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# OPTIMIZATION OF THRIE BEAM TERMINAL END SHOE CONNECTION



Pendulum testing performed at:  
TTI Proving Ground  
3100 SH 47, Building 7091  
Bryan, TX 77807

**Test Report 9-1002-15-6**

Cooperative Research Program

**TEXAS A&M TRANSPORTATION INSTITUTE**

**COLLEGE STATION, TEXAS**

in cooperation with the  
Federal Highway Administration and the  
Texas Department of Transportation  
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16. Abstract  Terminal thrie end shoes connect nested thrie beams to parapets or other bridge rail structure to provide a robust connectivity between a transition section and a rigid railing section. When connecting terminal end shoe to thrie beam transitions, the thrie section profile results in shifting of the connecting slots. This can result in slots misalignment, which makes installation and maintenance difficult. Multiple field adjustments are known to be used to fit the end shoe to the beam. Such methods include hammering drift pins to deform the metal, or torching or grinding away the interring material, all of which may compromise the integrity of the rail element.  The goal of this project is to evaluate existing end shoe design and develop design improvements that will reduce or eliminate the need for field adjustments.					
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This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. In addition, the above listed agencies assume no liability for its contents or use thereof. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report. The engineer in charge of the project was Roger P. Bligh, P.E. (Texas, #78550).

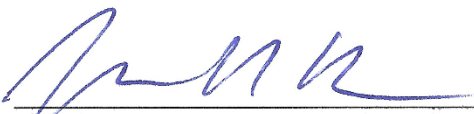
### TTI PROVING GROUND DISCLAIMER

The results of the pendulum testing reported herein apply only to the article being tested.



  
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# CHAPTER 1: INTRODUCTION

## 1.1 PROBLEM/BACKGROUND

Terminal thrie end shoes are commonly used to connect nested thrie beam rails to parapets or other bridge rail structure to provide robust connectivity between an approach rail transition section and a rigid railing section. When connecting terminal end shoe to nested thrie beam transition rails, the thrie beam section profile results in shifting of the splice bolt connecting slots. This can result in slots misalignment through the three material layers, which makes installation and maintenance difficult. Multiple field adjustments are known to be used to fit the end shoe to the beam. Such methods include hammering of drift pins, or torching grinding away interfering metal, all of which may compromise the integrity of the sections being connected.

The goal of this project is to evaluate existing end shoe design and develop design improvements that will reduce or eliminate the need for rail modifications in the field.

Placement of a nested thrie beam and an end shoe connector in several configurations confirmed that the slots on the thrie beam rail sections and end shoe do not provide adequate alignment for permitting the bolting process without substantial physical modification of the rail.

Figures 1.1 and 1.2 illustrate misalignment of the slots to a degree that makes it impossible to insert splice bolts without significant modifications.



**Figure 1.1. Thrie Beam and End Shoe.**



**Figure 1.2. Misalignment of Slots Due to Geometrical Shifting.**

## **1.2 WORK PLAN**

This research effort followed the tasks listed below to substantially reduce alignment problems as the splice bolt slots and permit attachment of a nested thrie-beam to an end shoe connector without rail modifications:

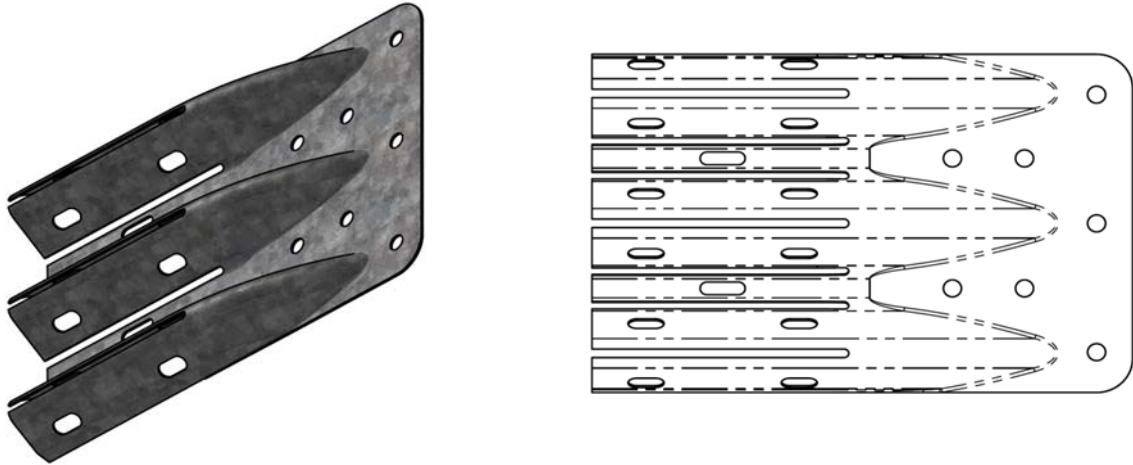
- Study previous crash tests to acquire accelerations histories for existing thrie beam transition,
- Develop a finite element model of nested thrie transition with end shoe connector,
- Compare the acceleration from the simulation to the crash test acceleration history to establish validity of the simulation,
- Obtain force history at the end shoe connector to determine needed capacity,
- Suggest end shoe design modifications, and
- Test candidate solution to verify structural capacity to withstand the needed axial forces.

## **1.3 RECOMMENDED END SHOE DESIGN MODIFICATIONS**

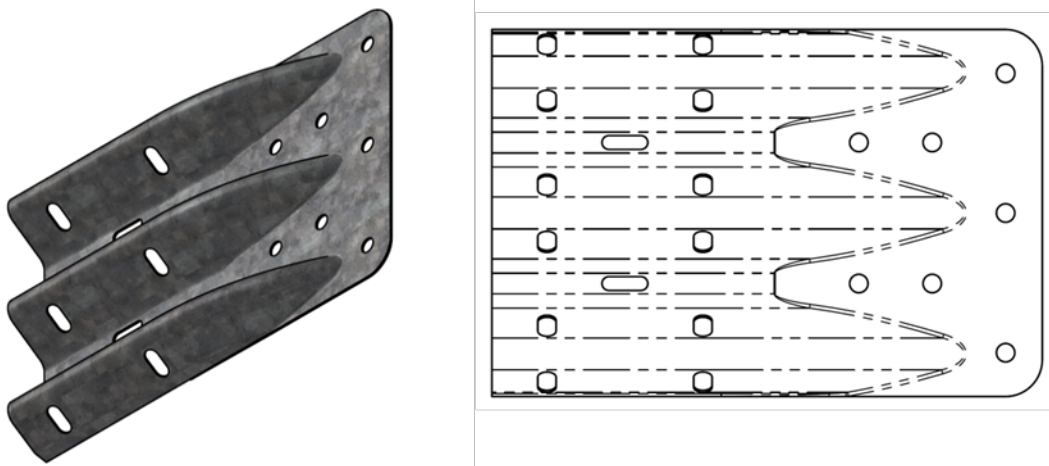
The research team developed the following end shoe design concepts as potential solutions to reduce or eliminate interference associated with field installation of splice bolts:

- The addition of longitudinal slots along the length of the end shoe to provide greater flexibility to facilitate connection,
- A vertical or perpendicular orientation of the splice bolt slots compared to the current horizontal or longitudinal slots, and
- Larger diameter round holes instead of slots.

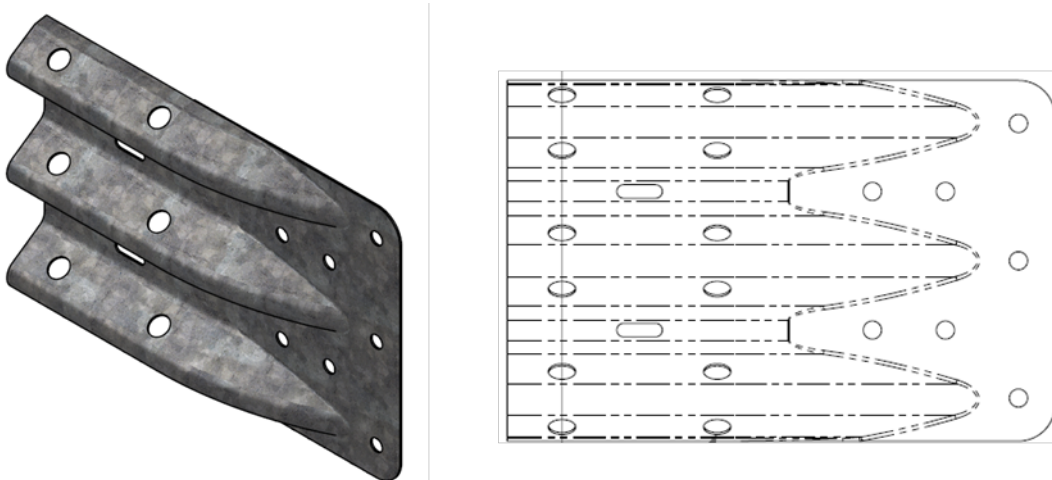
These concepts are shown in Figures 1.3 through 1.5, respectively. Upon evaluation of the practicality of manufacturing and installation, the research team recommended the end shoe design concept with vertical slots as the candidate option with the most promising installation ease.



**Figure 1.3. Longitudinal Slots Along Bend Lines.**



**Figure 1.4. Vertical Slots.**



**Figure 1.5. Larger Diameter Holes Instead of Horizontal Slots.**



## 1.4 REFERENCED TRANSITION TL-3 CRASH TESTS

Two crash tests were studied to quantify axial forces experienced by an end shoe connector (1). These tests were recently conducted per American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware (MASH)* testing guidelines at TL-3 impact severity (2). In these tests, the transition system was flared 4 degrees from the roadway path, thereby increasing the effective impact angle to 29 degrees (25 degree impact angle + 4 degree flare). Hence, these tests can be considered a practical worst case for TL-3 transition impacts in terms of the axial load imparted on the transition rail section and end shoe connector.

Specifically, the tests examined for the end shoe analysis were performed under Texas Department of Transportation (TxDOT) Project 0-6711, *Short Radius MASH TL-3 Guardrail Treatment*. This project sought to develop and test a new *MASH*-compliant short radius guardrail system for treatment of bridge ends in close proximity to an intersecting roadway/driveway. In this project, two tests were performed following *MASH* Test 3-35 impact conditions. Test 3-35 involves a 5,000-lb pickup truck impacting the beginning of length of need at a nominal speed of 62 mph and a nominal angle of 25-degrees relative to the edge of the roadway. However, with the 4-degree system flare that existed, the effective impact angle was 29 degrees.

In the first of two Test 3-35 impacts (Test No. 467114-6), the vehicle impacted the thrie beam rail 15 ft upstream of the end shoe connector. The vehicle was redirected, but rolled upon exiting the system. Figure 1.6 shows the 5016-lb pickup that was used for the crash test. Figure 1.7 shows an overall view of the short radius guardrail used for these tests.

### Test 467114-6

- Date: 2014-08-05
- Project: TxDOT Project 0-6711
- Vehicle: 2008 Dodge Ram 1500
  - Impact: 62.6 mph at 29 degree effective angle

#### Accelerations\*:

- Max longitudinal acceleration: 28.2 g
- Max lateral acceleration: 26.8 g

\*Class 60 filter



**Figure 1.6. Test No. 467114-6 Vehicle Setup.**



**Figure 1.7. Test 467114-6 Installation Setup.**

The second test, which also followed Test 3-35 impact conditions, is Test No. 467114-7. After the failed test, an extra post was added near the upstream end of the three-beam transition and the test was repeated. This test passed all relevant *MASH* evaluation criteria. The actual impact point was 14 ft upstream of the end shoe connector. Figure 1.8 shows the 5014-lb pickup used for the crash test. Figure 1.9 shows the short radius guardrail installation used for the test.

**Test 467114-7**

- Date: 2014-08-22
- Project : TxDOT Project 0-6711
- Vehicle: 2008 Dodge Ram 1500
- Impact: 64.5 mph at 25 degrees

Accelerations\*:

- Max longitudinal acceleration: 17.7 g
- Max lateral acceleration: 18.1 g

\*Class 60 filter

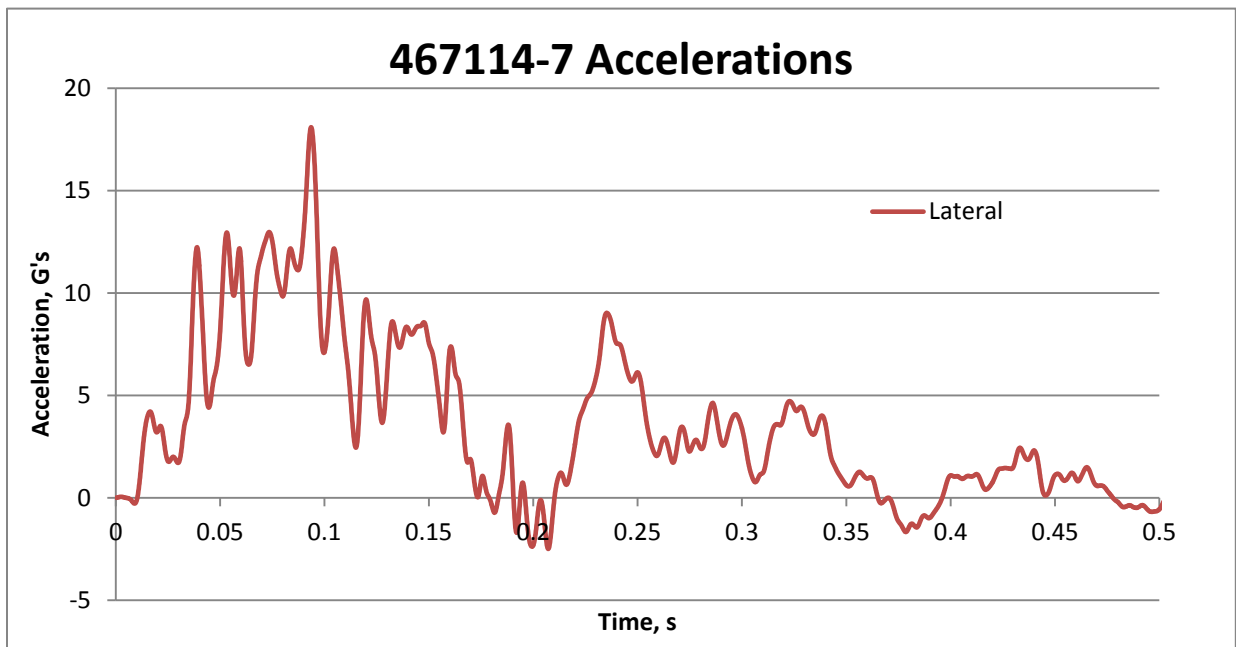
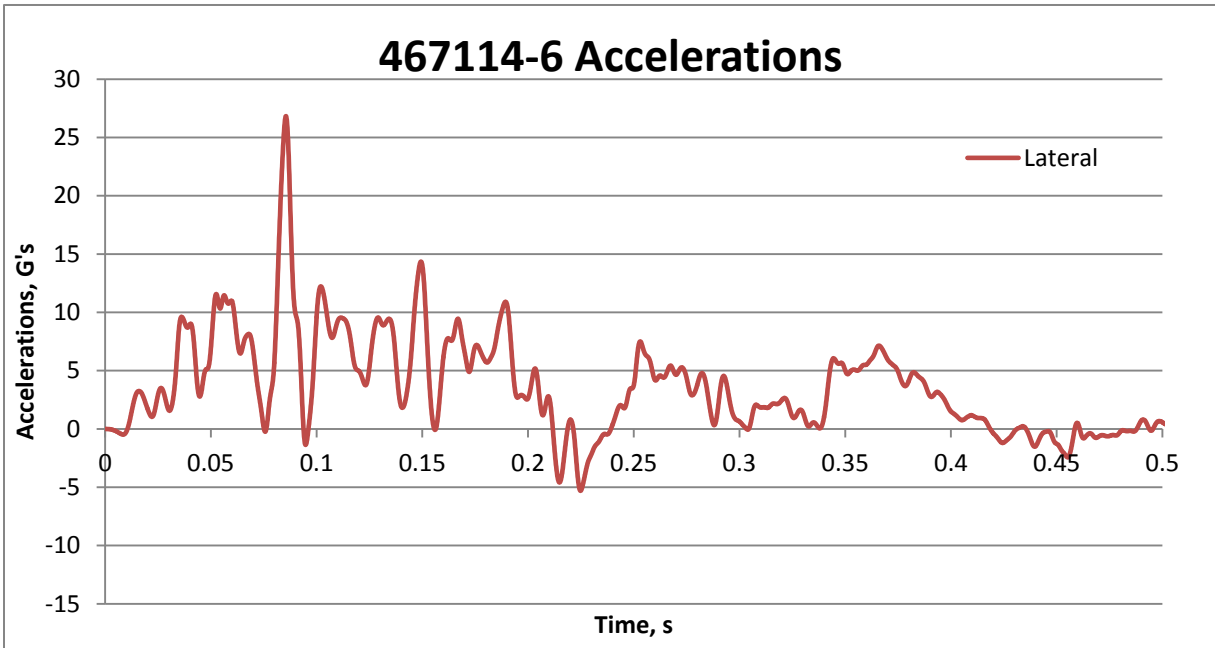


**Figure 1.8. Test No. 467114-7 Vehicle Setup.**



**Figure 1.9. Test No. 467114-7 Installation Setup.**

Figure 1.10 presents the accelerations experienced by the vehicle during the two tests. Accelerations were filtered using an SAE class 60 filter. The maximum lateral acceleration was 18.1 g in test 46711-7 and 26.8 g in test 467114-6 as summarized in Table 1.1.



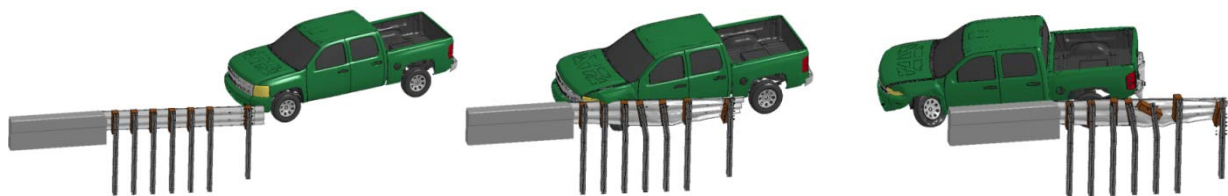
**Figure 1.10. Test Nos. 467114-6 and 467114-7 Lateral Acceleration Histories.**

**Table 1.1. Maximum Lateral Acceleration from Crash Tests.**

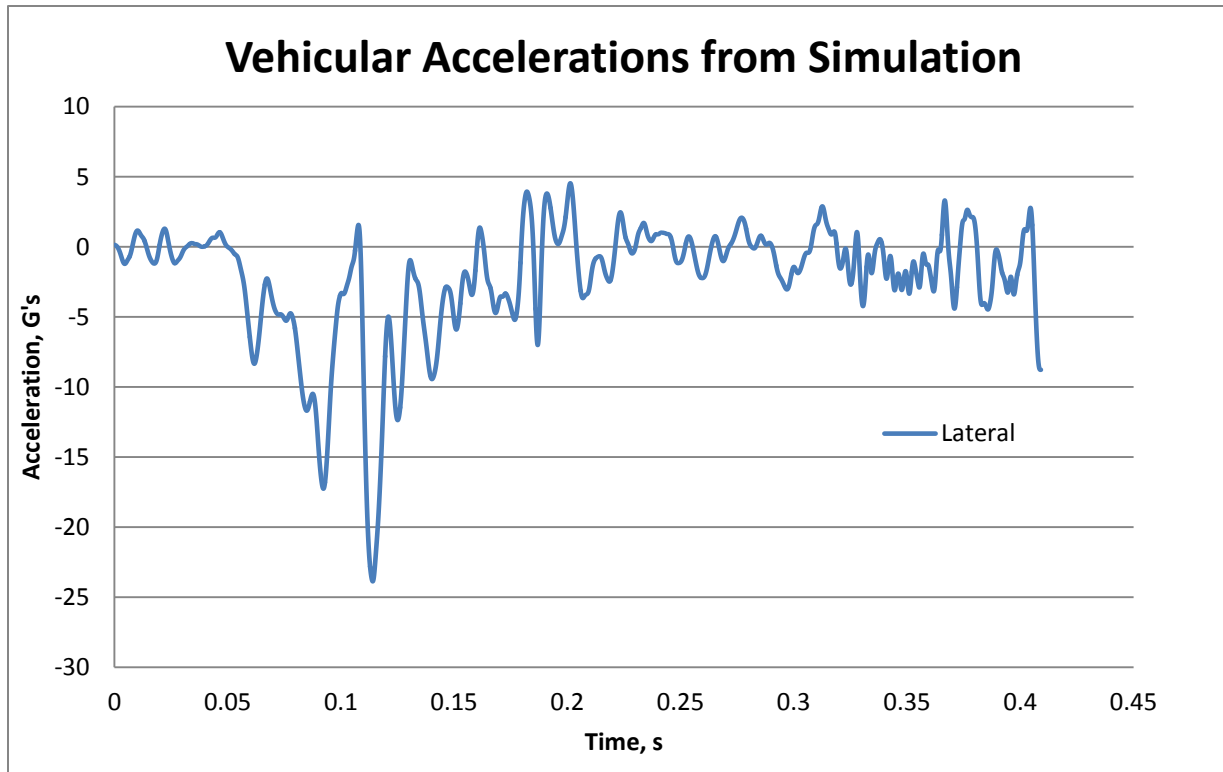
<b>Test No.</b>	<b>Max Lateral, g</b>
467114-6	26.8
467114-7	18.1

## **1.5 FINITE ELEMENT MODEL**

A finite element model of the short radius thrie beam transition section was modified to aid in quantifying the longitudinal forces experienced by the end shoe connector under design crash test conditions. The transition model was derived from the detailed finite element model of the short radius guardrail system that featured a validated guardrail and truck model. The model included the nested thrie beam transition section connected to a rigid parapet via an end shoe connector. The overall short radius system model upstream of the nested thrie beam transition was cut and replaced with end boundary springs at the free end to represent the stiffness of the rest of the system. An impact simulation was performed with a 2270P pickup truck model striking the transition model under the actual test conditions. Figure 1.11 shows a series of sequential images from the simulation. Two variations of the model were developed for evaluation: one with the original end shoe from the short radius model, and one featuring a scanned model of the modified end shoe developed under this project.



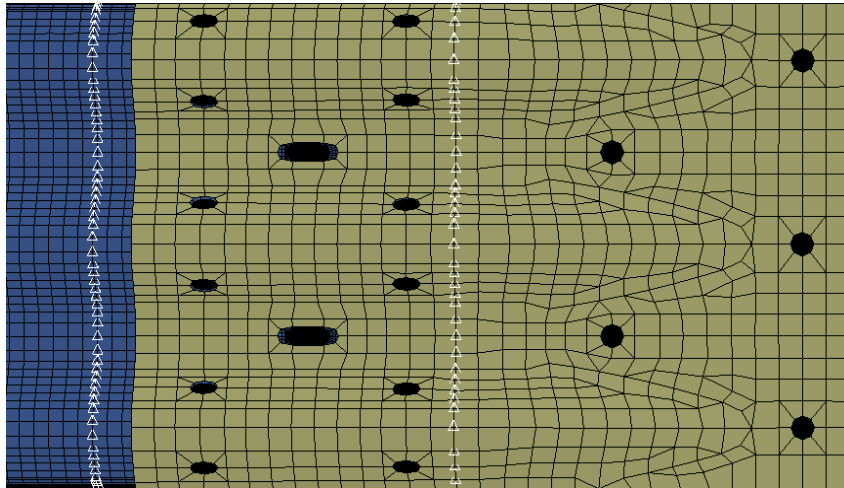
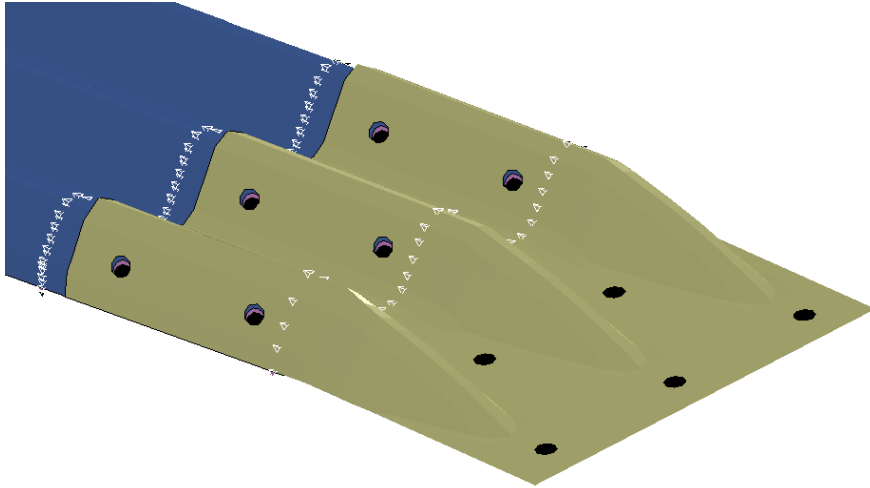
**Figure 1.11. Sequential Simulation Images.**



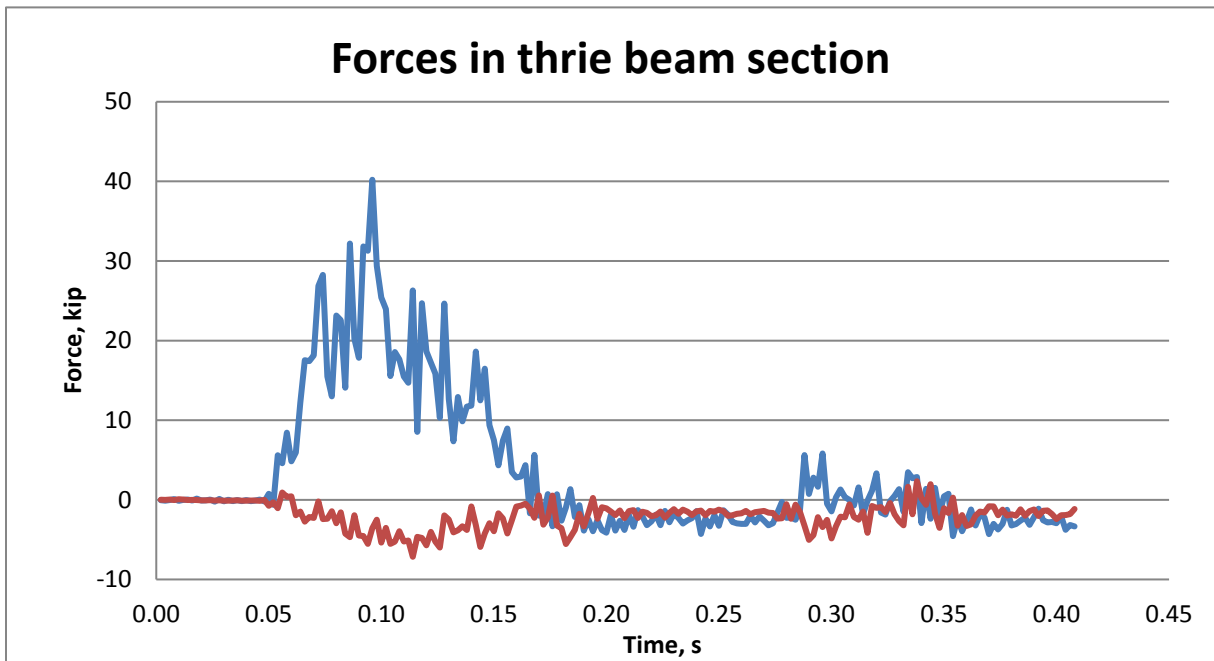
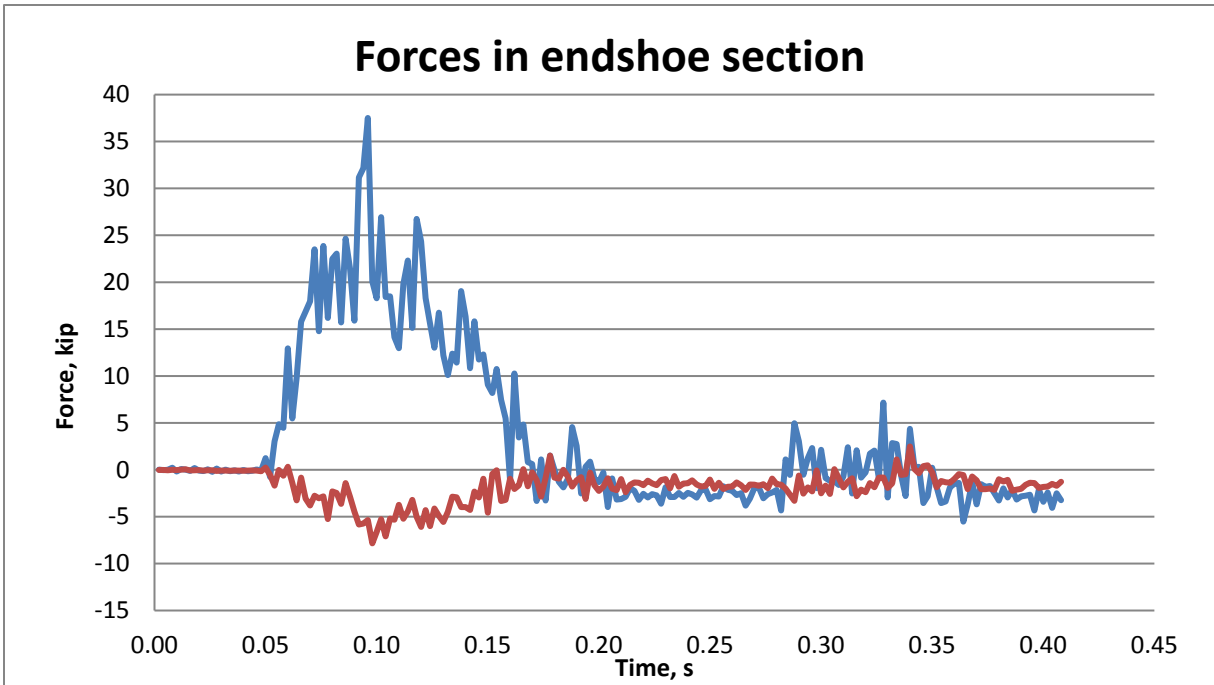
**Figure 1.12. Vehicular Acceleration from Short Transition Simulation.**

One of the advantages of using finite element modeling and simulation is that it allows for the examination of forces acting directly on the elements of the end shoe. This allows tracking of the force on these elements throughout the simulation. Cross-sections were defined through the end shoe part in the areas of interest, and forces were extracted at these cross-sections. Forces were obtained in both the parallel (along the length of the end shoe connector) and perpendicular (normal to the end shoe connector surface) directions. The resulting forces were filtered using an SAE class 60 filter. One cross-section was taken directly through the end shoe, and an additional cross-section was taken through the nested thrie beam rails for comparison. Figure 1.13 displays the cross-section locations evaluated in the original end shoe, and Figure 1.14 presents the forces obtained from the simulation. The max forces on the nested thrie beam section are three kips higher than in the end shoe. In all simulated cases, the vehicle impacted the transition 9.5 ft upstream of the end shoe, which corresponds to the critical impact point recommended in *MASH* for the system. The maximum forces captured in the impact simulations are:

- Maximum Parallel Force = 40.0 kip
- Maximum Perpendicular Force = 7.84 kip at 0.098 seconds



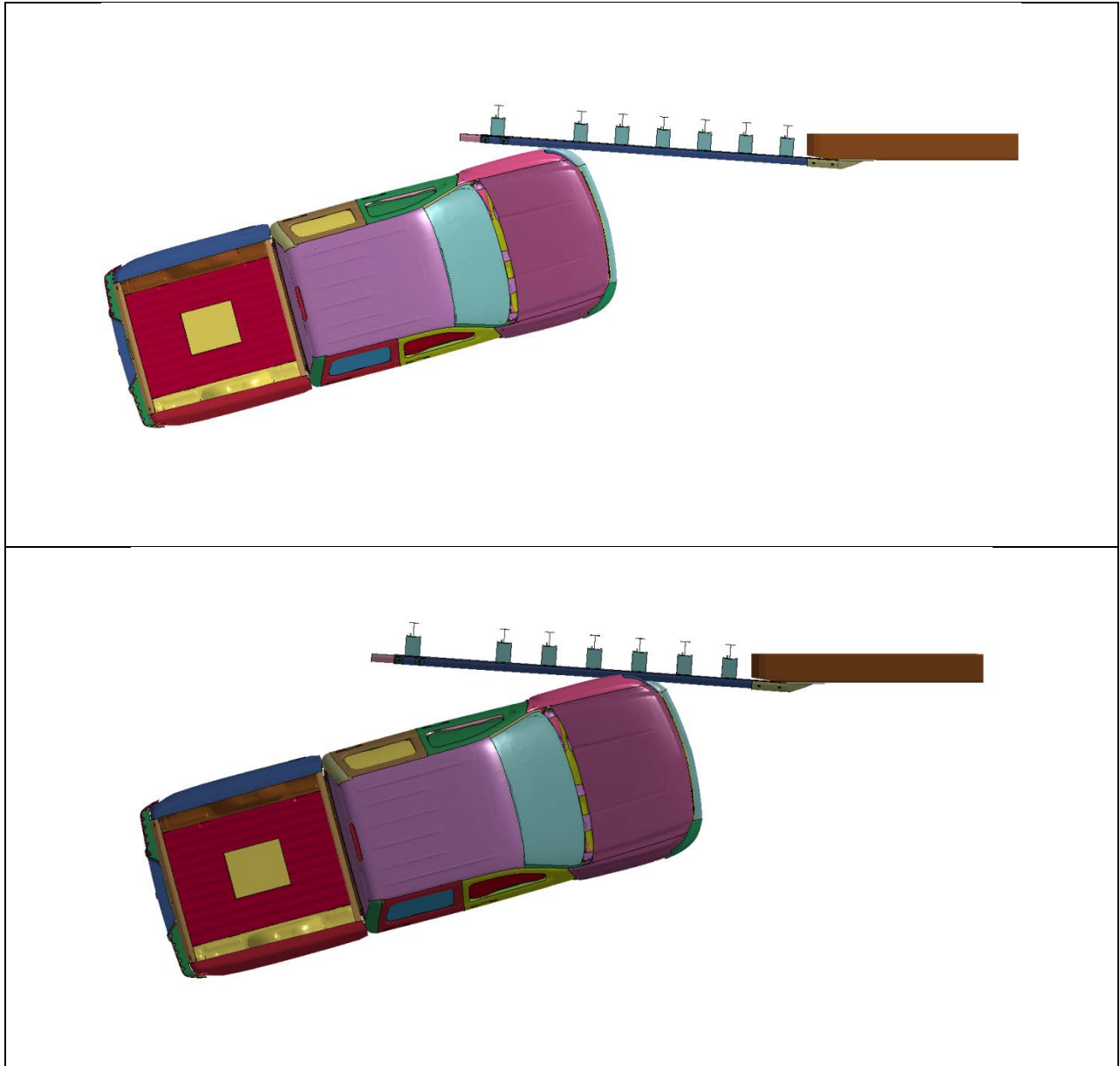
**Figure 1.13. Cross Sections Analyzed for End Shoe and Nested Thrie Beam.**



**Figure 1.14. Cross-Section Forces Obtained for Unmodified End Shoe.**

## 1.6 CHANGE OF IMPACT LOCATIONS

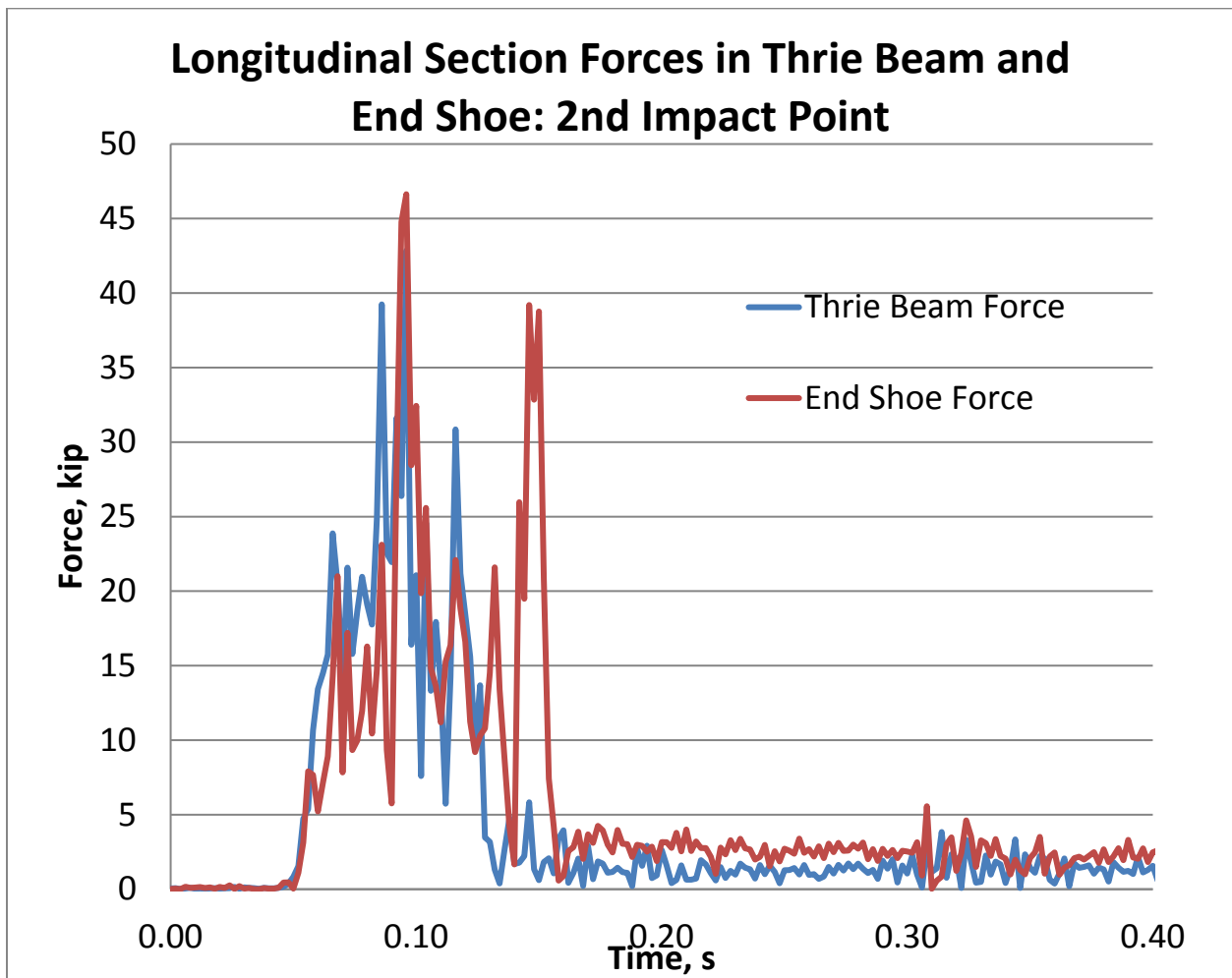
The research team investigated sensitivity of the longitudinal impact location on the maximum force applied to the end shoe. This involved moving the point of impact on the transition further downstream toward the end shoe connector as shown in the lower image of Figure 1.15.



**Figure 1.15. Two Impact Conditions Investigated Through Simulation.**



The simulated impact at the downstream impact location closer to the end shoe resulted in a higher axial forces in the nested thrie beams and end shoe connector. Figure 1.16 shows the time histories for these axial forces. The force-time history for the end shoe connector shows a second peak that is attributable to an edge contact of the vehicle with the end shoe. Based on these results, a design force was selected for the dynamic testing to demonstrate the structural adequacy of the modified end shoe connector design.



**Figure 1.16. Longitudinal Section Forces Measured at the Nested Thrie Beam Section and the End Shoe Connector Section for Downstream Impact Location.**



## CHAPTER 2: TEST PLAN

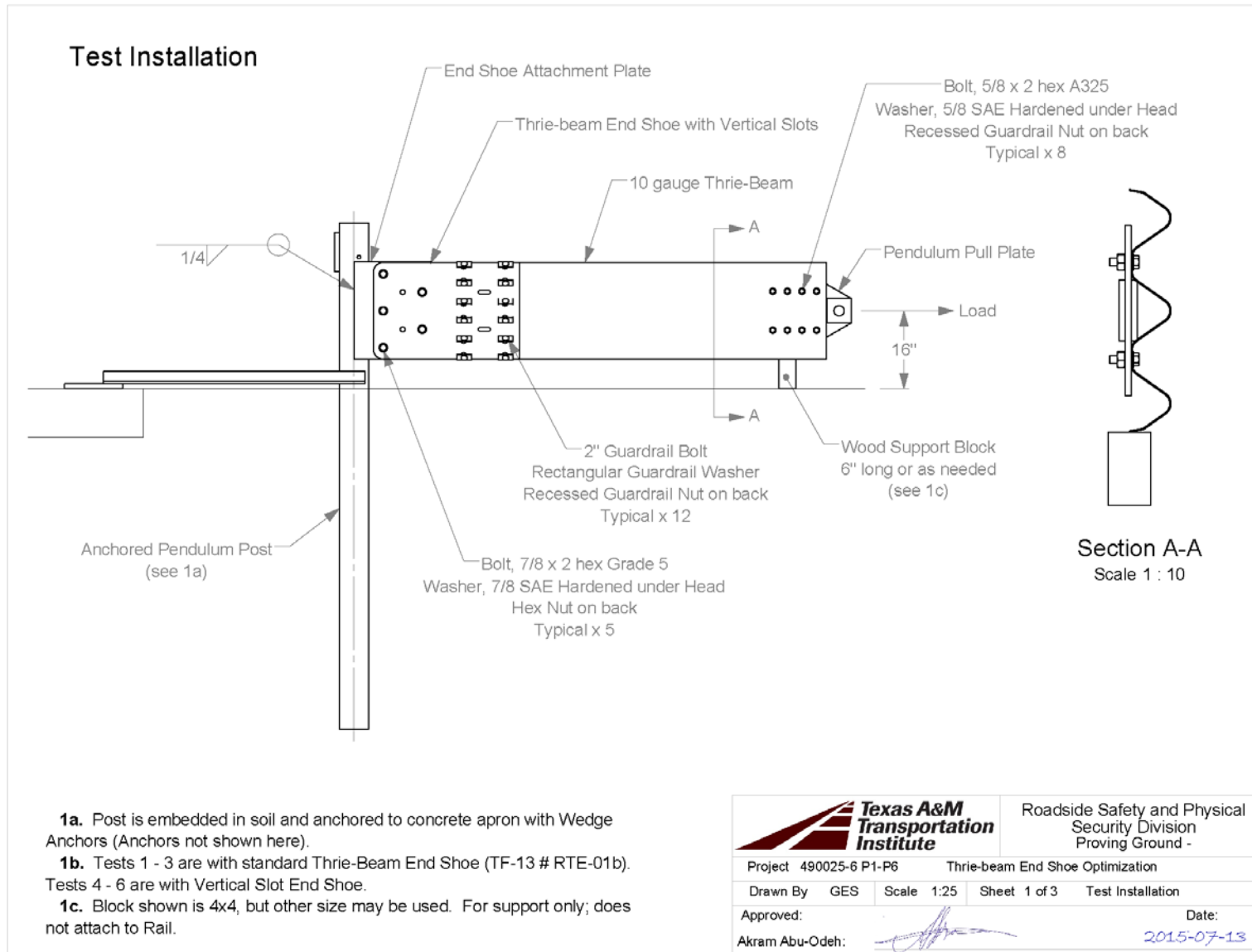
### 2.1 TEST ARTICLE DESIGN AND INSTALLATION DETAILS

The subject three beam end shoe was evaluated by dynamically loading a bolted connection between a 10-gauge end shoe and a section of 10-gauge three-beam (RTM-03b). Six tests were performed to assess the connection's performance when dynamically loaded/pulled in the axial direction by a 2062 lb pendulum bogie at a nominal speed of 20 mi/h. Figures 2.1 through 2.4 present details of the pendulum test setup.

The tested end shoes were anchored to a W6×25 post, which was embedded into compacted soil comprised of AASHTO M147-65 crushed limestone road base (compacted to 95 percent of standard proctor density American Society for Testing Materials (ASTM) D698) such that its top was 36 inches above grade. Two 2×3×<sup>3</sup>/<sub>16</sub>-inch angle ground struts, each 64 inches long, connected the W6×25 at grade to a 14-inch square × <sup>3</sup>/<sub>4</sub>-inch thick base plate, which was anchored to a concrete footing with six <sup>3</sup>/<sub>4</sub>-inch diameter embedded wedge anchors and bolts. The ground strut angles were welded to the inside of the W6×25 flanges and to the top of the base plate with <sup>1</sup>/<sub>4</sub>-inch fillet welds. The centerline of the post to the centerline of the base plate measured approximately 60 inches.

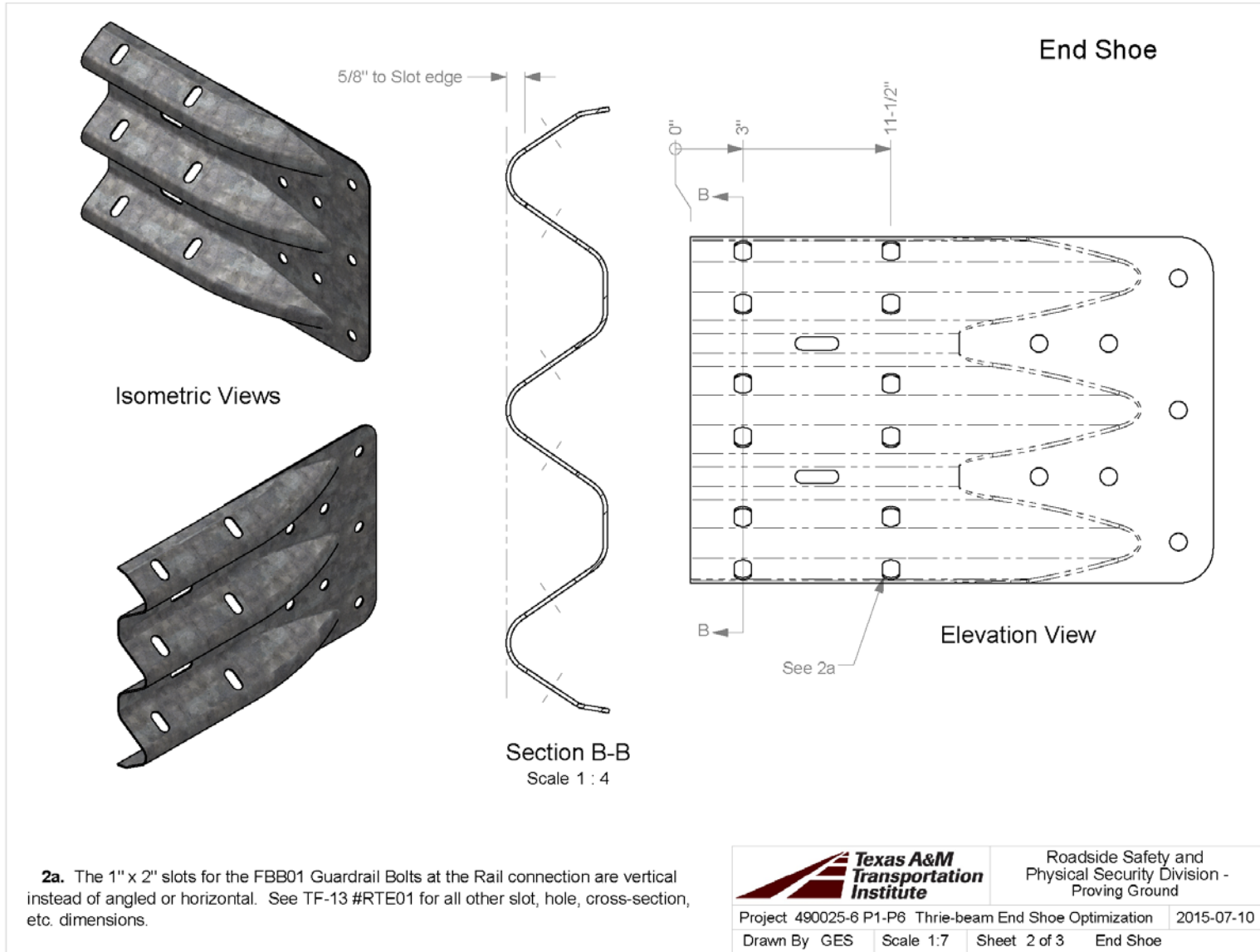
After Test No. 490025-6 P1, the W6×25 post was additionally reinforced. This reinforcement was comprised of two 3×3×<sup>1</sup>/<sub>2</sub>-inch angle knee braces, each 68 inches long, welded to the outside flanges of the W6×25 at 31<sup>1</sup>/<sub>2</sub> inches above grade, and to the base plate and ground struts.

Each end shoe was bolted to an attachment plate that was welded to the W6×25 post. The ASTM A36 attachment plate measured 20 inches tall × 16 inches wide × <sup>1</sup>/<sub>2</sub> inch thick, overlapped one flange of the W6×25 by 2<sup>1</sup>/<sub>2</sub> inches, and was fully welded to the W6×25 with a <sup>3</sup>/<sub>8</sub>-inch fillet weld. The attachment plate contained five 1-inch diameter holes: two located 2 inches from the edge and each 3<sup>13</sup>/<sub>16</sub>-inches off of the horizontal centerline, two located 10 inches from the edge and each 7<sup>9</sup>/<sub>16</sub> inches off of the horizontal centerline, and one located 10 inches from the edge and on the horizontal centerline. Each end shoe was bolted to the attachment plate with five <sup>7</sup>/<sub>8</sub>-inch diameter, 2-inch long grade 5 hex bolts, with SAE hardened washers under the heads and hex nuts. Photographs of a typical test installation and setup are shown in Figure 2.4



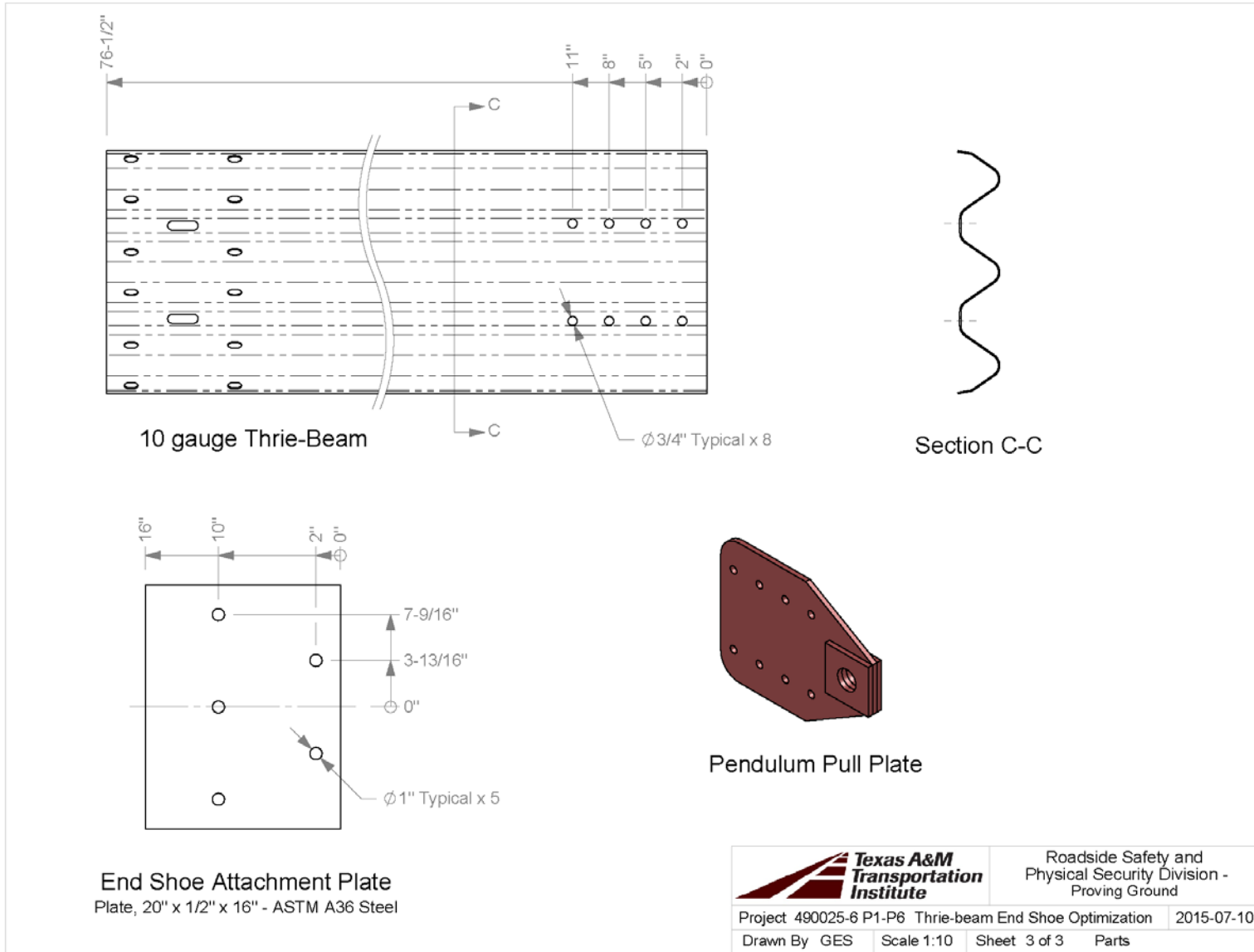
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**Figure 2.1. Test Installation Setup for Pendulum Testing.**



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Figure 2.2. End Shoe Details.



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Figure 2.3. Thrie Beam Attachment Details.



**Figure 2.4. End Shoe/Thrie Beam Test Setup.**

Each 6 ft-4½ inch long 10-gauge, thrie beam guardrail section was cut from a standard 3-space, 10-gauge thrie beam rail section (RTM-03b). One end of the thrie beam rail section contained a standard lap splice connection pattern consisting of twelve 1-inch wide × 1⅛-inch long slots oriented horizontally. Each thrie beam section was attached to a terminal end shoe using twelve ⅝-inch diameter, 2-inch long guardrail splice bolts (FBB01), rectangular guardrail washers under the bolt heads, and recessed guardrail nuts on the back. These splice bolts were arranged in two sets of six bolts on 8½-inch longitudinal centers.

The opposite end of the thrie beam had eight ¾-inch diameter holes that were used for attachment of the pendulum pull plate. The pendulum pull plate was connected to the thrie beam rail section using eight ⅝-inch diameter, 2-inch long ASTM A325 hex bolts, SAE hardened washers under the heads, and recessed guardrail nuts on the back. These bolts were arranged in four sets of two bolts on 3-inch longitudinal centers and 3<sup>13</sup>/<sub>16</sub>-inches off of the horizontal centerline.

The pendulum pull plate was a 17¾-inch long × 14-inch tall × ½-inch thick steel plate. One end of the plate was tapered and had a 2⅛-inch diameter hole for a shackle pin. The other end contained four sets of 1-inch diameter holes on 3-inch longitudinal centers and 3⅞-inches off of the horizontal centerline of the plate. The pendulum pull plate and the thrie beam were positioned horizontal to grade with the shackle pin hole centered 16 inches above grade. See Figures 2.1 and 2.3.

A 1-inch diameter wire rope with a clevis on each end connected the pendulum pull plate to either 1) an instrumented load cell that was attached to the pendulum, or 2) a custom tensile rod with 0.625 diameter × 1-inch long machined and polished frangible section (each rod was 10 inches long and cut from a single hardened 1½-inch diameter, 6 threads per inch, all-thread rod) that allowed a targeted 50,000 lb load on the test article. Refer to the test descriptions below for details of how each was used.

Figures 2.1 through 2.3 present details of the test installation setup, and Figure 2.4 provides photographs of the installation.

## **2.2 TEST NO. 490025-6 P1 END SHOE/THRIE BEAM CONNECTION DETAILS**

Test No. 490025-6 P1 was a pull/jerk test in the longitudinal direction wherein the test article was pulled by the pendulum bogie at a height of 16 inches above grade. This test utilized



a standard thrie beam end shoe (RTE-01b) containing twelve 1-inch wide × 3-inch long bolt slots oriented horizontally. For this test, the thrie beam was bolted to the back side of the end shoe. The height of the pendulum bogie upon release was 16.6 ft. An electronic load-cell was used to measure the applied force for Test No. 490025-6 P1, meaning that a load-limiting tensile rod was *not* used. This resulted in the pendulum bogie-to-load cell connecting pin being bent.

### **2.3 TEST NO. 490025-6 P2 END SHOE/THRIE BEAM CONNECTION DETAILS**

Test No. 490025-6 P2 was a pull/jerk test in the longitudinal direction wherein the test article was pulled by the pendulum bogie at a height of 16 inches above grade. As noted above, knee braces were added to the anchor post prior to this test. This test utilized a standard thrie beam end shoe (TF-13 #RTE-01b) containing twelve 1-inch wide × 3-inch long bolt slots oriented horizontally. For Test No. 490025-6 P2, the thrie beam was bolted to the back side of the end shoe. The height of the pendulum bogie upon release was 9 ft. For Test No. 490025-6 P2, neither the load-cell nor the tensile rod was employed. The cable clevis was directly pinned to the pendulum bogie.

### **2.4 TEST NO. 490025-6 P3 END SHOE/THRIE BEAM CONNECTION DETAILS**

Test No. 490025-6 P3 was a pull/jerk test in the longitudinal direction wherein the test article was yanked by the pendulum bogie at a height of 16 inches above grade. This test utilized a standard thrie beam end shoe (TF-13 #RTE-01b) containing twelve 1-inch wide × 3-inch long bolt slots oriented horizontally. For Test No. 490025-6 P3, the thrie beam was bolted to the front face of the end shoe. The height of the pendulum bogie upon release was 9 ft. For Test No. 490025-6 P3, a load-limiting tensile rod was used in lieu of the load cell in Test No. 490025-6 P1, and the rod severed under load as designed.

### **2.5 TEST NO. 490025-6 P4 END SHOE/THRIE BEAM CONNECTION DETAILS**

Test No. 490025-6 P4 was a pull/jerk test in the longitudinal direction wherein the test article was pulled by the pendulum bogie at a height of 16 inches above grade. This test utilized a modified thrie beam end shoe (similar to TF-13 #RTE-01b) that contained twelve 1-inch wide × 2-inch long bolt slots oriented *vertically*. For Test No. 490025-6 P4, the thrie-beam was bolted

to the back side of the end shoe. The height of the pendulum bogie upon release was 9 ft. A load-limiting tensile rod was used in lieu of the load cell, and the rod fractured under load as designed.

## **2.6 TEST NO. 490025-6 P5 END SHOE/THRIE BEAM CONNECTION DETAILS**

Test No. 490025-6 P5 was a pull/jerk test in the longitudinal direction wherein the test article was pulled by the pendulum bogie at a height of 16 inches above grade. This test utilized a modified thrie beam end shoe (similar to TF-13 #RTE-01b) that contained twelve 1-inch wide × 2-inch long bolt slots oriented vertically. For Test No. 490025-6 P5, the thrie beam was bolted to the front face of the end shoe. The height of the pendulum bogie upon release was 9 ft. A load-limiting tensile rod was used in lieu of the load cell, and the rod fractured under load as designed.

## **2.7 TEST NO. 490025-6 P6 END SHOE/THRIE BEAM CONNECTION DETAILS**

Test No. 490025-6 P6 was a pull/jerk test in the longitudinal direction wherein the test article was pulled by the pendulum bogie at a height of 16 inches above grade. This test utilized a modified thrie beam end shoe (similar to TF-13 #RTE-01b) that contained twelve 1-inch wide × 2-inch long bolt slots oriented vertically. For Test No. 490025-6 P6, the thrie beam was bolted to the back side of the end shoe. The height of the pendulum bogie upon release was 9 ft. Again for Test No. 490025-6 P6, a load-limiting tensile rod was used in lieu of the load cell, and the rod fractured under load as designed.

## **CHAPTER 3: TEST CONDITIONS**

### **3.1 TEST FACILITY**

The pendulum tests reported herein were performed at Texas A&M Transportation Institute (TTI) Proving Ground, an International Standards Organization (ISO) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing certificate 2821.01. The pendulum tests were performed according to TTI Proving Ground Quality System Procedure (QSP 5.4.20), and according to National Cooperative Highway Research Program (NCHRP) *Report 350* guidelines and standards.

The TTI Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons that are well-suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware.

### **3.2 PENDULUM FACILITY**

The end shoe/thrie beam connections were tested at the TTI outdoor pendulum testing facility. The pendulum bogie, built according the specifications of the Federal Outdoor Impact Laboratory's (FOIL) pendulum, and the testing area are shown in the adjacent figure. The end shoes were installed such that the pendulum jerked/pulled on the thrie beam and end shoe at a prescribed speed dictated by the height of the pendulum. A brief description of the testing procedures follows.

### **3.3 DATA ACQUISITION SYSTEMS**

#### **3.3.1 Electronic Instrumentation and Data Processing**

The pendulum was instrumented with two accelerometers mounted at the rear of the pendulum to measure longitudinal acceleration levels. The accelerometers were strain gage type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers were amplified and transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals were recorded before and after the test and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive switches on the nose of the bogie were actuated by wooden dowel rods and initial contact to produce speed trap and “event” marks on the data record to establish the exact instant of contact with the installation, as well as impact velocity.

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto TEAC® instrumentation data recorder. After the test, the data are played back from the TEAC® recorder and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R-cal and pre-zero values at 10,000 samples per second, per channel. WinDigit also provides Society of Automotive Engineers (SAE) J211 class 180 phaseless digital filtering and bogie impact velocity.

The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities and the highest 10-ms average ridedown acceleration. WinDigit calculates change in bogie velocity at the end of a given impulse period. In addition, maximum average accelerations over 50 ms are computed.

### **3.3.2 Photographic Instrumentation and Data Processing**

A high-speed digital camera, positioned perpendicular to the path of the bogie and the test article, was used to record the test period. The film from this high-speed camera was analyzed on a computer to observe phenomena occurring during the test and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras were used to document the pendulum nose and the end shoe/thrie beam connections before and after the test.

## CHAPTER 4: PENDULUM TESTING

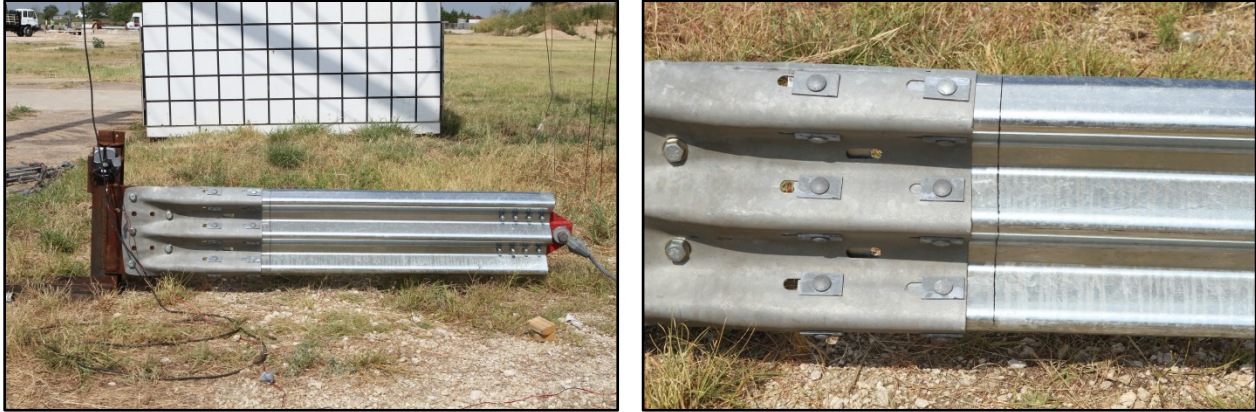
### 4.1 TEST NO. 490025-6 P1

Figure 4.1 shows the testing setup. The pendulum pulled on the thrie beam attached to the end shoe while traveling at 21.1 mi/h. Figure 4.2 shows the end shoe and thrie beam after Test No. 490025-6 P1. The thrie beam was pulled 1¾ inches and the anchor post rotated slightly and was leaning 1 degree downstream.

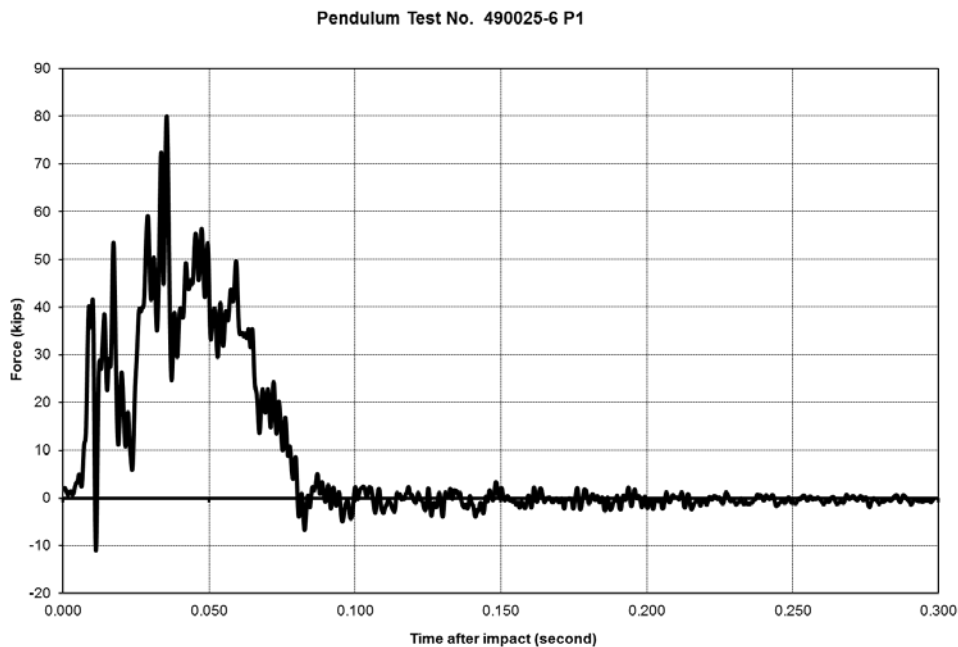
Maximum longitudinal 0.010-second (10-ms) average acceleration was -13.0 G, and the maximum 0.050-second (50-ms) average acceleration was -18.8 G. Peak force was 80.0 kips and maximum 10-ms average force was 51.7 kips. Figure 4.3 shows the force versus time trace for Test No. 490025-6 P1.



Figure 4.1. End Shoe before Test No. 490025-6 P1.



**Figure 4.2. End Shoe after Test No. 490025-6 P1.**



**Figure 4.3. Force Trace for Test No. 490025-P1.**

#### **4.2 TEST NO. 490025-6 P2**

Figure 4.4 shows the test setup. The pendulum pulled on the thrie beam attached to the end shoe while traveling at 17.3 mi/h. The thrie beam was pulled  $1\frac{5}{8}$  inches and the concrete failed around the anchor post. Figure 4.5 shows the end shoe and thrie beam after Test No. 490025-6 P2.

Maximum longitudinal 10-ms average acceleration was  $-30.7$  G, and the maximum 50-ms average acceleration was  $-18.0$  G. Peak force was 106.4 kips and maximum 10-ms average force was 63.5 kips. Figure 4.6 shows the force versus time trace for Test No. 490025-6 P2.

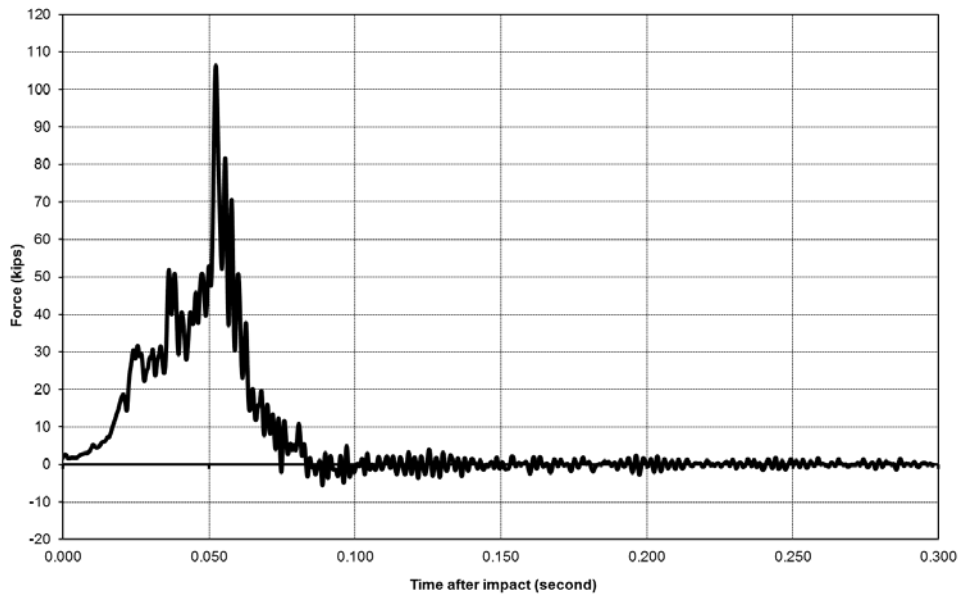


**Figure 4.4. End Shoe before Test No. 490025-6 P2.**



**Figure 4.5. End Shoe after Test No. 490025-6 P2.**

Pendulum Test No. 490025-6 P2

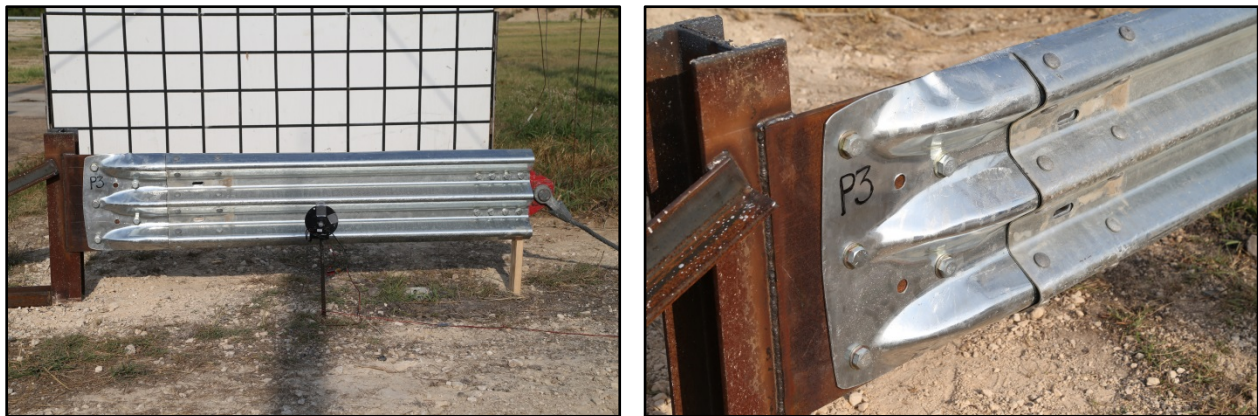


**Figure 4.6. Force Trace for Test No. 490025-6 P2.**

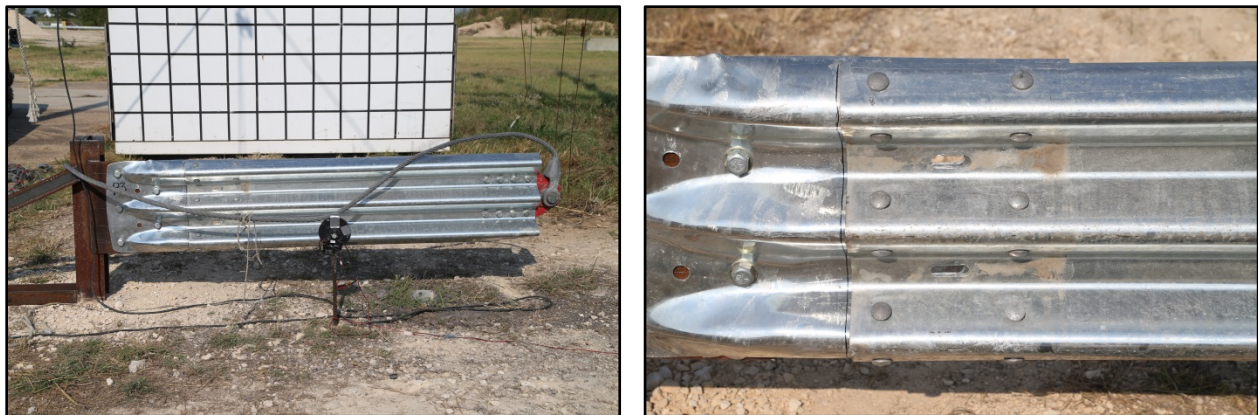
### 4.3 TEST NO. 490025-6 P3

Figure 4.7 shows the testing setup. The pendulum pulled on the thrie beam attached to the end shoe while traveling at 19.9 mi/h. Figure 4.8 shows the end shoe and thrie beam after Test No. 490025-6 P3. The thrie beam was pulled ½ inch and the in-line shear pin attached to the pendulum fractured and limited the applied force as designed.

Longitudinal 10-ms average acceleration was  $-14.6G$ , and longitudinal 50-ms average acceleration was  $-2.1 G$ . Peak force was 58.6 kips and maximum 10-ms average force was 30.5 kips. Figure 4.9 shows the force versus time trace for Test No. 490025-6 P3.

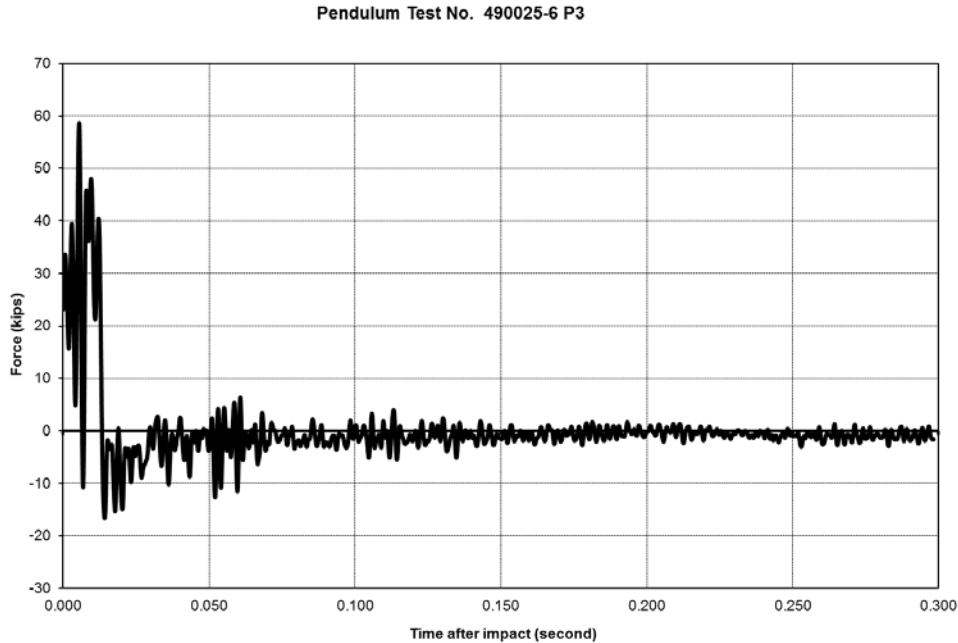


**Figure 4.7. End Shoe before Test No. 490025-6 P3.**



**Figure 4.8. End Shoe after Test No. 490025-6 P3.**





**Figure 4.9. Force Trace for Test No. 490025-6 P3.**

#### **5.4 TEST NO. 490025-6 P4**

A modified thrie beam end shoe with bolt slots oriented *vertically* and bolted to the back side of the end shoe was used for Test No. 490025-6 P4. Figure 4.10 shows the testing setup. The pendulum pulled on the thrie beam attached to the end shoe while traveling at 19.9 mi/h. The thrie beam was pulled  $\frac{3}{8}$  inch at the top rib and  $\frac{1}{2}$  inch at the middle and bottom rib. Figure 4.11 shows the end shoe and thrie beam after Test No. 490025-6 P4. The shear pin attached to the pendulum fractured as designed.

Maximum longitudinal 10-ms average acceleration was  $-13.6$  G, and maximum 50-ms average acceleration was  $-1.8$  G. Peak force was 62.7 kips and maximum 10-ms average force was 28.2 kips. Figure 4.12 shows the force versus time trace for Test No. 490025-6 P4.

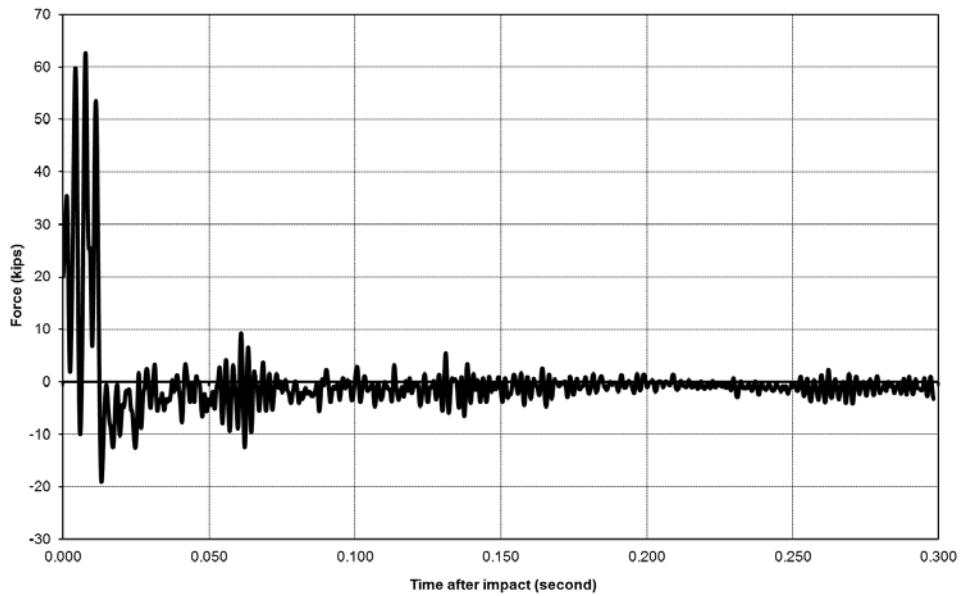


**Figure 4.10. End Shoe before Test No. 490025-6 P4.**



**Figure 4.11. End Shoe after Test No. 490025-6 P4.**

Pendulum Test No. 490025-6 P4

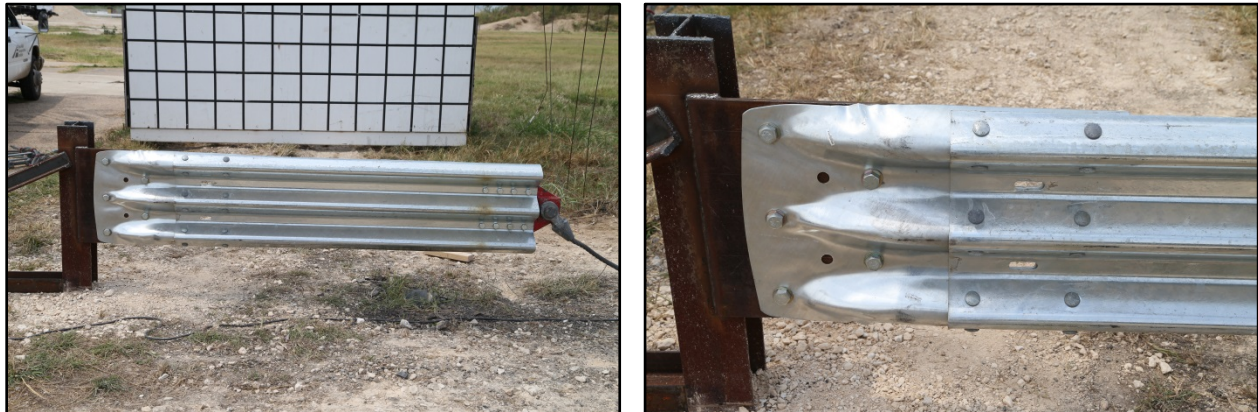


**Figure 4.12. Force Trace for Test No. 490025-6 P4.**

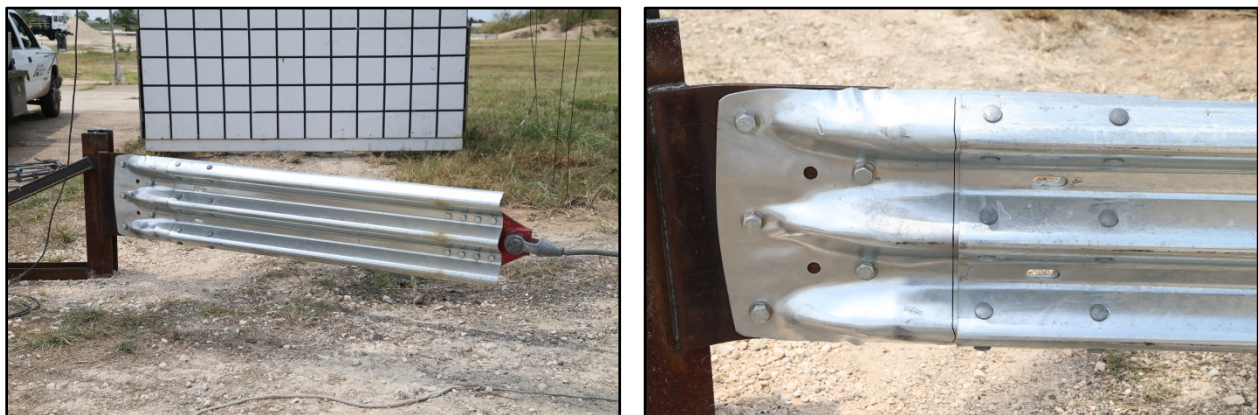
#### 4.5 TEST NO. 490025-6 P5

A modified thrie beam end shoe with bolt slots oriented vertically and bolted to the front face of the end shoe was used for Test No. 490025-6 P5. Figure 4.13 shows the testing setup. The pendulum pulled on the thrie beam attached to the end shoe while traveling at 20.0 mi/h. Figure 4.14 shows the end shoe and thrie beam after Test No. 490025-6 P5. The thrie beam was pulled  $\frac{3}{8}$  inch at the top rib and  $\frac{5}{16}$  inch at the middle and bottom rib. The shear pin attached to the pendulum fractured as designed.

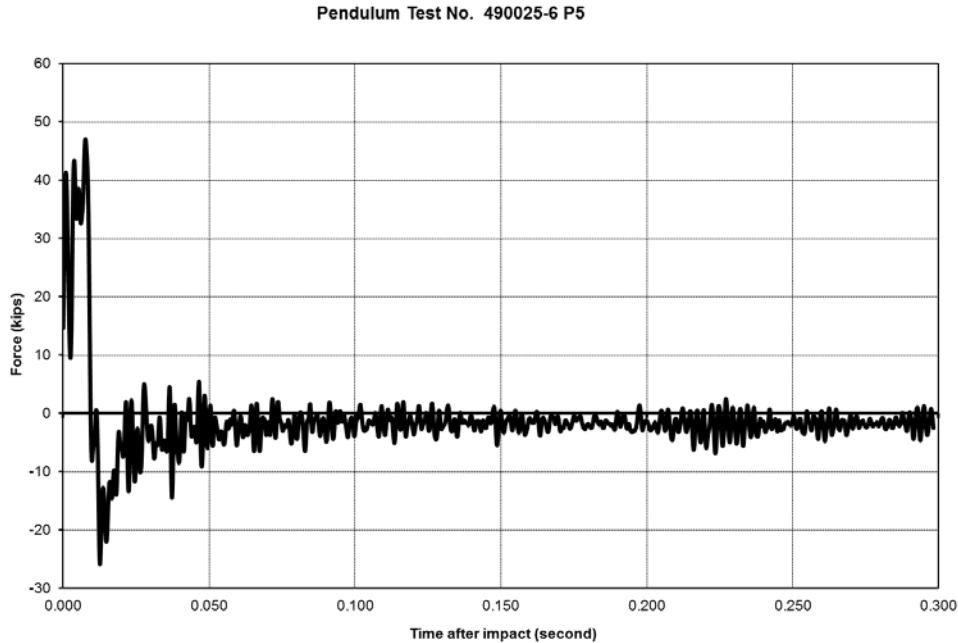
Maximum longitudinal 10-ms average acceleration was  $-13.6$  G, and maximum 50-ms average acceleration was  $2.5$  G. Peak force was  $47.0$  kips and maximum 10-ms average force was  $30.0$  kips. Figure 4.15 shows the force versus time trace for Test No. 490025-6 P5.



**Figure 4.13. End Shoe before Test No. 490025-6 P5.**



**Figure 4.14. End Shoe after Test No. 490025-6 P5.**



**Figure 4.15. Force Trace for Test No. 490025-6 P5.**

### **5.6 TEST NO. 490025-6 P6**

A modified thrie beam end shoe with bolt slots oriented vertically and bolted to the back side of the end shoe was used. Figure 4.16 shows the testing setup. The pendulum pulled on the thrie beam attached to the end shoe while traveling at 20.0 mi/h. Figure 4.17 shows the end shoe and thrie beam after Test No. 490025-6 P6. The thrie beam was pulled ½ inch at the top rib and ⅜ inch at the middle and bottom rib. The shear pin attached to the pendulum fractured as designed.

Maximum longitudinal 10-ms average acceleration was -17.9 G, and maximum 50-ms average acceleration was -4.9 G. Peak force was 79.6 kips and maximum 10-ms average force was 37.1 kips. Figure 4.18 shows the force versus time trace for Test No. 490025-6 P6.

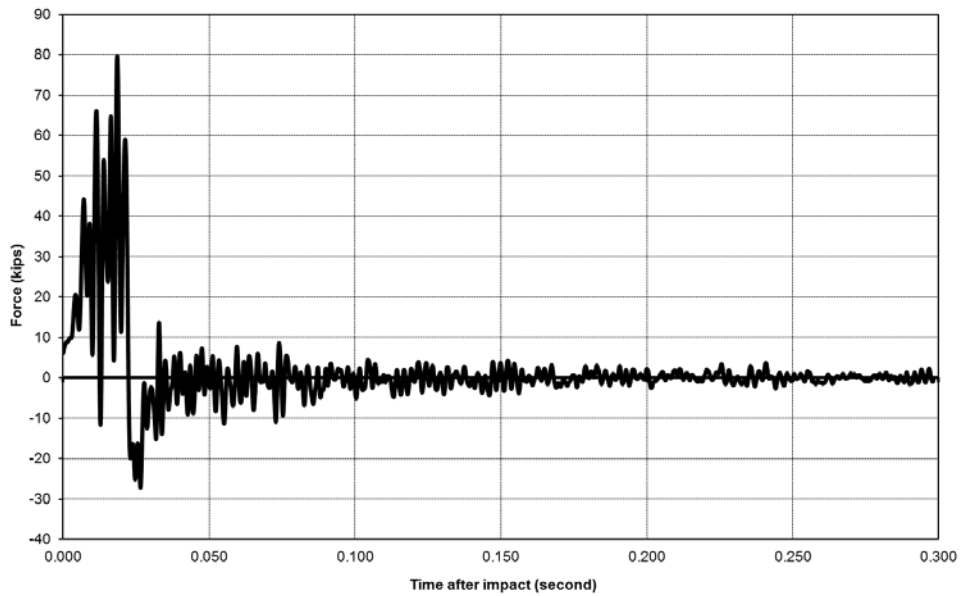


**Figure 4.16. End Shoe before Test No. 490025-6 P6.**



**Figure 4.17. End Shoe after Test No. 490025-6 P6.**

Pendulum Test No. 490025-6 P6



**Figure 4.18. Force Trace for Test No. 490025-6 P6.**



## **CHAPTER 5: SUMMARY AND CONCLUSIONS**

### **5.1 SUMMARY OF RESULTS**

The research team performed finite element impact simulations to determine the maximum axial force carried by a thrie beam end connector in a transition crash test. The scenario that was modeled was a nested thrie beam transition connected to a concrete parapet using a thrie beam end connector. The nested thrie beam transition rail was flared away from the roadway, thus increasing the effective impact angle and representing a more severe lateral impact condition that would generate a higher axial load in the transition rail and thrie beam end connector. MASH Test 3-21 was simulated to obtain the impact loads in the thrie beam end connector. The MASH 2270P pickup truck impacted the thrie beam at a nominal speed of 62 mi/h and an effective impact angle of 29 degrees. The location of the impact was varied along the transition to obtain the highest axial force in the thrie beam end connector. The highest axial force obtained in the thrie beam connector was 45 kips.

Six pendulum pull tests were conducted on a standard thrie beam end shoe connector and on a newly design end shoe connector with a vertical slots. These tests were meant to demonstrate equivalency of the new end shoe connector design in terms of withstanding axial design forces arising from vehicular impacts into transition sections. All of these tests were conducted at speeds that generated a pull force that met or exceeded the 45 kip design axial force obtained from the impact simulations. The new end shoe connector design performed well and showed no signs of damage or any performance issues in any of the tested cases.

### **5.2 CONCLUSIONS**

The new end shoe connector design with vertical slots performed satisfactorily when subjected to axial impact forces higher than the design impact loads associated with TL-3 impact conditions for a transition. This new end shoe design had a demonstrated capacity 186 percent greater than the transition design load determined through finite element impact simulation. The manufacturing process for this new end shoe connector should not be any different from the manufacturing process of the current end show connector design. The holes and slots are punched on a flat steel blank and then the punched steel blank sheet is cold formed into the end

shoe connector shape. Hence, the modified end shoe design can be readily fabricated and should not significantly affect the manufacturing process or cost.



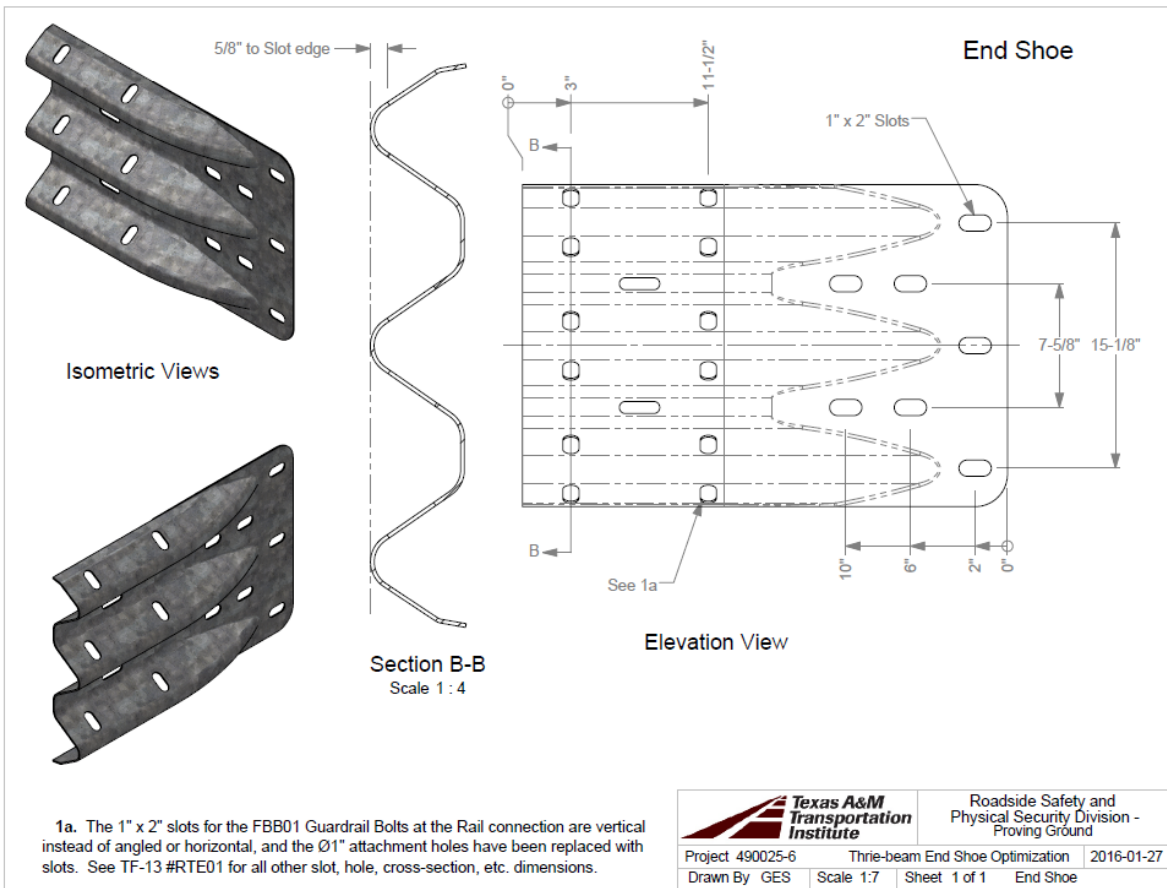
## **CHAPTER 6. IMPLEMENTATION PLAN**

The modified end shoe connector with vertical slots that was tested under this project used circular holes in the flat portion of the thrie beam end shoe that was connected to the load frame. This was done to provide a tighter connection that would have less slippage and, therefore, produce higher loads in the terminal connector.

In practice, some level of construction tolerance is preferred to facilitate field assembly. Since the vertical slots do not provide longitudinal construction tolerance, it is recommended that horizontal slots (rather than circular holes) be used in the flat portion of the terminal connector that connects the thrie beam end shoe to the bridge rail parapet. Use of the horizontal slots on the flat region of the connector will allow for field construction tolerance without changing the function or performance of the end shoe connector.

Figure 6.1 shows details of the design that is recommended for implementation. It incorporates 2-inch vertical slots to improve attachment of the end shoe connector with nested thrie beam rail, and 2-in wide horizontal slots on the flat area of the end shoe connector to provide field construction tolerance.

Use of this new end shoe connector should eliminate the need for field modification of the thrie beam rail while still maintaining field construction tolerance. The cost of the new end shoe connector should be comparable to the existing design.



T:\11-ProjectFiles\490025-TXDOT\6 End Shoe Optimization\Drafting\End Shoe Drawing - Jan2016

**Figure 6.1. Recommended End Shoe Design.**

## REFERENCES

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2. AASHTO. *Manual for Assessing Roadside Safety Hardware*. 2009, American Association of State Highway and Transportation Officials: Washington, D.C.

