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16. Abstract

The objectives of this portion of the project were to:

1. Determine if the subject variant of the Modified Kansas Corral (MKC) railing complies with the requirements of the *AASHTO LRFD Bridge Design Specifications* and *NCHRP Report 350*, Test Level 4.
2. Prepare a comprehensive report of the research findings that is suitable for submittal to the FHWA by the FDOT as part of a request for acceptance package.
3. If required, perform a full-scale crash test to verify the crash performance of the MKC railing.

The *AASHTO LRFD Bridge Design Specifications* give guidance on geometry of the traffic face of railing that can be expected to provide acceptable performance in full-scale crash tests. The relationships between geometric factors and performance are approximate and are based on information available at the time the Specifications were prepared. Since that time, many tests of bridge railings have been performed. Information from those recent tests was compiled and compared with the geometry of the MKC and with provisions of the *AASHTO LRFD Bridge Design Specifications* to provide insight concerning acceptability of the geometry of the MKC railing.

The FDOT variant of the MKC is similar to the original Kansas Corral bridge rail. Offset between the post and beams is 38 mm (1 1/2 inches) on the FDOT variant and 50 mm (2 inches) on the original Kansas Corral, and the post height is 305 mm (12 inches) on the FDOT variant and 330 mm (13 inches) on the Kansas Corral system. However, portions of the openings on the FDOT variant of the MKC have been reduced by the placement of a 152 mm (6 inch) curb in the openings and flush with the upper beam face, this modification should enhance impact performance by reducing the snagging potential. The overall height of both systems is 813 mm (32 inches).

Based on the comparison to the previously tested bridge rails and AASHTO guidelines, the FDOT variant of the MKC bridge rail is believed to meet the crash test performance of *NCHRP Report 350*.

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EVALUATION OF THE FDOT VARIANT OF THE MODIFIED KANSAS CORRAL BRIDGE RAILING

by

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Report 9-8132-2
Project Number 9-8132
Research Project Title: FDOT Bridge Rails

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Florida Department of Transportation
In Cooperation with the
Texas Department of Transportation
and the U.S. Department of Transportation
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CHAPTER 1. INTRODUCTION

PROBLEM

The Florida Department of Transportation (FDOT) has been provided a variant of the Modified Kansas Corral (MKC) bridge rail on a recent construction project. Since the variant MKC has not been full-scale crash tested, FDOT has requested Texas Transportation Institute (TTI) to evaluate the variant MKC for anticipated performance under National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* Test Level (TL) 3 and 4 conditions *(1)*.

BACKGROUND

The original MKC, a concrete post and beam bridge rail, was tested under Federal Highway Administration (FHWA) project DTFH61-84-C-00002 *(2)*. The MKC was 686 mm (27 inches) tall with a 356 mm (14 inch) top beam supported on 914 mm (3 ft) long posts. Lateral offset between the posts and beam is 38 mm (1 1/2 inches).

The American Association of State Highway and Transportation Official's (AASHTO) *Load Resistance Factor Design (LRFD) Bridge Design Specifications* Section 13 sets forth test levels and the required test conditions for demonstrating a bridge rail meets a certain test level *(3)*. The Appendix to Section 13 gives engineering guidelines for designing bridge rails that will perform satisfactorily in full-scale crash tests. The Appendix to Section 13 is not mandatory. Bridge rails may be designed by other methods and would be considered acceptable if the rail performed acceptably in crash tests.

Ideally, a bridge rail should contain and redirect errant vehicles with minimal damage to the bridge structure. As experience is gained with bridge rails, designs change. The geometry, such as height, shape, and openness, may change due to vehicle mix, vehicle design changes, or public opinion. However, a move to a new design does not necessarily negate the usefulness of older systems, nor does an upgrade in design automatically indicate the older system will not perform acceptably when impacted under new design conditions. The safety performance of bridge rails is ultimately evaluated by a performance-based test, i.e., a full-scale crash test.

OBJECTIVES/SCOPE OF RESEARCH

The objectives of this portion of the study were to:

1. Determine if the subject variant of the MKC railing complies with the requirements of the *AASHTO LRFD Bridge Design Specifications* and *NCHRP Report 350*, Test Level 4.

2. Prepare a comprehensive report of the research findings that is suitable for submittal to the FHWA by the FDOT as part of a request for acceptance package.

3. If required, perform a full-scale crash test to verify the crash performance of the MKC railing.

The *AASHTO LRFD Bridge Design Specifications* give guidance on geometry of the traffic face of railing that can be expected to provide acceptable performance in full-scale crash tests. The relationships between geometric factors and performance are approximate and are based on information available at the time the Specifications were prepared. Since that time, many tests of bridge railings have been performed. Information from those recent tests was compiled and compared with the geometry of the MKC and with provisions of the *AASHTO LRFD Bridge Design Specifications* to provide insight concerning acceptability of the geometry of the MKC railing.

CHAPTER 2. DESIGN CONSIDERATIONS

FACTORS AFFECTING DESIGNS

Parameters have already been established that greatly influence the search for alternative barrier and rail designs. Three of the most critical parameters are: 1) adequate rail height; 2) the need for a continuous solid surface (either rounded or flat) of adequate contact surface area on the traffic face; and 3) the absence or protection of any vertical edge that will snag a vehicle.

The dimensions may vary, but a representative example is shown in Figure 1. Of critical note is the 356 mm (14 inch) impact surface (and its location) and the 114 mm (4 1/2 inch) setback of the post. In the case of steel elements, the degree of deformation allowed during impact of the supporting member determines the dimensions of the element.

Section 13 of the *AASHTO LRFD Bridge Design Specifications* provides guidance for the design of bridge railings. The guidance provided for bridge rail design is useful when considering rail geometry and open design concepts. Figures 2 through 4 are taken from Section 13 of the *AASHTO LRFD Bridge Design Specifications*. Figure 2 illustrates typical "traditional" traffic rails and critical geometrical relationships requiring consideration during the design phase. Figure 3 graphically illustrates the potential for wheel, bumper or hood impact with a post for a given clear vertical opening and post setback distance. Additionally, Figure 4 illustrates the relationship between the post setback distance and the ratio of rail contact, width to height. It should be noted, the graphs presented in Figures 2 through 4 were developed from crash tests performed under the guidelines of *NCHRP Report 230 (4)*. For the purpose of discussion herein, the primary difference between *NCHRP Report 230* and *NCHRP Report 350* guidelines is the use of the 2000 kg (4405 lb) pickup truck in place of the 2041 kg (4496 lb) passenger sedan. The passenger sedan had a longer front overhang than the pickup truck, and a lower center of gravity.

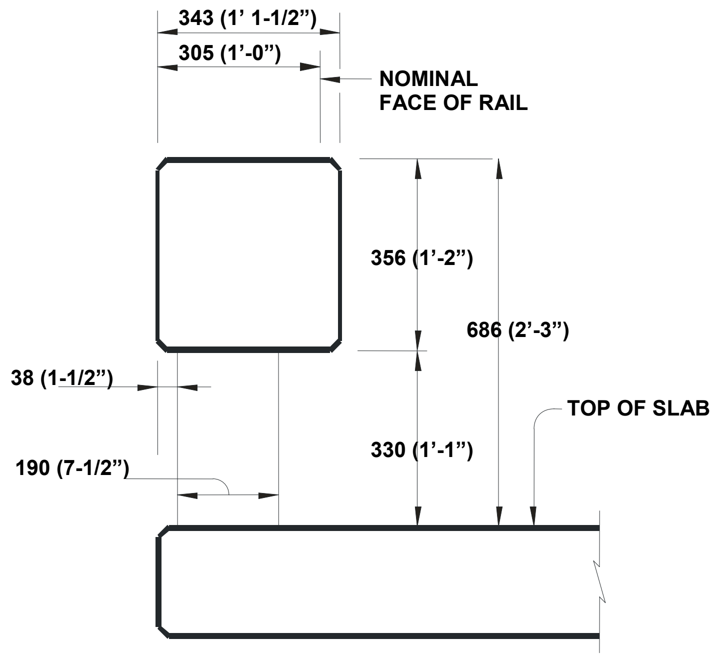

Figure 1. Example of Bridge Rail Parameters.

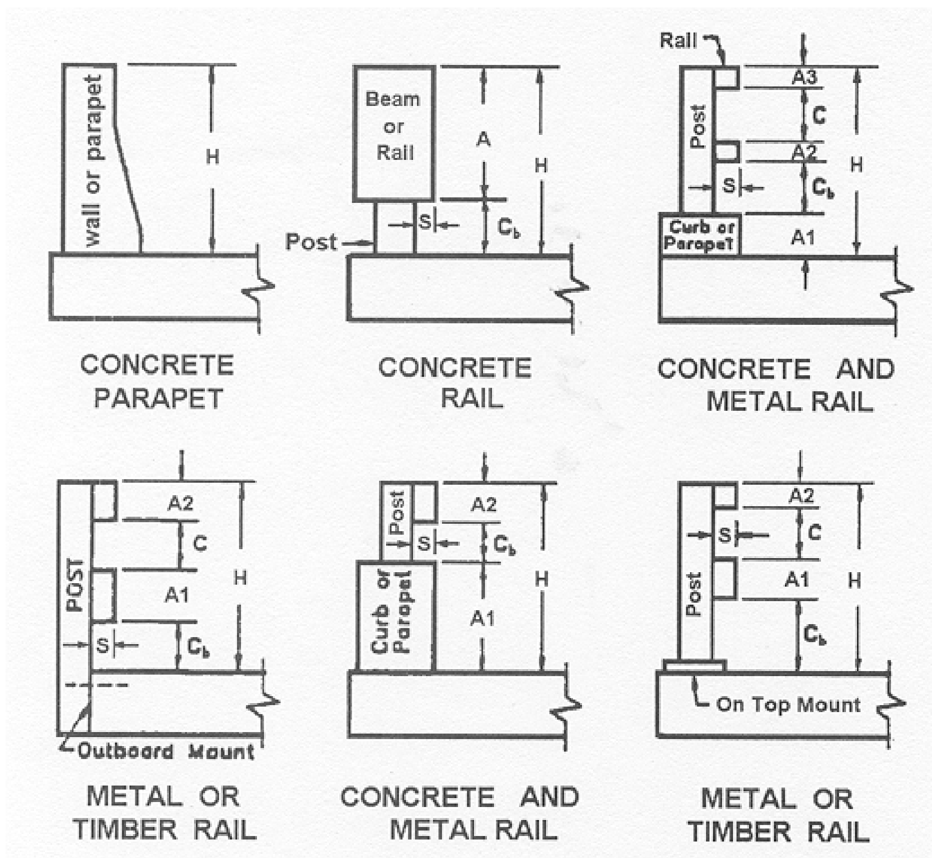

Figure 2. ***AASHTO LRFD Bridge Design Specifications*** **Figure A13.1.1-1.**

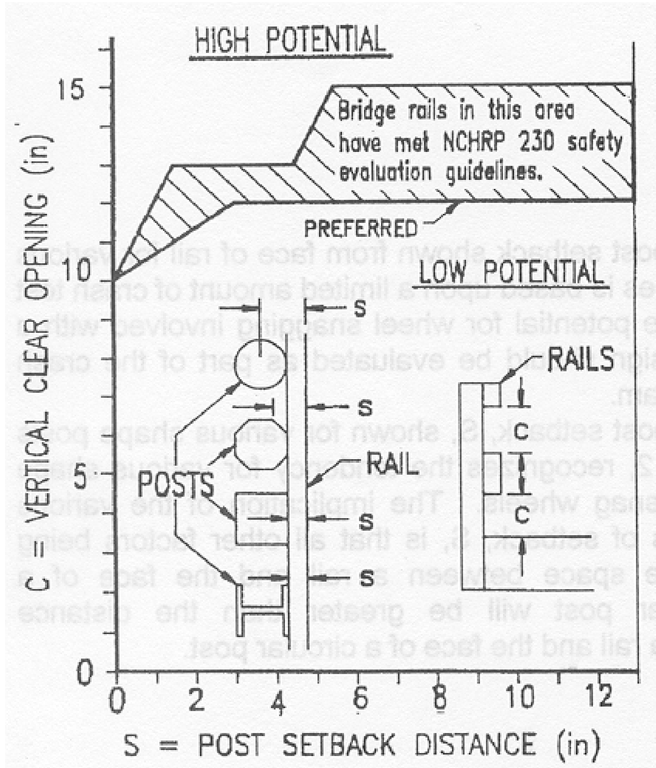

Figure 3. ***AASHTO LRFD Bridge Design Specifications*** **Figure A13.1.1-2.**

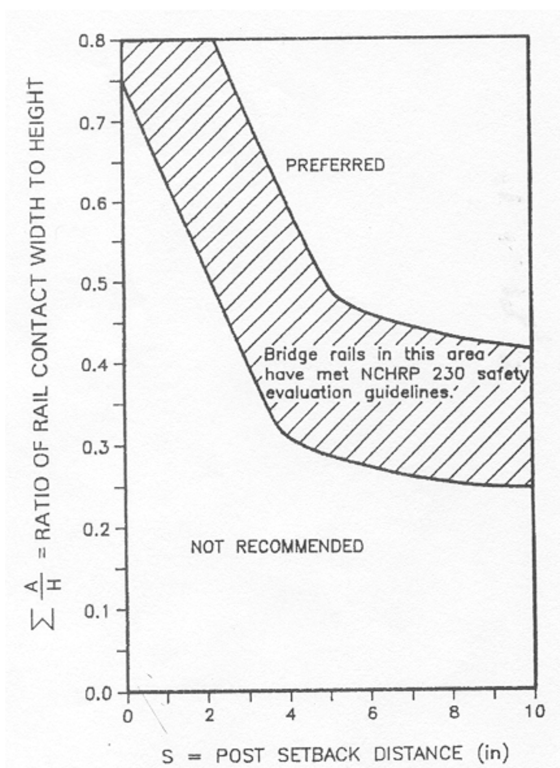

Figure 4. ***AASHTO LRFD Bridge Design Specifications*** **Figure A13.1.1-3.**

CHAPTER 3. DISCUSSION OF FDOT VARIANT OF MODIFIED KANSAS CORRAL

Originally the Kansas Corral bridge rail consisted of a 305 mm (12 inch) wide 483 mm (19 inch) tall concrete beam atop 254 mm (10 inch) wide, 330 mm (13 inch) tall posts. Thus the offset between the face of the beam and the face of the posts was 2.0 in. The overall height of the railing was 813 mm (32 inches) above the adjacent roadway. Center to center spacing on the posts is 3.0 m (10 ft) and the posts are 0.9 m (3 ft) long leaving 2.1 m (7 ft) openings. The detail shown in Figure 5 depicts an overlay of variable height but does show the overall height of 813 mm (32 inches) relative to the travel surface. This bridge rail is considered by FHWA to meet TL-4 under *NCHRP Report 350*. It and other similar rails with FHWA ratings can be found at: http://safety.fhwa.dot.gov/fourthlevel/hardware/pdf/appendixb5.pdf.

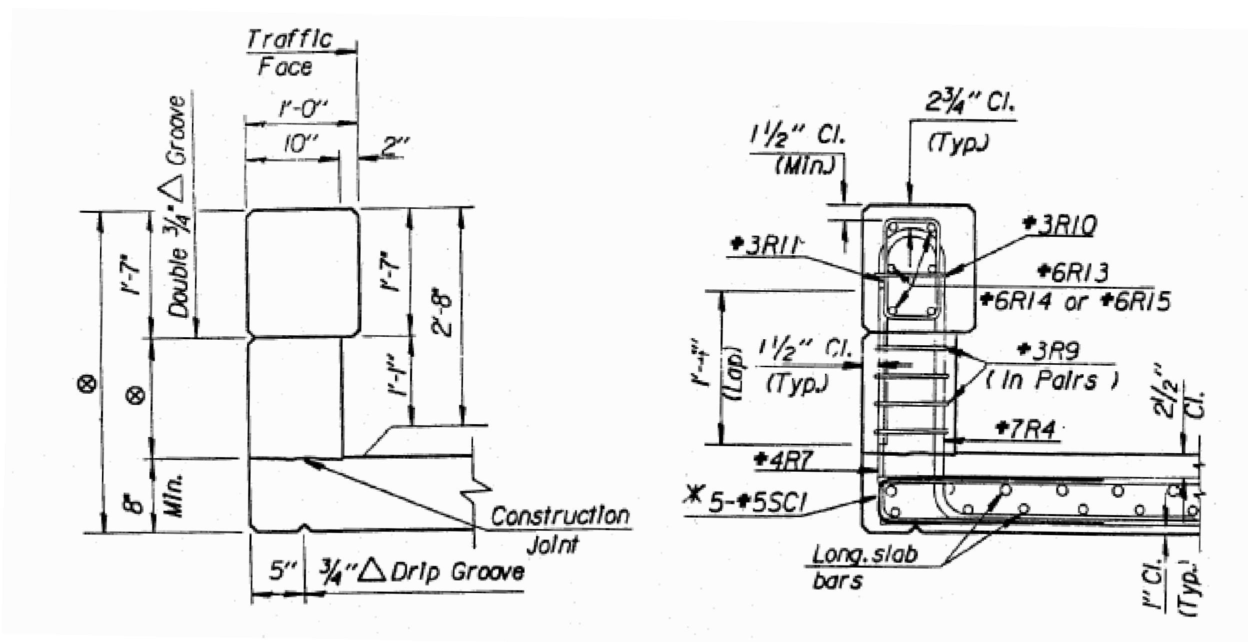

Figure 5. Kansas Corral Bridge Railing.

Similar to the original Kansas Corral, the MKC bridge rail has a 305 mm (12 inch) wide beam but is only 356 mm (14 inches) tall. The posts are the same at 254 mm (10 inches) thick, 330 mm (13 inches) tall, and 0.9 m (3 ft) long with the same 51 mm (2 inch) offset between the post and beam faces. With the shorter beam element, the overall height of the MKC is 686 mm (27 inches) compared to the 813 mm (32 inches) of the original Kansas Corral railing. The MKC is shown in Figure 6.

The FDOT variant of the MKC bridge rail is similar in many aspects to the original MKC. However, the FDOT variant of the MKC has a 317.5 mm (12 1/2 inch) wide, 508 mm (20 inch) tall beam atop 279 mm (11 inch) thick, 305 mm (12 inch) tall posts. The offset distance between the face of the beam and posts is 38 mm (1 1/2 inches). Furthermore, the openings between the posts have been reduced by the placement of a 152 mm (6 inch) tall curb, installed flush with the face of the posts. Details of the FDOT variant of the MKC are shown in Figure 7.

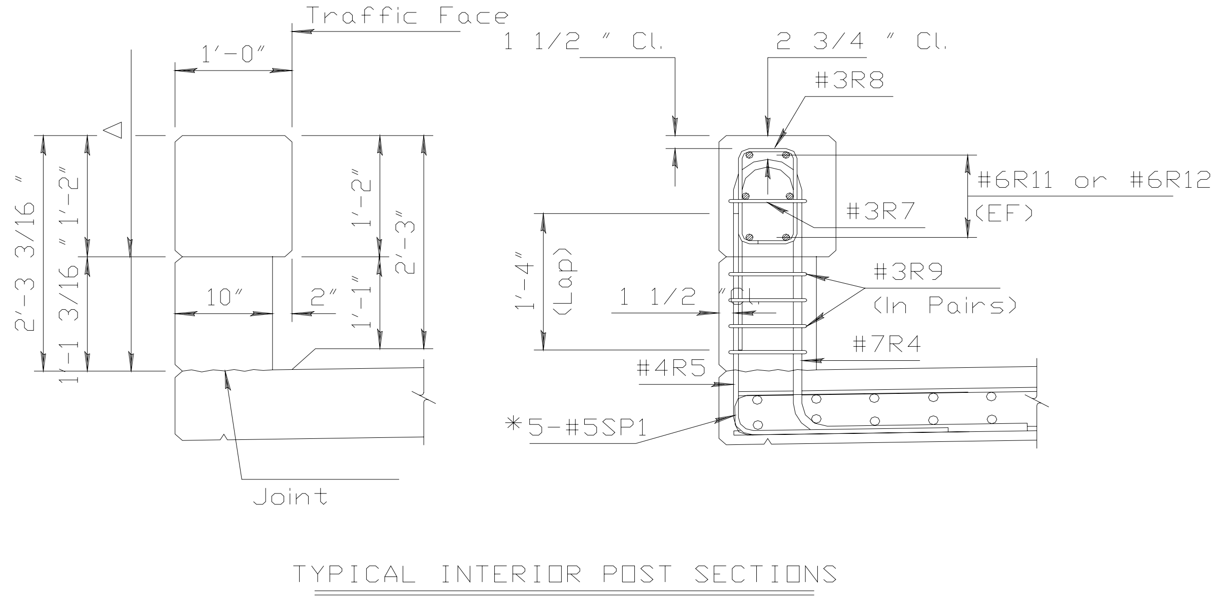

Figure 6. Modified Kansas Corral Bridge Railing.

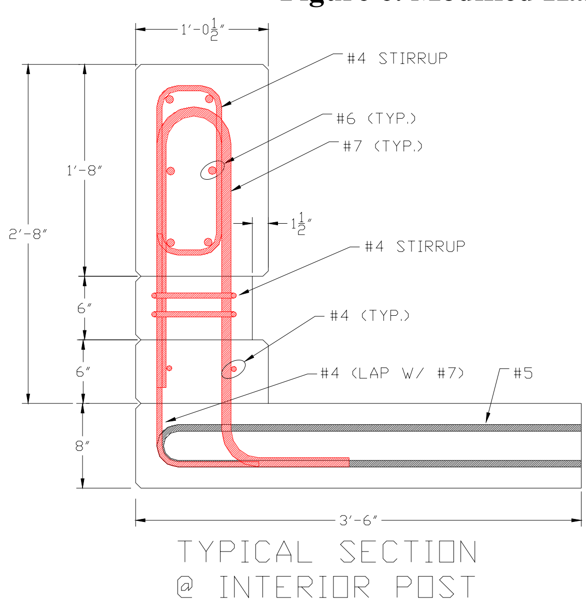

Figure 7. FDOT Variant of the Modified Kansas Corral Bridge Railing.

Structural capacity of the Florida variant of the MKC exceeds the original Kansas Corral that is classified as a TL-4 bridge rail. The beam element of the Florida variant of the MKC is 25 mm (1 inch) taller and 13 mm (0.5 inch) wider than the Kansas Corral beam element. With the addition of the integral curb on the Florida variant of the MKC, the post moment capacity exceeds the post capacity of the Kansas Corral.

Good vehicular impact performance, i.e., vehicle redirection, minimal structural damage, etc. is anticipated with this design. The increased size of the components and height of the system coupled with the 150 mm (6 inch) curb assure similar or better test results than previous versions of the MKC and original Kansas Corral.

CHAPTER 4. COMPARISON OF THE FDOT VARIANT MKC BRIDGE RAIL TO OTHER TESTED CONCRETE POST AND BEAM BRIDGE RAILS

Several bridge rails that have been successfully crash tested to *NCHRP Report 350* compare favorably with the FDOT variant of the MKC bridge rail. Early tests under *NCHRP Report 350* identified some potential problems with existing bridge rails. Most notably, the increased propensity of wheel snagging with the front wheels of vehicles. The vehicle fleet has changed over the years, sport utility and pickups have gained popularity, and consequently, they make up a large portion of the vehicles on the road today. As one inspects these types of vehicles, the distance between the front bumper and front wheel assembly is significantly shorter. Therefore, particular close attention needs to be paid to potential snagging of the wheel assembly on bridge rail openings.

NATCHEZ TRACE BRIDGE RAIL

Design and Construction

The Natchez Trace Bridge Rail, shown in Figure 8, is a concrete beam and post bridge rail mounted on top of a concrete curb. The bridge rail, which is 826 mm (32 1/2 inches) high, consists of a beam supported by 457 mm (18 inch) long by 229 mm (9 inch) wide posts spaced approximately 2.29 m (7.5 ft) apart and a 254 mm (10 inch) high curb. The bridge rail varies in width from 254 mm (10 inches) at the top to 305 mm (12 inches) at the bottom, with the traffic side face of the rail tapering the difference of 51 mm (2 inches). Details of the Natchez Trace Bridge Rail are shown in Figure 9.

Crash Test Results

NCHRP Report 350 Test 3-11

In this test of the Natchez Trace Bridge Rail, performed at Texas Transportation Institute, the installation contained and redirected the pickup truck *(5)*. The vehicle did not penetrate, underride, or override the bridge rail. No measurable deflection occurred. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present a hazard to others in the area. Maximum occupant compartment deformation was 103 mm (4.1 inches) in the center floor pan area over the transmission tunnel. The pickup truck remained upright during and after the collision period. The vehicle subsequently came to rest upright 45.7 m (150 ft) downstream of impact and 7.6 m (25 ft) forward of the face of the bridge rail. Longitudinal occupant impact velocity was 5.4 m/s (17.7 ft/s) and longitudinal ridedown acceleration was -11.8 gravity or acceleration (g’s). Exit angle at loss of contact was 5.2 degrees, which was 20 percent of the impact angle.

Figure 8. Natchez Trace Bridge Rail.

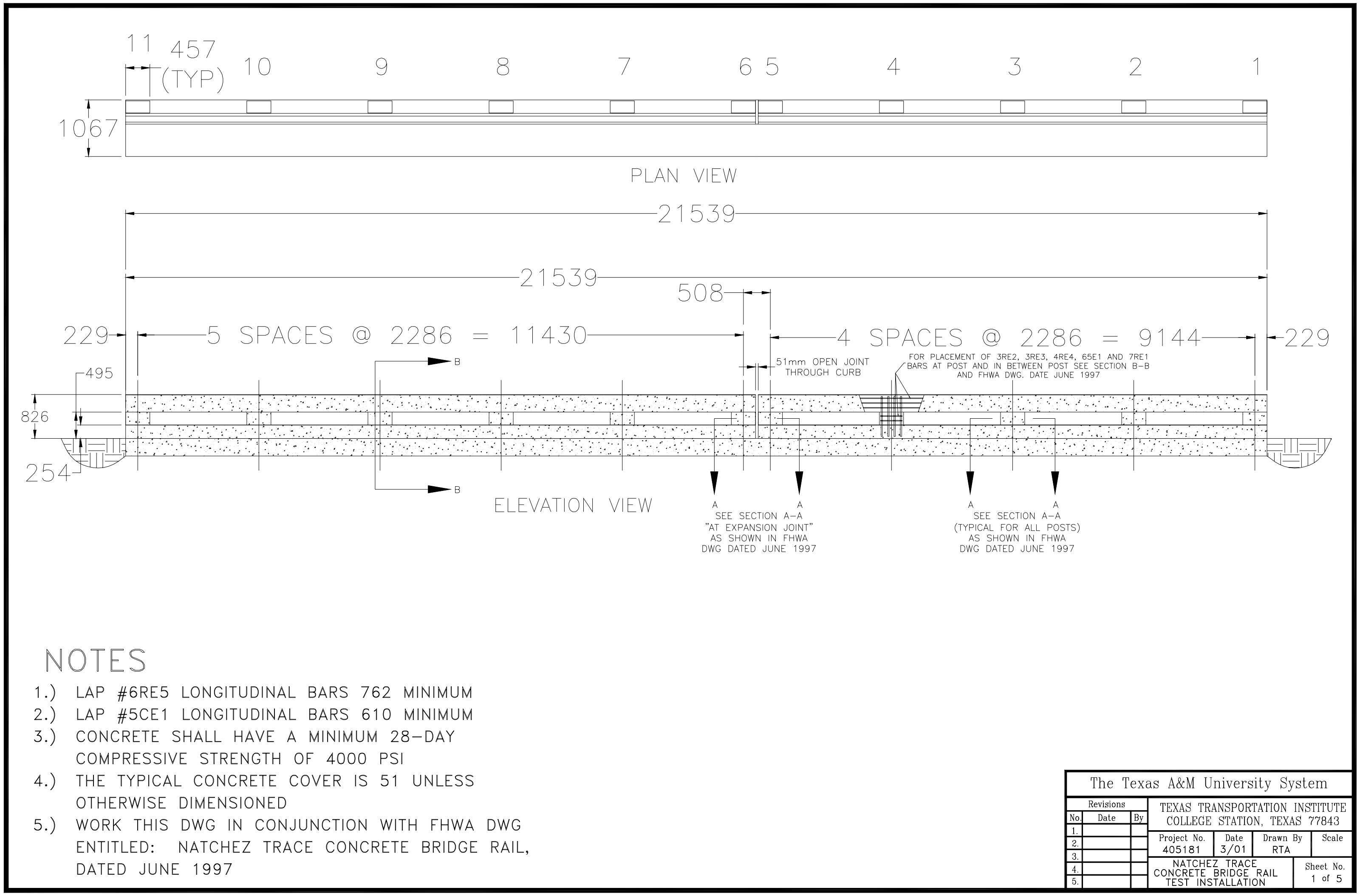

Figure 9. Details of Natchez Trace Bridge Rail.

The Natchez Trace Bridge Rail satisfied all requirements of *NCHRP Report 350* test designation 3-11. Table 1 presents a summary of the crash test results.

Table 1. Summary of Results for Natchez Trace Bridge Rail *NCHRP Report 350* Test 3-11.

General Information		**Occupant Risk Values**	
Test Agency	Texas Transportation Institute	Impact Velocity	
Test No.	405181-12	x-direction	5.4 m/s
Date	07/23/01	y-direction	7.4 m/s
Test Article		THIV	32.1 km/h
Type	Bridge Rail	Ridedown Accelerations	
Name	Natchez Trace Bridge Rail	x-direction	-11.8 g's
Installation Length	21.5 m	y-direction	-8.7 g's
Material or Key		PHD	13.8 g's
Elements	Concrete Beam and Post on Curb	ASI	1.50
Soil Type and		Max. 0.050-s Average	
Condition	Concrete Footing, Dry	x-direction	-9.6 g's
Test Vehicle		y-direction	-11.9 g's
Type	Production	z-direction	-4.3 g's
Designation	2000P		
Model	1997 Chev. 2500 Pickup Truck	**Vehicle Damage**	
Mass		Exterior	
Curb	2131 kg	VDS	01RFQ2
Test Inertial	2000 kg	CDC	01REK2 &
Dummy	116 kg		01RYEW2
Gross Static	2116 kg	Maximum Exterior	
Impact Conditions		Vehicle Crush	680 mm
Speed	98.3 km/h	Interior	
Angle	26.1 deg	OCDI	FS1112000
Exit Conditions		Max. Occ. Compartment	
Speed	73.7 km/h	Deformation	130 mm
Angle	5.2 deg		
Test Article		**Post-Impact Behavior**	
Deflections		(during 1.0 s after impact)	
Dynamic	N/A	Max. Yaw Angle	-33 deg
Permanent	N/A	Max. Pitch Angle	-12 deg
Working Width	0.59 m	Max. Roll Angle	15 deg

TEXAS TYPE 411 BRIDGE RAILS

Design and Construction

Texas Type T411 Bridge Rail

The Texas Type T411 Bridge Rail is constructed of reinforced concrete 813 mm (32 inches) high by 305 mm (12 inches) thick and contains 203 mm (8 inch) wide by 457 mm (18 inch) high openings at 457 mm (8 inch) center-to-center longitudinal spacing *(6)*.

Texas Type C411 Bridge Rail

The Texas Type C411 Bridge Rail is a combination traffic/pedestrian bridge rail and is constructed of reinforced concrete 1067 mm (42 inches) high by 305 mm (12 inches) thick and contains 152 mm (6 inch) wide by 711 mm (28 inch) high openings at 457 mm (18 inch) center-to-center longitudinal spacing. The Texas Type C411 is constructed with a sidewalk on the traffic side of the rail for accommodation of pedestrians *(7)*.

Texas Type F411 Bridge Rail

Both the Texas Type T411 and Texas Type C411 were tested and approved for *NCHRP Report 350* test level 2 conditions *(6, 7)*. The need for an aesthetic bridge rail to perform acceptably under the conditions of *NCHRP Report 350* test level 3 prompted the modification of the Texas Type T411 into the F411 *(8)*. The Texas Type F411 Bridge Rail, shown in Figure 10, is a 254 mm (10 inch) wide by 1.1 m (3.6 ft) high parapet wall with two concrete rails that project 152 mm (6 inches) toward the traffic side. The height of the lower rail is 0.5 m (1.6 ft) from the top of the deck and is 457 mm (18 inches) wide. The height of the upper rail is 1.1 m (3.6 ft) from the top of the deck and is 152 mm (6 inches) wide. The total width of the rail at the top is 0.4 m (1.3 ft). In addition, the rail is constructed with square aesthetic openings located between the projecting rails. These openings are 152 mm (6 inches) by 279 mm (11 inches) and are spaced 0.5 m (1.6 ft) apart. Details of the Texas Type F411 Bridge Rail are shown in Figure 11.

Crash Test Results

NCHRP Report 350 Test 3-11

In this test of the Texas Type F411 Bridge Rail, performed at Texas Transportation Institute, the bridge rail contained and redirected the pickup truck. No measurable deflection occurred. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Deformation of the occupant compartment was 118 mm (4.6 inches) in the instrument panel area and 105 mm (4.1 inches) in the firewall area. The factory-installed opening, which accommodates the manual transmission floor shift, tore at the forward and rear corners, increasing the opening to 180 mm (7.1 inches) long and 160 mm (6.3 inches) wide. (The dimensions of the factory-installed opening for the floor shift were originally 143 mm (5.6 inches) by 143 mm (5.6 inches).) No other separation in the floor pan or toe pan was noted. The pickup truck remained upright during and after the collision period. The pickup truck came to rest 67.5 m (221.5 ft) downstream of impact and 4.8 m (15.7 ft) forward of the traffic face of the bridge rail. Longitudinal occupant impact velocity was 7.5 m/s (24.6 ft/s) and longitudinal ridedown acceleration was -6.7 g's. Exit angle at loss of contact with the bridge rail was 4.5 degrees, which is 17 percent of the impact angle *(8)*.

As indicated in Table 2, the Texas Type F411 Bridge Rail met all required criteria for *NCHRP Report 350* test 3-11.

Figure 10. Texas Type F411 Bridge Rail.

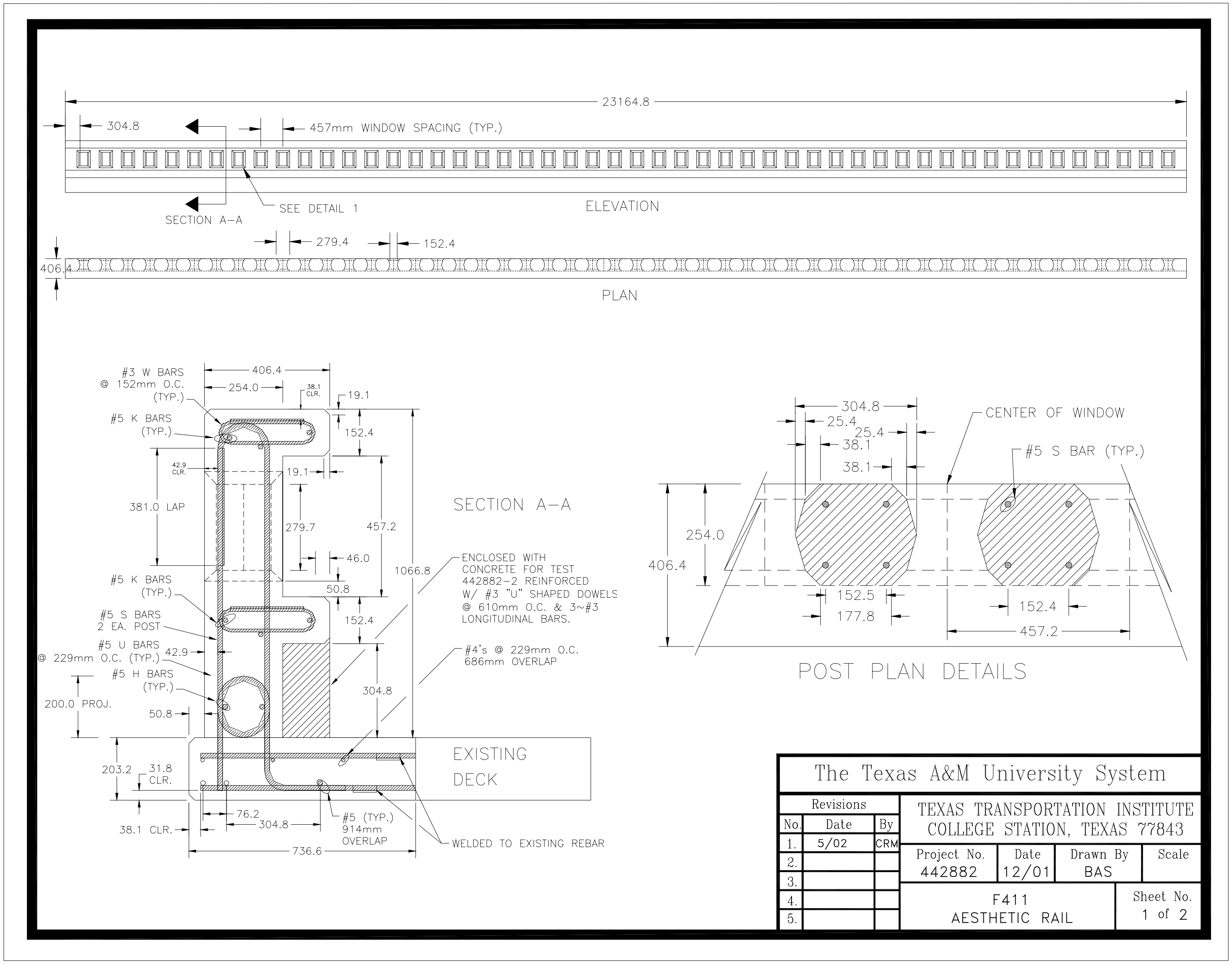

Figure 11. Details of Texas Type F411 Bridge Rail.

Table 2. Summary of Results for Texas Type F411 Bridge Rail *NCHRP Report 350* Test 3-11.

General Information	
Test Agency	Texas Transportation Institute
Test No.	442882-2
Date	07/18/02
Test Article	
Type	Bridge Rail
Name	Texas Type F411 Bridge Rail
Installation Length	23.2 m
Material or Key Elements	Concrete Bridge Rail With Two Concrete Rails and Aesthetic Openings
Soil Type and Condition	Concrete Footing, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1998 Chev. 2500 Pickup Truck
Mass	
Curb	2075 kg
Test Inertial	2052 kg
Dummy	N/A
Gross Static	2052 kg
Impact Conditions	
Speed	101.1 km/h
Angle	26.1 deg
Exit Conditions	
Speed	79.9 km/h
Angle	4.5 deg
Test Article Deflections	
Dynamic	None
Permanent	None
Working Width	0.52 m
Occupant Risk Values	
Impact Velocity	
x-direction	7.5 m/s
y-direction	8.7 m/s
THIV	41.0 km/h
Ridedown Accelerations	
x-direction	-6.7 g's
y-direction	8.0 g's
PHD	8.6 g's
ASI	1.76
Max. 0.050-s Average	
x-direction	-10.7 g's
y-direction	13.8 g's
z-direction	4.3 g's
Vehicle Damage	
Exterior	
VDS	11FL3
CDC	11FLAW3
Maximum Exterior Vehicle Crush	670 mm
Interior	
OCDI	LF2010000
Max. Occ. Compartment Deformation	118 mm
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle (deg)	33.5 deg
Max. Pitch Angle (deg)	-2.9 deg
Max. Roll Angle (deg)	-7.6 deg

TYPE 80SW BRIDGE RAIL WITH SIDEWALK

Design and Construction

The Type 80SW Bridge Rail with Sidewalk, shown in Figure 12, is a concrete beam and post bridge rail mounted on top of a concrete sidewalk. The bridge rail, which is 810 mm (32 inches) high, consists of a beam supported by 380 mm (15 inch) wide posts spaced 2.0 m (6.6 ft) apart. The sidewalk is 1500 mm (59 inches) wide and 225 mm (8 3/4 inches) high. The installation includes viewing spaces 280 mm (11 inches) high by 1620 mm (63 3/4 inches) long. A lower pedestrian rail is attached between the post elements. An upper pedestrian handrail is attached atop the upper concrete beam, making the total height of the bridge rail 1060 mm (41 3/4 inches) *(9)*. Details of the Type 80SW Bridge Rail with Sidewalk are shown in Figure 13.

Figure 12. Type 80SW Bridge Rail with Sidewalk.

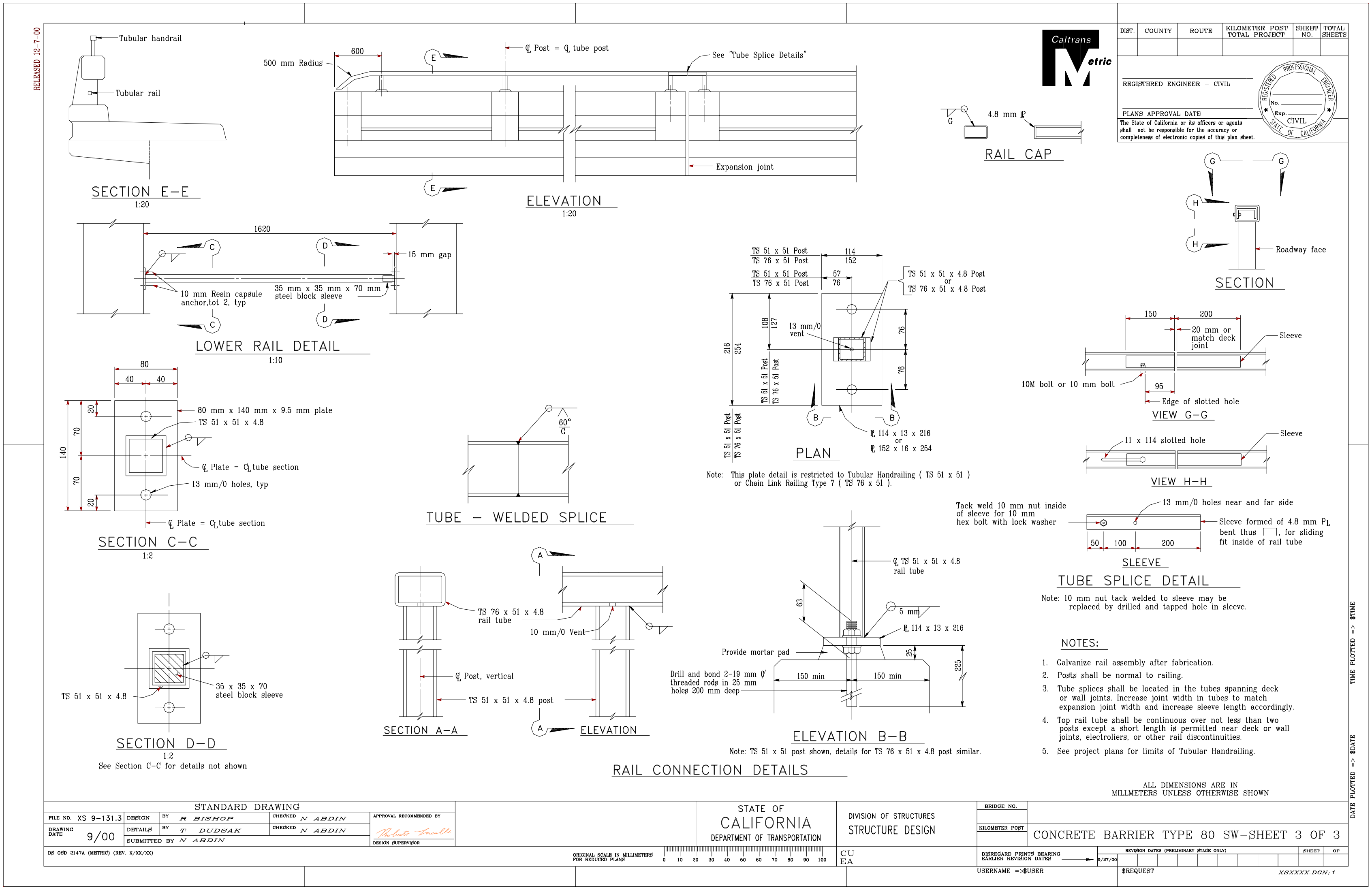

Figure 13. Details of Type 80SW Bridge Rail with Sidewalk.

Crash Test Results

NCHRP Report 350 Test 4-10

In this test of the Type 80SW Bridge Rail with Sidewalk, performed at California Department of Transportation, the installation contained and smoothly redirected the vehicle *(9)*. The impact resulted in a small amount of barrier spalling. Debris generated was insignificant. There was no significant deformation of the occupant compartment. Longitudinal occupant impact velocity was 5.98 m/s (19.6 ft/s) and longitudinal ridedown acceleration was -5.50 g's. The vehicle maintained a relatively straight course after exiting the barrier. The exit angle was 10 degrees, which was less than 60 percent of the impact angle.

The Type 80SW Bridge Rail with Sidewalk satisfied all requirements of *NCHRP Report 350* test designation 4-10. A summary of the crash test results is provided in Table 3.

NCHRP Report 350 Test 4-11

In this test of the Type 80SW Bridge Rail with Sidewalk, performed at California Department of Transportation, the vehicle was contained and smoothly redirected *(9)*. Only moderate amounts of spalling were created during impact. There was no significant debris from the vehicle. The vehicle hood snagged on the handrail, damaging but not penetrating the windshield. There was moderate occupant compartment deformation. The vehicle maintained a relatively straight course after exiting the barrier. Longitudinal occupant impact velocity was 9.37 m/s (30.7 ft/s) and longitudinal ridedown acceleration was -7.45 g's. Exit angle at loss of contact was 7 degrees, which was 28 percent of the impact angle.

The Type 80SW Bridge Rail with Sidewalk met all required criteria for *NCHRP Report 350* test designation 4-11. Table 4 presents a summary of the crash test results.

NCHRP Report 350 Test 4-12

The Type 80SW Bridge Rail with Sidewalk, tested at California Department of Transportation, contained and smoothly redirected the single-unit truck in this test *(9)*. There was not any significant debris from the test article and negligible deformation of the occupant compartment. The vehicle remained upright. The vehicle maintained a relatively straight course after exiting the barrier. Exit angle at loss of contact was 4 degrees, which was 27 percent of the impact angle.

The Type 80SW Bridge Rail with Sidewalk met all requirements for *NCHRP Report 350* test designation 4-12. A summary of the crash test results is shown in Table 5.

The FHWA approval letter for the Type 80SW Bridge Rail with Sidewalk can be accessed at: http://safety.fhwa.dot.gov/fourthlevel/hardware/barriers/pdf/b-53.pdf.

Table 3. Summary of Results for
Type 80SW Bridge Rail with Sidewalk *NCHRP Report 350* Test 4-10.

General Information		**Impact Conditions**	
Test Agency	California Department of Transportation	Speed	102.0 km/h
		Angle	20.0 deg
Test No.	541	**Exit Conditions**	
Date	12/10/97	Speed	75.0 km/h
Test Article		Angle	10.0 deg
Type	Bridge Rail	**Occupant Risk Values**	
Name	Type 80SW Bridge Rail with Sidewalk	Impact Velocity	
		x-direction	6.0 m/s
Installation Length	22.8 m	y-direction	6.3 m/s
Material or Key		Ridedown Accelerations	
Elements	Concrete Bridge Rail with Sidewalk and Vertical Openings	x-direction	-5.5 g's
		y-direction	-9.9 g's
Test Vehicle		Max. 0.050-s Average	
Type	Production	x-direction	-8.6 g's
Designation	820C	y-direction	-10.2 g's
Model	1992 Geo Metro	**Vehicle Damage**	
Mass		Exterior	
Curb	750 kg	VDS	FR5, RD4
Test Inertial	823 kg	CDC	02RFEW3
Dummy	75 kg	Interior	
Gross Static	898 kg	OCDI	RF0000000

Table 4. Summary of Results for
Type 80SW Bridge Rail with Sidewalk *NCHRP Report 350* Test 4-11.

General Information		**Impact Conditions**	
Test Agency	California Department of Transportation	Speed	110.2 km/h
		Angle	25.0 deg
Test No.	542	**Exit Conditions**	
Date	04/01/98	Speed	77.0 km/h
Test Article		Angle	7.0 deg
Type	Bridge Rail	**Occupant Risk Values**	
Name	Type 80SW Bridge Rail with Sidewalk	Impact Velocity	
		x-direction	9.4 m/s
Installation Length	22.8 m	y-direction	8.2 m/s
Material or Key		Ridedown Accelerations	
Elements	Concrete Bridge Rail with Sidewalk and Vertical Openings	x-direction	-7.5 g's
		y-direction	-12.8 g's
Test Vehicle		Max. 0.050-s Average	
Type	Production	x-direction	-9.3 g's
Designation	2000P	y-direction	-14.4 g's
Model	1993 Chev. 2500 Pickup Truck	**Vehicle Damage**	
Mass		Exterior	
Curb	1879 kg	VDS	FR5, RD6
Test Inertial	1954 kg	CDC	02FREW9
Dummy	N/A	Interior	
Gross Static	1954 kg	OCDI	RF2012110

Table 5. Summary of Results for Type 80SW Bridge Rail with Sidewalk *NCHRP Report 350* Test 4-12.

General Information	
Test Agency	California Department of Transportation
Test No.	543
Date	10/28/97
Test Article	
Type	Bridge Rail
Name	Type 80SW Bridge Rail with Sidewalk
Installation Length	22.8 m
Material or Key Elements	Concrete Bridge Rail with Sidewalk and Vertical Openings
Test Vehicle	
Type	Production
Designation	8000S
Model	1992 GMC Single-Unit Truck
Mass	
Curb	5102 kg
Test Inertial	8020 kg
Dummy	N/A
Gross Static	8020 kg
Impact Conditions	
Speed	80.8 km/h
Angle	15.0 deg
Exit Conditions	
Speed	72.0 km/h
Angle	2.0 deg
Occupant Risk Values	
Impact Velocity	
x-direction	Not measured
y-direction	Not measured
Ridedown Accelerations	
x-direction	Not measured
y-direction	Not measured
Max. 0.050-s Average	
x-direction	Not measured
y-direction	Not measured
Vehicle Damage	
Interior	
OCDI	RF0000000

TEXAS T203 (T202 (MOD)) BRIDGE RAIL

Design and Construction – Test 1

The bridge deck cantilever constructed for this project was 721 mm (2 ft-4 3/8 inches) in width and 203 mm (8 inches) thick. The bridge deck was constructed immediately adjacent to an existing concrete runway located at the TTI test facility. The concrete deck was anchored into the existing runway with #16 (#5) steel reinforcement in the bottom layer in the deck overhang. The transverse reinforcement in the top and bottom layers of reinforcing in the deck cantilever consisted of #19 (#6) glass fiber reinforced polymer (GFRP) bars spaced 140 mm (5 1/2 inches) apart. The longitudinal reinforcement in the top of the deck cantilever consisted of #16 (#5) GFRP bars spaced 229 mm (9 inches) apart. The longitudinal reinforcement in the bottom of the deck consisted of two #16 (#5) bars on the field side of the deck spaced 75 mm (3 inches) apart with the next adjacent #16 (#5) bar spaced 305 mm (12 inches) toward the traffic face. Transit Mix Concrete and Materials, Bryan, Texas, provided the concrete used for this project. TxDOT Class "S" concrete was used to construct the deck cantilever. The average compressive strength of the Class "S" concrete exceeded the required strength of 28 MPa (4000 psi) at the time the test was performed *(10)*.

The T202 (MOD) bridge rail consists of a 343 mm × 356 mm (1 ft-1 1/2 inch × 1 ft-2 inch) concrete bridge rail supported by 191 mm × 1524 mm (7 1/2 inch × 5 ft-0 inch) concrete posts spaced 1524 mm (5 ft-0 inch) apart. The total height of the T202 (MOD) bridge rail was 686 mm (2 ft-3 inches). Two separate designs were constructed within this test installation. The details of the maximum strength design (C_E = 0.7) are reported herein. For the maximum strength design, vertical reinforcement in each post consisted of 17 #19 (#6) "L" shaped GFRP bars equally spaced on the front face (traffic side) and nine straight #16 (#5) GFRP bars equally spaced on the back face (field side). Longitudinal reinforcement in each post consisted of a #13 (#4) GFRP bar located on the front and back faces. Reinforcement in the rail consisted of four longitudinal #16 (#5) GFRP bars equally spaced on both the front and back faces of the rail (eight total). This longitudinal reinforcement was enclosed by #13 (#4) GFRP stirrups spaced 114 mm (4 1/2 inches) apart. Each stirrup was constructed using two "U" shaped bars that were lapped together on the vertical faces of the rail. Hughes Brothers in Seward, Nebraska, provided all the GFRP reinforcement used for this project. TxDOT Class "C" concrete was used to construct the bridge rail. The average compressive strength of the Class "C" concrete exceeded the required strength of 25 MPa (3600 psi) at the time the test was performed. Please refer to Figure 14 for additional details. Figure 15 shows photographs of the completed installation.

Crash Test Results

NCHRP Report 350 Test 3-11

The TxDOT T202 (MOD) bridge rail with GFRP reinforcement contained and redirected the 2042 kg (4498-lb) pickup truck. The vehicle did not penetrate, underride, or override the bridge rail. No measurable deflection was noted. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 128 mm (5.0 inches) in the floor pan to instrument panel on the left side near the driver's feet. The 2042 kg (4498-lb) pickup truck rolled onto its left side after exiting the installation. The vehicle subsequently came to rest on the left side, 52.6 m (172.5 ft) downstream of impact and 9.5 m (31.2 ft) forward of the traffic face of the rail. Longitudinal occupant impact velocity was 6.2 m/s (20.3 ft/s) and longitudinal occupant ridedown acceleration was -5.3 g's. Exit angle at loss of contact was 18.9 degrees, which was 72 percent of the impact angle.

As seen in Table 6, the TxDOT T202 (MOD) bridge rail with GFRP reinforcement did not pass the required specifications for occupant risk during *NCHRP Report 350* Test 3-11 due to rollover.

No significant structural damage occurred to the rail or the deck. There was no indication that the GFRP exhibited any undesirable traits.

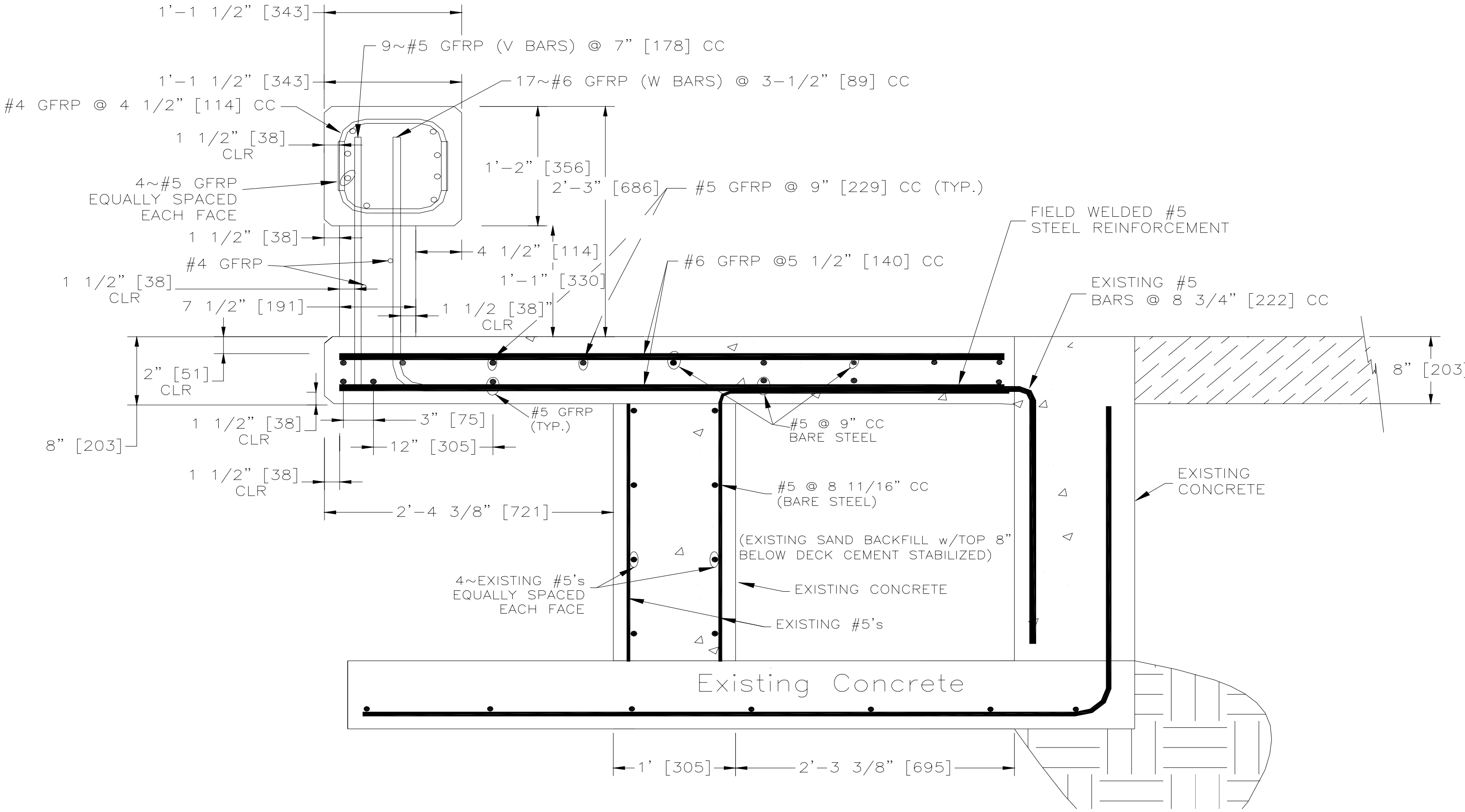

Figure 14. Details of Texas T202 (MOD) Bridge Rail with GFRP.

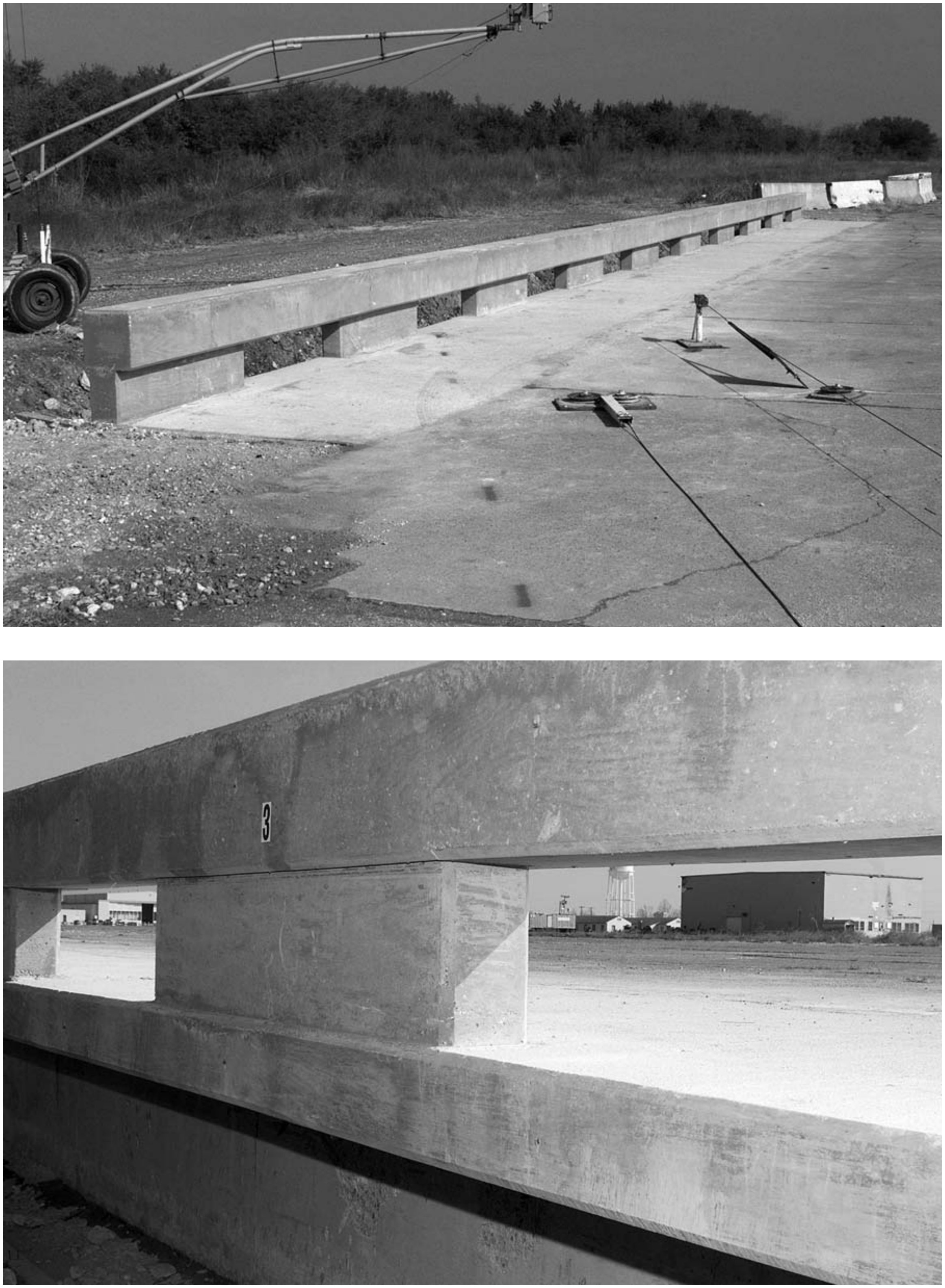

Figure 15. Texas T202 (MOD) Bridge Rail with GFRP.

Table 6. Summary of Results for Texas T202 (MOD) Bridge Rail with GFRP *NCHRP Report 350* Test 3-11.

General Information	
Test Agency	Texas Transportation Institute
Test No.	441382-1
Date	03/12/02
Test Article	
Type	Bridge Rail
Name	T202(M) Bridge Rail With GFRP
Installation Length	28.96 m
Material or Key Elements	T202(M) Concrete Bridge Rail With GFRP Reinforcement
Soil Type and Condition	Concrete Footing
Test Vehicle	
Type	Production
Designation	2000P
Model	1998 Chevrolet 2500 Pickup
Mass (lbs)	
Curb	2133 kg
Test Inertial	2042 kg
Dummy	N/A
Gross Static	2042 kg
Impact Conditions	
Speed (mi/h)	101 km/h
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	Not Attainable
Angle (deg)	Not Attainable
Test Article Deflections	
Dynamic	None
Permanent	None
Working Width	N/A

Occupant Risk Values	
Impact Velocity	
x-direction	6.2 m/s
y-direction	7.0 m/s
THIV (mi/h)	33.3 km/h
Ridedown Accelerations	
x-direction	-5.3 g's
y-direction	7.4 g's
PHD	7.7 g's
ASI	1.49
Max. 0.050-s Average	
x-direction	-10.3 g's
y-direction	11.2 g's
z-direction	-4.1 g's
Vehicle Damage	
Exterior	
VDS	11FL3
CDC	11FFAO3
Maximum Exterior Vehicle Crush	580 mm
Interior	
OCDI	LF0115000
Max. Occ. Compart. Deformation	128 mm
Post-Impact Behavior (during 1.0 s after impact)	
Max. Yaw Angle	80.6 deg
Max. Pitch Angle	-5.9 deg
Max. Roll Angle	-89.9 deg

Design and Construction – Test 2 – 762 mm (30 inch) High T202 (MOD)

The bridge deck cantilever constructed for this project was 721 mm (2 ft-4 3/8 inches) in width and 203 mm (8 inches) thick. The bridge deck was constructed immediately adjacent to an existing concrete runway located at the TTI test facility. The concrete deck was anchored into the existing runway with #16 (#5) steel reinforcement in the bottom layer in the deck overhang. The transverse reinforcement in the top and bottom layers of reinforcing in the deck cantilever consisted of #19 (#6) GFRP bars spaced 140 mm (5 1/2 inches) apart. The longitudinal reinforcement in the top of the deck cantilever consisted of #16 (#5) GFRP bars spaced 229 mm (9 inches) apart. The longitudinal reinforcement in the bottom of the deck consisted of two #16 (#5) bars on the field side of the deck spaced 75 mm (3 inches) apart with the next adjacent #16 (#5) bar spaced 305 mm (12 inches) toward the traffic face. Transit Mix Concrete and Materials, Bryan, Texas, provided the concrete used for this project. TxDOT Class “S” concrete was used to construct the deck cantilever. The average compressive strength of the Class “S” concrete exceeded the required strength of 28 MPa (4000 psi) at the time the test was performed.

The T202 (MOD) bridge rail consists of a 343 mm × 356 mm (1 ft-1 1/2 in. × 1 ft-2 inches) concrete bridge rail supported by 191 mm × 1524 mm (7 1/2 in. × 5 ft-0 inch) concrete posts spaced 1524 mm (5 ft-0 inch) apart. The total height of the T202 (MOD) bridge rail was 686 mm (2 ft-3 inches). Researchers constructed two separate designs within this test installation. The details of the reduced strength design (C_E = 1.0) are reported herein. For details of both designs, please refer to the drawings shown as Figure B-1 in this report. For the reduced strength design, vertical reinforcement in each post consisted of 13 #19 (#6) “L” shaped GFRP bars equally spaced on the front face (traffic side) and nine straight #16 (#5) GFRP bars equally spaced on the back face (field side). Longitudinal reinforcement in each post consisted of a #13 (#4) GFRP bar located on the front and back faces. Reinforcement in the rail consisted of four longitudinal #13 (#4) GFRP bars equally spaced on both the front and back faces of the rail (eight total). This longitudinal reinforcement was enclosed by #13 (#4) GFRP stirrups spaced 114 mm (4 1/2 inches) apart. Researchers constructed each stirrup using two “U” shaped bars that were lapped together on the vertical faces of the rail. Hughes Brothers in Seward, Nebraska, provided all the GFRP reinforcement used for this project. TxDOT Class “C” concrete was used to construct the bridge rail. The average compressive strength of the Class “C” concrete exceeded the required strength of 25 MPa (3600 psi) at the time the test was performed.

In an effort to enhance vehicle performance, the height of the rail was increased to 762 mm (30 inches). This modification was achieved by attaching a TS 152 mm × 76 mm × 6 mm (TS6×3×1/4) steel tube to the top of the concrete rail and flush with the traffic face of the rail. The steel tube was anchored to the top of the concrete rail using 19 mm (3/4-inch) diameter Hilti Kwik Bolt II anchor bolts spaced 0.76 m (2 ft-6 inches) apart. Please refer to Figure 16 for additional details. Figure 17 shows photographs of the completed installation.

Crash Test Results

NCHRP Report 350 Test 3-11 (Test 2 — 762 mm (30 inch) High T202 (MOD))

The TxDOT 762 mm (30-inch) high T202 (MOD) with GFRP reinforcement contained and redirected the 2044 kg (4502-lb) pickup truck. The vehicle did not penetrate, underride, or override the bridge rail. No measurable deflection was noted. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 143 mm (5.6 inches) in the kickpanel area on the passenger’s side. The 2044 kg (4502-lb) pickup truck remained upright during and after exiting the installation. The vehicle subsequently came to rest upright, 57.2 m (187.7 ft) downstream of impact and 4.8 m (15.7 ft) forward of the traffic face of the rail. Longitudinal occupant impact velocity was 6.5 m/s (21.3 ft/s), and longitudinal occupant ridedown acceleration was -4.6 g’s. Exit angle at loss of contact was 14.2 degrees, which was 57 percent of the impact angle.

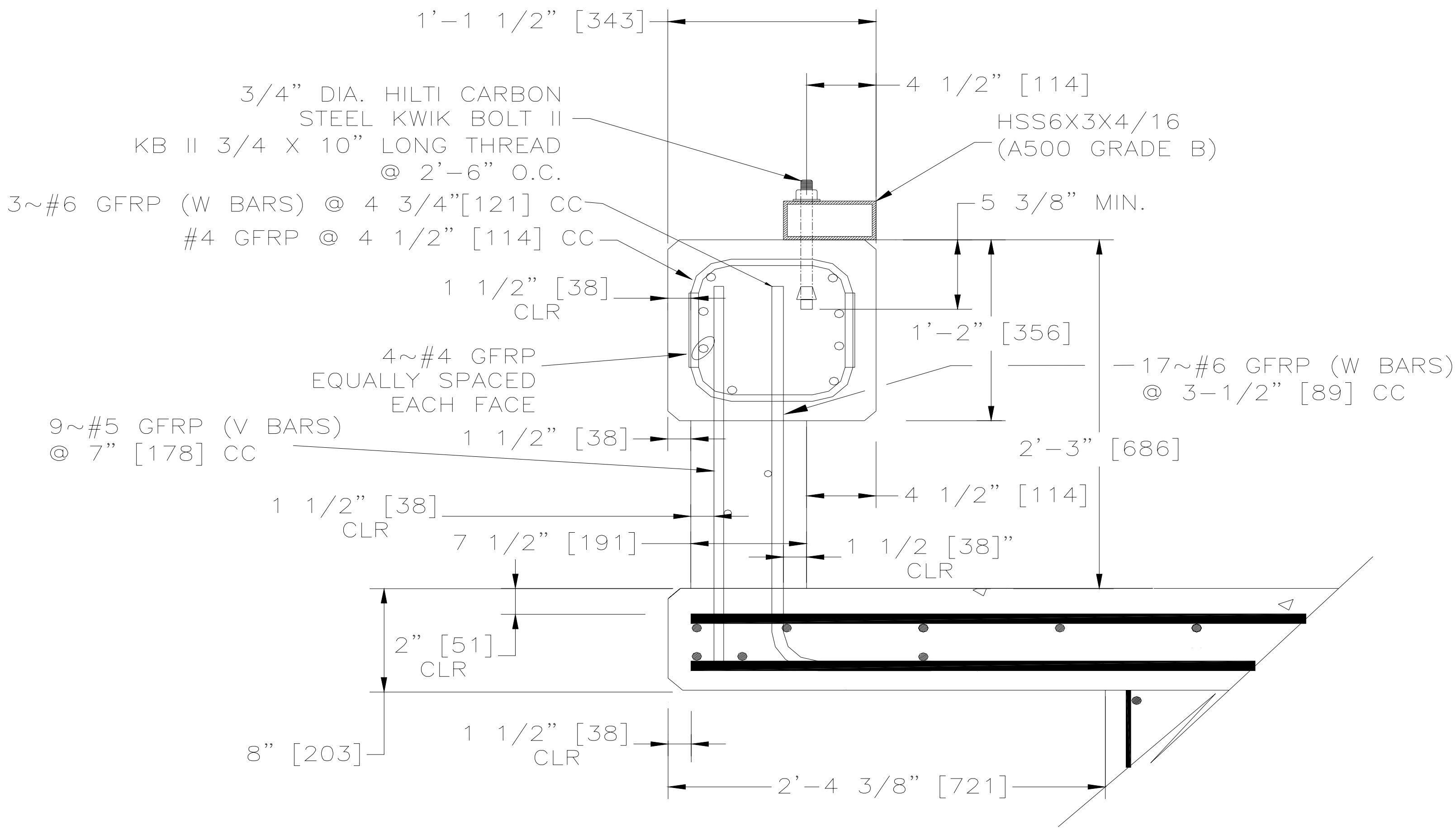

Figure 16. Details of Texas T202 (MOD) Bridge Rail with GFRP and Metal Rail.

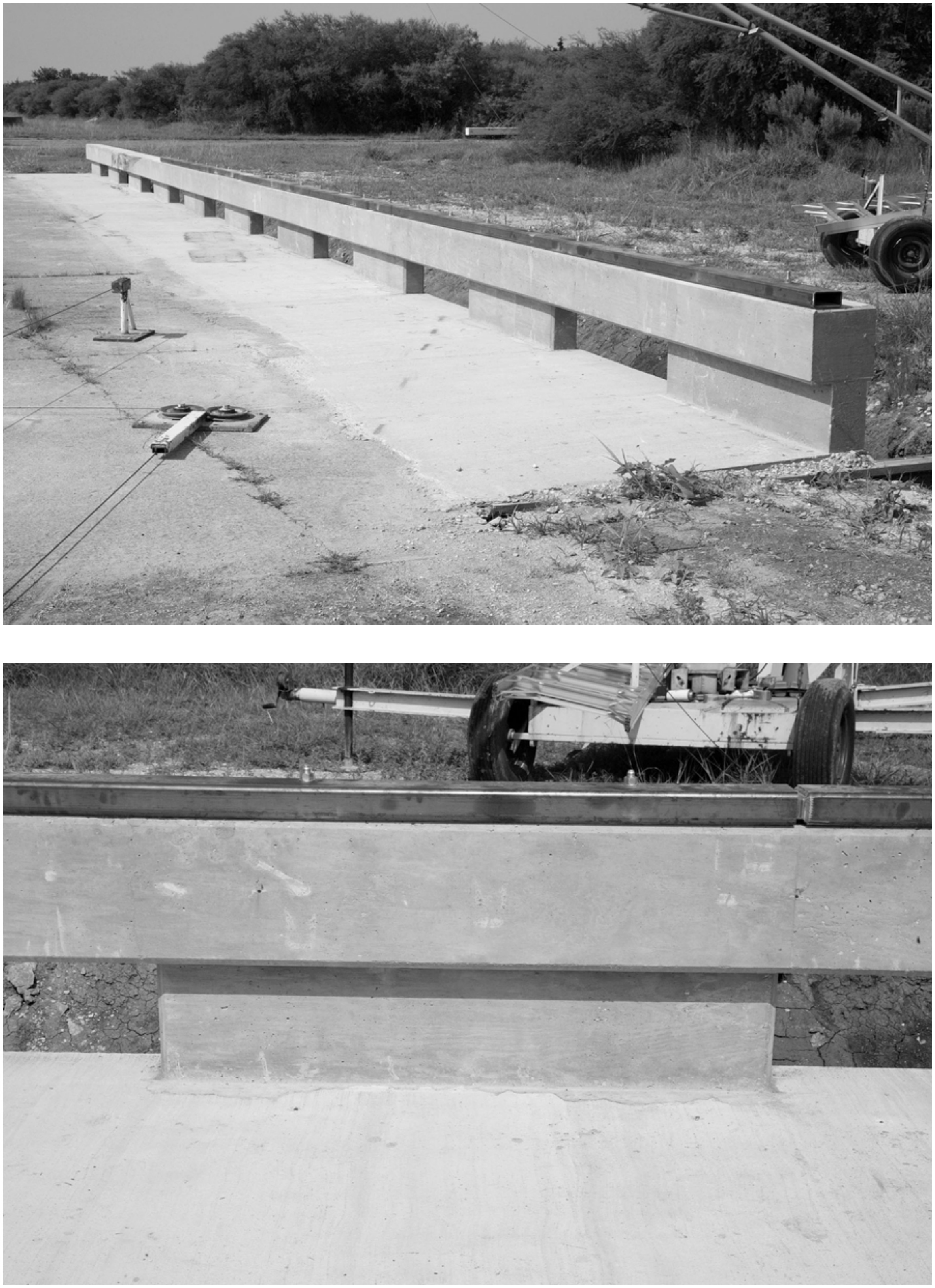

Figure 17. Texas T202 (MOD) Bridge Rail with GFRP and Metal Rail.

As seen in Table 7, the TxDOT T202 (MOD) bridge rail with GFRP reinforcement with metal rail on top passed the required specifications for occupant risk during *NCHRP Report 350* Test 3-11. No significant structural damage occurred to the rail or the deck. There was no indication that the GFRP exhibited any undesirable traits.

Table 7. Summary of Results for
Texas T202 (MOD) Bridge Rail with GFRP and Metal Rail
***NCHRP Report 350* Test 3-11.**

General Information		**Occupant Risk Values**	
Test Agency	Texas Transportation Institute	Impact Velocity	
Test No.	441382-2	x-direction	6.5 m/s
Date	06/14/02	y-direction	7.3 m/s
Test Article		THIV (mi/h)	34.6 km/h
Type	Bridge Rail	Ridedown Accelerations	
Name	T202(M) Bridge Rail With GFRP	x-direction	-4.6 g's
	And Metal Rail	y-direction	-7.0 g's
Installation Length (ft).	95 (29.0 m)	PHD (g's)	7.5 g's
Material or Key	T202(M) Concrete Bridge Rail	ASI	1.62
Elements	With GFRP Reinforcement And	Max. 0.050-s Average	
	Metal Rail	x-direction	-10.6 g's
Soil Type and		y-direction	-11.8 g's
Condition	Concrete Footing	z-direction	-4.0 g's
Test Vehicle		**Vehicle Damage**	
Type	Production	Exterior	
Designation	2000P	VDS	
Model	1997 Chevrolet 2500 Pickup	CDC	01FR3
Mass (lbs)		Maximum Exterior	01FREW3
Curb	4761 (2162 kg)	Vehicle Crush (in)	
Test Inertial	4501 (2044 kg)	Interior	5.6 (143 mm)
Dummy	N/A	OCDI	
Gross Static	4501 (2044 kg)	Max. Occ. Compart.	RF0111000
Impact Conditions		Deformation (in)	
Speed (mi/h)	62.6 (100.7 km/h)	**Post-Impact Behavior**	23.4 (600
Angle (deg)	25.0	(during 1.0 s after impact)	mm)
Exit Conditions		Max. Yaw Angle (deg)	
Speed (mi/h)	41.6 (66.9 km/h)	Max. Pitch Angle (deg)	
Angle (deg)	14.2	Max. Roll Angle (deg)	-44.1
Test Article Deflections			-3.6
Dynamic	None		15.4
Permanent	None		
Working Width	0.49 m		

BRIEF OVERVIEW

Of the four (4) crash tested bridge rails reviewed, the Texas 203 (TxDOT T202 (MOD)) and the California 80SW are the most similar to the FDOT variant of the MKC bridge rail. The profile of the Texas 203 with the attached structural tube presented to the impacting pickup is 51 mm (2 inches) shorter than the FDOT variant of the MKC. In the Texas T203, the post offset prevents wheel snagging and the curb prevents wheel interaction on the Florida variant of the MKC. The California 80SW has a curb that extends in front of the top beam with a slightly larger offset between the post and beam but the opening size is taller. Both the California 80SW and the Florida variant of the MKC are 810 mm (32 inches) tall.

As one reviews the *AASHTO LRFD Bridge Design Specifications* Figures A13.1.1-2 and A13.1.1-3, also reproduced in Figures 3 and 4 of this report, the anticipated performance should be good. With only 150 mm (6 inches) of clear vertical opening, the Florida variant of the MKC will always fall in the LOW POTENTIAL for snagging section of Figure A13.1.1-2. Furthermore, in the same figure, it should be noted there is low potential for wheel snagging with less than 250 mm (10 inches) of vertical clear opening, independent of post setback distance and vertical location of the opening. In Figure A13.1.1-3 for the Florida variant of the MKC, the A/H ratio is 0.8125 and the post setback distance is 38 mm (1.5 inches). This can be extrapolated just off the top of the chart and will fall in the acceptable (shaded) portion of the chart. This information is shown in Figure 18 below.

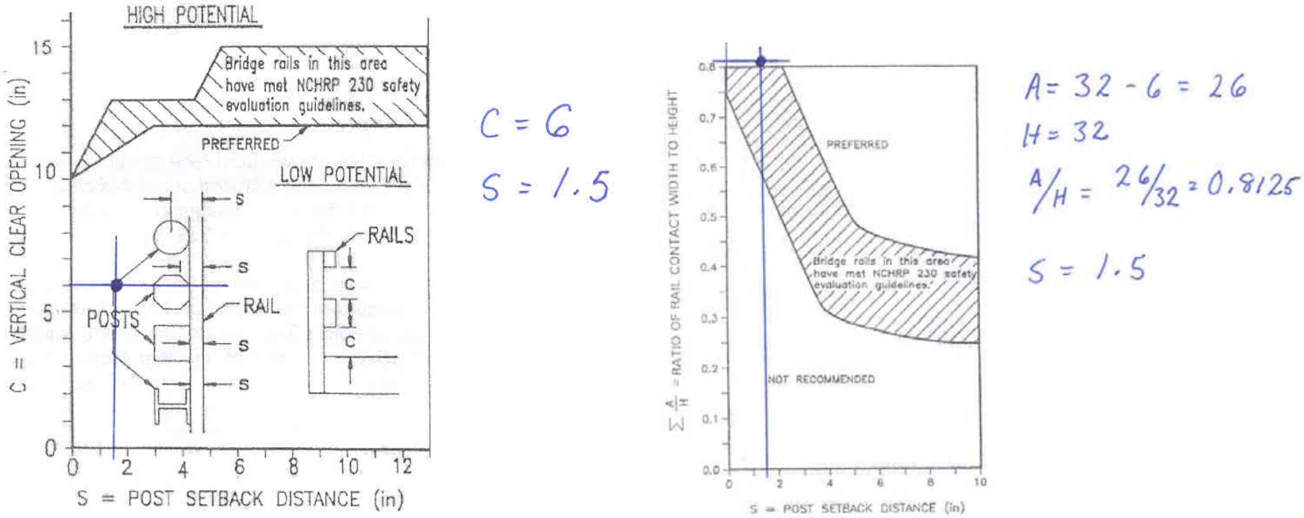

Figure 18. Anticipated Performance *AASHTO LRFD Bridge Design Specifications* Figures A13.1.1-2 and A13.1.1-3.

CHAPTER 5. SUMMARY AND CONCLUSION OF THE ANTICIPATED IMPACT PERFORMANCE OF THE FDOT VARIANT MKC BRIDGE RAIL

The FDOT variant of the MKC is similar to the previously crash tested Texas T203 (T202 (MOD)) and the California 80SW bridge rail. Offset between the post and beam on the T203 is 114 mm (4 1/2 inches) and 38 mm (1.5 inches) on the Florida variant of the MKC. The post height is 330 mm (13 inches) on both the T203 and the Florida variant of the MKC. However, portions of the openings on the FDOT variant of the MKC have been reduced by the placement of a 152 mm (6 inch) curb in the openings, this modification should enhance impact performance by reducing the snagging potential. The beam depth is also 51 mm (2 inches) greater on the FDOT variant of the MKC than the successfully crash tested Texas T203 bridge rail. This feature should again enhance the anticipated crash performance of the FDOT variant of the MKC bridge rail when compared to the T203. The California 80SW has a curb that extends in front of the top beam and slightly larger offset between the post and beam but the opening size is taller. Both the California 80SW and the Florida variant of the MKC are 810 mm (32 inches) tall. The curb and the shorter opening of the Florida variant of the MKC should produce similar crash test results to the California 80SW bridge rail.

Based on the comparison to the previously tested bridge rails and the design guidelines outlined in Chapter 13 of the *AASHTO LRFD Bridge Design Specifications*, the FDOT variant of the MKC bridge rail is believed to meet the crash test performance of *NCHRP Report 350*.

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