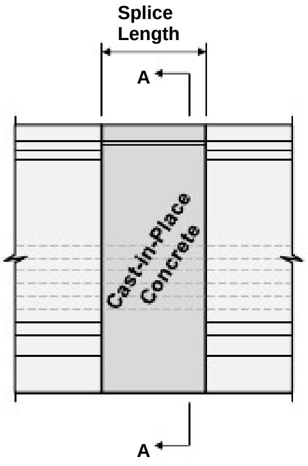
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☐ At the splice ☒ Away from the splice ☐ No preference

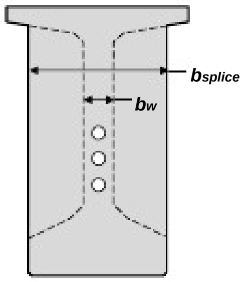


14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	Minimum	Maximum	Typical
Length	Br 1 - 4", Br 2 - 2'-0"	Br 1 - 6", Br 2 - 2'-6"	Br 1 - 4", Br 2 - 2'-0"
$b_{splice} - b_w$	Br 1 - 1'-2", Br 2 - 0"	Br 1 - 1'-2", Br 2 - 0"	Br 1 - 1'-2", Br 2 - 0"



Elevation



Section A-A

Please explain the factors that affect the **length** of the splice region?

The shape of the splice- See our two examples

Please explain the factors that affect the **width** of the splice region?

The width of the I-beam that is being spliced and weather there are any built-up areas in the vicinity of the splice.

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☒ Yes ☐ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

Leakage of the metal ducts.

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

We have two spliced I-girder bridges. The Talmadge Memorial Bridge approaches built in the early 1990's and the Skidaway Narrows Bridge that is being constructed now. Both are in Savannah, Georgia. This a viable structural design method but it usually difficult to construct in the field. Plans are being sent under another e-mail.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here: ____________

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

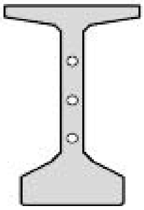
The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

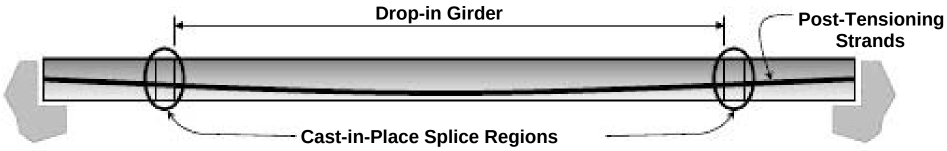
Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

Please return this survey **by April 30** to:

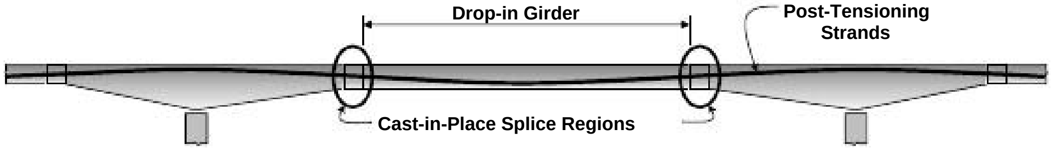
Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:	**The University of Texas Research Team:**
Greg Turco, PE **Address:** Bridge Division 125 East 11th St. Austin, TX 78701 **Phone:** 512-416-2580 **Email:** Greg.Turco@txdot.gov	Dr. Oguzhan Bayrak: bayrak@mail.utexas.edu Dr. James Jirsa: jirsa@uts.cc.utexas.edu Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu Chris Williams: chrisw05@utexas.edu Andy Moore: ammoore@utexas.edu **Address:** Ferguson Structural Engineering Laboratory The University of Texas at Austin 10100 Burnet Rd., Building 177 Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Paul Santo

Title: Bridge Design Engineer

State/District: Hawaii

Organization/Unit: Hawaii DOT, Bridge Design Section

Address: 601 Kamokila Blvd., Rm. 611
Kapolei, HI 96707

Phone: 808-692-7611

Fax: 808-692-7617

Email: paul.santo@hawaii.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ☒ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☒ Yes ☐ No

If *Yes,* please list the consultant(s).
KSF, Inc.

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 100 %
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☒ No

If *Yes,* please briefly describe the problem(s).

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☐ Yes ☒ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☒ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

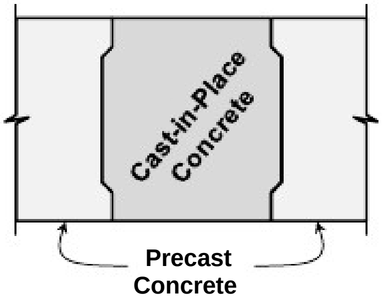
☐ Other; please specify: ______________________________

9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

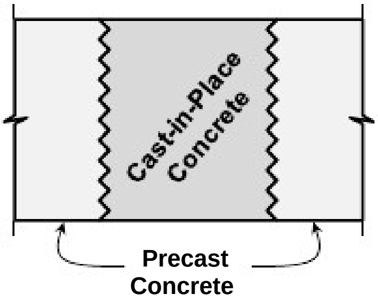
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

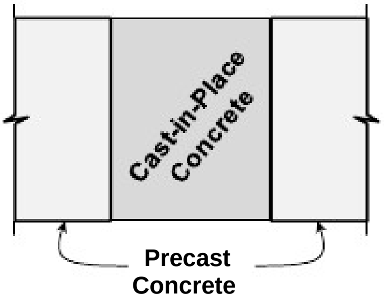
☐ Shear key: ________%



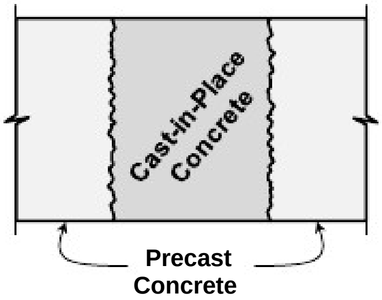
☒ Saw teeth: 100 %



☐ Plain: ________%



☐ Sandblasting or intentional roughening: ________%



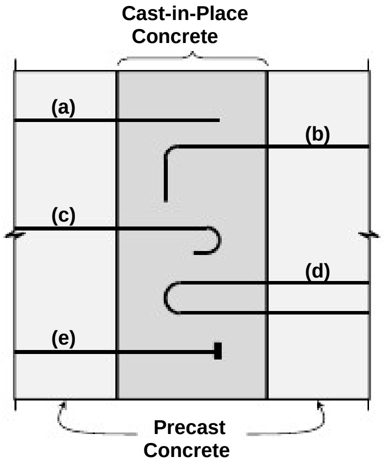
Please explain the factors that affect the type of interface that is chosen.

Complied with WSDOT Standard Details for projects that contained WSDOT Girders.

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☒ (a) Straight bars ☐ (b) 90-degree hooks ☐ (c) 180-degree hooks ☐ (d) Hairpins

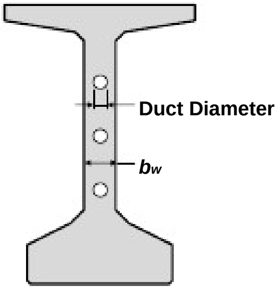
☐ (e) Headed bars ☐ Other; please describe: ______________________________



Please elaborate on the detailing of the interface reinforcement if necessary.

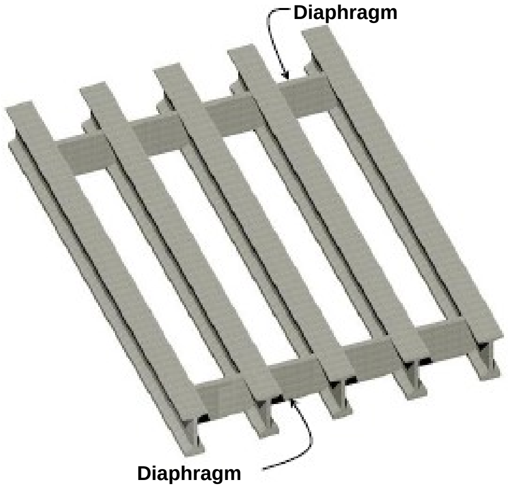
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
8 1/2"	4 5/8"	33 %
7 7/8"	4 3/8"	33 %
14"	4 3/8"	33 %
		%
		%



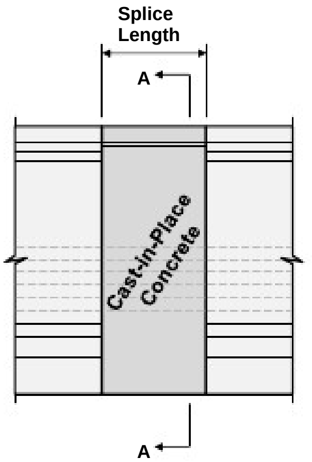
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☒ At the splice ☐ Away from the splice ☐ No preference

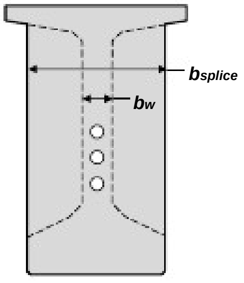


14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	**Minimum**	**Maximum**	**Typical**
Length	2 ft	3 ft	2 ft
$b_{splice} - b_w$			



Elevation



Section A-A

Please explain the factors that affect the **length** of the splice region?

1) Complied with WSDOT Standard Details for projects that contained WSDOT Girders.

2) Constructability

Please explain the factors that affect the **width** of the splice region?

1) Complied with WSDOT Standard Details for projects that contained WSDOT Girders.

2) Constructability

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

We have only had three bridges utilizing spliced girders. Two were I- girders but one of them was a varying section (arched shape) rectangular section.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here: ____________________

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

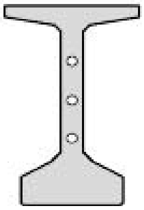
Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

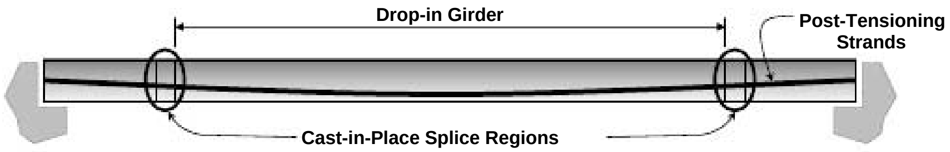
The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

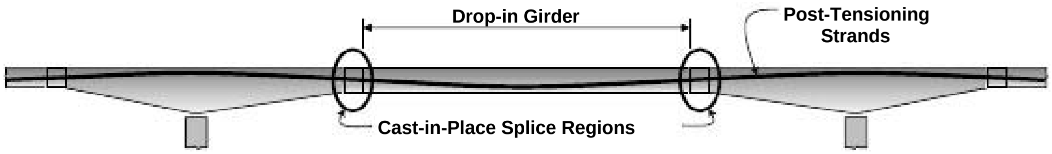
Please return this survey **by April 30** to:	Greg Turco, TxDOT Bridge Division Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
Greg Turco, PE

Address:
Bridge Division
125 East 11th St.
Austin, TX 78701

Phone: 512-416-2580
Email: Greg.Turco@txdot.gov

The University of Texas Research Team:
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Dr. James Jirsa: jirsa@uts.cc.utexas.edu
Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu
Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
Ferguson Structural Engineering Laboratory
The University of Texas at Austin
10100 Burnet Rd., Building 177
Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Carl Puzey

Title: Acting Engineer of Bridges and Structures

State/District: Illinois

Organization/Unit: Bureau of Bridges and Structures

Address: Illinois Department of Transportation
2300 S. Dirksen Parkway, Springfield, IL 62764

Phone: 217-782-2124

Fax: 217-782-7540

Email: Carl.Puzey@illinois.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☒ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

We have not given serious consideration to the use of spliced girders.

We have not used spliced girder technology and do not intend to, until such time the technology and practices are more widely accepted. I believe the Illinois Toll Highway Authority has used this technology, but they would have to be contacted separately.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

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Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

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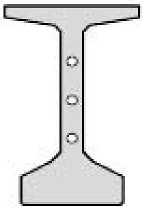
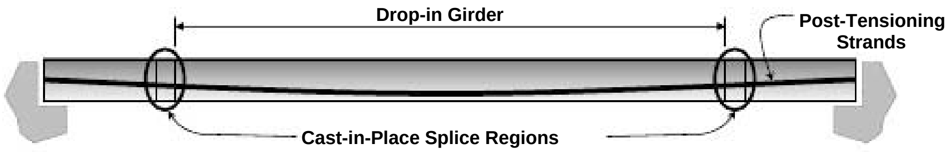
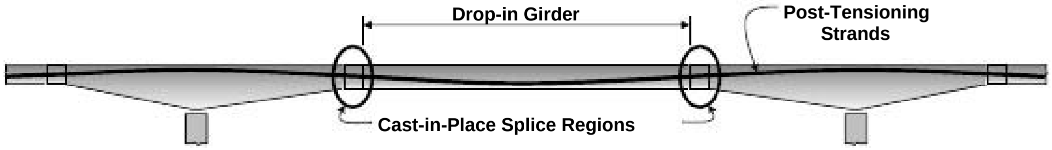
TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:	**The University of Texas Research Team:**
Greg Turco, PE **Address:** Bridge Division 125 East 11th St. Austin, TX 78701 **Phone:** 512-416-2580 **Email:** Greg.Turco@txdot.gov	Dr. Oguzhan Bayrak: bayrak@mail.utexas.edu Dr. James Jirsa: jirsa@uts.cc.utexas.edu Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu Chris Williams: chrisw05@utexas.edu Andy Moore: ammoore@utexas.edu **Address:** Ferguson Structural Engineering Laboratory The University of Texas at Austin 10100 Burnet Rd., Building 177 Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Ahmad Abu-Hawash

Title: Chief Structural Engineer

State/District: Iowa

Organization/Unit: Iowa Department of Transportation - Office of Bridges and Structures

Address: 800 Lincoln Way, Ames, Iowa 50010

Phone: 515-239-1393

Fax: 515-239-1978

Email: ahmad.abu-hawash@dot.iowa.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☒ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

The need for temporary supports makes this technology less attractive when compared to traditional welded steel plate girder system with bolted field splices.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

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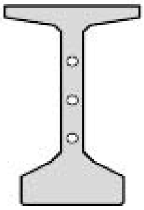
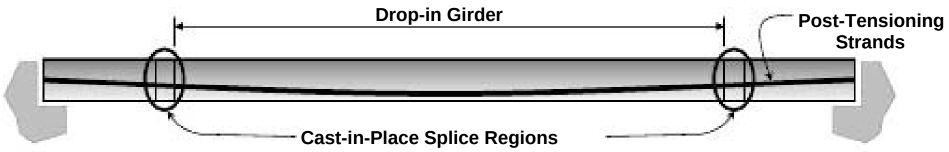
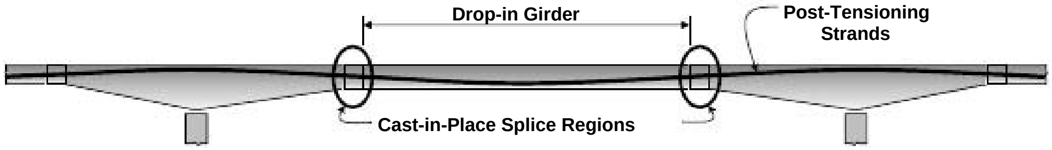
Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
Greg Turco, PE

Address:
Bridge Division
125 East 11th St.
Austin, TX 78701

Phone: 512-416-2580
Email: Greg.Turco@txdot.gov

The University of Texas Research Team:
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Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
Ferguson Structural Engineering Laboratory
The University of Texas at Austin
10100 Burnet Rd., Building 177
Austin TX, 78758

Contact Information

Name of Person Completing the Survey: John Patrick Jones

Title: Bridge Design Manual and Policy Engineer

State/District: Kansas

Organization/Unit: Design

Address: 700 SW Harrison

Phone: 785-368-7175

Fax:

Email: jjones@ksdot.org

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☒ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

■ Yes ☐ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

■ Yes ☐ No

If *Yes,* please list the consultant(s).

____

____

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: ________%
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

____

____

____

____

____

____

____

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ■ No

If *Yes,* please briefly describe the problem(s).

____

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____

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☐ Yes ☒ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☐ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

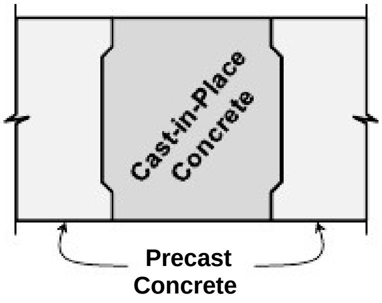
☐ Other; please specify: ____

9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

☐ Shear key: ________%



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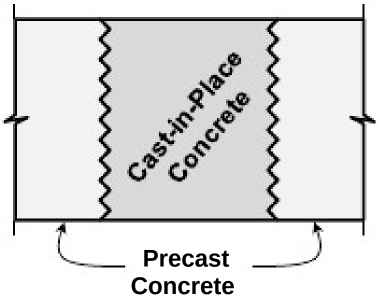

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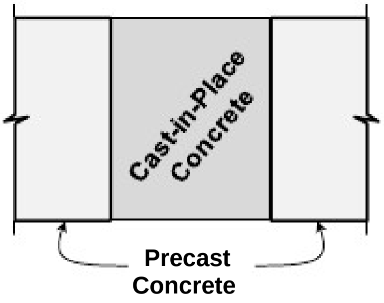
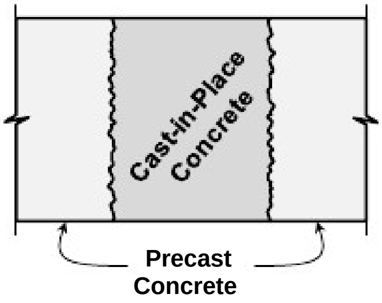


☐ Sandblasting or intentional roughening: ________%

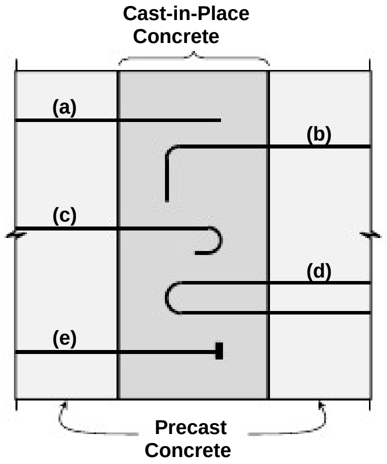


Please explain the factors that affect the type of interface that is chosen.

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☐ (a) Straight bars ☒ (b) 90-degree hooks ☐ (c) 180-degree hooks ☐ (d) Hairpins

☐ (e) Headed bars ☐ Other; please describe: ______________________



Please elaborate on the detailing of the interface reinforcement if necessary.

____

____

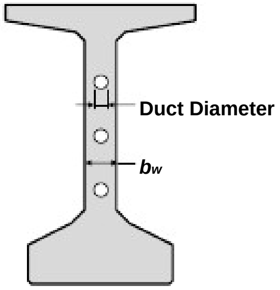
____

____

____

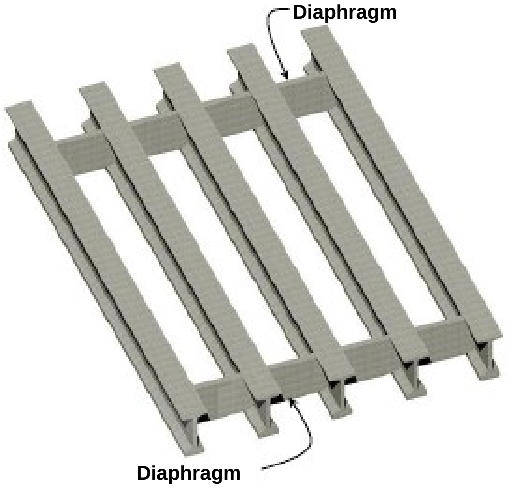
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
		%
		%
		%
		%
		%



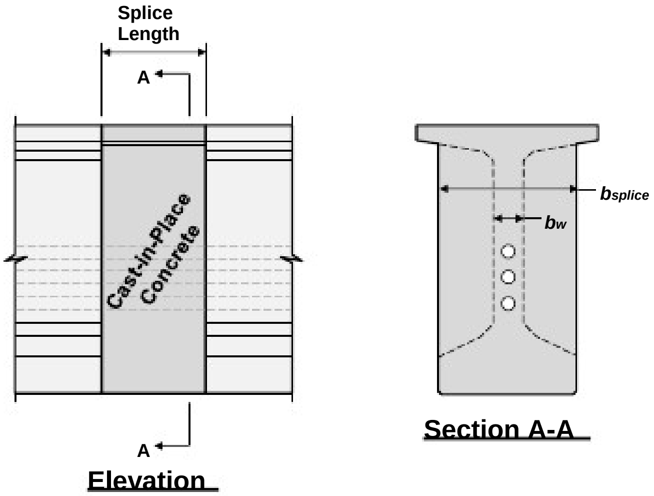
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☐ At the splice ☐ Away from the splice ■ No preference



14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	**Minimum**	**Maximum**	**Typical**
Length			
$b_{splice} - b_w$			



Please explain the factors that affect the **length** of the splice region?

Please explain the factors that affect the **width** of the splice region?

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here: ____________________

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

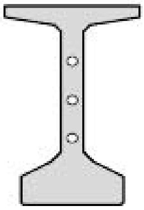
Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

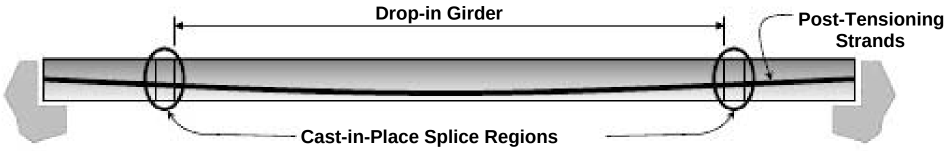
The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

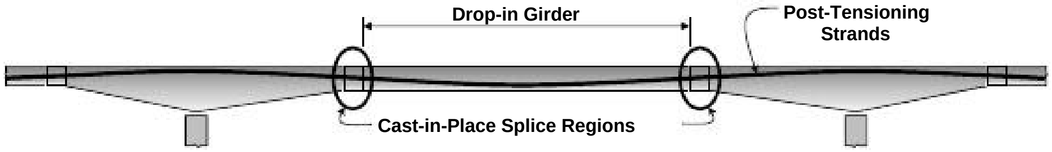
Please return this survey **by April 30** to: Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

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Contact Information

Name of Person Completing the Survey: Jeffrey Robert

Title: Senior Project Manager

State/District: Maryland

Organization/Unit: Maryland State Highway Administration / Office of Structures

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Phone: 410-545-8327

Fax: 410-209-5002

Email: jrobert@sha.state.md.us

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☒ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

We are not comfortable with this technology. For large spans that would require splicing of concrete girders, we would use steel girders.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

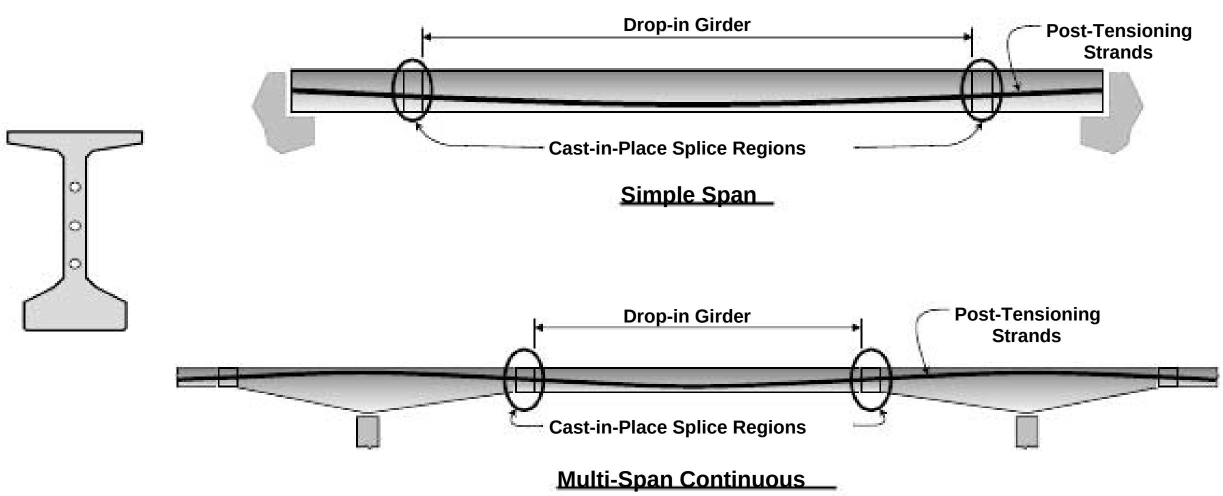
Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

Please return this survey **by April 30** to: Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS



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Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
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Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Maura Sullivan

Title: Project Manager - Structural Engineer

State/District: MA

Organization/Unit: MassDOT / Highway Division / Bridge Section

Address: 10 Park Plaza, Room 6430
Boston, MA 02116

Phone: 857-368-9283

Fax:

Email: Maura.Sullivan@dot.state.ma.us

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

   ☒ Yes ☐ No

   If *No,* has your state/district considered the use of spliced girder technology?

   ☐ Yes ☐ No

   If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

   If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

   ☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

   ☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☒ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☒ Yes ☐ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☒ Yes ☐ No

If *Yes,* please list the consultant(s).

AECOM (previous name Earth Tech)

Jacobs Engineering (previous name Edwards & Kelcey)

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 100 %
- Plastic (HDPE): 0 %

If one of the materials is preferred over the other, please explain why.

Steel is considered standard, therefor preferred by MassDOT.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☒ No

If *Yes,* please briefly describe the problem(s).

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☐ Yes ☒ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☐ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

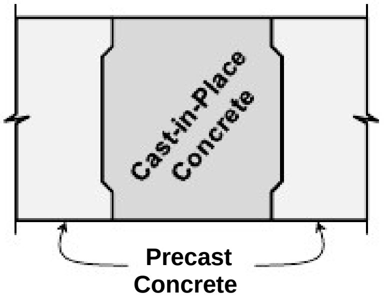
☐ Other; please specify: ____________________

9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

☒ Shear key: 100 %



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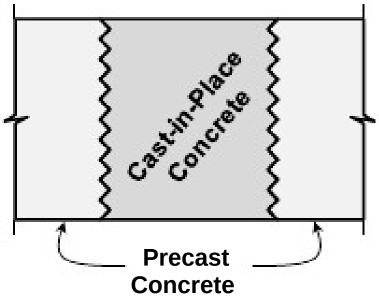

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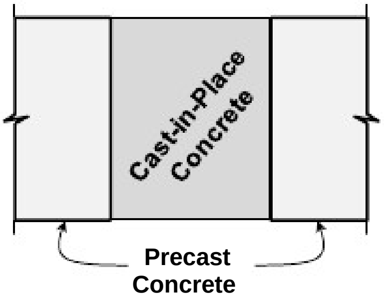
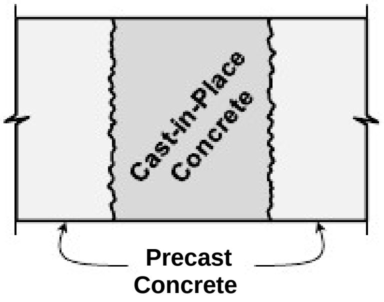


☐ Sandblasting or intentional roughening: ________%



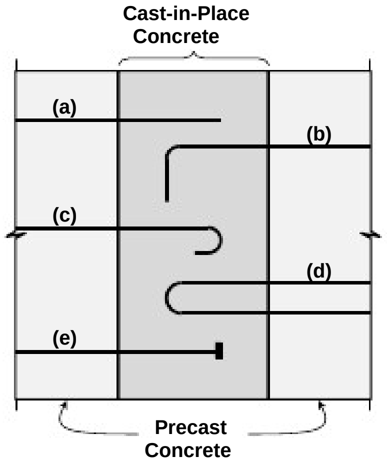
Please explain the factors that affect the type of interface that is chosen.

Interface: 3 - 4" x 10" recessed keys @ 2" deep (1 in web, 2 in bulb)

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☐ (a) Straight bars ☐ (b) 90-degree hooks ☐ (c) 180-degree hooks ☒ (d) Hairpins

☐ (e) Headed bars ☐ Other; please describe: ____________________



Please elaborate on the detailing of the interface reinforcement if necessary.

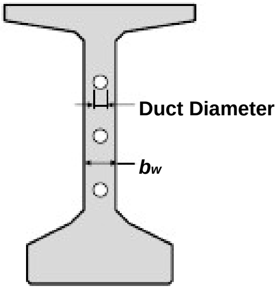
Splice with Transverse Diaphragms at the Splice location.

Interior Splice: #4 (d) Typ. with 4 - #4 @ 6'-0" Long Centered on Girder

Exterior Splice: #4 (d) Typ. with 1 - #4 @ 5'-0" Long at Top Frame and 3 - #4 (c) at Webs and Bulb

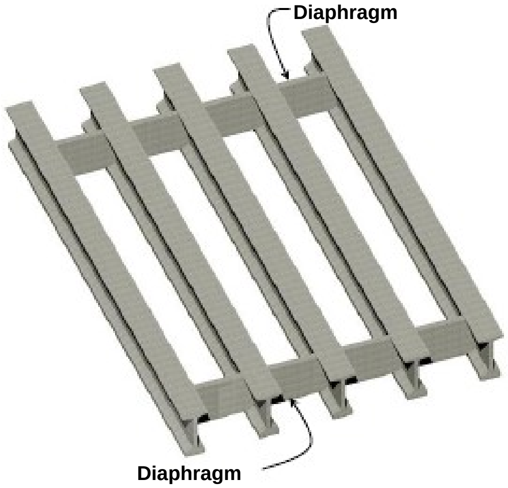
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
7"	3"	100 %
		%
		%
		%
		%



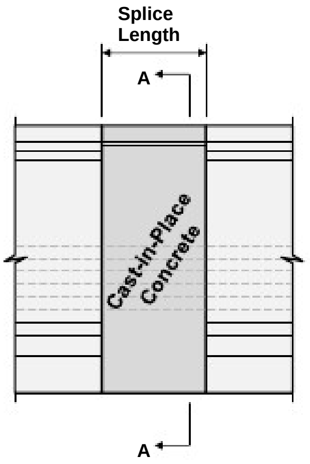
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☒ At the splice ☐ Away from the splice ☐ No preference

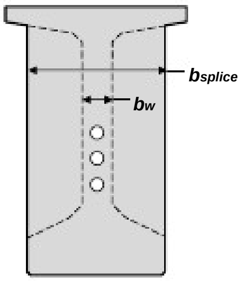


14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	Minimum	Maximum	Typical
Length	12"	14"	12"
b_{splice} - b_w	-	-	-



Elevation



Section A-A

Please explain the factors that affect the **length** of the splice region?

PCI guidelines on spliced girders recommended a splice length of 250mm, therefor 12" was used.

Please explain the factors that affect the **width** of the splice region?

N/A

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☒ Yes ☐ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

We were made aware of issues in the splice region during construction including misalignment and damage to ducts. A repair procedure for the duct was developed by inserting a smaller duct inside the existing duct. A mock up was created and splices were implemented in field.

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

See relevant drawing sheets which have been uploaded to your FTP site.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here: __________

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

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Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

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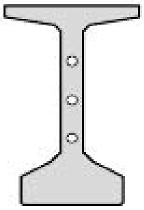
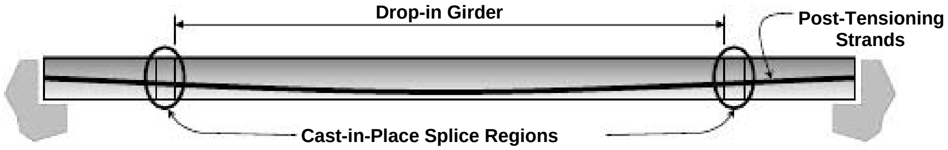
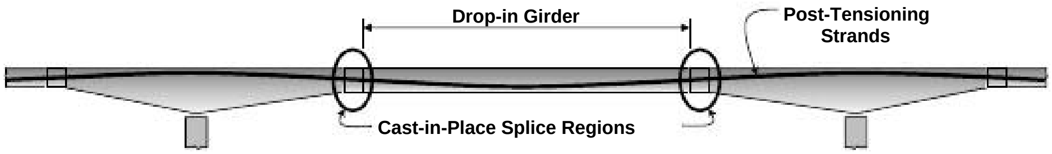
TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

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Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

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Contact Information

Name of Person Completing the Survey: Matt Chynoweth

Title: Engineer of Bridge Field Services

State/District: Michigan DOT/Central Office

Organization/Unit: Bureau of Field Services

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Lansing, MI 48917

Phone: 517-243-4302

Fax:

Email: chynowethm@michigan.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

   ☐ Yes ☒ No

   If *No,* has your state/district considered the use of spliced girder technology?

   ☒ Yes ☐ No

   If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

   We are considering it, however, we are still looking for the right location and application.
   MDOT would be very interested in the research results.

   If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

   ☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

   ☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

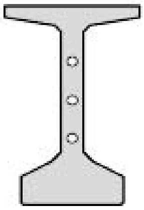
The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

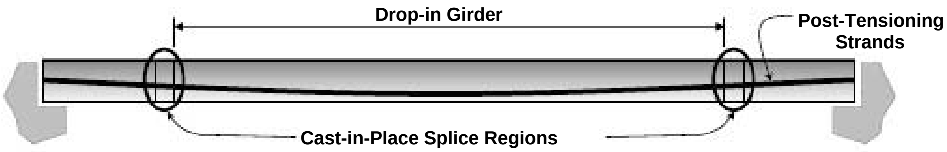
Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

Please return this survey **by April 30** to:

Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





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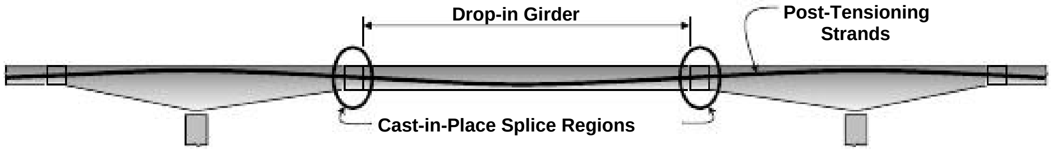

Multi-Span Continuous

Texas Department of Transportation Contact:
Greg Turco, PE

Address:
Bridge Division
125 East 11th St.
Austin, TX 78701

Phone: 512-416-2580
Email: Greg.Turco@txdot.gov

The University of Texas Research Team:
Dr. Oguzhan Bayrak: bayrak@mail.utexas.edu
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Contact Information

Name of Person Completing the Survey: Dave Dahlberg

Title: Bridge Design Manual & Policy Engineer

State/District: Minnesota

Organization/Unit: MnDOT - Bridge Office

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Oakdale, MN 55128-3307

Phone: 651-366-4491

Fax: 651-366-4509

Email: dave.dahlberg@state.mn.us

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

MnDOT has constructed 2 spliced prestressed girder bridges back in 1993. No other spliced girder bridges been
completed since that time, so only Part A of this survey has been completed as our experience on this is not current.
I will, however, provide pertinent sheets from the bridge plans (see attached file: br 70037 and 70038.pdf)

MnDOT does consider spliced girders as an option for new bridges.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ☒ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☒ Yes ☐ No

If *Yes,* please list the consultant(s).

SRF Consulting Group, Inc

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: ________%
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☐ No

If *Yes,* please briefly describe the problem(s).

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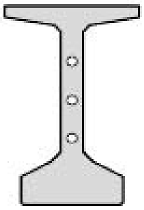

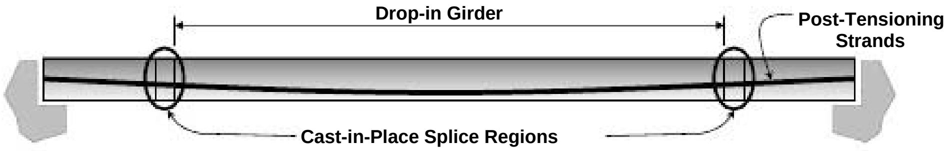

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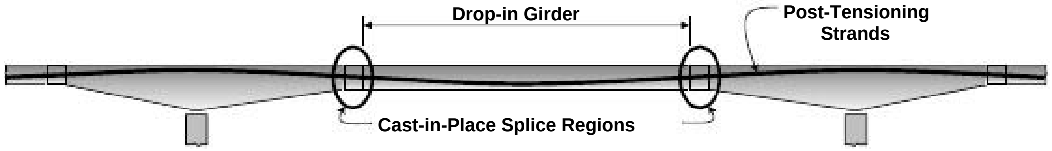

Multi-Span Continuous

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Phone: 512-416-2580
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Dr. James Jirsa: jirsa@uts.cc.utexas.edu
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Andy Moore: ammoore@utexas.edu

Address:
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Contact Information

Name of Person Completing the Survey: Suresh Patel

Title: Sr. Structural Engineer

State/District: Missouri

Organization/Unit: MoDOT (Bridge Division)

Address: P. O. Box 270
Jefferson City, MO 65101

Phone: 573-526-3030

Fax: 573-526-5488

Email: Suresh.Patel@modot.mo.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☒ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

Spliced girder technology was used on one, maybe two bridges in the past. However, that was was over 20 years ago, and we don't have technical expertise in this area to fill out the rest of the survey.

If spliced girder technology is reliable and cost effective then MoDOT may consider for long span bridges.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

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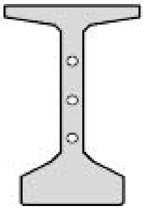

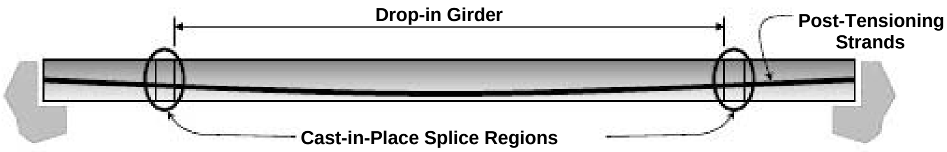

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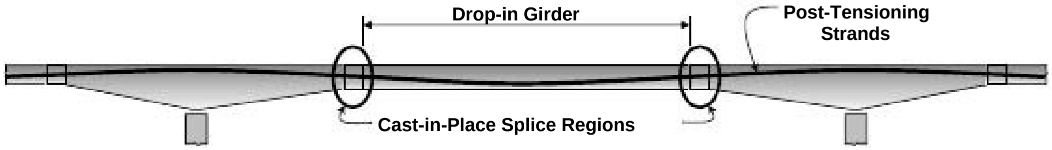

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Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

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Contact Information

Name of Person Completing the Survey: Kent Barnes

Title: Bridge Engineer

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Helena, MT 59620

Phone: 406.444.6260

Fax: 406.444.6155

Email: kbarnes@mt.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☒ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

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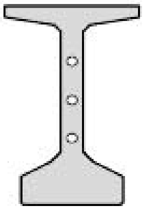

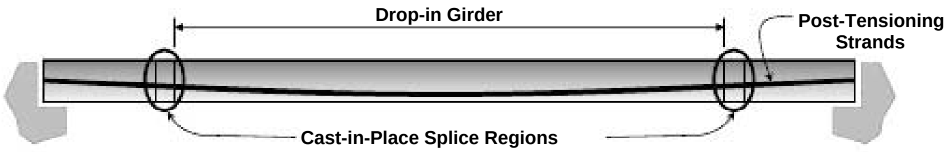

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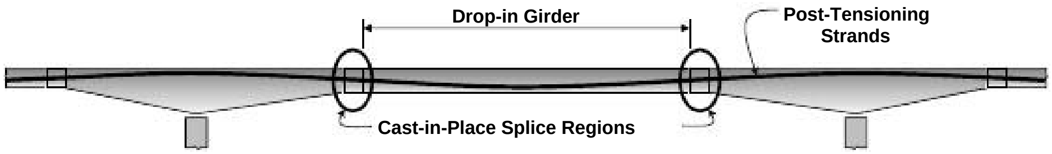

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Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
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The University of Texas at Austin
10100 Burnet Rd., Building 177
Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Mark Elicegui

Title: Chief Structures Engineer

State/District: Nevada

Organization/Unit: Department of Transportation

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Carson City, NV 89712

Phone: 775-888-7542

Fax: 775-888-7405

Email: melicegui@dot.state.nv.us

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

Precast girders are not typically cost competitive as no PCI certified precaster is located within the state. Contractor's may be allowed to site-cast the precast boxes and U's for bridge widenings, if the girder geometry is simple (i.e. little or no skew, no curvature). These type of girders were used on several projects from 1995-2000. We have also widened a couple of structures in the past 2-3 years with this method.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☒ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

■ Yes ☐ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

■ Yes ☐ No

If *Yes,* please list the consultant(s).

CH2M Hill, PB

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 100 %
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

Steel has been used for our box girder and u-girder bridges 100% of the time. As noted in Question #2, no spliced I girders have been used in Nevada.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ■ No

If *Yes,* please briefly describe the problem(s).

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☐ Yes ☒ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☐ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

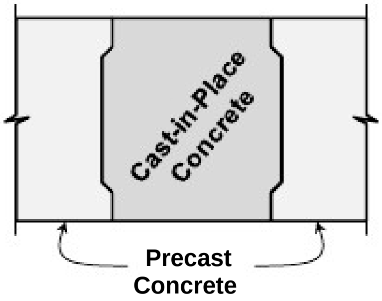
☐ Other; please specify: ____

9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

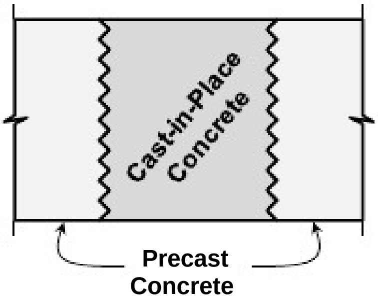
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

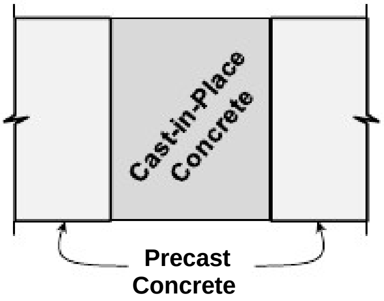
☐ Shear key: ________%



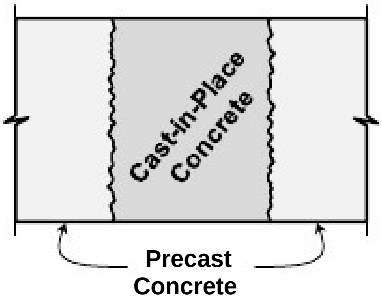
☒ Saw teeth: 100 %



☐ Plain: ________%



☐ Sandblasting or intentional roughening: ________%



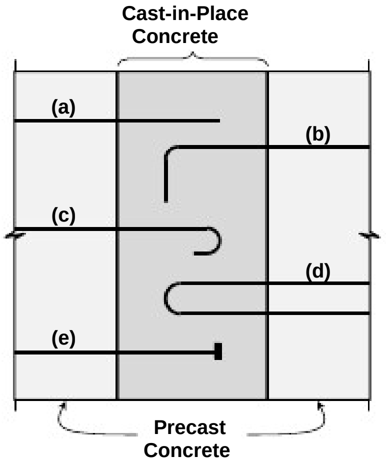
Please explain the factors that affect the type of interface that is chosen.

Saw tooth detail has been standard practice.

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☒ (a) Straight bars ☐ (b) 90-degree hooks ☐ (c) 180-degree hooks ☐ (d) Hairpins

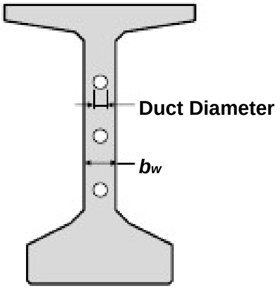
☐ (e) Headed bars ☐ Other; please describe: ____________________



Please elaborate on the detailing of the interface reinforcement if necessary.

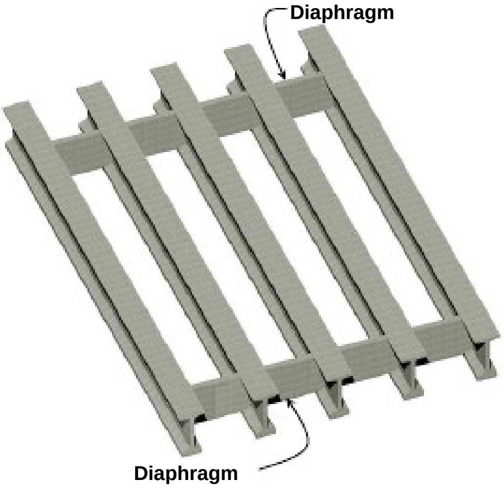
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
		%
		%
		%
		%
		%



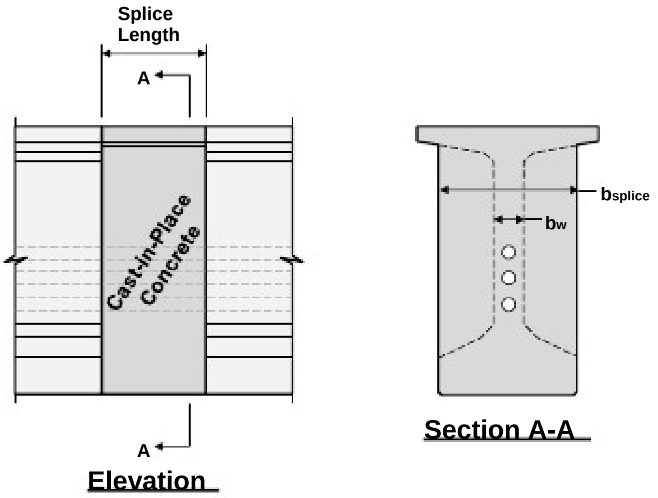
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☐ At the splice ☐ Away from the splice ☐ No preference



14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	**Minimum**	**Maximum**	**Typical**
Length			
$b_{splice} - b_w$			



Please explain the factors that affect the **length** of the splice region?

Typically, it is preferred to match existing pier diaphragm length and width if possible.

Please explain the factors that affect the **width** of the splice region?

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☒ Yes ☐ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

Potential rebar conflicts with vertical steel with columns (particularly hooks) and horizontal steel from girder webs needs to be addressed. A threading detail should be included if necessary.

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here:

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

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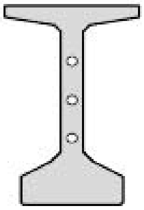

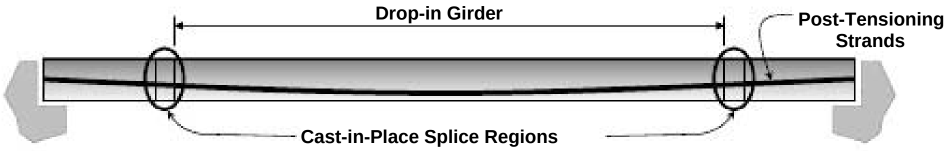

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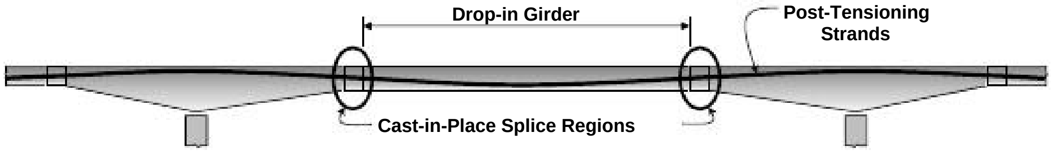

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Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu
Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
Ferguson Structural Engineering Laboratory
The University of Texas at Austin
10100 Burnet Rd., Building 177
Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Michael Twiss

Title:

State/District: New York State Department of Transportation

Organization/Unit: Office of Structures

Address: 50 Wolf Road
Albany, NY 12232

Phone: (518) 457-4534

Fax: (518) 457-6010

Email: mtwiss@dot.state.ny.us

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☒ Yes ☐ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☐ Yes ☒ No

If *Yes,* please list the consultant(s).

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 100 %
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☒ No

If *Yes,* please briefly describe the problem(s).

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☐ Yes ☒ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☐ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

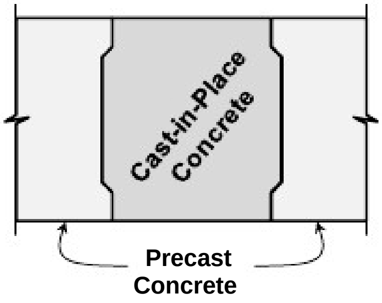
☐ Other; please specify: ____

9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

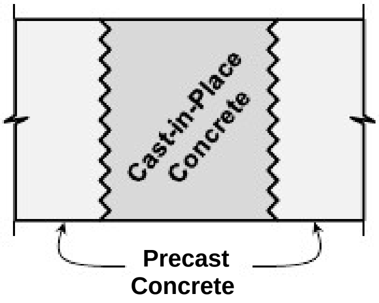
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

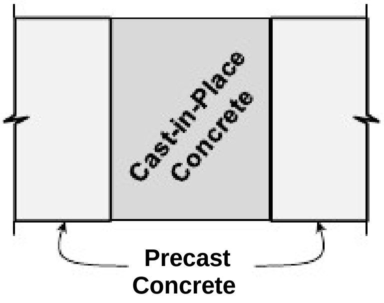
☒ Shear key: 100 %



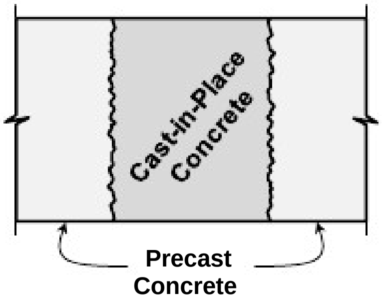
☐ Saw teeth: ________%



☐ Plain: ________%



☐ Sandblasting or intentional roughening: ________%



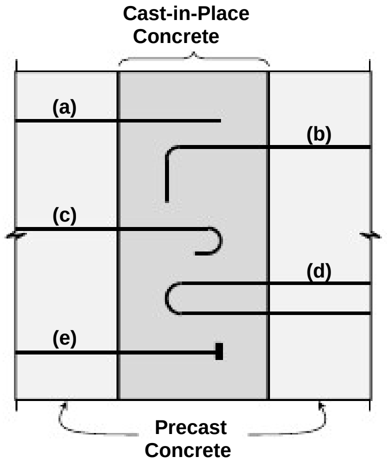
Please explain the factors that affect the type of interface that is chosen.

We believe a shear key provides the best shear transfer mechanism.

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☐ (a) Straight bars ☒ (b) 90-degree hooks ☐ (c) 180-degree hooks ☒ (d) Hairpins

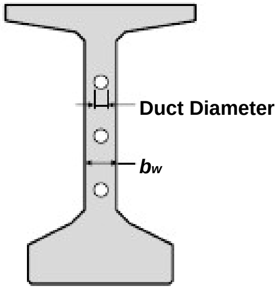
☐ (e) Headed bars ☐ Other; please describe: ____________________



Please elaborate on the detailing of the interface reinforcement if necessary.

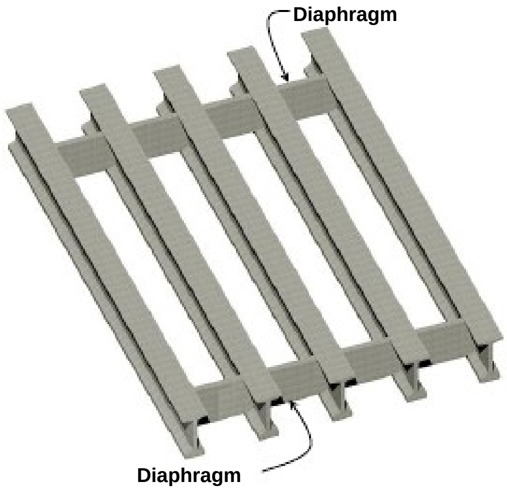
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
8	4	50 %
7	3	50 %
		%
		%
		%



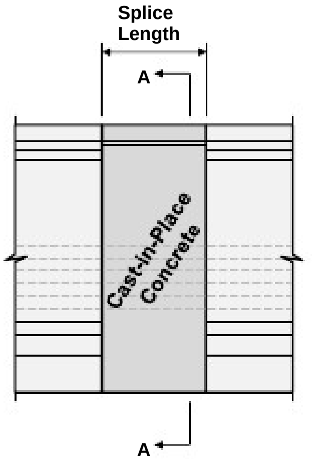
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☒ At the splice ☐ Away from the splice ☐ No preference

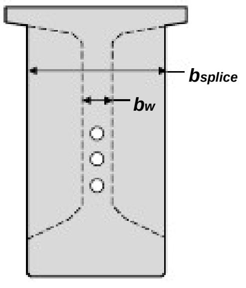


14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	**Minimum**	**Maximum**	**Typical**
Length	10"	None	10"
$b_{splice} - b_w$	-	-	-



Elevation



Section A-A

Please explain the factors that affect the **length** of the splice region?

Need enough room for the concrete to flow around the ducts.

Please explain the factors that affect the **width** of the splice region?

Aesthetics.

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☒ Yes ☐ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

Splice concrete color normally does not match the color of the girder.

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☒ Yes ☐ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

We have had issues with splice concrete not flowing properly resulting in voids and honeycombing. Splices had to be removed and re-poured.

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

Contract plans and shop drawings will be uploaded to the Texas DOT dropbox.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here: None

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

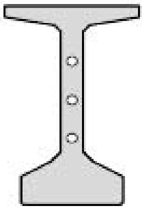
The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

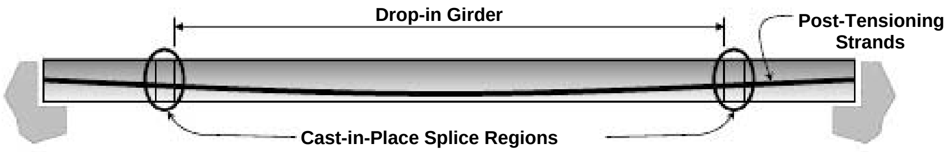
Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

Please return this survey **by April 30** to:

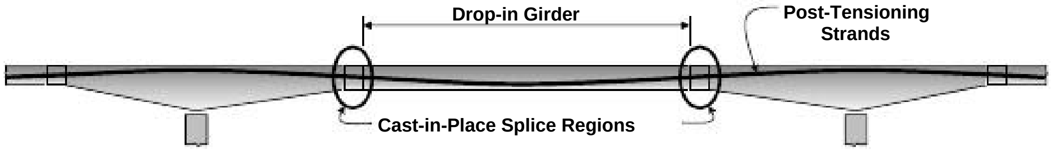
Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
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Phone: 512-416-2580
Email: Greg.Turco@txdot.gov

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Address:
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Contact Information

Name of Person Completing the Survey: Brian Hanks, PE

Title: Project Engineer

State/District: North Carolina

Organization/Unit: NCDOT/Structures Management Unit

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Raleigh, NC 27699

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Fax: (919) 250-4082

Email: bhanks@ncdot.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ☒ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☒ Yes ☐ No

If *Yes,* please list the consultant(s).

Wilbur Smith & Associates (Virginia Dare Bridge); TY Lin (Sunset Beach Bridge); NCDOT (Oak Island Bridge)

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 100 %
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

When comparing plastic ducts to galvanized corrugated metal ducts during the design/plan development stage, NCHRP Report 517 served as a reference. The report noted that metal ducts required less support to prevent misalignment and displacement during the casting of the girder.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☒ No

If *Yes,* please briefly describe the problem(s).

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☐ Yes ☒ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☐ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

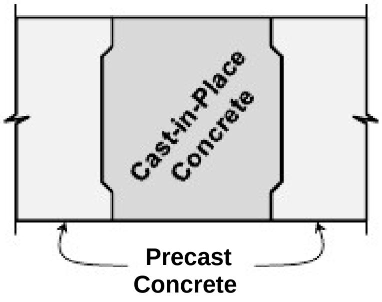
☐ Other; please specify: ____________________

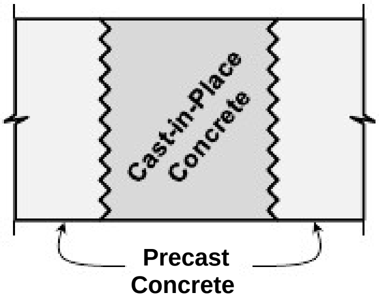
9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

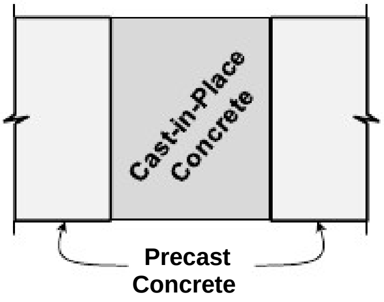
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

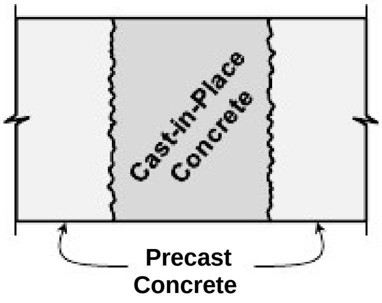
☒ Shear key: 100 % ☐ Saw teeth: ________% ☐ Plain: ________%







☐ Sandblasting or intentional roughening: ________%



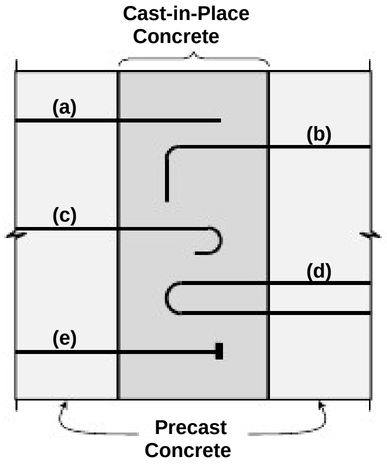
Please explain the factors that affect the type of interface that is chosen.

Simple detail that is easy to fabricate and control during fabrication

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☐ (a) Straight bars ☒ (b) 90-degree hooks ☒ (c) 180-degree hooks ☒ (d) Hairpins

☐ (e) Headed bars ☐ Other; please describe: ______________________

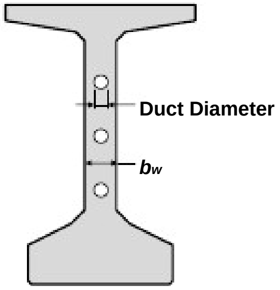


Please elaborate on the detailing of the interface reinforcement if necessary.

90-degree hooks are detailed in the web of the girder; 180-degree hooks are detailed in the top flange of the girder; Hairpins are detailed in the bulb of the girder.

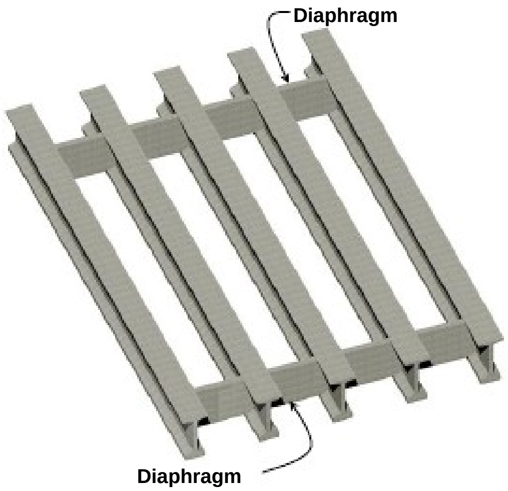
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
9"	3.82"	67 %
8"	3.42"	33 %
		%
		%
		%



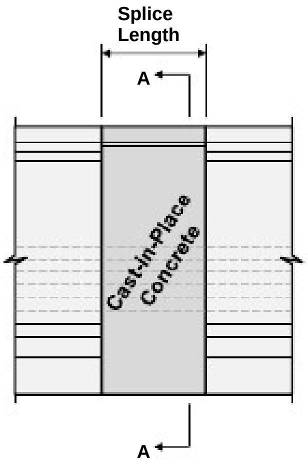
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☒ At the splice ☐ Away from the splice ☐ No preference

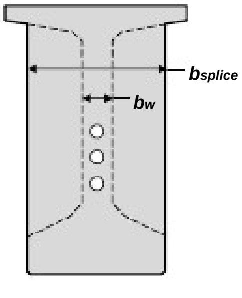


14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	**Minimum**	**Maximum**	**Typical**
Length	2'-0"	Dependent upon skew	2'-0"
$b_{splice} - b_w$			



Elevation



Section A-A

Please explain the factors that affect the **length** of the splice region?

The length should provide an adequate opening for proper placement of cast-in-place concrete.

Please explain the factors that affect the **width** of the splice region?

Transverse diaphragms are generally located at a splice location; therefore, the width is dependent upon the typical section.

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

■ Yes ☐ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

Strongback failure during girder erection. Spliced girder designs and falsework & formwork submittals are reviewed by an independent third party.

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here: ____________________

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

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Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

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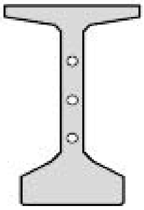
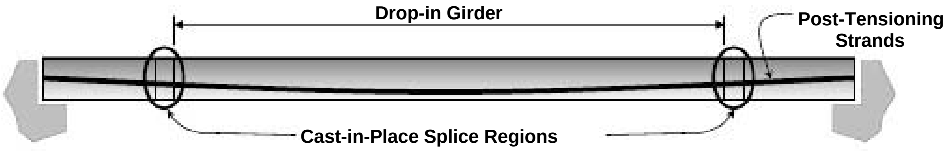
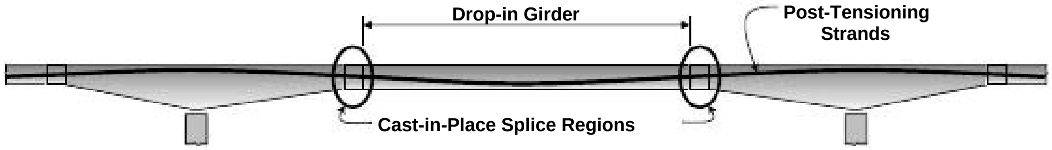
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
Greg Turco, PE

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Phone: 512-416-2580
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Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
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The University of Texas at Austin
10100 Burnet Rd., Building 177
Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Sean Meddles

Title: Assistant Administrator, Office of Structural Engineering

State/District: Ohio

Organization/Unit: Department of Transportation

Address: 1980 West Broad Street
Columbus, Ohio 43223

Phone: 614-466-2464

Fax: 614-752-4824

Email: Sean.Meddles@dot.state.oh.us

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☒ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

There have been 1-2 local projects that have utilized spliced I-beam designs and one contractor value engineering proposal that changed the original design to a spliced I-beam design. This is not a structure type that ODOT prefers due to the lack of ability to inspect the major load carrying component - PT Tendon.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

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4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ☒ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☒ Yes ☐ No

If *Yes,* please list the consultant(s).

Janssens & Spaans Engineering; HNTB

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: ________%
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☐ No

If *Yes,* please briefly describe the problem(s).

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

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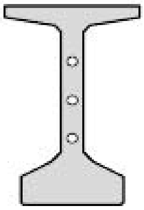
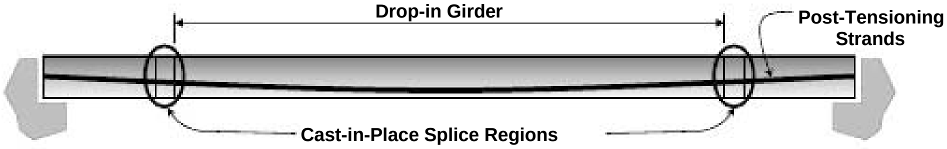
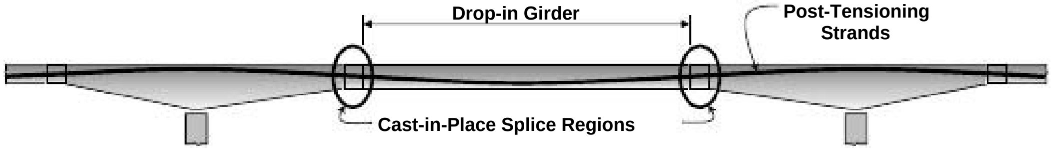
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
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Email: Greg.Turco@txdot.gov

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Andy Moore: ammoore@utexas.edu

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Contact Information

Name of Person Completing the Survey: Thomas P. Macioces, P.E.

Title: Chief Bridge Engineer, Commonwealth of Pennsylvania

State/District: Pennsylvania Department of Transportation

Organization/Unit: Bridge Design and Technology Division

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Harrisburg, PA 17120

Phone: 717-787-2881

Fax: 717-787-2882

Email: tmacioce@pa.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☒ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ☒ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☒ Yes ☐ No

If *Yes,* please list the consultant(s).

Pennsylvania will use a consultant to perform the girder design and a have a second consultant perform a peer review of the design for the first project to utilize spliced girders.

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: n/a %
- Plastic (HDPE): n/a %

If one of the materials is preferred over the other, please explain why.

Pennsylvania permits plastic ducts, if the tendon radius is greater than 30-feet (A5.4.6.1) and require galvanized steel ducts for smaller tendon radius.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☒ No

If *Yes,* please briefly describe the problem(s).

Indicated 'NO' since no project completed in Pennsylvania at this time.

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☒ Yes ☐ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☒ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

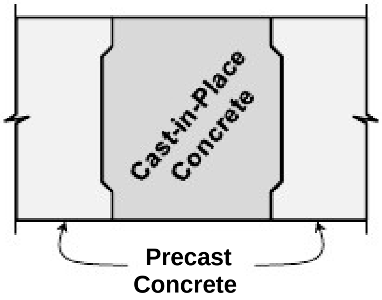
☐ Other; please specify: ______________________________

9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

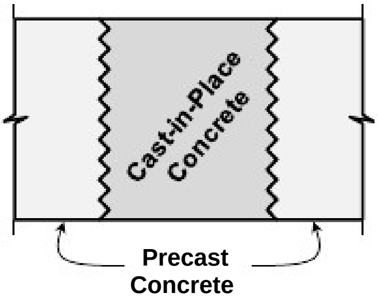
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

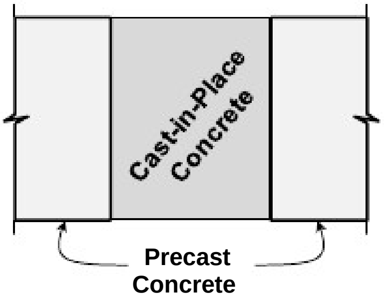
☐ Shear key: ________%



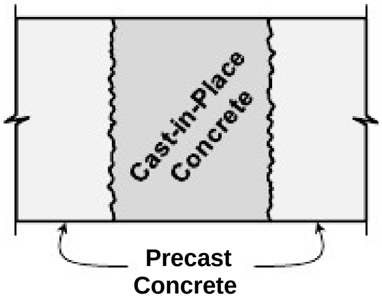
☒ Saw teeth: __n/a__%



☐ Plain: ________%



☐ Sandblasting or intentional roughening: ________%



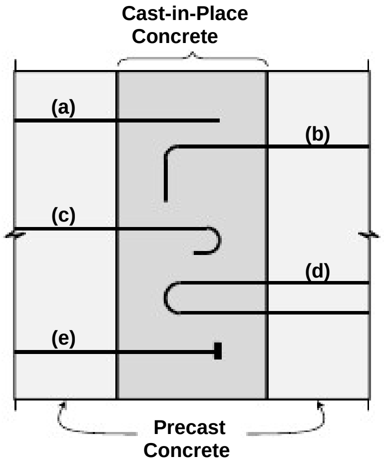
Please explain the factors that affect the type of interface that is chosen.

The saw tooth beam end treatment is specified on the standard drawings developed for spliced girder projects in Pennsylvania.

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☐ (a) Straight bars ☒ (b) 90-degree hooks ☐ (c) 180-degree hooks ☒ (d) Hairpins

☐ (e) Headed bars ☐ Other; please describe: ____________________

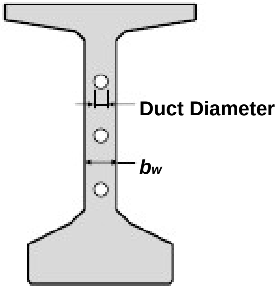


Please elaborate on the detailing of the interface reinforcement if necessary.

The standard drawings for simple span spliced girders utilizes a 90-degree hooked bar (b), that is bent in the field, in the top flange at the CIP splice. All other projecting reinforcement is detailed as hairpin bars (d). All projecting reinforcement for the continuous spliced girderstandards is detailed as hairpin bars (d).

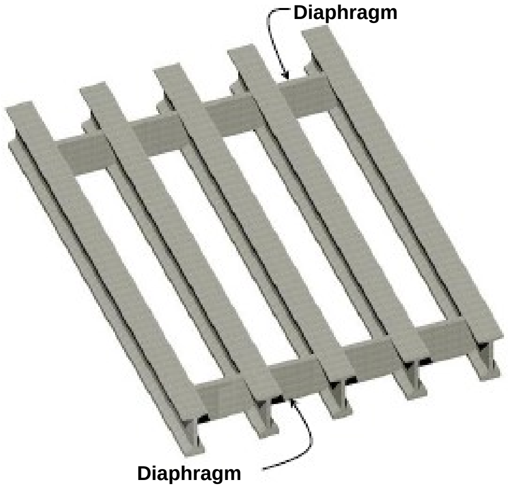
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
8"	3.25"	n/a %
		%
		%
		%
		%



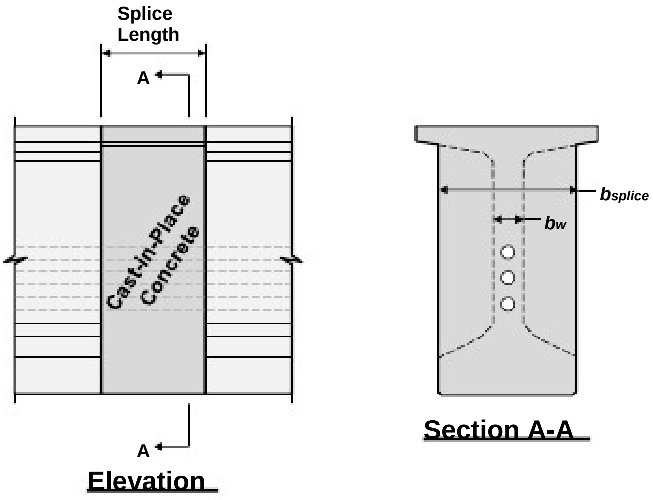
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☐ At the splice ☒ Away from the splice ☐ No preference



14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	**Minimum**	**Maximum**	**Typical**
Length	1'-6"	1'-6"	1'-6"
$b_{splice} - b_w$	0	0	0



Please explain the factors that affect the **length** of the splice region?

An alternate detail for a keyed joint (shear key in question #10 above) indicates 1'-0" minimum at the CIP splice with 3" deep keys on each beam end (i.e. 1'-6" between beam ends within key).

Please explain the factors that affect the **width** of the splice region?

The CIP splice is formed to match the beam dimensions (i.e. CIP web width is 8" to match precast web width). Only the ends of the structure where the post-tensioning anchors are located have increased web widths. For simple span spliced girders, the maximum web width at the anchorage is 2'-0". For continuous spliced girders, the maximum web width at the anchorage is 2'-9" (equal to bottom flange width).

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

Indicated 'NO' since no project completed in Pennsylvania at this time.

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

Indicated 'NO' since no project completed in Pennsylvania at this time.

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here: ftp://ftp.dot.state.pa.us/public/Bureaus/design/bqad/PDFS/newproducts/drawings/NP49.pdf

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

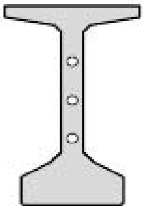
The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

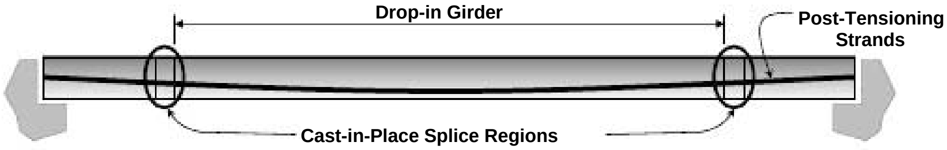
Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

Please return this survey **by April 30** to:

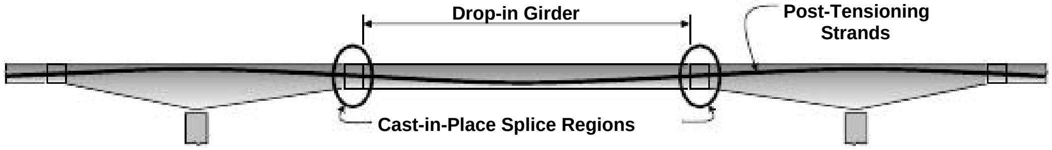
Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
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Dr. James Jirsa: jirsa@uts.cc.utexas.edu
Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu
Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
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The University of Texas at Austin
10100 Burnet Rd., Building 177
Austin TX, 78758

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State/District: South Dakota

Organization/Unit: South Dakota DOT

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Phone: (605)773-3285

Fax: (605)773-2614

Email: kevin.goeden@state.sd.us

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☒ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

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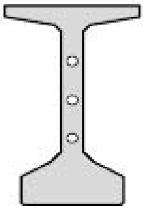
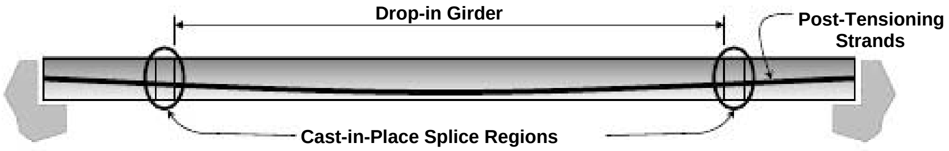
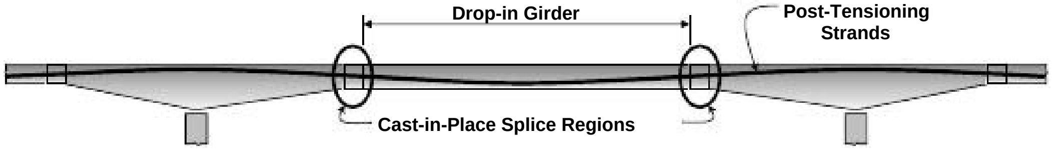
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
Greg Turco, PE

Address:
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Phone: 512-416-2580
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Dr. James Jirsa: jirsa@uts.cc.utexas.edu
Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu
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Address:
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Contact Information

Name of Person Completing the Survey: Wayne Symonds

Title: Structures Design Engineer

State/District: Vermont Agency of Transportation

Organization/Unit: Structures Section

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Phone: 802 828 0503

Fax:

Email: Wayne.Symonds@state.vt.us

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☐ Yes ☒ No

If *No,* has your state/district considered the use of spliced girder technology?

☒ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

Vermont has typically chosen steel as the material for bridge spans where spliced prestressed girders would be applicable. We have recently allowed this as an option on some design/build projects.

We have had a comfort level with steel and just have not tried this approach with traditional projects.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

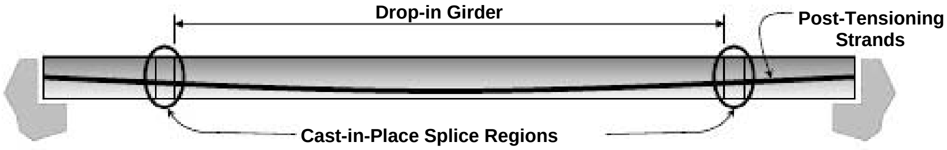
Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

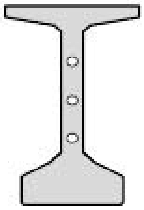
Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

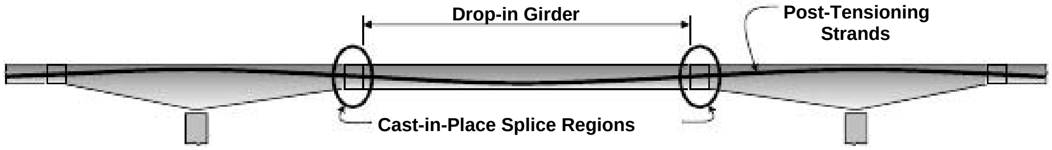
Please return this survey **by April 30** to:	Greg Turco, TxDOT Bridge Division Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS



Simple Span





Multi-Span Continuous

Texas Department of Transportation Contact: Greg Turco, PE **Address:** Bridge Division 125 East 11th St. Austin, TX 78701 **Phone:** 512-416-2580 **Email:** Greg.Turco@txdot.gov	**The University of Texas Research Team:** Dr. Oguzhan Bayrak: bayrak@mail.utexas.edu Dr. James Jirsa: jirsa@uts.cc.utexas.edu Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu Chris Williams: chrisw05@utexas.edu Andy Moore: ammoore@utexas.edu **Address:** Ferguson Structural Engineering Laboratory The University of Texas at Austin 10100 Burnet Rd., Building 177 Austin TX, 78758

Contact Information

Name of Person Completing the Survey: JULIUS F. J. VOLGYI, JR.

Title: ASSISTANT STATE STRUCTURE AND BRIDGE ENGINEER

State/District: VIRGINIA

Organization/Unit: DEPARTMENT OF TRANSPORTATION - STRUCTURE & BRIDGE DIVISION

Address: 1401 E. BROADT STREET
RICHMOND, VA 23219

Phone: 804-786-7537

Fax: ____________________

Email: julius.volgyi@vdot.virginia.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

____
____
____
____
____
____
____

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☒ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☒ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☐ Yes ■ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

■ Yes ☐ No

If *Yes,* please list the consultant(s).

Parsons Brinckerhoff

Moffatt & Nichol

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: ________%
- Plastic (HDPE): ________%

If one of the materials is preferred over the other, please explain why.

HDPE is perferred because of better durability and smaller chance of damage during construction; however, on one project Contractor sub- stitute polypropylene ducts w/o approval prior to fabrication of girder segments.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

■ Yes ☐ No

If *Yes,* please briefly describe the problem(s).

Problems with sealing of ducts allowed grout to transmit into an adjacent empty duct (prior to tendon placement). Subsequent hydrodemolition to remove the concrete material from inside the duct was apparently too aggressive and shredded the plastic duct material within the girder web.

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☑ Yes ☐ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☑ AASHTO LRFD Specifications ☑ AASHTO Segmental Bridge Specifications

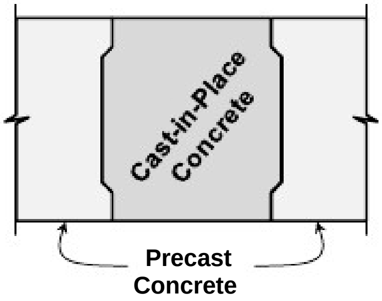
☐ Other; please specify: one on one project; one, on another.

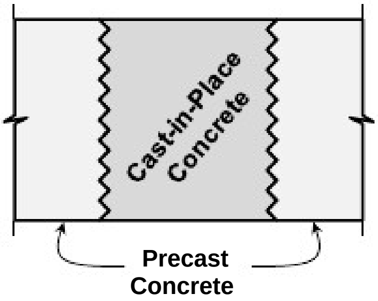
9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

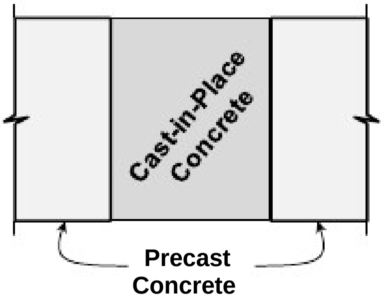
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

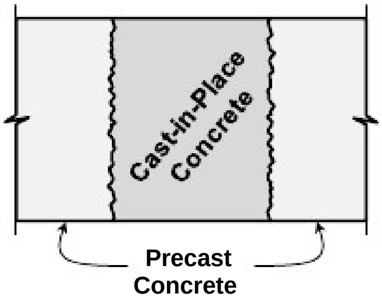
☑ Shear key: 100 % ☐ Saw teeth: ________% ☐ Plain: ________%







☐ Sandblasting or intentional roughening: ________%

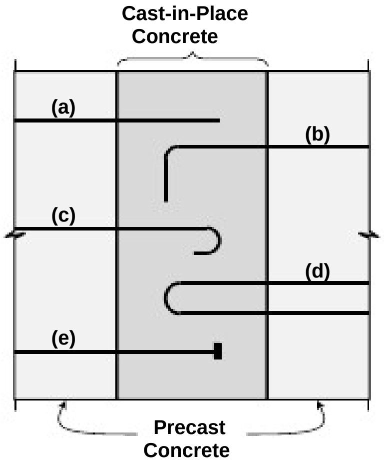


Please explain the factors that affect the type of interface that is chosen.

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☒ (a) Straight bars ☐ (b) 90-degree hooks ☐ (c) 180-degree hooks ☒ (d) Hairpins

☐ (e) Headed bars ☒ Other; please describe: Lapped embedded plates that were welded on one project.

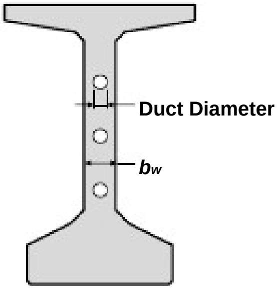


Please elaborate on the detailing of the interface reinforcement if necessary.

One project used hairpin and lapped embedded plates which were welded to each other to provide load transfer through the splice.

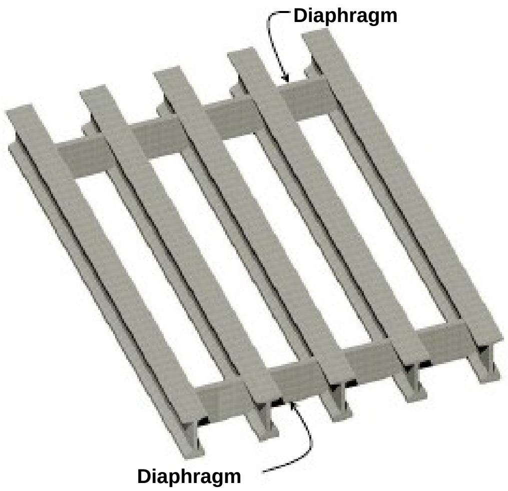
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
8"	3.25"	50 %
9"	3.7"	50 %
		%
		%
		%



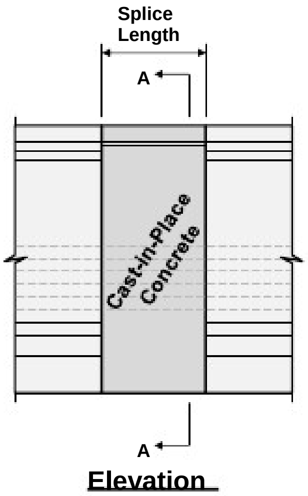
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

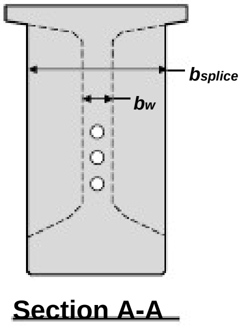
☒ At the splice ☐ Away from the splice ☐ No preference



14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	Minimum	Maximum	Typical
Length	1'-0"	1'-0"	
$b_{splice} - b_w$			





Please explain the factors that affect the **length** of the splice region?

Want to minimize the length of the splice region to ease forming and casting but make it long enough to allow ducts to be spliced.

Access for coupling of post-tensioning ducts, proper consolidation and vibration of concrete and lapping/splicing of reinforcement.

Please explain the factors that affect the **width** of the splice region?

Diaphragms were cast at the splices

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

☒ Yes ☐ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

Some cracking in early splices, but it was traced to shoring that was allowing the pier segments to rotate slightly.

Misalignment of the lapping embedded plates.

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

Comments received from two separate projects from two consultants.

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here:

Any other relevant information you can offer the research team will be greatly appreciated.

Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

Ferguson Structural Engineering Laboratory at The University of Texas at Austin in Collaboration with the Texas Department of Transportation (TxDOT)

Survey of Spliced I-Girder Bridge Construction and Design Practices Focusing on Details of the Splice Region

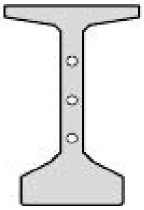
The objective of the following survey is to identify design and detailing practices that have been successfully implemented within cast-in-place (CIP) splice regions of spliced I-girder bridges. Based on the best practices that are identified, a full-scale testing program will be conducted in an effort to develop splice region detailing standards for TxDOT.

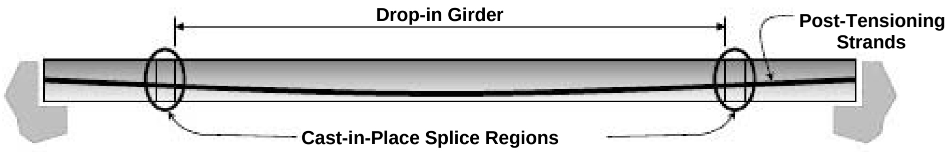
Your response to the following survey will be invaluable to the research team. Please answer the questions as thoroughly as possible, providing details where necessary. The research results will be available in a final project report. Your time is greatly appreciated.

Please return this survey **by April 30** to:

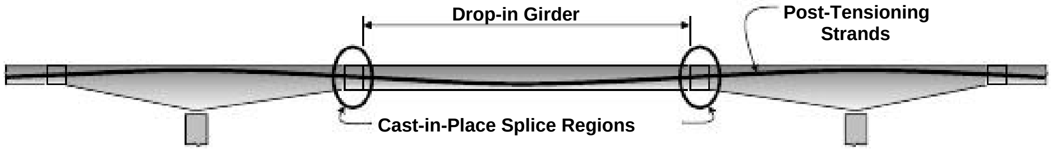
Greg Turco, TxDOT Bridge Division
Email: Greg.Turco@txdot.gov

TYPICAL SPLICED-GIRDER LAYOUTS





Simple Span



Multi-Span Continuous

Texas Department of Transportation Contact:
Greg Turco, PE

Address:
Bridge Division
125 East 11th St.
Austin, TX 78701

Phone: 512-416-2580
Email: Greg.Turco@txdot.gov

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Dr. Wassim Ghannoum: ghannoum@mail.utexas.edu
Chris Williams: chrisw05@utexas.edu
Andy Moore: ammoore@utexas.edu

Address:
Ferguson Structural Engineering Laboratory
The University of Texas at Austin
10100 Burnet Rd., Building 177
Austin TX, 78758

Contact Information

Name of Person Completing the Survey: Bijan Khaleghi

Title: State Bridge Design engineer

State/District: Washington

Organization/Unit: DOT

Address: 7345 Linderson Way SW
Tumwater, WA 98512

Phone: 360 705-7181

Fax: 360 705-6812

Email: khalegb@wsdot.wa.gov

A. General Information

1. Has your state/district had experience with the design and/or construction of spliced girder bridges?

☒ Yes ☐ No

If *No,* has your state/district considered the use of spliced girder technology?

☐ Yes ☐ No

If spliced girder technology is not **currently** being considered as a design option for new bridges, please explain why.

If your state/district has had experience with spliced girder technology, please proceed with the remainder of the survey. If not, thank you for providing the above information.

2. How many spliced **I-girder** bridges have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☐ 11 to 20 ☒ Greater than 20

3. How many spliced **U-girder or box-girder** bridges (not including segmental bridges) have been constructed in your state?

☐ None ☐ 1 to 5 ☐ 6 to 10 ☒ 11 to 20 ☐ Greater than 20

4. Does your state have any spliced girder bridges with **curved U-girders or box girders?**

☒ Yes ☐ No

5. Has your state used consulting engineers for the design of spliced girder bridges?

☐ Yes ☒ No

If *Yes,* please list the consultant(s).

B. Design and Construction Practices of Spliced I-Girder Bridges

The following questions refer to the cast-in-place (CIP) splice regions located within the span lengths of spliced I-girder bridges.

6. For what percent of the spliced I-girder bridge projects in your state/district have the following duct materials been specified?

- Steel: 80 %
- Plastic (HDPE): 20 %

If one of the materials is preferred over the other, please explain why.

corrugated galvanized steel ducts are preferred because of dimensions fitting the web width in case of I-girders, and ease of placement compare to HDPE ducts.

7. Are you aware of any problems encountered **due to the duct material** that was chosen for a particular project?

☐ Yes ☒ No

If *Yes,* please briefly describe the problem(s).

8. Does your state/district consider a reduction in shear strength due to the presence of the post-tensioning duct in the girder web?

☒ Yes ☐ No

If *Yes,* what design provisions are used to calculate the strength reduction?

☒ AASHTO LRFD Specifications ☐ AASHTO Segmental Bridge Specifications

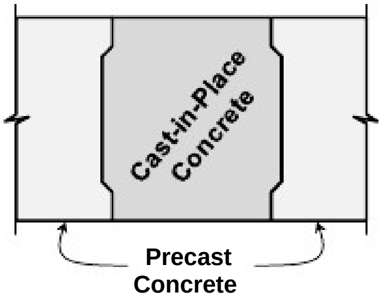
☐ Other; please specify: ____________________

9. Has your state/district ever used ungrouted ducts in spliced I-girder construction?

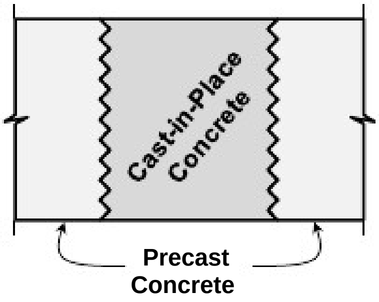
☐ Yes ☒ No

10. What shear transfer mechanism has been used in your state/district at the interface between the pretensioned I-girders and the cast-in-place splice region? Select all that apply, and estimate the percent of projects for which each interface has been specified.

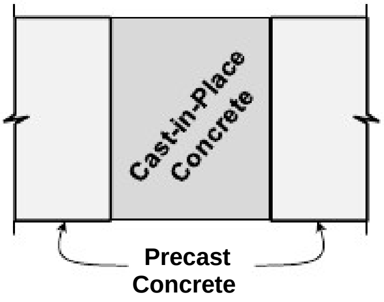
☐ Shear key: ________%



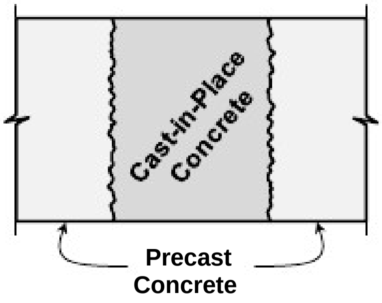
☒ Saw teeth: 100 %



☐ Plain: ________%



☐ Sandblasting or intentional roughening: ________%



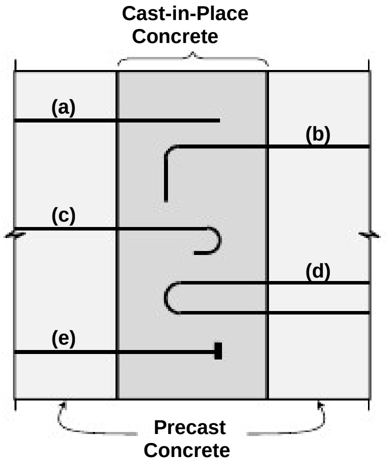
Please explain the factors that affect the type of interface that is chosen.

The saw teeth shear key is commonly used

11. How is the longitudinal reinforcement crossing the splice interface of I-girders **typically** detailed (refer to the figure below)? More than one answer can be selected.

☒ (a) Straight bars ☐ (b) 90-degree hooks ☐ (c) 180-degree hooks ☐ (d) Hairpins

☐ (e) Headed bars ☐ Other; please describe: ____________________

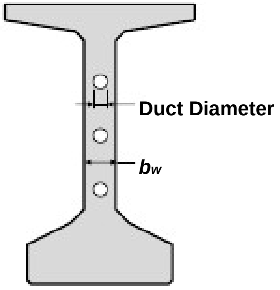


Please elaborate on the detailing of the interface reinforcement if necessary.

The closure is wide enough to allow lap splice.

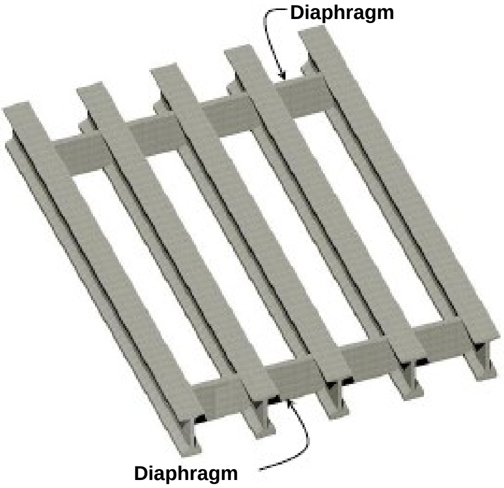
12. Please provide the combinations of the girder web width, b_w, and nominal duct diameter that have been used for spliced I-girder construction in your state/district. Estimate the percent of projects for which each combination has been specified.

Web Width, b_w	Duct Diameter	Percent of Projects
8.0 in. (I-Girder)	4.25 in.	50 %
10.0 in (Tubs)	4.25	50 %
		%
		%
		%



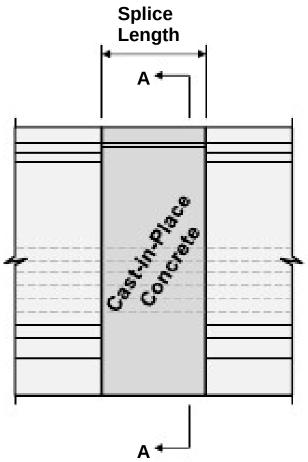
13. Where does your state/district prefer to locate transverse diaphragms (refer to the figure below)?

☐ At the splice ☒ Away from the splice ☐ No preference

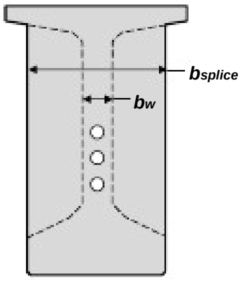


14. Please provide the minimum, maximum, and typical values specified for the length and width of the CIP splice region (refer to the figure below). For the width of the splice region (i.e., $b_{splice} - b_w$), **consider only cases when a transverse diaphragm is not located at the splice.** If transverse diaphragms are always located at the splice region, the ($b_{splice} - b_w$) cells of the table can be left blank.

Splice Region	Minimum	Maximum	Typical
Length	2.0 ft	Special cases	2.0 ft
$b_{splice} - b_w$	8 " (I-Girders), 10" (Tubs)	Special cases	8 " (I-Girders), 10" (Tubs)



Elevation



Section A-A

Please explain the factors that affect the **length** of the splice region?

Suitability for duct splicing, bar splicing and casting concrete.

Please explain the factors that affect the **width** of the splice region?

Adjacent precast girders width

15. Have you had any serviceability/aesthetic issues (e.g., cracking, discolored concrete, etc.) related to the splice region?

☐ Yes ☒ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

16. Have you had any constructability issues (e.g., concrete consolidation, formwork, shoring, etc.) related to the splice region?

■ Yes ☐ No

If *Yes,* please briefly describe the issue(s) and any actions that have been taken to resolve the problem(s).

Concrete consolidation in one project. Achieving high strength concrete at splice.

17. Please provide any additional information regarding your experience with the implementation of spliced girder technology that you believe may be useful to the research team. Feel free to give specific examples regarding any aspect of the design and construction of spliced girder bridges.

5.9.2 WSDOT Criteria for Use of Spliced Girders

http://www.wsdot.wa.gov/publications/manuals/fulltext/M23-50/BDM.pdf

C. Request for Additional Material

If possible, please attach **drawings of existing spliced girder bridges** in your state.

If your state/district has specific **design guidelines/requirements for spliced girder bridges,** please submit this material with the survey. Alternatively, a web link to the guidelines/requirements can be provided here: http://www.wsdot.wa.gov/publications/manuals/fulltext/M23-50/BDM.pdf

Any other relevant information you can offer the research team will be greatly appreciated.

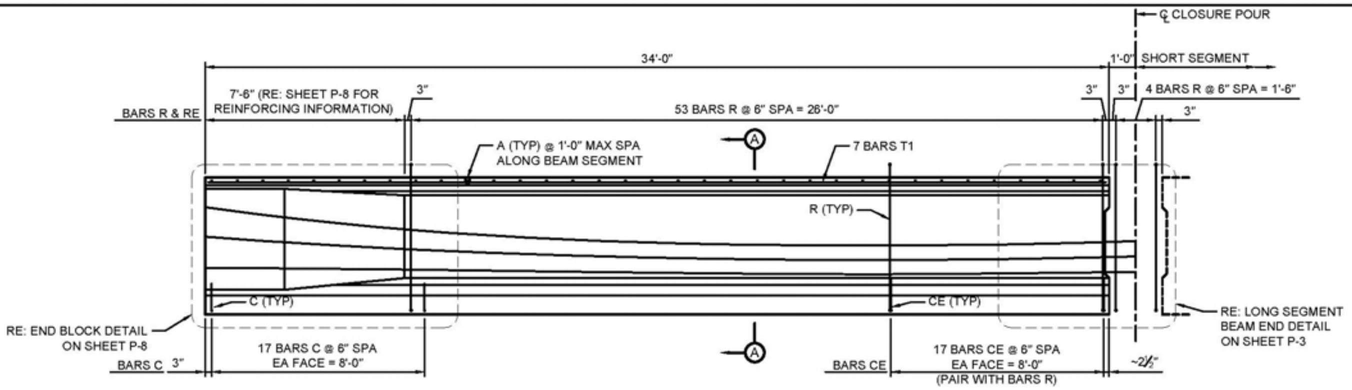
Please upload supplemental material to https://ftp.dot.state.tx.us/dropbox/.

Please return the survey by April 30 to Greg Turco (Greg.Turco@txdot.gov). Thank you for your response.

Appendix B. Test Specimen Drawings

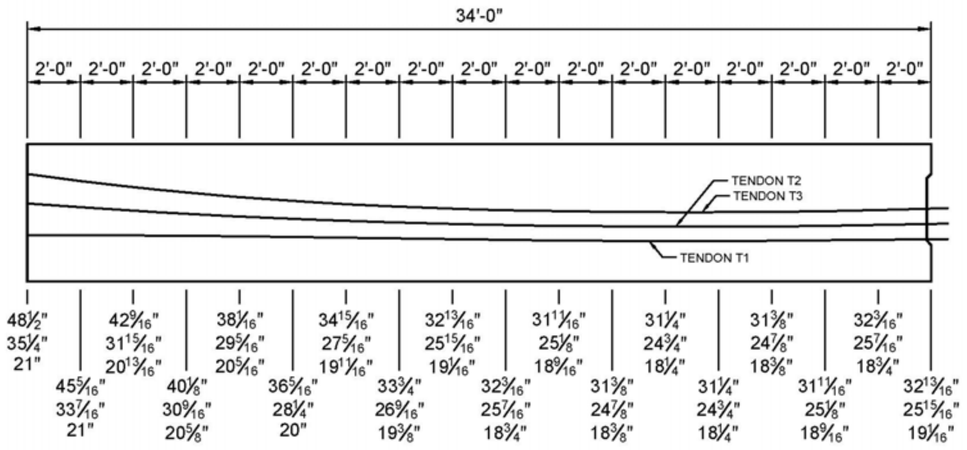
Introduction

Detailed drawings of the spliced girder test specimens of the Phase II experimental program are provided in this appendix. The cross-section of the specimens outside the end blocks followed the geometry of a Tx62 girder except that all horizontal (i.e., transverse) dimensions were increased by 2 in. Current Tx62 details can be downloaded from the website of the Texas Department of Transportation.



ELEVATION - LONG SEGMENT

SCALE: 1/4" = 1'-0"



TENDON PROFILES - LONG SEGMENT

SCALE: 1/4" = 1'-0"

NOTES:

1. TENDON PROFILE DIMENSIONS ARE FROM BOTTOM OF GIRDER TO CENTERLINE OF DUCTS

Ferguson Structural Engineering Laboratory

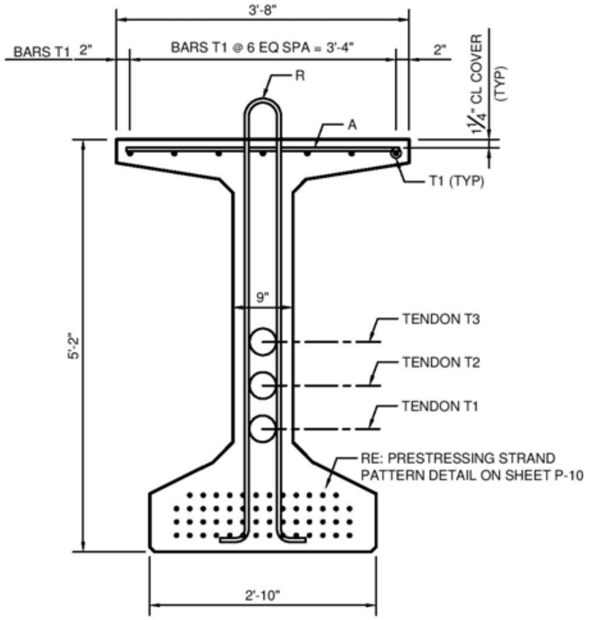
SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

ELEVATIONS - LONG SEGMENT

P-1



SECTION A-A

SCALE: ¾" = 1'-0"

Ferguson Structural Engineering Laboratory

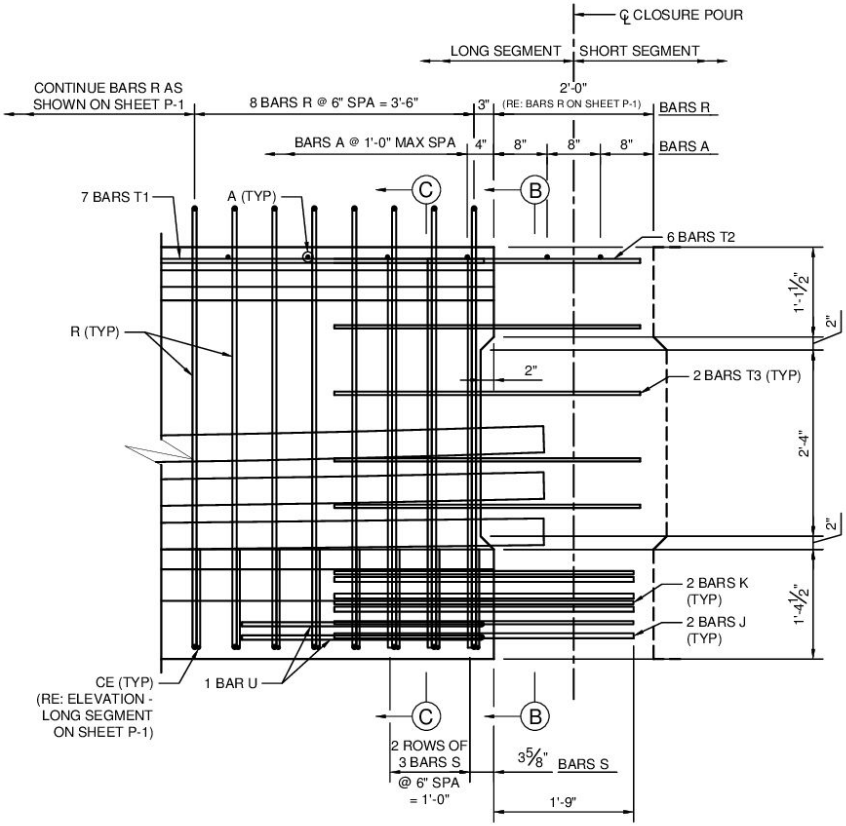
SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

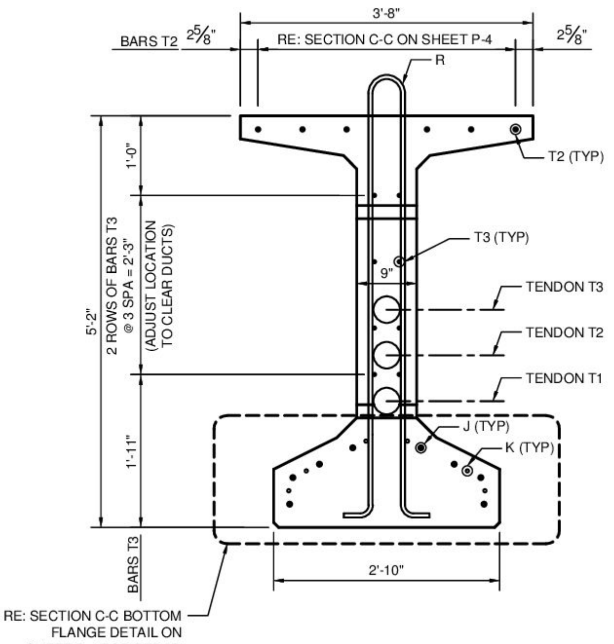
SECTION A-A

P-2



LONG SEGMENT BEAM END DETAIL

SCALE: ¾" = 1'-0"



SECTION B-B

SCALE: ¾" = 1'-0"
(SHOWING MILD REINFORCEMENT EXTERIOR TO PRECAST SEGMENTS)

NOTES:

1. EXTEND DUCTS 8" FROM BEAM FACE
2. CUT PRETENSIONED STRANDS WITHIN 3" OF BEAM FACE

Ferguson Structural Engineering Laboratory

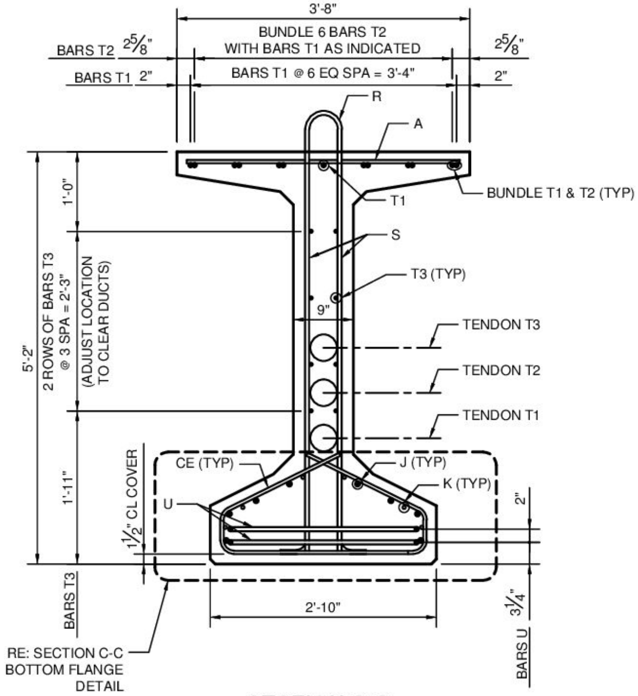
SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

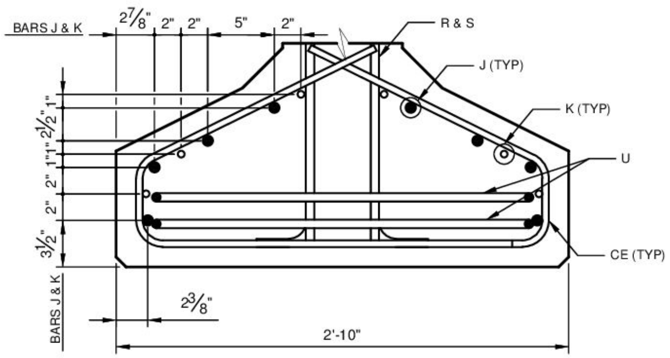
LONG SEGMENT BEAM END DETAILS

P-3



SECTION C-C

SCALE: 3/4" = 1'-0"
(PRESTRESSING NOT SHOWN FOR CLARITY)



SECTION C-C BOTTOM FLANGE DETAIL

SCALE: 1 1/2" = 1'-0"
(PRESTRESSING NOT SHOWN FOR CLARITY)

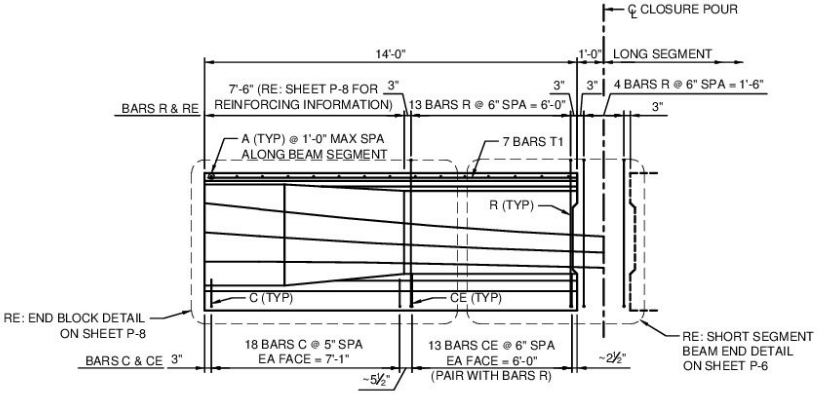
Ferguson Structural Engineering Laboratory

SPLICE REGION TEST SPECIMENS
TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

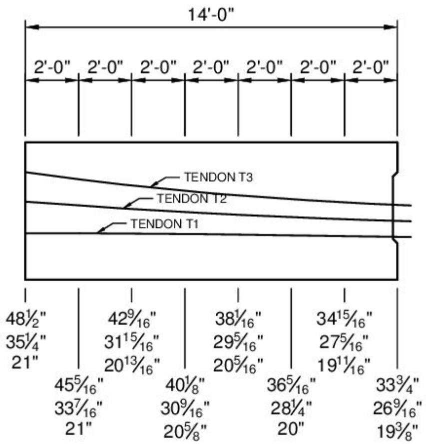
SECTION C-C

P-4



ELEVATION - SHORT SEGMENT

SCALE: 1/4" = 1'-0"



TENDON PROFILES - SHORT SEGMENT

SCALE: 1/4" = 1'-0"

NOTES:

1. TENDON PROFILE DIMENSIONS ARE FROM BOTTOM OF GIRDER TO CENTERLINE OF DUCTS

Ferguson Structural Engineering Laboratory

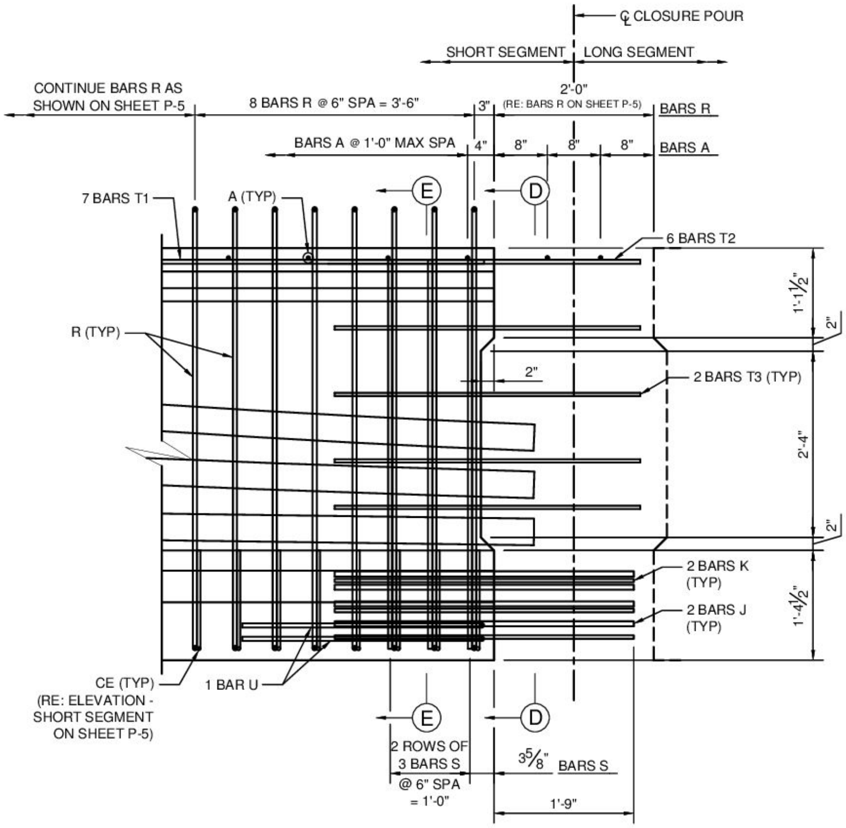
SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

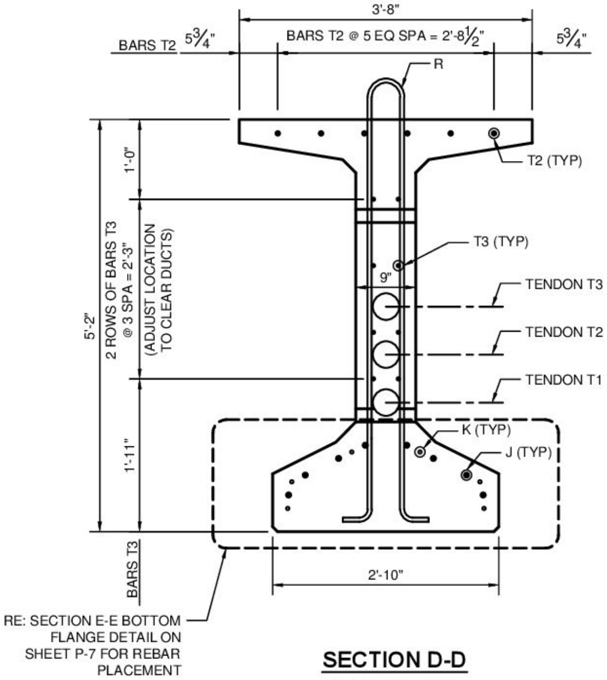
ELEVATIONS - SHORT SEGMENT

P-5



SHORT SEGMENT BEAM END DETAIL

SCALE: ¾" = 1'-0"



SECTION D-D

SCALE: ¾" = 1'-0"
(SHOWING MILD REINFORCEMENT EXTERIOR TO PRECAST SEGMENTS)

NOTES:

1. EXTEND DUCTS 8" FROM BEAM FACE
2. CUT PRETENSIONED STRANDS WITHIN 3" OF BEAM FACE

Ferguson Structural Engineering Laboratory

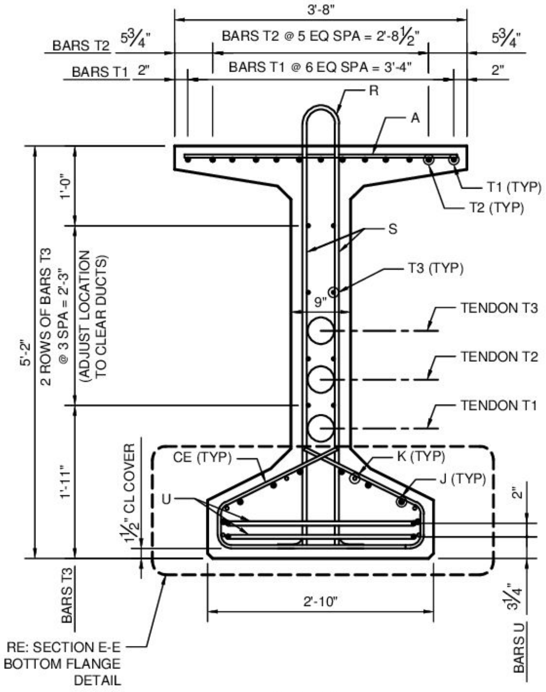
SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

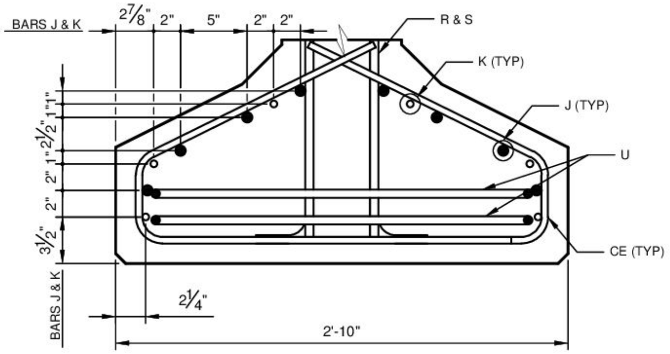
SHORT SEGMENT BEAM END DETAILS

P-6



SECTION E-E

SCALE: ⅜" = 1'-0"
(PRESTRESSING NOT SHOWN FOR CLARITY)



SECTION E-E BOTTOM FLANGE DETAIL

SCALE: 1½" = 1'-0"
(PRESTRESSING NOT SHOWN FOR CLARITY)

Ferguson Structural Engineering Laboratory

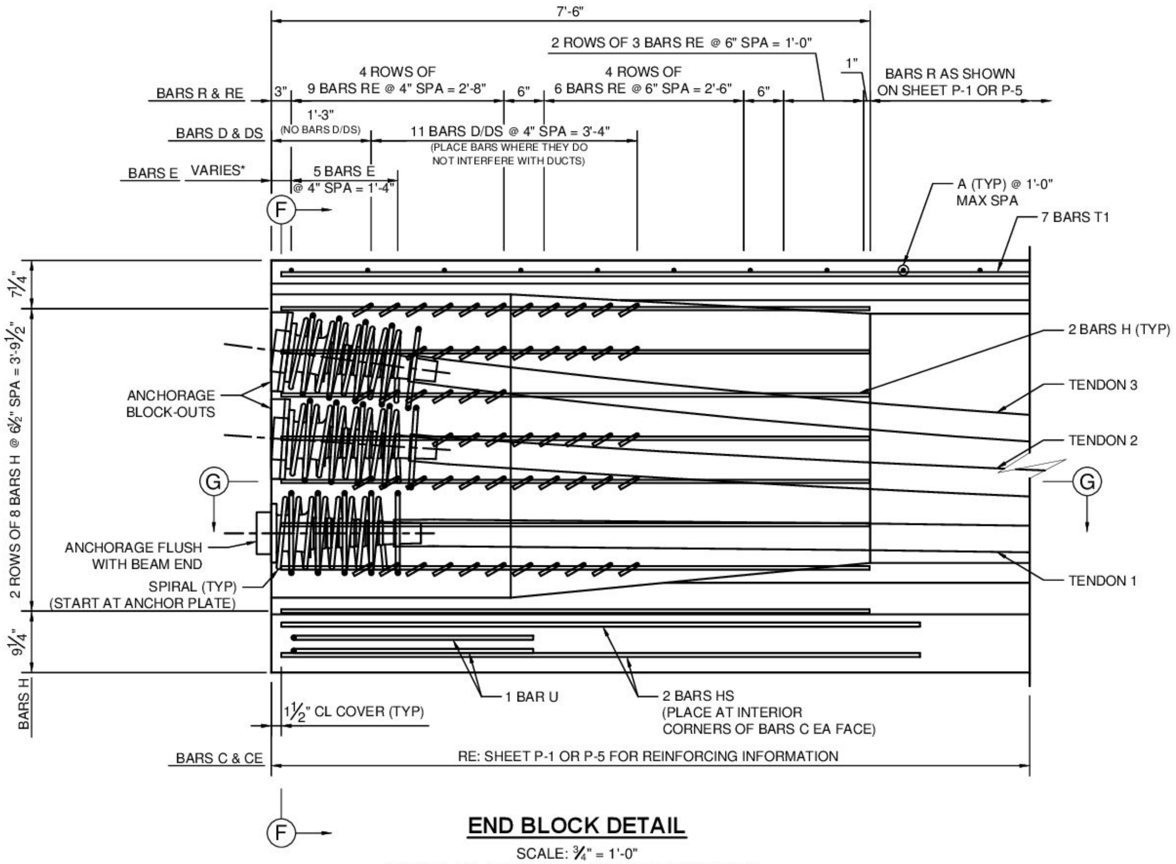
SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

SECTION E-E

P-7



END BLOCK DETAIL

SCALE: ¾" = 1'-0"

(BARS C, CE, R, AND RE NOT SHOWN FOR CLARITY)

NOTES:

* BEGIN BARS E AT 3" FROM OUTSIDE SURFACE OF ANCHOR PLATE

Ferguson Structural Engineering Laboratory

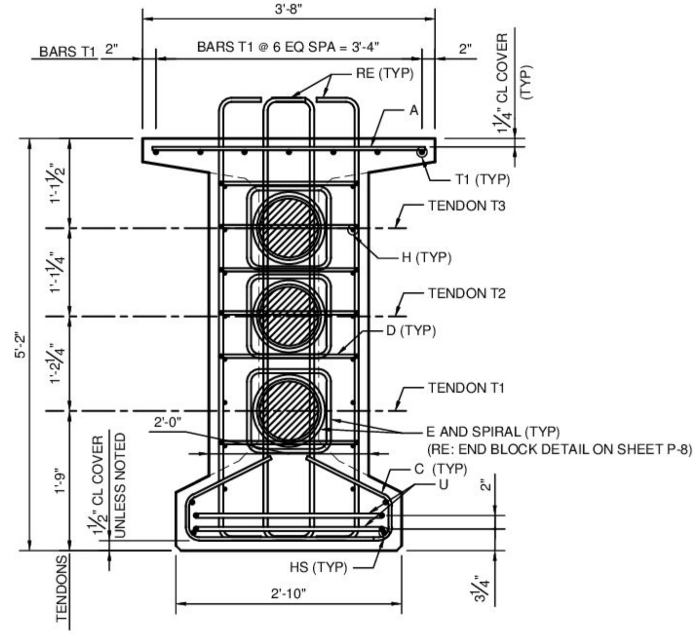
SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

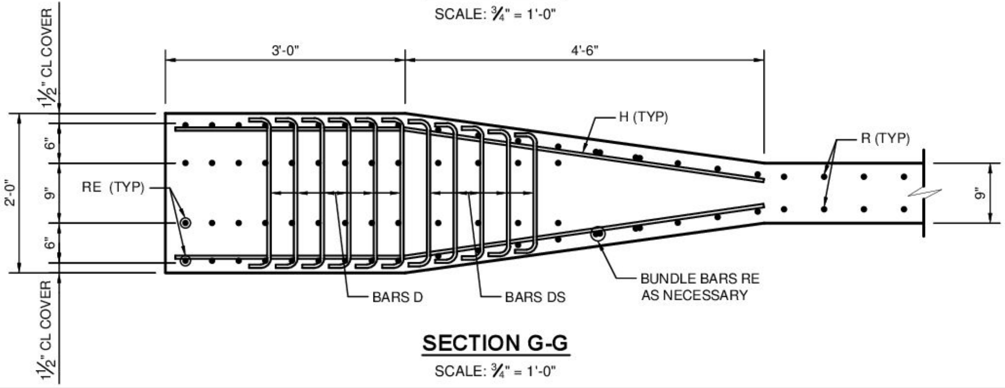
END BLOCK
ELEVATION

P-8



SECTION F-F

SCALE: ¾" = 1'-0"



SECTION G-G

SCALE: ¾" = 1'-0"

Ferguson Structural Engineering Laboratory

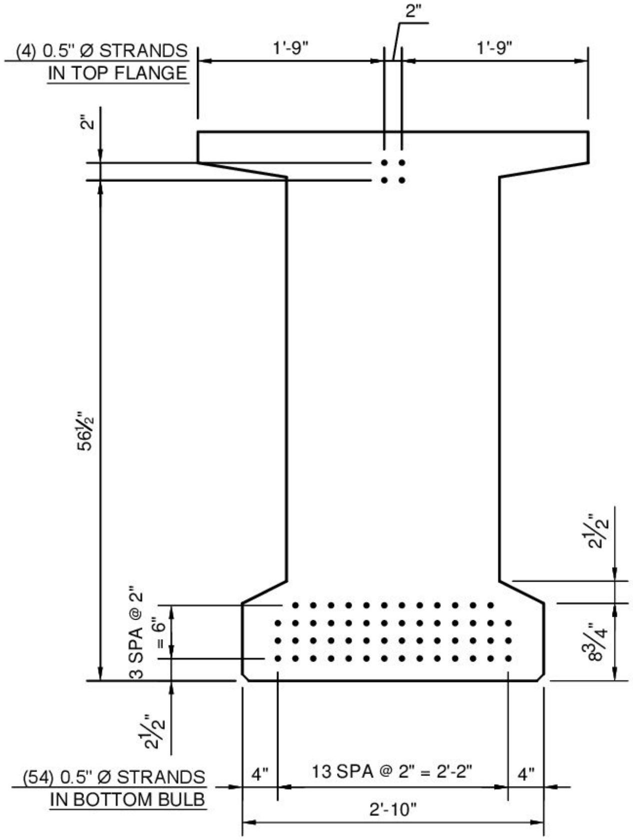
SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

SECTIONS F-F AND G-G (END BLOCK)

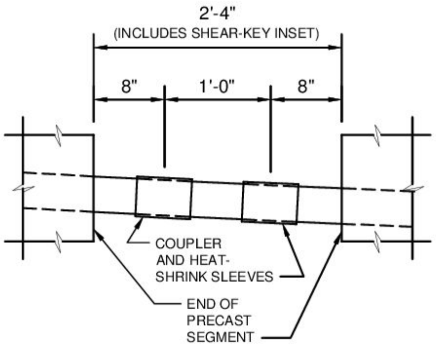
P-9



PRESTRESSING STRAND PATTERN DETAIL (58-0.5" Ø STRANDS)

SCALE: 1" = 1'-0"

● FULLY BONDED STRAND



DUCT SPLICE DETAIL

SCALE: 1" = 1'-0"

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SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

STRAND PATTERN DETAIL

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REINFORCING STEEL

BAR	SIZE	NO. OF BARS (SHORT SEGMENT)	NO. OF BARS (LONG SEGMENT)
A	3	15	39†
C	4	36	34
CE	4	26	34
D	4	36	36
DS	4	30	30
E	5	15	15
H	4	16	16
HS	5	4	4
J	6	8	8
K	4	6	6
R	5	18†	62†
RE	5	66	66
S	5	11†	11†
T1	4	7	14***
T2	4 OR 5††	6	6
T3	4	8	8
U	5	4	4
SPIRAL	5	3	3

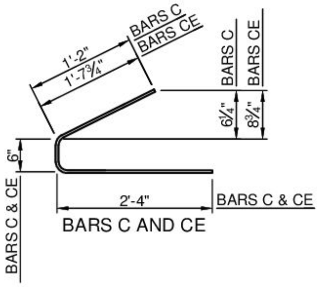
* DIMENSION "x" OF FIVE DS BARS: 1'-8", 1'-7", 1'-6", 1'-5", AND 1'-4'

** LAP BARS WHERE NECESSARY

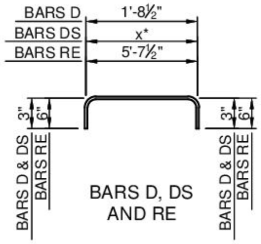
*** MAY VARY DEPENDING ON LENGTH OF INDIVIDUAL BARS

† EXTRA BARS ARE NEEDED IN ORDER TO BE TAKEN TO THE UNIVERSITY OF TEXAS

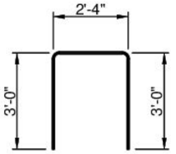
†† BARS T2 ARE NO. 4 FOR GIRDER 1 AND NO. 5 FOR GIRDER 2



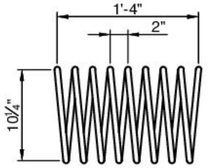
BARS C AND CE



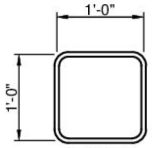
BARS D, DS AND RE



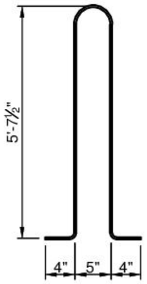
BARS U



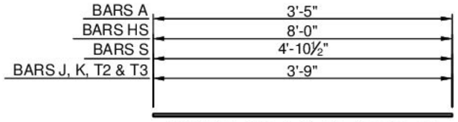
SPIRAL



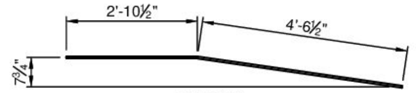
BARS E



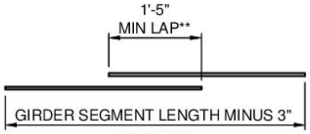
BARS R



BARS A, HS, J, K, S, T2 AND T3



BARS H



BARS T1

GENERAL NOTES

PRE-TENSIONED STEEL:

1. ALL PRE-TENSIONED STRANDS SHALL BE 0.5" DIA. ASTM A416 LOW RELAXATION STRANDS, f_{pu} = 270 KSI
2. ALL STRANDS SHALL BE BROUGHT TO FULL TENSION ($0.7f_{pu}$)

REINFORCING STEEL:

1. ALL MILD REINFORCING STEEL SHALL BE ASTM A615 GR 60, f_y = 60 KSI
2. ONLY DEFORMED BARS SHALL BE USED, NO WELDED WIRE REINFORCEMENT

POST-TENSIONED TENDONS:

1. 4" PLASTIC DUCT SHALL BE USED
2. ANCHORAGES, DUCTS, COUPLERS, AND SPIRAL REINFORCEMENT WILL BE PROVIDED TO THE PRECASTER BY THE UNIVERSITY OF TEXAS

CONCRETE:

1. CONCRETE FOR PRECAST GIRDER SEGMENTS: f'_c = 12.0 KSI (AT 28 DAYS), f'_{ci} = 6.0 KSI

Ferguson Structural Engineering Laboratory

SPLICE REGION TEST SPECIMENS

TxDOT SPLICED GIRDER PROJECT

Project #: 0-6652

REINFORCING DETAILS AND GENERAL NOTES

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Appendix C. Spliced Girder Specimen Shear Strength Calculations

Introduction and Notation

The following tables summarize the shear strength calculations for the spliced girder test specimens of the Phase II experimental program. All values correspond with the critical section located at the splice region interface. The notation used in the tables is as follows (adopted from AASHTO LRFD (2014)):

A_{ps} = area of prestressing steel on the flexural tension side of member (in.^{2})
A_v = area of shear reinforcement within distance s (in.^{2})
b_v = width of web adjusted for the presence of ducts (in.)
b_w = gross width of web (in.)
d_v = effective shear depth, not to be taken as less than the greater of $0.9d_e$ or $0.72h$ (in.)
d_e = effective depth from extreme compression fiber to the centroid of the tensile force in the tension reinforcement (in.)
f'_c = compressive strength of concrete at time of testing (ksi)
f_{po} = average of the stress in each tendon of the test girders after the anchorage is set (ksi)
f_y = measured yield strength of transverse reinforcing bars (ksi)
h = overall member depth (in.)
M_{sw} = moment at the critical section due to self-weight of the girder (kip-in.)
M_u = factored moment at the critical section, not to be taken as less than $(V_u - V_p)d_v$ (kip-in.)
s = spacing of transverse reinforcement (in.)
V_c = nominal shear resistance provided by the concrete (kip)
V_n = nominal shear resistance at the critical section (kip)
V_p = vertical component of the post-tensioning force (kip)
V_s = nominal shear resistance provided by shear reinforcement (kip)
V_{sw} = shear at the critical section due to self-weight of the girder (kip)
V_{test} = maximum shear force at the critical section during testing (kip)
V_u = factored shear force at the critical section (kip)
β = factor indicating ability of diagonally cracked concrete to transmit tension and shear
ε_s = net longitudinal tensile strain at the centroid of the tension reinforcement (in./in.)
θ = angle of inclination of diagonal compressive stresses (degrees)
λ_{duct} = proposed shear strength reduction factor to account for the reduction in the shear resistance provided by transverse reinforcement due to the presence of a post-tensioning duct
$\O_{duct}$ = diameter of post-tensioning duct (in.)

Shear Strength Calculations Using Current AASHTO LRFD (2014) General Procedure

Test Speci- men	f'_c (ksi)	b_w (in.)	$Ø_{duct}$ (in.)	b_v (in.)	d_v* (in.)	M_{sw} (kip-in.)	V_{sw} (kip)	M_u (kip-in.)	V_u (kip)	A_{ps} (in.^{2})	f_{po} (ksi)	ε_s (in./in.) $\times 10^3$	β	V_c (kip)	$A_v f_y$ (kip)	s (in.)	θ (deg.)	V_s (kip)	V_p (kip)	Max. V_n (kip)	V_n (kip)	$\frac{V_{test}}{V_n}$
No. 1	9.48	9	4	8	50.4	2027	20.5	58479	574	7.812	186.8	1.088	2.64	104	38.4	6	32.8	501	33.1	989	638	1.04
No. 2	10.07	9	4	8	50.4	2037	20.6	60167	591	7.812	185.3	1.364	2.37	95.9	42.0	6	33.8	527	33.0	1048	656	1.07

* d_v is governed by the expression $0.72h$

Shear Strength Calculations Using Proposed Modifications to AASHTO LRFD (2014) General Procedure

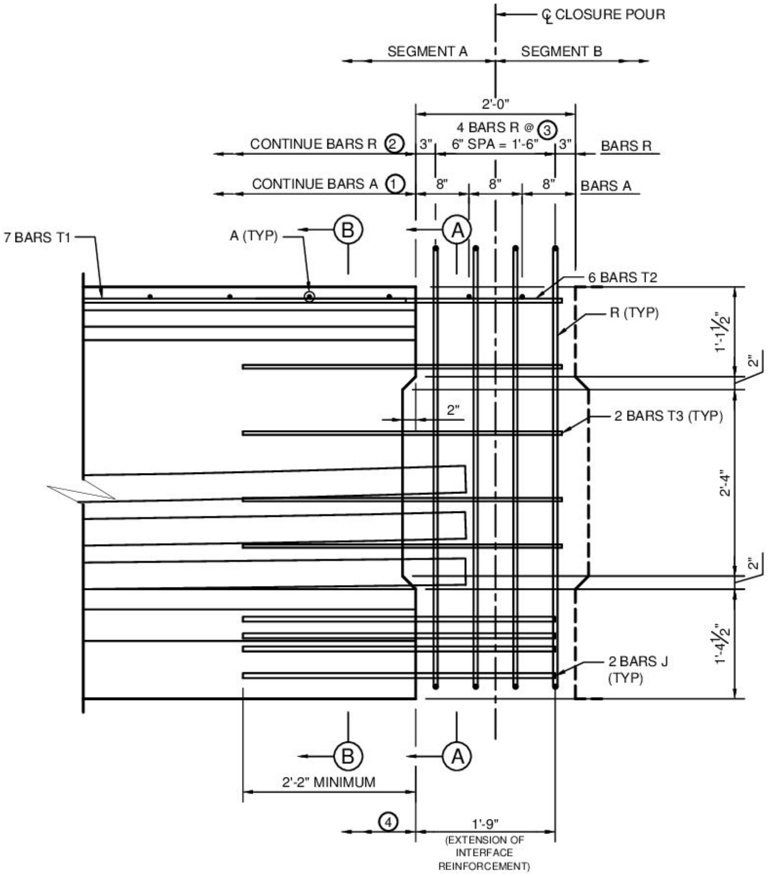
Test Spec.	f'_c (ksi)	b_w (in.)	$Ø_{duct}$ (in.)	d_v* (in.)	M_{sw} (kip-in.)	V_{sw} (kip)	M_u (kip-in.)	V_u (kip)	A_{ps} (in.^{2})	f_{po} (ksi)	ε_s (in./in.) $\times 10^3$	β	V_c (kip)	$A_v f_y$ (kip)	s (in.)	θ (deg.)	λ_{duct}	$\lambda_{duct} V_s$ (kip)	V_p (kip)	Max. V_n (kip)	V_n (kip)	$\frac{V_{test}}{V_n}$
No. 1	9.48	9	4	50.4	2027	20.5	51654	507	7.812	186.8	0.1788	4.23	187	38.4	6	29.6	0.60	343	33.1	1108	563	1.18
No. 2	10.07	9	4	50.4	2037	20.6	52515	515	7.812	185.3	0.3453	3.81	173	42.0	6	30.2	0.60	366	33.0	1175	573	1.23

* d_v is governed by the expression $0.72h$

Appendix D. Example Spliced Girder Standard Details

Introduction

Detailed drawings of the cast-in-place splice region details developed as a result of the Phase II research program are presented in this appendix. The details correspond with the recommendations discussed in Chapter 6. The cross-section of the girder shown in the example details follows the geometry of a Tx62 girder except that all horizontal (i.e., transverse) dimensions have been increased by 2 in. to accommodate the post-tensioning ducts in the web. Current Tx62 details can be downloaded from the website of the Texas Department of Transportation.

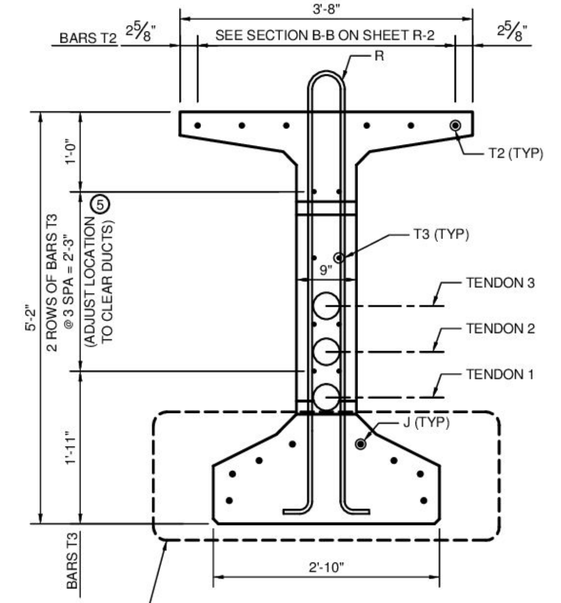


SEGMENT A BEAM END DETAIL

(BARS CE, S, AND U OF END REGION REINFORCEMENT NOT SHOWN)

GENERAL NOTES:

1. CUT PRETENSIONED STRANDS 2" TO 3" FROM BEAM FACE
2. TENDON LOCATIONS MAY VARY FROM THOSE SHOWN



SEE SECTION B-B BOTTOM FLANGE DETAIL ON SHEET R-2 FOR REBAR PLACEMENT

SECTION A-A

(SHOWING MILD REINFORCEMENT EXTERIOR TO PRECAST SEGMENTS)

① CONTINUE BARS A IN ACCORDANCE WITH TxDOT STANDARDS
② CONTINUE BARS R IN ACCORDANCE WITH TxDOT STANDARDS/DESIGN REQUIREMENTS
③ SPACING OF BARS R IN SPLICE REGION MAY VARY (SEE GENERAL NOTES ON SHEET R-6)
④ PROVIDE BARS CE, S, AND U IN ACCORDANCE WITH TxDOT STANDARDS
⑤ PLACEMENT OF BARS T3 SHOULD MATCH THAT OF ADJACENT GIRDER SEGMENT

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SPLICE REGION DETAILS

TxDOT SPLICED GIRDER PROJECT

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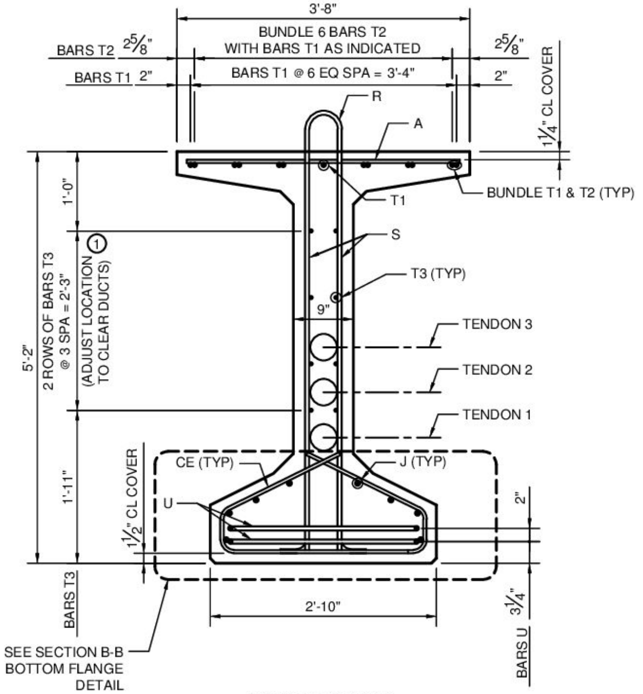
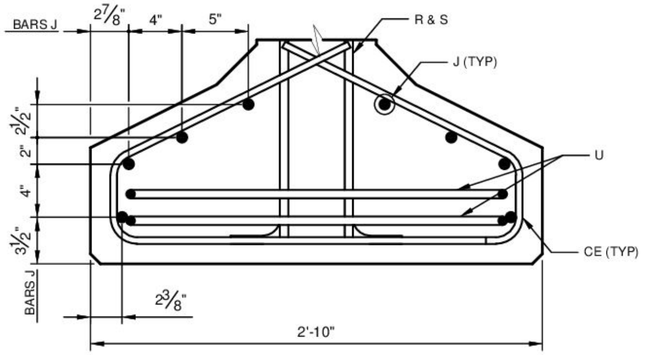
SEGMENT A BEAM END DETAILS

R-1



SECTION B-B

(PRESTRESSING NOT SHOWN)



SECTION B-B BOTTOM FLANGE DETAIL

(PRESTRESSING NOT SHOWN)

GENERAL NOTES:

1. TENDON LOCATIONS MAY VARY FROM THOSE SHOWN

① PLACEMENT OF BARS T3 SHOULD MATCH THAT OF ADJACENT GIRDER SEGMENT

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SPLICE REGION DETAILS

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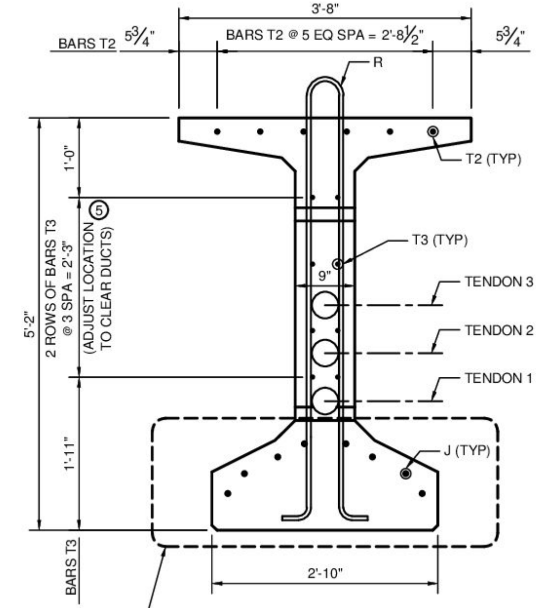
SECTION B-B

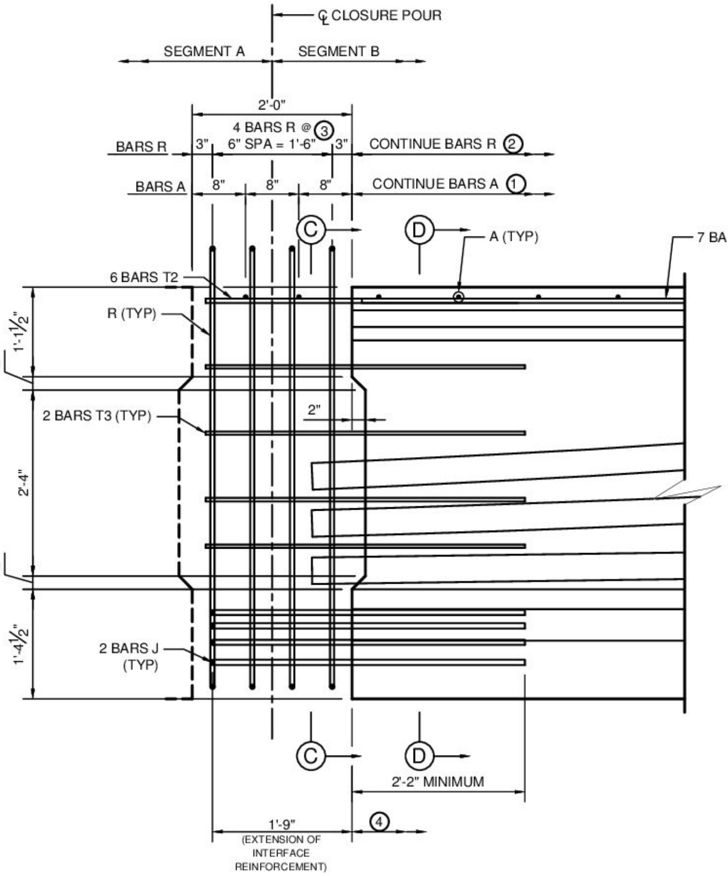
R-2



SEE SECTION D-D BOTTOM FLANGE DETAIL ON SHEET R-4 FOR REBAR PLACEMENT

SECTION C-C

(SHOWING MILD REINFORCEMENT EXTERIOR TO PRECAST SEGMENTS)



SEGMENT B BEAM END DETAIL

(BARS CE, S, AND U OF END REGION REINFORCEMENT NOT SHOWN)

① CONTINUE BARS A IN ACCORDANCE WITH TxDOT STANDARDS
② CONTINUE BARS R IN ACCORDANCE WITH TxDOT STANDARDS/DESIGN REQUIREMENTS
③ SPACING OF BARS R IN SPLICE REGION MAY VARY (SEE GENERAL NOTES ON SHEET R-6)
④ PROVIDE BARS CE, S, AND U IN ACCORDANCE WITH TxDOT STANDARDS
⑤ PLACEMENT OF BARS T3 SHOULD MATCH THAT OF ADJACENT GIRDER SEGMENT

GENERAL NOTES:
1. CUT PRETENSIONED STRANDS 2" TO 3" FROM BEAM FACE
2. TENDON LOCATIONS MAY VARY FROM THOSE SHOWN

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SPLICE REGION DETAILS

TxDOT SPLICED GIRDER PROJECT

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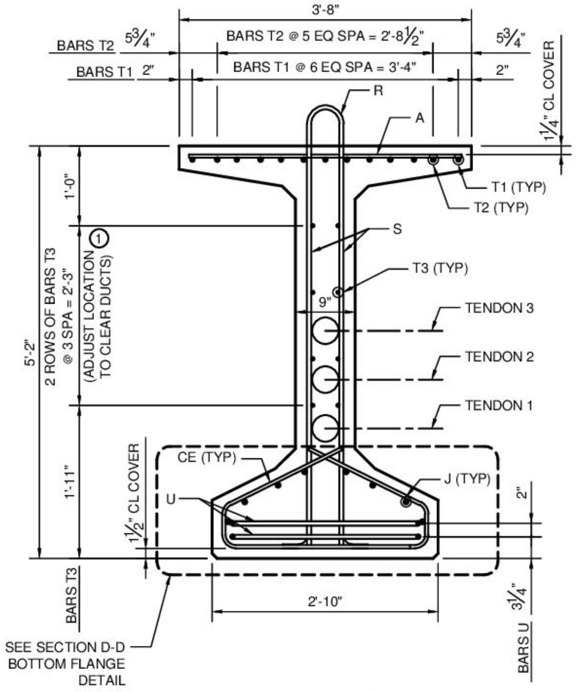
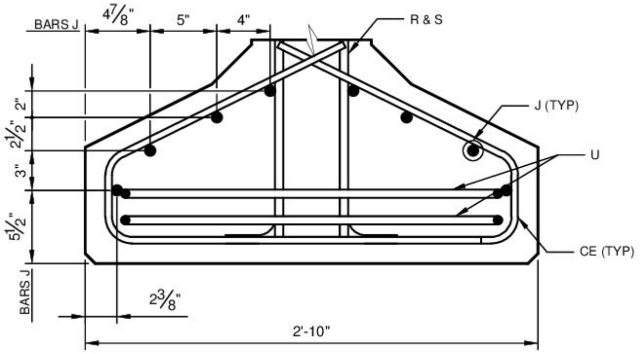
SEGMENT B BEAM END DETAILS

R-3



SECTION D-D

(PRESTRESSING NOT SHOWN)



SECTION D-D BOTTOM FLANGE DETAIL

(PRESTRESSING NOT SHOWN)

GENERAL NOTES:

1. TENDON LOCATIONS MAY VARY FROM THOSE SHOWN

① PLACEMENT OF BARS T3 SHOULD MATCH THAT OF ADJACENT GIRDER SEGMENT

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SPLICE REGION DETAILS

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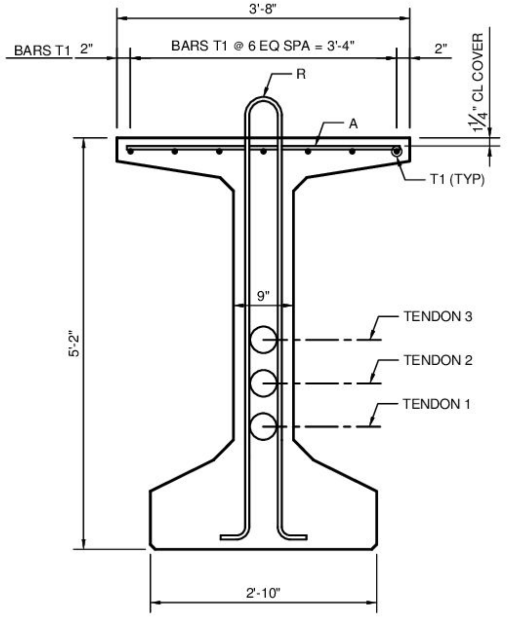
SECTION D-D

R-4



TYPICAL SECTION OUTSIDE OF END REGION

(PRESTRESSING NOT SHOWN)

GENERAL NOTES:

1. TENDON LOCATIONS MAY VARY FROM THOSE SHOWN

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SPLICE REGION DETAILS

TxDOT SPLICED GIRDER PROJECT

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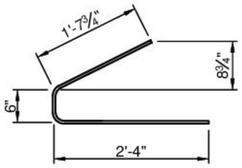
TYPICAL SECTION

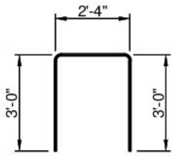
R-5

REINFORCING STEEL

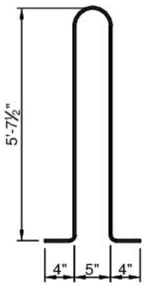
BAR	SIZE
A	3
CE	4
J	6
R	5
S	-
T1	4
T2	5
T3	4
U	5



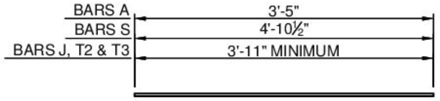
BARS CE



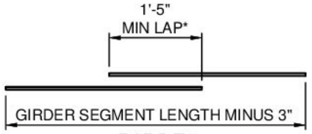
BARS U



BARS R



BARS A, J, S, T2 AND T3



BARS T1

* LAP BARS WHERE NECESSARY ALONG LENGTH OF GIRDER SEGMENT

GENERAL NOTES

1. SHEAR REINFORCEMENT IN THE SPLICE REGION SHALL BE THE LARGER OF THAT PROVIDED IN THE ADJACENT PRECAST GIRDER SEGMENTS
2. ENSURE CLEAR COVER REQUIREMENTS TO TRANSVERSE REINFORCEMENT ARE SATISFIED WITH SPECIFIED COMBINATION OF WEB WIDTH AND DUCT DIAMETER. SIZE OF DUCT COUPLERS SHOULD ALSO BE CONSIDERED.

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SPLICE REGION DETAILS

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REINFORCING DETAILS AND GENERAL NOTES

R-6

Appendix E. Proposed Modifications to the AASHTO LRFD (2014) General Shear Procedure

Introduction

The proposed modifications to the AASHTO LRFD (2014) general shear procedure that were developed during Phase I of the spliced girder research program are restated from Moore et al. (2015) in this appendix for the reader's convenience. Details leading to the development of the proposed procedure can be found in Moore et al. (2015).

Proposed Shear Design Procedure

Based on the findings of Phase I of the spliced girder research program, the following modifications to the AASHTO LRFD (2014) general shear procedure are proposed:

- The transverse reinforcement contribution to shear strength, V_s, should be modified by a quadratically decreasing strength reduction factor, λ_{duct} (defined below), to account for the reduction in the shear strength of a girder containing a post-tensioning duct within its web.
- On the condition that the recommendation of the strength reduction factor, λ_{duct}, is adopted, the provisions of Article 5.4.6.2 of AASHTO LRFD (2014) should be amended to remove the current maximum duct diameter limit of 40 percent of the web width.
- On the condition that the recommendation of the strength reduction factor, λ_{duct}, is adopted, the web-width reduction specified in Article 5.8.2.9 of AASHTO LRFD (2014) should be removed.
- On the condition that the recommendation of the strength reduction factor, λ_{duct}, is adopted, the gross web width, b_w, should be used to calculate the shear strength of a member within the General Procedure of AASHTO LRFD (2014).

Implementation of these proposed revisions results in the following shear design procedure (modifications to AASHTO LRFD (2014) are shown in bold):

For sections containing at least the minimum amount of shear reinforcement:

$$\beta = \frac{4.8}{(1+750\varepsilon_s)} \tag{E.1}$$

For all cases:

$$\theta = 29 + 3500\varepsilon_s \tag{E.2}$$

where:

$$\varepsilon_s = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + |V_u - V_p| - A_{ps}f_{po}\right)}{E_s A_s + E_p A_{ps}} \qquad \textit{(E.3)}$$

where:

A_s = area of nonprestressed steel on the flexural tension side of the member (in.^{2})

A_{ps} = area of prestressing steel on the flexural tension side of the member (in.^{2})

d_v = effective shear depth taken as the distance measure perpendicular to the neutral axis, between the resultants of the tensile and compressive forces due to flexural, not to be taken as less than the greater of $0.9d_e$ or $0.72h$ (in.)

d_e = effective depth from extreme compression fiber to the centroid of the tensile force in the tension reinforcement (in.)

E_s = modulus of elasticity of reinforcing bars (ksi)

E_p = modulus of elasticity of prestressing strand (ksi)

f_{po} = $\Delta\varepsilon_p \times E_p$ (ksi)

h = overall member depth (in.)

N_u = factored axial force in member, taken as positive if tensile (kip)

$|M_u|$ = absolute value of factored moment, not to be taken as less than $|V_u - V_p|d_v$ (kip-in.)

V_p = component of the effective prestressing force in the direction of the applied shear, taken as positive if resisting the applied shear (kip)

V_u = factored shear force (kip)

β = factor indicating ability of diagonally cracked concrete to transmit tension and shear

$\Delta\varepsilon_p$ = locked-in difference in strain between the prestressing tendons and the surrounding concrete (in./in.)

ε_s = net longitudinal tensile strain at the centroid of the tension reinforcement (in./in.)

θ = angle of inclination of diagonal compressive stresses (degrees)

The nominal shear resistance, V_n, of a concrete member shall be taken as:

$$V_n = V_c + V_s + V_p \leq 0.25f'_c \boldsymbol{b_w} d_v + V_p \qquad \textit{(E.4)}$$

where the concrete contribution to the shear strength of the member shall be taken as:

$$V_c = 0.0316\beta\sqrt{f'_c}\,\boldsymbol{b_w} d_v \qquad \textit{(E.5)}$$

and the steel contribution to the shear strength of the member shall be taken as:

$$V_s = \frac{\boldsymbol{\lambda_{duct}}\, A_v f_y d_v (\cot\theta + \cot\alpha)\sin\alpha}{s} \qquad \textit{(E.6)}$$

where:

$$\boldsymbol{\lambda_{duct} = 1 - \delta\left(\frac{\varnothing_{duct}}{b_w}\right)^2} \tag{E.7}$$

where:

A_v = area of shear reinforcement within distance s (in.^{2})
b_w = gross width of web, not reduced to account for post-tensioning ducts (in.)
f'_c = specified compressive strength of concrete (ksi)
f_y = specified minimum yield strength of reinforcing bars (ksi)
s = spacing of transverse reinforcement measured in the direction parallel to the longitudinal reinforcement (in.)
α = angle of inclination of transverse reinforcement to longitudinal axis (degrees)
λ_{duct} = proposed shear strength reduction factor to account for the reduction in the shear resistance provided by transverse reinforcement due to the presence of a post-tensioning duct
δ = duct diameter correction factor, taken as 2.0 for grouted ducts
$\varnothing_{duct}$ = diameter of post-tensioning duct present in the girder web within depth d_v (in.)