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16. Abstract

The T6 tubular W-beam bridge rail has seen widespread use across the state of Texas. However, because it was unable to satisfy Test Level 3 (TL-3) impact performance requirements of *NCHRP Report 350*, it is no longer eligible for use on high-speed roadways. A new flexible bridge rail system, referred to herein as the T8 rail, has been designed for use on culverts and thin deck structures as a replacement for the T6 rail in high-speed applications.

The T8 rail incorporates a tubular thrie beam rail element. Use of a tubular thrie beam provides additional rail height to improve stability for light truck vehicles, reduced clear opening to minimize the potential for vehicle underride, and a standard rail shape for ease of transitioning to approach guardrail. The anchor bolt pattern or "footprint" for the T8 post is the same as that used for the T6 post. This facilitates upgrade of existing T6 installations.

Finite element impact simulations were conducted to evaluate the performance of the new tubular thrie beam bridge rail. The simulations indicated that the T8 rail should be capable of meeting TL-3 impact conditions of *NCHRP Report 350*. It is recommended that full-scale crash testing be conducted to verify the impact performance of the T8 bridge rail. Details of the recommended T8 bridge rail system are included in the report.

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ANALYSIS OF A FLEXIBLE BRIDGE RAIL SYSTEM FOR HIGH-SPEED ROADWAYS

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This research project was conducted under a cooperative program between the Texas Transportation Institute, the Texas Department of Transportation, and the Federal Highway Administration. The TxDOT program coordinator and project director for this research was Rory Meza, P.E. (Design Division). John Holt, P.E. (Bridge Division), Jon Ries (Bridge Division), Mark Steves, P.E. (Bridge Division), Bobby Dye (Design Division), Chris Hehr, P.E. (Design Division), and Duane Browning, P.E. (BMT) served on the project advisory committee and helped guide this research. The authors acknowledge and appreciate their assistance.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Since its original development in 1978, the Texas Type T6 bridge rail system has been widely used as a bridge rail in Texas *(1)*. A typical T-6 bridge rail installation is shown in Figure 1.1. The system was specifically designed for use on culverts and thin bridge decks. A breakaway mechanism incorporated into the posts helps minimize the transfer of forces to the concrete deck, thus reducing the extent of damage to the deck.

Figure 1.1. T-6 Bridge Rail System.

Primary components include a tubular W-beam rail element and W6×9 steel posts welded to baseplates, which are bolted to the deck. The tubular rail is fabricated by welding two standard 12-gauge W-beams back to back using a 6-inch long intermittent skip weld. The two beam sections are also staggered 1.25 ft in order to accommodate a bolted lap splice connection. The rail is mounted on the standard W6×9 posts spaced 6.25 ft on center with a 5/8-inch diameter button head bolt. A pipe sleeve is used between the tubular rail and post.

The baseplates to which the support posts are attached are anchored into or bolted through the concrete deck. The original breakaway post connection was accomplished by completely welding the tension flange, only slightly welding the inside of the compression flange, and providing no welds on the web. The T6 system was originally tested under *Transportation Research Circular 191* and was later judged to be acceptable under *National Cooperative Highway Research Program (NCHRP) Report 230 (2,3)*. This certification required full-scale crash testing of two scenarios: a 4500-lb passenger vehicle impacting at 25 degrees traveling at 60 mi/h, and a 2250-lb passenger vehicle impacting at 15 degrees traveling at 60 mi/h.

With the adoption of *NCHRP Report 350*, a re-evaluation of the T6 bridge rail was necessary to determine if it could accommodate the pickup truck design vehicle. Test Level Three (TL-3) of *NCHRP Report 350* includes a test of a 4409-lb pickup truck impacting the rail at 62 mi/h and 25 degrees *(4)*. In the first full-scale crash test (Test No. 418048-2) of the T6 bridge rail system, which followed the impact conditions of *NCHRP Report 350* test designation 3-11, the T6 system did not perform satisfactorily *(5)*. Although the bridge rail contained and redirected the pickup truck, the pickup truck eventually rolled onto its left side as it exited the installation. Static load tests on posts taken from the prototype rail installation showed that the capacity of the breakaway weld exceeded the plastic moment of the post. Consequently, rupture of the post flange occurred before failure of the baseplate weld. The lack of a reliable breakaway mechanism led to undesired wheel snagging on several posts, which likely contributed to the vehicle instability.

A series of static tests and dynamic pendulum tests was subsequently conducted to assist with evaluation of a revised post-to-baseplate connection. The objective was to reduce the capacity of the connection by inducing controlled failure of the welds rather than requiring rupture of the post flange. Findings of this study resulted in a revised weld detail shown in Figure 1.2 *(6)*. The primary difference was the reduction of the fillet weld on the front flange from a two-sided to a single-sided configuration.

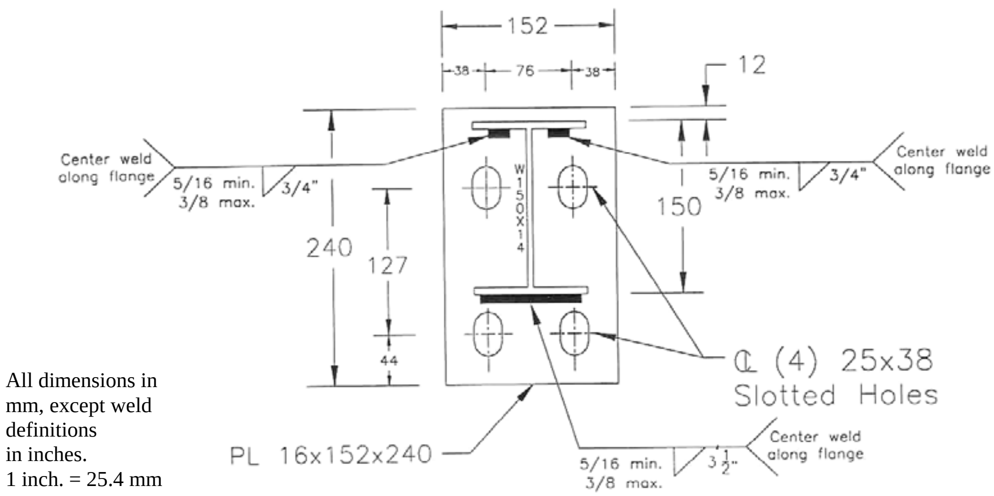


Figure 1.2. Modified Weld Detail for the T-6 Breakaway Post.

A second full-scale crash test (Test No. 418048-3) was conducted on a T6 rail that incorporated this modification *(7)*. Results of this test were also unsatisfactory. Analysis of the test results revealed that the weak-axis strength of the modified post-to-baseplate connection was inadequate. Consequently, the longitudinal rail forces applied to the posts through the post bolts led to premature breakaway of a large number of posts both upstream and downstream from the impacting vehicle. The associated loss in rail stiffness subsequently led to large rail deflections, which permitted the impacting vehicle to extend completely off of and drop below the bridge deck.

In response to this identified issue, a third breakaway post concept was conceived and incorporated into the T6 design. Details of this new post connection are shown in Figure 1.3 and Figure 1.4. The front flange of the post was fully welded to the baseplate to achieve improved weak axis capacity. The strong-axis capacity was controlled through the introduction of slots in the front flange of the post (see Figure 1.4). A backup plate was welded to the field side of the back flange to facilitate failure of the two welds on the back flange and permit complete release of the post from the baseplate. The size and thickness of the baseplate were increased to help distribute the impact load into the deck and further reduce deck damage. A photograph of the new post connection is shown in Figure 1.5.

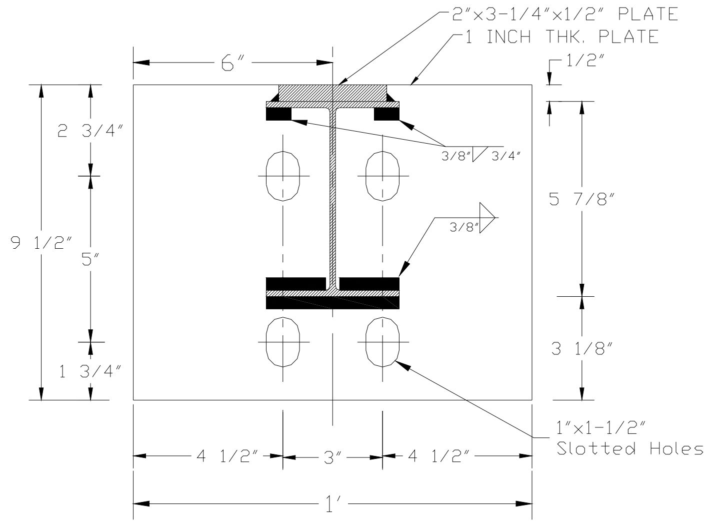


Figure 1.3. Revised Breakaway Connection for the T-6 Post.

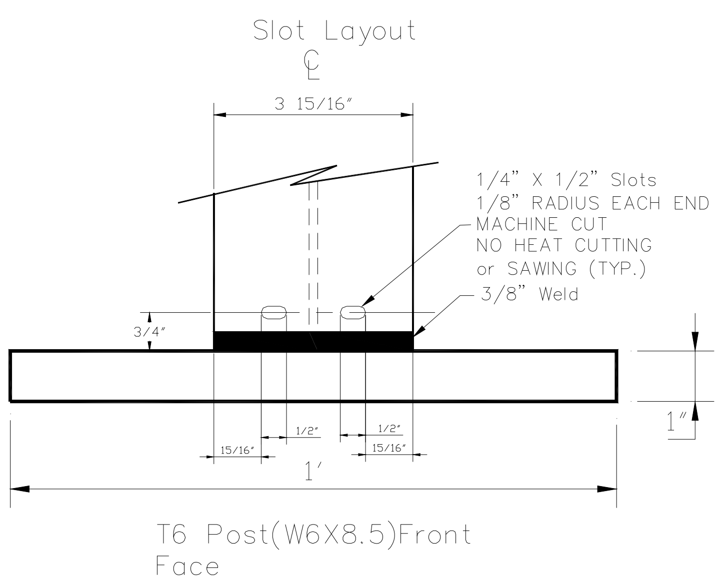


Figure 1.4. Slots Details on the Front (Tension) Flange.

Figure 1.5. New Post Connection Design.

The T6 bridge rail with revised breakaway connection was evaluated in a third full-scale crash test (Test No. 418048-12) *(8)*. The revised post connection performed as designed and eliminated the wheel snagging and excessive deflections observed in the previous tests. However, after being contained and redirected, the pickup truck test vehicle rolled as it exited the barrier. In the absence of wheel snagging, the researchers were able to conclude that there was a basic height incompatibility between the vehicle and rail system. The force imparted to the vehicle from the rail was below the center of gravity (C.G.) of the pickup truck and induced a roll moment that resulted in the instability. Further research was needed to develop a TL-3 bridge rail system suitable for use on thin deck structures.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this research is to develop a flexible bridge rail system suitable for use on culverts and thin deck structures. The rail system is intended as a replacement for the TxDOT Type T6 rail. The design should be capable of meeting the impact performance requirements of *NCHRP Report 350* TL-3 and should limit deck damage to avoid extensive and costly repairs after an impact. It is preferable that the rail be capable of serving as a direct retrofit for existing T6 rail installations and be fabricated from readily available or easily fabricated parts.

The design and development of the new bridge rail system consisted of engineering analysis, dynamic pendulum testing, and finite element modeling and simulation. This report documents the development process and presents recommended design details for the new bridge rail. The full-scale crash testing of the system will be performed under separate contract.

CHAPTER 2. FINITE ANALYSIS OF T6 BRIDGE RAIL

It is desirable to calibrate and/or validate a finite element model to the extent existing data and resources will allow prior to using the model in a finite element crash simulation to predict impact performance. Initial modeling efforts therefore focused on modeling and validation of the T6 bridge rail system. Once validated, the model can be used to evaluate various design modifications to the T6 bridge rail. The objective is to develop a breakaway bridge rail system similar to the T6 rail suitable for use on high-speed roadways.

The T6 bridge rail was originally modeled under a previous research project (0-1804). The model was updated under the current effort to reflect updates in the LS-DYNA analysis code and advancements in modeling techniques.

COMPONENT TESTING AND SIMULATION

A key component of the T6 bridge rail is the breakaway support post. The posts are designed to breakaway or release from their baseplates at a prescribed level of force to prevent vehicle snagging and minimize damage to the underlying deck structure. Considerable effort was devoted to modeling the breakaway post in order to improve the accuracy of the system model.

Two dynamic pendulum tests were conducted to evaluate the behavior of the T6 post and provide data for calibration of a finite element model of the post. One test was conducted about the strong axis of the post and the other about the weak axis of the post. The gravitational pendulum was outfitted with a crushable honeycomb nose assembly that simulates the frontal crush stiffness of a small passenger car. The pendulum was instrumented with a uniaxial accelerometer. The impact speed for the pendulum tests was nominally 22 mi/h.

Figure 2.1 and Figure 2.2 show results of the tests about the strong and weak axes of the post, respectively. Note that during the strong-axis impact (Figure 2.1), the post completely breaks away from the baseplate, as designed. In the weak axis direction, the post hinges and does not release (Figure 2.2). This is the desired weak-axis behavior to resist longitudinal rail forces imparted to the posts through the post connection bolts.

The corresponding finite element model of the post is depicted in Figure 2.3. The post model was calibrated against the pendulum test data prior to being incorporated into the model of the T6 bridge rail system. This was accomplished by simulating the dynamic pendulum tests. The results of the simulated pendulum tests about the strong and weak axes of the post are depicted in Figures 2.4 and 2.5, respectively. As can be seen in these figures, the model captured the general physical behavior of the post observed in the pendulum tests.

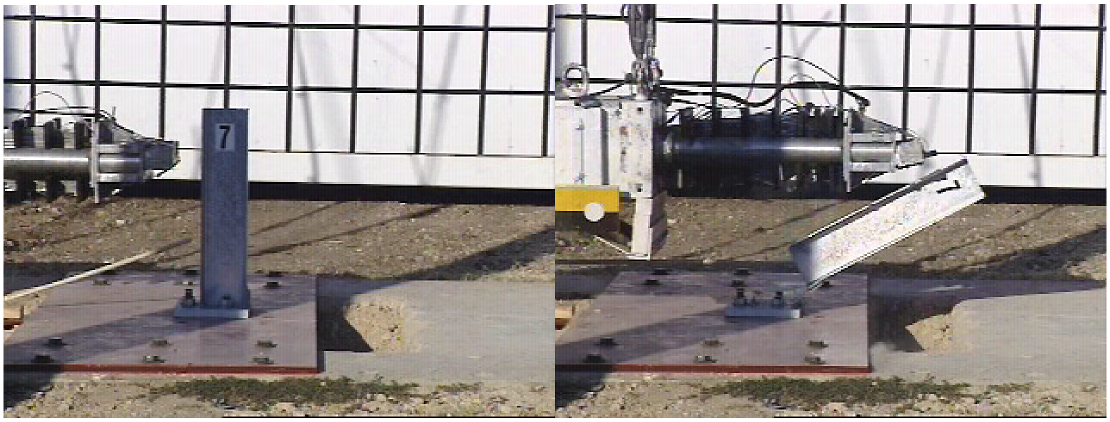


Figure 2.1. Strong Axis Pendulum Test of T6 Breakaway Post.

Figure 2.2. Weak Axis Pendulum Test of T6 Breakaway Post.

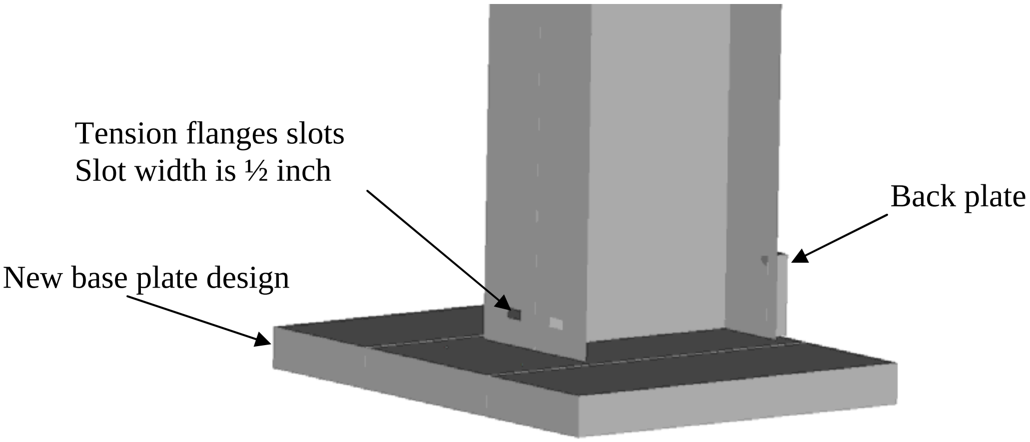


Figure 2.3. Finite Element Model of T6 Breakaway Post.

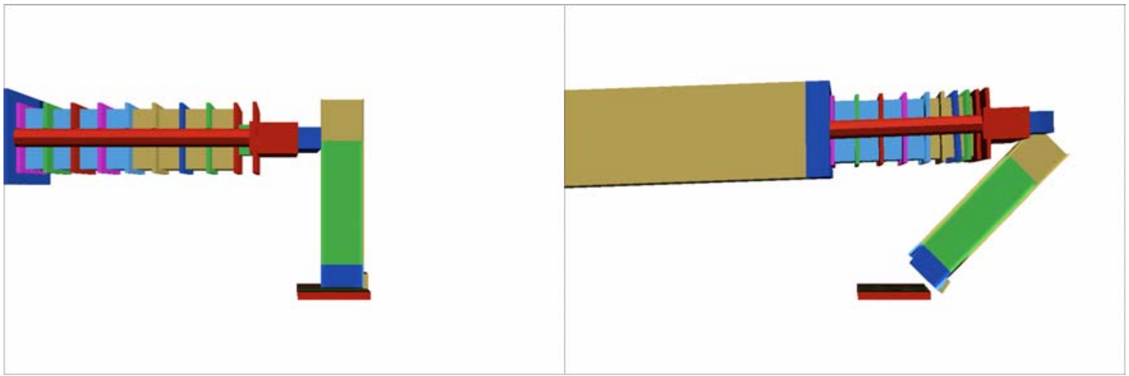


Figure 2.4. Simulation of Pendulum Impact about Strong Axis of Post.

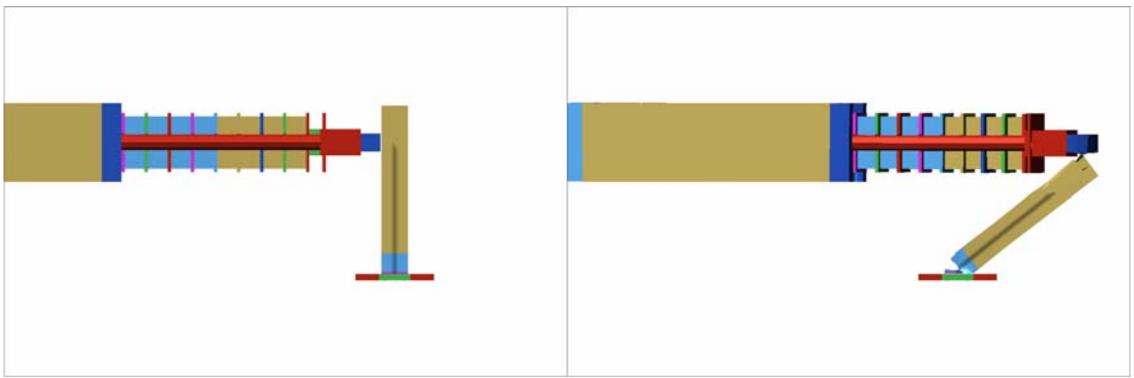


Figure 2.5. Simulation of Pendulum Impact about Weak Axis of Post.

The measured acceleration signals from the pendulum tests were compared to those obtained from the LS-DYNA simulations. The comparison for the strong and weak axes impacts are shown in Figure 2.6 and Figure 2.7, respectively. The correlation achieved between the test and simulation data was considered sufficient to proceed with the modeling and simulation of the T6 bridge rail system.

UPDATED IMPACT SIMULATION OF T6 BRIDGE RAIL

Although simulation of the T6 bridge rail system was performed in a previous study (0-1804), the system model was revisited to verify that recent releases of the LS-DYNA software and newer versions of the C2500 pickup truck vehicle model did not affect the validity of the model. Livermore Software Technology Corporation (LSTC) is continually enhancing the LS-DYNA analysis code, and the 2007 production version of LS-DYNA incorporates significant changes and improvements over the production release in the 1998-1999 time period. More importantly, the public domain vehicle models have been updated and enhanced over the years to reflect input from the roadside safety community.

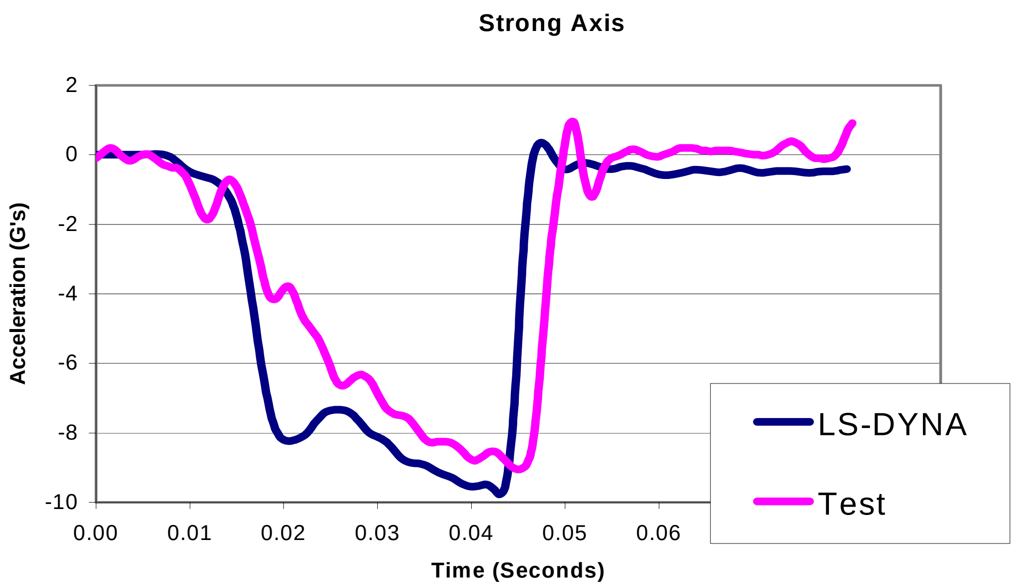


Figure 2.6. Acceleration Signal for Strong Axis Post Test.

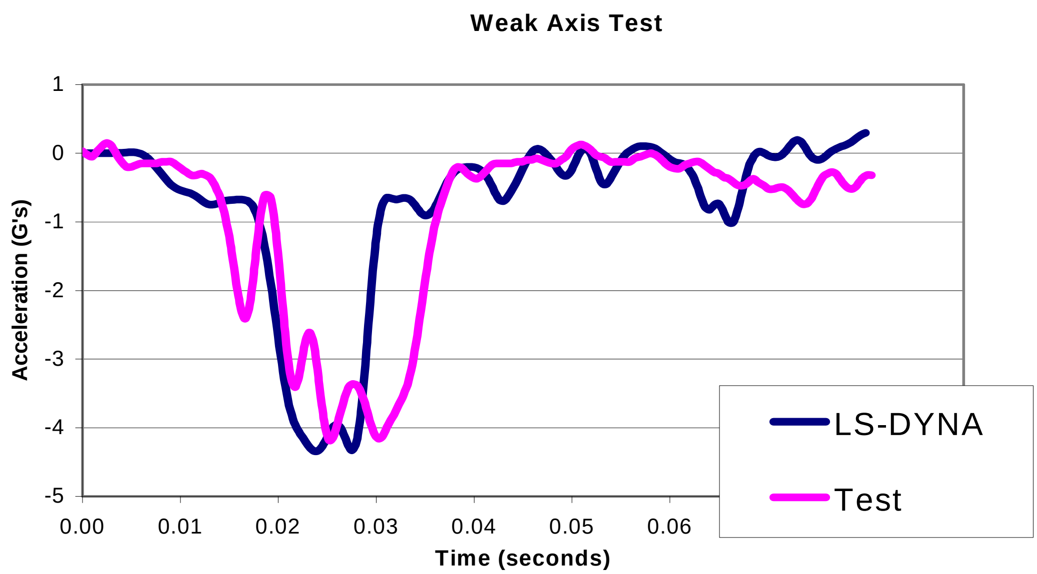


Figure 2.7. Acceleration Signal for Weak Axis Post Test.

The original T6 simulation was performed in 1999 using the reduced version (approximately 14,000 elements) of the C2500 pick truck model developed by the National Crash Analysis Center (NCAC) under sponsorship of the Federal Highway Administration (FHWA). The vehicle model used for this phase of the study is the detailed version of the C2500 pickup truck, which has approximately 62,000 elements. Images of both the reduced and detailed C2500 pickup truck models are shown in Figure 2.8. While the detailed version of the truck is more finely meshed throughout, most of the additional elements are located across the front end of the truck.

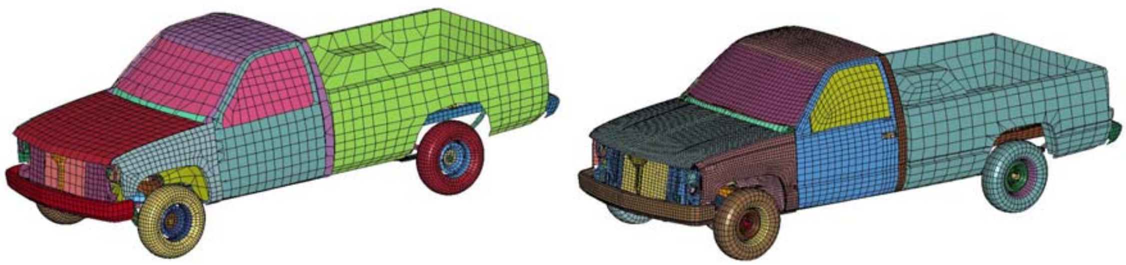


Figure 2.8. Reduced (Left) and Detailed (Right) Versions of the C2500 Truck Model.

After incorporating the updated breakaway post model and performing other miscellaneous updates to the system model, a new impact simulation was conducted using the latest release of LS-DYNA nonlinear finite element code. The detailed pickup truck model impacted the T6 bridge rail at a nominal speed of 62 mi/h and a nominal angle of 25 degrees in conformance with the impact performance requirements of *NCHRP Report 350* Test Level 3.

A visual comparison between the simulation and full-scale crash test of the revised T6 bridge rail system (Test No. 418048-12) is sequentially shown with respect to time in Figure 2.9 through Figure 2.12. The simulation and test show reasonable agreement through 500 ms, and the resulting instability of the impacting pickup truck is evident. Table 2.1 presents selected metrics for additional comparison between the simulation and crash test. The agreement, while not exact, was considered to be sufficient to use the updated T6 system model to evaluate design alternatives. The primary goal was to develop a design that mitigated the vehicle instability observed in the full-scale crash test and could be used on thin deck structures with minimal damage to the deck after impact.

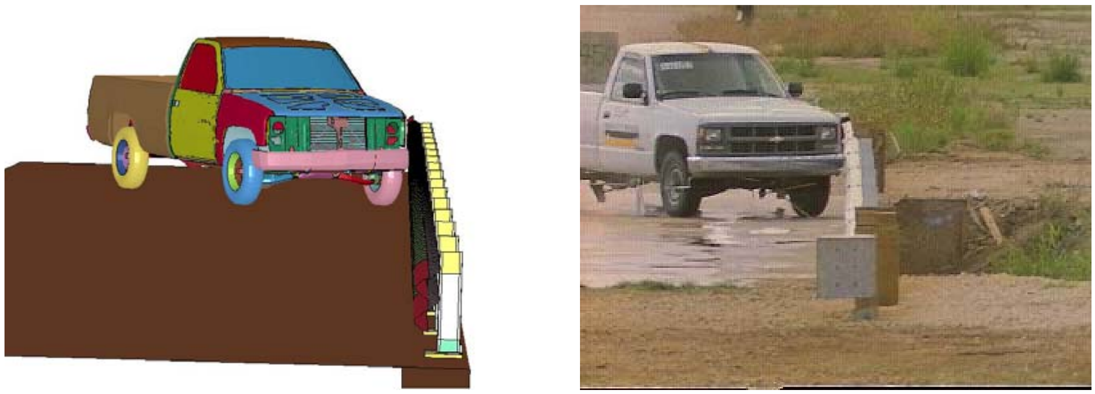


Figure 2.9. Test and Updated T6 Simulation at 0.000 Seconds.

Figure 2.10. Test and Updated T6 Simulation at 0.060 Seconds.

Figure 2.11. Test and Updated T6 Simulation at 0.300 Seconds.

Figure 2.12. Test and Updated T6 Simulation at 0.493 Seconds.

Table 2.1. Comparison of Full-Scale Crash Test and Updated T6 Simulation with Detailed C2500 Truck.

	Crash Test 418048-12	**Updated T6 Simulation**
Maximum dynamic rail deflection	3.0 ft	2.43 ft
Maximum static rail deflection	2.6 ft	1.9 ft
Number of posts broken	5	4
Backslap time	0.247 sec	0.252 sec
Exit conditions		
Speed	40.3 mph	43.6 mph
Angle (deg)	27.7	15

CHAPTER 3. DEVELOPMENT OF THE T8 BRIDGE RAIL CONCEPT

Given the unsuccessful impact performance of the T-6 tubular W-beam bridge rail with the new breakaway post design, TTI engineers investigated changes to the system to enhance its performance. As mentioned previously, the research team linked the instability of the vehicle (i.e., rollover) to the height of the rail system. It was concluded that the impact force imparted to the vehicle from the tubular W-beam rail was below the C.G. of the pickup truck and induced a roll moment that resulted in the instability. It was theorized that increasing the rail height of the system would increase the height of the resultant impact exerted upon the vehicle and thereby improve the performance of the system in terms of vehicle stability.

Design options considered included raising the tubular W-beam rail element, using multiple rail elements of another type (e.g., tubular steel), and using a tubular thrie beam rail. Raising the height of the tubular W-beam rail element a sufficient amount to stabilize the pickup truck might require the use of a rub rail or secondary rail member to limit the underride potential for small cars associated with the increased clear opening beneath the rail. Similar to more conventional bridge rail systems, the number and size of tubular steel rails required to provide the necessary height, contact surface area, and clear openings to contain and redirect vehicles of various sizes could be determined. However, the use of multiple steel tube rails would require a more complex transition to the standard approach guardrail. Use of a tubular thrie beam offered additional rail height to improve stability for light truck vehicles, reduced clear opening to minimize the potential for vehicle underride, and a standard rail shape for ease of transitioning to approach guardrail. Since vehicle underride is eliminated as an issue, use of a tubular thrie beam rail removes the need to conduct further evaluation with the 820C design vehicle of *NCHRP Report 350*.

Therefore, in consultation with TxDOT personnel, the design alternative selected for further evaluation through finite element modeling and simulation was a tubular thrie-beam rail mounted on breakaway steel posts. A tubular thrie beam rail element is depicted in Figure 3.1. As with the tubular W-beam rail, the tubular thrie beam rail consists of welding the free edges of two standard thrie beam sections in a back-to-back fashion to create a tubular section that has significantly increased flexural and torsional strength.

The typical mounting height of thrie-beam rail is 31 inches compared to 27 inches for a W-beam rail. The thrie-beam rail section is 20 inches deep compared to the 12¼ inch deep W-beam rail section. This places the bottom of the tubular thrie beam 11 inches from the bridge deck compared to approximately 15 inches for the tubular W-beam. The connection of the tubular thrie-beam rail to the breakaway posts consisted of one 5/8-inch diameter button-head bolt through the upper of the two post bolt slots in the thrie beam section. As with the T6 rail, a pipe sleeve was used to bridge the gap between the valley of the tubular thrie beam and the flange of the support post.

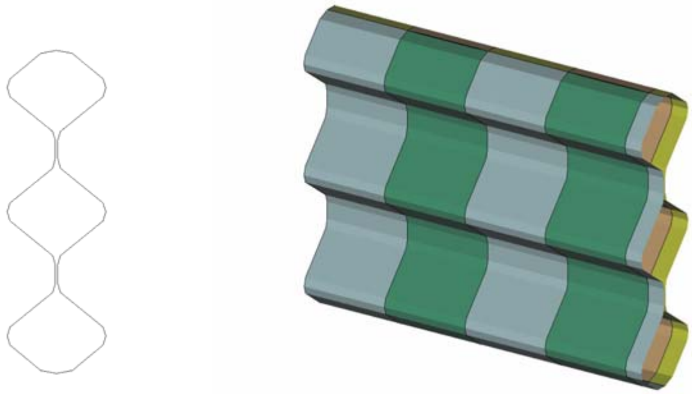


Figure 3.1. Tubular Thrie-Beam Rail Section.

SIMULATION OF THE T8 SYSTEM USING THE T6 POST

The coin termed for the new bridge rail system under investigation was the T8. It was anticipated that the impact loading applied by the impacting vehicle on the taller tubular thrie beam rail would occur at a higher position than on the tubular W-beam rail. This would induce greater bending moment in the posts that, in turn, would result in more posts breaking away from their baseplates. However, prior to adjusting the strength of the breakaway post, an impact simulation was conducted on a tubular thrie beam system that incorporated the T6 post. This analysis provides a more direct comparison of the effect of rail height on the stability of the pickup truck. Therefore, in the initial simulation of the T8, the post detail was left unchanged (i.e., ½-inch slots in the tension flange of the post) rather than increased in height to accommodate the taller rail.

Figure 3.2 shows sequential images for the TL-3 impact simulation of a 2000-kg pickup truck with the T8 tubular thrie beam rail system. As expected, more posts broke away in the simulation of the tubular thrie-beam (7 posts) than in the tubular W-beam simulation (4 posts). The vehicle was much more stable and exhibited a relatively small maximum roll angle of approximately 20 degrees.

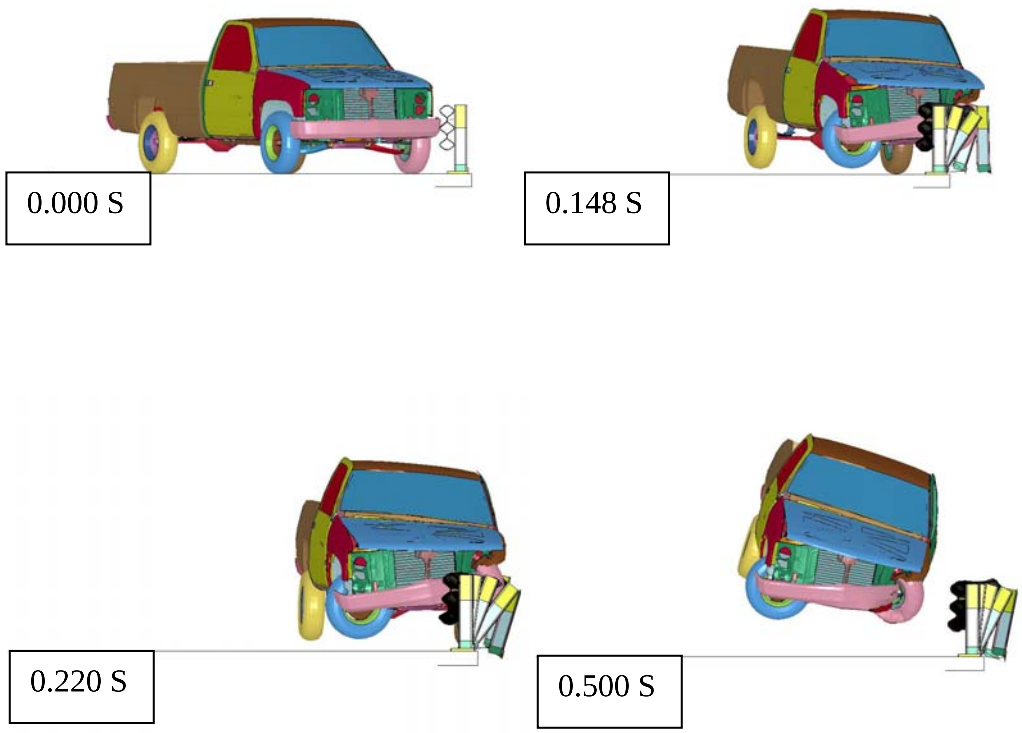


Figure 3.2. Sequential Images of Initial Tubular Thrie Beam Impact Simulation.

CHAPTER 4. DYNAMIC IMPACT TESTING OF T8 POST

The results of the initial impact simulation demonstrated the feasibility of the T8 concept. To further explore the applicability of the T8 to thin deck structures, additional dynamic-impact testing was conducted on the breakaway support posts. The objective was to determine the optimal post configuration for use on decks as thin as 6.5 inches having a concrete compressive strength of 3000 psi.

PENDULUM FACILITY AND TEST PROCEDURES

Variations of the T6/T8 breakaway post were tested at the Texas Transportation Institute (TTI) outdoor pendulum testing facility shown in Figure 4.1. The pendulum bogie is built according to the specifications of the Federal Outdoor Impact Laboratory (FOIL) pendulum. Cartridges of expendable aluminum honeycomb material of differing densities are placed in a reusable sliding nose assembly. The crushable nose configuration used in the breakaway post testing is the FOIL ten stage bogie nose, which has been calibrated to simulate the front crush stiffness of a small passenger car. Further details of the crushable nose assembly are presented in Appendix A. After each test, the honeycomb material was replaced and the bogie was reused.

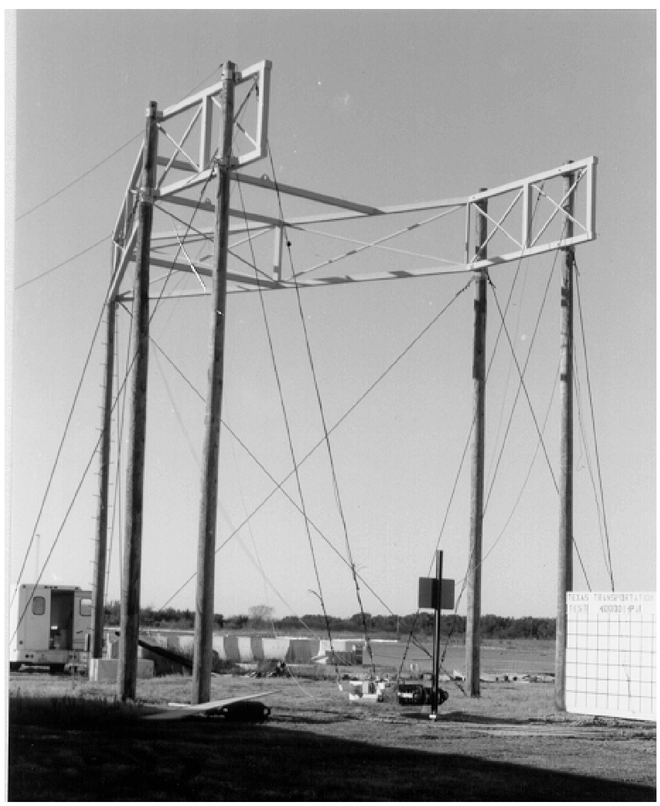


Figure 4.1. TTI Outdoor Pendulum Test Facility.

The pendulum bogie was equipped with a pair of uniaxial accelerometers to obtain acceleration versus time data for the impact event from which force-displacement data for the post can be derived. The pendulum was raised in a circular arc to a height required to achieve the desired nominal impact speed of 22 mi/h. The pendulum impacted the breakaway posts about their strong axes at a height of 21 inches above the ground, which is the height to the center of the tubular thrie beam rail. Testing was performed in accordance with *NCHRP Report 350*, and a description of the test procedures is presented in Appendix B.

TEST PLAN

The T6/T8 post is designed to breakaway in advance of an impacting vehicle to eliminate post snagging and minimize unwanted damage to the underlying deck structure. As previously discussed and shown in Figure 1.4, the T6 post incorporates two ¼-inch wide x ½-inch long slots in the front flange – one on each side of the web – to control the breakaway strength of the post. Structural analyses indicated that the strength of this post may exceed the capacity of a 6.5-inch thick concrete deck. Failure of the deck prior to activation of the post can lead to severe post snagging, vehicle instability, and costly repair.

Two series of four pendulum tests were, therefore, conducted to evaluate variations of the T6/T8 breakaway post. The testing examined the effect of the length of the weakening slots in the front flange of the post on the breakaway strength of the post.

In the first series of tests, the modified breakaway posts were anchored to a steel reaction plate. Data from each test were used to obtain the moment required to activate and release the post from its baseplate. The moment capacities of the posts were compared to the computed capacity of a 6.5-inch thick concrete deck with a compressive strength of 3,000 psi. The results were used to confirm the feasibility of designing a post that would breakaway prior to causing catastrophic damage to the thin deck.

In the second series of tests, the performance of the modified posts was further evaluated on actual concrete deck specimens. These tests provided a direct evaluation of post activation and deck damage, and the results were used to select an optimal post configuration for use in the T8 bridge rail system. Further details of the tests are described in the following sections of this chapter.

SERIES 1: POSTS ATTACHED TO STEEL REACTION PLATE

In the first series of tests, the modified T8 bridge rail posts were anchored to a steel reaction plate. The posts were comprised of a 29.75-inch tall section of a hot rolled W6x8.5 steel I-beam welded to a 9.5 inch x 12 inch x 1-inch thick baseplate. A ¼-inch wide slot was cut into the front flange of the post on both sides of the web at a distance of 0.75 inches above the base plate. A drawing for a typical post is shown in Figure 4.2. Note that the length of the slots varied. In test P1, the slots were 7/8-inch long, in test P2, the slots were 3/4-inch long, and in tests P3 and P4, the slots were 1-inch long.

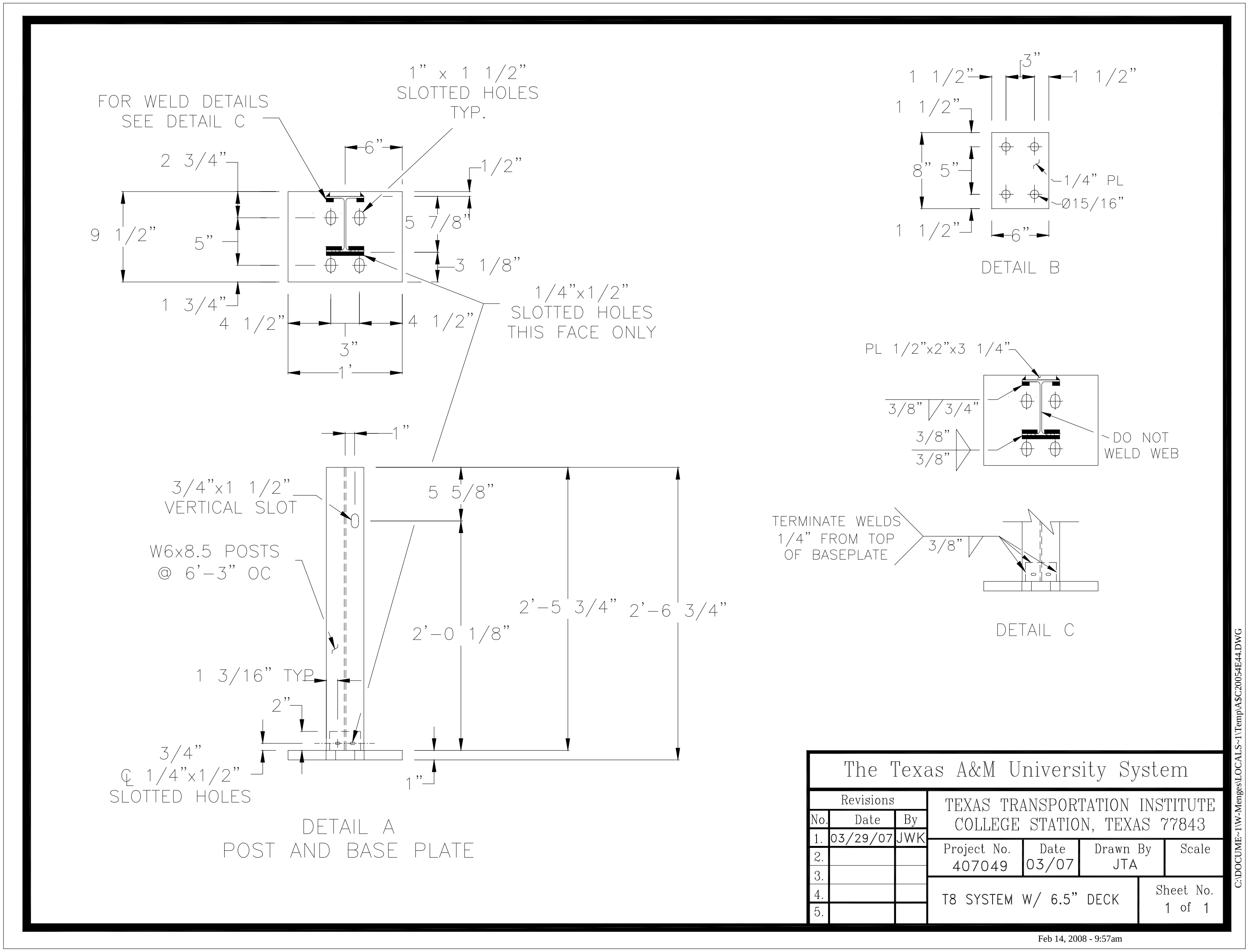


Figure 4.2. Post Detail for Series 1.

Test P1

The pendulum bogie, traveling at a speed of 21.7 mi/h, impacted the T8 bridge rail post with 7/8-inch long slots at a height of 21 inches. The post separated from the base plate at 0.065 s, and the pendulum lost contact with the post at 0.076 s. At loss of contact, the pendulum was traveling at a speed of 17.7 mi/h. The post came to rest 13 ft downstream of impact. Total crush of the honeycomb nose was 6.5 inches. Photographs of the bridge rail post before and after the test are shown in Figures 4.3 and 4.4, respectively. A summary of the pertinent data is presented in Table 4.1. Graphs of acceleration time and force time are shown in Appendix C, Figures C1 and C2, respectively. The maximum 10-ms average impact force was 12.9 kips, and the maximum moment applied to the post was 23 kip-ft.

Test P2

The pendulum bogie, traveling at a speed of 21.7 mi/h, impacted the T8 bridge rail post with ¾-inch long slots at a height of 21 inches. The post began to deflect at 0.010 s, and the post began to separate from the baseplate at 0.036 s. The post broke free of the baseplate at 0.058 s, and the pendulum lost contact with the post at 0.070 s. At loss of contact, the pendulum was traveling at a speed of 18.6 mi/h. The post came to rest 12 ft downstream of impact. Total crush of the honeycomb nose was 6.1 inches. Photographs of the bridge rail post before and after the test are shown in Figures 4.5 and 4.6, respectively. A summary of the pertinent data is presented in Table 4.2. Graphs of acceleration time and force time are shown in Appendix C, Figures C3 and C4, respectively. The maximum 10-ms average impact force was 13.5 kips, and the maximum moment applied to the post was 24 kip-ft.

Test P3

The pendulum bogie, traveling at a speed of 21.7 mi/h, impacted the T8 bridge rail post with 1-inch long slots at a height of 21 inches. The front of the post began to separate from the baseplate at 0.039 s, and the post broke free of the baseplate at 0.063 s. At 0.070 s, the pendulum lost contact with the post and was traveling at a speed of 18.3 mi/h. The post came to rest 11.6 ft downstream of impact. Total crush of the honeycomb nose was 6.0 inches. Photographs of the bridge rail post before and after the test are shown in Figures 4.7 and 4.8, respectively. A summary of the pertinent data is presented in Table 4.3. Graphs of acceleration time and force time are shown in Appendix C, Figures C5 and C6, respectively. The maximum 10-ms average impact force was 12.8 kips, and the maximum moment applied to the post was 22 kip-ft.

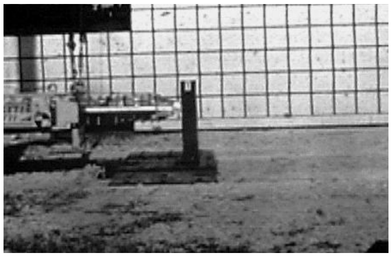
Test P4

The pendulum bogie, traveling at a speed of 21.7 mi/h, impacted the T8 bridge rail post with 1-inch long slots at a height of 21 inches. The post began to deflect at 0.005 s, and the post began to separate from the baseplate at 0.041 s. The post broke free of the baseplate at 0.067 s, and the pendulum lost contact with the post at 0.072 s. At loss of contact, the pendulum was traveling at a speed of 18.3 mi/h. The post came to rest 12 ft downstream of impact. Total crush

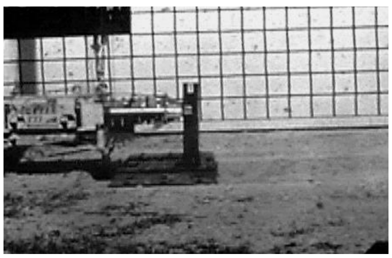
Figure 4.3. T8 Post with 7/8-Inch Slot Prior to Test P1.

Figure 4.4. T8 Post with 7/8-Inch Slots after Test 452107-P1.

Table 4.1. Summary of Results for Pendulum Test 452107-P1.



0.000 s



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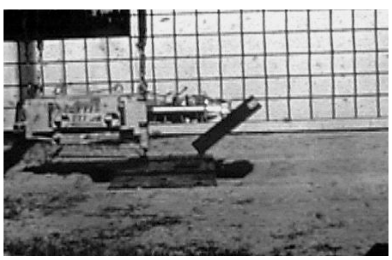
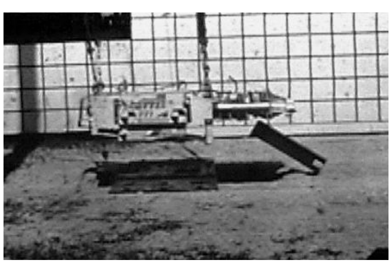


0.072 s



0.144 s

General Information
Test Agency............................Texas Transportation Institute
Test No. 452107-P1
Date 06-06-2007

Test Article
Type...Bridge Rail Post
Name ....TxDOT T8 Bridge Rail Post
Installation Height (m)...30.75 inches
Material of Key Element ....W6x8.5 with 7/8 inch slot on 9.5 x 12 x 1 inch thick plate

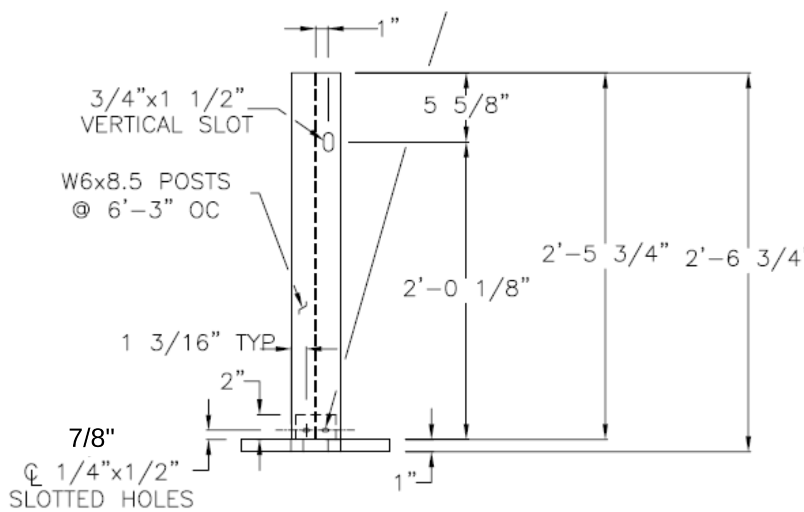
Soil Type... Metal Reaction Plate

Test Vehicle
Type... Bogie
Designation.. Pendulum
Test Inertia Mass ....839 kg

Impact Conditions
Speed ....21.7 mi/h
Angle .... 90 deg

Occupant Risk Values
Impact Velocity
Longitudinal direction.. No Contact
Ridedown Accelerations
Longitudinal direction... N/A

Maximum Change in Velocity ....5.9 ft/s



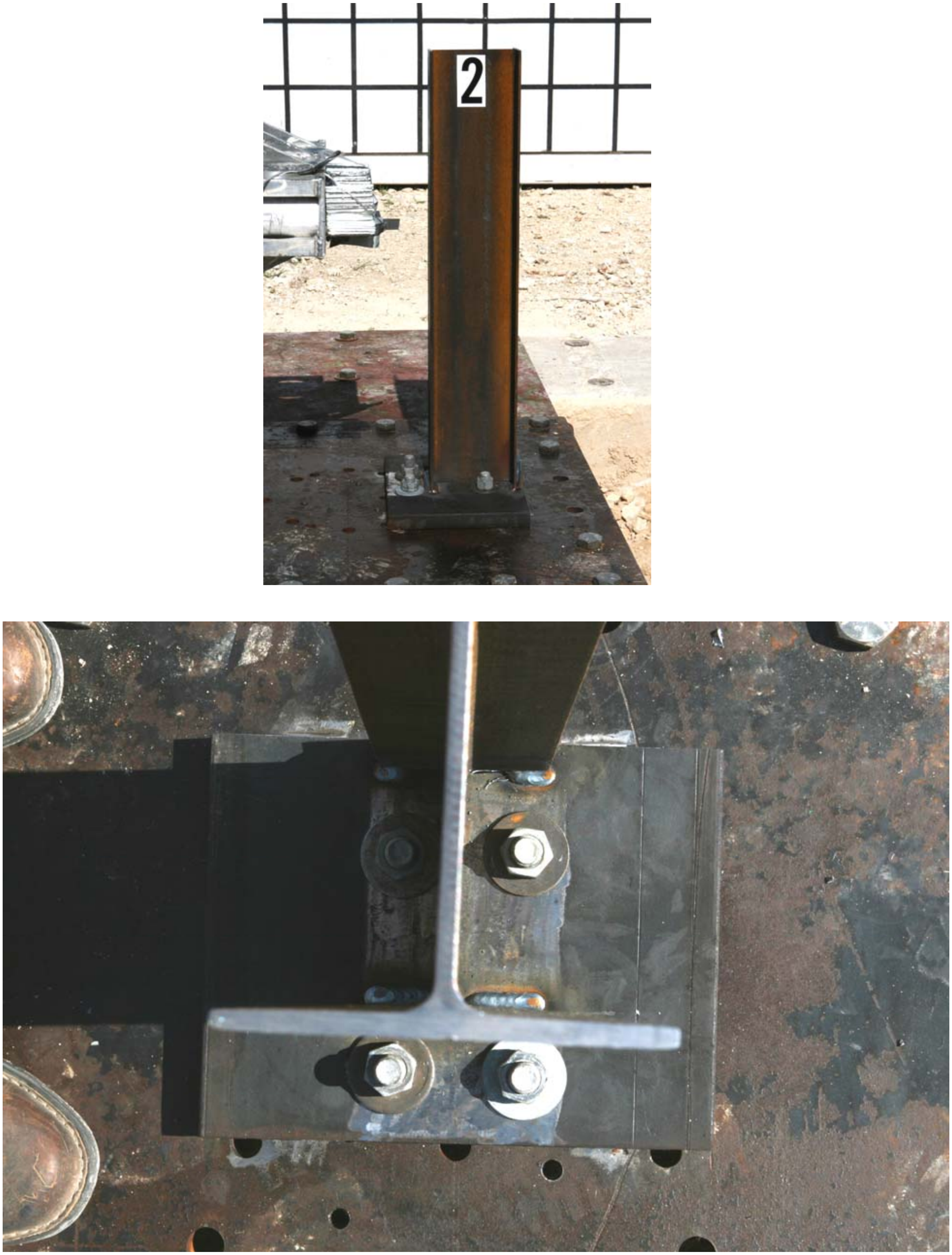


Figure 4.5. T8 Post with ¾-Inch Slot before Test 452107-P2.

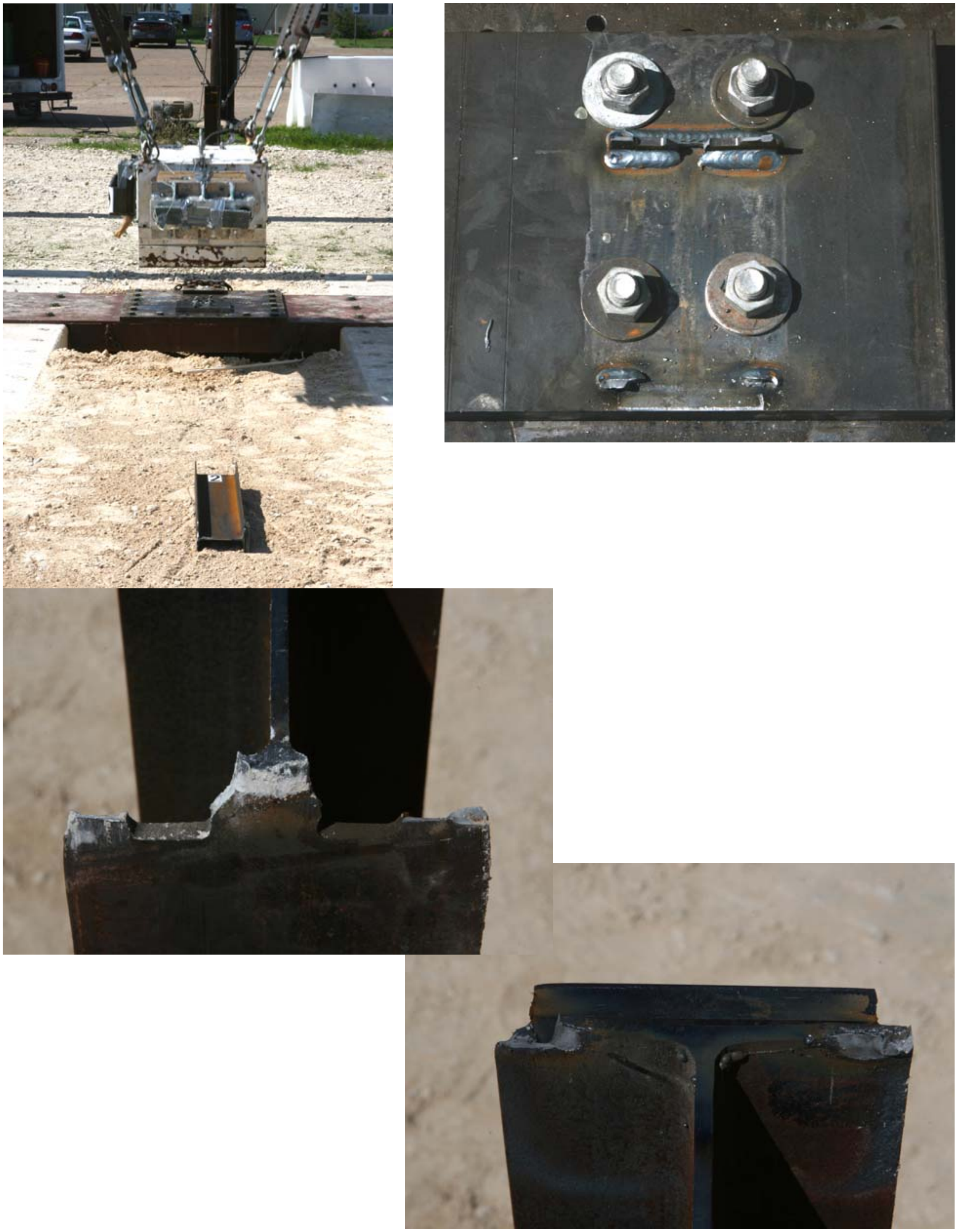
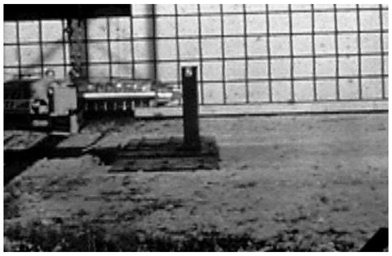
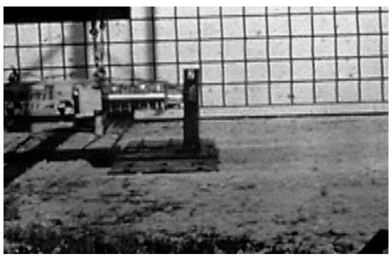
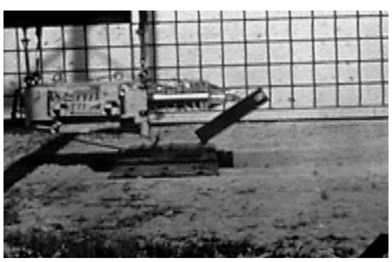


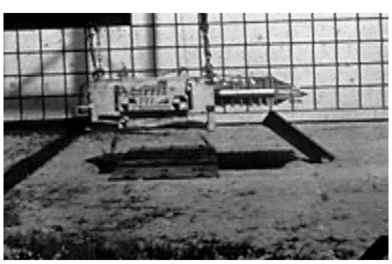
Figure 4.6. T8 Post with ¾-Inch Slots after Test 452107-P2.

Table 4.2. Summary of Results for Pendulum Test 452107-P2.


0.000 s


0.024 s


0.072 s


0.145 s

General Information	
Test Agency	Texas Transportation Institute
Test No.	452107-P2
Date	06-06-2007
Test Article	
Type	Bridge Rail Post
Name	TxDOT T8 Bridge Rail Post
Installation Height (m)	30.75 inches
Material of Key Element	W6x8.5 with ¾ inch slot on 9.5 x 12 x 1 inch thick plate
Soil Type	Metal Reaction Plate
Test Vehicle	
Type	Bogie
Designation	Pendulum
Test Inertia Mass	839 kg
Impact Conditions	
Speed	21.7 mi/h
Angle	90 deg
Occupant Risk Values	
Impact Velocity	
Longitudinal direction	No Contact
Ridedown Accelerations	
Longitudinal direction	N/A
Maximum Change in Velocity	4.5 ft/s

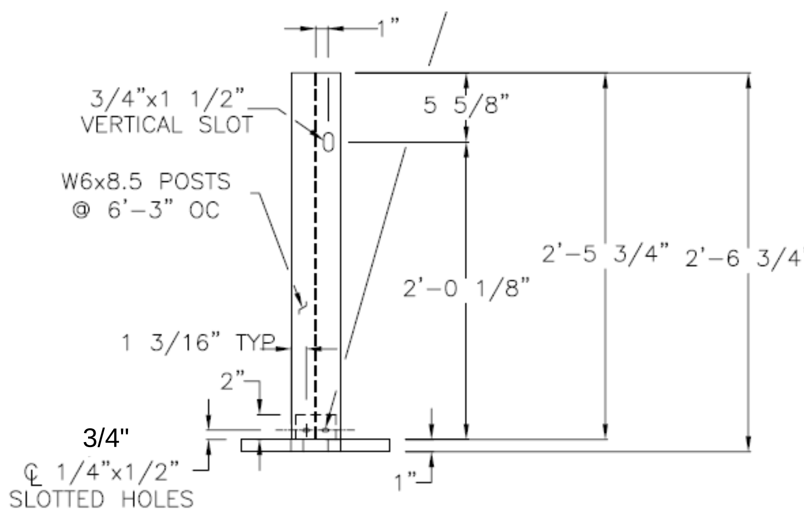
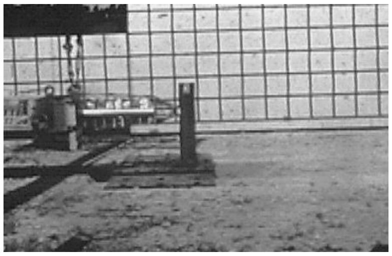


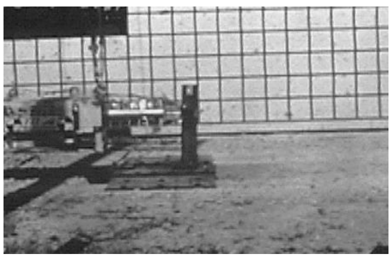
Figure 4.7. T8 Post with 1-Inch Slot before Test 452107-P3.

Figure 4.8. T8 Post with 1-Inch Slot after Test 452107-P3.

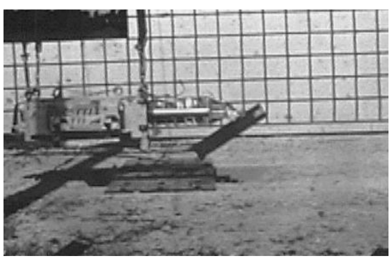
Table 4.3. Summary of Results for Pendulum Test 452107-P3.



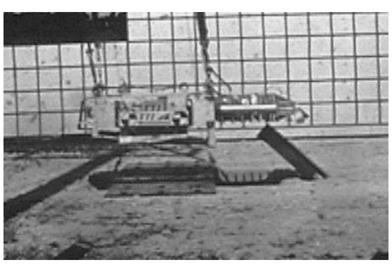
0.000 s



0.024 s

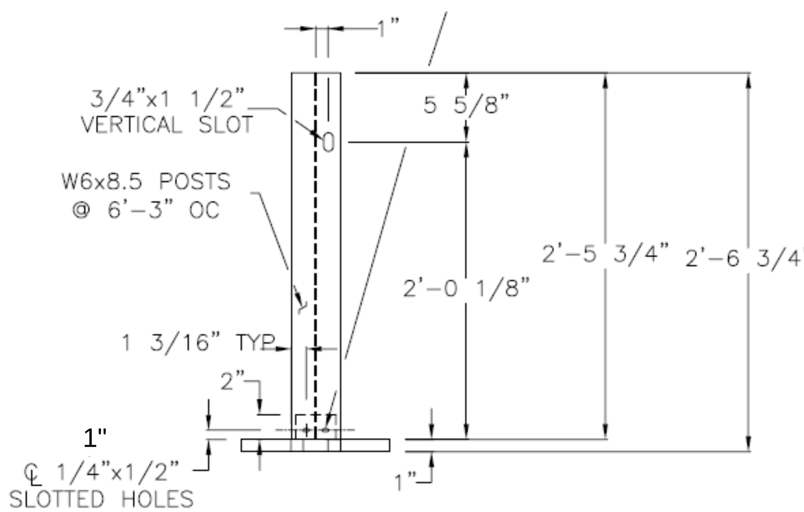


0.072 s



0.145 s

General Information	
Test Agency	Texas Transportation Institute
Test No.	452107-P3
Date	06-06-2007
Test Article	
Type	Bridge Rail Post
Name	TxDOT T8 Bridge Rail Post
Installation Height (m)	30.75 inches
Material of Key Element	W6x8.5 with 1 inch slot on 9.5 x 12 x 1 inch thick plate
Soil Type	Metal Reaction Plate
Test Vehicle	
Type	Bogie
Designation	Pendulum
Test Inertia Mass	839 kg
Impact Conditions	
Speed	21.7 mi/h
Angle	90 deg
Occupant Risk Values	
Impact Velocity	
Longitudinal direction	No Contact
Ridedown Accelerations	
Longitudinal direction	N/A
Maximum Change in Velocity	5.0 ft/s



of the honeycomb nose was 4.7 inches. Photographs of the bridge rail post before and after the test are shown in Figures 4.9 and 4.10, respectively. A summary of the pertinent data is presented in Table 4.4. Graphs of acceleration time and force time are shown in Appendix C, Figures C7 and C8, respectively. The maximum 10-ms average impact force was 12.5, and the maximum moment applied to the post was 22 kip-ft.

SERIES 2: POSTS ATTACHED TO CONCRETE DECK

In the second series of tests, the modified T8 bridge rail posts were anchored to the edge of a 6.5-inch concrete deck specimen. The sides of the deck specimen were bolted to concrete foundation walls in the pendulum test pit. The back edge of the deck specimen to which the post was attached was unsupported and unrestrained. The deck specimens were fabricated for use in two tests each – one on each end. After the first test on a deck specimen, it was unbolted and rotated 180 degrees for use in a second test. Details of the 6.5-inch thick concrete deck specimen are shown in Figures 4.11 and 4.12. The concrete compressive strengths of the two deck specimens on the day of testing were 2511 psi and 2812 psi.

The T8 posts were mounted to the concrete deck sections using four 7/8-inch diameter, 9-inch long A-307 anchor bolts that passed through the deck. The length of the weakening slots in the front flanges of the posts varied. In tests P5 and P7, the slots were 1-inch long, in test P6, the slots were 3/4-inch long, and in tests P8 and P9, the slots were 7/8-inch long.

Test P5

The pendulum bogie, traveling at a speed of 21.9 mi/h, impacted the T8 bridge rail post with 1-inch long weakening slots at a height of 21 inches. Approximately 0.022 s after impact, the T8 bridge rail post began to deflect toward the field side, and at 0.032 s, the post began to fracture at its base. The post separated from the baseplate at 0.049 s, and the pendulum lost contact with the post at 0.071 s. At loss of contact, the pendulum was traveling at a speed of 19.3 mi/h. The post came to rest just to the field side of the bridge deck sample. Total crush of the honeycomb nose was 5.8 inches. The post fractured at the slots. The deck sustained cracks that radiated out at an approximate 45 degree angle from the rear anchor bolts to the free edge of the deck. The cracks traveled down the edge of the deck through its thickness. Photographs of the bridge rail post before and after the test are shown in Figures 4.13 and 4.14, respectively. A summary of the pertinent data is presented in Table 4.5. Graphs of acceleration time and force time are shown in Appendix C, Figures C9 and C10, respectively. The maximum 10-ms average impact force was 11.9 kips, and the maximum moment applied to the post was 21 kip-ft.

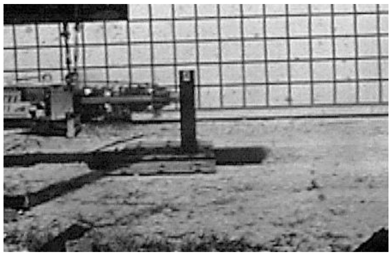
Test P6

The pendulum bogie, traveling at a speed of 21.6 mi/h, impacted the T8 bridge rail post with ¾-inch long slots at a height of 21 inches. The post began to deflect toward the field side at 0.022 s. At 0.052 s, the concrete around the base of the post began to fracture, and at 0.057 s, the

Figure 4.9. T8 Post with 1-Inch Slots before Test 452107-P4.

Figure 4.10. T8 Post with 1-Inch Slot after Test 452107-P4.

Table 4.4. Summary of Results for Pendulum Test 452107-P4.



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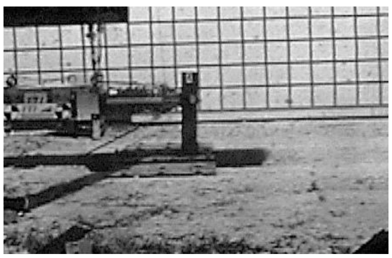

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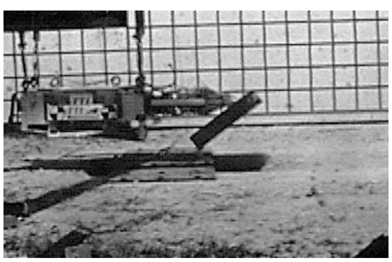
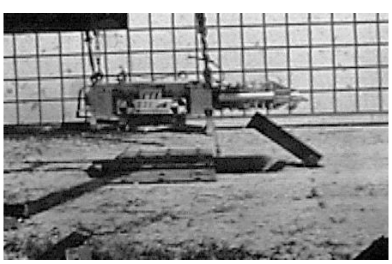
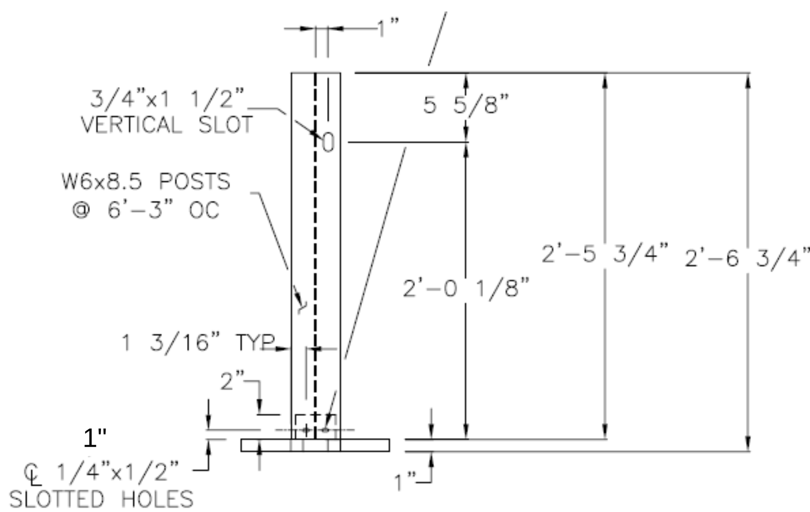


0.072 s



0.145 s

General Information	
Test Agency	Texas Transportation Institute
Test No.	452107-P4
Date	06-06-2007
Test Article	
Type	Bridge Rail Post
Name	TxDOT T8 Bridge Rail Post
Installation Height (m)	30.75 inches
Material of Key Element	W6x8.5 with 1 inch slot on 9.5 x 12 x 1 inch thick plate
Soil Type	Metal Reaction Plate
Test Vehicle	
Type	Bogie
Designation	Pendulum
Test Inertia Mass	839 kg
Impact Conditions	
Speed	21.7 mi/h
Angle	90 deg
Occupant Risk Values	
Impact Velocity	
Longitudinal direction	No Contact
Ridedown Accelerations	
Longitudinal direction	N/A
Maximum Change in Velocity	5.0 ft/s



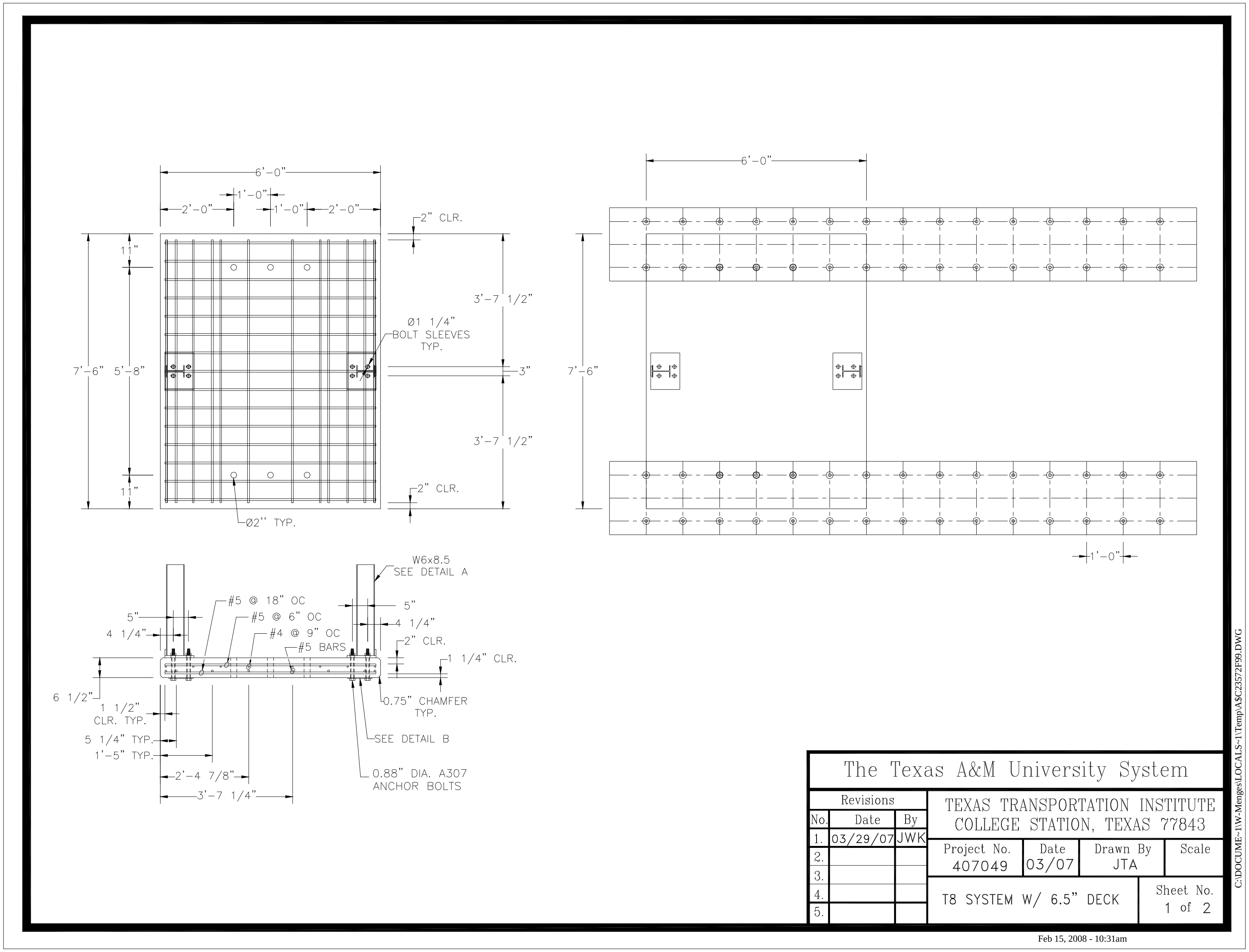


Figure 4.11. Details of the Deck Used for Pendulum Tests 452107-P5–P9.

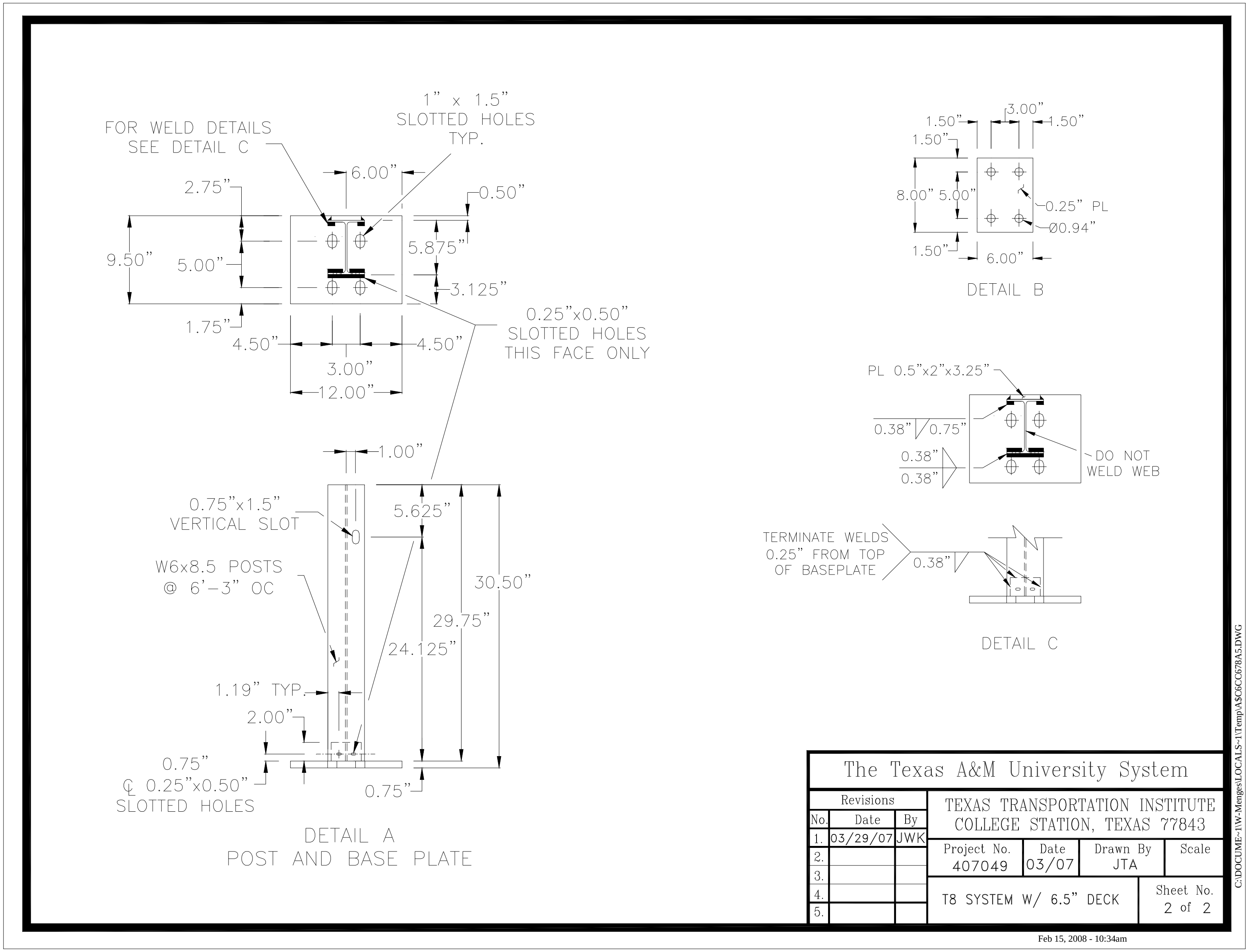
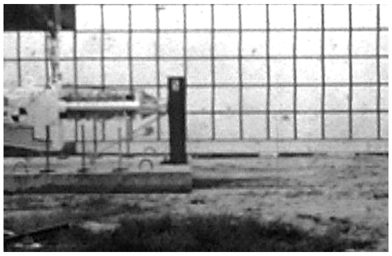


Figure 4.12. Details of T6 Post Used for Pendulum Tests 452107-P5–P9.

Figure 4.13. T8 Post with 1-Inch Slot before Test 452107-P5.

Figure 4.14. T8 Post with 1-Inch Slots after Test 452107-P5.

Table 4.5. Summary of Results for Pendulum Test 452107-P5.



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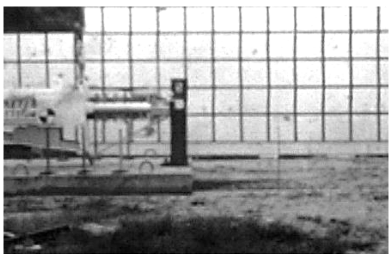

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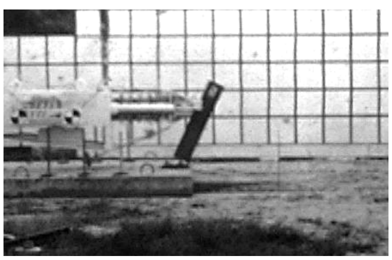
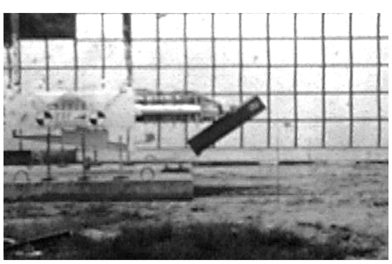


0.049 s



0.073 s

General Information
- Test Agency .... Texas Transportation Institute
- Test No. 452107-P5
- Date 07-05-2007

Test Article
- Type .... Bridge Rail Post
- Name .... TxDOT T8 Bridge Rail Post
- Installation Height (m) .... 30.75 inches
- Material of Key Element .... W6x8.5 with 1 inch slot on 9.5 x 12 x 1 inch thick plate

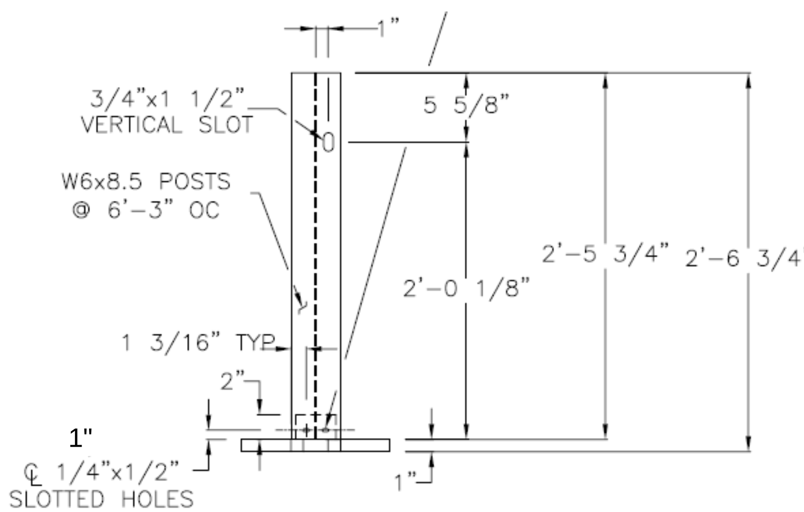
Soil Type .... Metal Reaction Plate

Test Vehicle
- Type .... Bogie
- Designation .... Pendulum
- Test Inertia Mass .... 839 kg

Impact Conditions
- Speed .... 21.9 mi/h
- Angle .... 90 deg

Occupant Risk Values
- Impact Velocity
  - Longitudinal direction .... No Contact
- Ridedown Accelerations
  - Longitudinal direction .... N/A

Maximum Change in Velocity .... 2.6 ft/s



base of the post began to move downward. The pendulum lost contact with the post at 0.155 s, while traveling at a speed of 18.7 mi/h. The post remained attached to the baseplate at the rear flange. Total crush of the honeycomb nose was 8.6 inches. The deck failed catastrophically beneath the post, and the post rotated about the damaged deck section without releasing from its baseplate. Photographs of the bridge rail post before and after the test are shown in Figures 4.15 and 4.16, respectively. A summary of the pertinent data is presented in Table 4.6. Graphs of acceleration time and force time are shown in Appendix C, Figures C11 and C12, respectively. The maximum 10-ms average impact force was 16.2 kips, and the maximum moment applied to the post was 28 kip-ft.

Test P7

The pendulum bogie, traveling at a speed of 21.4 mi/h, impacted the T8 bridge rail post with 1-inch long slots at a height of 21 inches. The post began to deflect toward the field side at 0.022 s. The front of the post began to separate from the base plate at 0.035 s, and the post separated from the base at 0.059 s. At 0.067 s, the pendulum lost contact with the post and was traveling at a speed of 17.9 mi/h. The post came to rest just behind the bridge deck sample. Total crush of the honeycomb nose was 6.3 inches. The deck sustained cracks that radiated out at an approximate 45 degree angle from the rear anchor bolts to the free edge of the deck. The cracks traveled down the edge of the deck through its thickness. Photographs of the bridge rail post before and after the test are shown in Figures 4.17 and 4.18, respectively. A summary of the pertinent data is presented in Table 4.7. Graphs of acceleration time and force time are shown in Appendix C, Figures C13 and C14, respectively. The maximum 10-ms average impact force was 12.8 kips, and the maximum moment applied to the post was 22 kip-ft.

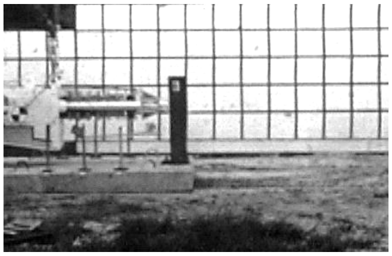
Test P8

The pendulum bogie, traveling at a speed of 21.6 mi/h, impacted the T8 bridge rail post with 7/8-inch long slots at a height of 21 inches. The post began to deflect at 0.008 s, and the post began to separate from the base plate at 0.030 s. The post broke free of the baseplate at 0.048 s, and the pendulum lost contact with the post at 0.062 s. Due to camera malfunction, speed of the pendulum at loss of contact with the post was not obtainable. The post came to rest just behind the bridge deck sample. Total crush of the honeycomb nose was not obtainable because the nose piece fell out. The deck sustained cracks that radiated out at an approximate 45 degree angle from the rear anchor bolts to the free edge of the deck. The cracks traveled down the edge of the deck through its thickness. Photographs of the bridge rail post before and after the test are shown in Figures 4.19 and 4.20, respectively. A summary of the pertinent data is presented in Table 4.8. Graphs of acceleration time and force time are shown in Appendix C, Figures C15 and C16, respectively. The maximum 10-ms average impact force was 13.3 kips, and the maximum moment applied to the post was 23 kip-ft.

Figure 4.15. T8 Post with ¾-Inch Slot before Test 452107-P6.

Figure 4.16. T8 Post with ¾-Inch Slots after Test 452107-P6.

Table 4.6. Summary of Results for Pendulum Test 452107-P6.



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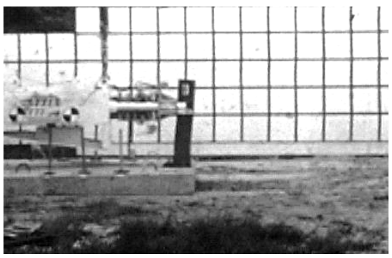

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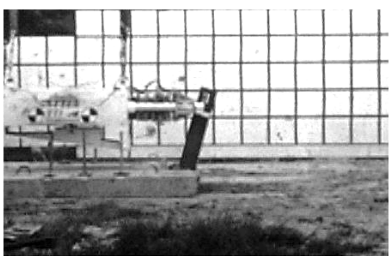
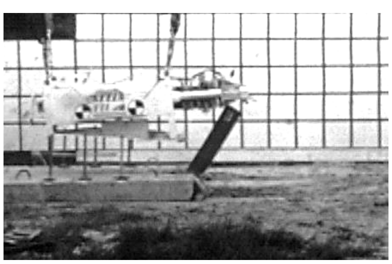


0.098 s



0.147 s

General Information
Test Agency............................Texas Transportation Institute
Test No. 452107-P6
Date 07-05-2007

Test Article
Type..Bridge Rail Post
Name ....TxDOT T8 Bridge Rail Post
Installation Height (m)..30.75 inches
Material of Key Element ....W6x8.5 with ¾ inch slot
on 9.5 x 12 x 1 inch thick plate

Soil Type.. Metal Reaction Plate

Test Vehicle
Type.. Bogie
Designation.. Pendulum
Test Inertia Mass ....839 kg

Impact Conditions
Speed ....21.6 mi/h
Angle .... 90 deg

Occupant Risk Values
Impact Velocity
Longitudinal direction...4.7 m/s
Ridedown Accelerations
Longitudinal direction..-1.2 g's

Maximum Change in Velocity ....4.2 ft/s

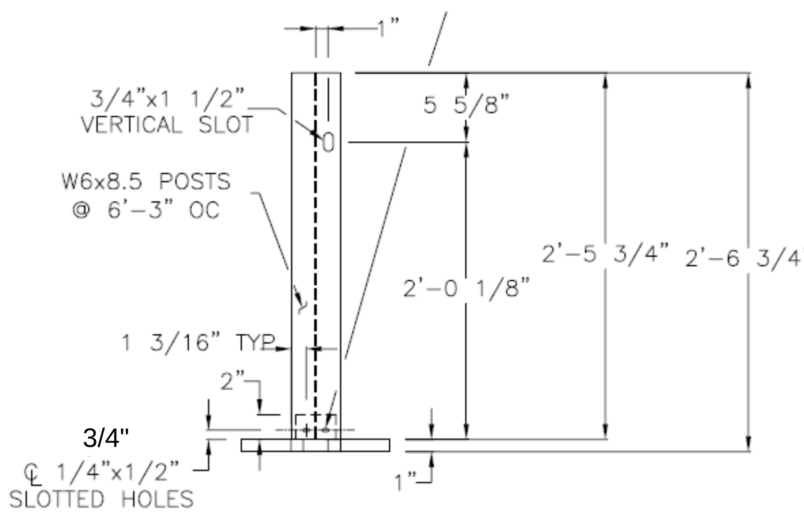
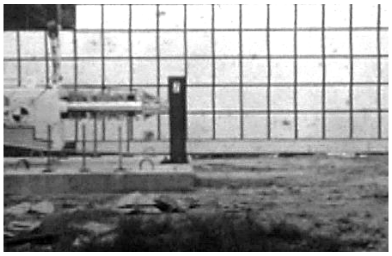


Figure 4.17. T8 Post with 1-Inch Slot before Test 452107-P7.

Figure 4.18. T8 Post with 1-Inch Slot after Test 452107-P7.

Table 4.7. Summary of Results for Pendulum Test 452107-P7.



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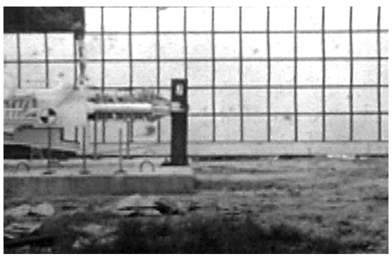

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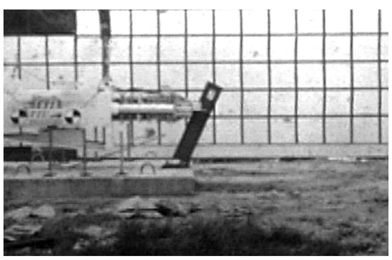

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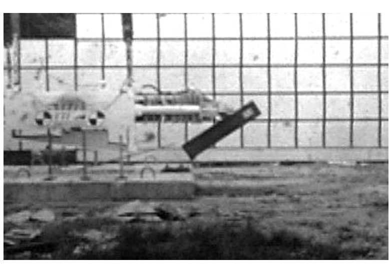


0.074 s

General Information	
Test Agency	Texas Transportation Institute
Test No.	452107-P7
Date	07-05-2007
Test Article	
Type	Bridge Rail Post
Name	TxDOT T8 Bridge Rail Post
Installation Height (m)	30.75 inches
Material of Key Element	W6x8.5 with 1 inch slot on 9.5 x 12 x 1 inch thick plate
Soil Type	Metal Reaction Plate
Test Vehicle	
Type	Bogie
Designation	Pendulum
Test Inertia Mass	839 kg
Impact Conditions	
Speed	21.4 mi/h
Angle	90 deg
Occupant Risk Values	
Impact Velocity	
Longitudinal direction	No Contact
Ridedown Accelerations	
Longitudinal direction	N/A
Maximum Change in Velocity	5.1 ft/s

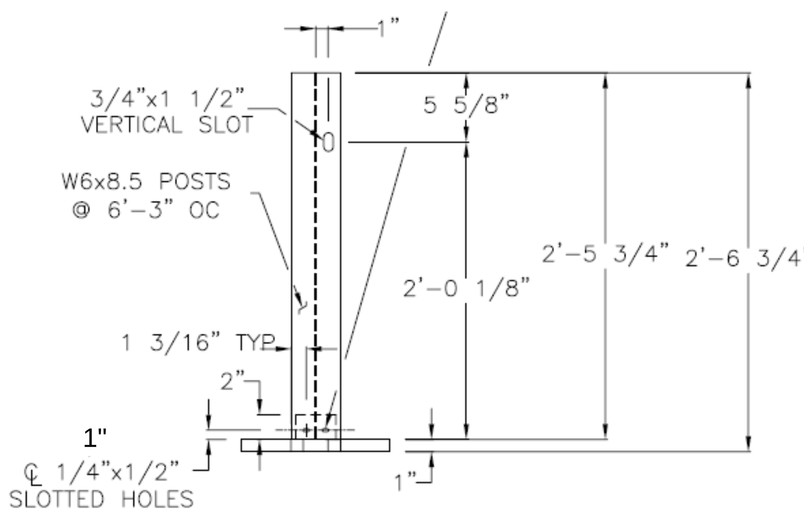
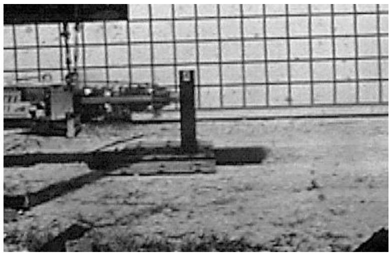


Figure 4.19. T8 Post with 7/8-Inch Slots before Test 452107-P8.

Figure 4.20. T8 Post with 7/8-Inch Slot after Test 452107-P8.

Table 4.8. Summary of Results for Pendulum Test 452107-P8.



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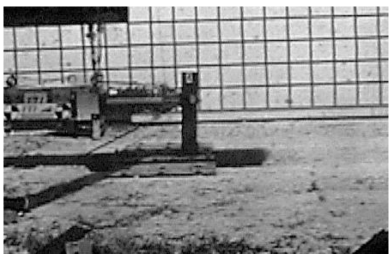

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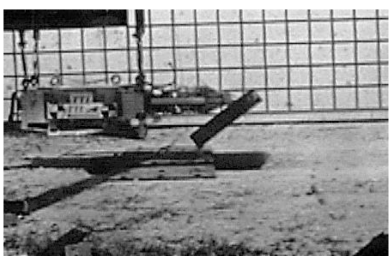

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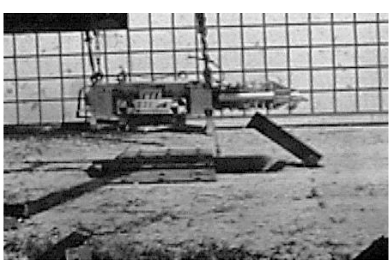


0.145 s

General Information

Test Agency	Texas Transportation Institute
Test No.	452107-P8
Date	07-05-2007

Test Article

Type	Bridge Rail Post
Name	TxDOT T8 Bridge Rail Post
Installation Height (m)	30.75 inches
Material of Key Element	W6x8.5 with 7/8 inch slot on 9.5 x 12 x 1 inch thick plate

Soil Type	Metal Reaction Plate

Test Vehicle

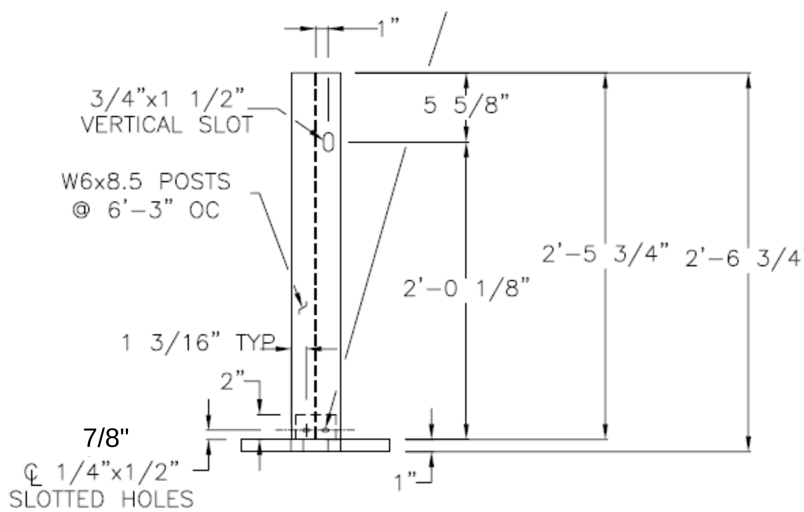
Type	Bogie
Designation	Pendulum
Test Inertia Mass	839 kg

Impact Conditions

Speed	21.6 mi/h
Angle	90 deg

Occupant Risk Values

Impact Velocity	
Longitudinal direction	No Contact
Ridedown Accelerations	
Longitudinal direction	N/A
Maximum Change in Velocity	Not obtainable



Test P9

The pendulum bogie, traveling at a speed of 21.7 mi/h, impacted the T8 bridge rail post with 7/8-inch long slots at a height of 21 inches. The post began to deflect at 0.010 s, and the post began to separate from the baseplate at 0.036 s. The post broke free of the baseplate at 0.058 s, and the pendulum lost contact with the post at 0.062 s. Due to camera malfunction, speed of the pendulum at loss of contact with the post was not obtainable. The post came to rest just behind the bridge deck sample. Total crush of the honeycomb nose was not obtainable because the nose piece fell out. The deck sustained cracks that radiated out at an approximate 45 degree angle from the rear anchor bolts to the free edge of the deck. The cracks traveled down the edge of the deck through its thickness. Photographs of the bridge rail post before and after the test are shown in Figures 4.21 and 4.22, respectively. A summary of the pertinent data is presented in Table 4.9. Graphs of acceleration time and force time are shown in Appendix C, Figures C17 and C18, respectively. The maximum 10-ms average impact force was 14.0 kips, and the maximum moment applied to the post was 24 kip-ft.

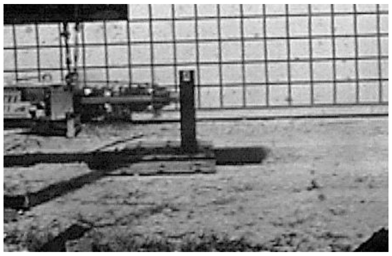
SUMMARY

The performance of modified T8 bridge rail posts was evaluated through a series of dynamic pendulum tests. The tests provided a direct evaluation of post activation and deck damage as a function of length of the weakening slots on the front flange of the posts. A post configuration with 7/8-inch long weakening slots was selected for further evaluation through finite element impact simulation of the T8 bridge rail. This post configuration had the shortest slot length that permitted the post to breakaway prior to inducing catastrophic damage to the thin deck section. The shortest acceptable slot length was chosen in order to maintain as much lateral strength in the post as possible to help keep the number of posts damaged and dynamic rail deflection during an impact to a minimum.

Figure 4.21. T8 Post with 7/8-Inch Slots before Test 452107-P9.

Figure 4.22. T8 Post with 7/8-Inch Slot after Test 452107-P9.

Table 4.9. Summary of Results for Pendulum Test 452107-P9.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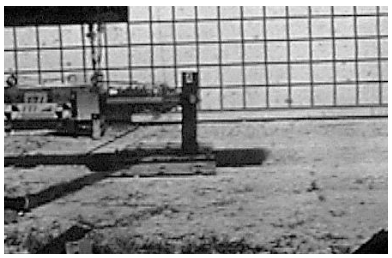
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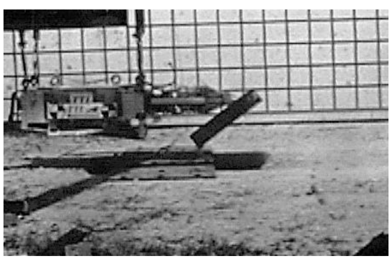
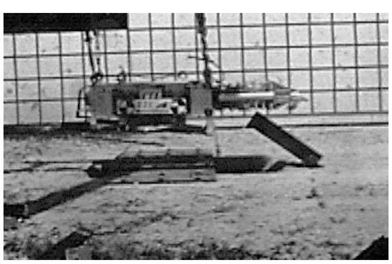
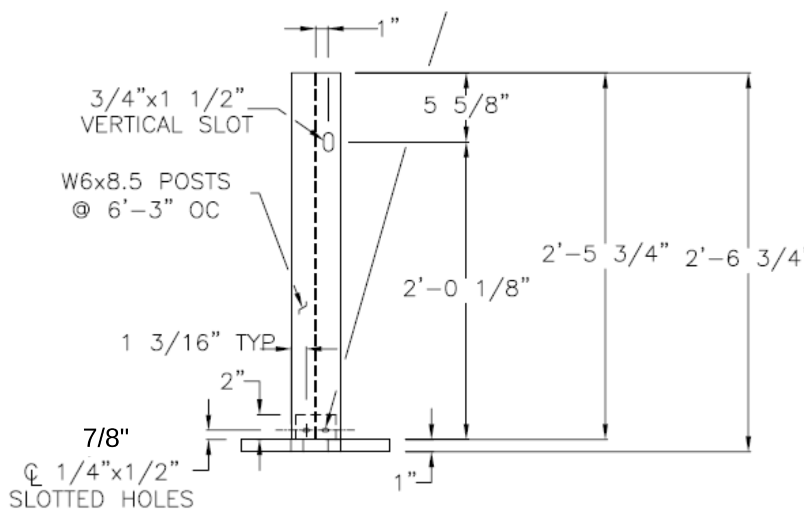

0.072 s


0.145 s

General Information	
Test Agency	Texas Transportation Institute
Test No.	452107-P9
Date	07-05-2007
Test Article	
Type	Bridge Rail Post
Name	TxDOT T8 Bridge Rail Post
Installation Height (m)	30.75 inches
Material of Key Element	W6x8.5 with 7/8 inch slot on 9.5 x 12 x 1 inch thick plate
Soil Type	Metal Reaction Plate
Test Vehicle	
Type	Bogie
Designation	Pendulum
Test Inertia Mass	839 kg
Impact Conditions	
Speed	21.7 mi/h
Angle	90 deg
Occupant Risk Values	
Impact Velocity	
Longitudinal direction	No Contact
Ridedown Accelerations	
Longitudinal direction	N/A
Maximum Change in Velocity	Not obtainable



CHAPTER 5. ANALYSIS OF T8 RAIL WITH MODIFIED POST

Upon completion of the pendulum testing, a finite element analysis effort was undertaken to evaluate the performance of the modified post with 7/8-inch long weakening slots in the T8 bridge rail system. The first step was to modify the post model and calibrate it against the pendulum testing. Once satisfactory correlation was achieved, the modified post was incorporated into the system model, and a full-scale impact simulation was conducted using *NCHRP Report 350* TL-3 impact conditions.

MODELING AND SIMULATION OF MODIFIED POST

Based on the pendulum testing, a post with 7/8-inch long weakening slots was selected for numerical analysis as a candidate for use in the T8 system. The model of the T8 post was modified to include the longer weakening slots. The model was used in a pendulum impact simulation to assess its performance and validity. Note that since the pendulum testing confirmed that the post would breakaway prior to failing the deck structure, the reinforced concrete deck was not explicitly modeled. The comparison between pendulum impact test and simulation focused on the force-time history and release of the post from the baseplate.

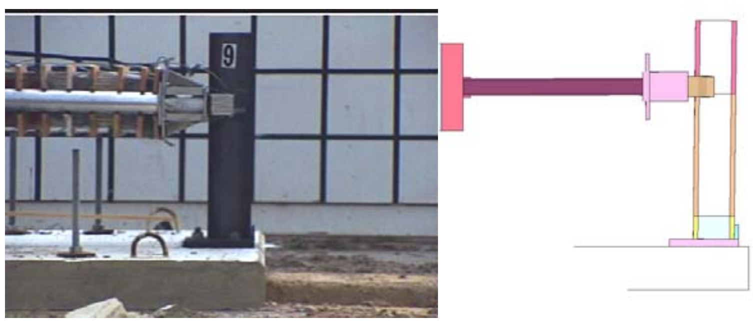
Figure 5.1 shows a comparison between pendulum testing and simulation of the modified T8 post with 7/8-inch weakening slots at different time intervals. The sequential images show good physical agreement between the simulation and the pendulum test in terms of post deflection and activation. Moreover, the force-time histories, shown in Figure 5.2, show reasonable agreement with one another. The initial peak in the force-time trace from the pendulum simulation is related to the stiffness and crush characteristics of the model of the pendulum nose. It can be seen that the force-time history begins to track in close agreement at about 15 ms, which is prior to any significant deflection of the post. The peak force and duration of the impact event are subsequently captured.

IMPACT SIMULATION OF T8 SYSTEM WITH MODIFIED POST

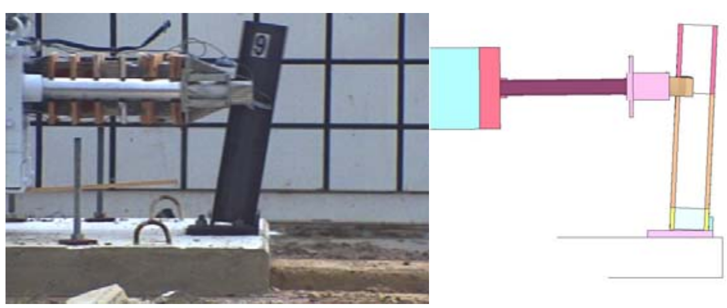
Based on the good agreement of the pendulum impact simulation, the T8 system model was modified to incorporate the post with 7/8-inch weakening slots. Because the deck was not damaged in the pendulum testing, a rigid representation of the concrete deck was retained in the revised system model of the T8 bridge rail.

A TL-3 impact simulation was conducted with a 4409-lb pickup truck contacting the T8 rail at a speed of 62 mi/h and an angle of 25 degrees. The simulation indicates that the T8 system should successfully contain and redirect the pickup truck. Sequential images from the simulated impact are shown in Figure 5.3. Figure 5.4 shows the deflected shape of the tubular thrie beam rail at time of maximum dynamic deflection. The maximum dynamic deflection predicted by the simulation is approximately 37 inches.

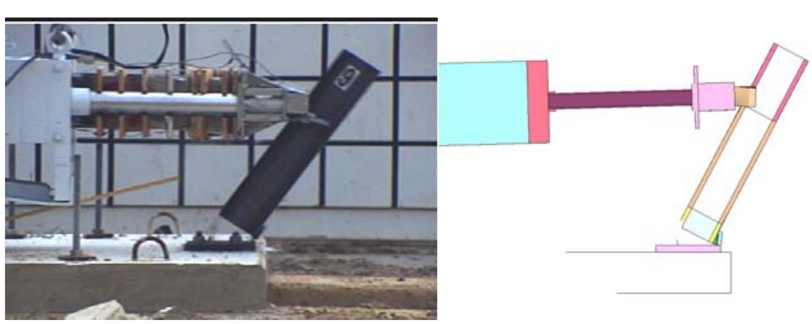
T=0 s



T=20 ms



T=40 ms



T=60 ms

Figure 5.1. Comparison between Pendulum Test (TTI 452107-P9) and Simulation.

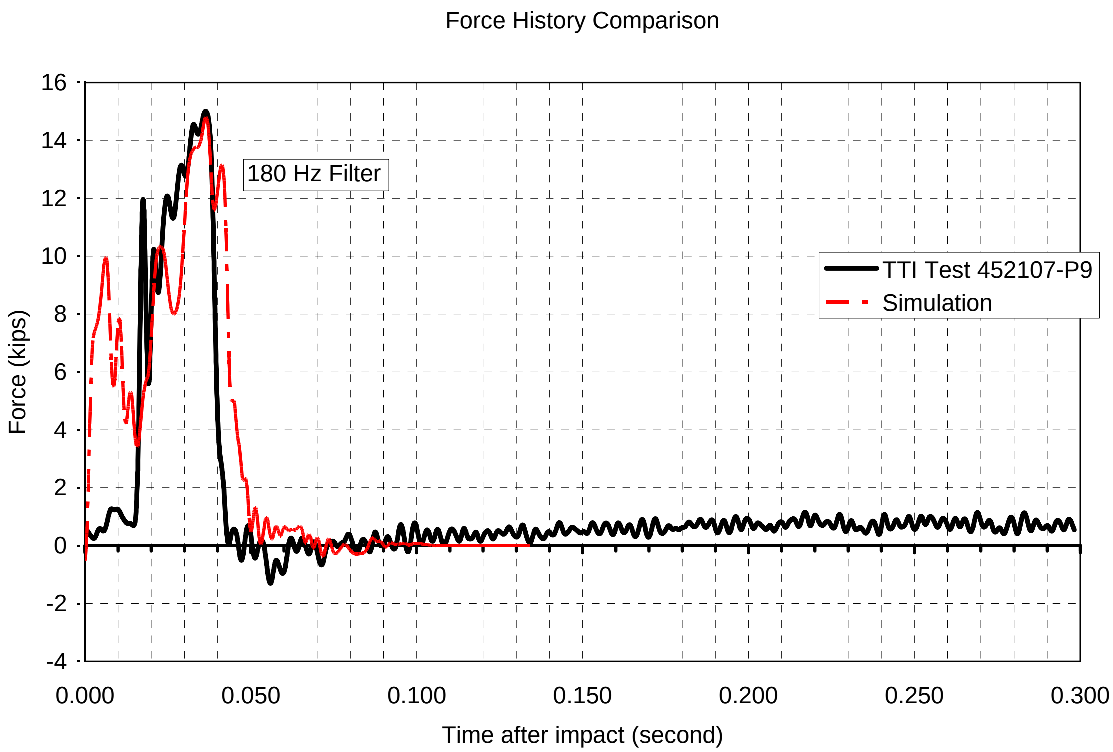
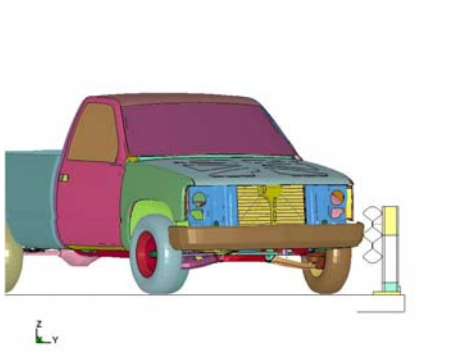
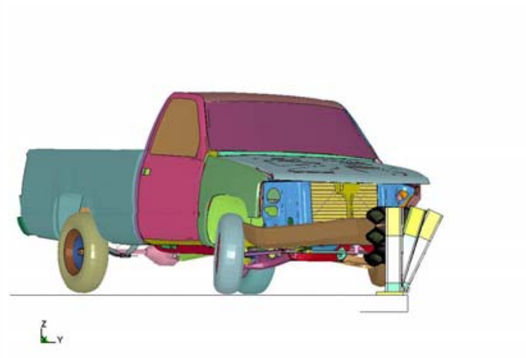


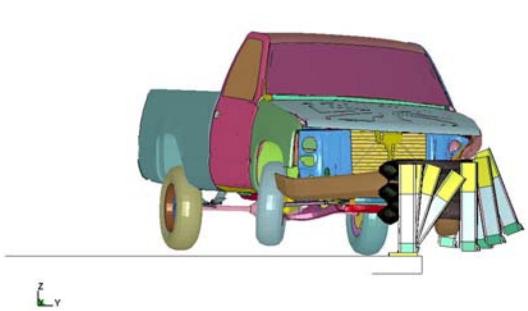
Figure 5.2. Force-Time History Comparison between Pendulum Test and Simulation of Modified T8 Post.



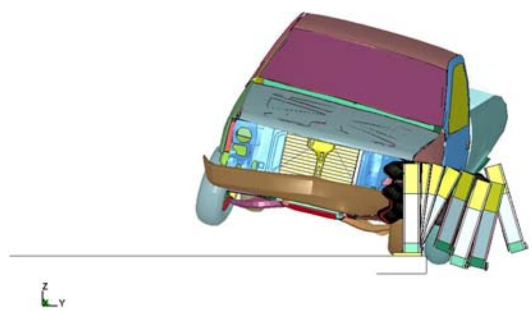
T=000 sec



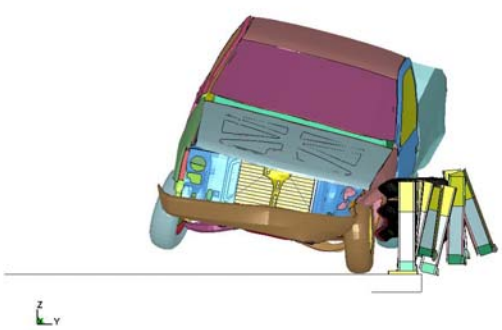
T=0.065 sec



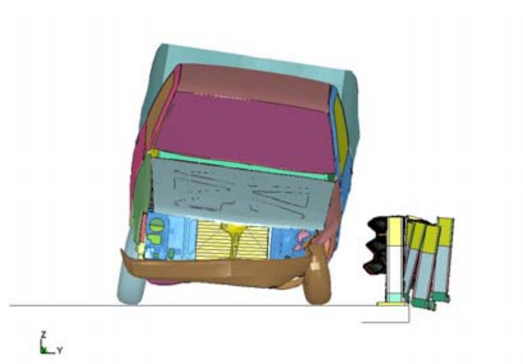
T=0.175 sec



T=0.340 sec



T=0.460 sec



T=0.585 sec

Figure 5.3. Sequential Images of Impact Simulation of Modified T8 System.

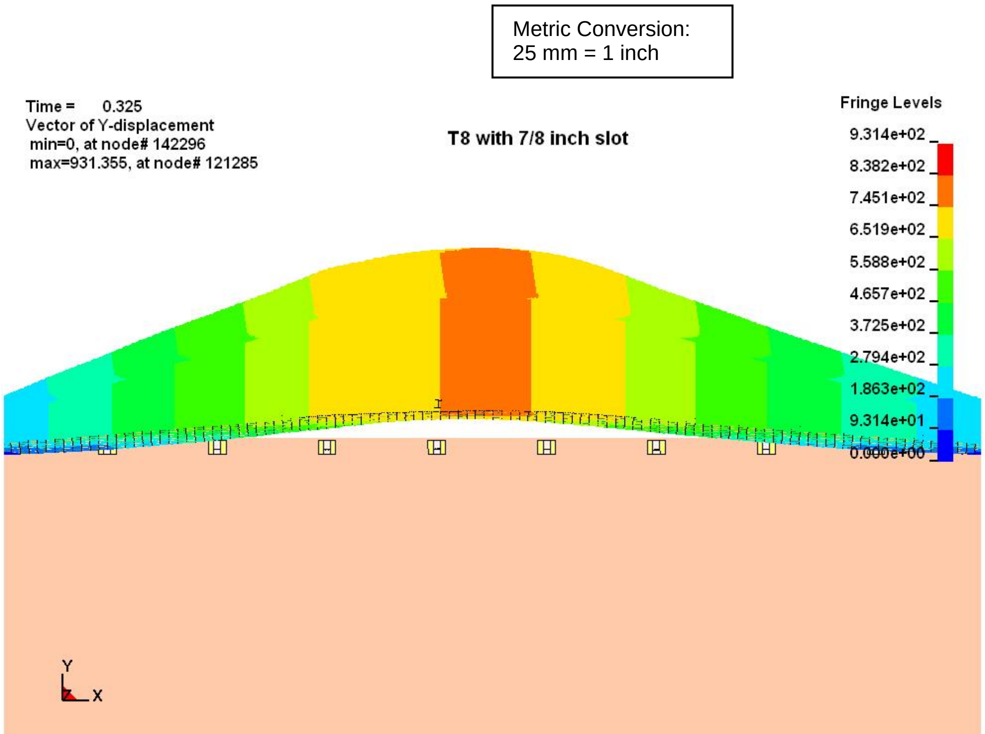


Figure 5.4. Maximum Lateral Deflection of the Rail.

CHAPTER 6. CONCLUSIONS

Impact simulations were conducted on two different versions of a newly developed tubular thrie beam bridge rail. The simulations involved a 4409-lb, C2500 pickup truck model impacting the barrier at a speed of 62 mi/h and an angle of 25 degrees, per *NCHRP Report 350* TL-3 conditions.

The difference between the two rail configurations that were analyzed was the strength of the breakaway post connection. Two slots are fabricated into the front flange of the post near its attachment to the baseplate. Upon loading in the lateral direction about the strong axis of the post, the flange ruptures and releases the post from the baseplate, thereby eliminating the potential for vehicle-post snagging. The length of these slots controls the force or moment at which the post will breakaway. The initial configuration analyzed had posts that incorporated ½-inch long weakening slots. This is the same configuration used with the T6 tubular W-beam rail system.

The desire to use the T8 rail on very thin (i.e., 6.5 inch thick) deck structures lead to an investigation of the performance of several different post configurations with various weakening slot lengths. Based on the results of dynamic pendulum testing, a post with 7/8-inch long weakening slots was selected as the second post configuration analyzed for use in the T8 bridge rail system.

The simulation results indicated that T8 systems with both post configurations should be able to redirect and contain the 4409-lb pickup truck under design impact conditions. By design, the posts with the longer 7/8-inch weakening slots activate at a lower lateral load to prevent failure of a thin deck. Consequently, as shown in Table 6.1, the system with the larger 7/8-inch weakening slots is expected to have almost twice the number of posts activate during impact and have a 32 percent increase in dynamic deflection compared to the T8 system that has posts with ½-inch weakening slots.

Table 6.1. Comparison of T8 Impact Simulations with Different Post Configurations.

	Post Configuration	
	½-inch weakening slots	7/8-inch weakening slots
Number of posts released	6 posts	11 posts
Max. dynamic rail deflection	28 inches	37 inches
Max. vehicle roll angle	~20 degrees	~10 degrees
Max. vehicle pitch angle	~10 degrees	~17 degrees

CHAPTER 7. IMPLEMENTATION RECOMMENDATIONS

The T6 tubular W-beam bridge rail has seen widespread use across the state of Texas. However, because it was unable to satisfy TL-3 impact performance requirements of *NCHRP Report 350*, it is no longer eligible for use on high-speed roadways. A new, flexible bridge rail system, referred to herein as the T8 rail, has been designed as a replacement for the T6 rail in high-speed applications.

The T8 incorporates a tubular thrie beam rail element. Use of a tubular thrie beam provides additional rail height that improves stability for light truck vehicles. Compared with the tubular W-beam, the tubular thrie beam rail has a reduced clear opening that minimizes the potential for vehicle underride. Additionally, use of the thrie beam rail, which is an industry standard rail shape, facilitates the transition to the approach guardrail using "off-the-shelf" components.

The anchor bolt pattern or "footprint" for the T8 post is the same as that used for the T6 post. This facilitates upgrade of existing T6 installations.

As with the T6 system, the posts in the T8 rail are designed to breakaway to prevent vehicle snagging and control deck damage. Two different post configurations were evaluated for use in the T8 rail. One incorporates ½-inch weakening slots similar to the post used in the T6 rail. The other has longer 7/8-inch weakening slots to further reduce the lateral capacity of the post for applications on very thin deck structures.

It is recommended that full-scale crash testing be conducted to verify the impact performance of the T8 bridge rail. The TL-3 test matrix for longitudinal barriers in *NCHRP Report 350* includes two tests: test designations 3-10 and 3-11. Test 3-10 involves an 1800-lb passenger car impacting the barrier at a speed of 62 mi/hr and an angle of 20 degrees. Test 3-11 involves a 4409-lb pickup truck impacting the rail at a speed of 62 mi/h and an angle of 25 degrees. Since use of the tubular thrie beam rail eliminates vehicle underride as an issue, test 3-10 is not considered necessary. Compliance with *NCHRP Report 350* can, therefore, be satisfactorily evaluated with test 3-11.

Many of the applications for the T8 rail are expected to be on thin bridge decks and culverts. Therefore, the version recommended for full-scale crash testing is the system that incorporates posts with the longer 7/8-inch weakening slots. This configuration is designed for use on decks as thin as 6.5 inches and having a compressive strength of 3000 psi or greater. Details of the recommended T8 bridge rail system are shown in Figures 7.1 through 7.6.

If the full-scale crash test is successful, the new T8 bridge rail can be implemented on a state-wide basis through development of a new standard detail sheet.

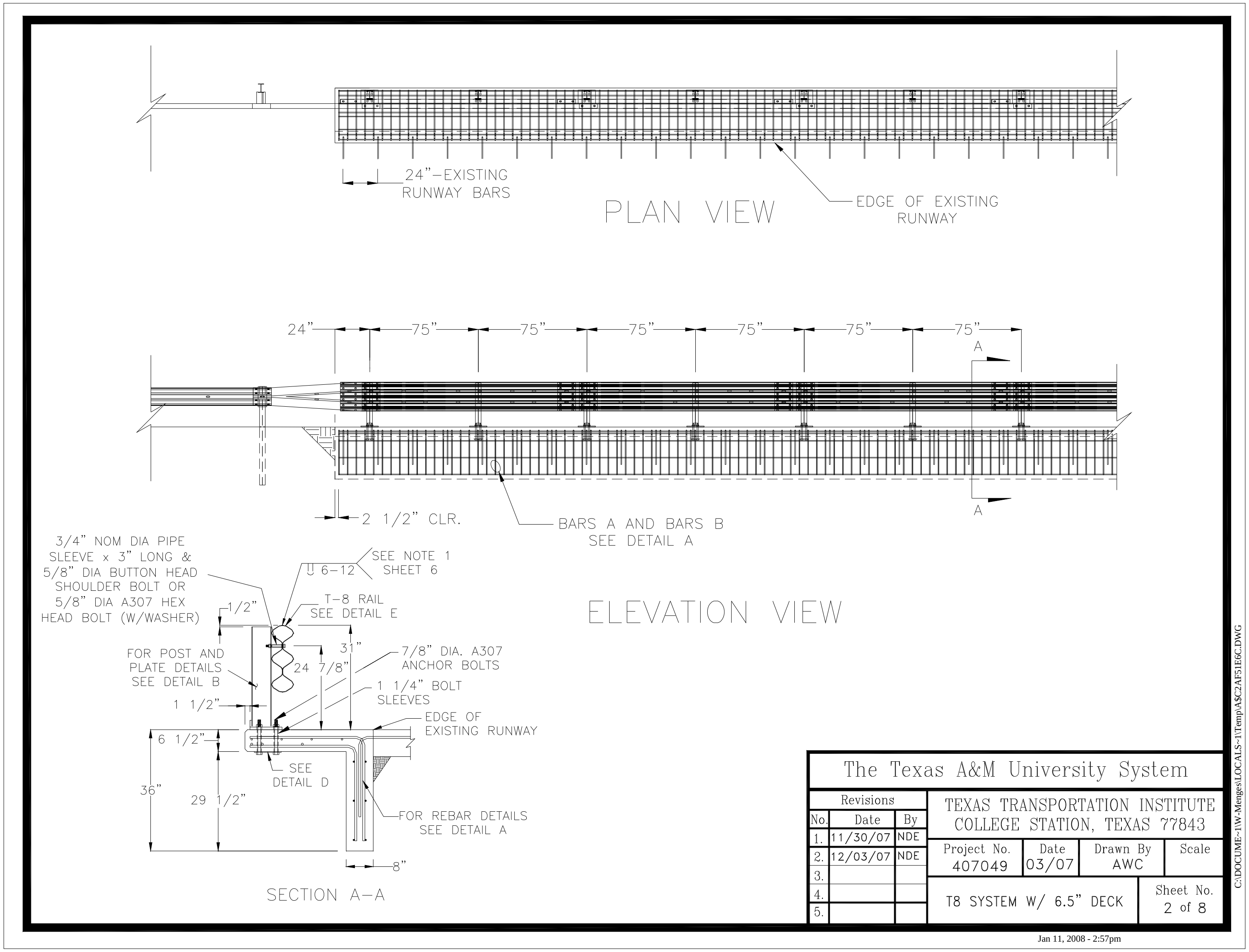


Figure 7.1. Details of the Deck of the TxDOT Type T8 Bridge Rail Test Installation.

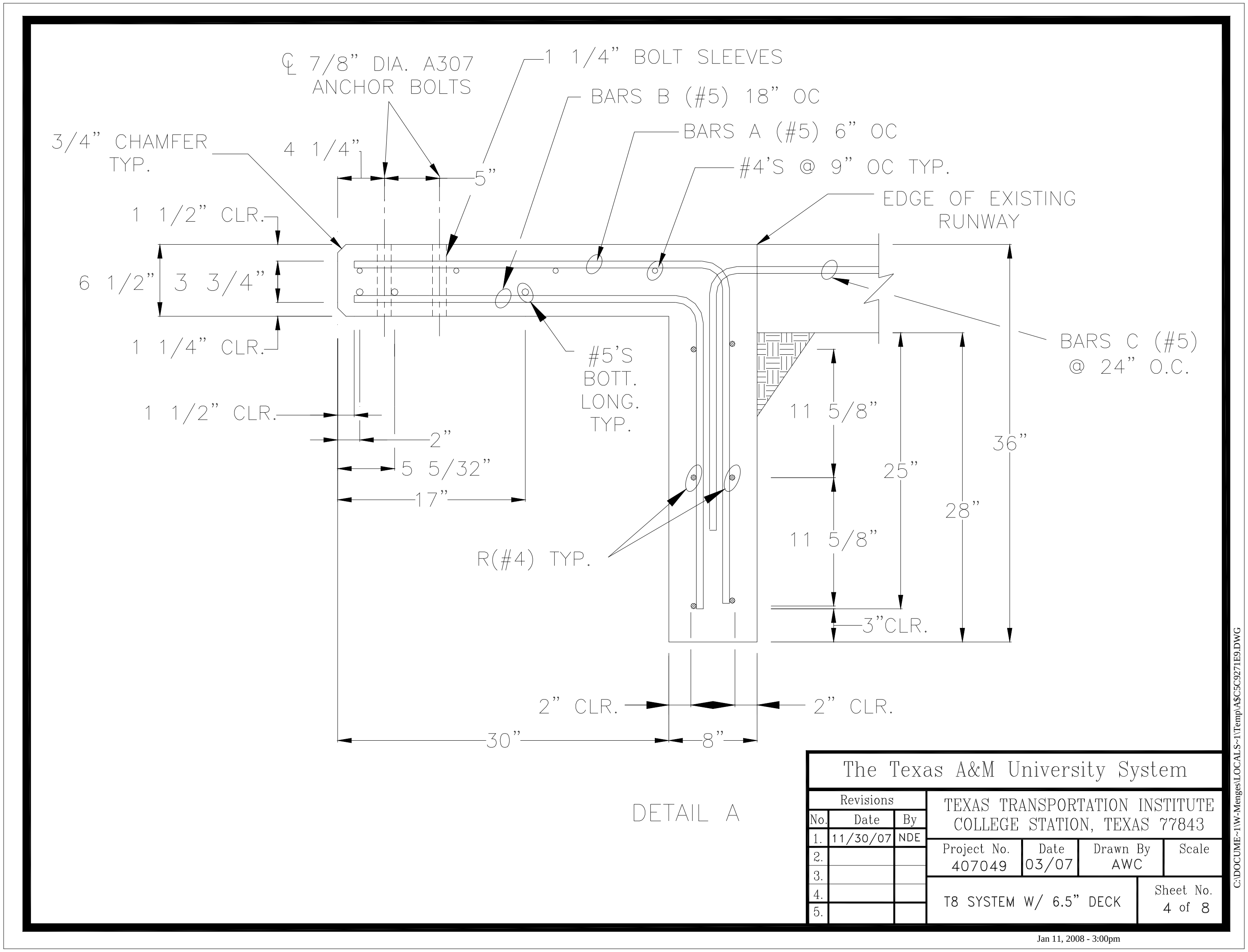


Figure 7.2. Details of the Deck Reinforcement of the TxDOT Type T8 Bridge Rail Test Installation.

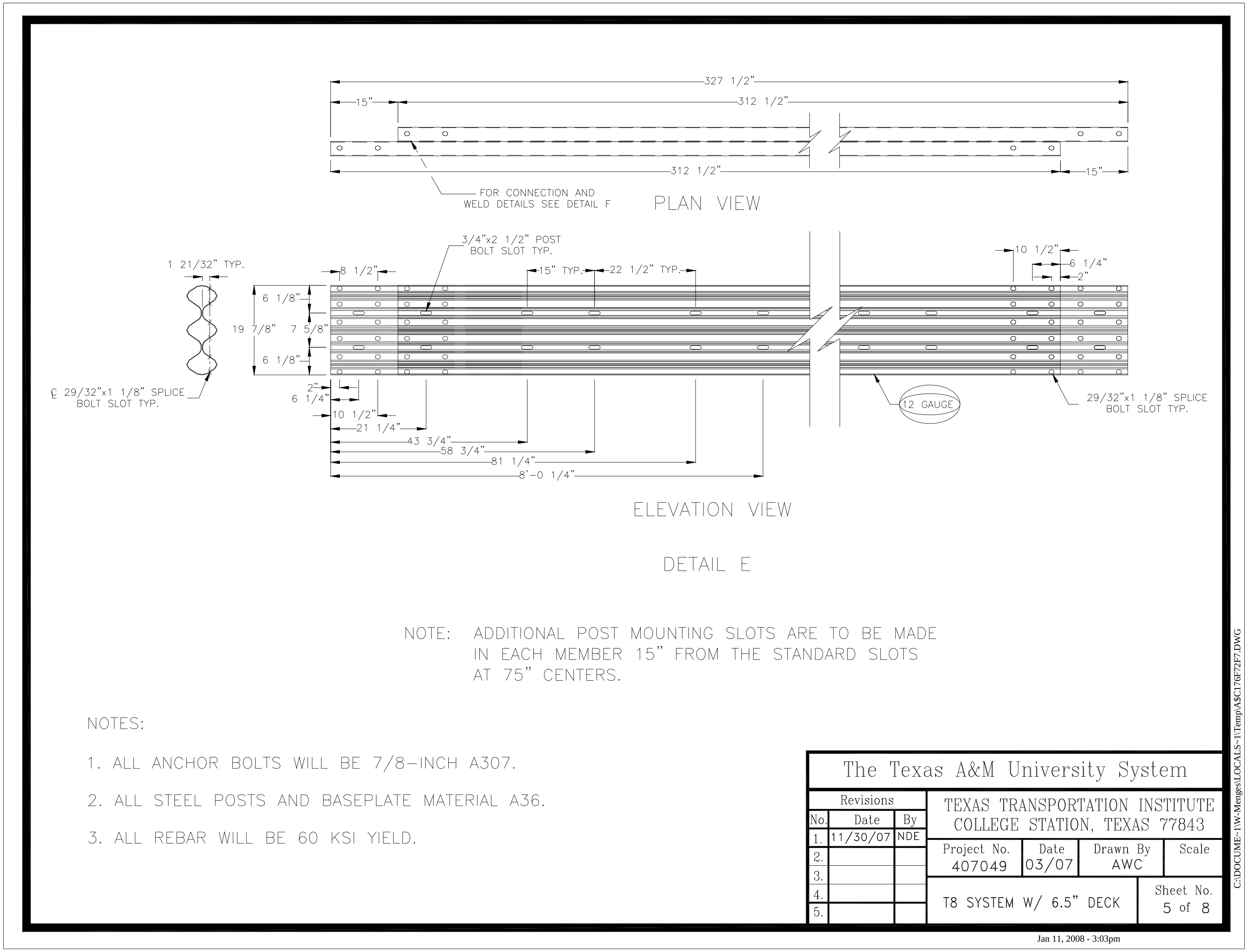


Figure 7.3. Details of the Tubular Rail Element of the TxDOT Type T8 Bridge Rail Test Installation.

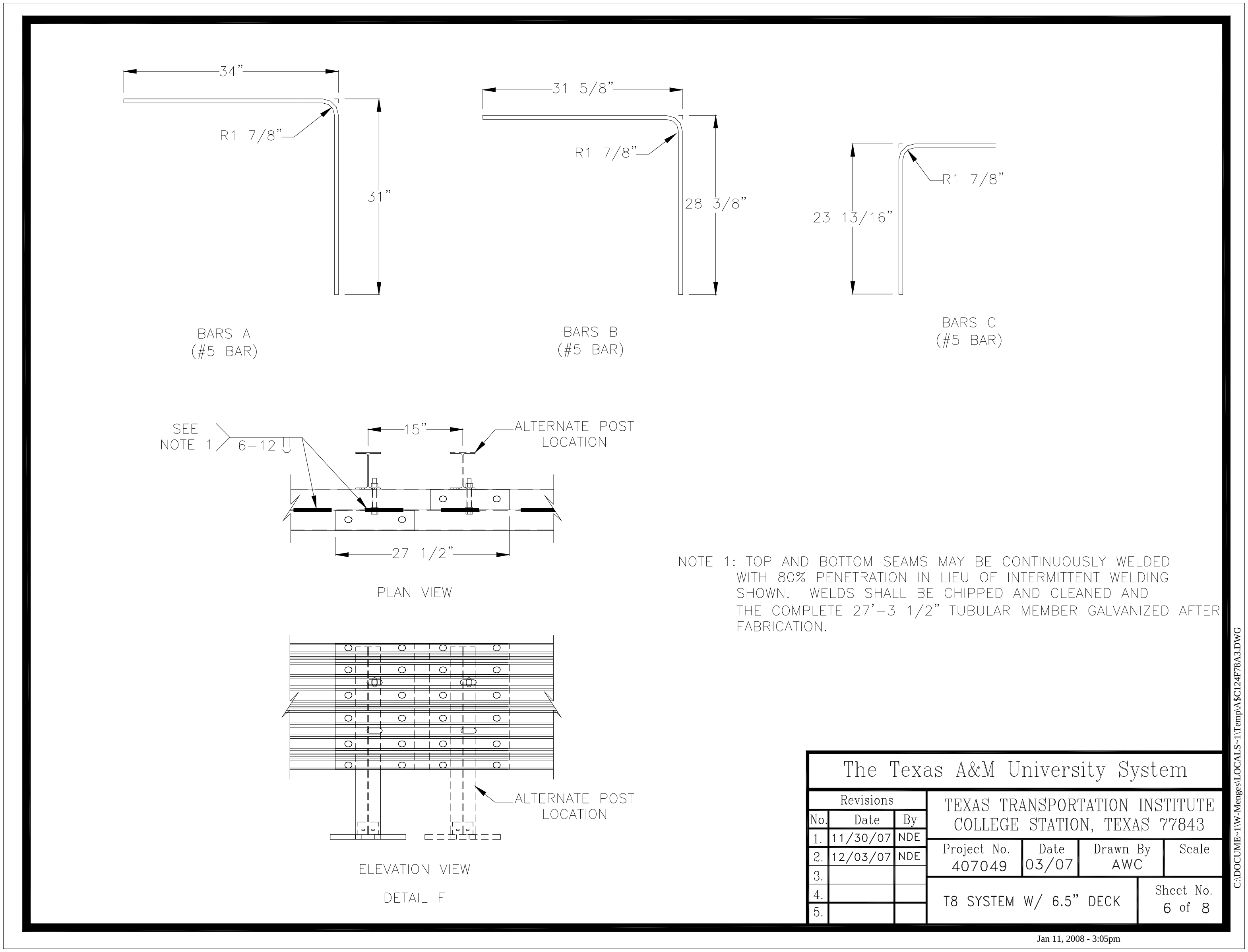


Figure 7.4. Details of the Rebar of the TxDOT Type T8 Bridge Rail Test Installation.

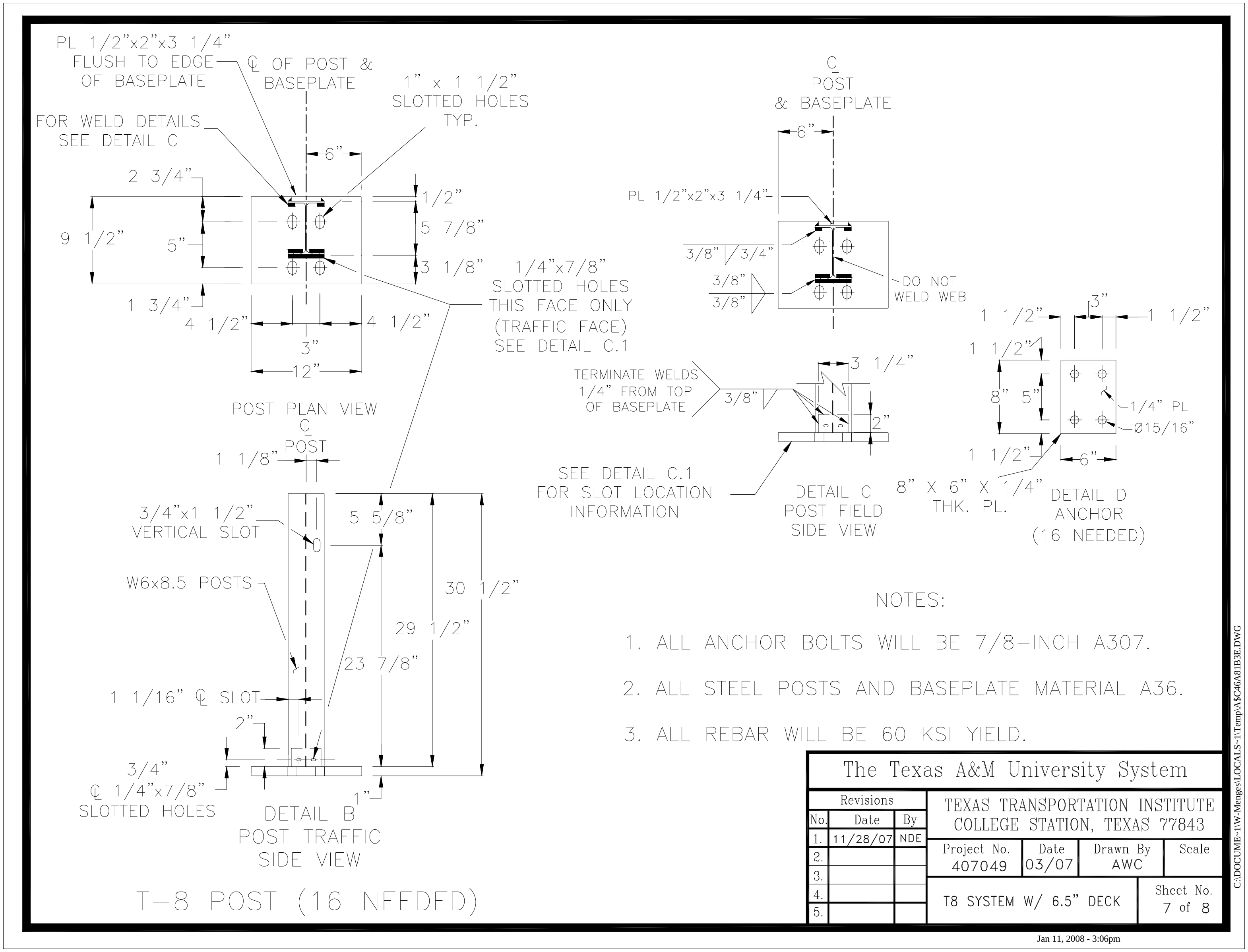


Figure 7.5. Details of the Post of the TxDOT Type T8 Bridge Rail Test Installation.

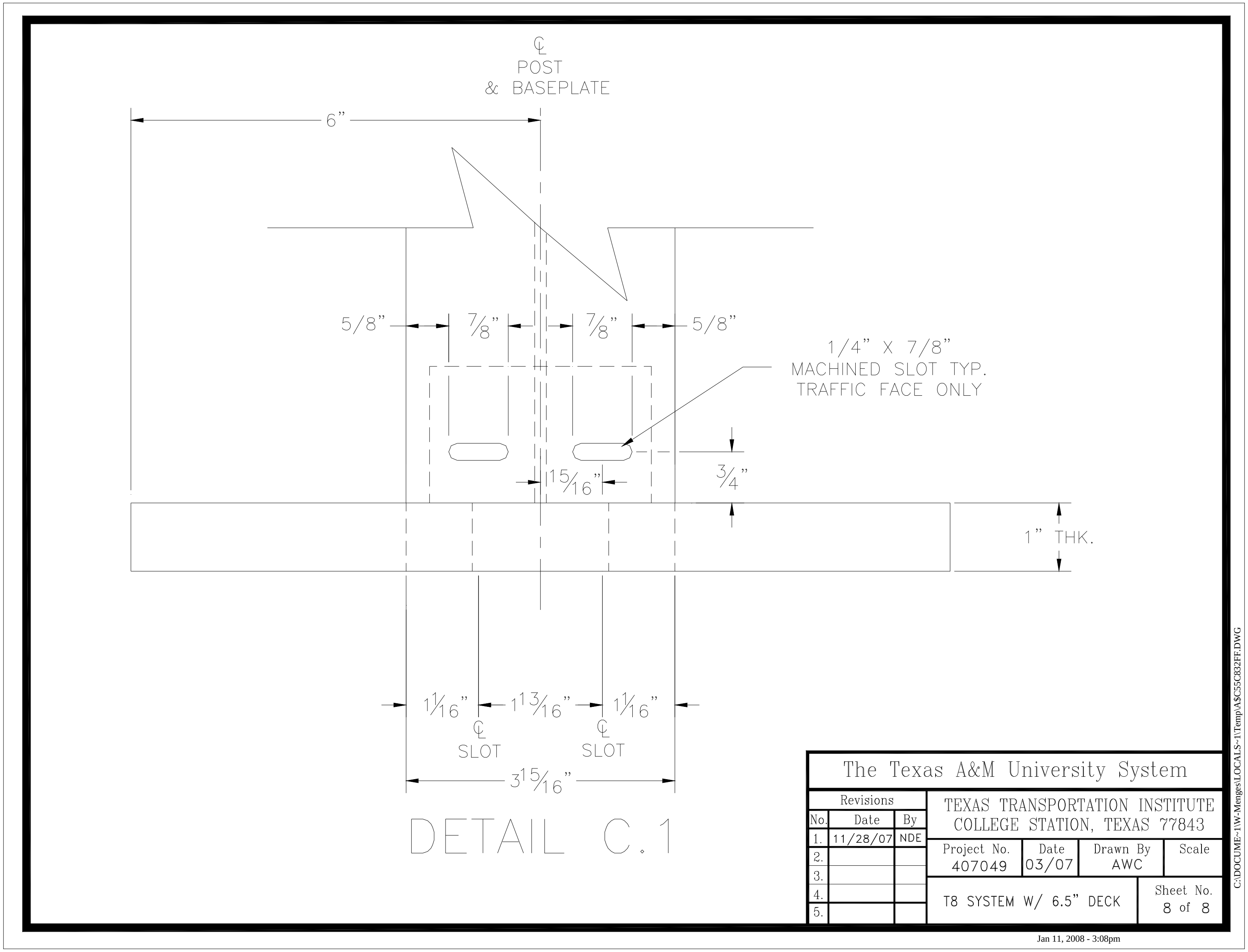


Figure 7.6. Details of the Slots in Post of the TxDOT Type T8 Bridge Rail Test Installation.

REFERENCES

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2. *TRC 191: Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances*. Transportation Research Board, National Research Council, Washington, D.C., February 1978.

3. J.D. Michie. *NCHRP Report 230: Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*. National Cooperative Highway Research Program Report 350, TRB, National Research Council, Washington, D.C., March 1981.

4. H.E. Ross, D.L. Sickling, R.A. Zimmer, and J.D. Michie. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features*. TRB, National Research Council, Washington, D.C., 1993.

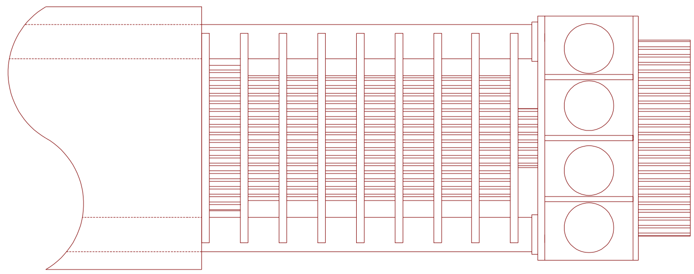
5. C.E. Buth, R.P. Bligh, and W.L. Menges. *NCHRP Report 350 Test 3-11 of the Texas Type 6 Bridge Rail.* Report FHWA/TX-98/1804-4. Texas Transportation Institute, Texas A&M University, College Station, Texas, July 1998.

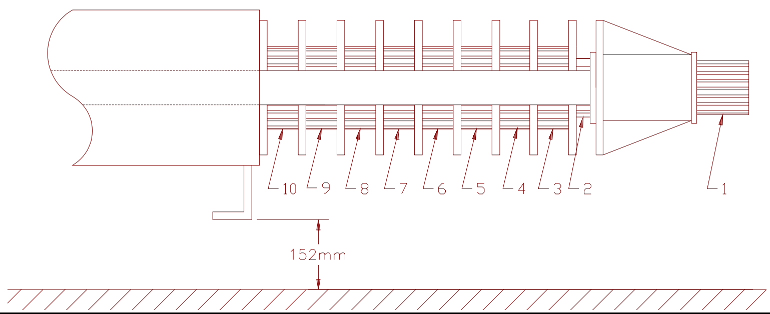
6. W.F. Williams. *Texas Department of Transportation "T6" Bridge Rail Post to Baseplate Weld Investigation.* TTI Contract No. 418048. Texas Transportation Institute, Texas A&M University, College Station, Texas, July 1998.

7. C.E. Buth, R.P. Bligh, and W.L. Menges. *NCHRP Report 350 Test 3-11 of the Texas Type 6 Bridge Rail on Bridge Deck.* Report FHWA/TX-98/1804-3. Texas Transportation Institute, Texas A&M University, College Station, Texas, October 1998.

8. C.E. Buth, W. F. Williams, R.P. Bligh, and W.L. Menges. *Test 12- NCHRP Report 350 Test 3-11 of the Modified Texas Type 6 Bridge Rail on Bridge Deck.* Report FHWA/TX-00/1804-10. Texas Transportation Institute, Texas A&M University, College Station, Texas, February 2000.

APPENDIX A. PENDULUM BOGIE DETAILS





Cartridge Number	Size (mm)	Area Effectively Removed by Pre-Crushing (mm^2)	Static Crush Strength (kPa)	Total Crush Force for Each Cartridge (kN)
1	69.9 × 406 × 76		896.3	25.4
2	102 × 127 × 51		172.4	2.2
3	203 × 203 × 76	13549	896.3	24.8
4	203 × 203 × 76	9678	1585.8	50.0
5	203 × 203 × 76	3871	1585.8	59.2
6	203 × 203 × 76		1585.8	65.3
7	203 × 203 × 76	13549	2757.9	76.3
8	203 × 203 × 76	7742	2757.9	92.3
9	203 × 203 × 76		2757.9	113.6
10	203 × 254 × 76		2757.9	142.3

APPENDIX B. PENDULUM TEST PROCEDURES AND DATA ANALYSIS

The pendulum test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The bogie was instrumented with two accelerometers mounted at the rear of the bogie 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, time of occupant/compartment impact after bogie impact, and 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. For reporting purposes, the data from the bogie-mounted accelerometers were then filtered with a 180 Hz digital filter and plotted using a commercially available software package (Microsoft EXCEL).

PHOTOGRAPHIC INSTRUMENTATION

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

APPENDIX C. ACCELERATION AND FORCE TRACES

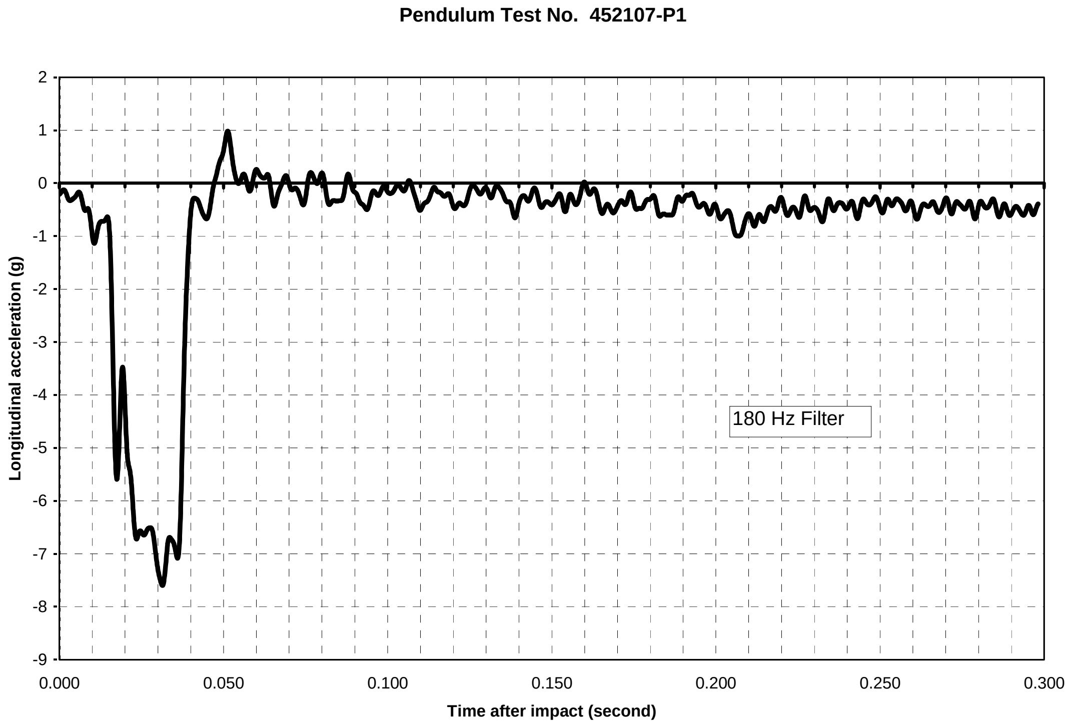


Figure C1. Accelerometer Trace for Test 4452107-P1.

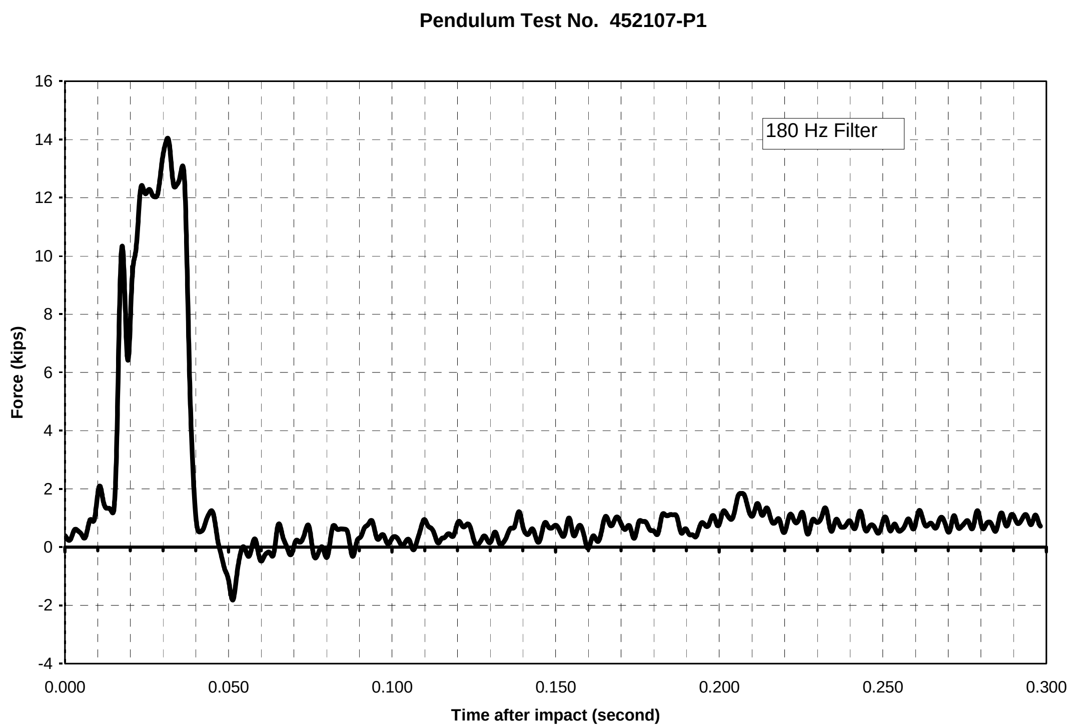


Figure C2. Force Trace for Test 452107-P1.

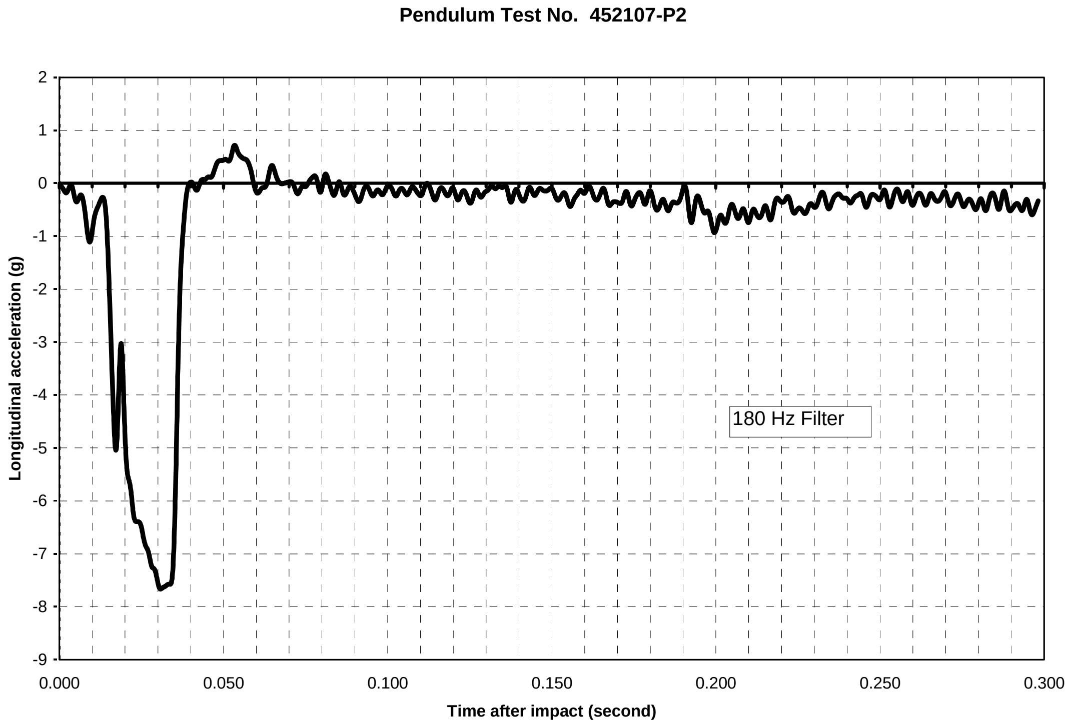


Figure C3. Acceleration Trace for Test 452107-P2.

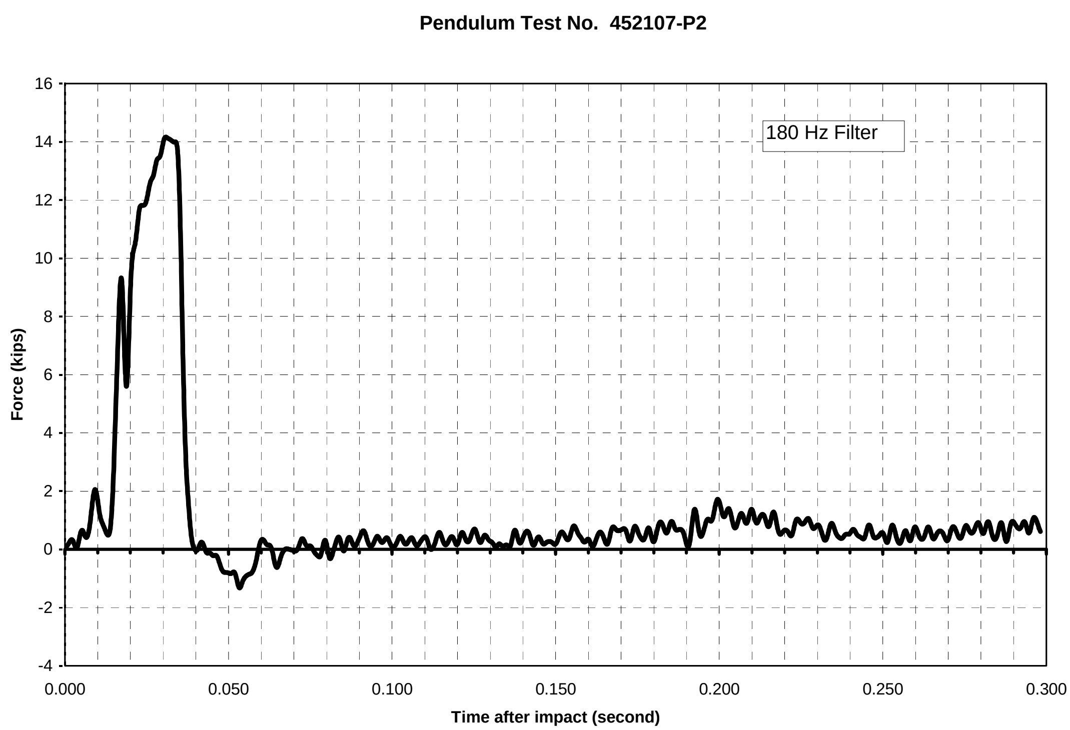


Figure C4. Force Trace for Test 452107-P2.

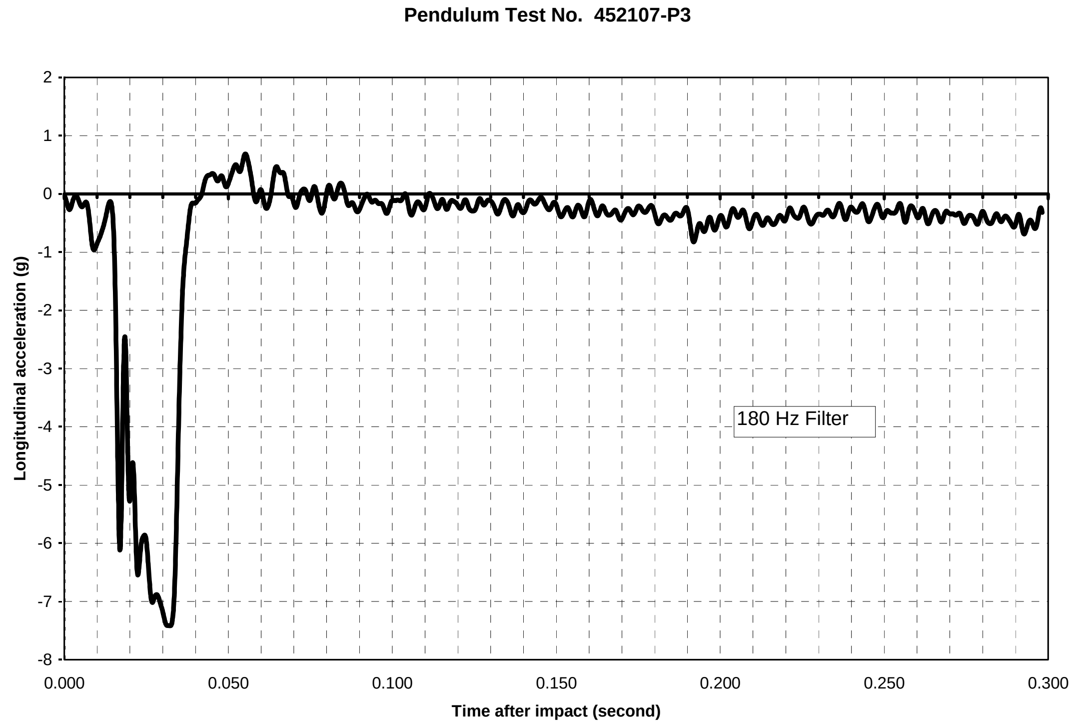


Figure C5. Acceleration Trace for Test 452107-P3.

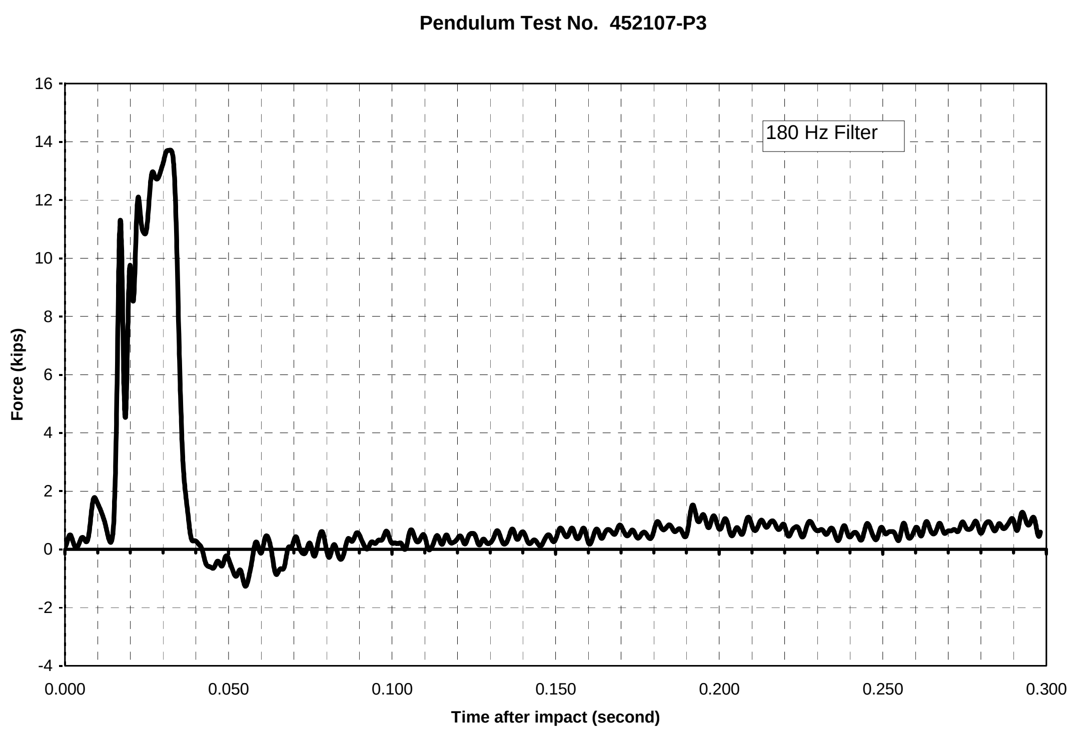


Figure C6. Force Trace for Test 452107-P3.

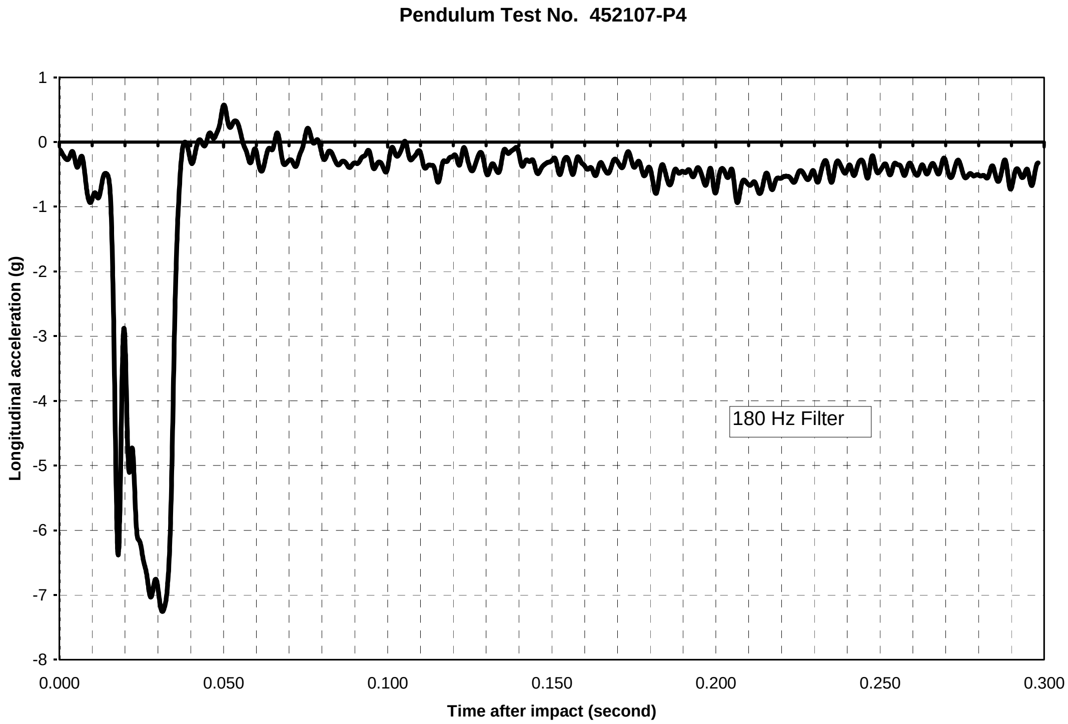


Figure C7. Acceleration Trace for Test 452107-P4.

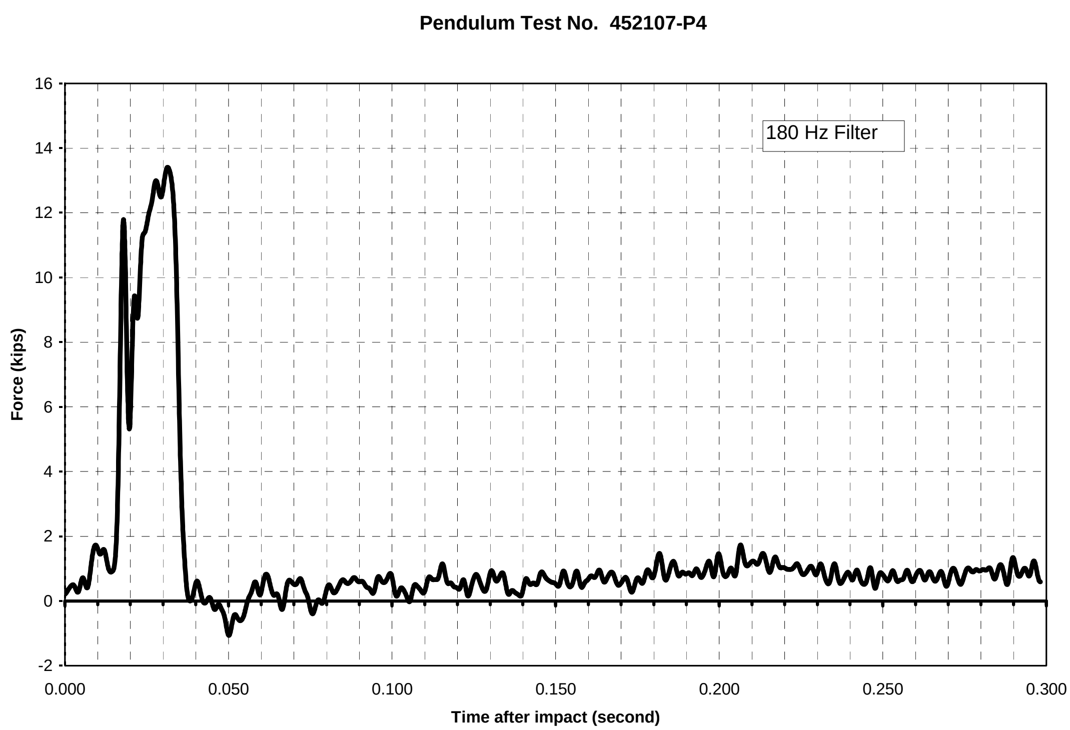


Figure C8. Force Trace for Test 452107-P4.

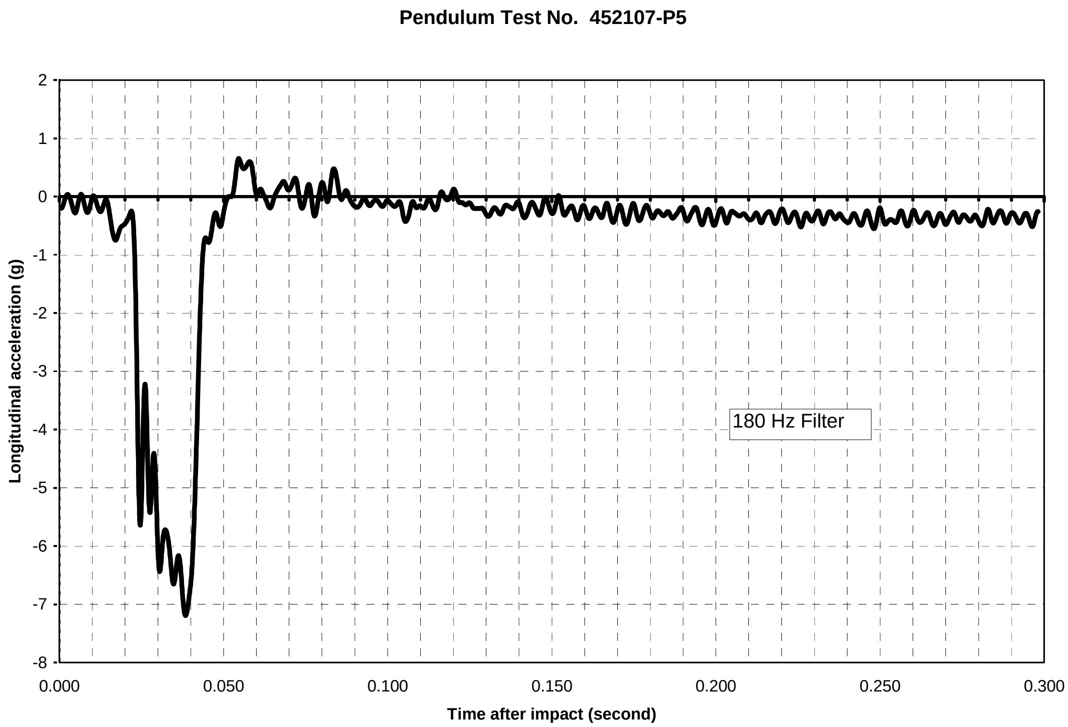


Figure C9. Accelerometer Trace for Test 4452107-P5.

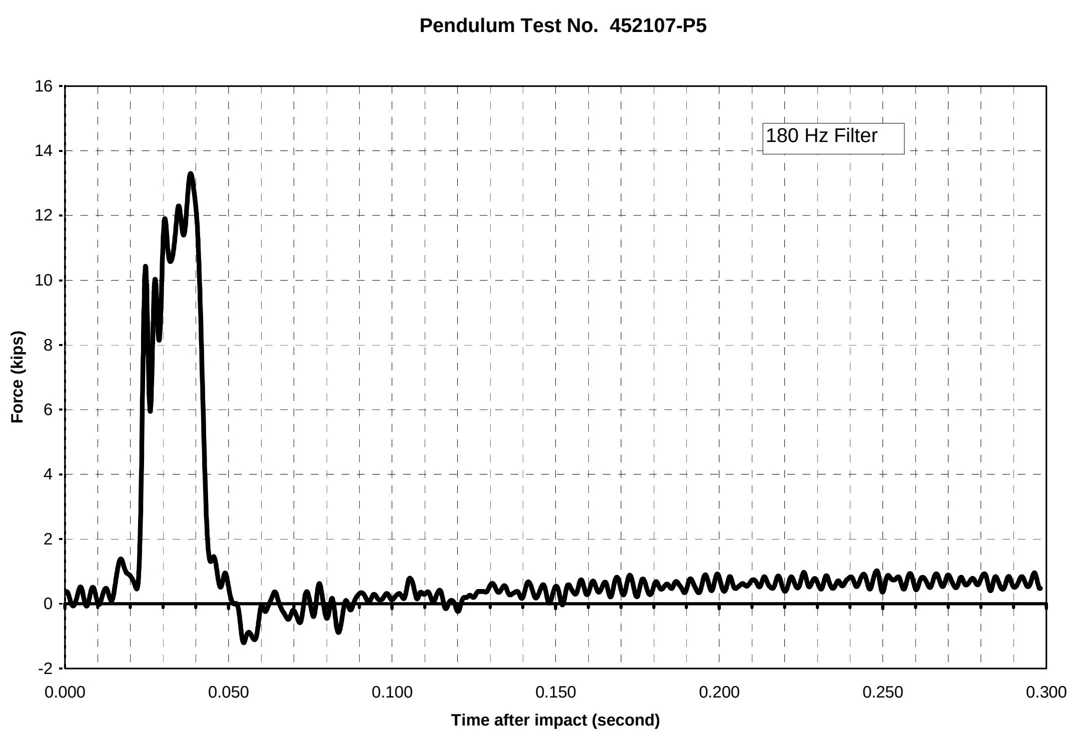


Figure C10. Force Trace for Test 452107-P5.

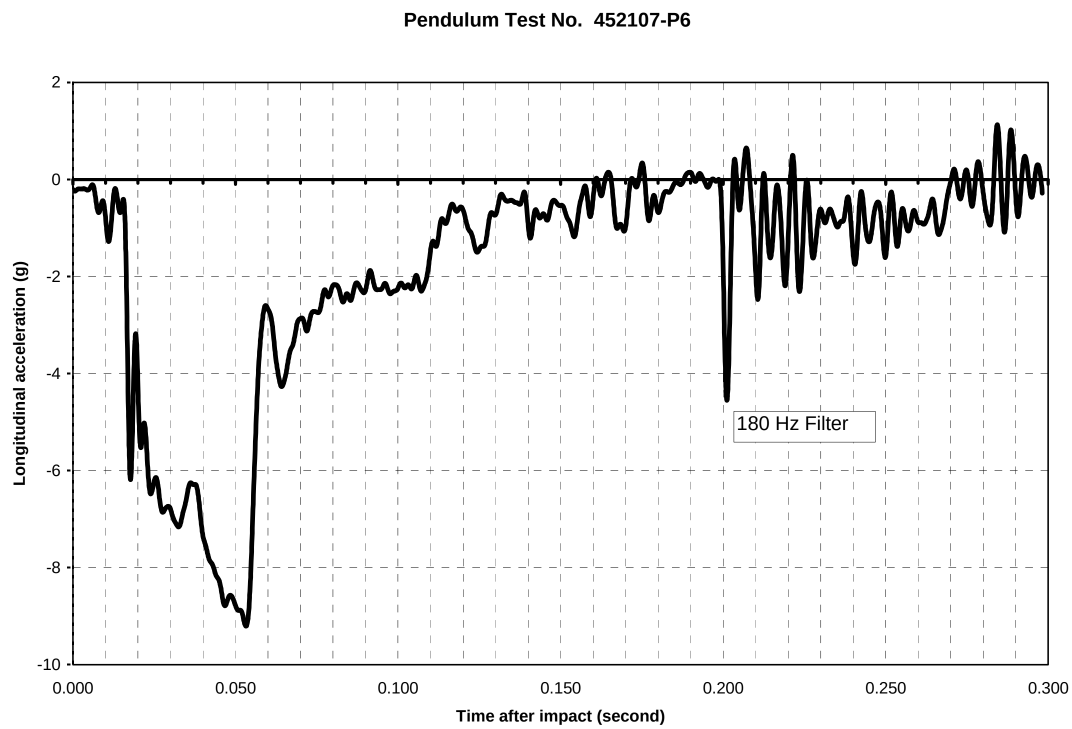


Figure C11. Acceleration Trace for Test 452107-P6.

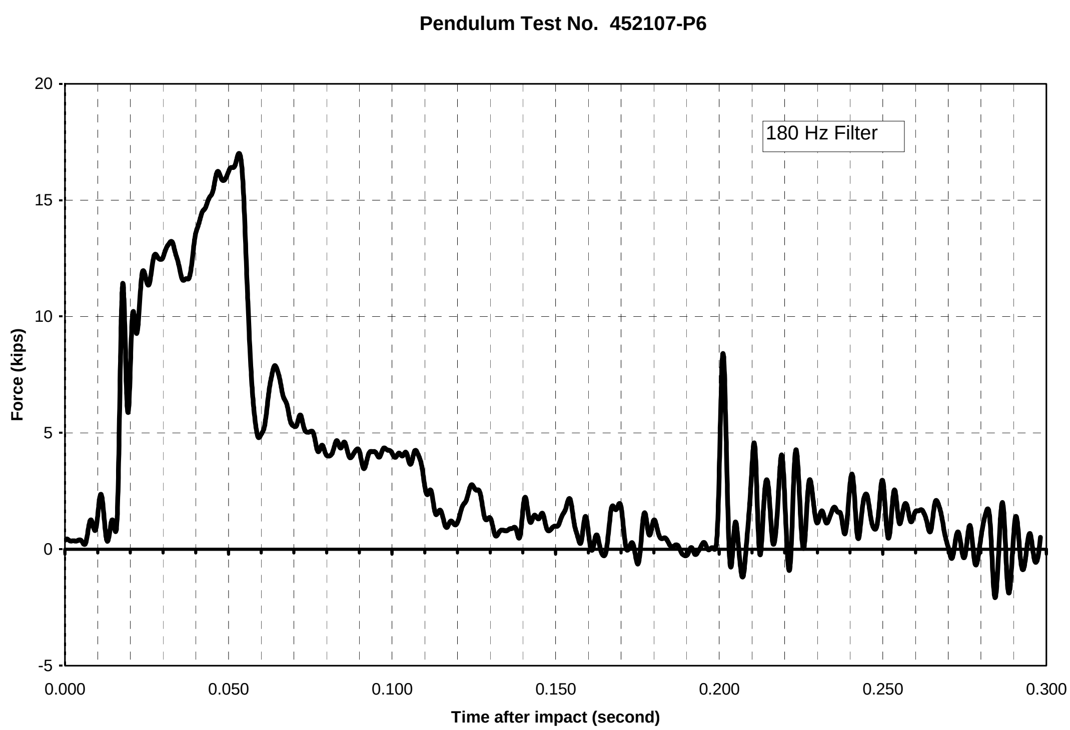


Figure C12. Force Trace for Test 452107-P6.

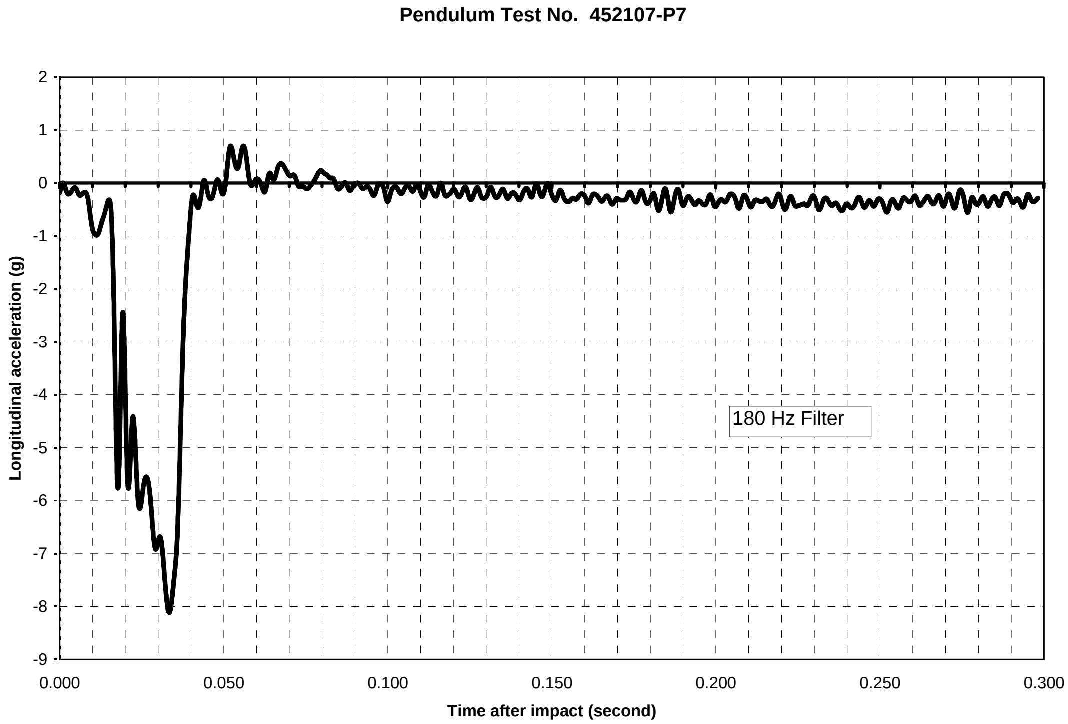


Figure C13. Acceleration Trace for Test 452107-P7.

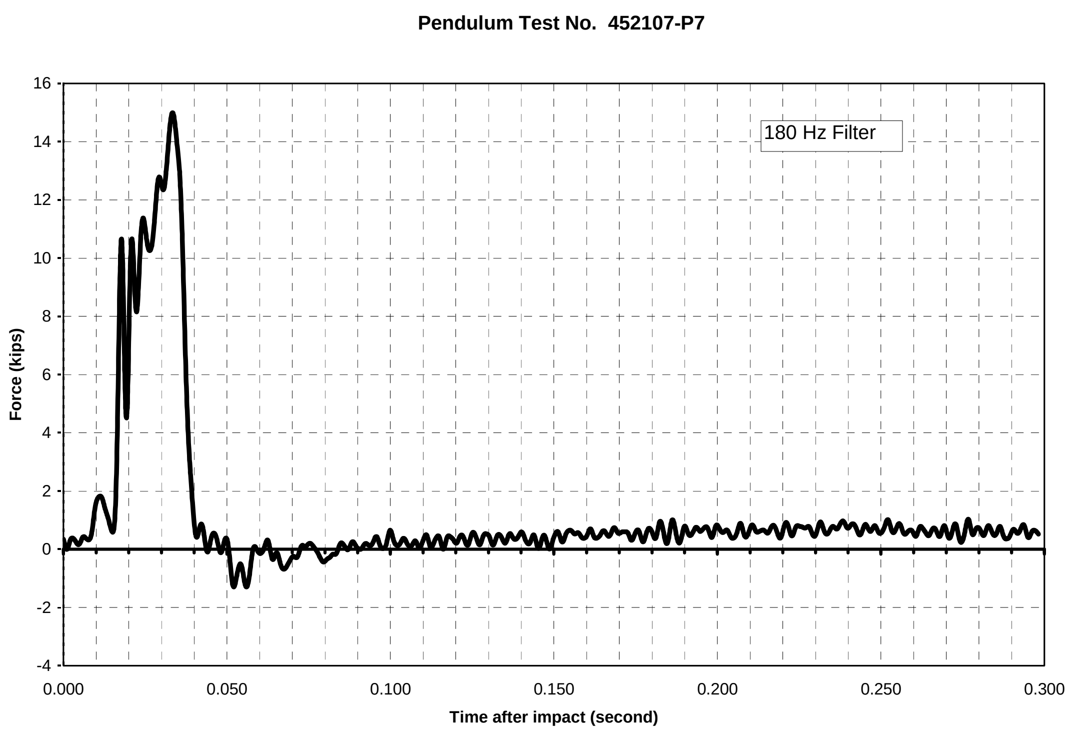


Figure C14. Force Trace for Test 452107-P7.

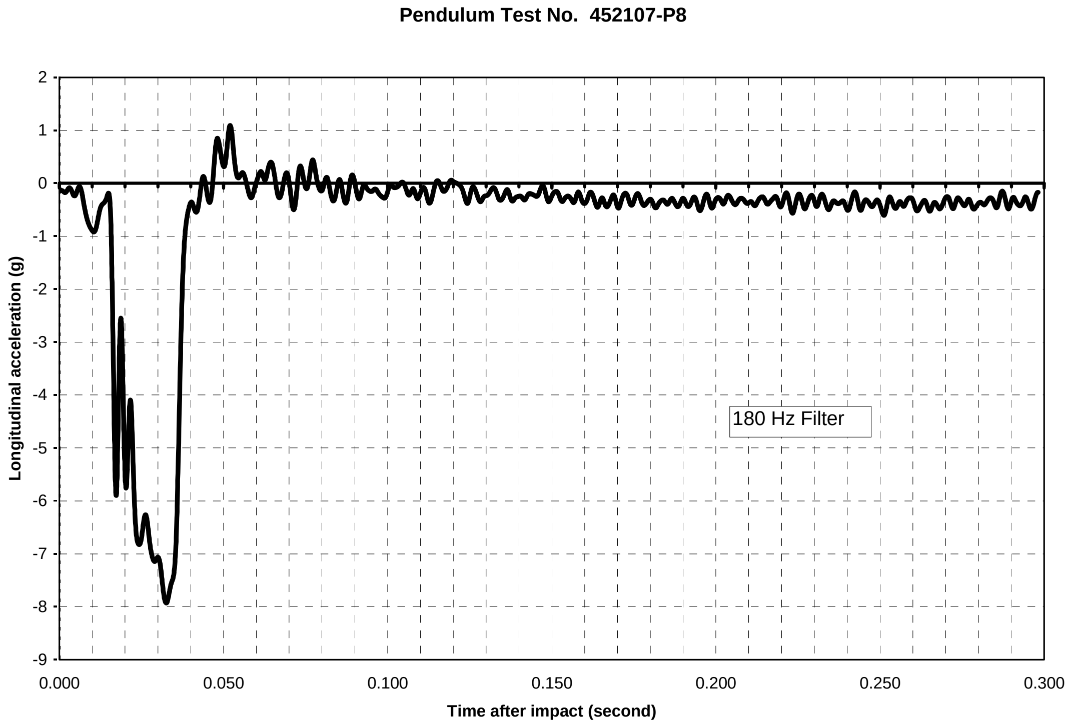


Figure C15. Acceleration Trace for Test 452107-P8.

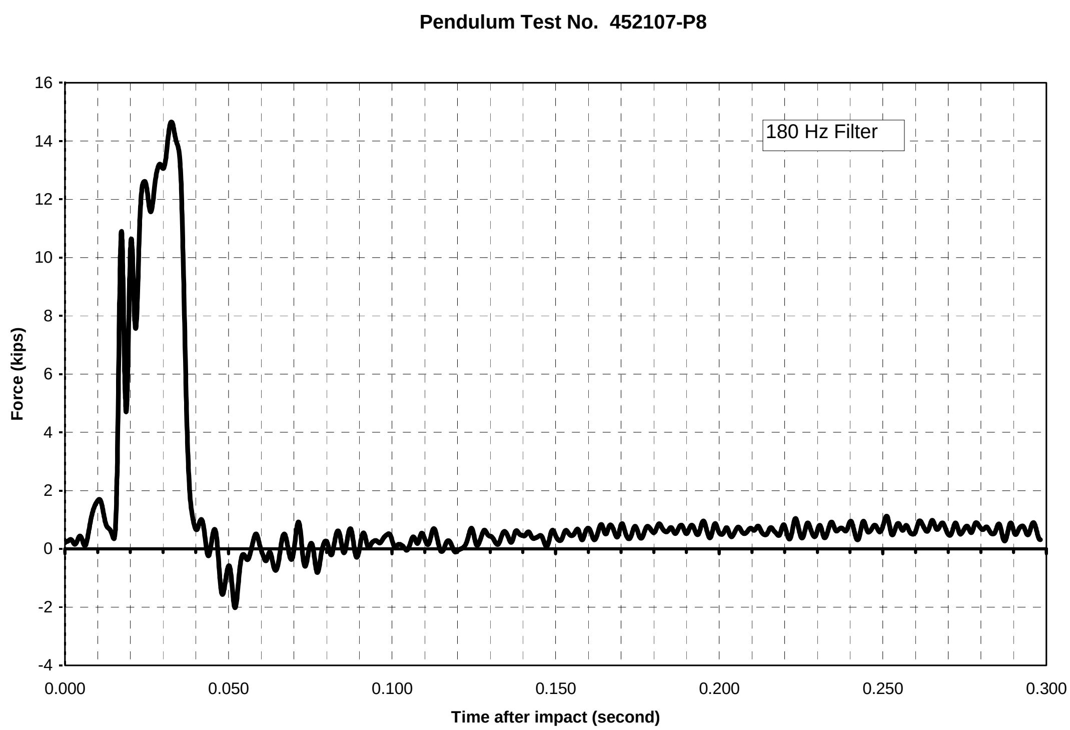


Figure C16. Force Trace for Test 452107-P8.

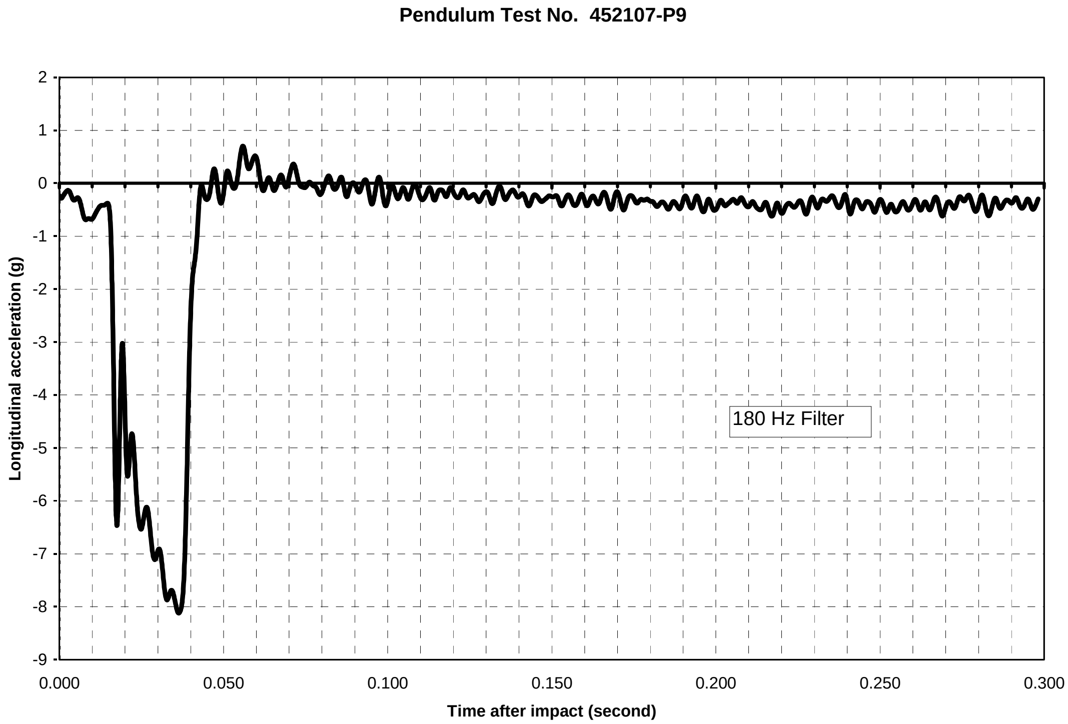


Figure C17. Acceleration Trace for Test 452107-P9.

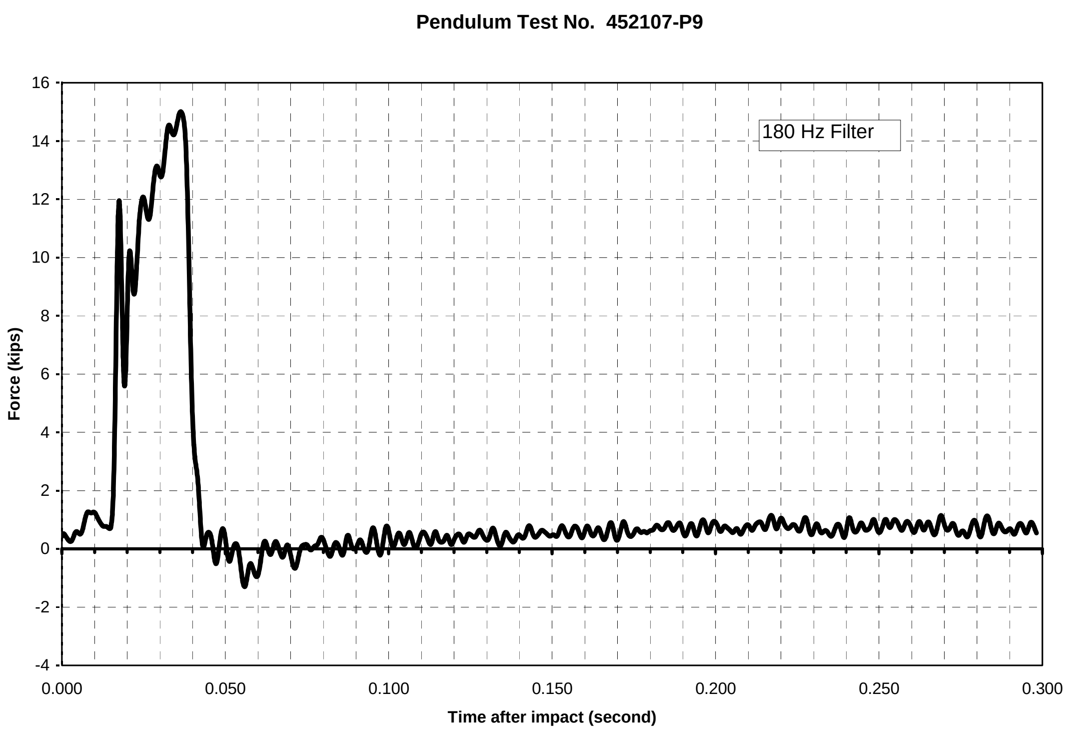


Figure C18. Force Trace for Test 452107-P9.