Development of a TL-3 Deep Beam Tubular Backup Bridge Rail

Final Report

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<tr><td colspan="4">16. Abstract
The objective of this study is to investigate the performance of the Ohio Department of Transportation (ODOT) Deep Beam bridge rail system per the National Cooperative Highway Research Program (NCHRP) Report 350 TL-3. Analytical study, computer simulation, and testing approach are to be addressed to accomplish the objective of this study. The final expected product is a design of the ODOT Deep Beam bridge rail system with any needed retrofit that will bring the system in compliance with the NCHRP Report 350 performance criteria per TL-3.
The modified ODOT Deep Beam bridge rail design is shown to be successfully able to pass NCHRP Report 350 Test Level 3 assessment criteria. This conclusion is based on engineering strength analysis and nonlinear finite element simulation. The added rail on the top of the bridge rail helped reduced potential vehicular dynamics instability that may occur if only the original rail (less height) was used. Also, the additional lower rail (rub rail) provided protection against tire snagging in the opening below the main rail and the deck. This snagging mode could be detrimental for small vehicle impacts due to the subsequent excessive deformation and increased ridedown acceleration.
This system can be implemented in the field subsequent to Federal Highway Administration (FHWA) Office of Safety approval of the simulation results presented herein or the full scale crash tests that were recommended. The modified design presented herein represents a retrofit that can be installed by a qualified construction crew.
The research team recommends using the ODOT transition GR-3.4. A modification is suggested for that transition detail to accommodate the added top and rub rails in the modified ODOT Deep Beam bridge rail. One example would be to turn the top rail toward the middle rail at an angle and to extend the rub rail along a few transition posts and then turn it back toward the field side.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

DEVELOPMENT OF A TL-3 DEEP BEAM TUBULAR BACKUP BRIDGE RAIL

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1. INTRODUCTION

1.1. STATEMENT OF THE PROBLEM

The Ohio Department of Transportation's (ODOT) Office of Structural Engineering has a need to evaluate and, if necessary, improve an existing bridge rail design with, ideally, a simple retrofitting procedure to meet current or proposed crash testing standards. This bridge rail, as shown in Figure 3.1 from the ODOT Standard Bridge Drawing DBR-2-73 *(1)* (APPENDIX A), has been accepted to the *National Cooperative Highway Research Program* (NCHRP) *Report 350 (2)* Test Level (TL) 2 acceptance. For this reason, the bridge rail cannot be constructed or—more importantly, cannot remain—in many locations.

The current policy for bridge rail requires upgrading non-conforming railing systems to the TL-3 acceptance level during certain types of structural rehabilitations. When the recommended structural rehabilitation involves refinishing or overlaying the concrete bridge wearing surface, the resulting upgrade to the railing system will require complete removal and replacement of the concrete deck edges to accommodate the new railing anchorages. When the main structural elements are precast, prestressed concrete box beams, the fascia beams will require complete removal and replacement to accommodate the new railing anchorages. The costs associated with such railing upgrades will often exceed the allotted budget for the project, resulting in rehabilitations that are not performed and non-conforming railing systems left in service.

1.2. FOCUS OF THE STUDY

The objective of this study is to investigate the performance of the ODOT Deep Beam bridge rail system per the *NCHRP Report 350* TL-3. Analytical study, computer simulation, and testing approach are followed to accomplish the objective of this study. The final expected product is a design of the ODOT Deep Beam bridge rail system with any needed retrofit that will bring the system in compliance with the *NCHRP Report 350* performance criteria per TL-3.

2. RESEARCH OBJECTIVES

The research plan for accomplishing the project objective to investigate the ODOT Deep Beam bridge rail system per the *NCHRP Report 350* TL-3 consisted of two phases, as detailed below.

2.1. PHASE 1

In this phase the researchers reviewed and analyzed the ODOT Deep Beam bridge rail. Based on the review, the research team developed a retrofit design for the ODOT Deep Beam bridge rail. Once the design was selected, computer simulation was conducted to evaluate the performance of the design per the *NCHRP Report 350* criteria.

2.1.1 Task 1

In this Task, the research team reviewed available literature to identify performance issues related to the deep beam tubular backup design, including the original Texas Department of Transportation (TxDOT) Type T101 design and the original ODOT bridge rail design. Other sources were the Federal Highway Administration's (FHWA) theoretical evaluation of the system and Battelle Memorial Institute's recent research *(3)* on the roadside application and its associated research on the corresponding bridge terminal assembly (transition). Additionally, similar side-mounted railing hardware were reviewed to identify performance limits and issues with these types of bridge rails.

2.1.2 Task 2

The researchers performed structural analyses of the current design, including post mounting methods to develop concepts for improving the design. Strength and capacity analyses were performed to identify performance limits of the railing system. This included checking for potential pocketing for the small car impact per the American Association of State Highway and Transportation Officials (AASHTO) *Load Resistance Factor Design* (*LRFD*) *Bridge Design Specifications (4)*. Finite element (FE) simulation of promising concepts was performed to predict performance in actual crash testing. LS-DYNA FE code was used to simulate the *NCHRP Report 350* TL-3 impact conditions (tests 3-10 and 3-11). Models developed by Battelle Memorial Institute for ODOT's Type 5 Guardrail with Tubular Backup were utilized. However, model changes and augmentations reflected the railing system components. The spacers, anchor bolts, and the concrete deck with rebars were additional components incorporated into the model of this railing system. The deck model included concrete material model as much as possible to capture anchor bolts-deck interaction. After altering the element models to represent the rail and mounting conditions under scrutiny, the most promising simulated design was presented to FHWA for their acceptance. If FHWA requires a crash test to verify the simulation, Phase 2 may be authorized by ODOT's Office of Research and Development (R&D). An interim report was submitted at the conclusion of Phase 1 for ODOT review and approval. If Phase 2 is not approved, the interim report will be published as the final report and this project is finalized. The researcher will deliver all other pertinent deliverables to ODOT. If Phase 2 is approved, the interim report will serve as a basis for the final report to be presented at the end of Phase 2.

2.2. PHASE 2

This phase is meant for crash testing of a single design and is subject to successful completion of Phase 1 above. Written authorization from ODOT's Office of R&D must be received before proceeding with Phase 2.

2.2.1 Task 1

If FHWA acceptance was not granted based on the analytical design, *NCHRP Report 350* test 3-10 and test 3-11 crash tests will be conducted on the bridge rail by the Texas Transportation Institute (TTI). This includes building a test article, procurement of a test vehicle, and conducting a crash test. All necessary test data, including cameras, film, data recorders, etc. to develop a FHWA acceptable crash test report will be generated and reported.

Specifically, TTI will build a 75 ft (23 m) long test installation of the ODOT Deep Beam bridge rail. The construction and fabrication costs include all parts, materials, fabrication, and labor required to build reinforced deck cantilever and attached side-mounted deep beam tubular bridge rail as specified on ODOT Standard Drawing DBR-2-73 (*1*). The cost estimate assumes a bridge deck cantilever width up to 30 inches (0.76 m), deck thickness less than or equal to 18 inches (0.46 m), standard ODOT deck reinforcement, and Type 2 bridge rail posts. Other deck and rail configurations can be accommodated as requested by ODOT and agreed upon by TTI.

The two crash tests are *NCHRP Report 350* Test 3-10: 1807 lb (820 kg) passenger car impacting the barrier at 62 mi/h (100 km/h) and 20 degrees; and *NCHRP Report 350* Test 3-11: 4408 lb (2000 kg), standard cab pickup truck impacting the bridge at 62 mi/h (100 km/h) and 25 degrees.

2.2.2 Task 2

Upon completion of crash testing the research team will return the crash site to a level acceptable to the test agency (e.g., demolition of bridge rail and salvage of vehicle, etc.). If the testing was successful, the research team will submit all relevant data to FHWA (or its consultant) for approval. Once the system design is approved by FHWA to TL-3, a final report will be completed, including engineering drawings, complete material and post mounting specifications. If the testing was unsuccessful or FHWA declines to accept the design as TL-3, the researcher will prepare a final report on all aspects of Phase 1 and 2, and include analysis of design problems and recommendations on how to overcome these issues.

2.3. REPORT SCOPE

This report documents the research efforts, findings, and recommendations of this project. The report includes details of the state-of-practice of deep beam rail, the engineering analyses and design retrofit candidates for the ODOT Deep Beam rail, and finite element modeling.

3. LITERATURE REVIEW

3.1. BACKGROUND OF BRIDGE RAIL DESIGN GUIDELINES

Guidelines and existing bridge rail designs that are relevant to this study were reviewed to investigate the performance aspects of similar railing systems. The current guideline for evaluating bridge rail (and roadside safety structures in general) is *NCHRP Report 350* "Recommended Procedures for the Safety Performance Evaluation of Highway Features" *(2)*. *NCHRP Report 350* recommends certain test conditions for different test levels. The conditions pertaining to this project are those for TL-3 for longitudinal barrier (length of need), as shown in Table 3.1.

Table 3.1 Condition of TL-3 for longitudinal barrier

Test Designation	Vehicle	Nominal speed	Nominal angle (degree)
3-10	1807 lb (820 kg) (designated as 820C)	62 mi/h (100 km/h)	20
3-11	4408 lb (2000 kg) (designated as 2000P)	62 mi/h (100 km/h)	25

The other guideline referenced herein is the 1989 AASHTO *Guide Specifications for Bridge Railings (5)*. Two performance levels are of relevance to this review, Performance Level 1 (PL-1) and Performance Level 2 (PL-2), as shown in Table 3.2.

Table 3.2 Condition of PL-1 and PL-2 for longitudinal barrier

Performance Level	Vehicle	Nominal speed	Nominal angle (degree)
PL-1 small automobile	1800 lb (817 kg)	50 mi/h (81 km/h)	20
PL-1 pickup truck	5400 lb (2450 kg)	45 mi/h (72 km/h)	20
PL-2 small automobile	1800 lb (817 kg)	60 mi/h (97 km/h)	20
PL-2 pickup truck	5400 lb (2450 kg)	60 mi/h (97 km/h)	20

Although the *AASHTO Guide (5)* uses a heavier pickup truck, the 5 degrees extra on the impact angle of test 3-11 in *NCHRP Report 350* increases the impact severity since it is related to the square of the lateral component of the impact velocity.

3.2. SIGNIFICANCE OF WORK

The ODOT Deep Beam bridge rail system *(1)* consists of a standard W-beam rail element attached to a longitudinal TS 8×4×3/16 inch (203×101×4.8 mm) tubing. These elements are attached to a W6×25 (W150×37.1) steel post with an additional two 6 inches (152.4 mm) long TS 8×4×3/16 inch (203×101×4.8 mm) that serve to block the railing members out from the post. The post itself is mounted to the side of the bridge deck by four anchor bolts, as shown in Figure

3.1(a). The side mounting can also be achieved by adding a trapezoidal spacer between the post and the deck as shown in Figure 3.1(b). The system has not been tested to *NCHRP Report 350*.

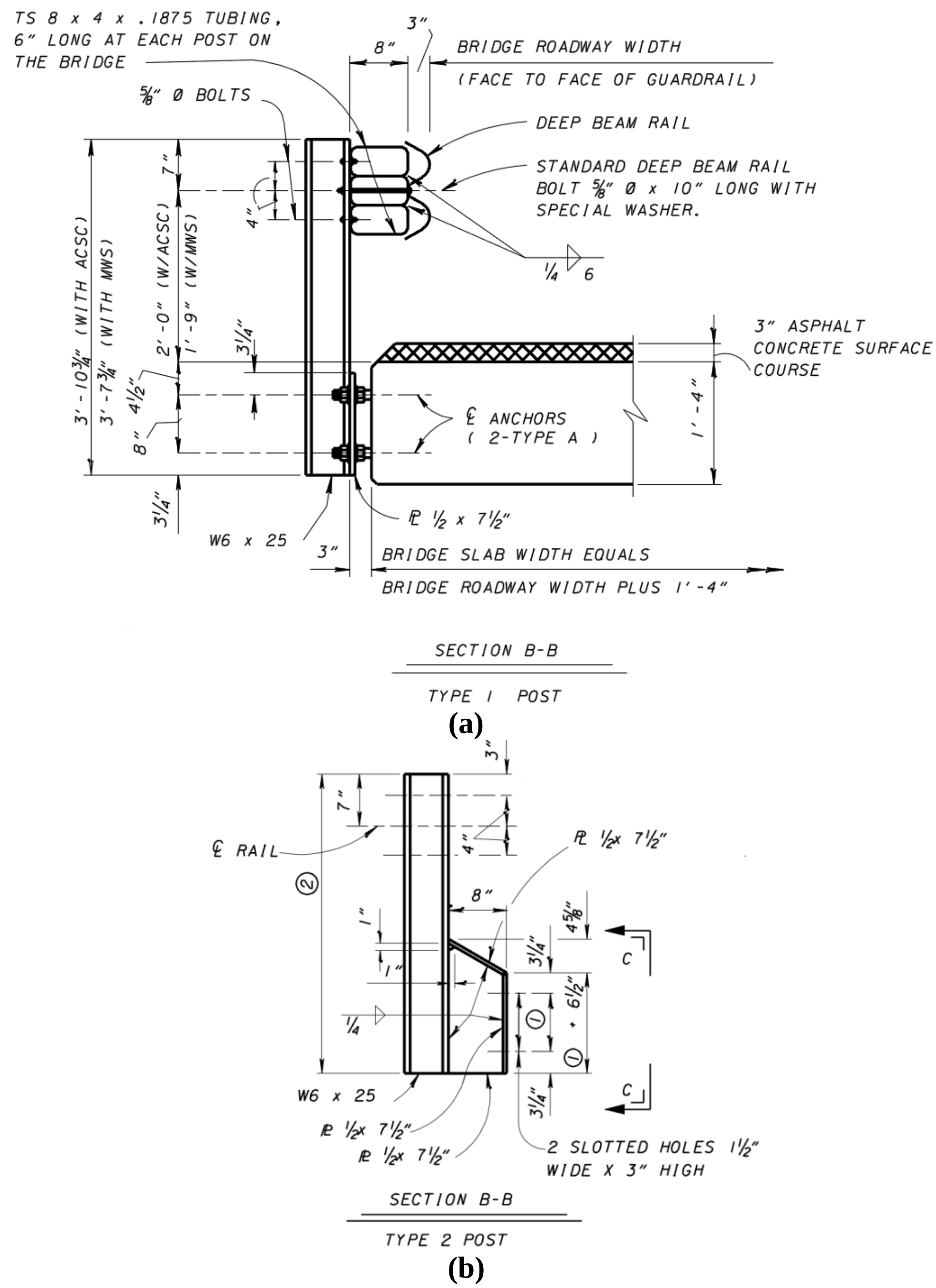


Figure 3.1 ODOT Deep Beam bridge rail (a) Type 1 post and (b) Type 2 post *(1)*

Some of the railing systems that share characteristics of the ODOT Deep Beam bridge rail are the TxDOT Type T101 *(6)*, the Illinois side-mounted rail *(7)*, and the Oregon side-mounted bridge rail *(8)*.

The TxDOT Type T101 Bridge Rail, as shown in Figure 3.2 *(9)*, is a steel post and rail system that is bolted to the concrete deck. The bridge rail incorporates two TS 4×3×3/16 inch (101×76×4.8 mm) tubular rail members with a W-beam railing element on the traffic side face. The two tubular rail members are nested between the steel posts and within the corrugations of the W-beam railing element. The height of the bridge rail system is 27 inches (0.686 m) above the top of the concrete deck surface. The steel posts are fabricated from W6×20 (W150×29.8) structural shape and are anchored to the concrete deck with a 9×10×7/8 inch (228.6×254×22.2 mm) thick base plate that is welded to the steel posts and anchored to the deck using four 3/4-inch (19 mm) diameter A325 anchor bolts. The steel posts are spaced 8 ft-4 inches (2.54 m) on centers. In addition to the steel bridge rail system, the TxDOT Type T101 bridge rail incorporates a steel strap anchoring system that is cast within the concrete deck. This steel plate anchoring system provides additional transverse resistance for the TxDOT Type T101 anchor bolts from crash impact forces. This anchoring system is used for concrete decks as well as for TxDOT Type T101 Bridge Rail applications where the railing is constructed on top of a concrete curb.

Figure 3.2 Texas Type T101 bridge rail *(9)*

The Texas Transportation Institute (TTI) has performed extensive analytical design and crash testing on the TxDOT Type T101 Bridge Rail System. In 1978 a series of several crash tests were performed on the T101 Bridge Rail Design. These crash tests involved several vehicles ranging in size from a small 1974 Chevrolet Vega to a large inter-city bus. In all, a total of seven crash tests were performed on the TxDOT Type T101 Bridge Rail in 1978 *(10)*. In summary, the crash performance of the TxDOT Type T101 Bridge Rail was deemed acceptable.

In 2003, TTI performed extensive full-scale crash testing on the TxDOT Type T101 to reduce the cost of the anchoring system used in the concrete decks and curbs *(11)*. Analytical design calculations as well as full-scale crash testing was performed to determine the crash forces transmitted to the embedded anchoring systems for both the concrete deck and curb applications. Results from this testing provided cost-effective design changes for these anchoring systems without reducing the strength performance of the overall TxDOT Type T101 post design. A cross sectional image of the TxDOT Type T101 is shown in Figure 3.3 *(12)*.

In 2004, TTI performed analytical design and full-scale crash testing on a retrofit anchorage design for the TxDOT Type T101 Bridge Rail *(11)*. The new retrofit design incorporated a commercial adhesive anchoring system in lieu the cast-in-place anchorage straps and anchor bolts that are traditionally used for the TxDOT Type T101 Bridge Rail system. The crash performance of the new retrofit design that incorporates the commercial adhesive anchoring design met the strength performance of the cast-in-place post anchorage design.

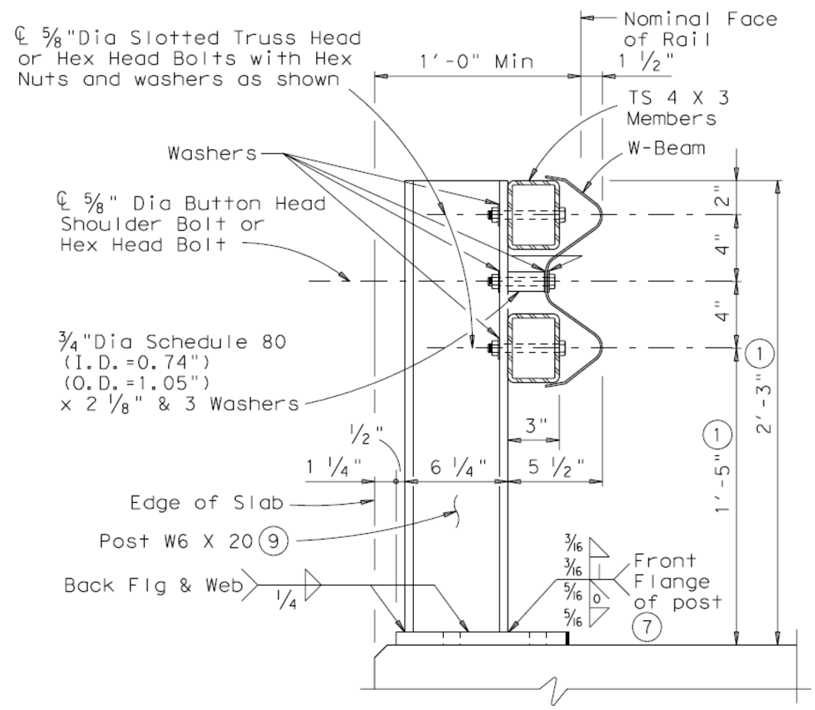


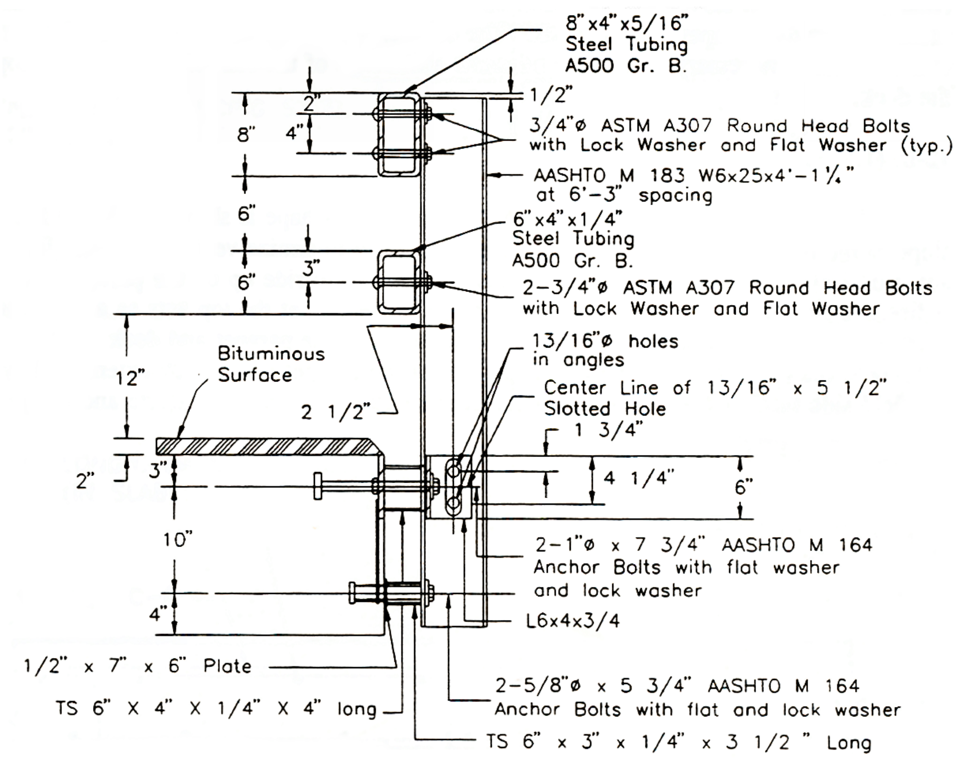
Figure 3.3 TxDOT Type T101 bridge rail section *(12)*

Battelle Memorial Institute, Columbus, Ohio, performed computer simulation of ODOT Type 5 Guardrail with Tubular Backup *(***Error! Reference source not found.***)*. The purpose of the project was to assess the performance of both ODOT's GR-2.2 guardrail and the ODOT GR-3.4 transition system. Many features of the guardrail and transition in the Battelle model were similar to the features used for the Deep Beam bridge rail.

Two other railing designs share the side-mounting characteristics of the ODOT Deep Beam bridge rail. They are the Illinois side-mounted bridge rail *(7)* and the Oregon side-mounted bridge rail *(8)*. Both of these railing systems utilize anchors to mount the posts to the side of the deck. The Illinois side-mounted bridge rail utilizes two tubular elements to function as railing section, while the Oregon railing uses a thrie-beam element as a rail section.

The Illinois side-mounted bridge rail design consists of W6×25 (W150×37.1) posts spaced at 6 ft-3 inches (1.905 m) with two tubular rails, TS 8×4×5/16 inch (203×102×8 mm) for the top rail and TS 6×4×1/4 inch (152×102×6 mm). The height of the top rail above the asphalt surface is 32 inches (813 mm). The railing was mounted to the side of a prestressed-concrete deck using four AASHTO M164 anchor bolts, as shown in the Figure 3.4.

The Illinois side-mounted bridge rail was successfully tested to AASHTO PL-2 including the single unit truck. The damage to the rail system was moderate in terms of deformation and bending of post flanges. Figure 3.5 shows a twisted post as a result of the pickup truck test.



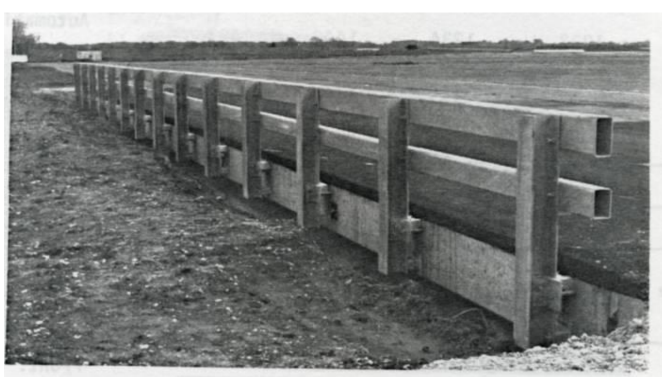


Figure 3.4 The Illinois side-mounted bridge rail *(7)*

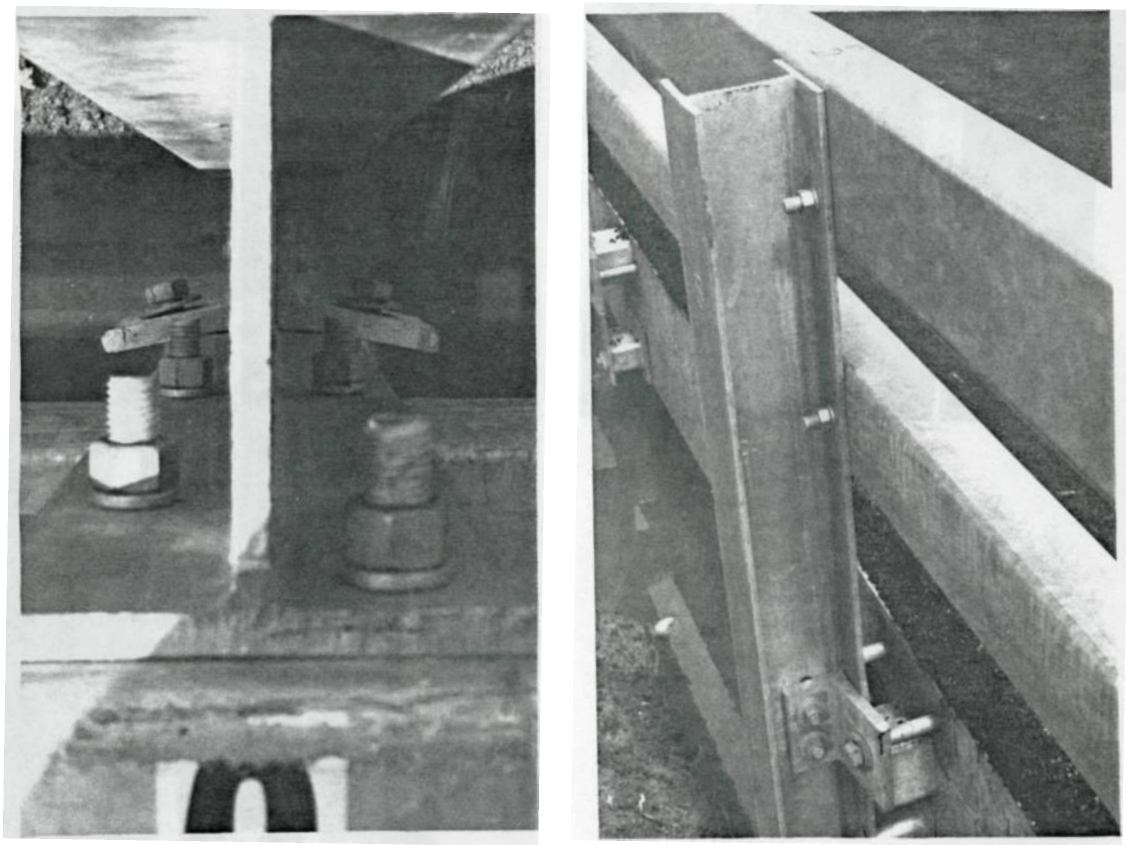


Figure 3.5 Damage at a post of the Illinois rail after a PL-2 test with a pickup *(7)*

The Oregon side-mounted rail was tested per AASHTO PL-1 conditions that are less severe than the PL-2 due to the lower impact velocity specified. The rail consists of W6×15 (W150×22) steel posts spaced at 6 ft-3 inches (1905 mm). The posts were mounted to the side face of the prestressed concrete deck via four 3/4-inch (19 mm) high strength bolts. The rail member was a 10 gauge thrie-beam shaped rail. Oregon side-mounted bridge rail installation is shown in Figure 3.6. Figure 3.7 shows damage sustained by the Oregon side-mounted bridge rail after PL-1 pickup truck test.

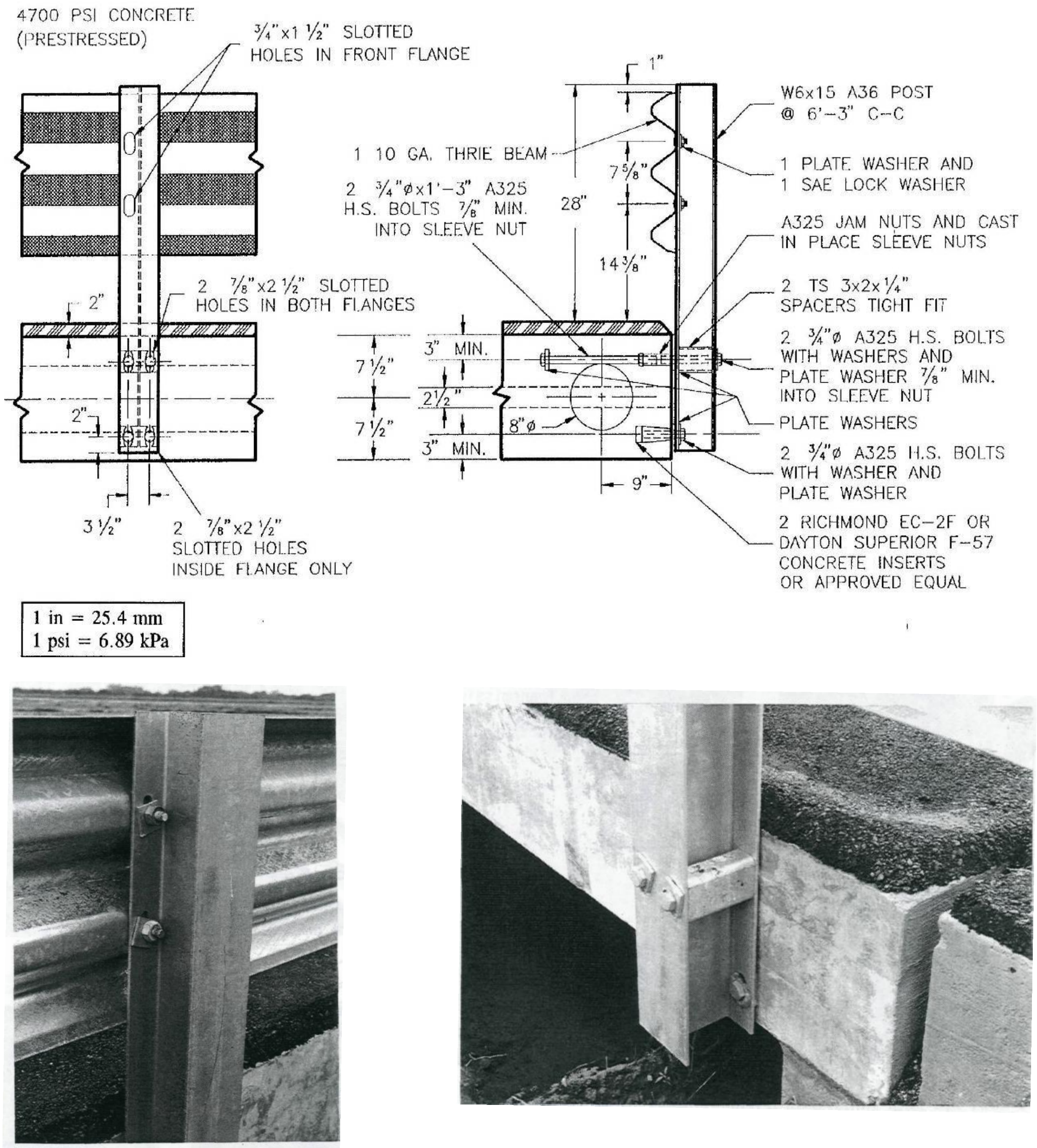


Figure 3.6 Oregon side-mounted bridge rail installation *(8)*

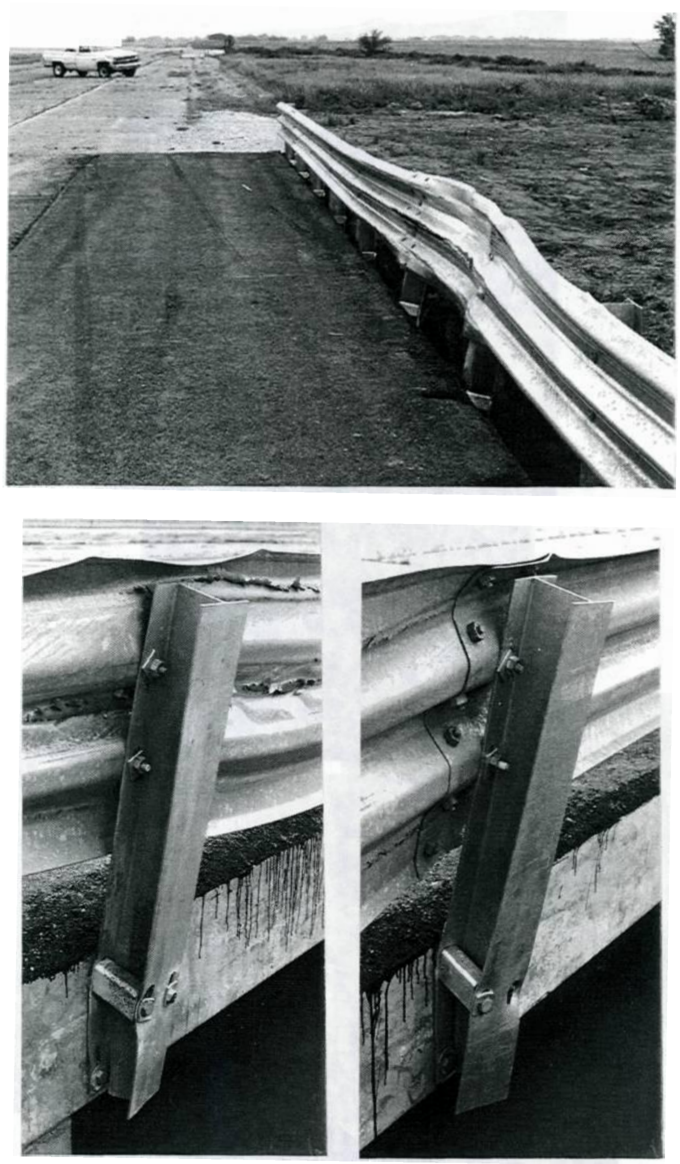


Figure 3.7 Damage to the Oregon side-mounted rail after PL-1 pickup test *(8)*

3.3. BACKGROUND OF FINITE ELEMENT ANALYSIS

Recently, finite element analyses (FEA) using LS-DYNA *(13)* commercial nonlinear finite element code has been utilized heavily in analyzing and designing roadside safety features. It is feasible to capture nonlinear response using different materials, including metals and concrete damage with state of the art modeling and simulation. Over the past 10 years, LS-DYNA has been extensively used in the performance evaluation of roadside safety hardware. TTI researchers have modeled and simulated bridge rails, transitions, and concrete decks using LS-DYNA. Figure 3.8 shows concrete damage from test and simulation for a bogie impact of a safety shape barrier *(14)*. Comparison of the failure between the test and simulation of concrete barrier and deck shows good correlation of failure profile.

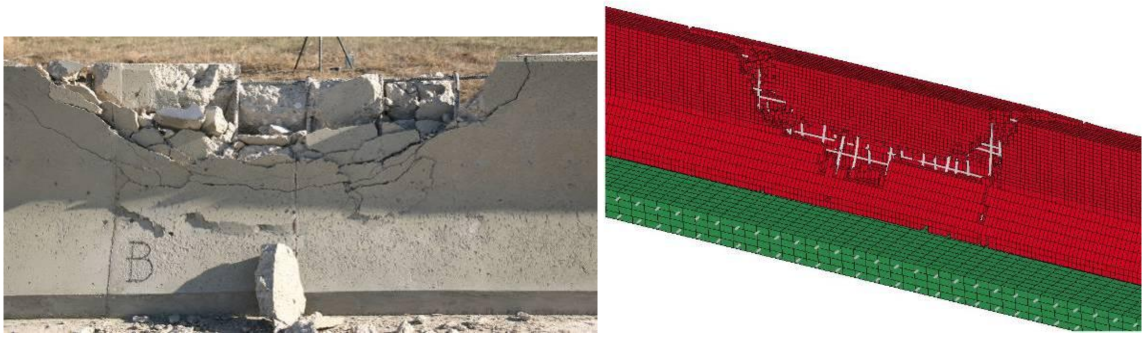


Figure 3.8 Test and simulation of concrete barrier and deck *(14)*

Additionally, model of New York (NY) transition is an example of the finite element capability of capturing detailed feature of a transition system. Figure 3.9 shows model and test setup of the NY tubular transition to tubular bridge rail *(15)*. The simulation of the NY bridge transition predicted the outcome of the test.

Figure 3.9 Model and physical setup of the New York transition to tubular bridge rail *(15)*

4. ENGINEERING REVIEW, ANALYSIS, AND MODIFICATION OF THE OHIO DEEP BEAM BRIDGE RAIL

The current ODOT Deep Beam bridge rail system has been reviewed and analyzed. The suggested retrofits are basically two additional tubular members to help improve the performance of the ODOT Deep Beam bridge rail. These two rail members have been added in such a way as to utilize the current bridge rail hardware and minimize retrofitting the existing bridge rail post. A new tubular member has been added at 8 inches (230 mm) above the pavement surface to improve the crash performance for the small car (820C) in *NCHRP Report 350* TL-3 conditions.

A second tubular member has been added to the top of the existing tubular blockout to increase the overall height to 31 inches (787 mm) above the pavement surface. Increasing the height of the bridge rail is considered to be an improvement in crash performance by the design team, particularly for impact conditions that involve the pickup truck (2000P). Strength analyses were conducted to determine the strength of the retrofit rail design with respect to *AASHTO LRFD Bridge Design Specifications* (*3*). Figure 4.1 and Figure 4.2 show the suggested retrofit. Figure 4.3 shows similar retrofit but with an additional plate (backing or shim) at the post location.

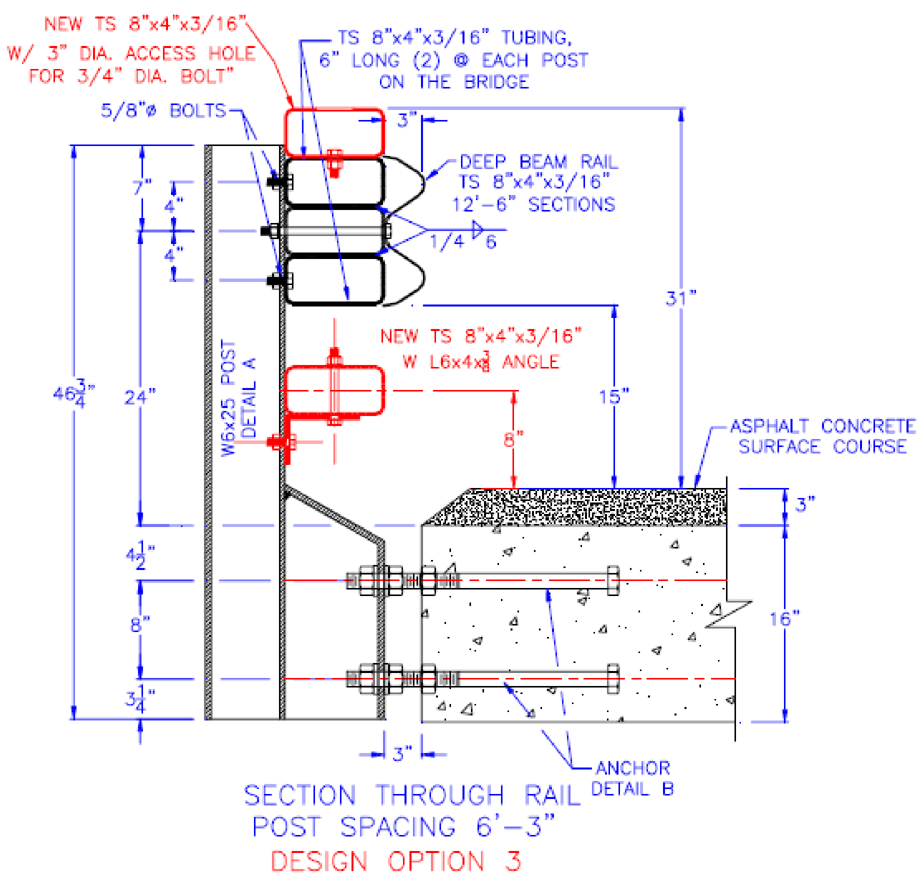


Figure 4.1 Section through the suggested (retrofit) rail at post location

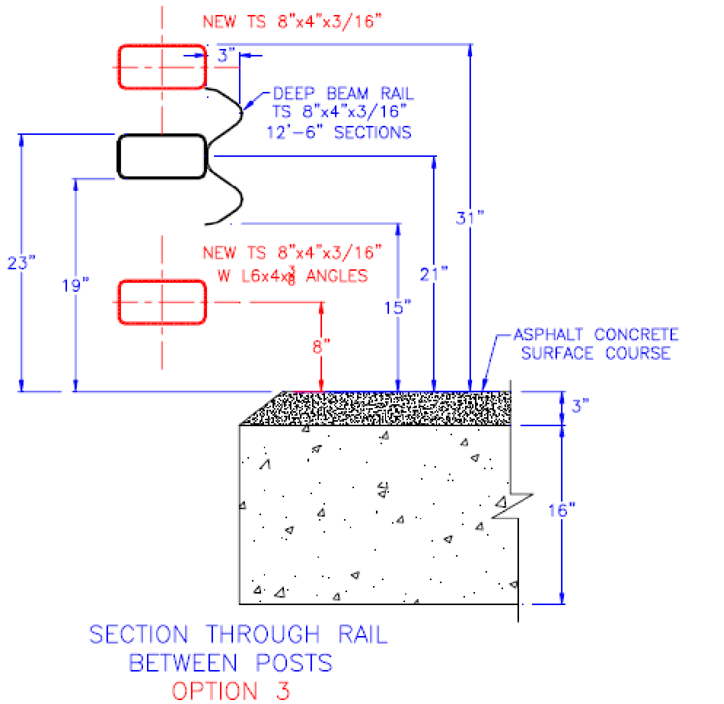


Figure 4.2 Section through the suggested (retrofit) rail in between posts

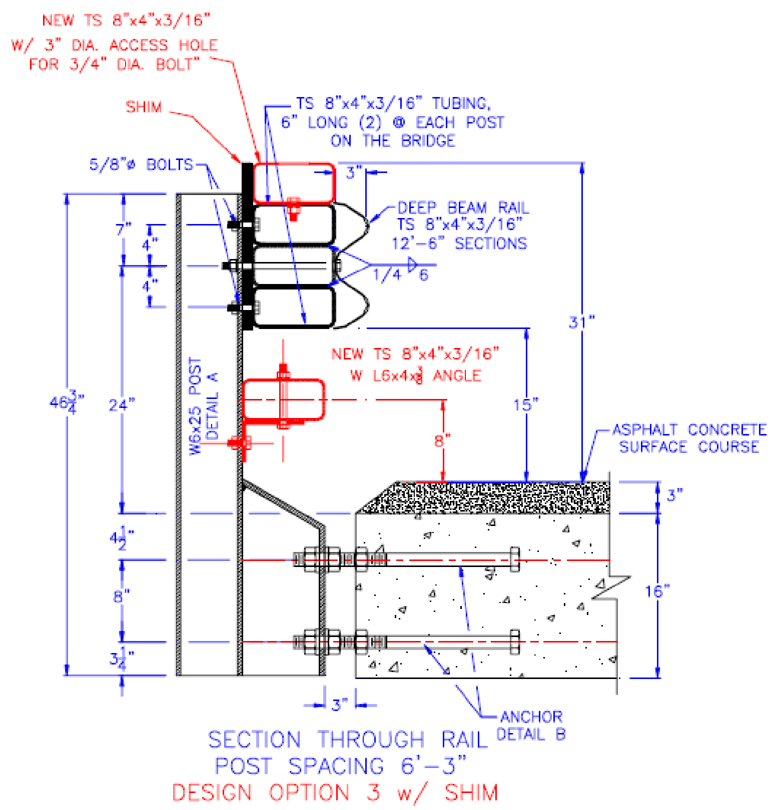


Figure 4.3 Retrofit with a shim plate at the post section

The details of the 16 inches (406 mm) concrete deck have developed and these details were approved by ODOT. These details (Figure 4.4 and Figure 4.5) are incorporated into the analyses for the retrofit bridge rail design.

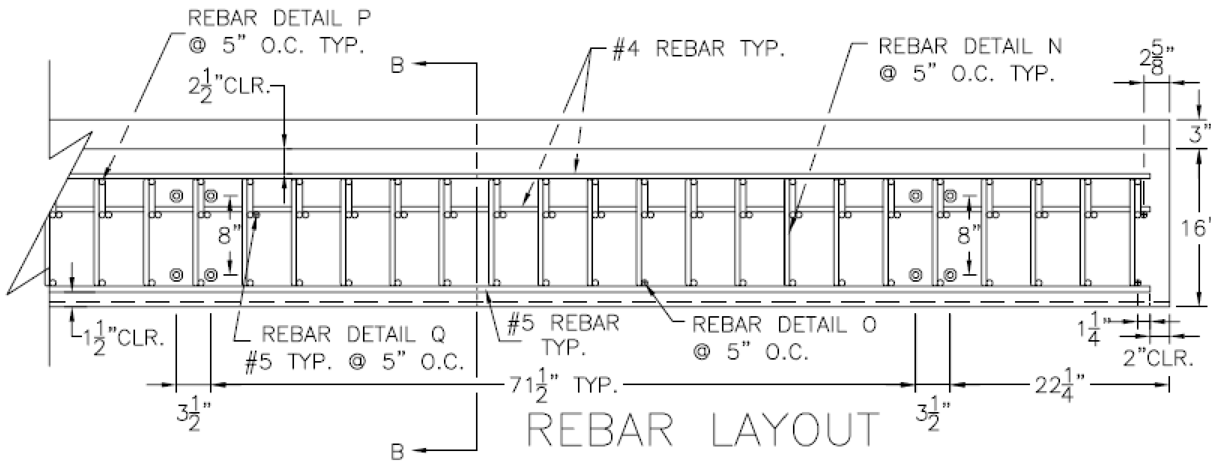


Figure 4.4 TTI drawing of the deck rebar (layout)

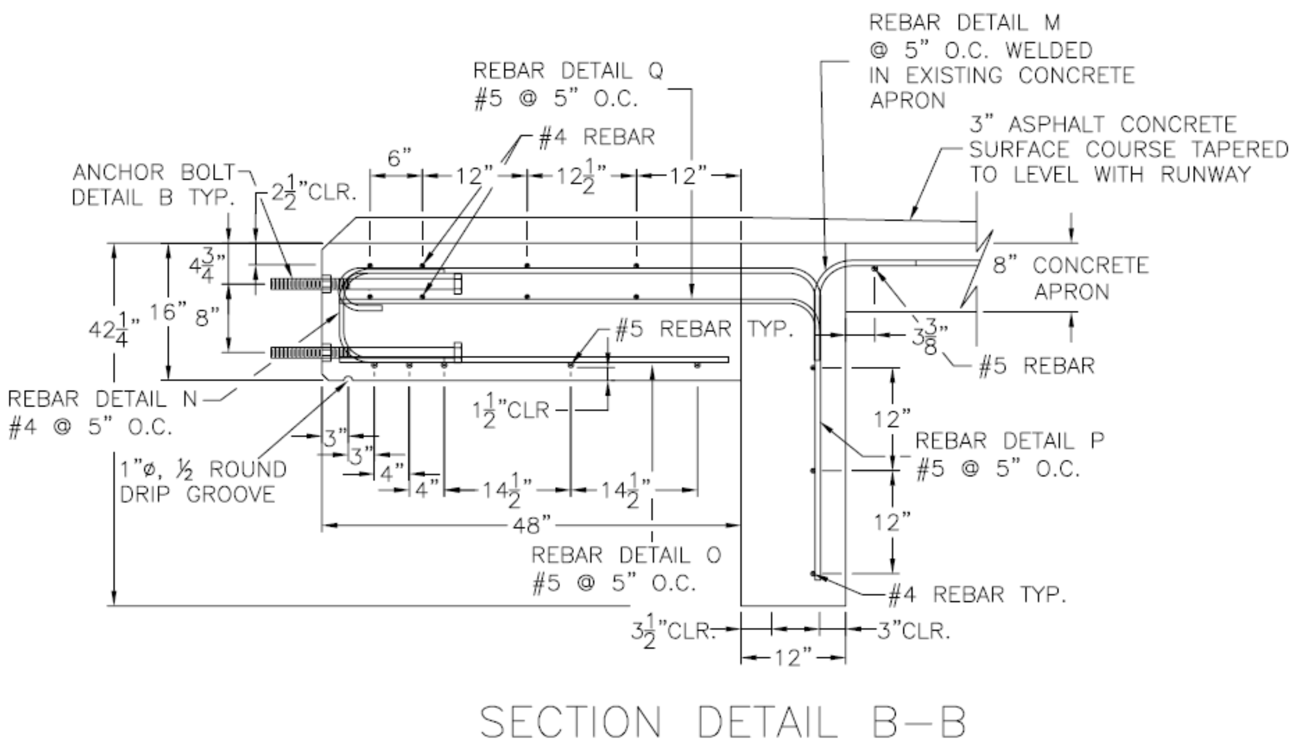


Figure 4.5 TTI drawing of the deck rebar (cross section)

Calculation details of the modified ODOT Deep Beam bridge rail system are presented in APPENDIX B. Table 4.1 and Table 4.2 from the 2004 *AASHTO LRFD Bridge Design Specifications (4)* were used to calculate the strength of the modified ODOT Deep Beam bridge rail system.

Table 4.1 Bridge rail test levels and crash test criteria (*AASHTO LRFD* Table 13.7.2-1) *(4)*

Vehicle Characteristics	**Small automobiles**		**Pickup Truck**	**Single-Unit Van Truck**	**Van-Type Tractor-Trailer**		**Tractor-Tanker Trailer**
W (kips)	1.55	1.8	4.5	18.0	50.0	80.0	80.0
B (ft)	5.5	5.5	6.5	7.5	8.0	8.0	8.0
G (inches)	22	22	27	49	64	73	81
Crash angle, θ	20°	20°	25°	15°	15°	15°	15°
Test Level	**Test Speeds (mi/h)**						
TL-1	30	30	30	N/A*	N/A	N/A	N/A
TL-2	45	45	45	N/A	N/A	N/A	N/A
TL-3	60	60	60	N/A	N/A	N/A	N/A
TL-4	60	60	60	50	N/A	N/A	N/A
TL-5	60	60	60	N/A	N/A	50	N/A
TL-6	60	60	60	N/A	N/A	N/A	50

*N/A: Not Applicable

Table 4.2 Design forces for traffic railings (*AASHTO LRFD* Table A13.2-1) *(4)*

Design forces and Designations	**Railing Test Level**					
	TL-1	**TL-2**	**TL-3**	**TL-4**	**TL-5**	**TL-6**
F_t Transverse (kips)	13.5	27.0	54.0	54.0	124.0	175.0
F_L Longitudinal (kips)	4.5	9.0	18.0	18.0	41.0	58..0
F_v Vertical (kips) Down	4.5	4.5	4.5	18.0	80.0	80.0
L_t and L_L (ft)	4.0	4.0	4.0	3.5	8.0	8.0
L_v (ft)	18.0	18.0	18.0	18.0	40.0	40.0
H_e (min) (inches)	18.0	20.0	24.0	32.0	42.0	56.0
Minimum H Height of Rail (inches)	27.0	27.0	27.0	32.0	42.0	90.0

5. FINITE ELEMENT ANALYSIS OF ODOT DEEP BEAM BRIDGE RAIL

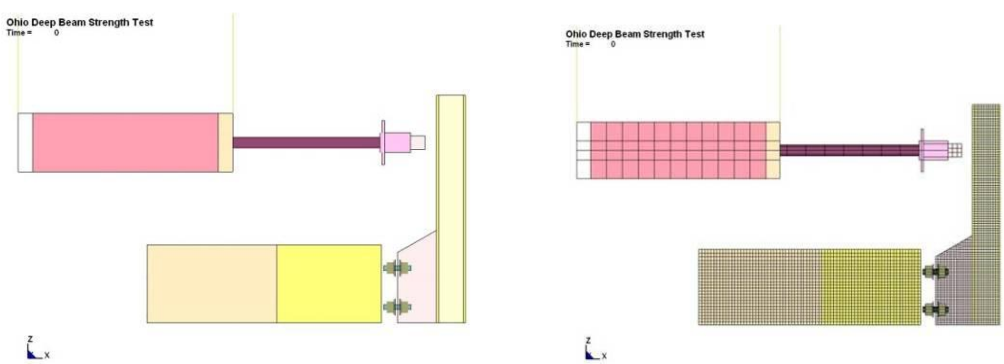
A detailed finite element model was built for the ODOT deep beam post assembly. The assembly includes the W6×25 (W150×37.1) post, the stiffening plates, the 1-1/4 inches (31.75 mm) diameter A325 anchor bolt, the 16 inches (406 mm) deck, and the detailed reinforcement per the system drawings, as shown in APPENDIX C.

5.1. STRENGTH EVALUATION OF POST-DECK SUB-SYSTEM

5.1.1 Post-Deck Model

TTI's 1851 lb (840 kg) pendulum model with a crushable honeycomb nose was used to evaluate the strength of the post-deck sub-system of the ODOT Deep Beam bridge rail. The pendulum nose impacted the post at a speed of 21.9 mi/h (35.2 km/h) at a height of 21 inches (533 mm). Details of the assembly along with the pendulum setup are shown in Figure 5.1.

The deck was modeled using brick element meshed finely in order to accurately capture the damage and the fracture of the concrete. The rebars and anchors were modeled explicitly using beam elements that were embedded into the solid deck model, as shown in Figure 5.2. The inner side of the deck was modeled as an elastic concrete material since no damage was expected to develop in that region. Hence, the fracture capable concrete model covers 21.4 inches (544 mm) of the overhang portion of the deck. Figure 5.3 shows the two deck components with different material models.



(a) Component **(b) Meshed**

Figure 5.1 Pendulum impact setup for the post-anchor-deck assembly

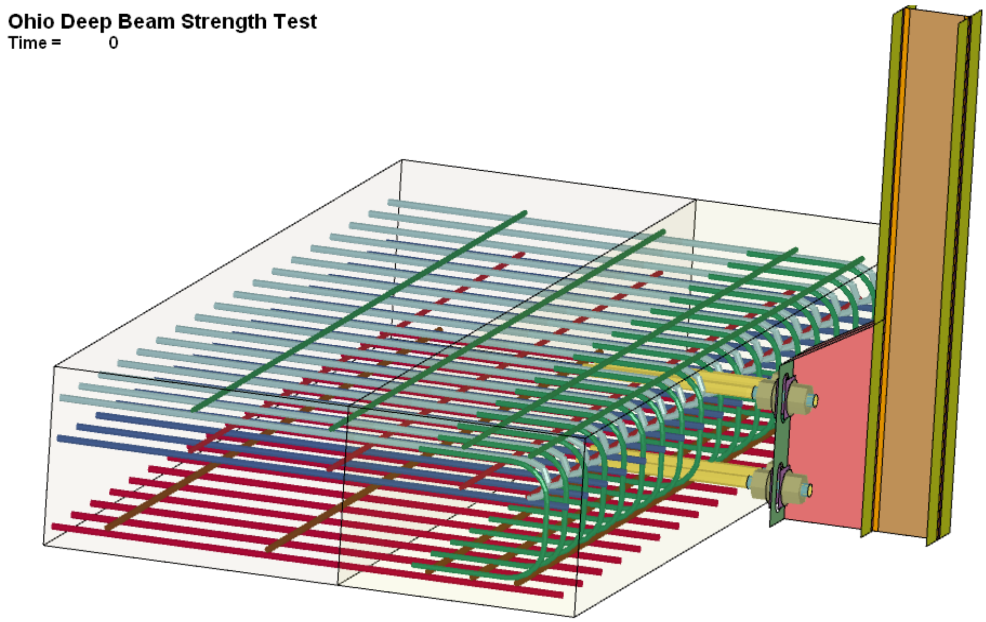


Figure 5.2 Model view showing the reinforcement and anchor details of the deck

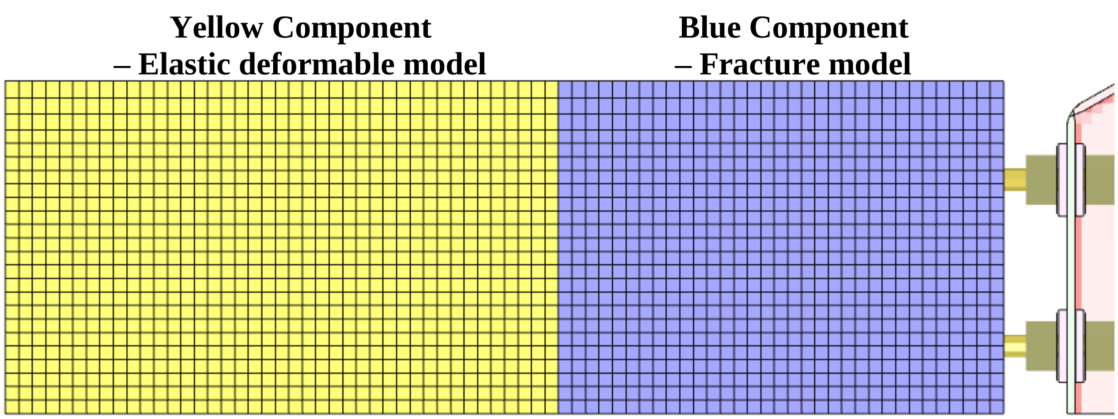


Figure 5.3 Concrete deck model and mesh

The concrete material property used was validated using a previously conducted experiment of a concrete deck with an unconfined compressive strength of 3000 psi (21 MPa). This strength is much lower than that specified (4000 psi or 28 MPa) for the ODOT deck used in this study. Thus the damage of the deck in this analysis would be considered conservative. The material properties model for the steel post and the steel stiffening plates are represented using an elastic-plastic material model. The steel rebars and anchor material models were obtained from published literature and specifications.

The anchors were initialized to account for initial tensioning in the anchors due to the applied torque of the nuts, as shown in Figure 5.4. This provides a "tied" assembly with no loose connections as is expected from proper construction practice.

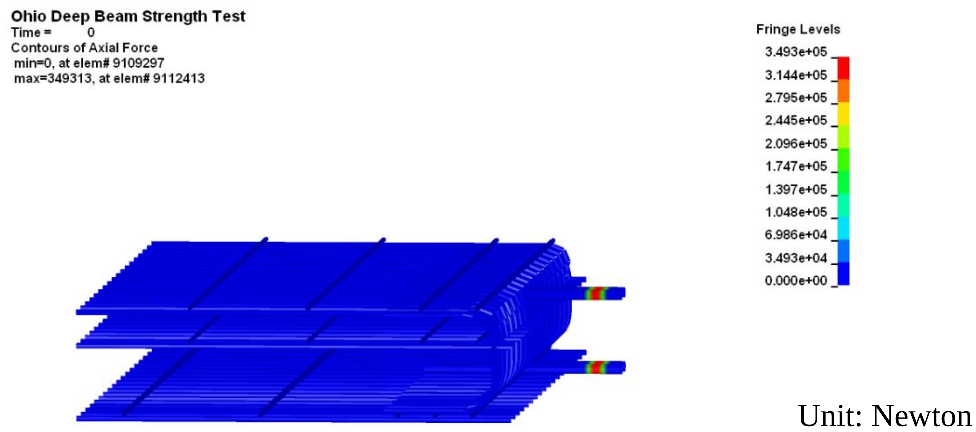


Figure 5.4 Initialized force in the anchors to represent the connectivity of the nuts (torque) (Unit: Newton)

5.1.2 Results of Post-Deck Model or Pendulum (Impactor) Model

The simulation of this setup resulted in the pendulum being stopped and rebounded after impacting the post flange. There was no excessive deformation to the system, as shown in Figure 5.5.

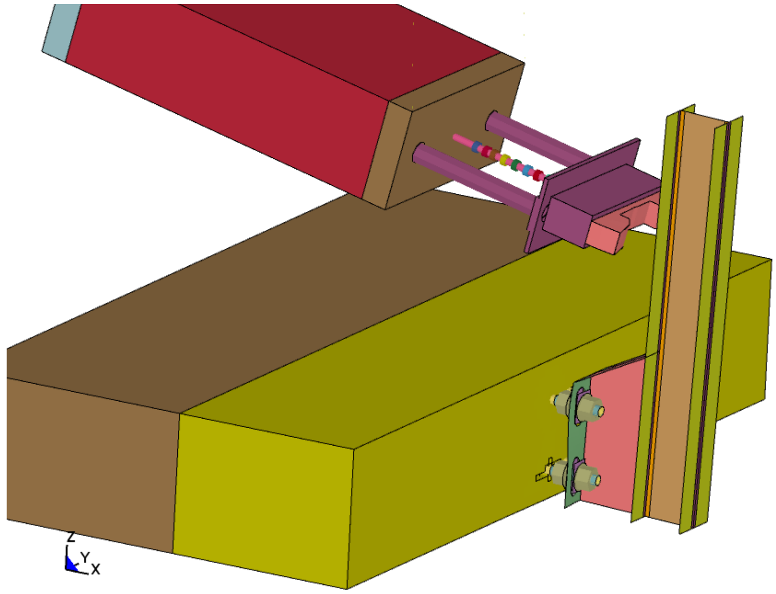


Figure 5.5 Post-deck assembly after impact

The damage to the deck was localized in the region around the anchor—in particular the lower set of anchors, as shown in Figure 5.6.

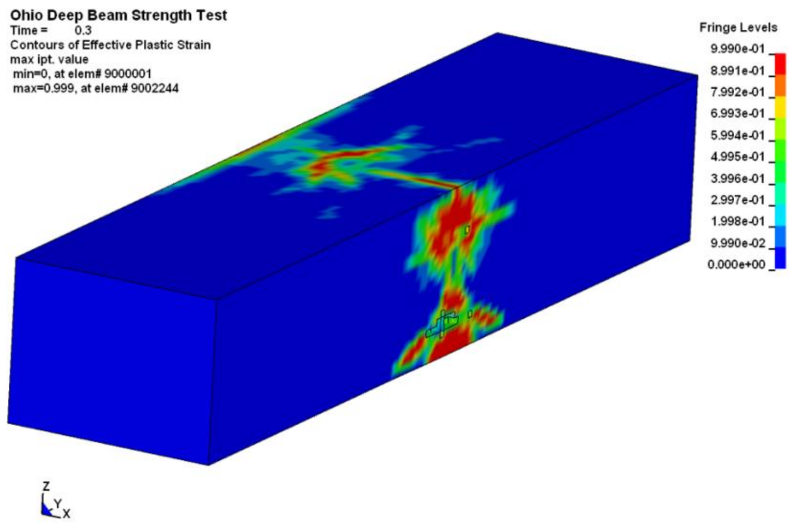


Figure 5.6 Damage to the concrete deck

However, few elements were eroded (fractured) according to the simulation, which is indicative of crack type damage and not a catastrophic fracturing of the deck. Given the fact that this deck model was based on a 3000 psi (21 MPa) material model, then it is expected that a 4000 psi (28 MPa) deck would exhibit less damage upon experiencing similar loading conditions.

As for the post assembly, the post and the stiffening steel plates experienced a low level of yielding, mainly at the stiffening plate with slots. A highly localized 5 percent magnitude of plastic strain was calculated by the numerical simulation. However, the overall plastic strain seems to be around 3.2 percent, as shown in Figure 5.7.

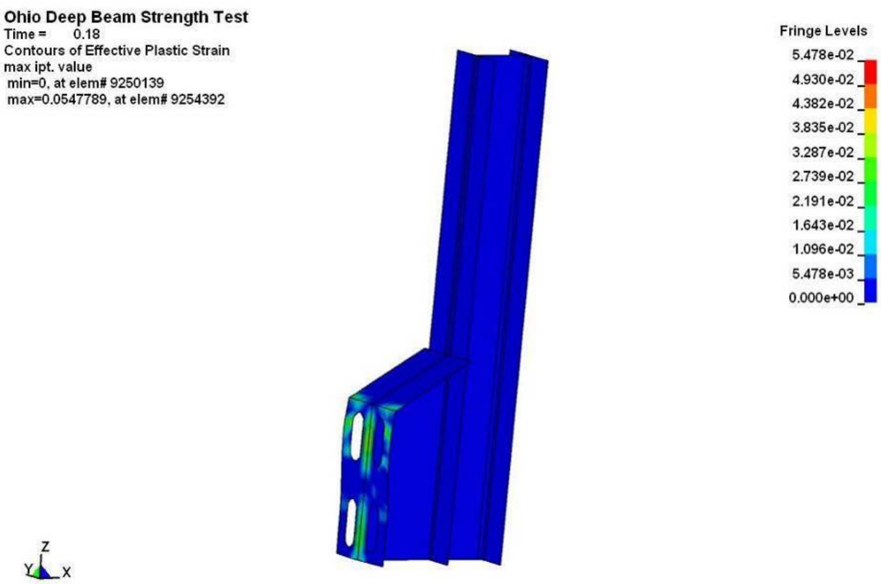


Figure 5.7 Maximum plastic strain distribution in the post assembly

The forces in the anchors were limited to a maximum of 83 kips (370 kN) in tension and 46.4 kips (206 kN) in compression, as shown in Figure 5.8. The American Society for Testing and Materials (ASTM) rating for these anchors is 81 ksi (560 MPa) for yield and at 105 ksi (725 MPa) for ultimate strength. For the 1-1/4-inch (31.75 mm) anchor, that would be 99 kips (440 kN) for yield and 129 kips (574 kN) for ultimate strength. Based on this simulation, the maximum forces in the anchors are below the yield limit.

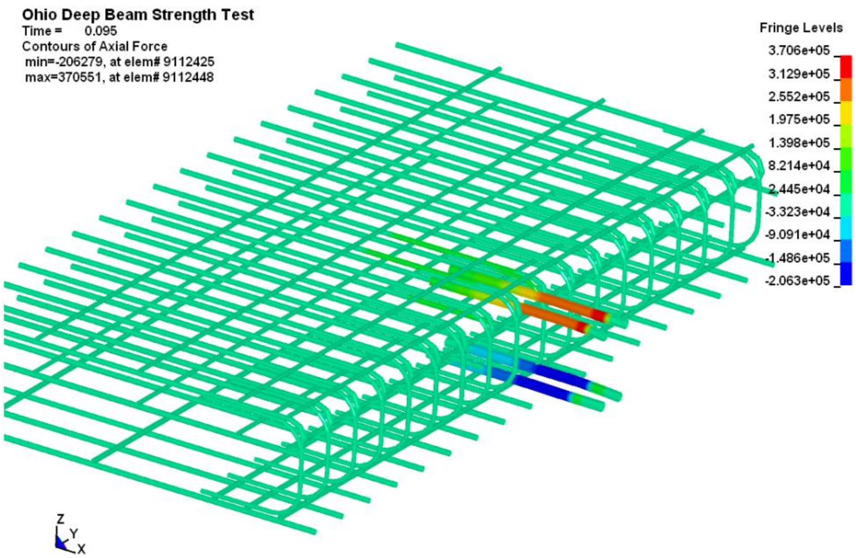


Figure 5.8 Anchor forces (Unit: Newton)

The stresses in the rebars were limited to a maximum of 60 ksi (414 MPa) in tension and 5.5 ksi (38 MPa) in compression, as shown in Figure 5.9. Assuming that the rebars have a 60 ksi (267 kN) yield then only short segments of a few rebars would be at yield as the legend indicates in Figure 5.9.

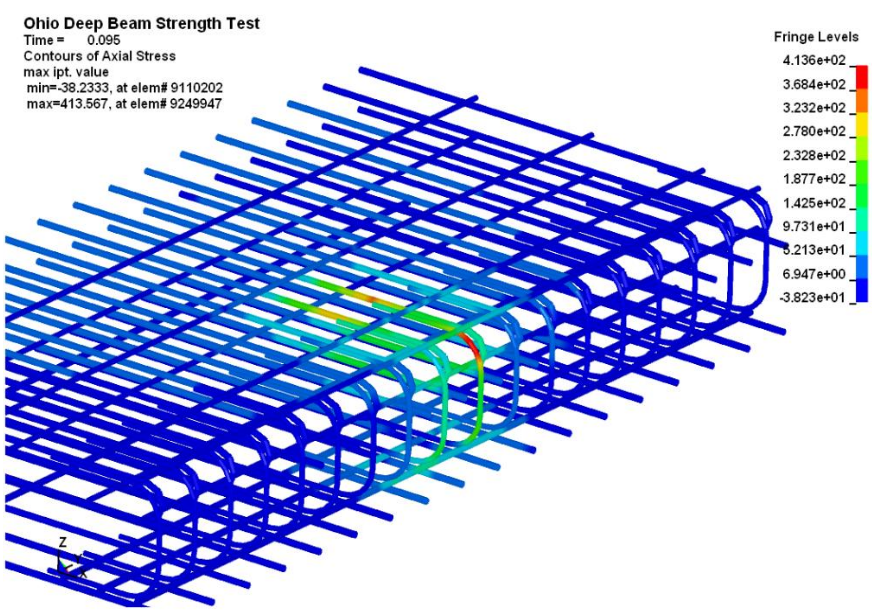


Figure 5.9 Maximum axial stress in the deck steel reinforcement (Unit: N/mm^2)

The impact force history is shown in Figure 5.10. The history (filtered to Society of Automotive Engineers (SAE) 180) indicates that the post-deck assembly can withstand a 30 kips (133 kN) impact force with minimum damage.

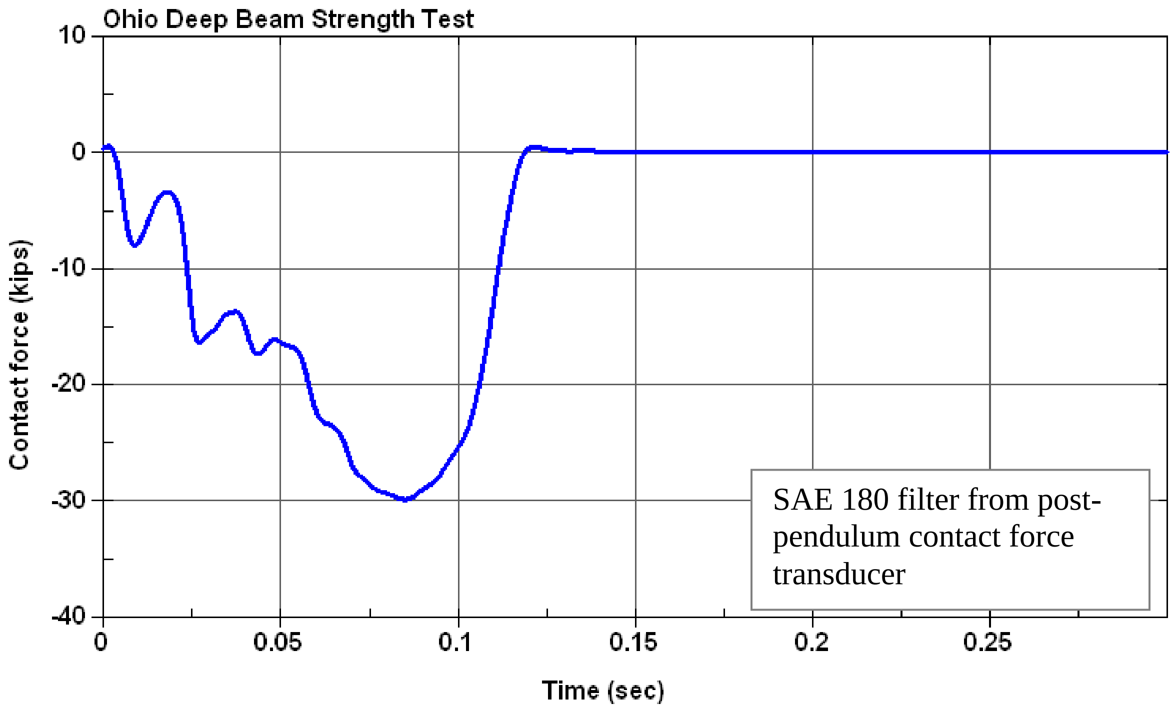


Figure 5.10 Impact force history

Based on this numerical analysis and the previously conducted engineering analysis, it is expected that the post-deck assembly would have the capacity to withstand its portion of the 54 kips (240 kN) load imparted by the 2000P test vehicle (per *NCHRP Report 350* TL-3) without any significant damage.

5.2. FULL SYSTEM PERFORMANCE EVALUATION

5.2.1 Full System Model

The research team constructed the full model of a representative installation of the modified ODOT Deep Beam bridge rail per *NCHRP Report 350* test requirements for rigid barrier. The model consists of 75 ft (22.86 m) long rail that includes six W-beam rail segments and 13 (thirteen) post assemblies. Although the deck is modeled in the full system model, the deck is assumed to be rigid to provide geometrical contacts with the vehicle tires. The sub-system analysis indicates that the deck strength is adequate for such an impact condition. In the full model, the anchors have boundary condition at the maximum rotation point in the sub-model, as shown in Figure 5.11. Figure 5.12 depicts the model of the retrofitted ODOT Deep Beam bridge rail.

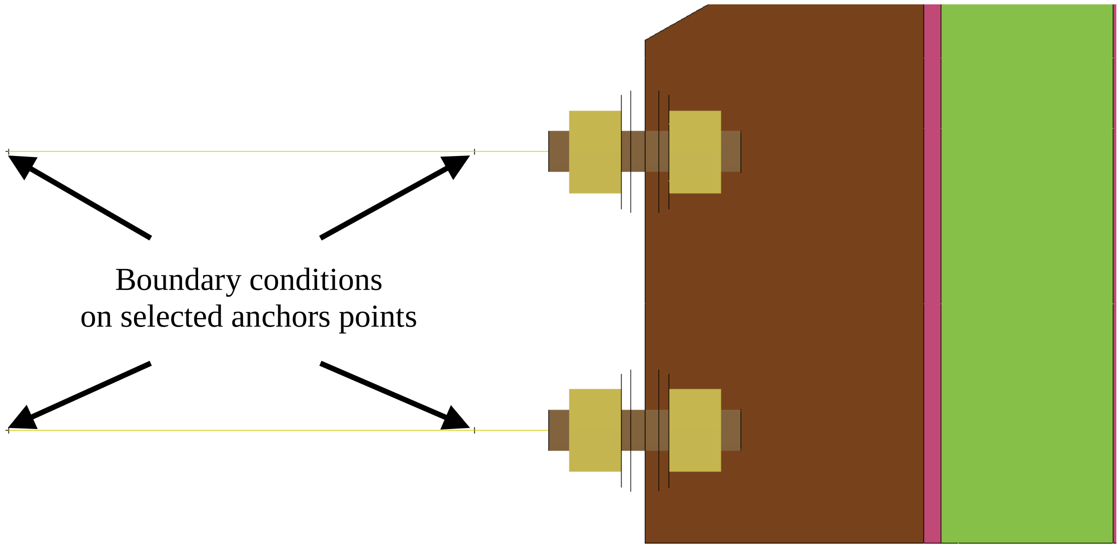


Figure 5.11 Anchors inflection points and boundary conditions

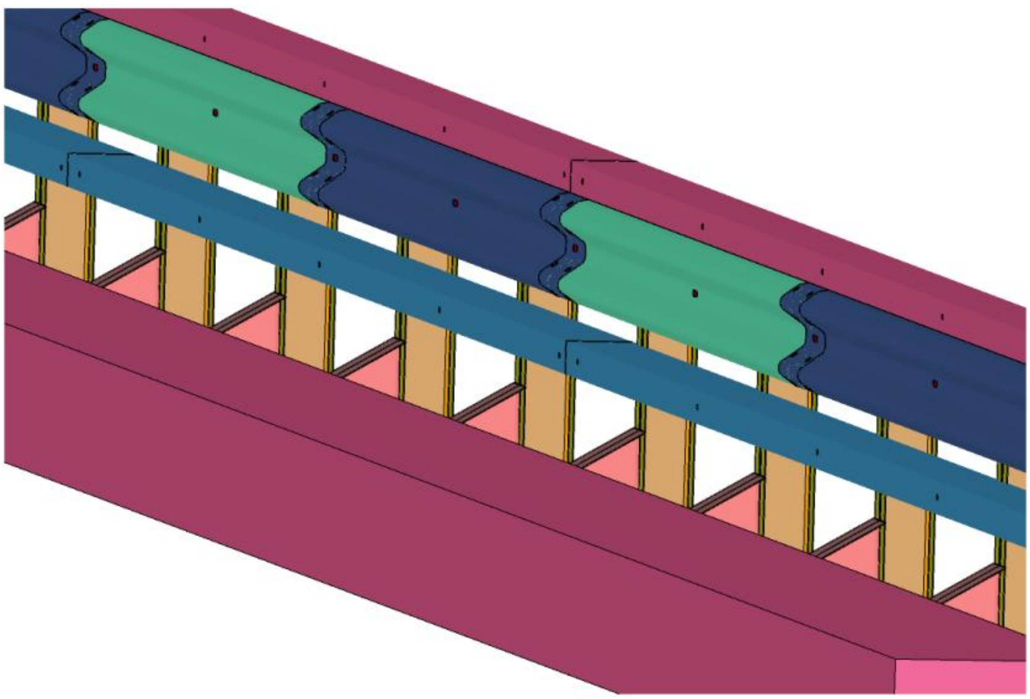


Figure 5.12 Close up of the full system model

Some of the key components from the GR-2.2 rail study *(***Error! Reference source not found.***)* had to be reconstructed and re-meshed to increase the fidelity of the model. The GR-2.2 system model incorporated a nested rail configuration. This ended up with a pre-deformed rail geometry to account for multiple rails at the splice, as shown in Figure 5.13.

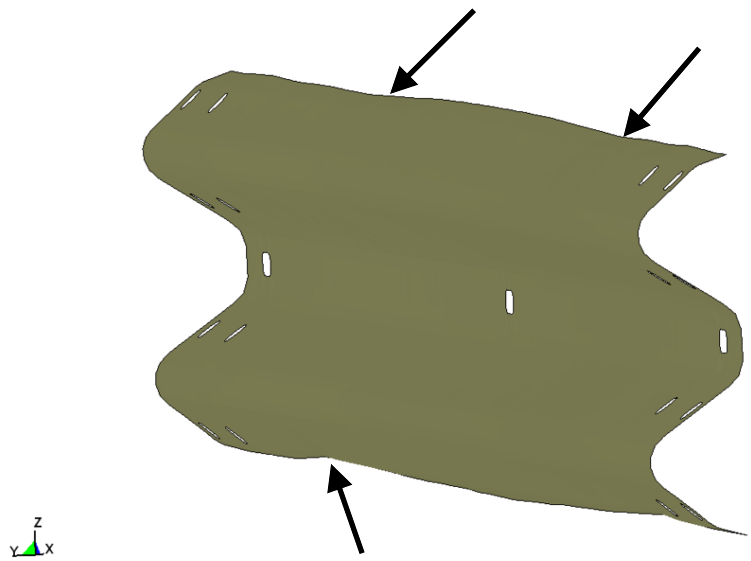


Figure 5.13 W-beam model from the GR-2.2 model (arrows point to the pre-bent geometry)

Hence, the W-beam rail model per the roadside hardware guide specifications built using SolidWorks *(16)* was used to reconstruct a new W-beam mesh. This new model is shown in Figure 5.14.

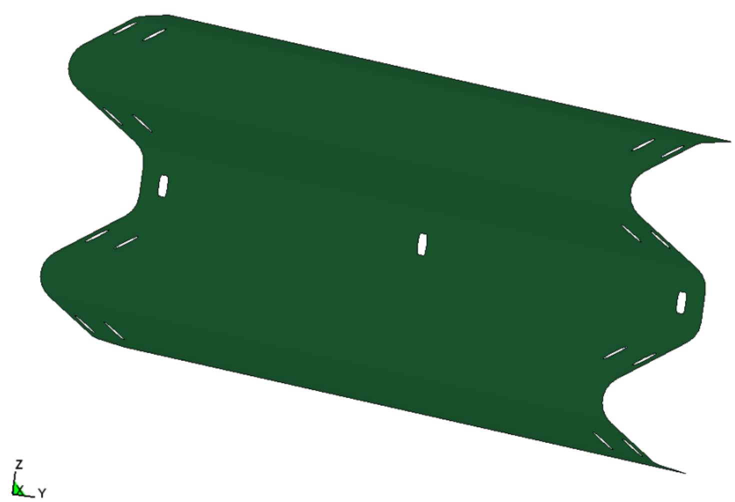


Figure 5.14 Reconstructed W-beam model to be implemented in the Deep Beam rail system

Figure 5.15 shows an iso-parametric view of the ODOT Deep Beam bridge rail system model as it is mounted into a deck. Figure 5.16 is a close-up view of the lower box rail (rub rail) and Figure 5.17 is a close-up showing the detailed meshing of the ODOT Deep Beam bridge rail. The details of ODOT Deep Beam bridge rail used in FE models are presented in APPENDIX C.

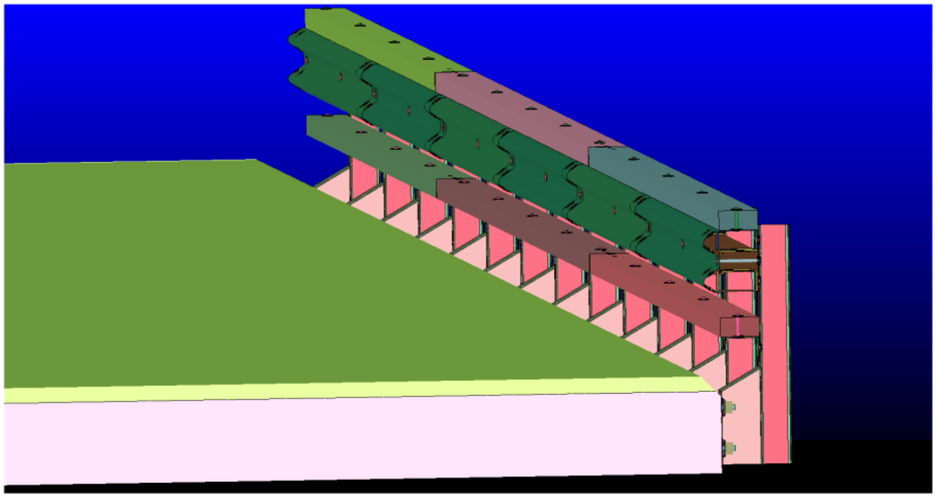


Figure 5.15 Model setup with 3-inch thick pavement overlay

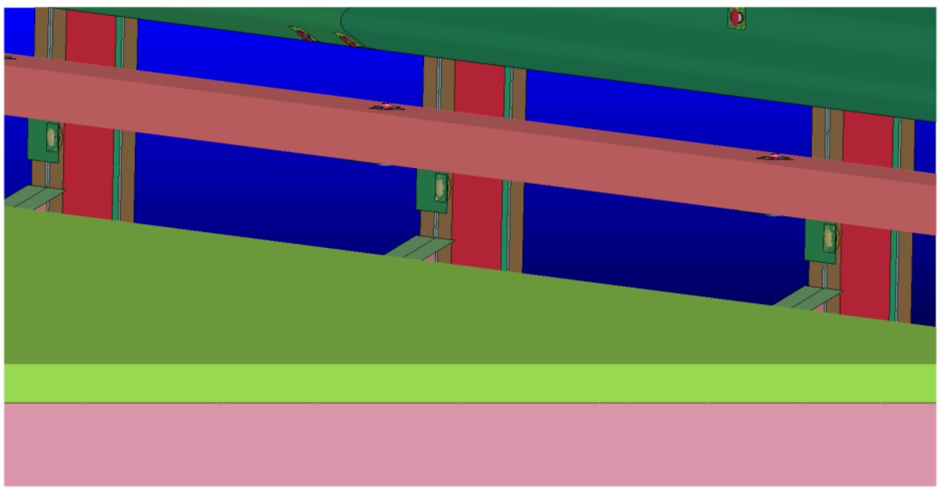


Figure 5.16 Close up on setup showing lower box rail (rub rail) with pavement

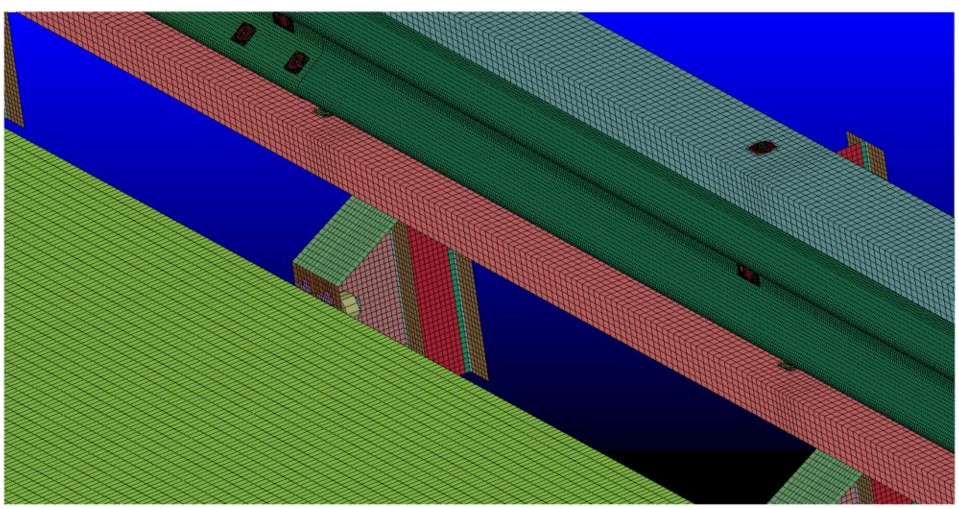


Figure 5.17 View of the model showing the meshing details with pavement

The previous GR-2.2 simulation was conducted using the C2500 reduced vehicle model that shown in Figure 5.18. However, the research team believes that the C2500 detailed vehicle model shown in Figure 5.19 is better suited for this study since it has a better history of refinement and suspension compliance improvement *(17)*. Therefore, this vehicle model was used in the ODOT Deep Beam bridge rail system simulation.

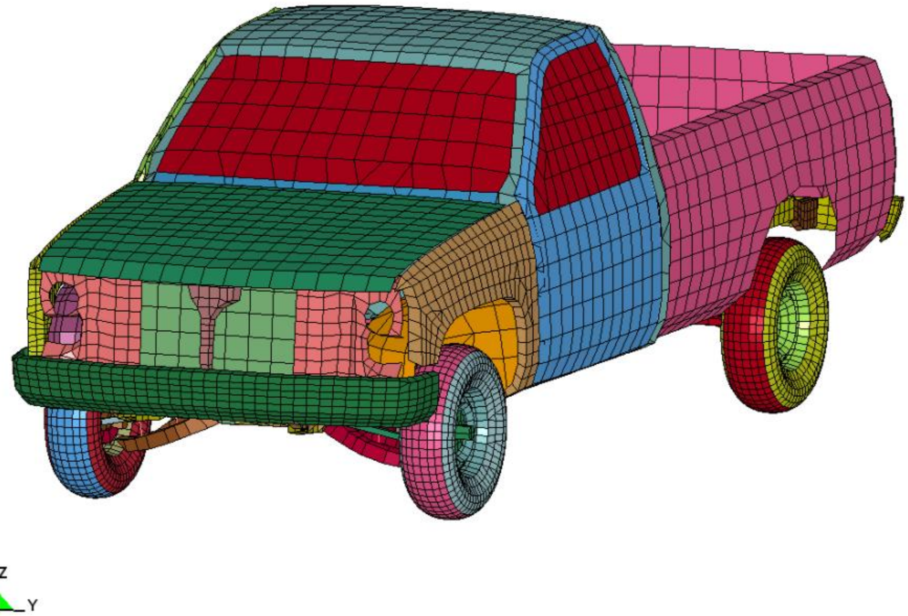


Figure 5.18 C2500 (reduced truck model) similar to the one used in the GR-2.2 simulation

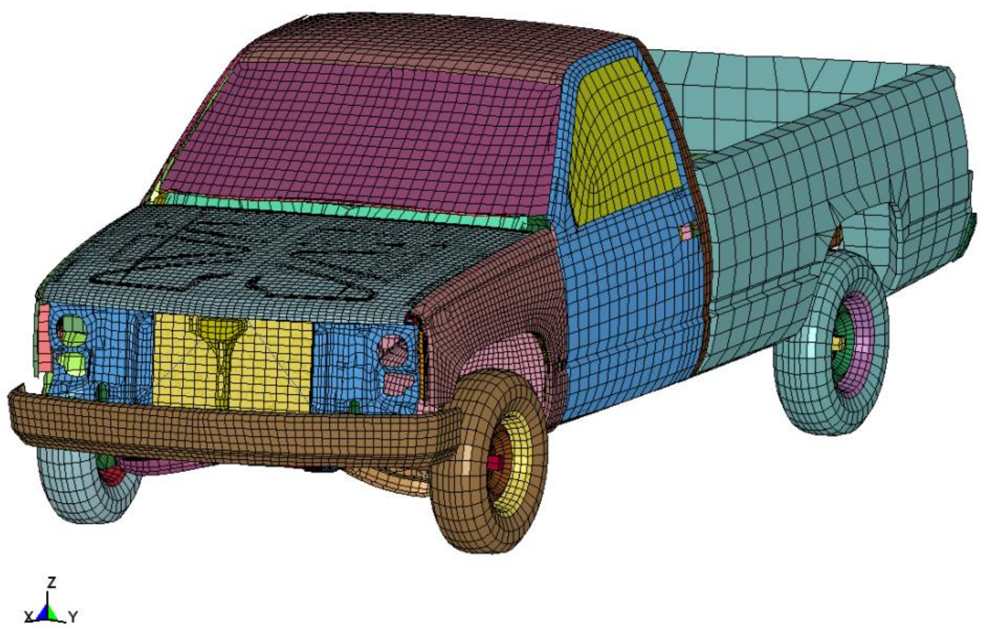


Figure 5.19 C2500 (detailed truck model) to be used in the Deep Beam bridge rail system simulation

As for the small passenger car, the 820C vehicle model (Geo Metro) *(18)* was used for simulating *NCHRP Report 350* Test 3-10, as shown in Figure 5.20.

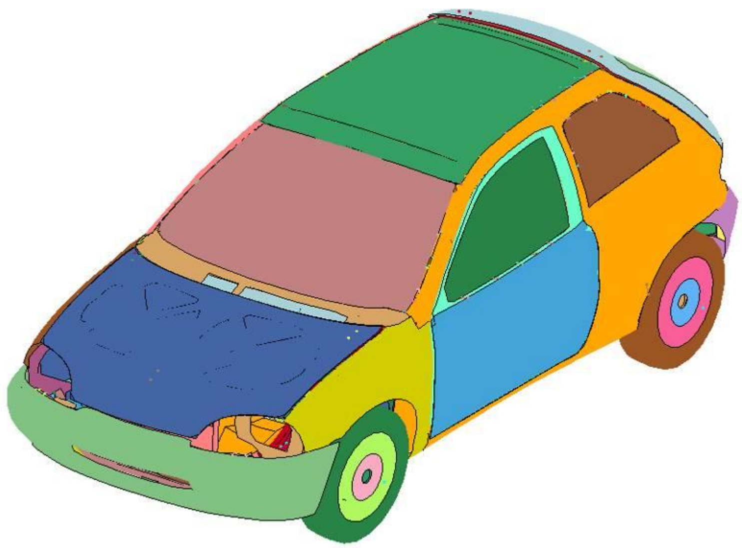


Figure 5.20 820C test vehicle model

5.2.2 Full System Performance with Pavement Overlay using 3-11 Test Conditions

The simulation of the *NCHRP Report 350* TL-3 impact condition was conducted to quantify the performance of the ODOT Deep Beam bridge rail. Figure 5.21 shows sequential images from the numerical simulation of a 2000P test vehicle impacting the rail at 62 mi/h (100 km/h) and 25 degrees impact angle.

The system was able to contain and redirect the vehicle, as shown in Figure 5.21. The vehicle had a moderate roll angle (18 degrees) around 0.52 seconds (sec), as shown in Figure 5.22 but it became upright late in the simulation. The simulation calculated the maximum tensile force in the deck anchors to be 88.91 kips (395 kN). This is below the yield rating of these anchors of 99 kips (440 kN) presented earlier.

Additionally, TTI researchers used the Test Risk Assessment Program (TRAP) to calculate occupant severity indices. TRAP uses signal data from simulation (or test) to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10 millisecond (ms) average ridedown acceleration. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP. TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at about 0.0001 sec intervals and then plots yaw, pitch, and roll versus time. These angular displacements use the vehicle-fixed coordinate system. The vehicle-fixed coordinate system uses the initial position and orientation of the vehicle as the origin..

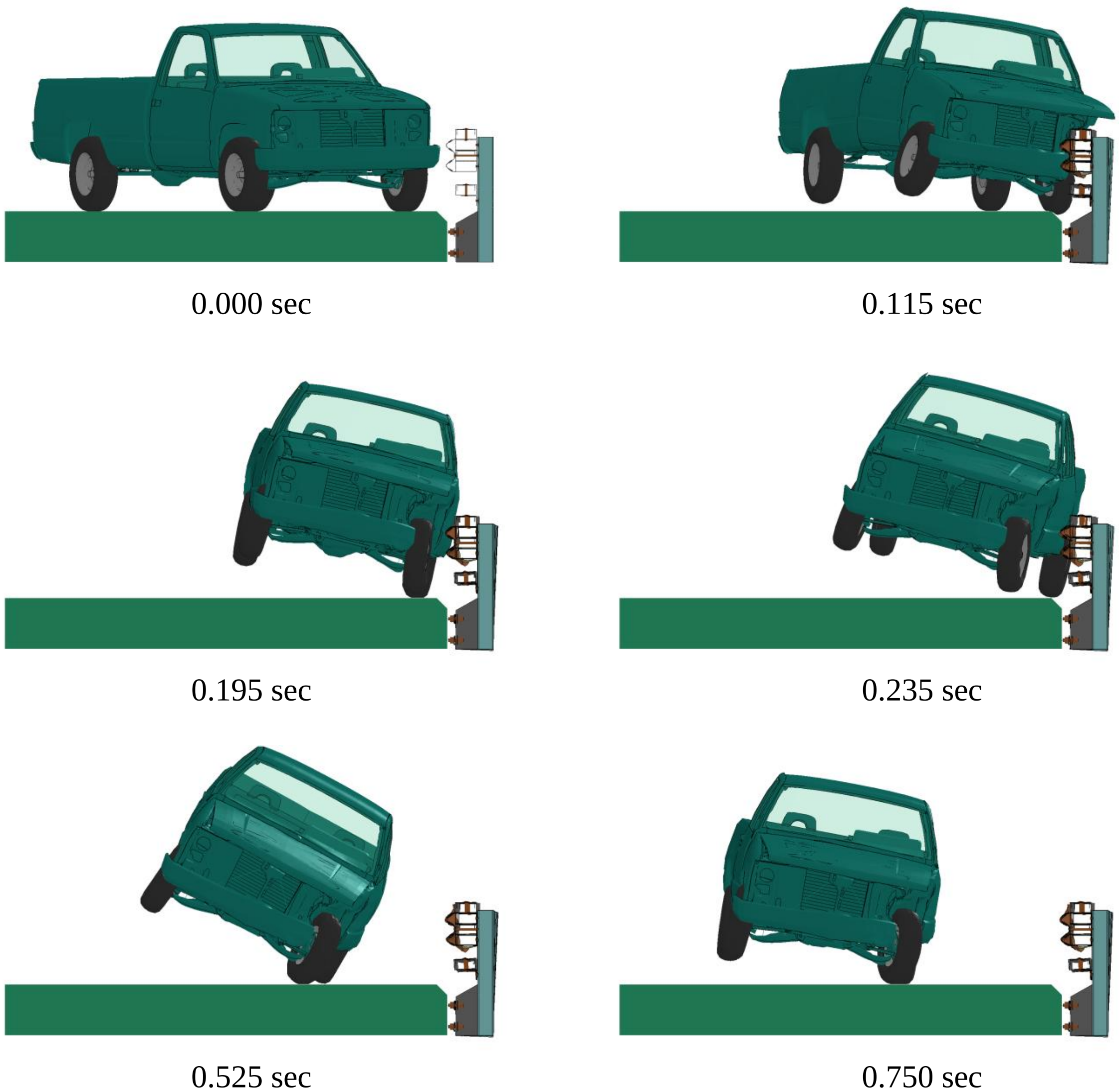


Figure 5.21 Gut view (looking upstream) showing 2000P test vehicle interacting with the modified deep beam system from initial impact till exit and rolling back

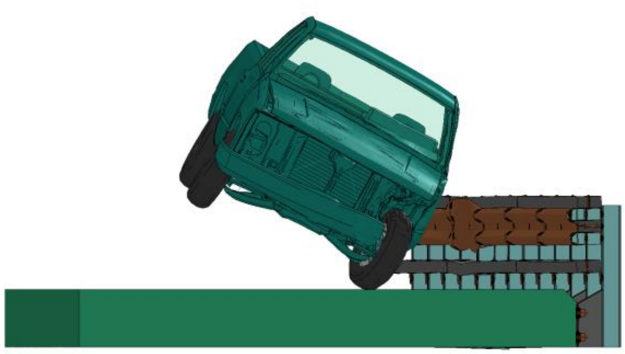


Figure 5.22 Vehicle dynamics at maximum roll angle

Occupant impact severity indices were all below the allowable limits of *NCHRP Report 350*. The occupant impact velocity (OIV) was -28.2 ft/s (-8.6 m/sec) in lateral direction (preferred 30 ft/s (9 m/sec) and maximum allowable is 40 ft/s (12 m/sec)) while the ridedown acceleration was 9.1 g's (preferred 15 g's and maximum allowable is 20 g's) in lateral direction per the LS-DYNA simulation. Details of acceleration data are presented in Figure 5.23. Figure 5.24, Figure 5.25, and Figure 5.26 show the acceleration histories at the center of gravity (C.G.) of the 2000P finite element model. The vehicular angular displacement, yaw, pitch, and roll rate are shown in Figure 5.27. The summary of the simulation results are presented in Figure 5.28.

General Information
Test Agency: Texas Transportation Institute
Test Number: 2000P Simulation, TL-3-11
Test Date:
Test Article: Modified Ohio Deep Beam Bridge Rail with Pavement

Test Vehicle
Description: C2500 detailed FE Model
Test Inertial Mass: 2000 kg
Gross Static Mass: 2000 kg

Impact Conditions
Speed: 100.0 km/hr
Angle: 25.0 degrees

Occupant Risk Factors

Impact Velocity (m/s)		at 0.1031 seconds on left side of interior
x-direction	7.9	
y-direction	-8.6	
THIV (km/hr):	40.4	at 0.1009 seconds on left side of interior
THIV (m/s):	11.2	
Ridedown Accelerations (g's)		
x-direction	-10.9	(0.1250 - 0.1350 seconds)
y-direction	9.1	(0.2399 - 0.2499 seconds)
PHD (g's):	12.5	(0.1227 - 0.1327 seconds)
ASI:	1.74	(0.0447 - 0.0947 seconds)

Max. 50msec Moving Avg. Accelerations (g's)

x-direction	-11.3	(0.0466 - 0.0966 seconds)
y-direction	13.7	(0.0598 - 0.1098 seconds)
z-direction	-5.7	(0.0242 - 0.0742 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)

Roll	-18.5	(0.4391 seconds)
Pitch	-4.1	(0.4325 seconds)
Yaw	29.4	(0.2940 seconds)

Figure 5.23 Signal data from TRAP of the 2000P FE model

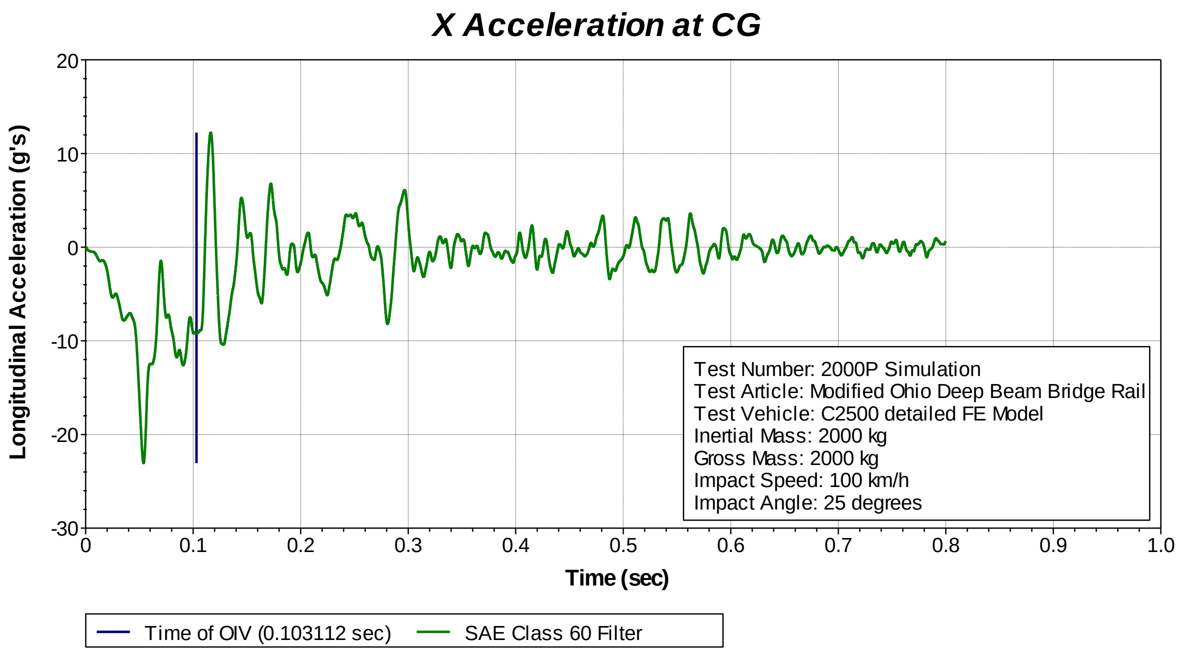


Figure 5.24 X acceleration history at the C.G. of the 2000P FE model

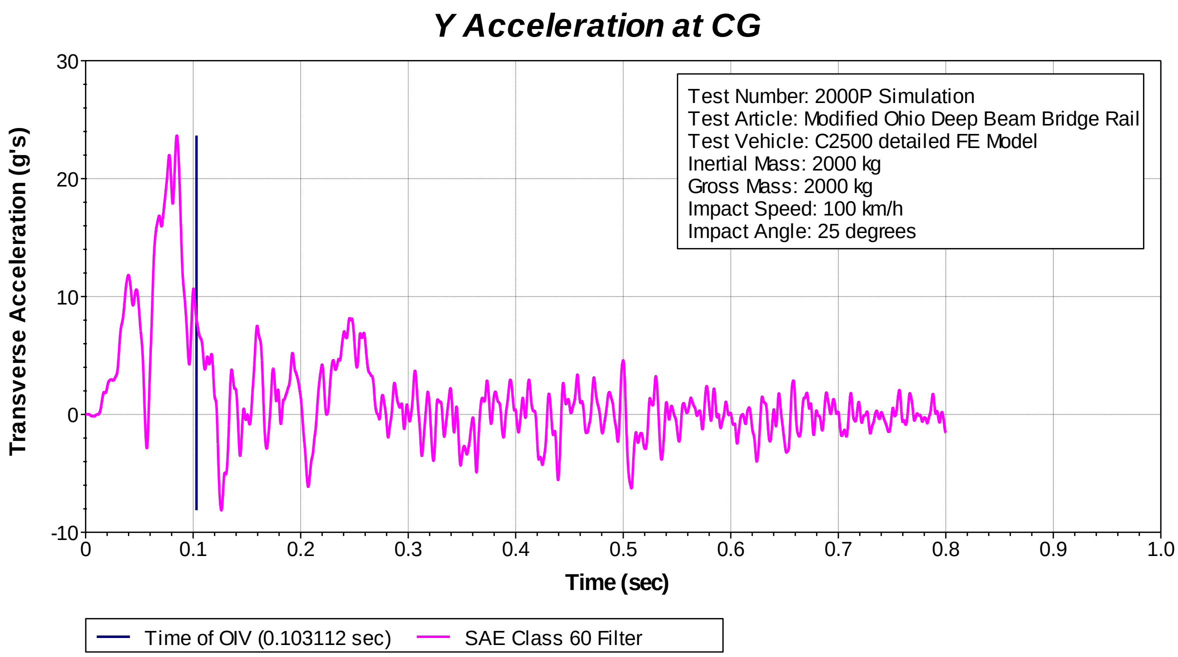


Figure 5.25 Y acceleration history at the C.G. of the 2000P FE model

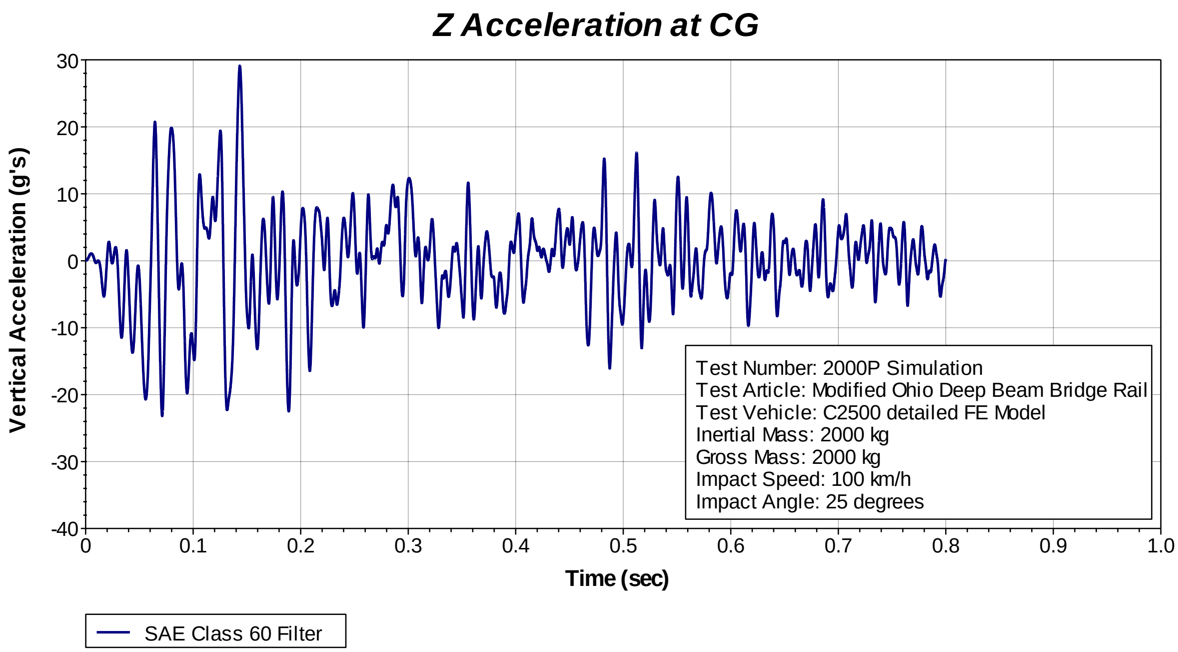


Figure 5.26 Z acceleration histories at the C.G. of the 2000P FE model

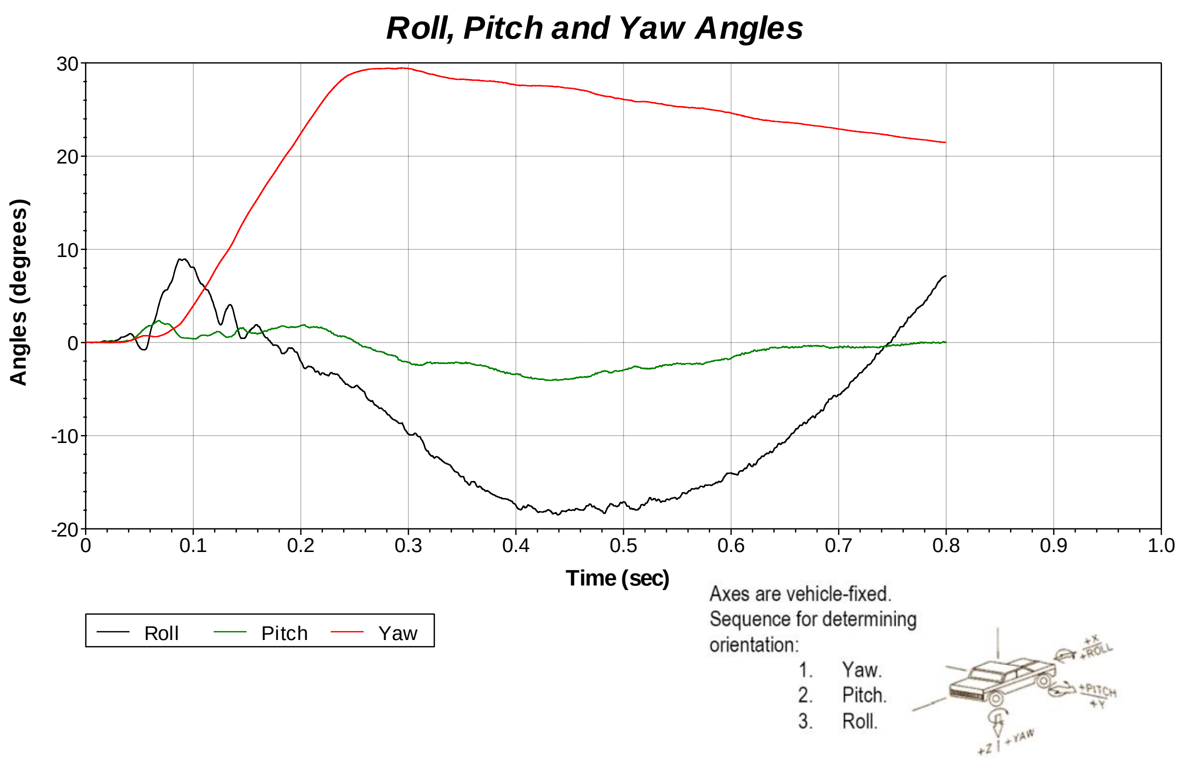
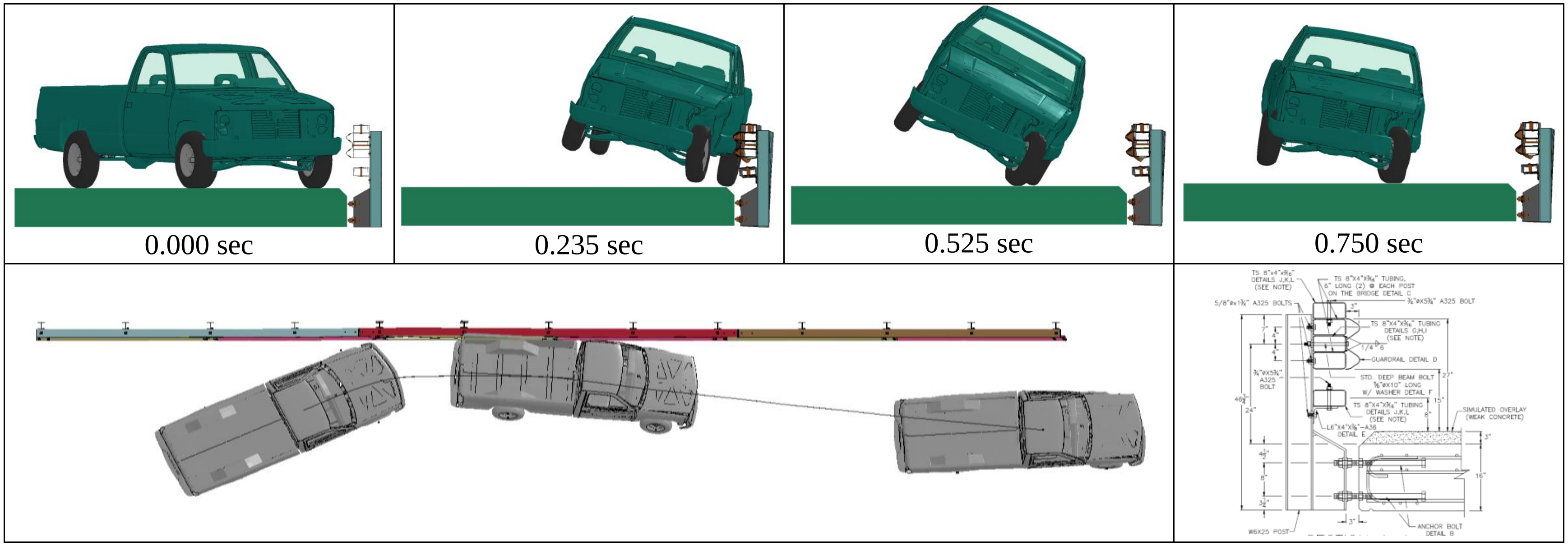


Figure 5.27 Vehicle angular displacements for test 3-11 simulation



General Information	
Test Agency	Texas Transportation Institute
Test No.	*NCHRP Report 350* Test 3-11
Date	N/A
Test Article	
Type	Bridge Rail
Name	31 inch Modified Ohio Deep Beam Bridge Rail
Installation Length	75 ft
Material or Key Elements	Bridge rail supported by W6x25 steel post
Soil Type and Condition	
Test Vehicle	
Type/Designation	2000P
Make and Model	C2500 detailed vehicle
Curb	4408 lb
Test Inertial	4408 lb
Dummy	No. Dummy
Gross Static	4408 lb

Impact Conditions	
Speed	62 mi/h
Angle	25 degrees
Location/Orientation	
Exit Conditions	
Speed	46.3 mi/h
Angle	5 degrees
Occupant Risk Values	
Impact Velocity	
Longitudinal	25.9 ft/s
Lateral	-28.2 ft/s
Ridedown Accelerations	
Longitudinal	-10.9 g
Lateral	9.1 g
THIV	40.4 km/h
PHD	12.5 g
Max. 0.050-s Average	
Longitudinal	-11.3 g
Lateral	13.7 g
Vertical	-5.7 g

Post-Impact Trajectory	
Stopping Distance	N/A
Vehicle Stability	
Maximum Yaw Angle	29.4 degrees @ 0.294 sec
Maximum Pitch Angle	-4.1 degrees @ 0.432 sec
Maximum Roll Angle	-18.5 degrees @ 0.439 sec
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	2.56 inches (top of barrier)
Permanent	N/A
Working Width	2.56 inches
Vehicle Damage	
VDS	N/A
CDC	N/A
Max. Exterior Deformation	N/A
Max. Occupant Compartment Deformation	N/A
OCD	N/A

Figure 5.28 Summary of results of *NCHRP Report 350* test 3-11 simulation

5.2.3 Full System Performance with Pavement Overlay using 3-10 Test Conditions

A simulation was conducted with an 820C vehicle model (Geo Metro) *(18)*. The vehicle had an initial velocity of 62 mi/h (100 km/h) and it was oriented 20 degrees per *NCHRP Report 350* test 3-10 conditions. The ODOT Modified Deep Beam bridge rail with pavement overlay model was able to contain and redirect the impact vehicle per the nonlinear finite element simulation. Figure 5.29 shows sequential images from the simulation that includes impact, redirection, rear wheel impact, and vehicular exit.

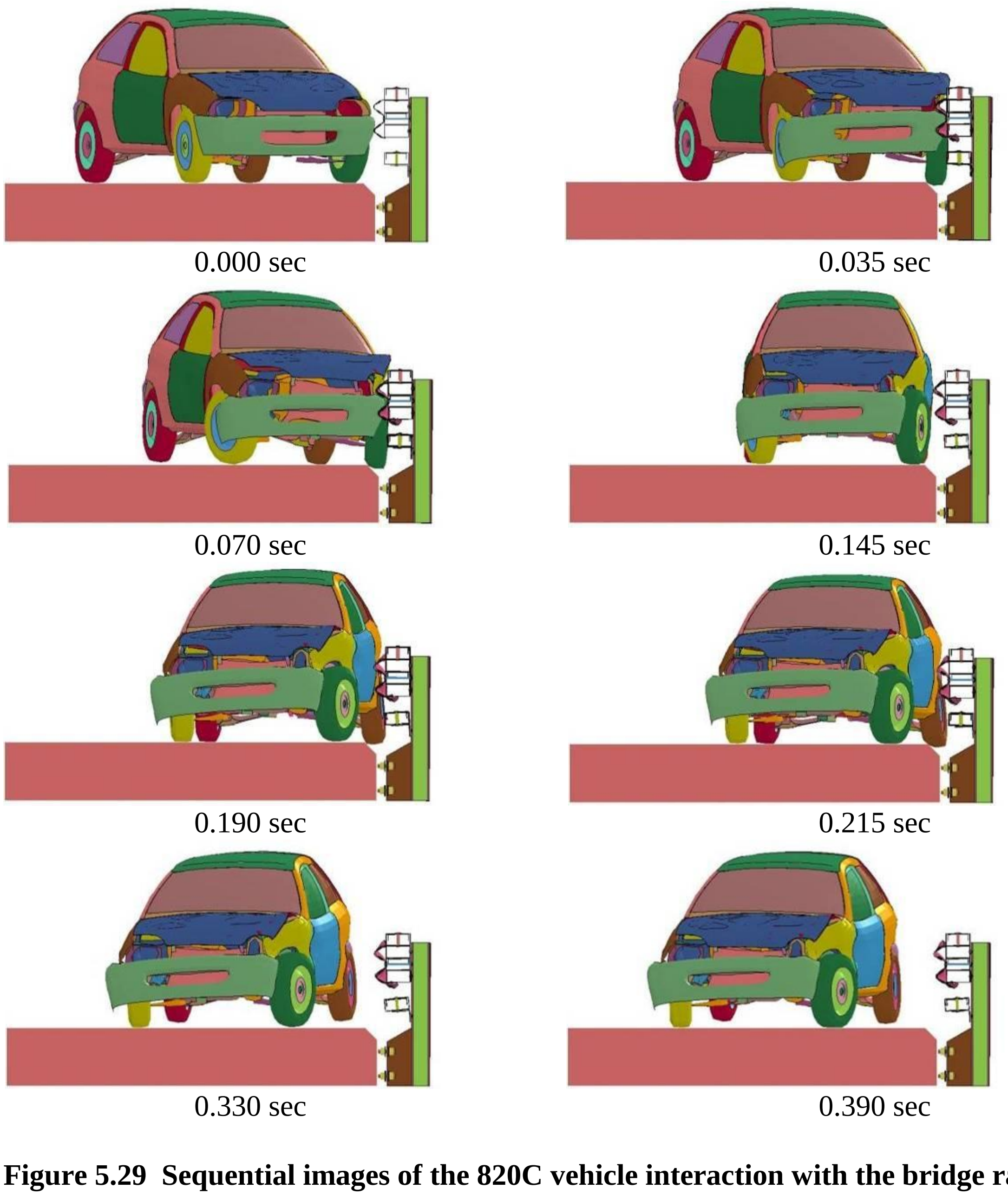


Figure 5.29 Sequential images of the 820C vehicle interaction with the bridge rail model with pavement overlay

The signal analysis of the accelerometer at the C.G of the 820C model is presented in Figure 5.30 with a maximum OIV of -28.9 ft/s (8.8 m/s) in the lateral direction (preferred 30 ft/s (9 m/s) and maximum allowable is 40 ft/s (12 m/s)) while the ridedown acceleration was 12.3 g's (preferred 15 g's and maximum allowable is 20 g's) in the lateral direction as well per LS-DYNA simulation. Figure 5.31, Figure 5.32, and Figure 5.33 show the acceleration histories at the C.G. of the 820C finite element model. The vehicular angular displacement, yaw, pitch, and roll rate are shown in Figure 5.34. The summary of the simulation results is presented in Figure 5.35.

General Information
Test Agency: Texas Transportation Institute
Test Number: 820c Simulation, TL-3-10
Test Date:
Test Article: Modified Ohio Deep Beam Bridge Rail with Pavement

Test Vehicle
Description: 820C FE Model
Test Inertial Mass: 820 kg
Gross Static Mass: 820 kg

Impact Conditions
Speed: 100.0 km/h
Angle: 20.0 degrees

Occupant Risk Factors
Impact Velocity (m/s) at 0.0829 seconds on left side of interior
x-direction 5.8
y-direction -8.8

THIV (km/hr): 37.1 at 0.0809 seconds on left side of interior
THIV (m/s): 10.3

Ridedown Accelerations (g's)
x-direction -7.0 (0.0873 - 0.0973 seconds)
y-direction 12.3 (0.1916 - 0.2016 seconds)

PHD (g's): 12.4 (0.1916 - 0.2016 seconds)

ASI: 1.98 (0.0255 - 0.0755 seconds)

Max. 50msec Moving Avg. Accelerations (g's)
x-direction -10.8 (0.0226 - 0.0726 seconds)
y-direction 16.0 (0.0255 - 0.0755 seconds)
z-direction -4.1 (0.0042 - 0.0542 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)
Roll 4.0 (0.3137 seconds)
Pitch 3.0 (0.2255 seconds)
Yaw 29.2 (0.3999 seconds)

Figure 5.30 Signal data from TRAP of the 820C model impacting the bridge rail with pavement overlay

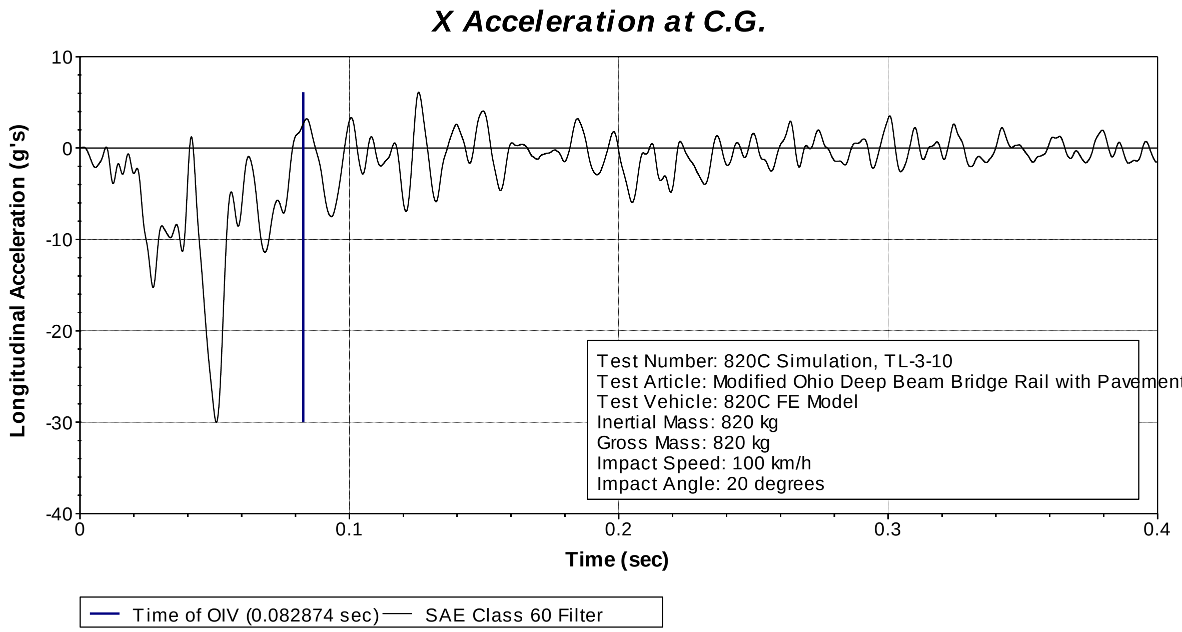


Figure 5.31 X acceleration history at the C.G. of the 820C FE model with pavement

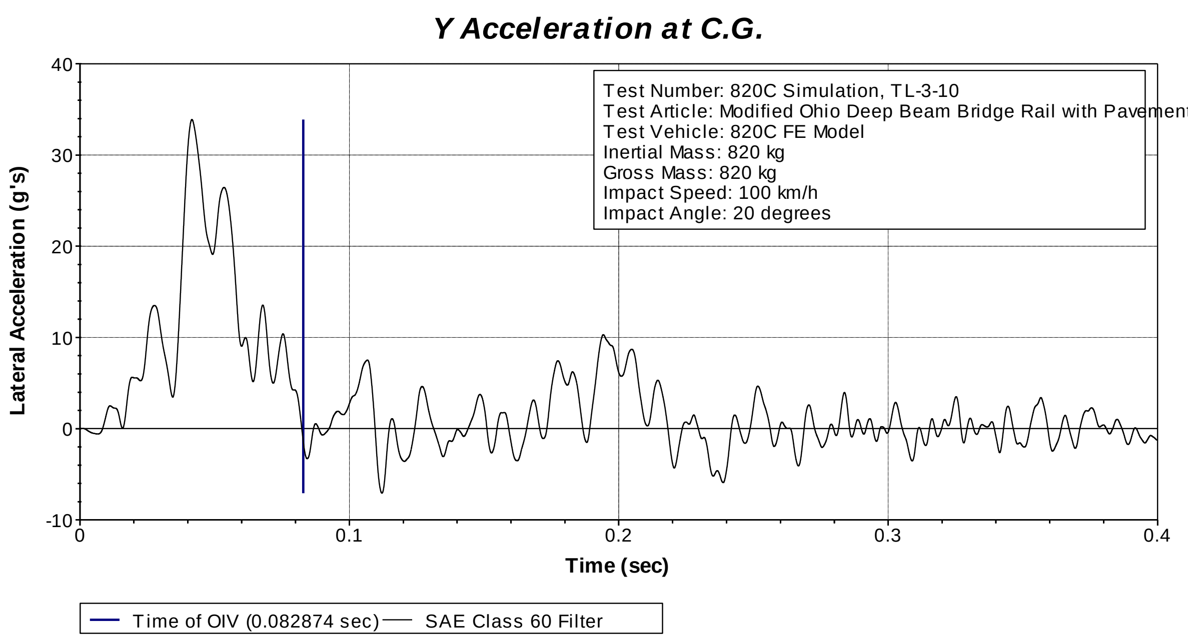


Figure 5.32 Y acceleration history at the C.G. of the 820C FE model with pavement

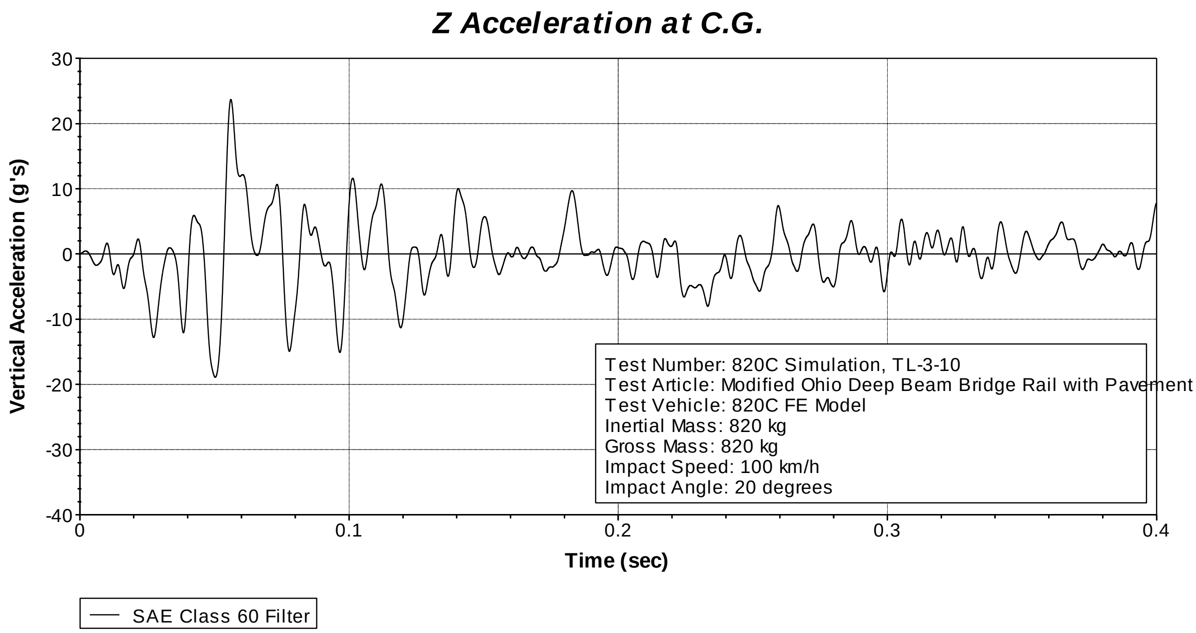


Figure 5.33 Z acceleration history at the C.G. of the 820C FE model with pavement

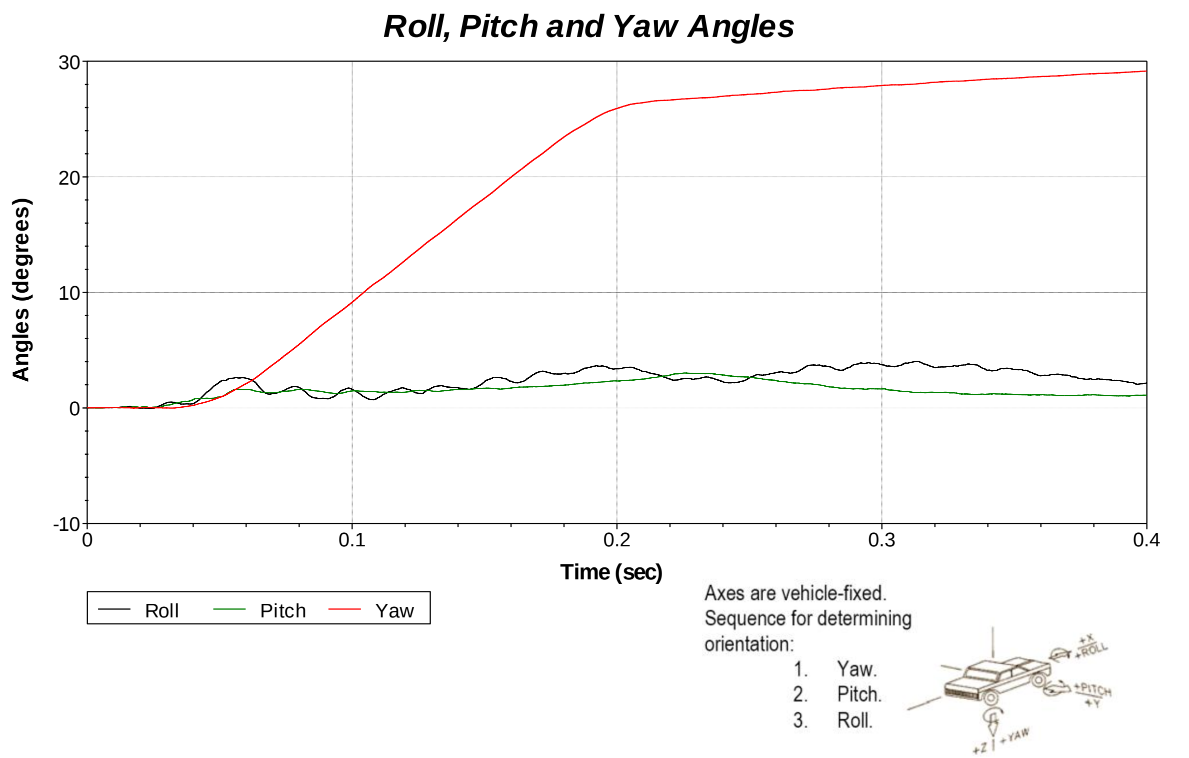
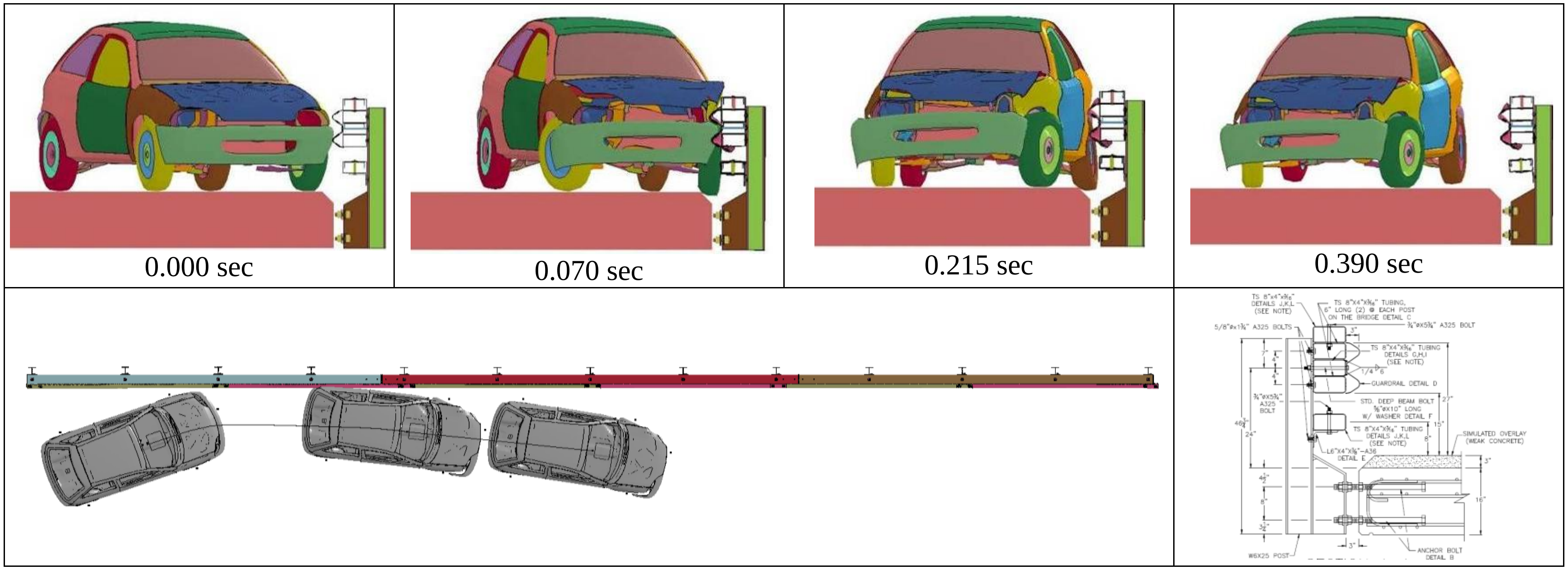


Figure 5.34 Vehicle angular displacements for the 820C FE model with pavement



General Information

Test Agency	Texas Transportation Institute
Test No.	*NCHRP Report 350* Test 3-10
Date	N/A

Test Article

Type	Bridge Rail
Name	31 inch Modified Ohio Deep Beam Bridge Rail
Installation Length	75 ft
Material or Key Elements	Bridge rail supported by W6x25 steel post

Soil Type and Condition...........

Test Vehicle

Type/Designation	820C
Make and Model	Geo Metro
Curb	1807 lb
Test Inertial	1807 lb
Dummy	No. Dummy
Gross Static	1807 lb

Impact Conditions

Speed	62 mi/h
Angle	20 degrees
Location/Orientation	

Exit Conditions

Speed	48.1 mi/h
Angle	8 degrees

Occupant Risk Values

Impact Velocity	
Longitudinal	5.8 ft/s
Lateral	-8.8 ft/s
Ridedown Accelerations	
Longitudinal	-7.0 g
Lateral	12.3 g
THIV	35.3 km/h
PHD	12.4 g
Max. 0.050-s Average	
Longitudinal	-10.8 g
Lateral	16.0 g
Vertical	-4.1 g

Post-Impact Trajectory

Stopping Distance	N/A

Vehicle Stability

Maximum Yaw Angle	29.2 degrees @ 0.399 sec
Maximum Pitch Angle	3.0 degrees @ 0.226 sec
Maximum Roll Angle	4.0 degrees @ 0.314 sec
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	0.758 in
Permanent	N/A
Working Width	N/A

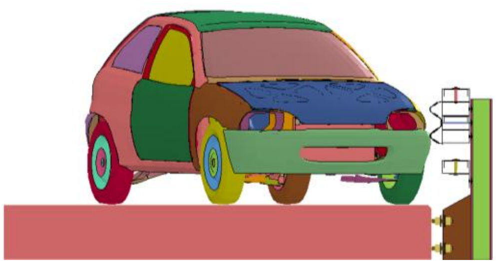
Vehicle Damage

VDS	N/A
CDC	N/A
Max. Exterior Deformation	N/A
Max. Occupant Compartment Deformation	N/A
OCDI	N/A

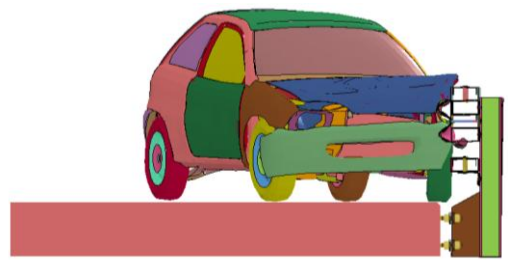
Figure 5.35 Summary of results of *NCHRP Report 350* test 3-10 simulation of the bridge rail with pavement overlay

5.2.4 Full System Performance without Pavement Overlay using 3-10 Test Conditions

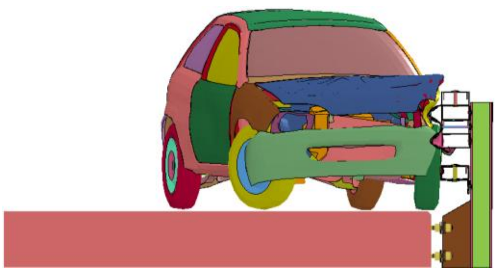
Another simulation was conducted with an 820C vehicle model (Geo Metro), but using the ODOT Deep Beam bridge rail without the pavement overlay model. The vehicle had an initial velocity of 62 mi/h (100 km/h) and it was oriented 20 degrees per *NCHRP Report 350* test 3-10 conditions. This simulation was conducted to investigate the potential of small car tire entrapping in the opening below the lower rail. The ODOT Modified Deep Beam bridge rail was able to contain and redirect the impact vehicle per the nonlinear finite element simulation. The simulation indicates that the Geo Metro tire would engage over the deck edge without significant snagging, as show in Figure 5.36.



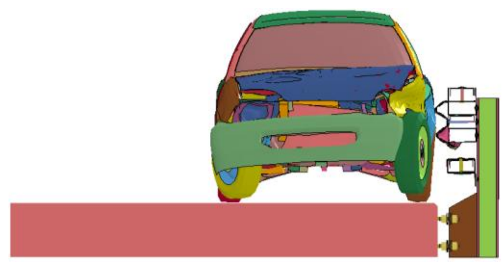
0.000 sec



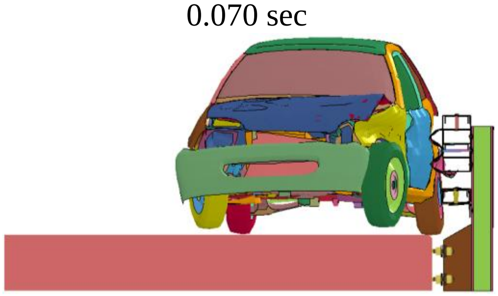
0.040 sec



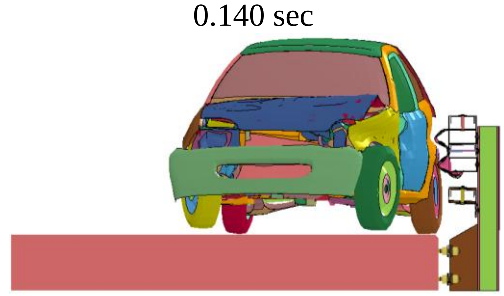
0.070 sec



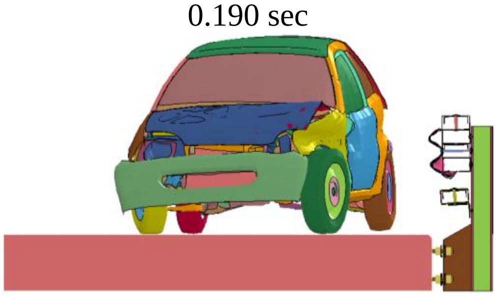
0.140 sec



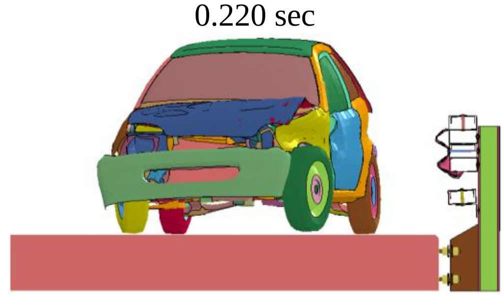
0.190 sec



0.220 sec



0.330 sec



0.390 sec

Figure 5.36 Sequential images of the impact vehicle interaction of the bridge rail model without pavement

The signal analysis of the accelerometer at the C.G of the 820C model without pavement is presented in Figure 5.37 with a maximum OIV of -28 ft/s (-8.6 m/s) in the lateral direction (preferred 30 ft/s (9 m/s) and maximum allowable is 40 ft/s (12 m/s)) while the ridedown acceleration was 12.6 g's (preferred 15 g's and maximum allowable is 20 g's) in the lateral direction as well per LS-DYNA simulation. Figure 5.38, Figure 5.39, and Figure 5.40 show the acceleration histories at the C.G. of the 820C finite element model. The vehicular angular displacement, yaw, pitch, and roll rate are shown in Figure 5.41. The summary of the simulation results is presented in Figure 5.42.

General Information
Test Agency: Texas Transportation Institute
Test Number: 820C Simulation, TL-3-10
Test Date:
Test Article: Modified Ohio Deep Beam Bridge Rail without Pavement

Test Vehicle
Description: 820C FE Model
Test Inertial Mass: 820 kg
Gross Static Mass: 820 kg

Impact Conditions
Speed: 100.0 km/hr
Angle: 20.0 degrees

Occupant Risk Factors

Impact Velocity (m/s)		at 0.0826 seconds on left side of interior
x-direction	5.3	
y-direction	-8.6	
THIV (km/hr):	34.9	at 0.0807 seconds on left side of interior
THIV (m/s):	9.7	
Ridedown Accelerations (g's)		
x-direction	-6.2	(0.0900 - 0.1000 seconds)
y-direction	12.6	(0.1866 - 0.1966 seconds)
PHD (g's):	12.6	(0.1866 - 0.1966 seconds)
ASI:	1.94	(0.0202 - 0.0702 seconds)

Max. 50msec Moving Avg. Accelerations (g's)

x-direction	-10.3	(0.0224 - 0.0724 seconds)
y-direction	15.6	(0.0200 - 0.0700 seconds)
z-direction	-3.9	(0.0041 - 0.0541 seconds)

Max Roll, Pitch, and Yaw Angles (degrees)

Roll	3.7	(0.1548 seconds)
Pitch	3.2	(0.2126 seconds)
Yaw	28.4	(0.4934 seconds)

Figure 5.37 Signal data from TRAP of the 820C model impacting the bridge rail without pavement overlay

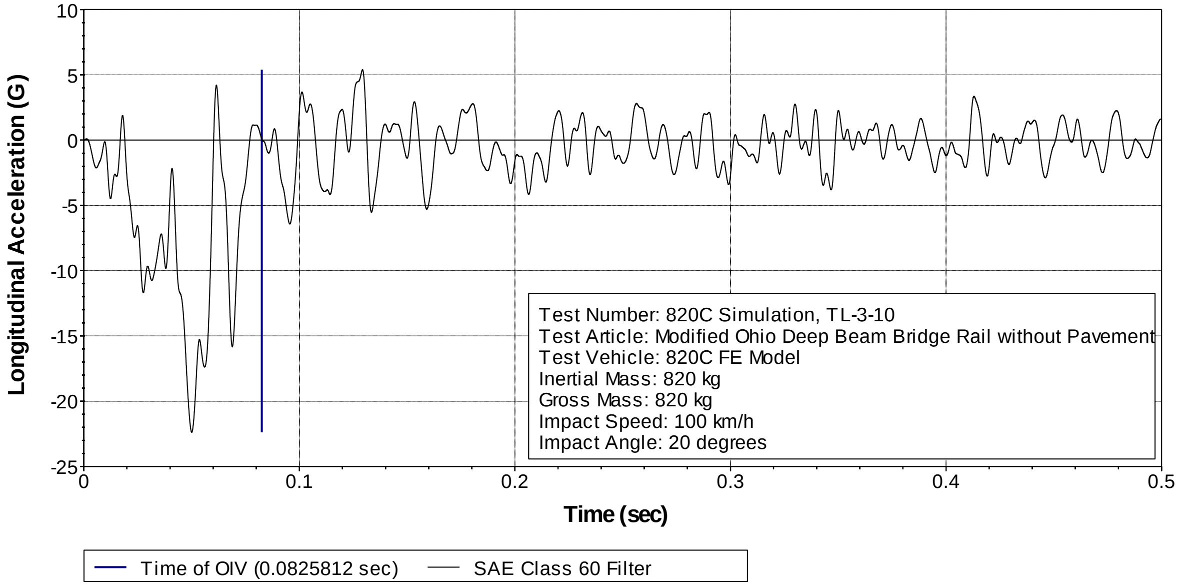


Figure 5.38 X acceleration history at the C.G. of the 820C FE model without pavement

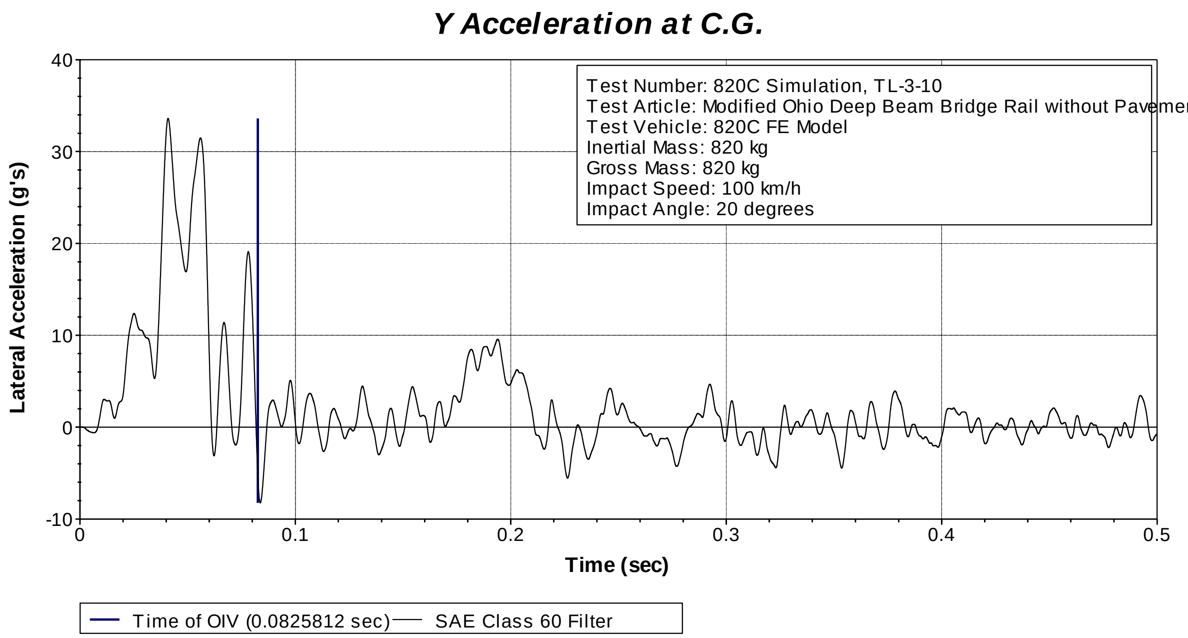


Figure 5.39 Y acceleration history at the C.G. of the 820C FE model without pavement

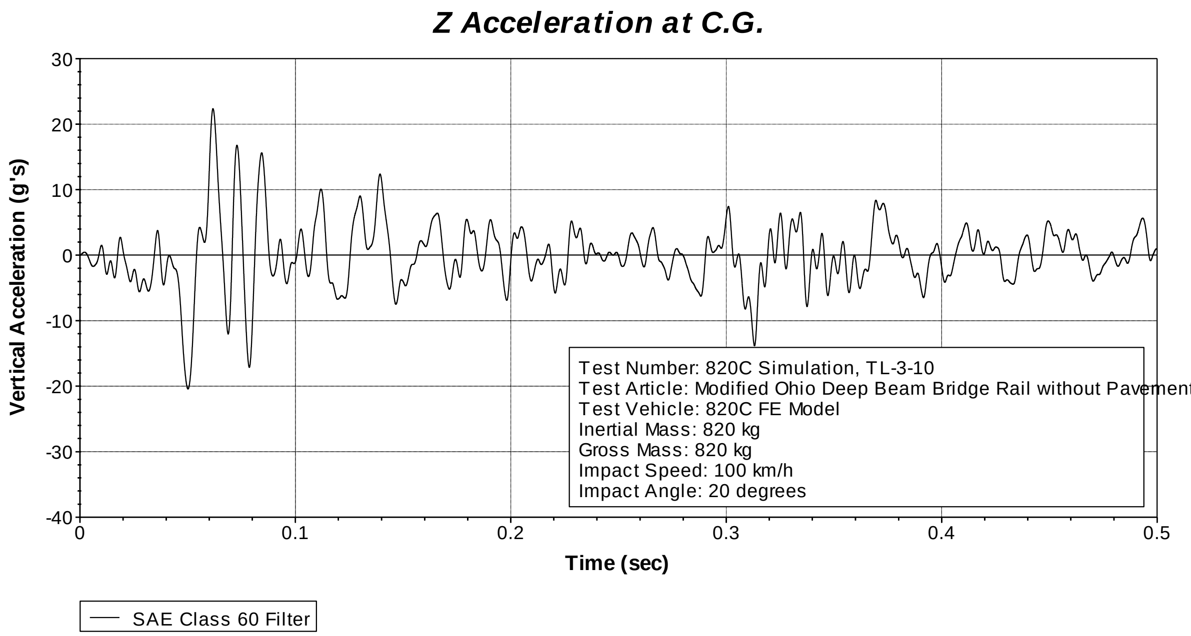


Figure 5.40 Z acceleration history at the C.G. of the 820C FE model without pavement

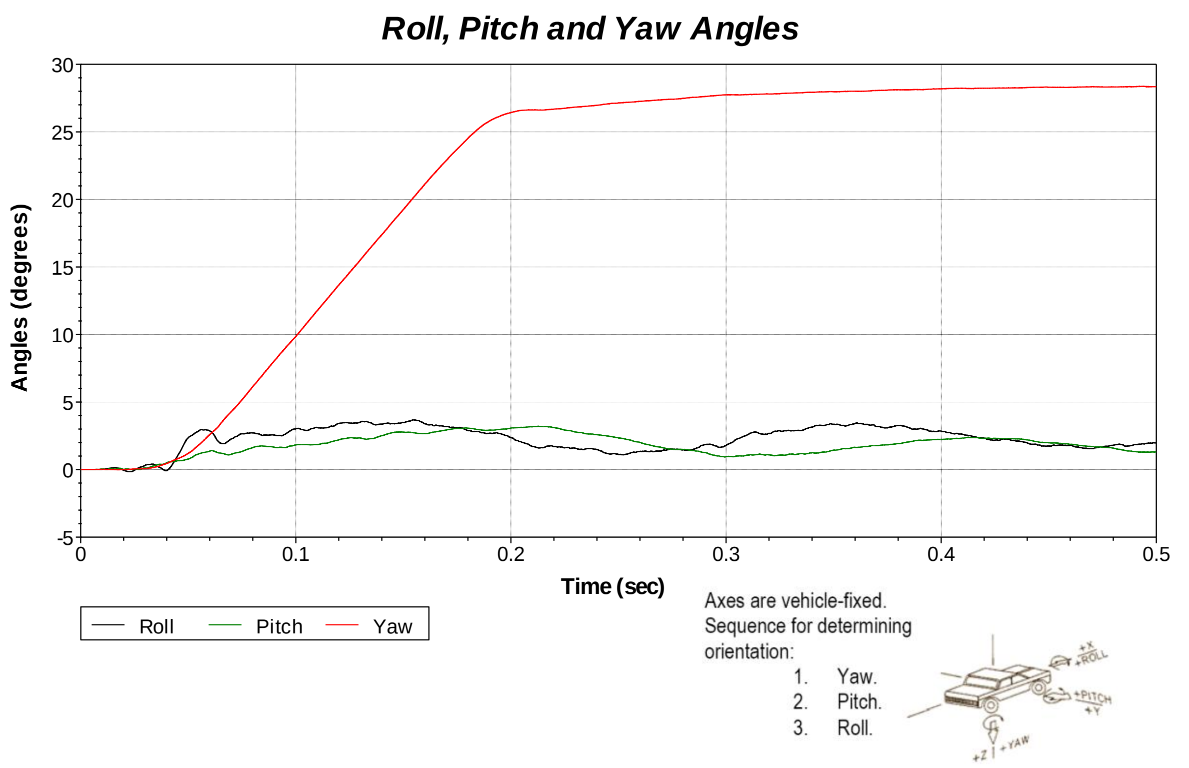
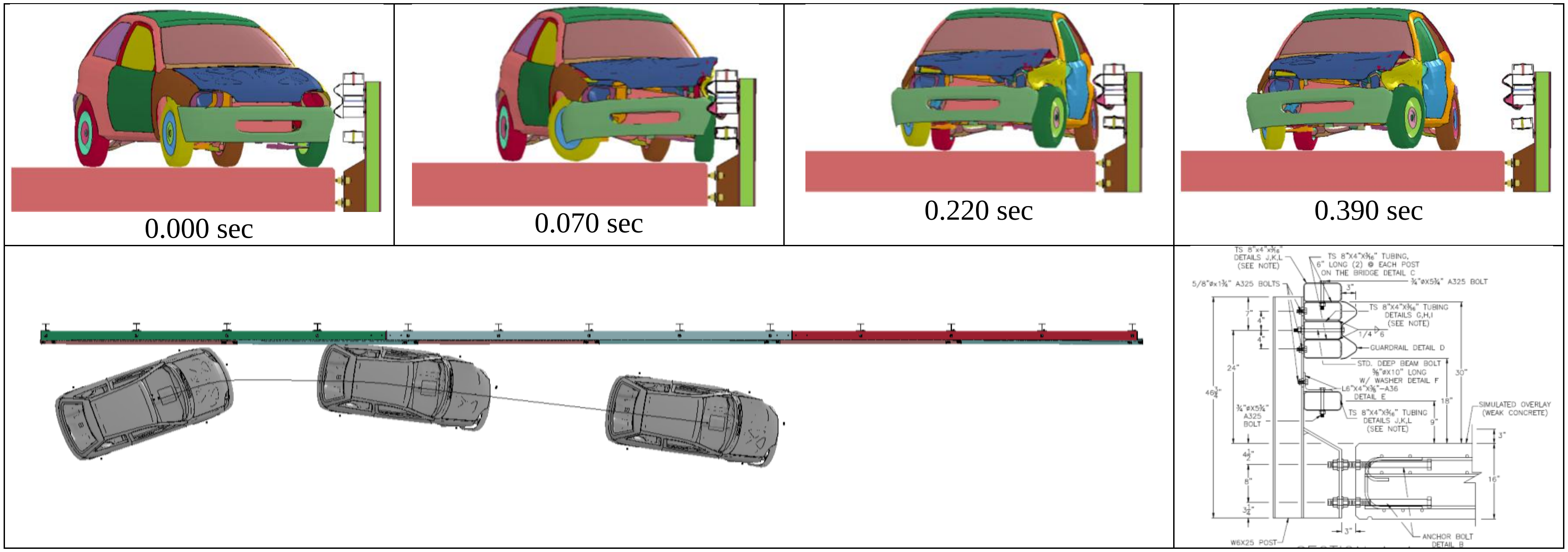


Figure 5.41 Vehicle angular displacements for the 820C FE model without pavement



General Information
Test Agency .... Texas Transportation Institute
Test No. .... Simulation
Date .... N/A

Test Article
Type....................................... Bridge Rail
Name .... 34 inch Modified Ohio Deep Beam Bridge Rail
Installation Length .... 75 ft
Material or Key Elements .... Bridge rail supported by W6x25 steel post
Soil Type and Condition...........
Test Vehicle
Type/Designation 820C
Make and Model...................... Geo Metro
Curb .... 1807 lb
Test Inertial .... 1807 lb
Dummy.................................... No. Dummy
Gross Static............................ 1807 lb

Impact Conditions
Speed.................................... 62 mi/h
Angle...................................... 20 degrees
Location/Orientation ....
Exit Conditions
Speed....................................49 mi/h
Angle.......................................10 degrees
Occupant Risk Values
Impact Velocity
Longitudinal......................... 5.3 ft/s
Lateral................................. -8.6 ft/s
Ridedown Accelerations
Longitudinal......................... -6.2 g
Lateral................................. 12.6 g
THIV....................................... 34.9 m/s
PHD .... 12.6 g
Max. 0.050-s Average
Longitudinal......................... -10.3 g
Lateral................................. 15.6 g
Vertical................................ -3.9 g

Post-Impact Trajectory
Stopping Distance ....N/A.

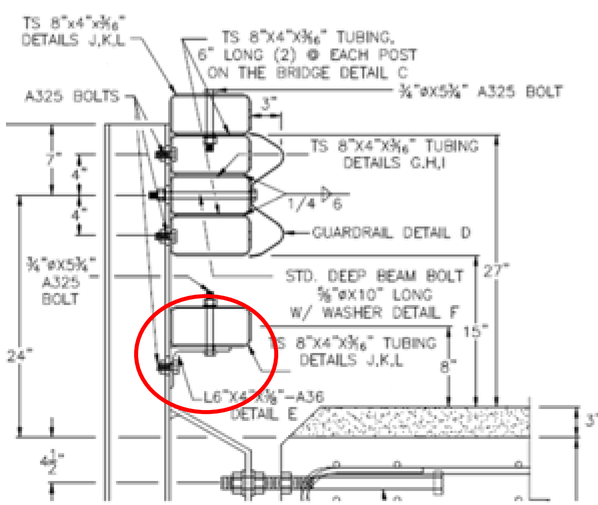
Vehicle Stability
Maximum Yaw Angle................. 28.4 degrees @ 0.493 sec
Maximum Pitch Angle................ 3.2 degrees @ 0.213 sec
Maximum Roll Angle.................. 3.7 degrees @ 0.155 sec
Vehicle Snagging ....No
Vehicle Pocketing......................No
Test Article Deflections
Dynamic ....0.55 inches (top of barrier)
Permanent................................N/A
Working Width ....N/A
Vehicle Damage
VDS..N/A
CDC ....N/A
Max. Exterior Deformation ....N/A
Max. Occupant Compartment Deformation.........................N/A
OCDI ....N/A

Figure 5.42 Summary of results of *NCHRP Report 350* test 3-10 simulation of the bridge rail without pavement overlay

6. CONCLUSIONS AND RECOMMENDATIONS

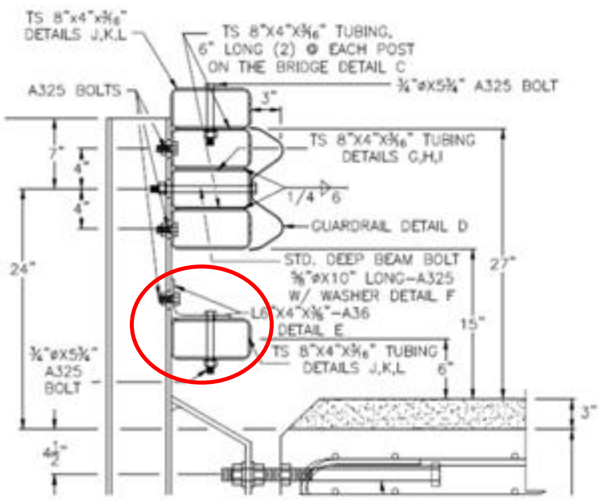
The modified ODOT Deep Beam bridge rail design is shown to be successfully able to pass *NCHRP Report 350* Test Level 3 assessment criteria. This conclusion is based on engineering strength analysis and nonlinear finite element simulation. The added rail on the top of the bridge rail helped reduced potential vehicular dynamics instability that may occur if only the original rail (less height) was used. Also, the additional lower rail (rub rail) provided a protection against tire snagging in the opening below the main rail and the deck. This snagging mode could be detrimental for small vehicle impacts due to the subsequent excessive deformation and increased ridedown acceleration.

The set of drawings of the modified ODOT Deep Beam bridge rail used in the simulation models is shown in APPENDIX C. In this set, lower rail attached to the post using an A36 angle shaped steel plate, as shown in Figure 6.1(a). The distance from the middle of this rail to the top of the asphalt overlay is 8 inches (230 mm). However the concern about tire snagging led the researchers to recommend reducing that distance. Therefore, the drawing was modified as shown in Figure 6.1 (b) to reduce the distance from middle of the rub rail to the top of the asphalt overlay to 6 inches (152 mm). In the case of an installation without asphalt overlay, the distance from the middle of the rub rail to the top of the deck will be 9 inches (229 mm), as shown in Figure 6.1 (c). Consequently, the shelf angle that holds the rub rail in the simulated design would have to be located on the top of the rub rail due to space restriction, as shown in Figure 6.1 (b) and (c). The full sets of drawings for the suggested installations are presented in APPENDIX D.

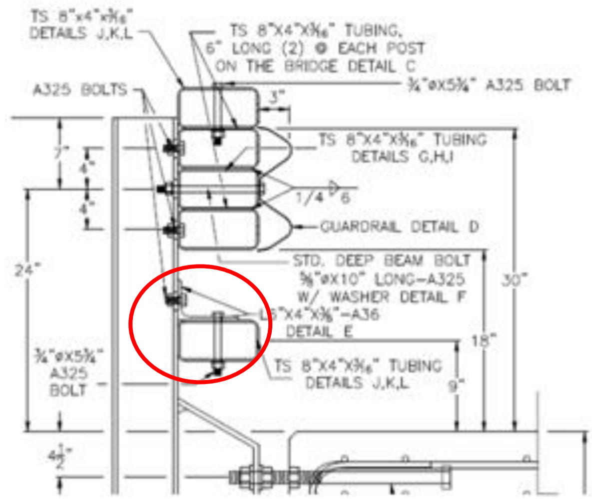


(a) Design used in simulation

Figure 6.1 Comparison of design of the ODOT Deep Beam bridge rail



(b) Final design with pavement overlay



(c) Final design without pavement overlay

Figure 6.1 Comparison of design of the ODOT Deep Beam bridge rail (continued)

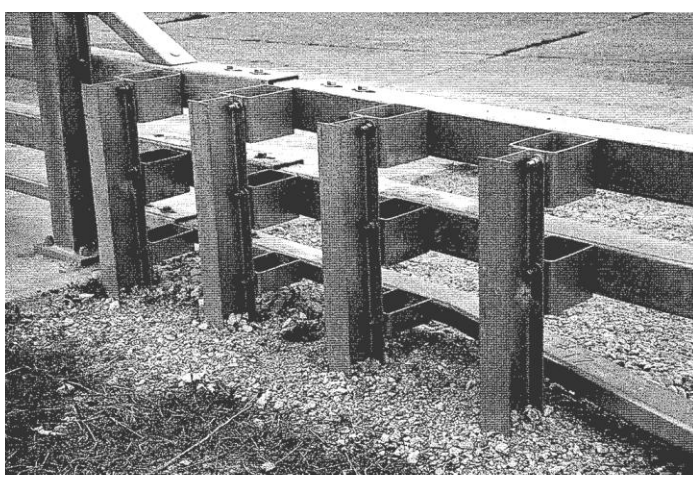
Although details were explicitly modeled in the nonlinear modeling simulation task of this research, some uncertainties are still not quantifiable through simulation. Specifically, damage to the suspension system of the vehicle and the failure of tire and wheels are not represented in current vehicle models. Tire failure (debeading, blown out…etc), wheel failure (rim separation and damage), and suspension failure (A-Arm rupture, joints failure …etc.) can lead to a variation of vehicular dynamical response as well as changes to the occupant severity of a given test. Hence, the research team recommends conducting the two *NCHRP Report 350* tests (3-11 and 3-10). For the 3-11 test, the research team recommends using the bridge rail installation that incorporates the pavement overlay to maximize vehicular dynamics. For the 3-10 test, the research team recommends using the installation that does not have pavement overlay to maximize the potential of snagging of the small car with the opening between the rub rail and the top of the deck.

7. IMPLEMENTATION PLAN

This system can be implemented in the field subsequent to FHWA Office of Safety approval of the simulation results presented herein or the full scale crash tests recommend in Chapter 6. The modified design presented herein represents a retrofit that can be installed by a qualified construction crew.

The research team recommends using the ODOT transition GR-3.4 shown in APPENDIX E. A modification is suggested for that transition detail to accommodate the added top and rub rails in the modified ODOT Deep Beam bridge rail. One example, as shown in Figure 7.1, would be to turn the top rail toward the middle rail at an angle and to extend the rub rail along a few transition posts and then turn it back toward the field side.

(a)



(b)

Figure 7.1 NY DOT bridge rail transition *(15)*

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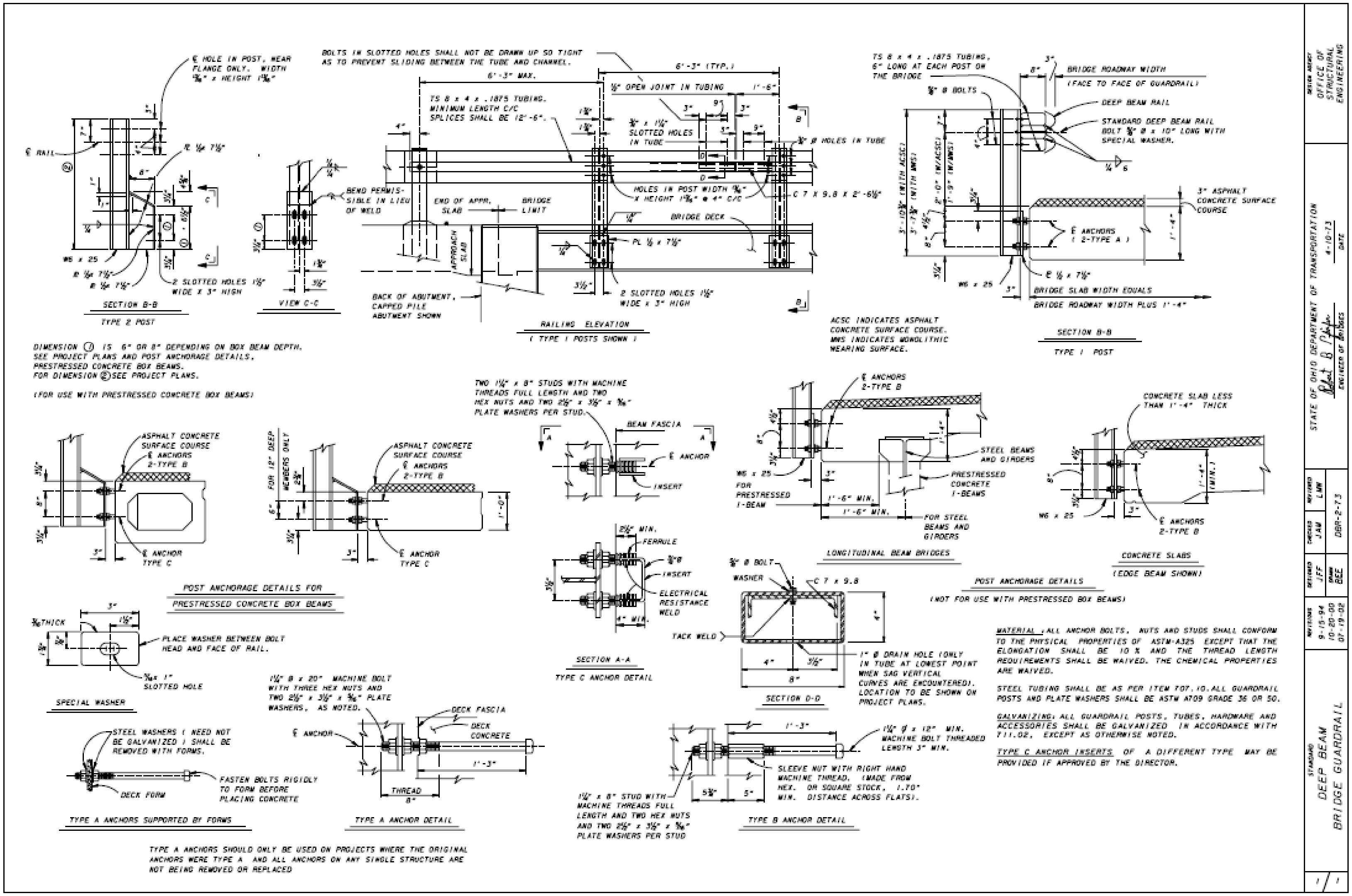


Figure A 1 ODOT Standard Bridge Drawing DBR-2-73

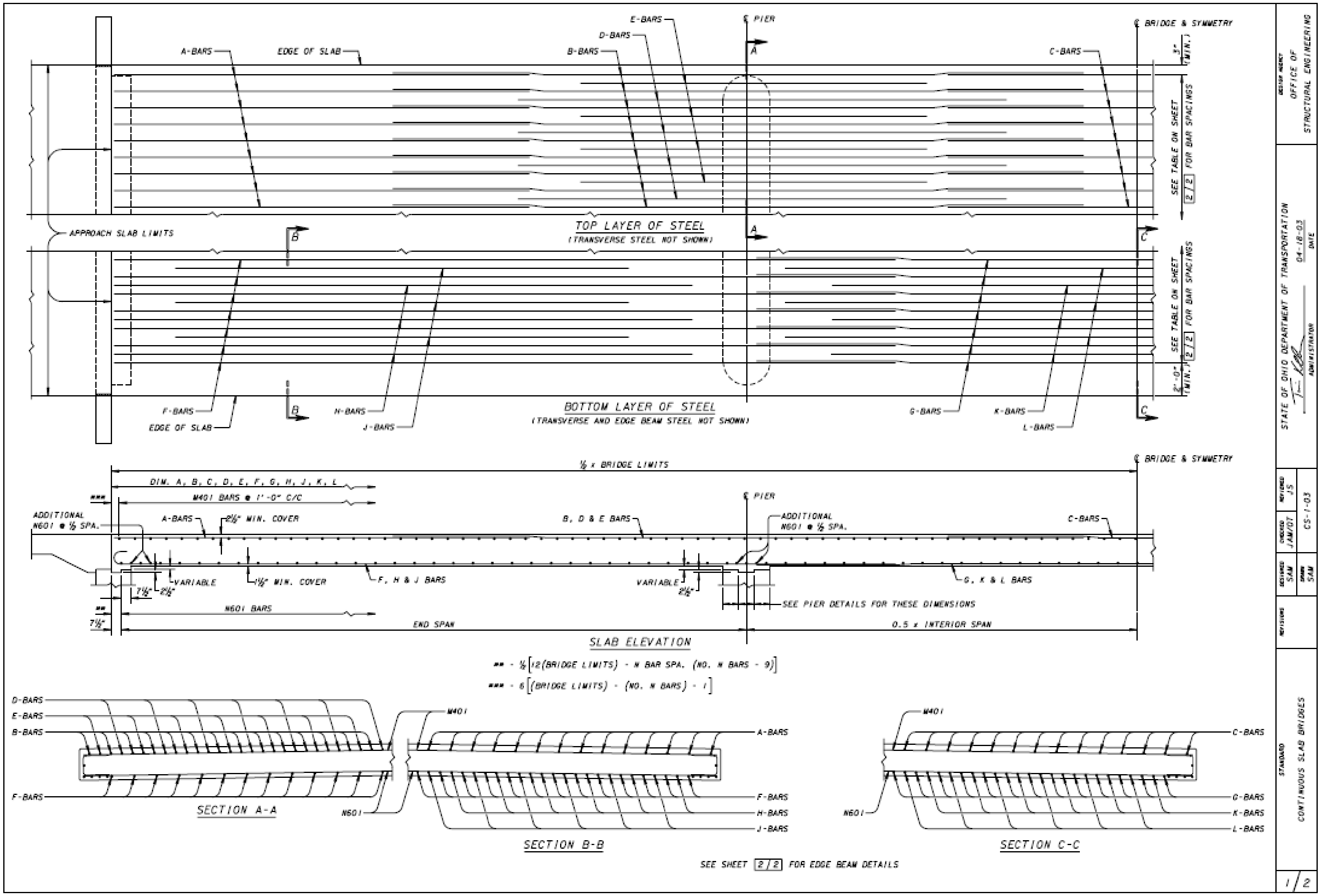


Figure A 2 Details of reinforcing in the slab

SLAB DATA

SPANS (Feet)	T (Inches)	A BARS SIZE	A SPA.	A LENGTH	B BARS SIZE	B SPA.	B DIM. B	B LENGTH	C BARS SIZE	C SPA.	C DIM. C	C LENGTH	D BARS SIZE	D SPA.	D DIM. D	D LENGTH	E BARS SIZE	E SPA.	E DIM. E	E LENGTH	F BARS SIZE	F SPA.
14 - 17.5 - 14	11	8	14½"	26'-4"	-	-	-	-	-	-	-	-	8	29"	2"	26'-11"	8	29"	2'-6"	24'-6"	8	13"
15 - 18.75 - 15	11⅝	8	14"	27'-11"	-	-	-	-	-	-	-	-	8	28"	1'-5"	27'-3"	8	28"	2'-11"	18'-3"	8	13"
16 - 20 - 16	12	8	14"	29'-7"	-	-	-	-	-	-	-	-	8	28"	1'-9"	28'-7"	8	28"	3'-4"	19'-0"	8	13"
17 - 21.25 - 17	12⅝	8	14"	31'-2"	-	-	-	-	-	-	-	-	8	28"	2'-0"	29'-11"	8	28"	5'-5"	18'-0"	8	13"
18 - 22.5 - 18	13	8	14"	32'-10"	-	-	-	-	-	-	-	-	8	28"	4'-1"	29'-5"	8	28"	13'-1"	11'-5"	8	13"
19 - 23.75 - 19	13⅝	8	14"	34'-5"	-	-	-	-	-	-	-	-	8	28"	4'-6"	30'-8"	8	28"	14'-0"	11'-8"	8	13"
20 - 25 - 20	14	8	14"	36'-1"	-	-	-	-	-	-	-	-	8	28"	4'-11"	29'-4"	8	28"	14'-11"	11'-10"	8	13"
21 - 26.25 - 21	14⅝	8	13½"	37'-8"	-	-	-	-	-	-	-	-	8	27"	5'-4"	30'-6"	8	27"	15'-10"	12'-1"	8	13"
22 - 27.5 - 22	15	8	13½"	39'-4"	-	-	-	-	-	-	-	-	8	27"	5'-9"	31'-7"	8	27"	16'-9"	12'-4"	8	13"
23 - 28.75 - 23	15⅝	8	13"	40'-11"	-	-	-	-	-	-	-	-	8	26"	6'-1"	32'-8"	8	26"	17'-7"	12'-7"	8	13"
24 - 30 - 24	16	8	13"	43'-0"	-	-	-	-	-	-	-	-	8	26"	8'-5"	32'-4"	8	26"	18'-0"	13'-9"	8	13"
25 - 31.25 - 25	16⅝	8	13"	44'-7"	-	-	-	-	-	-	-	-	8	26"	8'-11"	33'-4"	8	26"	18'-11"	14'-0"	8	12½"
26 - 32.5 - 26	17	8	12½"	46'-3"	-	-	-	-	-	-	-	-	8	25"	9'-5"	34'-4"	8	25"	19'-10"	14'-3"	8	12½"
27 - 33.75 - 27	17⅝	8	12"	47'-10"	-	-	-	-	-	-	-	-	8	24"	9'-11"	35'-4"	8	24"	20'-9"	14'-5"	8	12"
28 - 35 - 28	18	8	12"	49'-6"	-	-	-	-	-	-	-	-	8	24"	10'-5"	36'-4"	8	24"	21'-7"	14'-8"	8	12"
29 - 36.25 - 29	18⅝	9	13½"	52'-0"	-	-	-	-	-	-	-	-	9	27"	9'-11"	32'-1"	9	27"	21'-6"	16'-11"	9	15"
30 - 37.5 - 30	19	9	13"	53'-7"	-	-	-	-	-	-	-	-	9	26"	10'-5"	32'-10"	9	26"	22'-5"	17'-2"	9	14½"
31 - 38.75 - 31	19⅝	9	13"	55'-3"	-	-	-	-	-	-	-	-	9	26"	10'-11"	33'-7"	9	26"	23'-4"	17'-4"	9	14½"
32 - 40 - 32	20	9	12½"	56'-10"	-	-	-	-	-	-	-	-	9	25"	11'-5"	34'-4"	9	25"	24'-3"	17'-7"	9	14"
33 - 41.25 - 33	20⅝	9	12½"	58'-6"	-	-	-	-	-	-	-	-	9	25"	11'-11"	35'-1"	9	25"	25'-1"	17'-10"	9	14"
34 - 42.5 - 34	21	5	12"	19'-7"	9	12"	12'-5"	40'-1"	5	12"	45'-3"	21'-2"	9	24"	12'-5"	35'-10"	9	24"	26'-0"	18'-0"	9	14"
35 - 43.75 - 35	21⅝	5	12"	20'-1"	9	12"	12'-11"	41'-0"	5	12"	46'-8"	21'-8"	9	24"	12'-11"	36'-7"	9	24"	26'-11"	18'-3"	9	13½"
36 - 45 - 36	22	5	13½"	24'-2"	10	13½"	15'-7"	41'-2"	5	13½"	48'-0"	22'-2"	10	27"	15'-7"	36'-7"	10	27"	26'-5"	21'-4"	9	13½"
37 - 46.25 - 37	22⅝	5	13½"	24'-9"	10	13½"	16'-2"	41'-11"	5	13½"	49'-5"	22'-8"	10	27"	16'-2"	37'-3"	10	27"	27'-4"	21'-6"	9	13½"
38 - 47.5 - 38	23	5	13"	25'-5"	10	13"	16'-10"	42'-8"	5	13"	50'-9"	23'-2"	10	26"	20'-7"	34'-1"	10	26"	28'-2"	21'-9"	9	13"
39 - 48.75 - 39	23⅝	5	12½"	26'-0"	10	12½"	17'-5"	43'-5"	5	12½"	52'-2"	23'-8"	10	25"	21'-4"	34'-8"	10	25"	29'-1"	22'-0"	9	13"
40 - 50 - 40	24	5	12½"	26'-7"	10	12½"	18'-0"	44'-2"	5	12½"	53'-6"	24'-2"	10	25"	22'-0"	35'-2"	10	25"	30'-0"	22'-2"	9	13"
41 - 51.25 - 41	24⅝	5	12"	27'-2"	10	12"	18'-7"	45'-0"	5	12"	54'-11"	24'-8"	10	24"	26'-10"	31'-8"	10	24"	30'-11"	22'-5"	9	12½"
42 - 52.5 - 42	25	5	12"	27'-9"	10	12"	19'-2"	45'-9"	5	12"	56'-3"	25'-2"	10	24"	27'-7"	32'-1"	10	24"	31'-10"	22'-8"	9	12½"
43 - 53.75 - 43	25⅝	5	13"	28'-5"	11	13"	18'-5"	49'-4"	5	13"	57'-8"	25'-8"	11	26"	27'-0"	35'-5"	11	26"	31'-3"	25'-9"	9	12½"
44 - 55 - 44	26	5	13"	29'-0"	11	13"	19'-0"	50'-2"	5	13"	59'-0"	26'-2"	11	26"	27'-9"	35'-10"	11	26"	32'-2"	25'-11"	9	12½"
45 - 56.25 - 45	26⅝	5	12½"	29'-7"	11	12½"	19'-7"	50'-11"	5	12½"	60'-5"	26'-8"	11	25"	28'-7"	36'-3"	11	25"	33'-1"	26'-2"	9	12"
46 - 57.5 - 46	27	5	12½"	30'-2"	11	12½"	20'-2"	51'-8"	5	12½"	61'-5"	27'-2"	11	25"	29'-5"	36'-9"	11	25"	34'-0"	26'-5"	9	12"

SPANS (Feet)	F BARS LENGTH	G BARS SIZE	G SPA.	G DIM. G	G LENGTH	H BARS SIZE	H SPA.	H LENGTH	J BARS SIZE	J SPA.	J DIM. J	J LENGTH	K BARS SIZE	K SPA.	K DIM. K	K LENGTH	L BARS SIZE	L SPA.	L DIM. L	L LENGTH	#401 No.	#601 SPA.	#601 No.	U BARS No.
14 - 17.5 - 14	20'-6"	8	13"	13'-7"	19'-7"	8	26"	16'-9"	8	26"	2"	15'-4"	8	26"	12'-8"	21'-4"	8	26"	14'-5"	17'-10"	46	14"	48	80
15 - 18.75 - 15	21'-7"	8	13"	14'-8"	20'-8"	8	26"	17'-8"	8	26"	2"	16'-2"	8	26"	13'-10"	22'-4"	8	26"	15'-8"	18'-7"	49	12½"	55	94
16 - 20 - 16	22'-8"	8	13"	15'-9"	21'-9"	8	26"	18'-7"	8	26"	2"	17'-0"	8	26"	14'-11"	23'-4"	8	26"	16'-11"	19'-4"	52	15"	49	82
17 - 21.25 - 17	23'-9"	8	13"	16'-10"	22'-10"	8	26"	19'-6"	8	26"	2"	17'-9"	8	26"	16'-1"	24'-4"	8	26"	20'-4"	15'-10"	56	15"	52	88
18 - 22.5 - 18	24'-10"	8	13"	17'-11"	23'-11"	8	26"	20'-4"	8	26"	2"	18'-7"	8	26"	17'-2"	25'-4"	8	26"	21'-8"	16'-4"	59	15"	55	94
19 - 23.75 - 19	25'-11"	8	13"	19'-0"	25'-0"	8	26"	21'-3"	8	26"	2"	19'-4"	8	26"	18'-4"	26'-4"	8	26"	23'-1"	16'-10"	62	15"	58	100
20 - 25 - 20	27'-0"	8	13"	20'-1"	26'-1"	8	26"	22'-2"	8	26"	2"	19'-4"	8	26"	19'-5"	27'-4"	8	26"	21'-11"	22'-4"	65	15"	61	106
21 - 26.25 - 21	28'-1"	8	13"	21'-2"	27'-2"	8	26"	23'-1"	8	26"	2"	20'-0"	8	26"	20'-7"	28'-4"	8	26"	23'-2"	23'-1"	69	15½"	61	106
22 - 27.5 - 22	29'-2"	8	13"	22'-3"	28'-3"	8	26"	24'-0"	8	26"	2"	20'-7"	8	26"	21'-8"	29'-4"	8	26"	24'-5"	23'-10"	72	16½"	61	106
23 - 28.75 - 23	30'-3"	8	13"	23'-4"	29'-4"	8	26"	24'-10"	8	26"	2"	22'-7"	8	26"	22'-10"	30'-4"	8	26"	25'-8"	24'-7"	75	17½"	61	106
24 - 30 - 24	31'-4"	8	13"	24'-5"	30'-5"	8	26"	25'-9"	8	26"	2"	23'-4"	8	26"	23'-11"	31'-4"	8	26"	26'-11"	25'-4"	78	18"	61	106
25 - 31.25 - 25	32'-5"	8	12½"	25'-6"	31'-6"	8	25"	26'-8"	8	25"	2"	24'-2"	8	25"	25'-1"	32'-4"	8	25"	28'-2"	26'-1"	82	15"	74	132
26 - 32.5 - 26	33'-6"	8	12½"	26'-7"	32'-7"	8	25"	27'-7"	8	25"	2"	25'-0"	8	25"	30'-7"	33'-4"	8	25"	29'-5"	26'-10"	85	16½"	71	126
27 - 33.75 - 27	34'-7"	8	12"	27'-8"	33'-8"	8	24"	28'-6"	8	24"	2"	25'-9"	8	24"	31'-0"	34'-4"	8	24"	30'-8"	27'-7"	88	15"	78	140
28 - 35 - 28	35'-8"	8	12"	28'-9"	34'-9"	8	24"	29'-4"	8	24"	2"	26'-7"	8	24"	28'-5"	35'-4"	8	24"	31'-11"	28'-4"	91	17½"	71	126
29 - 36.25 - 29	38'-1"	9	15"	29'-4"	35'-10"	9	30"	34'-0"	9	30"	2"	28'-2"	9	30"	25'-1"	45'-3"	9	30"	32'-4"	30'-9"	95	15"	84	152
30 - 37.5 - 30	39'-2"	9	14½"	30'-5"	37'-11"	9	29"	32'-0"	9	29"	2"	27'-0"	9	29"	30'-8"	37'-6"	9	29"	33'-7"	31'-6"	98	18"	74	132
31 - 38.75 - 31	40'-3"	9	14½"	31'-6"	39'-0"	9	29"	32'-11"	9	29"	2"	29'-10"	9	29"	27'-1"	40'-0"	9	29"	34'-10"	32'-3"	101	15½"	87	158
32 - 40 - 32	41'-4"	9	14"	32'-7"	40'-1"	9	28"	33'-10"	9	28"	2"	28'-3"	9	28"	33'-1"	39'-0"	9	28"	36'-1"	33'-0"	104	16"	87	158
33 - 41.25 - 33	42'-5"	9	14"	33'-8"	41'-2"	9	28"	34'-8"	9	28"	2"	31'-5"	9	28"	34'-4"	39'-9"	9	28"	37'-4"	33'-9"	108	16½"	87	158
34 - 42.5 - 34	43'-6"	9	14"	34'-9"	42'-3"	9	28"	35'-7"	9	28"	2"	32'-2"	9	28"	35'-7"	40'-6"	9	28"	38'-7"	34'-6"	111	17"	87	158
35 - 43.75 - 35	44'-7"	9	13½"	35'-10"	43'-4"	9	27"	36'-6"	9	27"	2"	33'-0"	9	27"	36'-10"	41'-3"	9	27"	39'-10"	35'-3"	114	17½"	87	158
36 - 45 - 36	45'-8"	9	13½"	36'-11"	44'-5"	9	27"	37'-5"	9	27"	2"	33'-10"	9	27"	38'-1"	42'-0"	9	27"	41'-1"	36'-0"	117	18"	87	158
37 - 46.25 - 37	46'-9"	9	13½"	38'-0"	45'-6"	9	27"	38'-4"	9	27"	2"	34'-7"	9	27"	39'-4"	42'-9"	9	27"	42'-4"	36'-9"	121	15"	104	192
38 - 47.5 - 38	47'-10"	9	13"	39'-1"	46'-7"	9	26"	39'-2"	9	26"	3'-8"	31'-10"	9	26"	43'-7"	37'-6"	9	26"	48'-4"	28'-0"	124	15"	107	198
39 - 48.75 - 39	48'-11"	9	13"	40'-2"	47'-8"	9	26"	36'-2"	9	26"	3'-11"	32'-5"	9	26"	44'-10"	38'-3"	9	26"	49'-9"	28'-6"	127	16½"	101	186
40 - 50 - 40	50'-0"	9	13"	41'-3"	48'-9"	9	26"	37'-0"	9	26"	2"	37'-0"	9	26"	46'-1"	39'-0"	9	26"	51'-1"	29'-0"	130	15"	113	210
41 - 51.25 - 41	51'-1"	9	12½"	42'-4"	49'-10"	9	25"	37'-10"	9	25"	4'-3"	29'-6"	9	25"	47'-4"	39'-9"	9	25"	52'-6"	29'-6"	134	15"	114	212
42 - 52.5 - 42	52'-2"	9	12½"	43'-5"	50'-11"	9	25"	38'-7"	9	25"	4'-6"	30'-0"	9	25"	48'-7"	40'-6"	9	25"	53'-10"	30'-0"	137	17½"	101	186
43 - 53.75 - 43	53'-3"	9	12½"	44'-6"	52'-0"	9	25"	39'-5"	9	25"	2"	35'-1"	9	25"	46'-10"	47'-3"	9	25"	45'-10"	41'-3"	140	15"	120	224
44 - 55 - 44	54'-4"	9	12½"	45'-7"	53'-1"	9	25"	40'-2"	9	25"	2"	35'-10"	9	25"	48'-1"	48'-0"	9	25"	51'-1"	42'-0"	143	16½"	113	210
45 - 56.25 - 45	55'-5"	9	12"	46'-8"	54'-2"	9	24"	41'-0"	9	24"	5'-1"	31'-6"	9	24"	49'-4"	48'-9"	9	24"	52'-4"	42'-9"	147	15"	126	236
46 - 57.5 - 46	56'-6"	9	12"	47'-9"	55'-3"	9	24"	41'-10"	9	24"	5'-3"	32'-0"	9	24"	50'-7"	49'-6"	9	24"	53'-7"	43'-6"	150	17½"	113	210

DIM. A = 2"   DIM. F = 2"   DIM. H = 2"

GENERAL: THIS DRAWING PROVIDES DESIGN AND GENERAL CONSTRUCTION DETAILS FOR THREE SPAN SLAB BRIDGES. THE PROJECT PLANS FOR EACH STRUCTURE WILL SHOW SPAN LENGTHS, ROADWAY WIDTHS, SKEW, CURVE AND SUPERELEVATION (IF ANY), ELEVATIONS, SLAB REINFORCEMENT DETAILS IN PLAN AND CROSS SECTIONS, SUBSTRUCTURE DETAILS, ESTIMATED QUANTITIES, REINFORCING STEEL LIST AND OTHER NECESSARY DETAILS AND SPECIAL NOTES.

ADDITIONAL INTERIOR SPANS, THE SAME LENGTH AS THE MIDDLE SPAN, MAY BE INCORPORATED INTO THE STRUCTURE WITHOUT CHANGE IN SLAB THICKNESS OR AREA OF REINFORCING STEEL. WHEN SPANS ARE ADDED, THE PROJECT PLANS WILL SHOW THE REVISED DETAILS.

DESIGN SPECIFICATIONS: THIS DRAWING CONFORMS TO THE "STANDARD SPECIFICATIONS FOR HIGHWAY BRIDGES" ADOPTED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS, 1996, INCLUDING THE 1997 - 2002 INTERIMS, AND THE OHIO BRIDGE DESIGN MANUAL, 2003.

DESIGN DATA:
DESIGN METHOD - LOAD FACTOR DESIGN
DESIGN LOADING - HS25 AND THE ALTERNATE MILITARY LOADING
SUPERIMPOSED DEAD LOAD - 60 LB/FT²
WEARING SURFACE - ONE INCH MONOLITHIC

DESIGN STRESSES:
CONCRETE - COMPRESSIVE STRENTH - 4500 PSI
REINFORCING STEEL - MIN. YIELD STRENGTH - 60 KSI

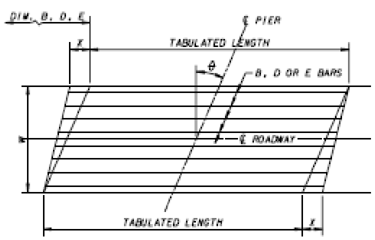
EDGE BEAM OPTION: IN LIEU OF FORMING AN EDGE BEAM, AT NO ADDITIONAL COST TO THE OWNER, THE CONTRACTOR MAY FURNISH AN 18" SLAB OR A SLAB VARYING IN THICKNESS FROM 18" AT THE EDGE TO "T" AT THE CENTER OF THE ROADWAY.

CAMBER: TO COMPENSATE FOR FALSEWORK DEFLECTION AND FOR THE DEFLECTION OF THE SLAB AFTER THE FALSEWORK IS REMOVED, BUILD CAMBER INTO THE FALSEWORK ACCORDING TO CMS 508.02.

SKEW: FOR BRIDGES WITH SKEW, PLACE LONGITUDINAL BARS PARALLEL TO THE CENTERLINE OF THE ROADWAY AND TRANSVERSE BARS PARALLEL TO THE PIERS AND ABUTMENTS. DO NOT USE THIS STANDARD FOR SKEWS GREATER THAN 30°. FOR SKEWS FROM 10° TO 30°, LENGTHEN B, D AND E BARS AND SHORTEN C BARS BY DIMENSION X. PLACE B, C, D, AND E BARS AS SHOWN IN THE SKEW PLACEMENT DIAGRAM BELOW.

$$X = \frac{1}{150} \times W \times S \times \tan\theta \text{ (IN FEET)}$$

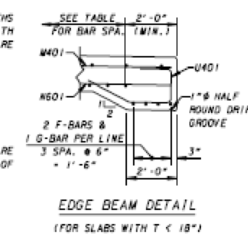
W = BRIDGE SLAB WIDTH IN FEET
S = LENGTH OF MIDDLE SPAN IN FEET
θ = SKEW ANGLE



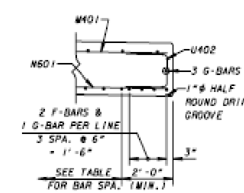
REINFORCING STEEL: FURNISH THE REINFORCING STEEL LENGTHS AS INDICATED IN THE TABLE OR PROVIDE LAP SPLICES WITH THE MINIMUM LAP LENGTHS SHOWN BELOW. IF LAP SPLICES ARE PROVIDED, STAGGER THE LOCATION OF THE SPLICES.

NO. 4 LAP = 2'-9"   NO. 8 LAP = 7'-3"
NO. 5 LAP = 3'-5"   NO. 9 LAP = 9'-2"
NO. 6 LAP = 4'-1"   NO. 10 LAP = 11'-7"
NO. 7 LAP = 5'-6"   NO. 11 LAP = 14'-3"

DIMENSIONS: THE DIMENSIONS SHOWN IN THE TABLE ABOVE ARE MEASURED FROM THE END OF THE SLAB TO THE NEAREST END OF THE REINFORCING STEEL BAR INDICATED BY LETTER.

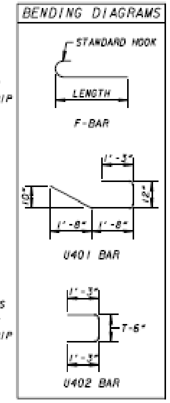


EDGE BEAM DETAIL
(FOR SLABS WITH T < 18")



EDGE BEAM DETAIL
(FOR SLABS WITH T ≥ 18")

BENDING DIAGRAMS



DESIGN AGENCY: OFFICE OF STRUCTURAL ENGINEERING

STATE OF OHIO DEPARTMENT OF TRANSPORTATION
ADMINISTRATOR
04-18-03
DATE

REVIEWED: JS
CHECKED: JAM/DT
DESIGNED: SAM
DRAWN: SAM
REVISIONS

CS-1-03

STANDARD: CONTINUOUS SLAB BRIDGES

2/2

Figure A 3 Details of reinforcing in the slab (continued)

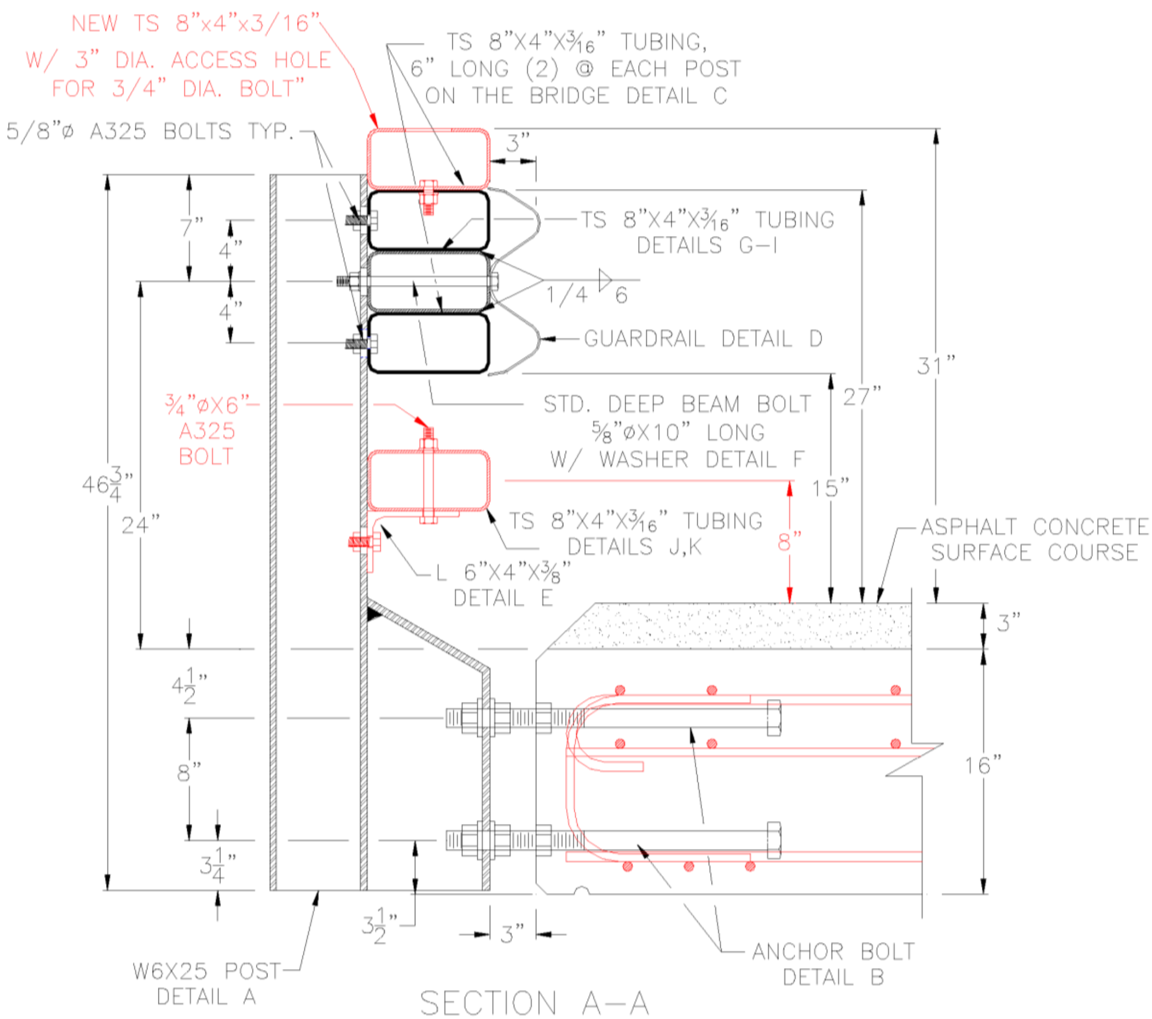
APPENDIX B ANALYSIS OF ODOT MODIFIED BRIDGE RAIL

Texas Transportation Institute

Project #: 476890-01

Subject: Ohio TL-3 Deep Beam Bridge Guardrail

Sponsor: Ohio DOT



OhioTL-3BridgeRailLRFDWFWrev1.xmcd
12/10/2010
10:39 AM

William Williams, P.E.
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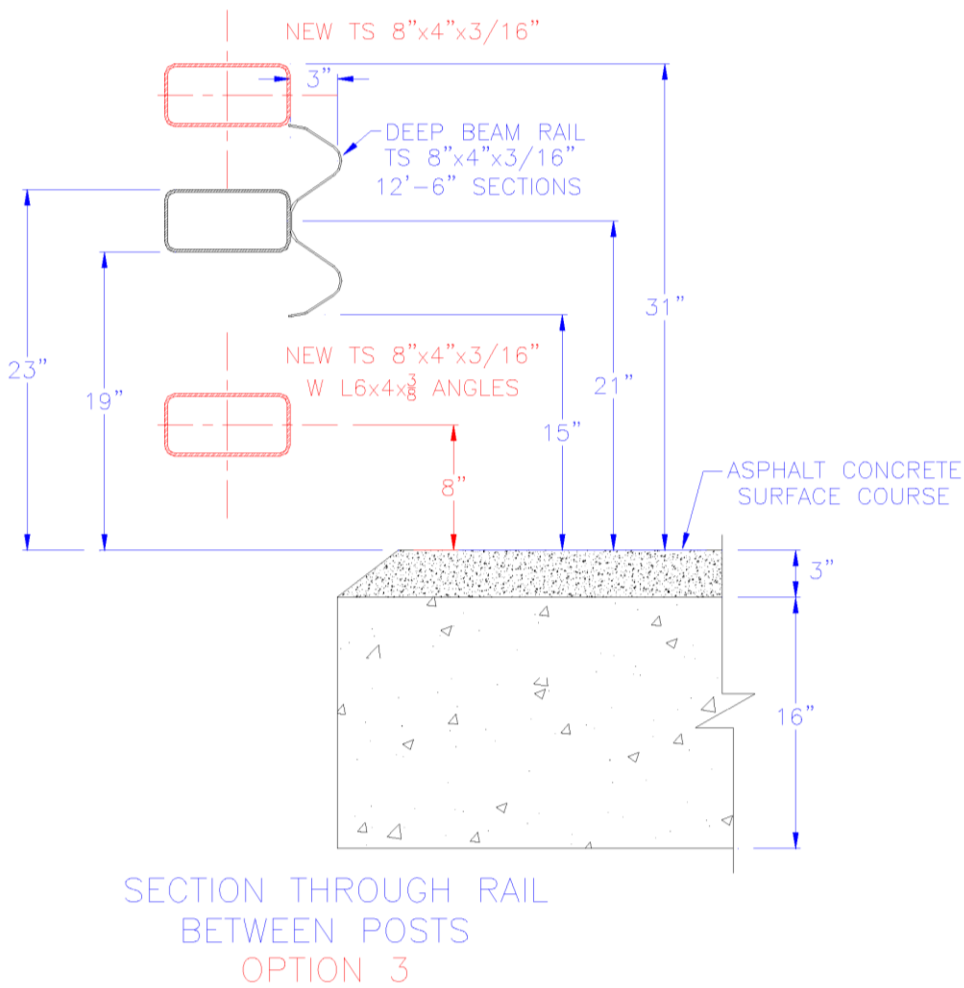
w-williams@tamu.edu

1

Figure B 1 Analysis of Modified ODOT Deep Beam Bridge Rail 1

Project #: **476890-01**

Subject: **Ohio TL-3 Deep Beam Bridge Guardrail** Sponsor: **Ohio DOT**



OhioTL-3BridgeRailLRFDWFWrev1.xmcd
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10:39 AM

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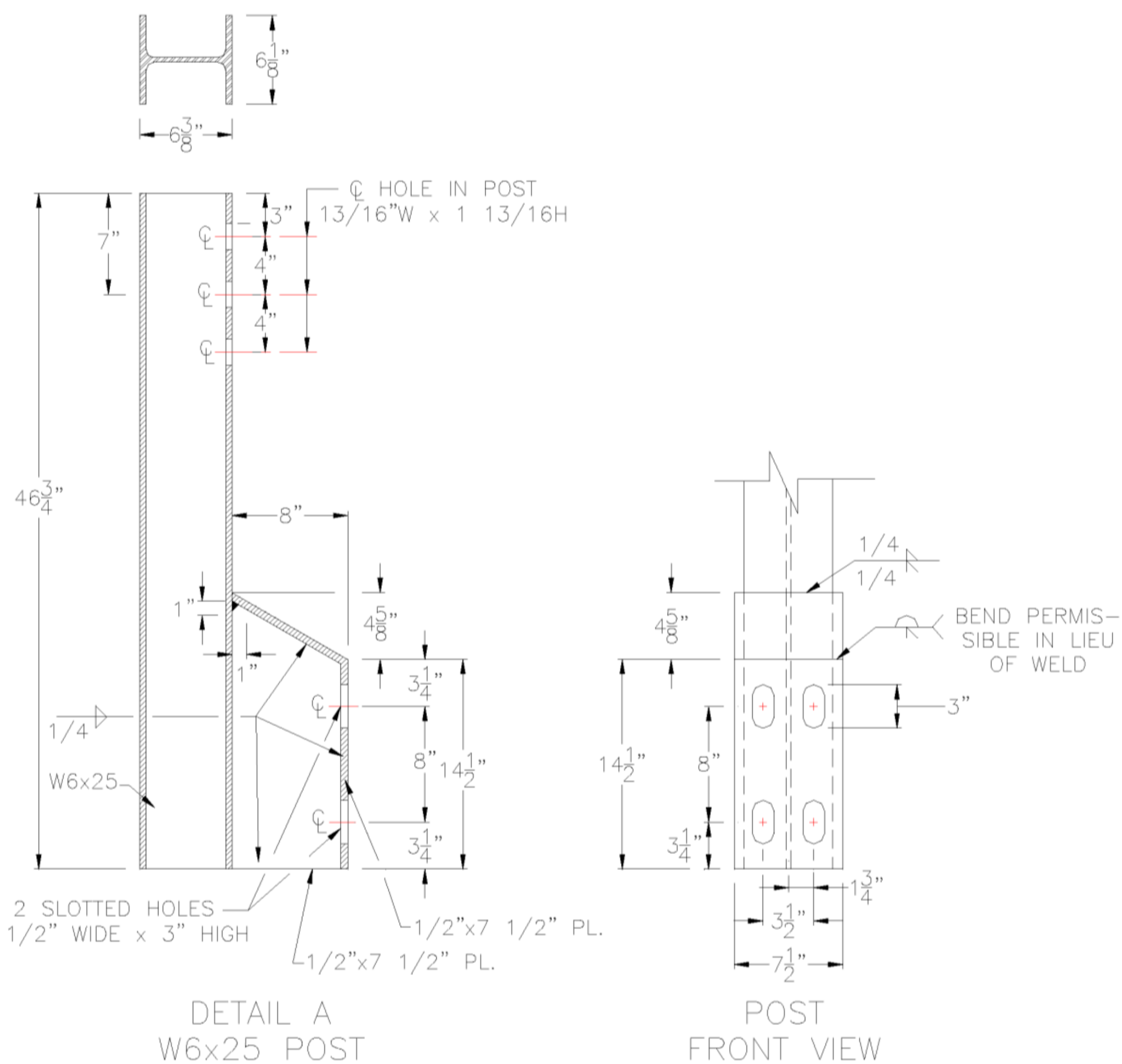
2

Figure B-2 Analysis of Modified ODOT Deep Beam Bridge Rail 2

Texas Transportation Institute

Project #: **476890-01**

Subject: **Ohio TL-3 Deep Beam Bridge Guardrail** Sponsor: **Ohio DOT**



OhioTL-3BridgeRailLRFDWFWrev1.xmcd
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10:39 AM

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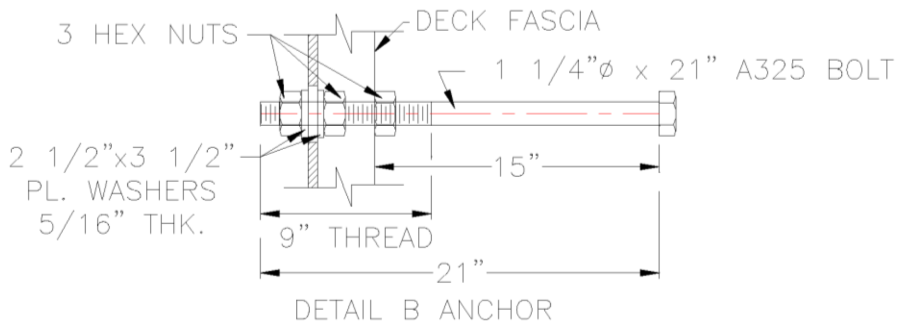
3

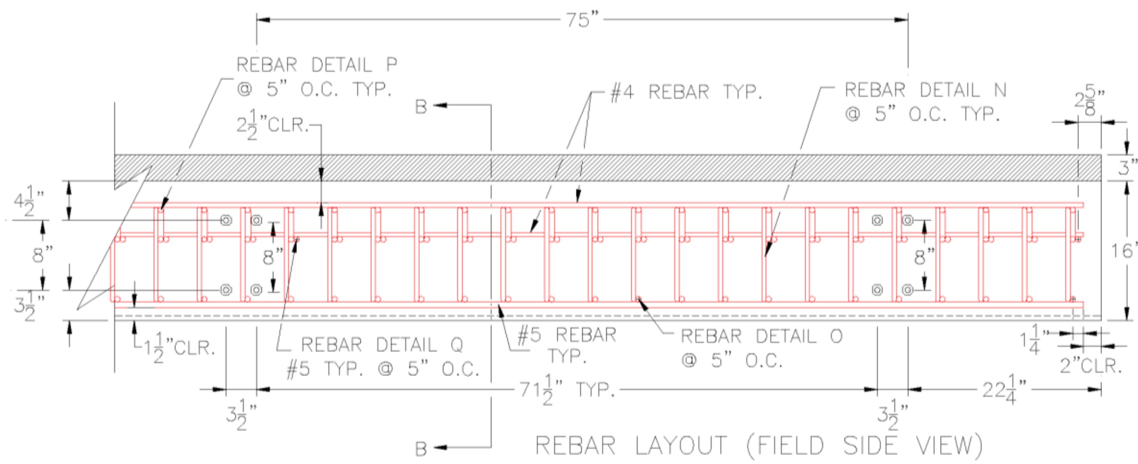
Figure B 3 Analysis of Modified ODOT Deep Beam Bridge Rail 3

Texas Transportation Institute

Project #: **476890-01**

Subject: **Ohio TL-3 Deep Beam Bridge Guardrail** Sponsor: **Ohio DOT**





OhioTL-3BridgeRailLRFDWFWrev1.xmcd
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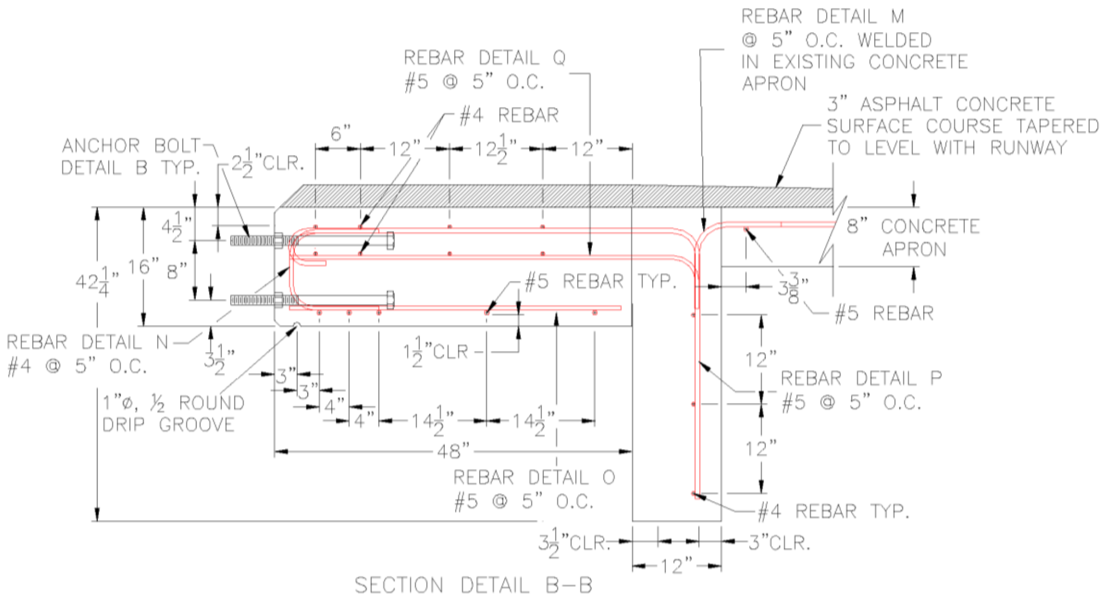
4

Figure B 4 Analysis of Modified ODOT Deep Beam Bridge Rail 4

Texas Transportation Institute

Project #: **476890-01**

Subject: **Ohio TL-3 Deep Beam Bridge Guardrail** Sponsor: **Ohio DOT**



MCAD 14

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Figure B 5 Analysis of Modified ODOT Deep Beam Bridge Rail 5

Texas Transportation Institute

Project #: **476890-01**

Subject: **Ohio TL-3 Deep Beam Bridge Guardrail** Sponsor: **Ohio DOT** kips $\equiv$ kip

1.) Given the following information from AASHTO Section 13, A13.3.2

$L := 6ft + 3in$ Post Spacing

$L_t := 4.0ft$ Load Length (ft.)

$Anchor_{ht} := 7.5in$ Dist from Top Anchor to Top of Paving (in.)

$F_t := 54kips$ TL-3 Loading

$H := 27in$

2.) Input for Top Rail Properties (TS8x4x3/16):

$Z_{top} := 10.2in^3$ Plastic Section Modulus of Top Rail

$Y_{top} := 28in$ height to the Center of the top Rail

$F_{ytop} := 42ksi$ Yield of Top Rail Material, (ksi)

3.) Input for Middle Rail Properties (TS8x4x3/16):

$Z_{mid} := 10.2in^3$ Plastic Section Modulus of Bottom Rail

$Y_{mid} := 21in$ height to the Center of the top Rail

$F_{ymid} := 42ksi$ yield of Top Rail Material, (ksi)

4.) Input for Bottom Rail Properties (TS8x4x3/16):

$Z_{bott} := 10.2in^3$ Plastic Section Modulus of Middle Rail

$Y_{bott} := 8in$ height to the Center of the top Rail

$F_{ybott} := 42ksi$ yield of Top Rail Material, (ksi)

5.) Input for W-Beam Properties:

$Z_{wbeam} := 1.93in^3$ $Y_{wbeam} := 21in$ Height ot center of W-Beam

$F_{ywbeam} := 50ksi$ Yield of W-Beam Material, (ksi)

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Figure B 6 Analysis of Modified ODOT Deep Beam Bridge Rail 6

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Project #: **476890-01**

Subject: **Ohio TL-3 Deep Beam Bridge Guardrail** Sponsor: **Ohio DOT**

6.) Input for Post properties:

$Z_{post} := 19.0in^3$ Plastic Modulus of W6x25

$F_{ypost} := 36ksi$ Yield of post material.

7.) Input Properties for the Deck Concrete & Anchor Bolts

$f'_c := 4000psi$ Compressive Strength of the Deck Concrete (psi)

$dia := 1.25in$ Anchor Bolt Dia. (inches)

$F_u := 105ksi$ Bolt Tension Strengths for A325 (ksi)

8.) Calculate the Total Rail Resitance of Rail Elements

$M_{ptop} := Z_{top} \cdot F_{ytop}$ $M_{pmid} := Z_{mid} \cdot F_{ymid}$

$M_{ptop} = 35.7 \cdot kip \cdot ft$ $M_{pmid} = 35.7 \cdot kip \cdot ft$

$M_{pbott} := Z_{bott} \cdot F_{ybott}$ $M_{wbeam} := Z_{wbeam} \cdot F_{ywbeam}$

$M_{pbott} = 35.7 \cdot kip \cdot ft$ $M_{wbeam} = 8.042 \cdot kip \cdot ft$

$M_p := M_{ptop} + M_{pbott} + M_{wbeam} + M_{pmid}$

$M_p = 115.142 \cdot kip \cdot ft$ Total Resistance of the Rails

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Figure B 7 Analysis of Modified ODOT Deep Beam Bridge Rail 7

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Subject: **Ohio TL-3 Deep Beam Bridge Guardrail** Sponsor: **Ohio DOT**

9.) Calculate the Average Height of Combined Rail Resistances Y_{bar} (ft.)

$Y_{top} = 28 \cdot in$ $Y_{mid} = 21 \cdot in$

$Y_{bott} = 8 \cdot in$ $Y_{wbeam} = 21 \cdot in$

$$Y_{bar} := \frac{\left[\left(M_{ptop} \cdot Y_{top}\right) + \left(M_{pbott} \cdot Y_{bott}\right) + \left(M_{wbeam} \cdot Y_{wbeam}\right) + \left(M_{pmid} \cdot Y_{mid}\right)\right]}{M_p}$$

$Y_{bar} = 1.595 \cdot ft$ Average Height of Combined Rail Resistances

10.) Calculate the Ultimate transverse Load Resistance of a Single Post located @ Y_{bar} above the deck based on **Post Plastic Strength** (P_{p1}):

$Anchor_{ht} = 0.191\,m$ $Y_{bar} = 19.14 \cdot in$

$$P_{p1} := \frac{Z_{post} \cdot F_{ypost}}{Y_{bar}}$$

$P_{p1} = 35.737 \cdot kips$ Strength based on Plastic Post Strength right @ pavement elevation

11.) Calculate the Ultimate transverse Load Resistance of a Single Post located @ Y_{bar} above the deck based on FEA Analysis of Post (P_{p2}):

Based on RISA 3D Analysis 13 kips on Post @ 21 inches is design load from FEA analysis

$$P_{p2} := \frac{16.25kips \cdot 21in}{Y_{bar}}$$

$P_{p2} = 17.829 \cdot kips$ Strength of Post based on simple FEA Analysis of Post with welded bracket

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Figure B 8 Analysis of Modified ODOT Deep Beam Bridge Rail 8

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12.) Calculate the Strength of the Post to cause Anchor Bolt Failure (P_{p3}):

Reference: Steel Structures Design & Behavior, Salmon & Johnson, 4th Edition

Calculated Area of Bolts (No threads included) (in^2)

$dia = 1.25 \cdot in$ Diameter of Anchor Bolts $A_b := \frac{\pi \cdot dia^2}{4}$ $A_b = 1.227 \cdot in^2$

$F_u = 105 \cdot ksi$ Anchor Bolt Strength (ksi)

$\phi_s := 1.0$ LRFD Reduction Factor for shear (0.75 ~LRFD, see pg. 120, Steel Structures, 4th Ed.)

$\phi_t := 1.0$ LRFD Reduction Factor for tension (0.75 ~ LRFD, see pg. 121, Steel Structures, 4rd Ed.)

$m := 1$ # of Shear Planes per bolt

$n := 2$ # of Bolts

Threads in the Shear Plane? (See Equation 4.6.3, Steel Structures Design & Behavior, page 124.)

Yes.... **ε = 0.75:**

No .... **ε = 1.0** $\varepsilon := 0.75$

Bolt Shear Strength (Eq. 4.7.4 pg. 120):

$$\phi R_{nshear} := \phi_s \cdot 0.8 \cdot (\varepsilon \cdot m \cdot A_b) \cdot (0.62 \cdot F_u) \cdot n$$

Bolt Tension Strength (Eq. 4.7.6 pg. 120):

$$\phi R_{ntension} := \phi_t \cdot A_b \cdot (0.75 \cdot F_u) \cdot n$$

$\phi R_{ntension} = 193.282 \cdot kips$ Ultimate Tension Strength of 2 Anchors

$\phi R_{nshear} = 95.868 \cdot kips$ Ultimate Tension Strength of 2 Anchors

13.) Sum moment about bottom Anchor bolts to Frid P_{p3} in top rail to cause ultimate tension failure in top bolts

$$P_{p3} := \frac{\phi R_{ntension} \cdot 8in}{(8in + Anchor_{ht} + Y_{bar})}$$

Sum moment about bottom anchors and solve for P_{p3}

$P_{p3} = 44.638 \cdot kips$ Post Strength based on tension strength of anchors

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Figure B 9 Analysis of Modified ODOT Deep Beam Bridge Rail 9

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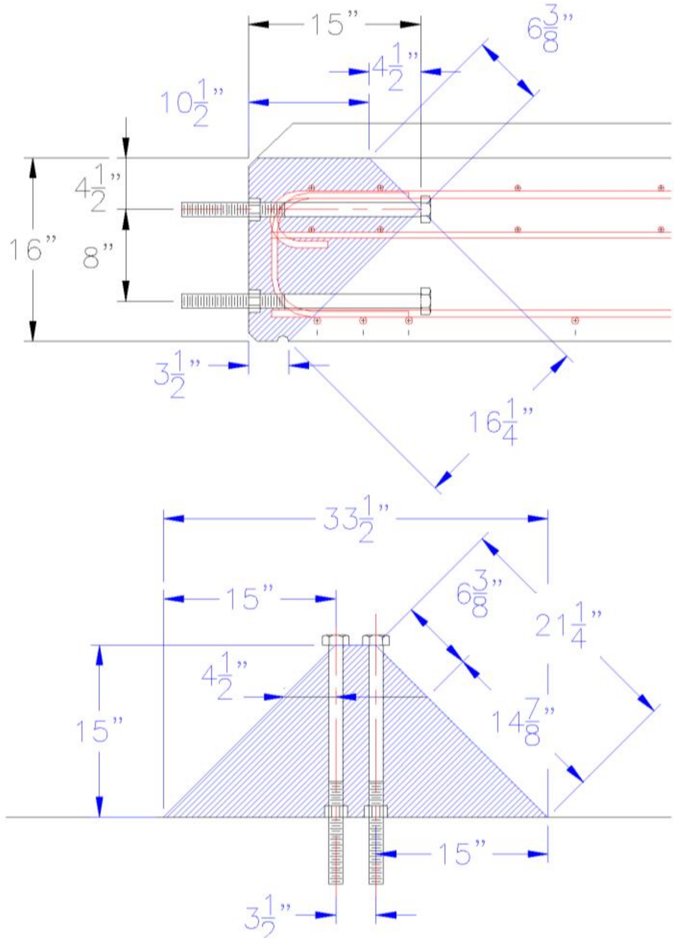
Subject: **Ohio TL-3 Deep Beam Bridge Guardrail** Sponsor: **Ohio DOT**

14.) Calculate the Strength of the Post to cause concrete pull-out failure for the 2 bolts in tension (P_{p4}):



10a.) Calculate the tension strength of the concrete

$$\phi_c := 1.0$$

$$V_c := \phi_c \cdot 4 \cdot \sqrt{\frac{f'_c}{psi}} \cdot psi$$

$$V_c = 0.253 \cdot ksi$$

For the Failure Area... calculate the are of 4 sides

Area of the top

$$A_{top} := (3.5in \cdot 6.375in) \ldots + (6.375in \cdot 6.375in)$$

$$A_{bott} := (3.5in \cdot 16.25in) \ldots + (16.25in \cdot 16.25in)$$

$$A_{sides} := \left[\left(\frac{21.25in \cdot 11.5in}{2}\right) + \left(\frac{6.375in \cdot 6.375in}{2}\right) + (14.875in \cdot 4.5in)\right] \cdot 2$$

$$A_{total} := A_{top} + A_{bott} + A_{sides} \qquad A_{total} = 802.781 \cdot in^2$$

Total approximate areas of pull-out cone for top 2 anchor bolts

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Figure B 10 Analysis of Modified ODOT Deep Beam Bridge Rail 10

15.) Calculate the force on the post @ Ybar to cause concrete oull-out cone failure (P_{p4}):

$$F_{concretecone} := V_c \cdot A_{total}$$

$$F_{concretecone} = 203.089 \cdot kips$$ Force to fail concrete in the shaded area above

$$P_{p4} := \frac{F_{concretecone} \cdot 8in}{\left(8in + Anchor_{ht} + Y_{bar}\right)}$$

$$P_{p4} = 46.903 \cdot kips$$ Post Strength based on Concrete Cone failure for top anchors

16.) Summarize Post Strengths to use in the LRFD Strength Analysis

$P_{p1} = 35.737 \cdot kips$ Strength based on Plastic Post Strength right @ pavement elevation

$P_{p2} = 17.829 \cdot kips$ Strength of Post based on RISA FEA Analysis of Post with welded bracket

$P_{p3} = 44.638 \cdot kips$ Post Strength based on tension strength of anchors

$P_{p4} = 46.903 \cdot kips$ Post Strength based on Concrete Cone failure for top anchors

Use Pp2 as the limiting ppost strength for analysis purposes

$$P_p := P_{p2}$$

Figure B 11 Analysis of Modified ODOT Deep Beam Bridge Rail 11

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Subject: **Ohio TL-3 Deep Beam Bridge Guardrail** Sponsor: **Ohio DOT**

17.) Calculate the Rail Strength for Multiple Spans @ H_e height:

$H = 27 \cdot in$

**** 1 Span Case ****

$Y_{bar} = 19.14 \cdot in$

$N_1 := 1$ 1 Span Case

$M_p = 115.142 \cdot kip \cdot ft$ $P_p = 17.829 \cdot kips$ $L = 1.905\,m$ $L_t = 1.219\,m$

$$R_1 := \frac{16 \cdot M_p + (N_1 - 1) \cdot (N_1 + 1) \cdot P_p \cdot L}{2 \cdot N_1 \cdot L - L_t} \cdot \left(\frac{Y_{bar}}{H}\right)$$

$R_1 = 153.64 \cdot kips$ Resistance for 1 Span

**** 2 Span Case ****

$N_2 := 2$ 2 Span Case $Y_{bar} = 19.14 \cdot in$

$M_p = 115.142 \cdot kip \cdot ft$ $P_p = 17.829 \cdot kips$ $L = 1.905\,m$ $L_t = 1.219\,m$

$$R_2 := \frac{16 \cdot M_p + N_2^{\,2} \cdot P_p \cdot L}{2 \cdot N_2 \cdot L - L_t} \cdot \left(\frac{Y_{bar}}{H}\right)$$

$R_2 = 77.234 \cdot kips$ Resistance for 2 Spans

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Figure B 12 Analysis of Modified ODOT Deep Beam Bridge Rail 12

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**** 3 Span Case *****

$N_3 := 3$ 3 Span Case $Y_{bar} = 19.14 \cdot in$

$M_p = 115.142 \cdot kip \cdot ft$ $P_p = 17.829 \cdot kips$ $L = 1.905\,m$ $L_t = 1.219\,m$

$$R_3 := \frac{16 \cdot M_p + (N_3 - 1) \cdot (N_3 + 1) \cdot P_p \cdot L}{2 \cdot N_3 \cdot L - L_t} \cdot \left(\frac{Y_{bar}}{H}\right)$$

$R_3 = 57.847 \cdot kips$ Resistance for 3 Spans

**** 4 Span Case ****

$N_4 := 4$ 4 Span Case $Y_{bar} = 19.14 \cdot in$ $H = 27 \cdot in$

$M_p = 115.142 \cdot kip \cdot ft$ $P_p = 17.829 \cdot kips$ $L = 1.905\,m$

$$R_4 := \frac{16 \cdot M_p + N_4^{\,2} \cdot P_p \cdot L}{2 \cdot N_4 \cdot L - L_t} \cdot \left(\frac{Y_{bar}}{H}\right)$$

$R_4 = 55.866 \cdot kips$ Resistance for 4 Spans

**** 5 Span Case *****

$N_5 := 5$ 5 Span Case $Y_{bar} = 19.14 \cdot in$

$M_p = 115.142 \cdot kip \cdot ft$ $P_p = 17.829 \cdot kips$ $L = 1.905\,m$ $L_t = 1.219\,m$

$$R_5 := \frac{16 \cdot M_p + (N_5 - 1) \cdot (N_5 + 1) \cdot P_p \cdot L}{2 \cdot N_5 \cdot L - L_t} \cdot \left(\frac{Y_{bar}}{H}\right)$$

$R_5 = 54.731 \cdot kips$ Resistance for 5 Spans

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Figure B 13 Analysis of Modified ODOT Deep Beam Bridge Rail 13

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**** 6 Span Case ****

$N_6 := 6$ 6 Span Case $Y_{bar} = 19.14 \cdot in$ $H = 27 \cdot in$

$M_p = 115.142 \cdot kip \cdot ft$ $P_p = 17.829 \cdot kips$ $L = 1.905\,m$

$$R_6 := \frac{16 \cdot M_p + N_6^{\,2} \cdot P_p \cdot L}{2 \cdot N_6 \cdot L - L_t} \cdot \left(\frac{Y_{bar}}{H}\right)$$

$R_6 = 58.446 \cdot kips$ Resistance for 6 Spans

Summary: Resistance of multiple Spans is greater than 54 kips as specified in AASHTO LRFD Section 13 Specifications for Test Level 3

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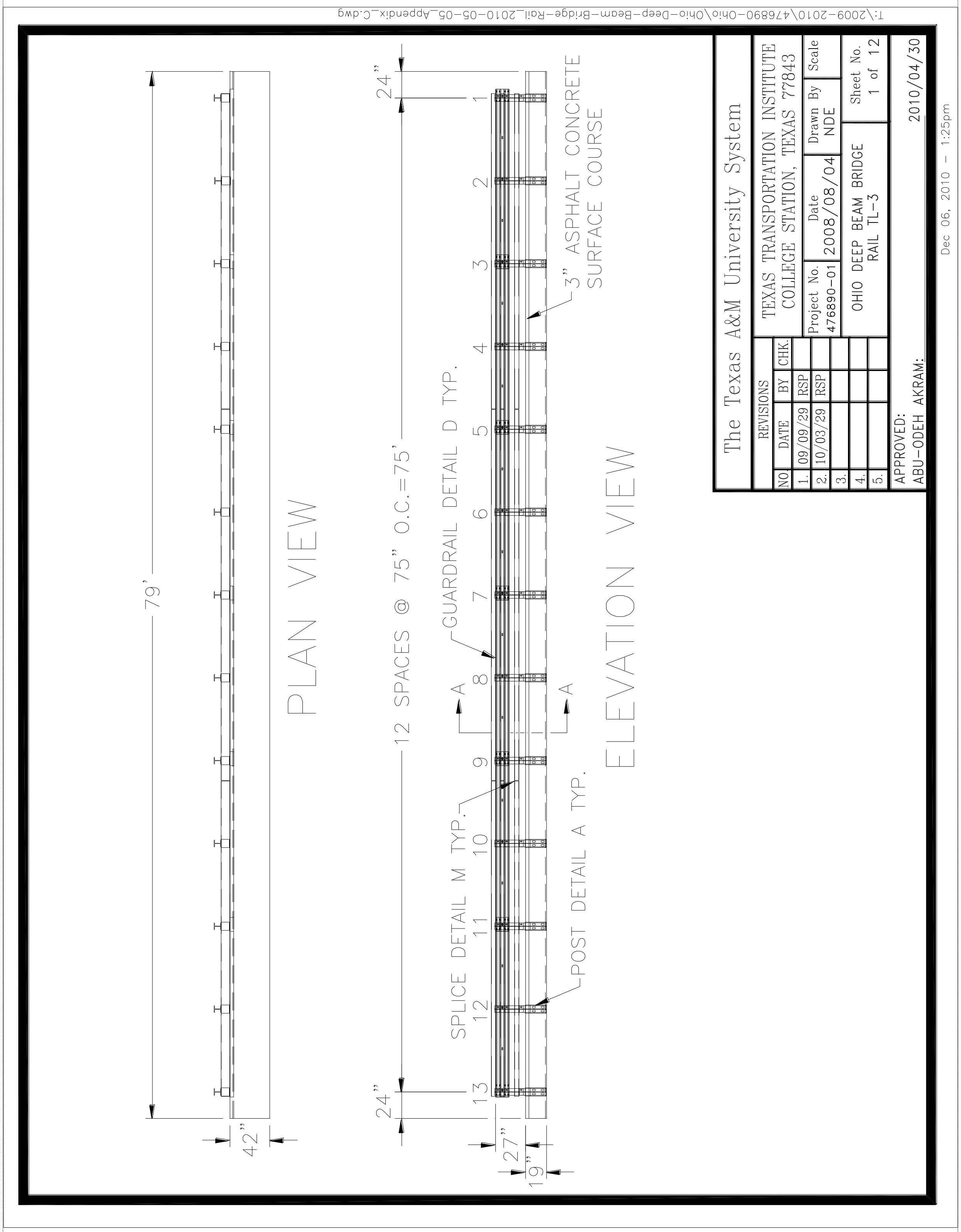
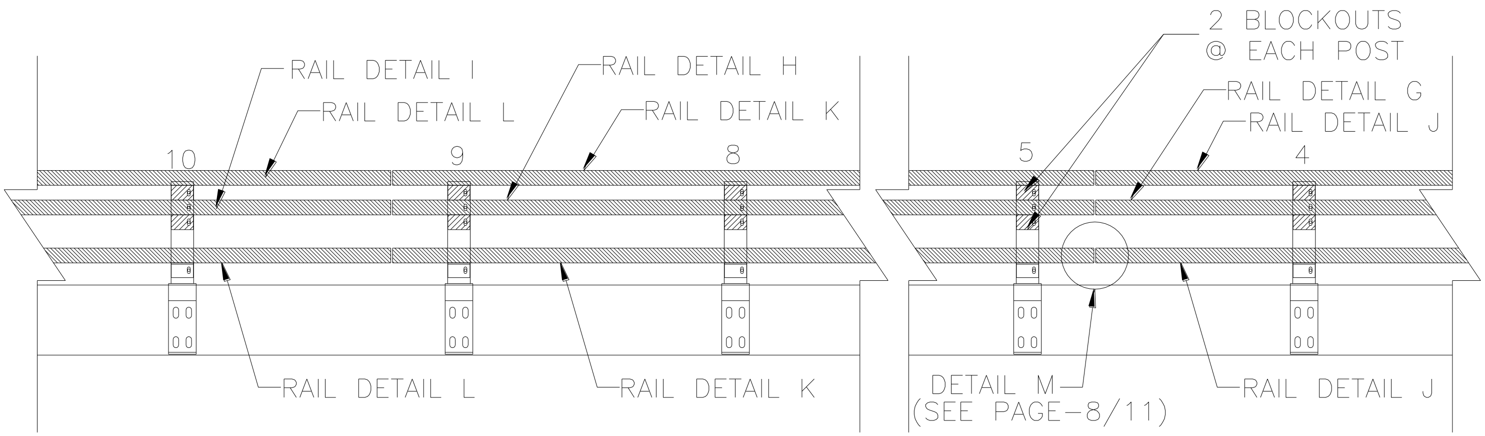
Figure B 14 Analysis of Modified ODOT Deep Beam Bridge Rail 14

APPENDIX C DRAWINGS OF ODOT MODIFIED BRIDGE RAIL USED IN FEM

C1. ODOT MODIFIED BRIDGE RAIL WITH OVERLAY





RAIL ELEVATION–DETAIL
(WITHOUT W-BEAM)

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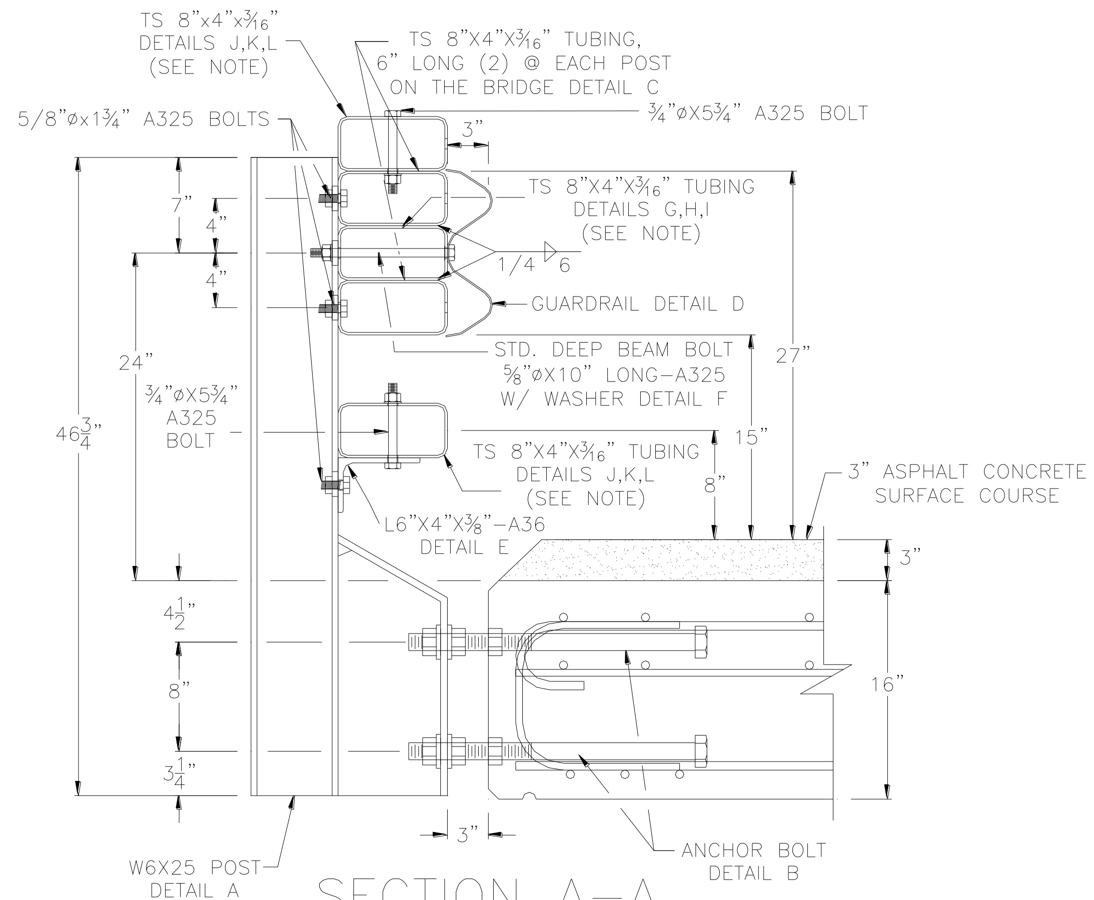

SECTION A-A

NOTE: CONCRETE STRENGTH f'c=4000psi
DETAIL G&J-RIGHT END RAIL
DETAIL H&K- CENTER RAIL
DETAIL I&L- LEFT END RAIL
ALL NUTS TO BE HEAVY HEX ASTM A563
ALL WASHERS TO BE ASTM F436
PLATE WASHER-DETAIL F IS USED BETWEEN NUT AND POST

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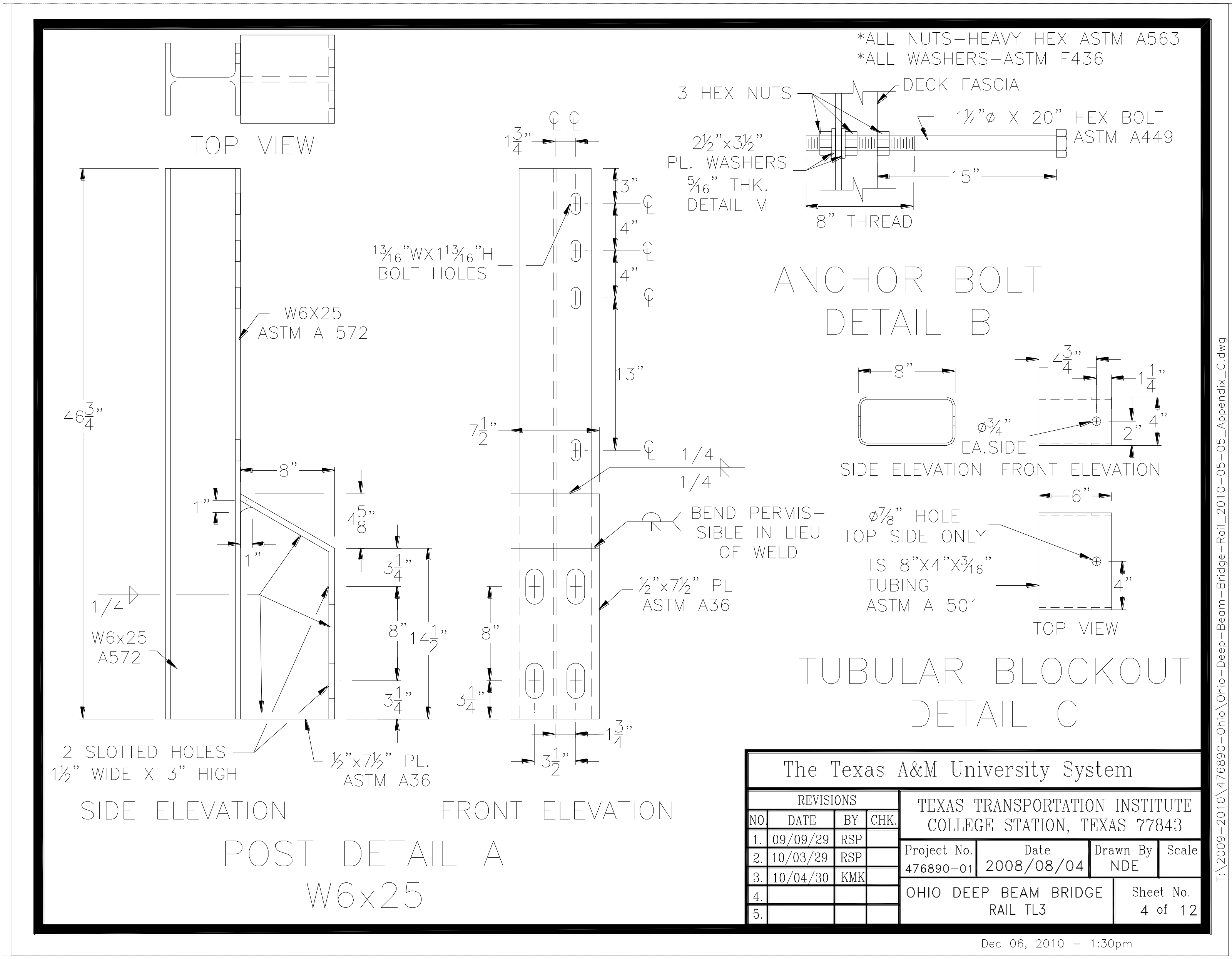
*ALL NUTS-HEAVY HEX ASTM A563
*ALL WASHERS-ASTM F436
3 HEX NUTS
DECK FASCIA
1¼"ø X 20" HEX BOLT
ASTM A449
2½"x3½"
PL. WASHERS
5⁄16" THK.
DETAIL M
15"
8" THREAD
ANCHOR BOLT
DETAIL B
TOP VIEW
13⁄16"WX1 13⁄16"H
BOLT HOLES
W6X25
ASTM A 572
46¾"
8"
1"
1"
4⅝"
3¼"
8"
14½"
3¼"
1/4
W6x25
A572
2 SLOTTED HOLES
1½" WIDE X 3" HIGH
½"x7½" PL.
ASTM A36
SIDE ELEVATION
1¾"
3"
4"
4"
13"
7½"
1/4
1/4
BEND PERMIS-
SIBLE IN LIEU
OF WELD
½"x7½" PL
ASTM A36
8"
3¼"
1¾"
3½"
FRONT ELEVATION
POST DETAIL A
W6x25
8"
SIDE ELEVATION
4¾"
1¼"
ø¾"
EA.SIDE
2"
4"
FRONT ELEVATION
6"
ø⅞" HOLE
TOP SIDE ONLY
TS 8"X4"X3⁄16"
TUBING
ASTM A 501
4"
TOP VIEW
TUBULAR BLOCKOUT
DETAIL C
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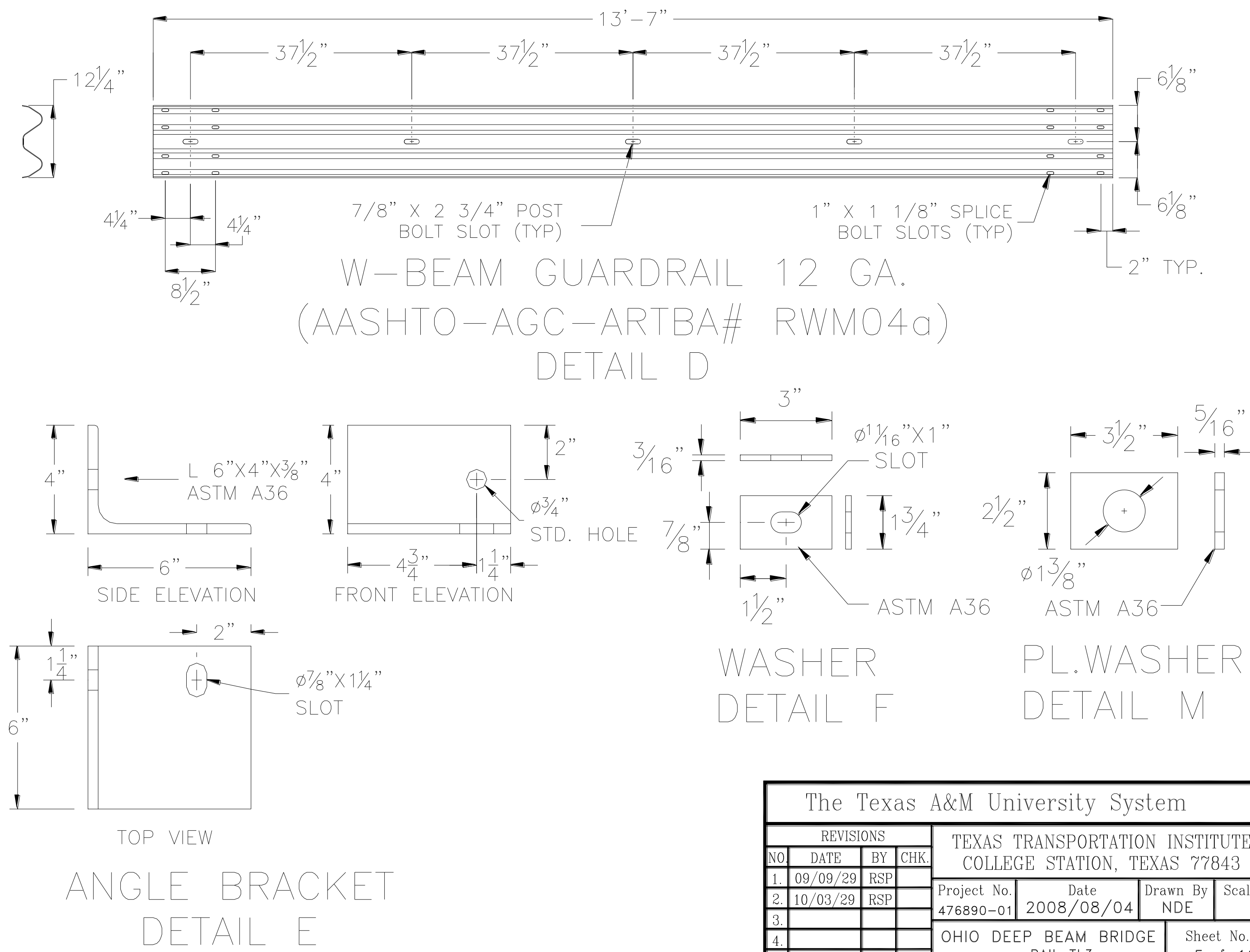

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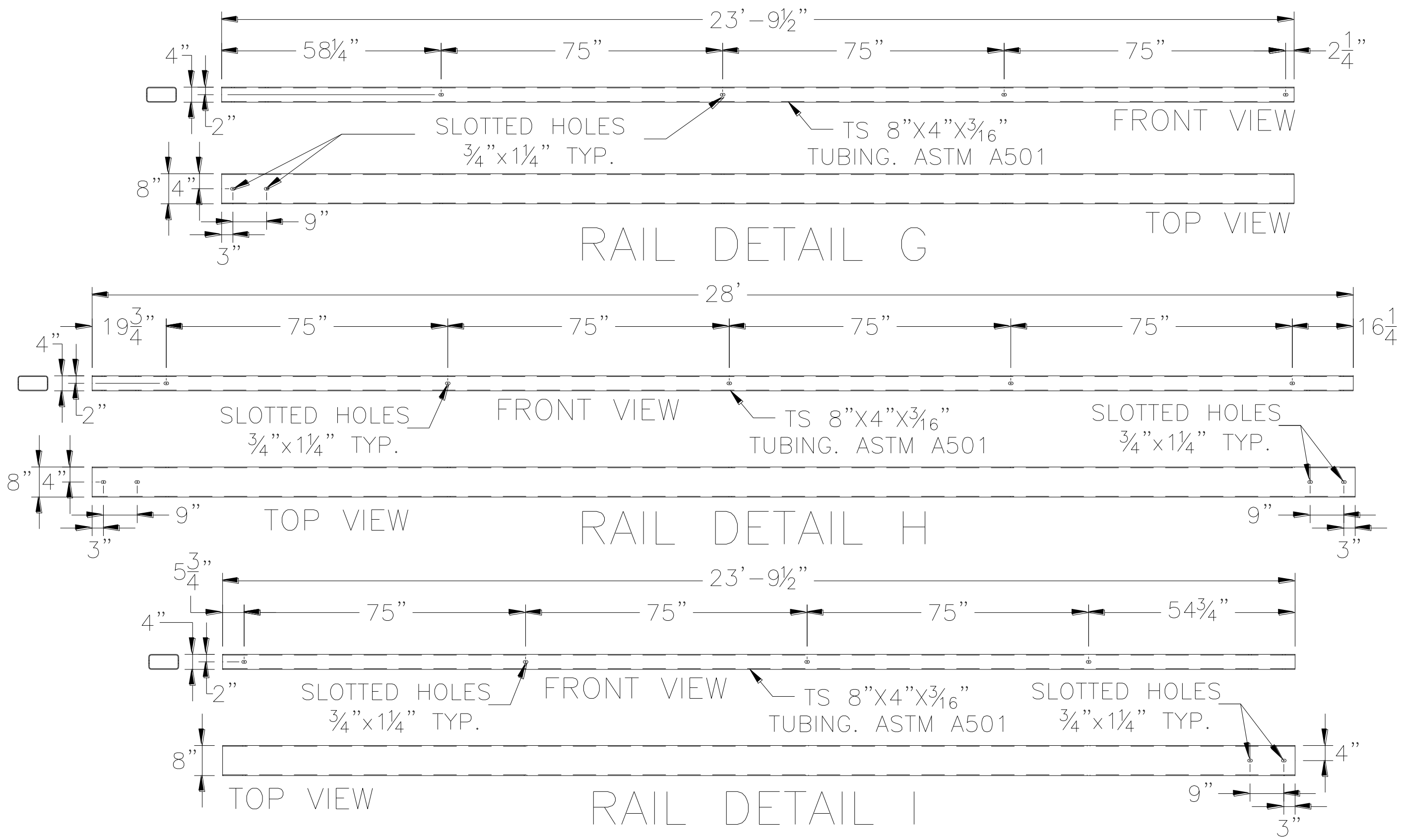

NOTE: ALL SPLICE HOLES ø¾"x1¼" TYP.

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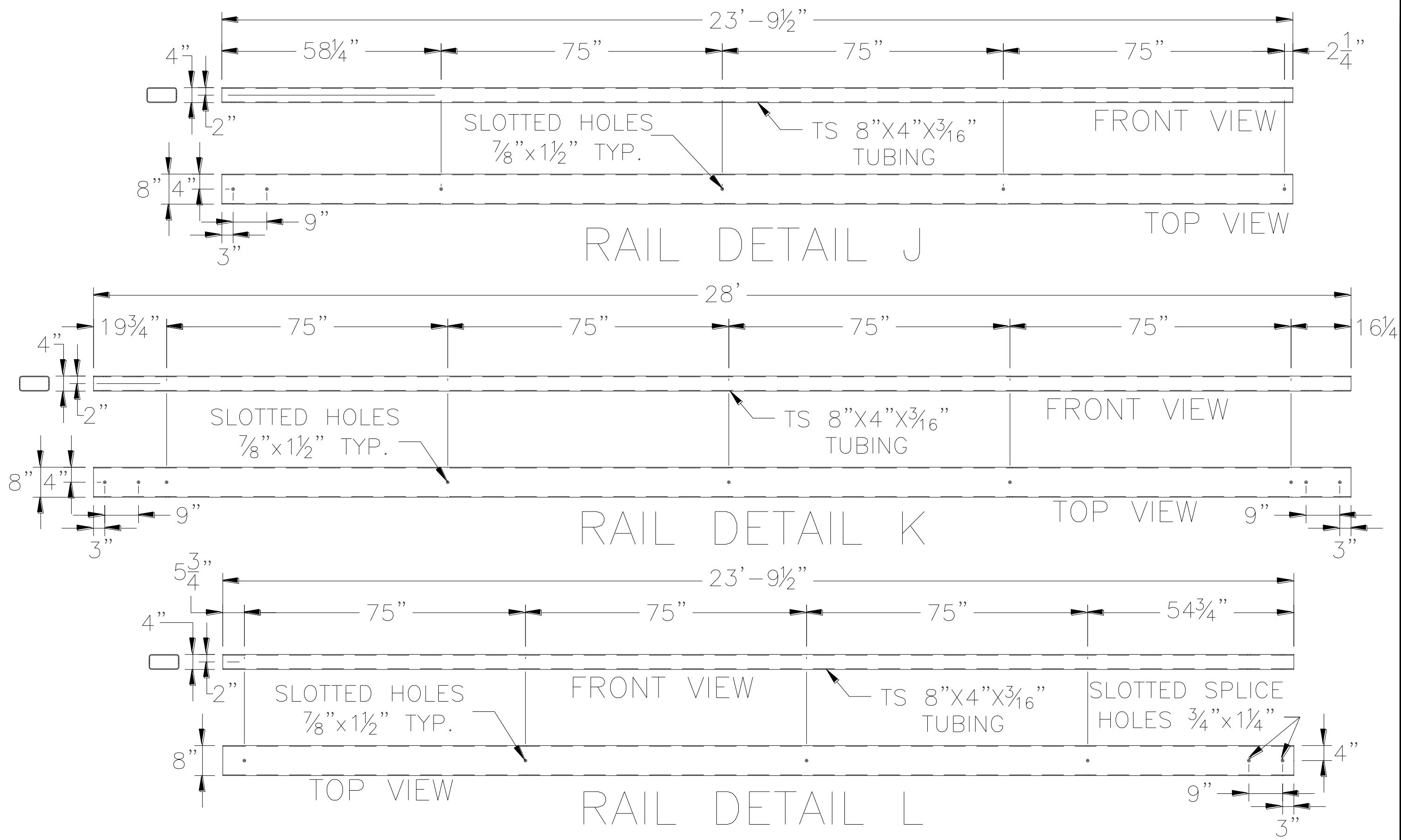

NOTE: ALL SPLICE HOLES ∅¾"x1¼" TYP.

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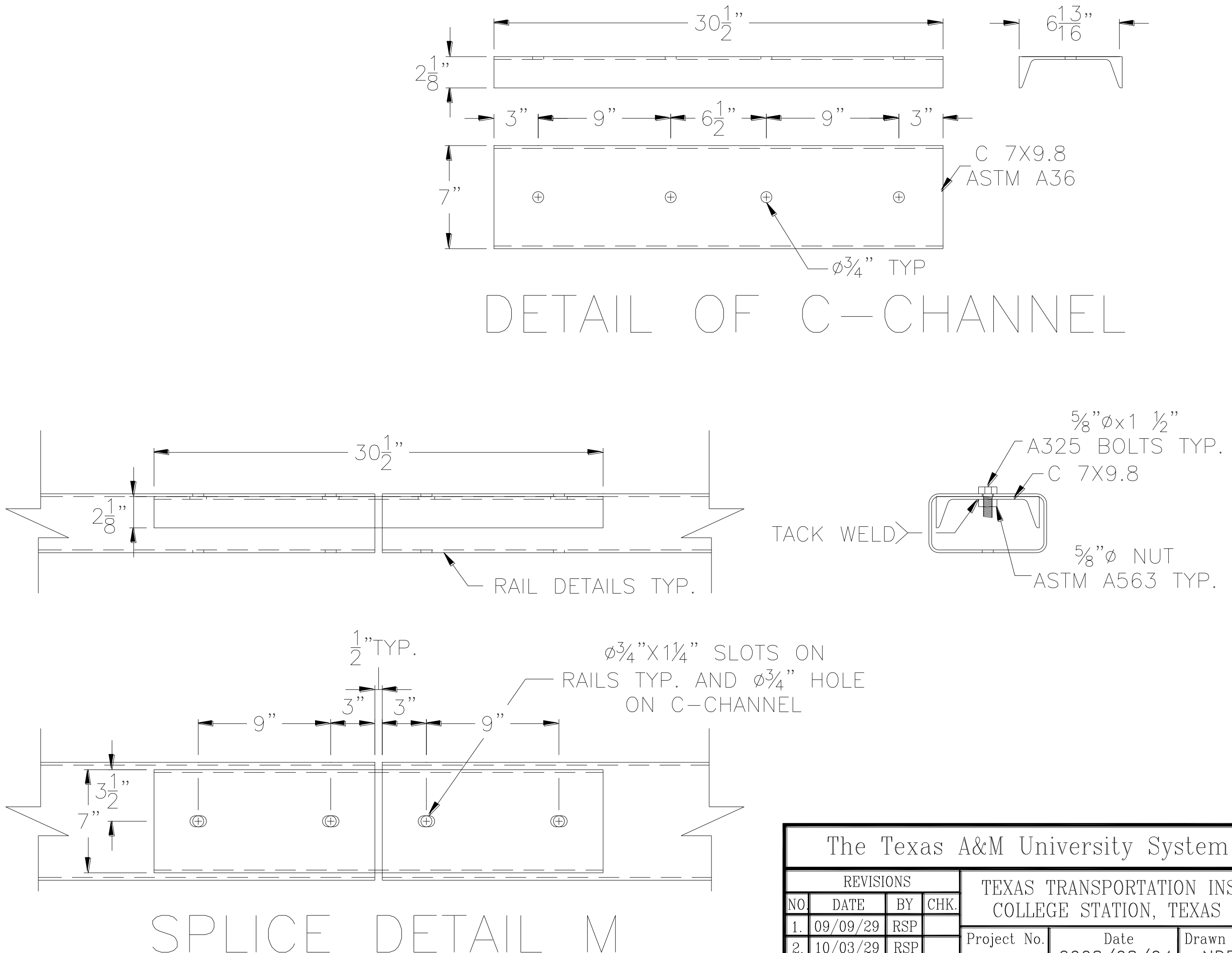

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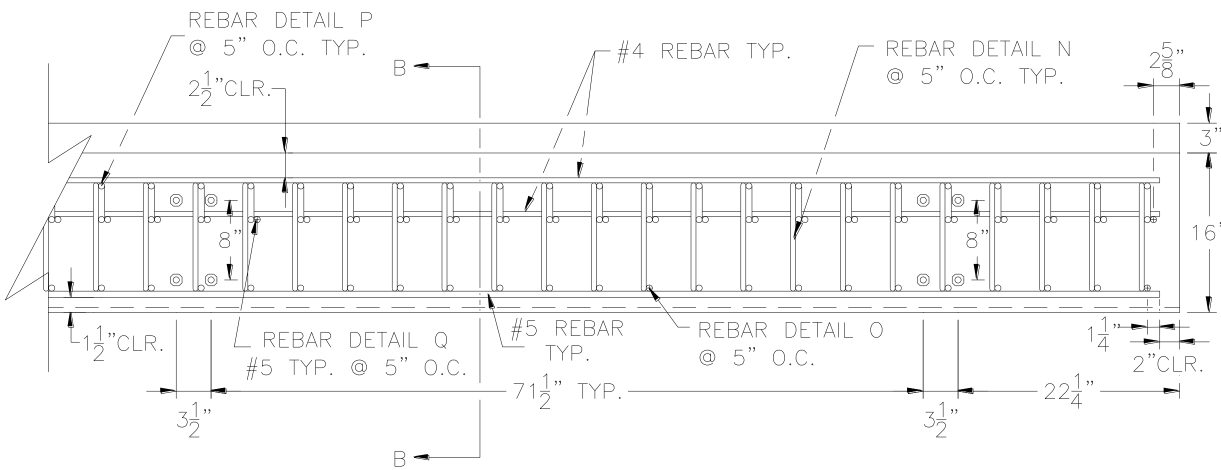

REBAR LAYOUT

DECK–ELEVATION VIEW

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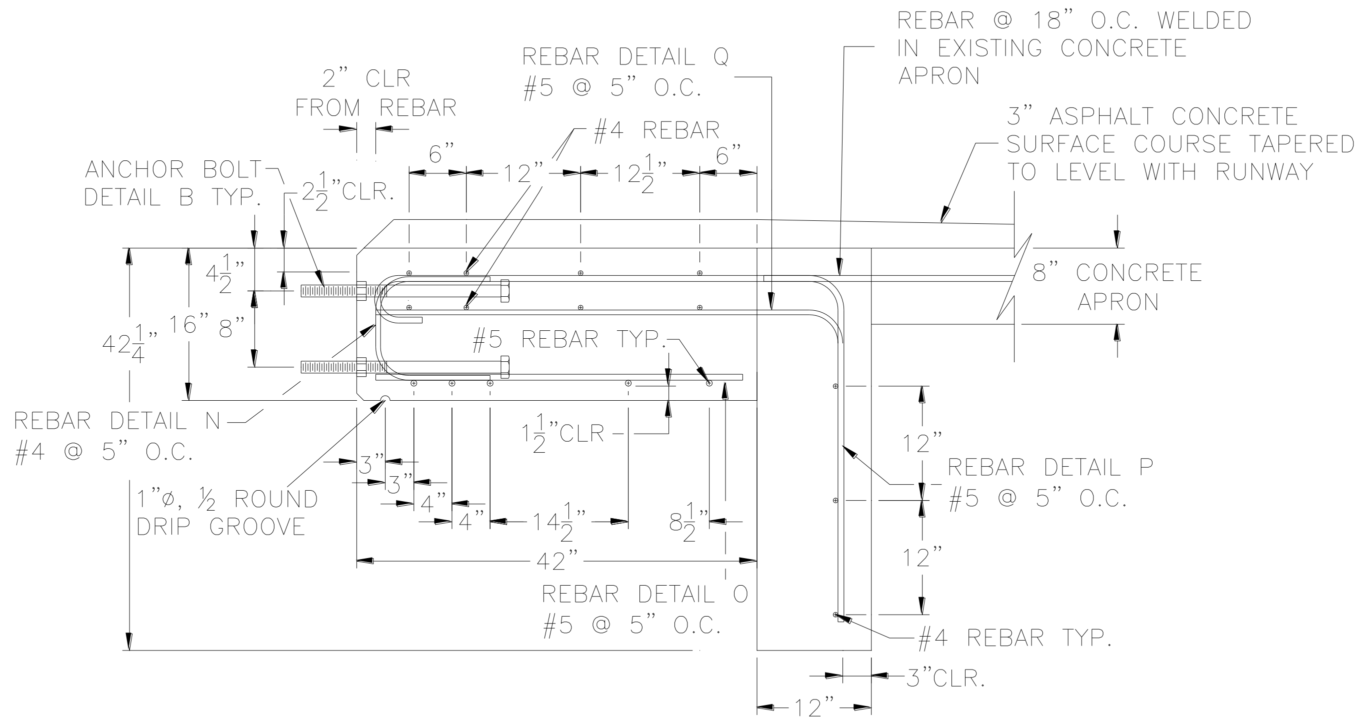

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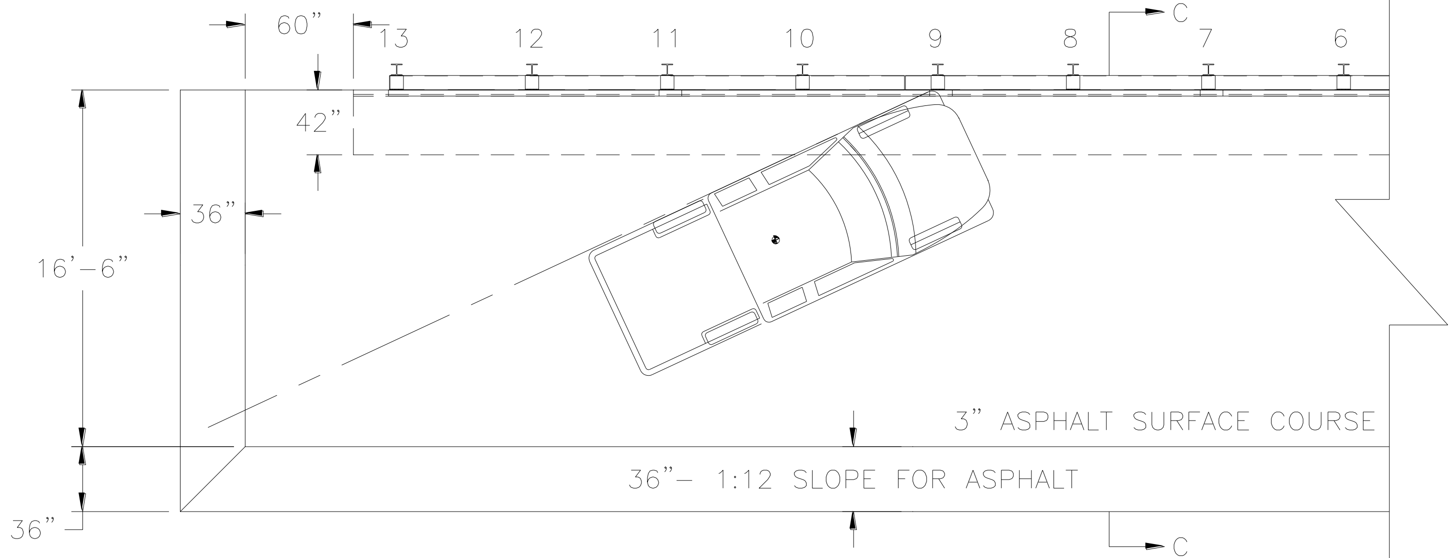
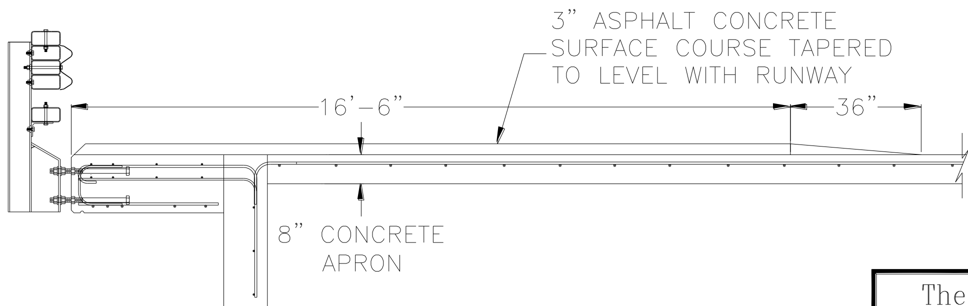


IMPACT DIRECTION AND ASPHALT DETAILS



SECTION DETAIL C–C

NOTE: ASPHALT LAID TILL THE OTHER END OF INSTALLATION
SLOPE NOTE TO PROVIDED ON THE OTHER END

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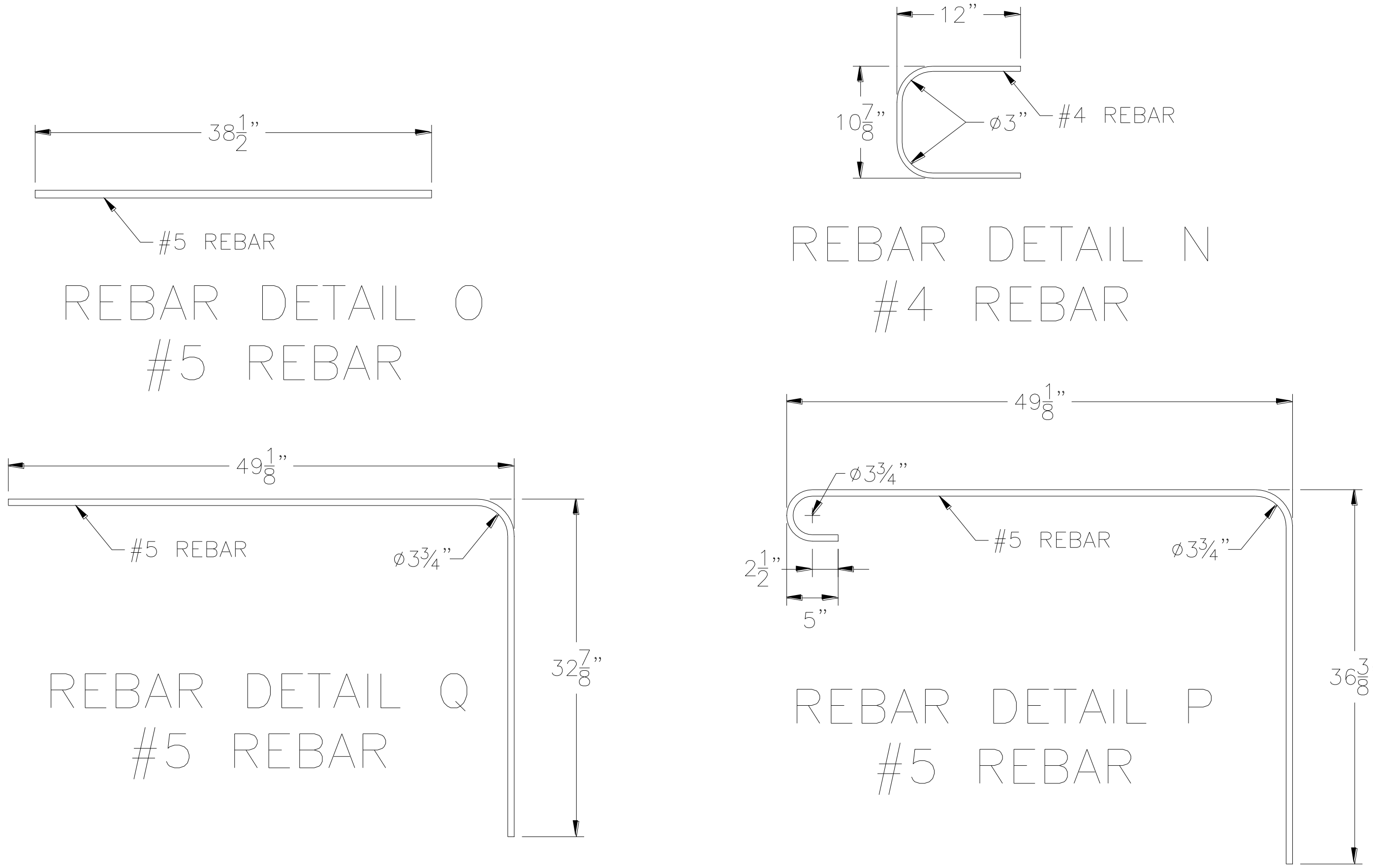
OHIO DEEP BEAM BRIDGE RAIL TL3	Sheet No. 11 of 12

T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_2010-05-05_Appendix_C.dwg

Dec 06, 2010 – 1:40pm



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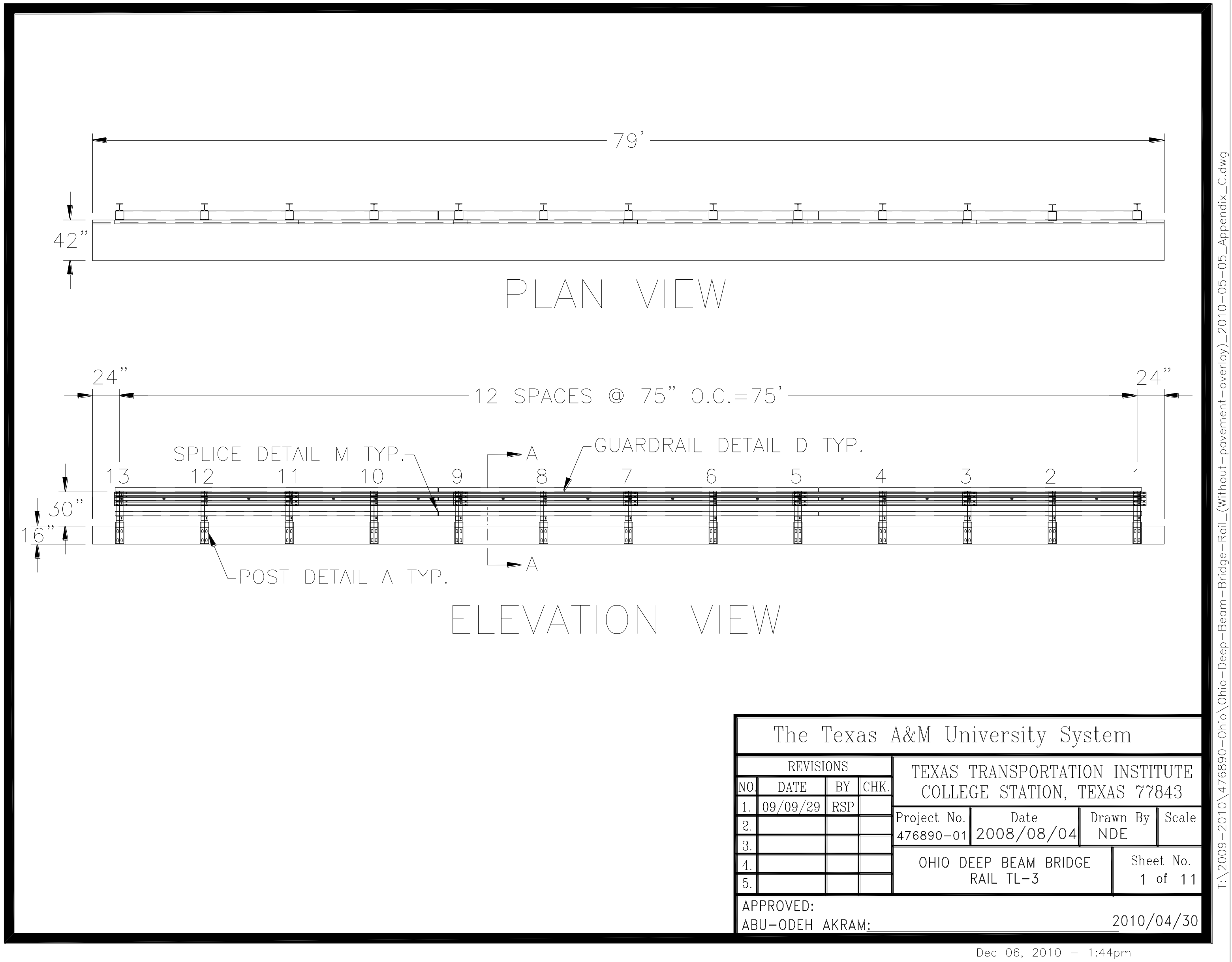
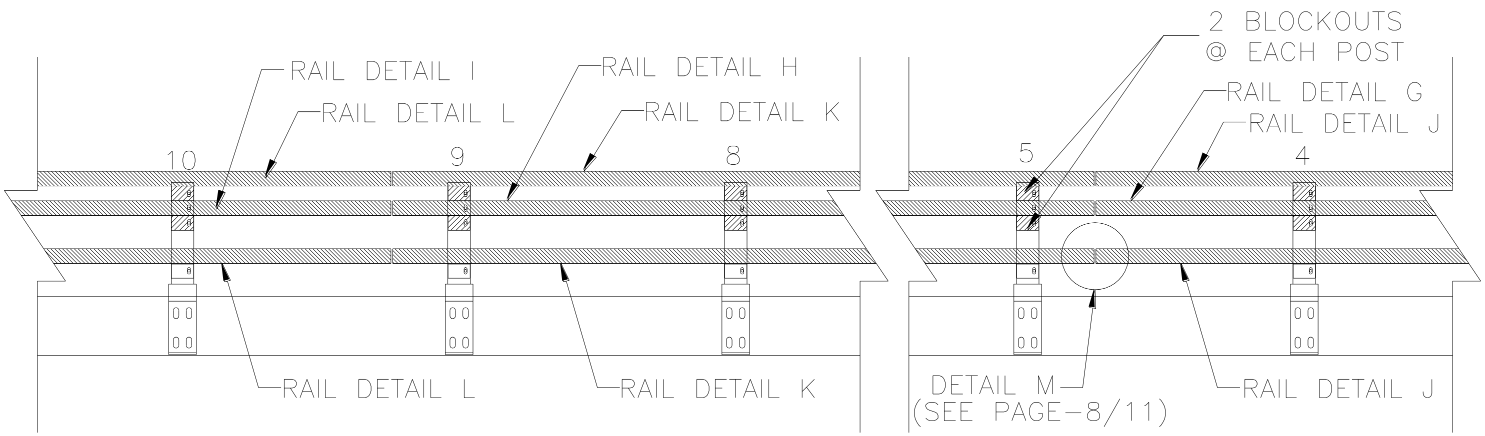
1.	09/09/29	RSP		Project No. 476890-01 / Date 2008/08/04 / Drawn By NDE / Scale
2.	10/03/29	RSP		
3.				OHIO DEEP BEAM BRIDGE RAIL TL3 / Sheet No. 12 of 12
4.				
5.				

T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_2010-05-05_Appendix_C.dwg

Dec 06, 2010 - 1:42pm

C2. ODOT MODIFIED BRIDGE RAIL WITHOUT OVERLAY





RAIL ELEVATION–DETAIL

(WITHOUT W–BEAM)

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OHIO DEEP BEAM BRIDGE
RAIL TL3

Sheet No. 2 of 11

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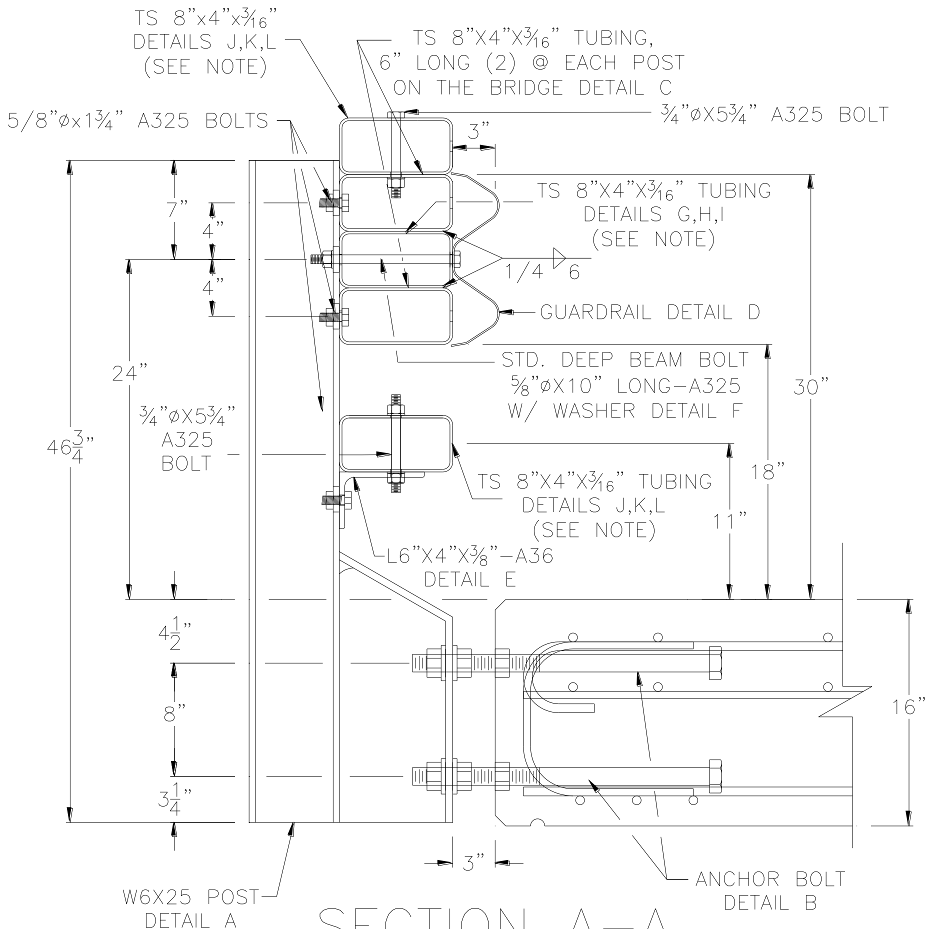
T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_(Without-pavement-overlay)_2010-05-05_Appendix_C.dwg



SECTION A–A

NOTE: CONCRETE STRENGTH f'c=4000psi
DETAIL G&J–RIGHT END RAIL
DETAIL H&K– CENTER RAIL
DETAIL I&L– LEFT END RAIL
ALL NUTS TO BE HEAVY HEX ASTM A563
ALL WASHERS TO BE ASTM F436
PLATE WASHER–DETAIL F IS USED BETWEEN NUT AND POST

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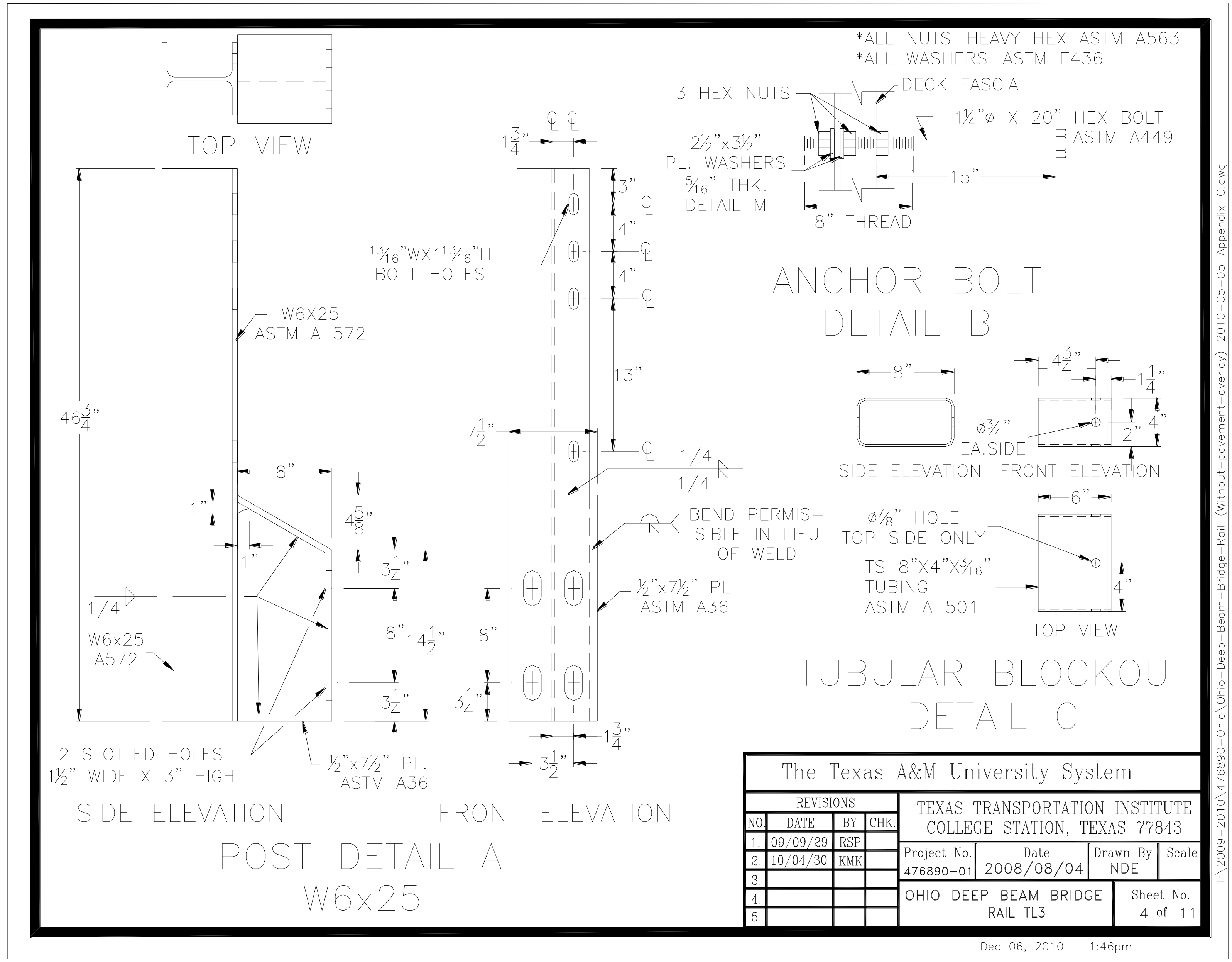
OHIO DEEP BEAM BRIDGE RAIL TL3

Sheet No. 3 of 11

Dec 06, 2010 – 1:46pm

T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_(Without-pavement-overlay)_2010-05-05_Appendix_C.dwg


*ALL NUTS-HEAVY HEX ASTM A563
*ALL WASHERS-ASTM F436
3 HEX NUTS
DECK FASCIA
1¼"ø X 20" HEX BOLT
ASTM A449
2½"x3½"
PL. WASHERS
5⁄16" THK.
DETAIL M
15"
8" THREAD
ANCHOR BOLT
DETAIL B
TOP VIEW
13⁄16"WX1 13⁄16"H
BOLT HOLES
W6X25
ASTM A 572
46 3/4"
7 1/2"
13"
1/4
1/4
8"
1"
1"
4 5/8"
3 1/4"
8"
14 1/2"
3 1/4"
1/4
W6x25
A572
BEND PERMIS-
SIBLE IN LIEU
OF WELD
½"x7½" PL
ASTM A36
2 SLOTTED HOLES
1½" WIDE X 3" HIGH
½"x7½" PL.
ASTM A36
1 3/4"
3 1/2"
SIDE ELEVATION
FRONT ELEVATION
POST DETAIL A
W6x25
8"
4 3/4"
1 1/4"
ø¾"
EA.SIDE
2"
4"
SIDE ELEVATION
FRONT ELEVATION
6"
ø⅞" HOLE
TOP SIDE ONLY
TS 8"X4"X3⁄16"
TUBING
ASTM A 501
4"
TOP VIEW
TUBULAR BLOCKOUT
DETAIL C
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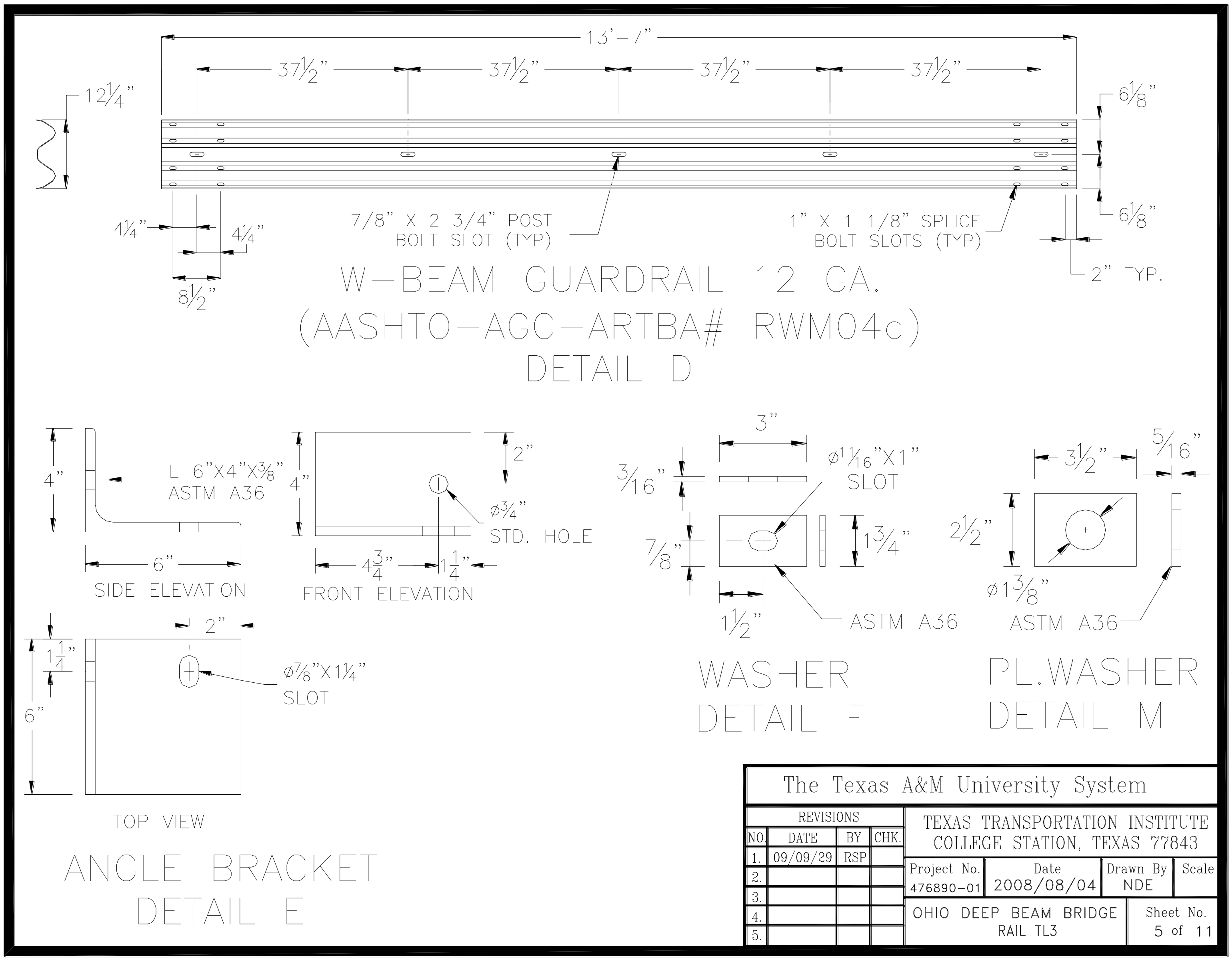
OHIO DEEP BEAM BRIDGE
RAIL TL3
Sheet No. 4 of 11
Dec 06, 2010 - 1:46pm
T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_(Without-pavement-overlay)_2010-05-05_Appendix_C.dwg



Dec 06, 2010 - 1:47pm

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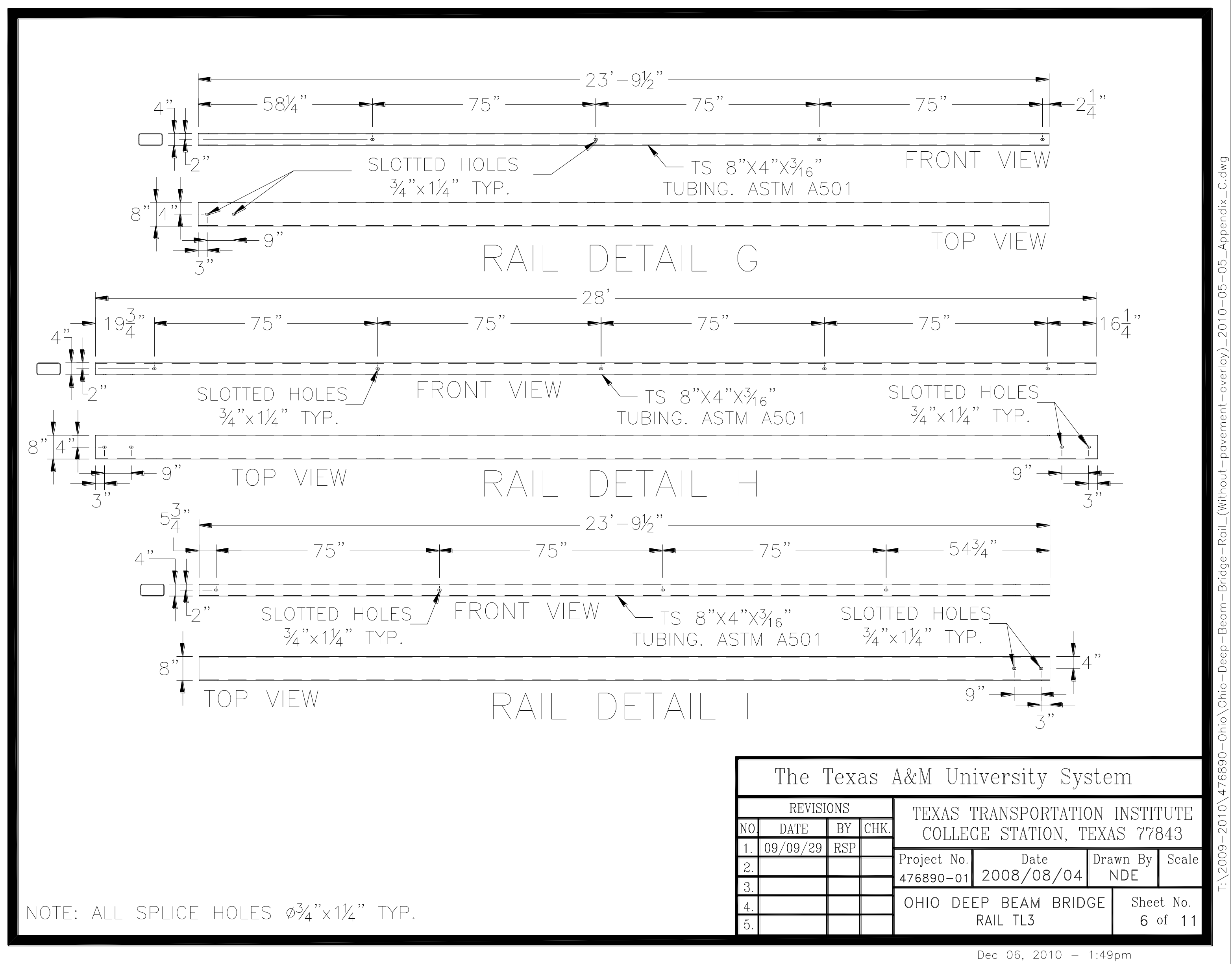
23'-9½"
58¼"
75"
75"
75"
2¼"
4"
2"
SLOTTED HOLES
¾"x1¼" TYP.
TS 8"X4"X3⁄16"
TUBING. ASTM A501
FRONT VIEW
8"
4"
9"
3"
TOP VIEW
RAIL DETAIL G
28'
19¾"
75"
75"
75"
75"
16¼"
4"
2"
SLOTTED HOLES
¾"x1¼" TYP.
FRONT VIEW
TS 8"X4"X3⁄16"
TUBING. ASTM A501
SLOTTED HOLES
¾"x1¼" TYP.
8"
4"
9"
3"
TOP VIEW
RAIL DETAIL H
9"
3"
5¾"
23'-9½"
4"
75"
75"
75"
54¾"
2"
SLOTTED HOLES
¾"x1¼" TYP.
FRONT VIEW
TS 8"X4"X3⁄16"
TUBING. ASTM A501
SLOTTED HOLES
¾"x1¼" TYP.
8"
4"
TOP VIEW
RAIL DETAIL I
9"
3"
NOTE: ALL SPLICE HOLES ø¾"x1¼" TYP.
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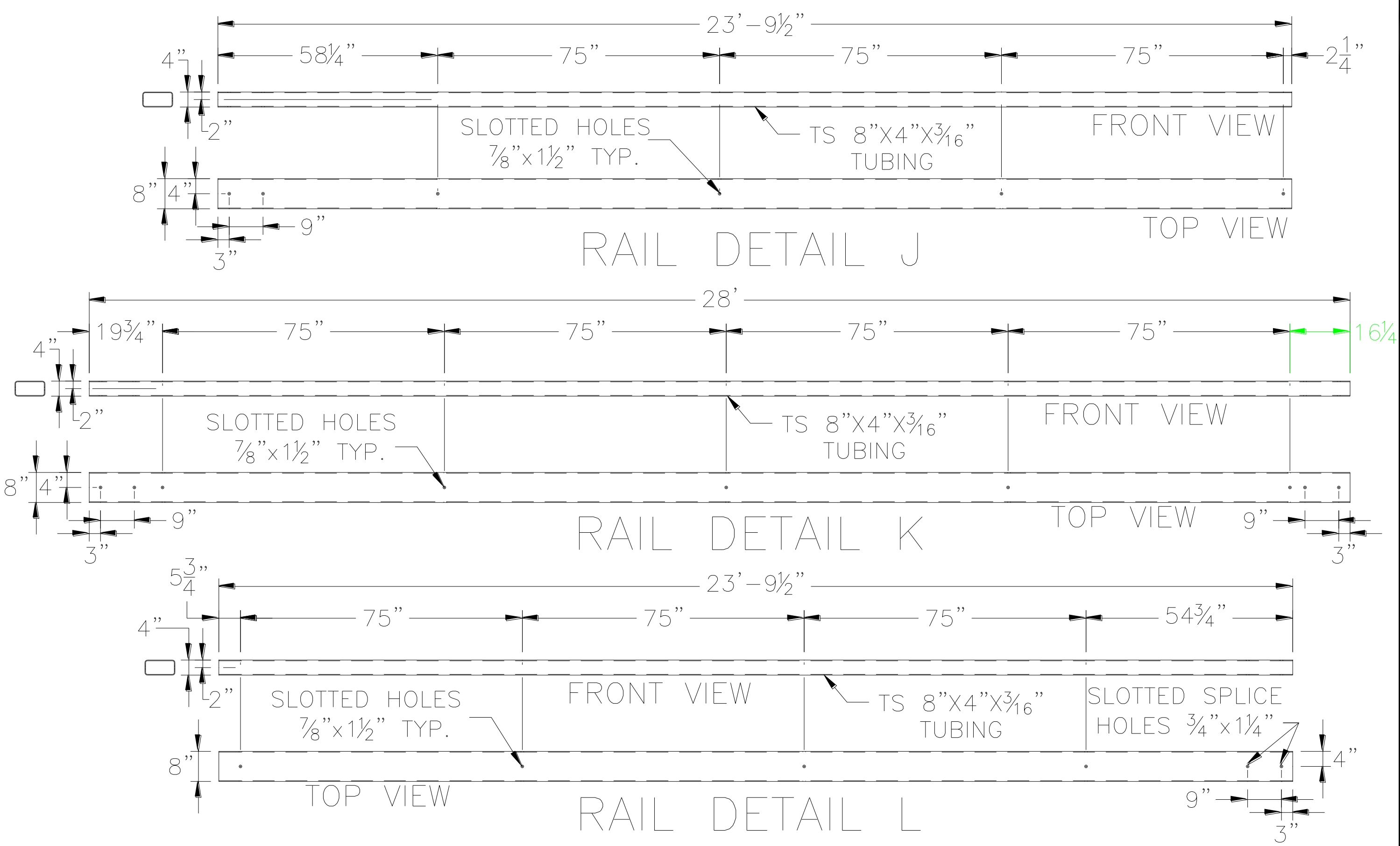
Scale
OHIO DEEP BEAM BRIDGE
RAIL TL3
Sheet No. 6 of 11
Dec 06, 2010 - 1:49pm
T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_(Without-pavement-overlay)_2010-05-05_Appendix_C.dwg



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2.							
3.							
4.				OHIO DEEP BEAM BRIDGE RAIL TL3			Sheet No. 7 of 11
5.							

NOTE: ALL SPLICE HOLES ø¾"x1¼" TYP.

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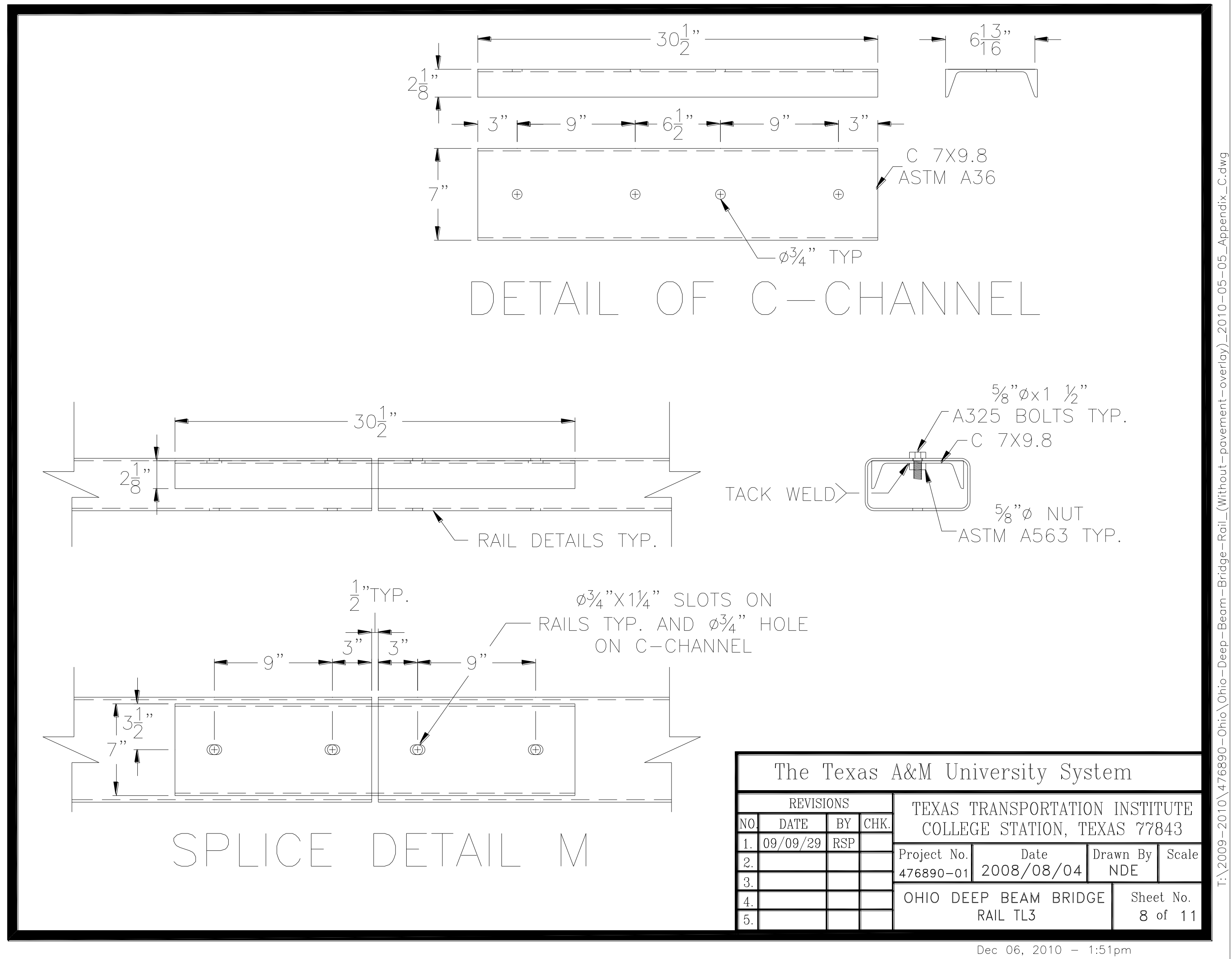
30 1/2"
6 13/16"
2 1/8"
3" 9" 6 1/2" 9" 3"
7"
C 7X9.8
ASTM A36
ø3/4" TYP
DETAIL OF C-CHANNEL
30 1/2"
2 1/8"
RAIL DETAILS TYP.
5/8"øx1 1/2"
A325 BOLTS TYP.
C 7X9.8
TACK WELD
5/8"ø NUT
ASTM A563 TYP.
1/2"TYP.
ø3/4"X1 1/4" SLOTS ON
RAILS TYP. AND ø3/4" HOLE
ON C-CHANNEL
9" 3" 3" 9"
3 1/2"
7"
SPLICE DETAIL M
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3.
4.
5.
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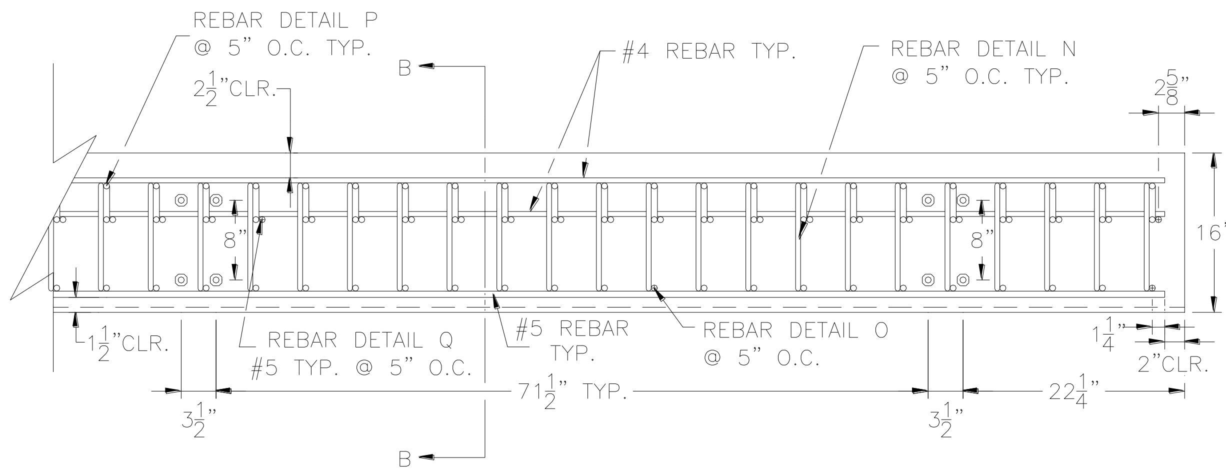
Drawn By NDE
Scale
OHIO DEEP BEAM BRIDGE
RAIL TL3
Sheet No. 8 of 11
T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_(Without-pavement-overlay)_2010-05-05_Appendix_C.dwg
Dec 06, 2010 - 1:51pm



REBAR LAYOUT

DECK–ELEVATION VIEW

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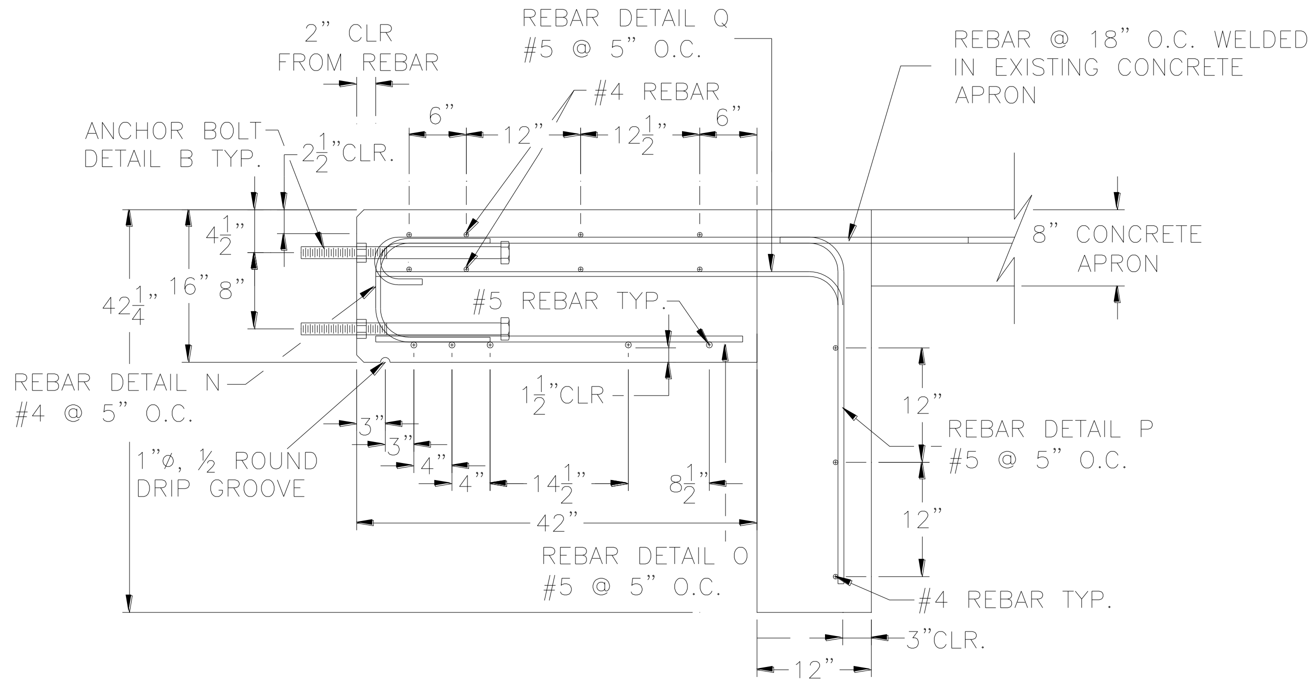
OHIO DEEP BEAM BRIDGE
RAIL TL3

Sheet No.
9 of 11

Dec 06, 2010 – 1:51pm

T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_(Without-pavement-overlay)_2010-05-05_Appendix_C.dwg



SECTION DETAIL B-B

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OHIO DEEP BEAM BRIDGE
RAIL TL3

Sheet No.
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T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_(Without-pavement-overlay)_2010-05-05_Appendix_C.dwg

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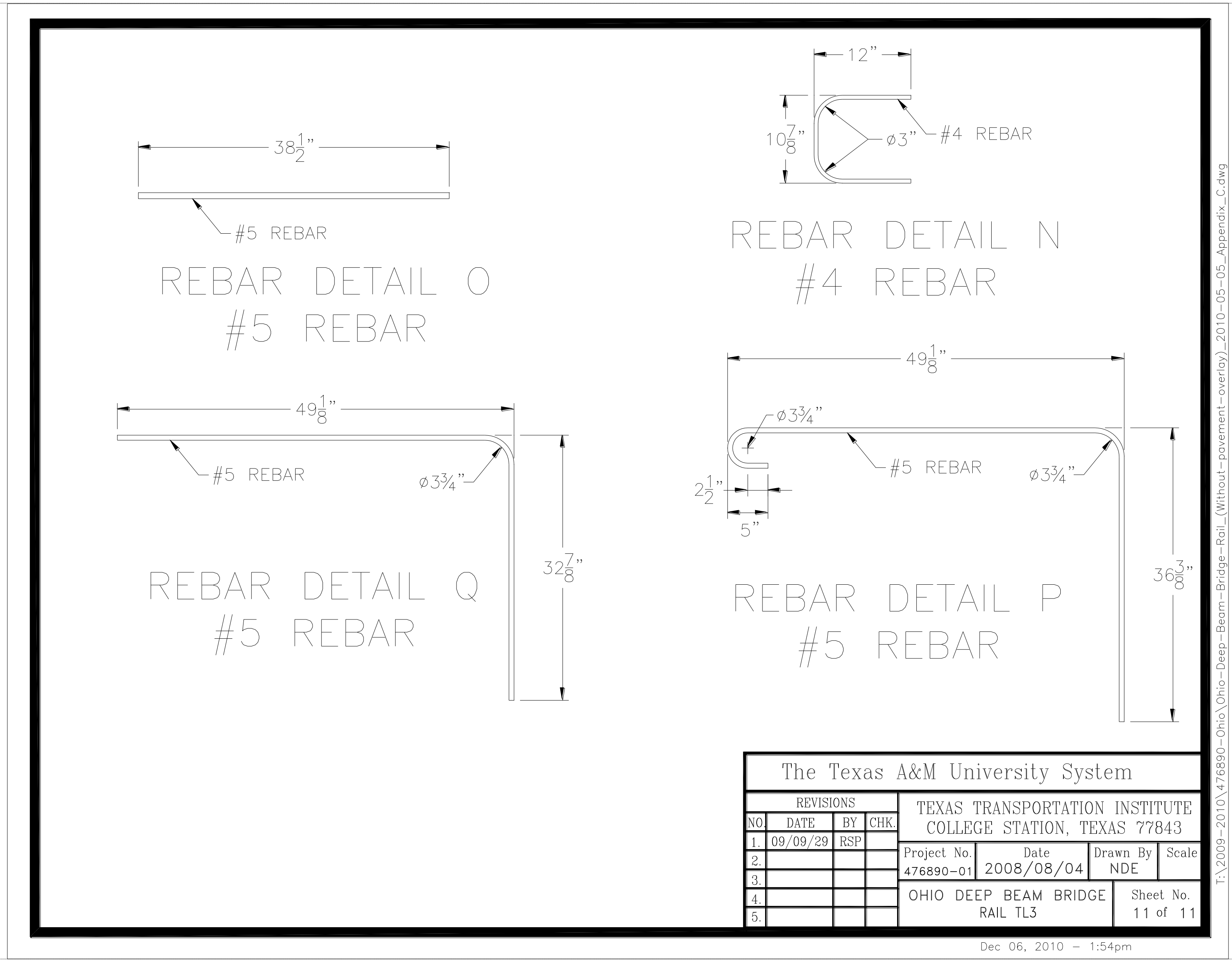
38½"
#5 REBAR
REBAR DETAIL O
#5 REBAR
12"
10⅞"
ø3"
#4 REBAR
REBAR DETAIL N
#4 REBAR
49⅛"
#5 REBAR
ø3¾"
32⅞"
REBAR DETAIL Q
#5 REBAR
49⅛"
ø3¾"
#5 REBAR
ø3¾"
2½"
5"
36⅜"
REBAR DETAIL P
#5 REBAR
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4.
5.
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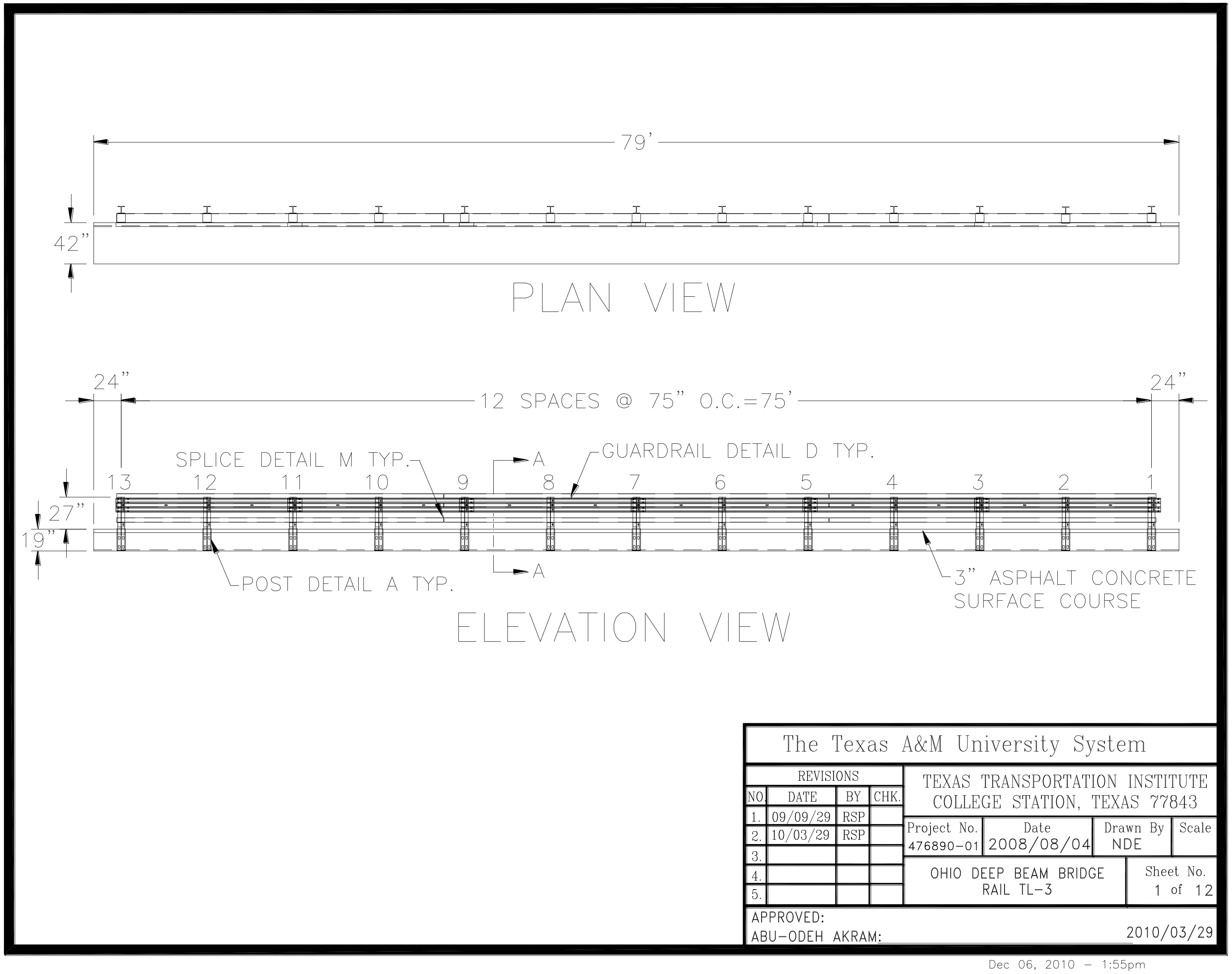
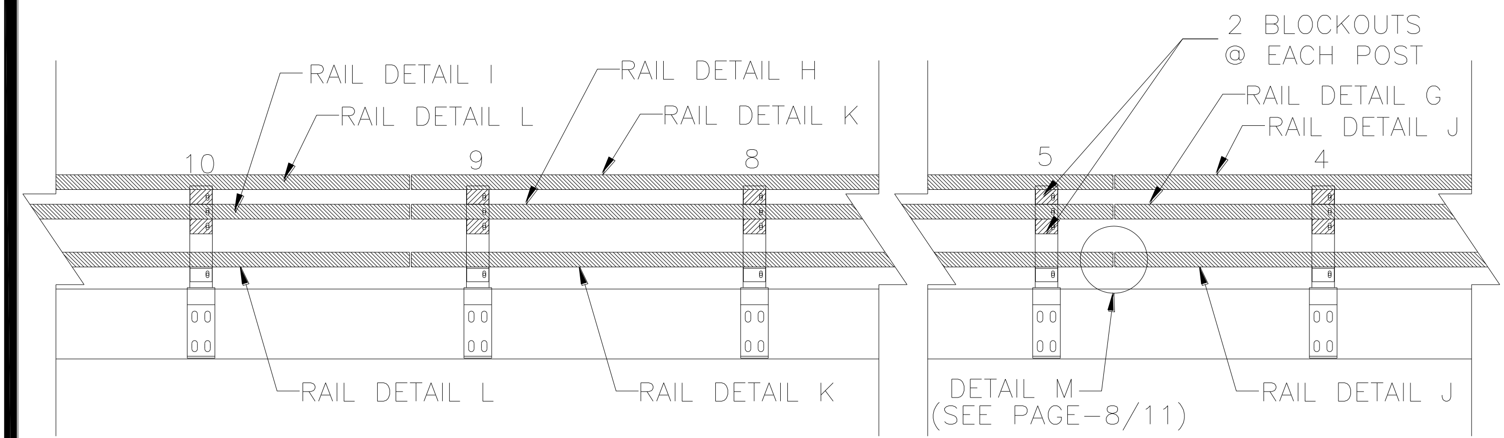
Scale
OHIO DEEP BEAM BRIDGE
RAIL TL3
Sheet No. 11 of 11
Dec 06, 2010 - 1:54pm
T:\2009-2010\476890-Ohio\Ohio-Deep-Beam-Bridge-Rail_(Without-pavement-overlay)_2010-05-05_Appendix_C.dwg

APPENDIX D DRAWINGS OF ODOT MODIFIED BRIDGE RAIL WITH PAVEMENT OVERLAY





RAIL ELEVATION-DETAIL

(WITHOUT W-BEAM)

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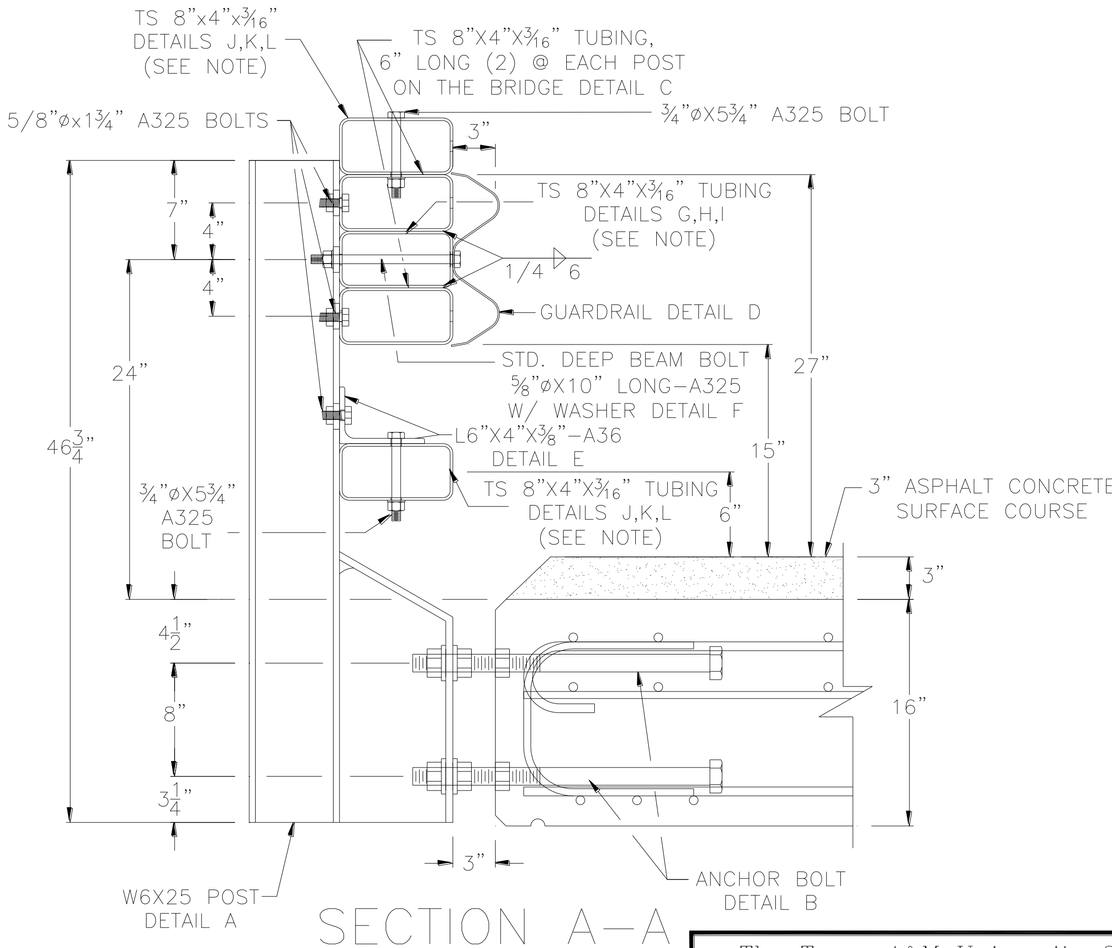
OHIO DEEP BEAM BRIDGE
RAIL TL3

Sheet No.
2 of 12

T:\2009-2010\476890-Ohio\Deep beam Bridge Guardrail_2010-02-26_Appendix_D.dwg

Dec 06, 2010 - 1:57pm



SECTION A–A

NOTE: DETAIL G&J–RIGHT END RAIL
DETAIL H&K– CENTER RAIL
DETAIL I&L– LEFT END RAIL
ALL NUTS TO BE HEAVY HEX ASTM A563
ALL WASHERS TO BE ASTM F436
PLATE WASHER–DETAIL F IS USED BETWEEN NUT AND POST

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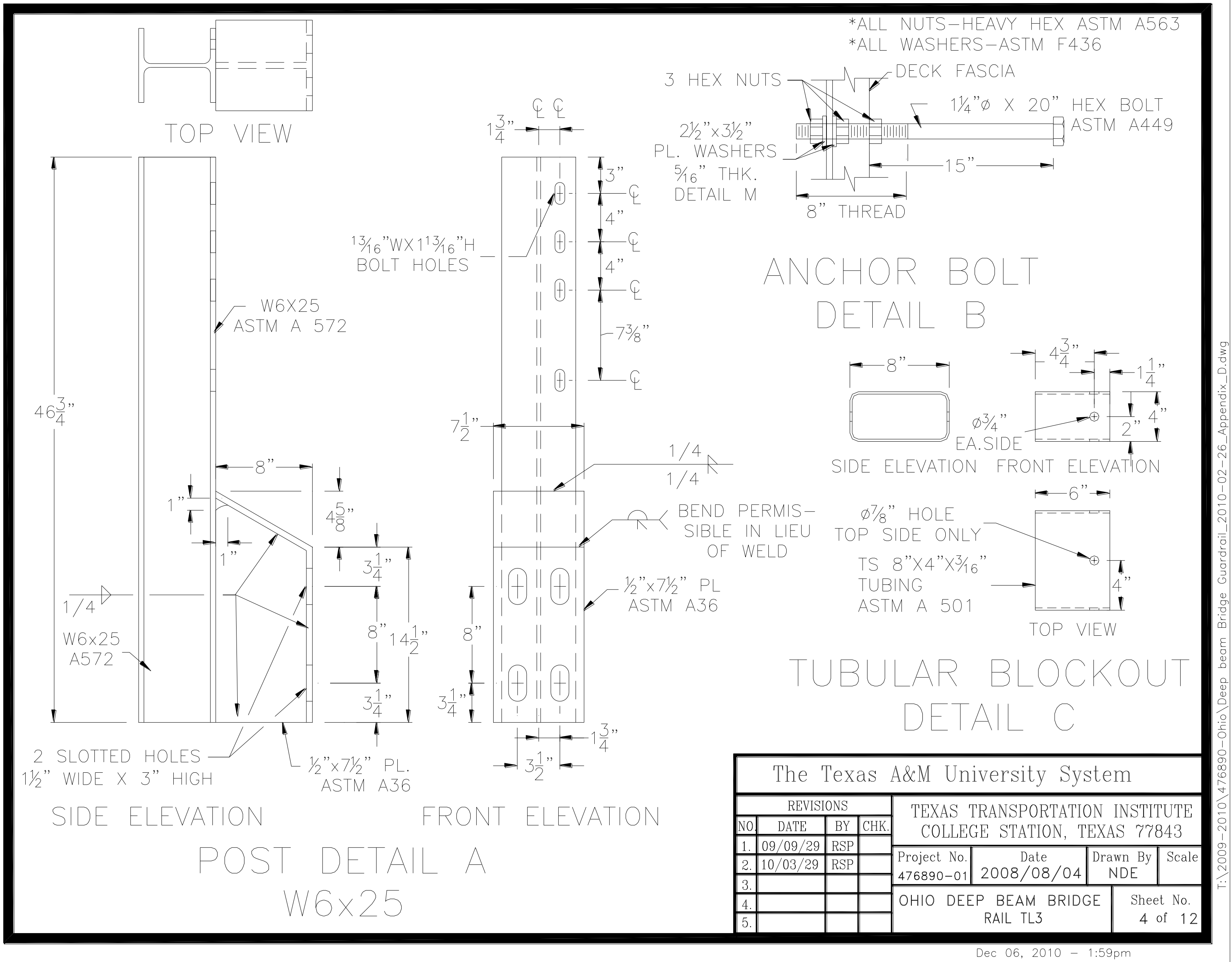
OHIO DEEP BEAM BRIDGE RAIL TL3

Sheet No. 3 of 12

T:\2009-2010\476890-Ohio\Deep beam Bridge Guardrail_2010-02-26_Appendix_D.dwg

Dec 06, 2010 – 1:58pm


*ALL NUTS–HEAVY HEX ASTM A563
*ALL WASHERS–ASTM F436
TOP VIEW
3 HEX NUTS
DECK FASCIA
1¼"ø X 20" HEX BOLT ASTM A449
2½"x3½" PL. WASHERS 5/16" THK. DETAIL M
15"
8" THREAD
ANCHOR BOLT DETAIL B
13/16"WX1 13/16"H BOLT HOLES
W6X25 ASTM A 572
46 3/4"
8"
1"
4 5/8"
3 1/4"
8"
14 1/2"
1/4
W6x25 A572
2 SLOTTED HOLES 1½" WIDE X 3" HIGH
½"x7½" PL. ASTM A36
SIDE ELEVATION
1 3/4"
3"
4"
7 3/8"
7 1/2"
1/4
BEND PERMISSIBLE IN LIEU OF WELD
½"x7½" PL ASTM A36
3 1/2"
FRONT ELEVATION
POST DETAIL A W6x25
SIDE ELEVATION
FRONT ELEVATION
ø¾" EA.SIDE
4 3/4"
1 1/4"
2"
6"
ø⅞" HOLE TOP SIDE ONLY
TS 8"X4"X3/16" TUBING ASTM A 501
TOP VIEW
TUBULAR BLOCKOUT DETAIL C
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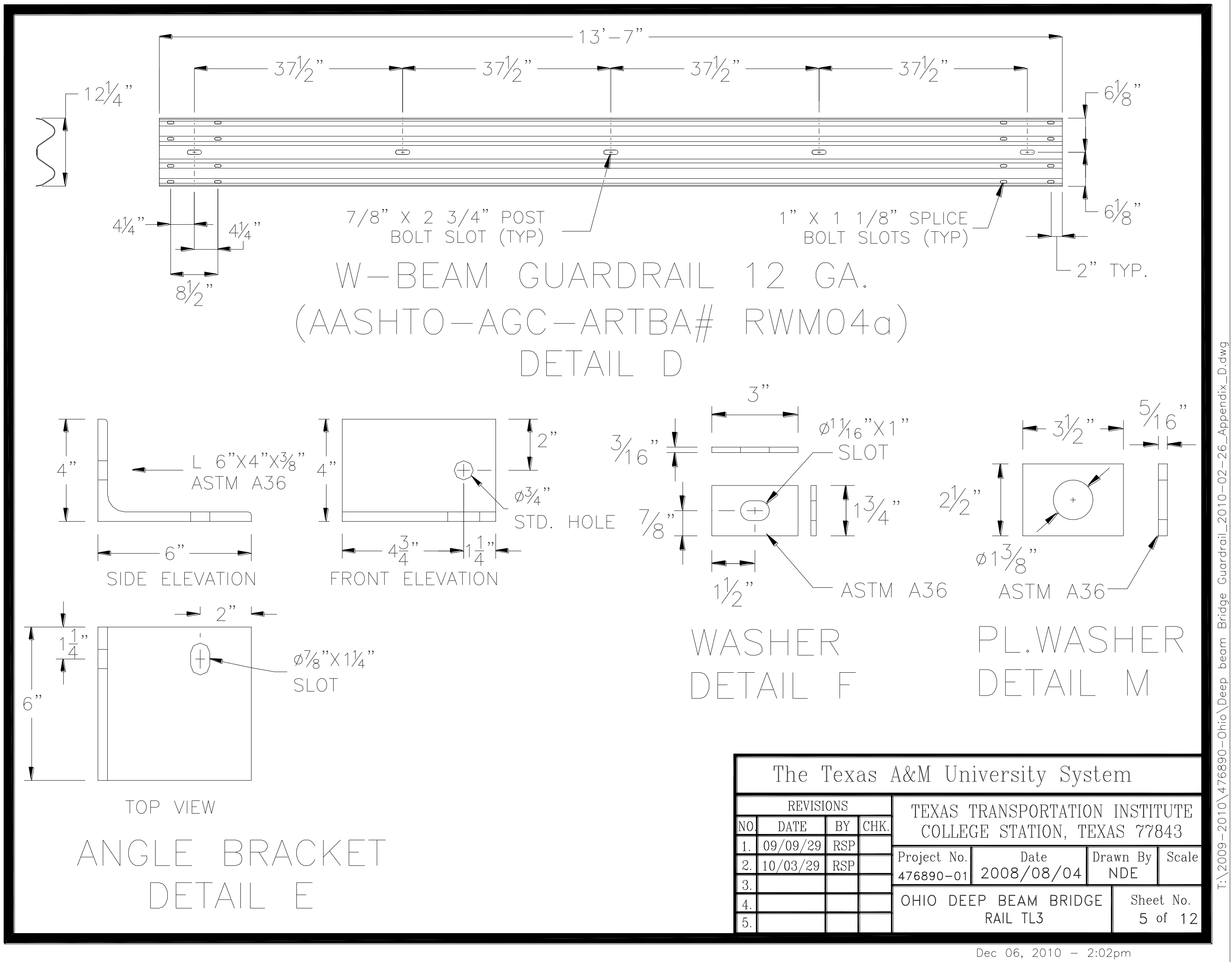
OHIO DEEP BEAM BRIDGE RAIL TL3
Sheet No. 4 of 12
T:\2009-2010\476890-Ohio\Deep beam Bridge Guardrail_2010-02-26_Appendix_D.dwg
Dec 06, 2010 – 1:59pm


13'-7"
37½"
37½"
37½"
37½"
12¼"
6⅛"
6⅛"
4¼"
4¼"
8½"
7/8" X 2 3/4" POST BOLT SLOT (TYP)
1" X 1 1/8" SPLICE BOLT SLOTS (TYP)
2" TYP.
W-BEAM GUARDRAIL 12 GA.
(AASHTO-AGC-ARTBA# RWM04a)
DETAIL D
4"
L 6"X4"X⅜" ASTM A36
6"
SIDE ELEVATION
4"
2"
ø¾" STD. HOLE
4¾"
1¼"
FRONT ELEVATION
1¼"
2"
ø⅞"X1¼" SLOT
6"
TOP VIEW
ANGLE BRACKET
DETAIL E
3"
3⁄16"
ø1⅟16"X1" SLOT
⅞"
1¾"
1½"
ASTM A36
WASHER
DETAIL F
3½"
5⁄16"
2½"
ø1⅜"
ASTM A36
PL.WASHER
DETAIL M
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4.
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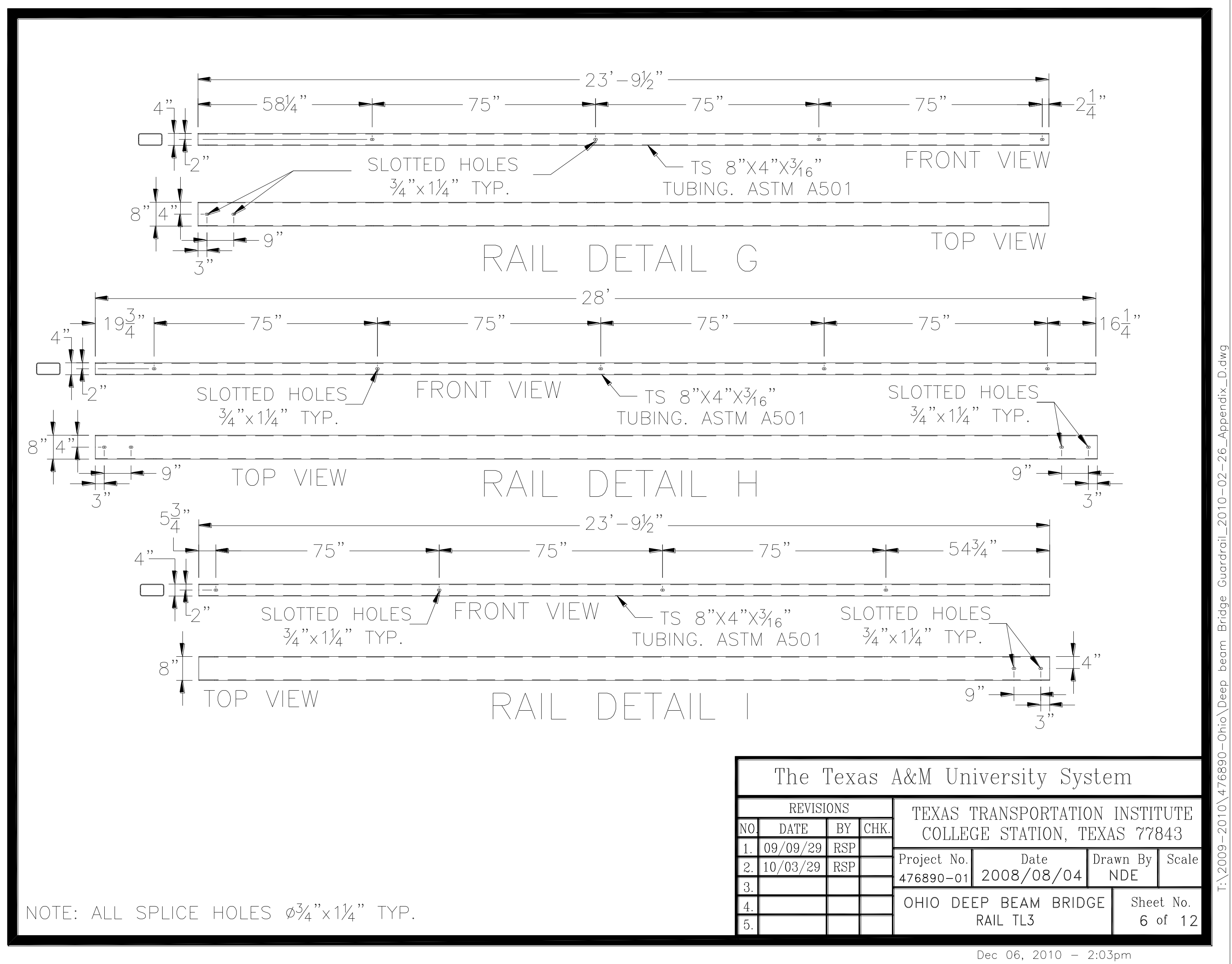
OHIO DEEP BEAM BRIDGE RAIL TL3
Sheet No. 5 of 12
T:\2009-2010\476890-Ohio\Deep beam Bridge Guardrail_2010-02-26_Appendix_D.dwg
Dec 06, 2010 - 2:02pm


23'-9½"
58¼"
75"
75"
75"
$2\frac{1}{4}$"
4"
2"
SLOTTED HOLES
¾"x1¼" TYP.
TS 8"X4"X3⁄16"
TUBING. ASTM A501
FRONT VIEW
8"
4"
9"
3"
TOP VIEW
RAIL DETAIL G
28'
$19\frac{3}{4}$"
75"
75"
75"
75"
$16\frac{1}{4}$"
4"
2"
SLOTTED HOLES
¾"x1¼" TYP.
FRONT VIEW
TS 8"X4"X3⁄16"
TUBING. ASTM A501
SLOTTED HOLES
¾"x1¼" TYP.
8"
4"
9"
3"
TOP VIEW
RAIL DETAIL H
9"
3"
$5\frac{3}{4}$"
23'-9½"
4"
75"
75"
75"
54¾"
2"
SLOTTED HOLES
¾"x1¼" TYP.
FRONT VIEW
TS 8"X4"X3⁄16"
TUBING. ASTM A501
SLOTTED HOLES
¾"x1¼" TYP.
8"
4"
TOP VIEW
RAIL DETAIL I
9"
3"
NOTE: ALL SPLICE HOLES ø¾"x1¼" TYP.
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2. 10/03/29 RSP
3.
4.
5.
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OHIO DEEP BEAM BRIDGE
RAIL TL3
Sheet No. 6 of 12
T:\2009-2010\476890-Ohio\Deep beam Bridge Guardrail_2010-02-26_Appendix_D.dwg
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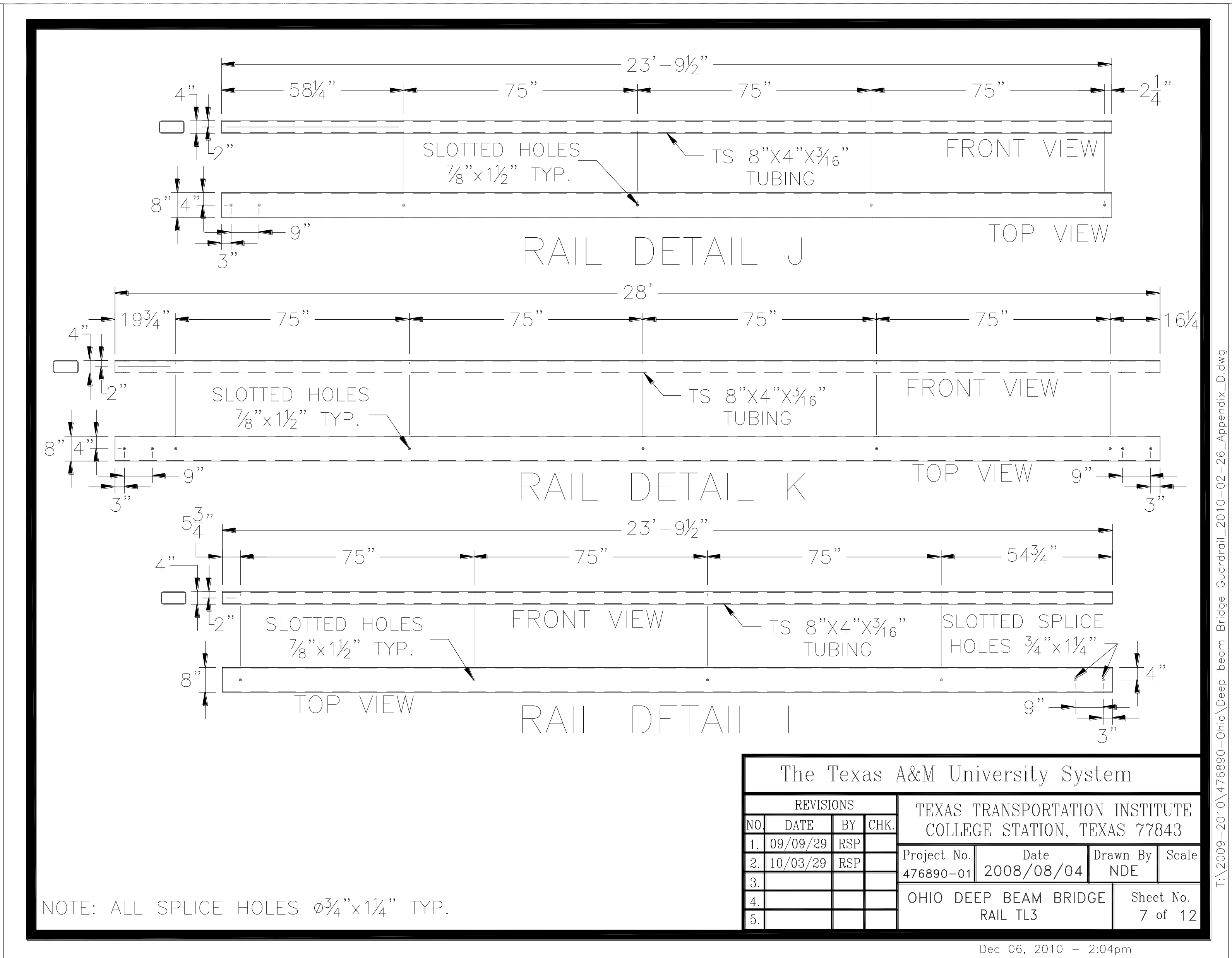
23'-9½"
58¼"
75"
75"
75"
2¼"
4"
2"
SLOTTED HOLES
⅞"x1½" TYP.
TS 8"X4"X3⁄16"
TUBING
FRONT VIEW
8"
4"
9"
3"
TOP VIEW
RAIL DETAIL J
28'
19¾"
16¼
RAIL DETAIL K
5¾"
54¾"
SLOTTED SPLICE
HOLES ¾"x1¼"
RAIL DETAIL L
NOTE: ALL SPLICE HOLES ø¾"x1¼" TYP.
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2. 10/03/29 RSP
3.
4.
5.
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Date 2008/08/04
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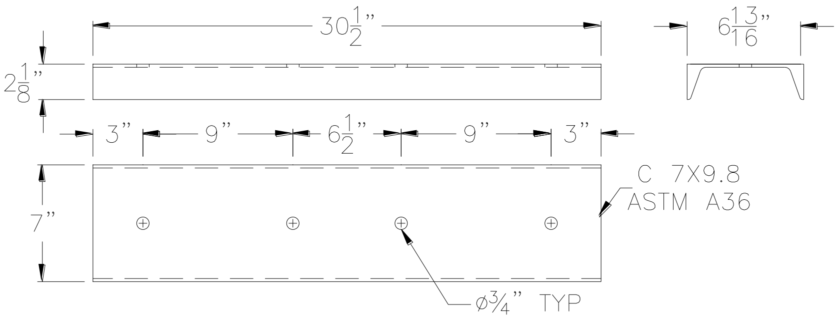
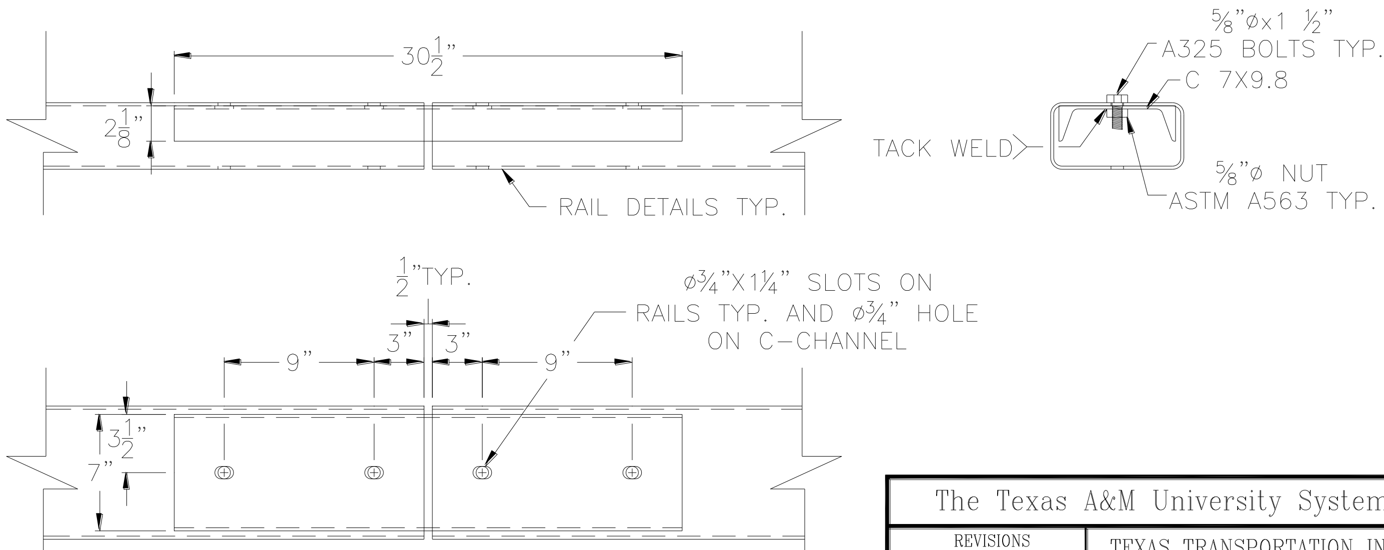
Scale
OHIO DEEP BEAM BRIDGE
RAIL TL3
Sheet No. 7 of 12
T:\2009-2010\476890-Ohio\Deep beam Bridge Guardrail_2010-02-26_Appendix_D.dwg
Dec 06, 2010 - 2:04pm



DETAIL OF C-CHANNEL



SPLICE DETAIL M

The Texas A&M University System							
REVISIONS				TEXAS TRANSPORTATION INSTITUTE COLLEGE STATION, TEXAS 77843			
NO.	DATE	BY	CHK.				
1.	09/09/29	RSP		Project No. 476890-01	Date 2008/08/04	Drawn By NDE	Scale
2.	10/03/29	RSP					
3.				OHIO DEEP BEAM BRIDGE RAIL TL3		Sheet No. 8 of 12	
4.							
5.							

Dec 06, 2010 – 2:06pm

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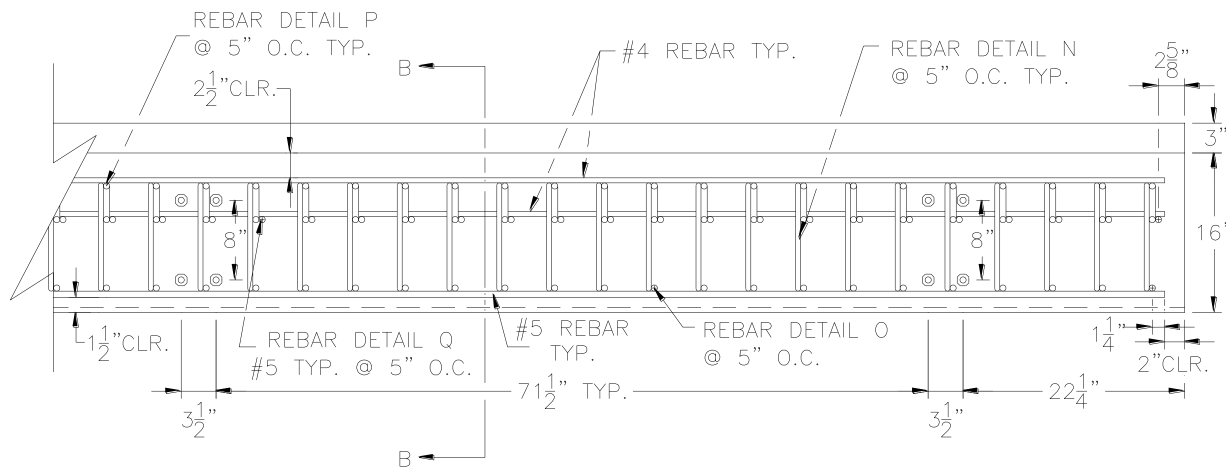

REBAR LAYOUT

DECK–ELEVATION VIEW

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COLLEGE STATION, TEXAS 77843

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NO.	DATE	BY	CHK.
1.	09/09/29	RSP	
2.	10/03/29	RSP	
3.			
4.			
5.			

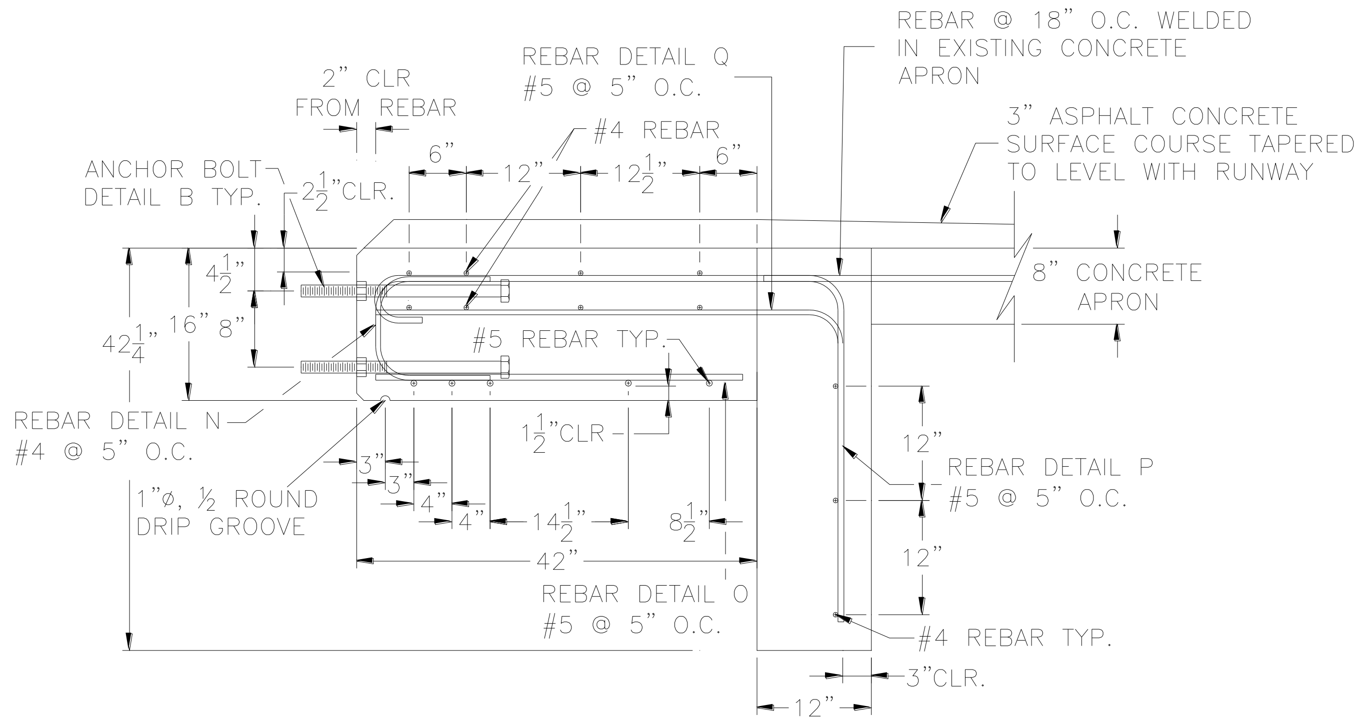
Project No.	Date	Drawn By	Scale
476890-01	2008/08/04	NDE	

OHIO DEEP BEAM BRIDGE RAIL TL3

Sheet No. 9 of 12

T:\2009-2010\476890-Ohio\Deep beam Bridge Guardrail_2010-02-26_Appendix_D.dwg

Dec 06, 2010 – 2:15pm

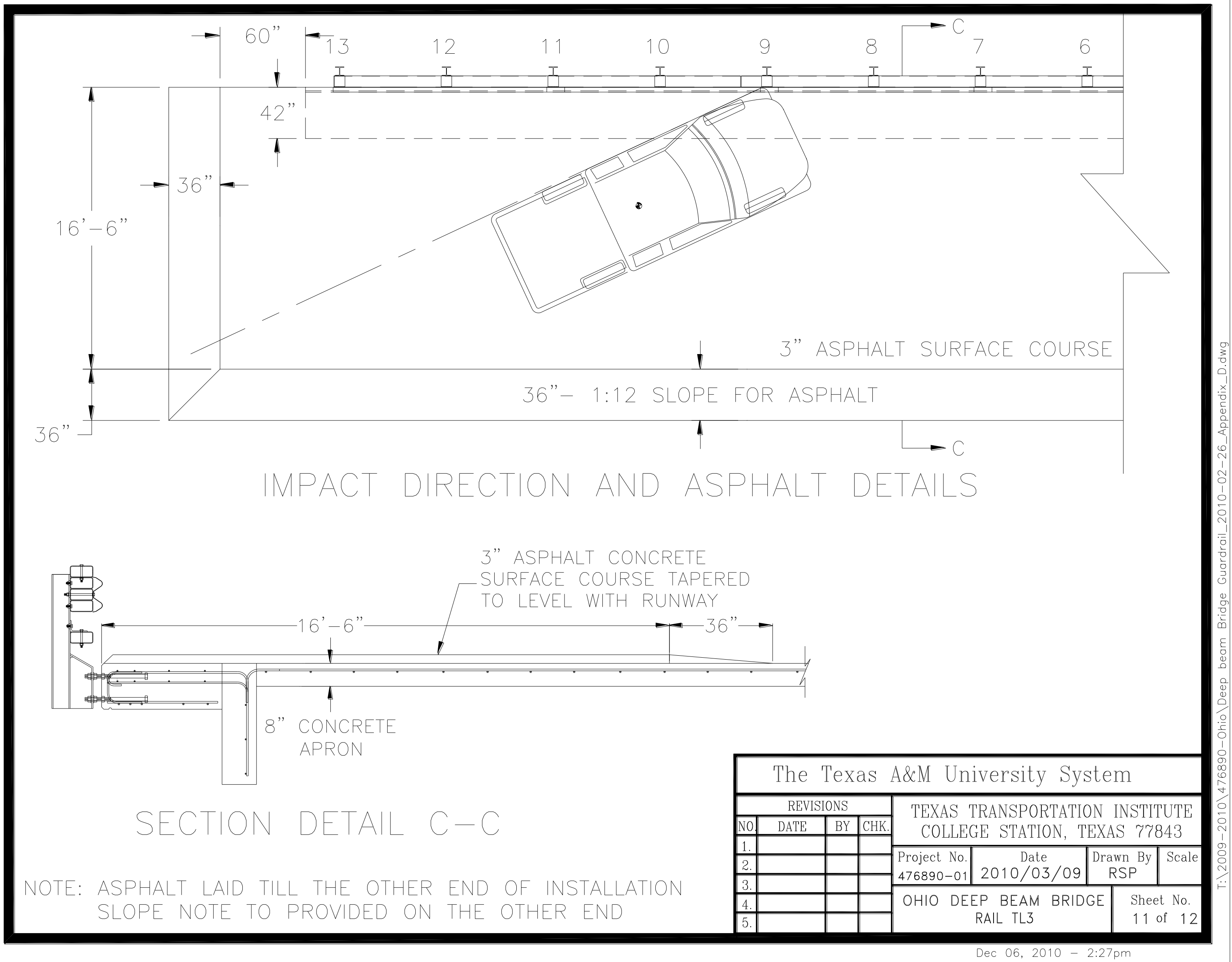


SECTION DETAIL B-B

The Texas A&M University System							
REVISIONS				TEXAS TRANSPORTATION INSTITUTE COLLEGE STATION, TEXAS 77843			
NO.	DATE	BY	CHK.				
1.	09/09/29	RSP		Project No. 476890-01	Date 2008/08/04	Drawn By NDE	Scale
2.	10/03/29	RSP					
3.							
4.				OHIO DEEP BEAM BRIDGE RAIL TL3		Sheet No. 10 of 12	
5.							

T:\2009-2010\476890-Ohio\Deep beam Bridge Guardrail_2010-02-26_Appendix_D.dwg

Dec 06, 2010 – 2:16pm



60"
13
12
11
10
9
8
7
6
C
42"
36"
16'-6"
3" ASPHALT SURFACE COURSE
36"- 1:12 SLOPE FOR ASPHALT
36"
C
IMPACT DIRECTION AND ASPHALT DETAILS
3" ASPHALT CONCRETE SURFACE COURSE TAPERED TO LEVEL WITH RUNWAY
16'-6"
36"
8" CONCRETE APRON
SECTION DETAIL C-C
NOTE: ASPHALT LAID TILL THE OTHER END OF INSTALLATION
SLOPE NOTE TO PROVIDED ON THE OTHER END
The Texas A&M University System
REVISIONS
NO. DATE BY CHK.
1.
2.
3.
4.
5.
TEXAS TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS 77843
Project No. 476890-01
Date 2010/03/09
Drawn By RSP
Scale
OHIO DEEP BEAM BRIDGE RAIL TL3
Sheet No. 11 of 12
Dec 06, 2010 - 2:27pm
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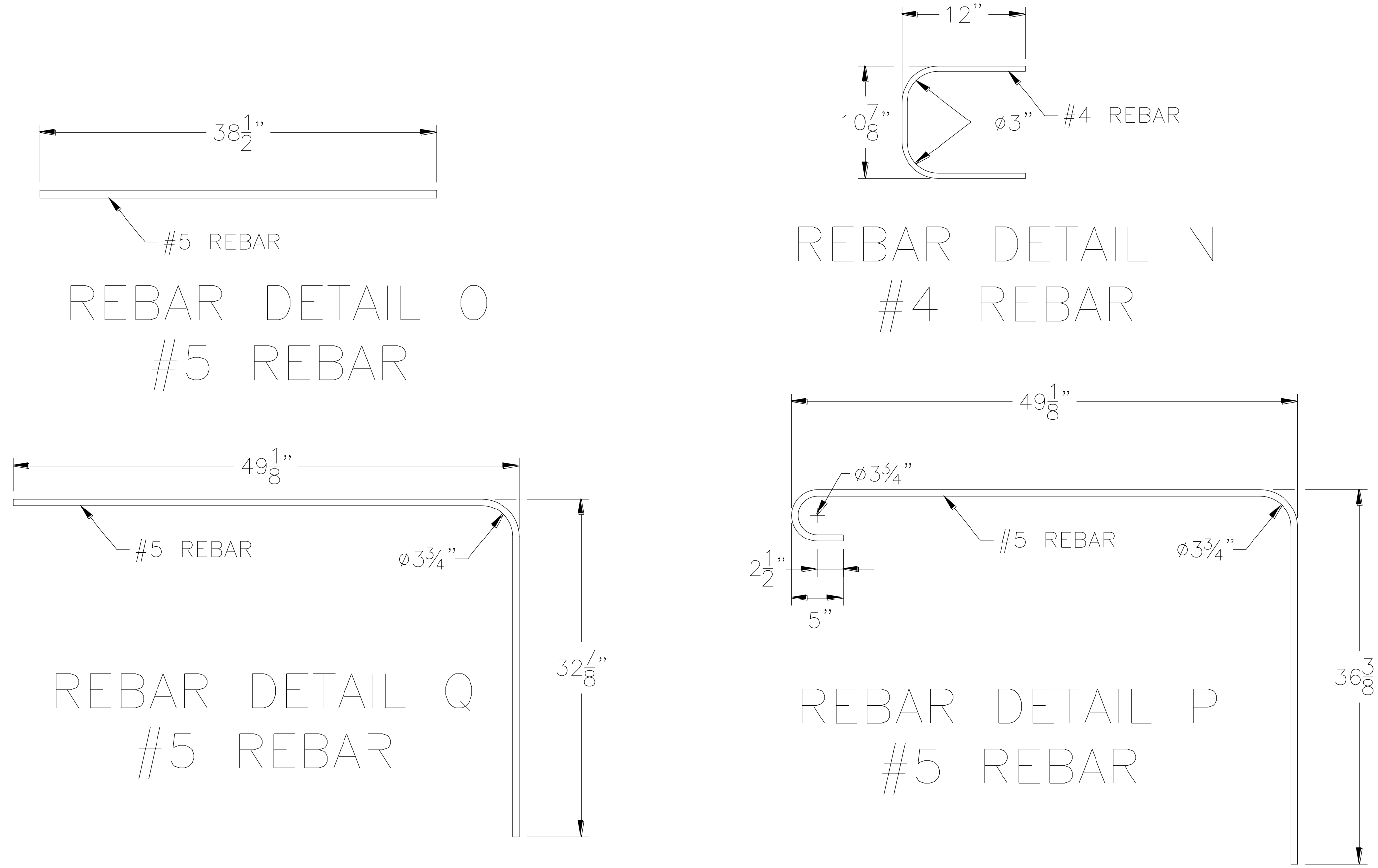

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REVISIONS			
NO.	DATE	BY	CHK.
1.	09/09/29	RSP	
2.	10/03/29	RSP	
3.			
4.			
5.			

Project No.	Date	Drawn By	Scale
476890-01	2008/08/04	NDE	

OHIO DEEP BEAM BRIDGE RAIL TL3	Sheet No. 12 of 12

T:\2009-2010\476890-Ohio\Deep beam Bridge Guardrail_2010-02-26_Appendix_D.dwg

Dec 06, 2010 - 2:28pm

APPENDIX E THE ODOT GR-3.4 TRANSITION ASSEMBLY