Texas A&M Transportation Institute
Proving Ground

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TECHNICAL MEMORANDUM

Contract No.:	**T4541-BT**
Test Report No.:	**TM602371-P1-P4**
Project Name:	**Guidance for Raising Beam Guardrail Block**
Sponsor:	**Roadside Safety Pooled Fund**

DATE: **September 23, 2013**

TO: **Aurora (Rory) Meza, P.E.**
Roadway Design Section Director
Texas Department of Tansportation

COPY TO: Erlinda Olivarez, TTI RDO
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FROM: **Chiara Silvestri Dobrovolny**, Associate Research Scientist, Texas A&M Transportation Institute

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SUMMARY REPORT:

DISCLAIMER

INTRODUCTION

The objective of the pendulum tests on the raised 8-inch wood blockout on wood posts embedded in soil is to evaluate the system impact response and allow understanding whether the bending moment induced by the impact is sufficient to fail the wood blockout in bending. Blockout failure mode (if any) and force-displacement data was recorded to understand the strength of the raised blockout on wood post system and its capacity to transmit the impact forces into the soil.

Pendulum testing was performed September 11, 2013. Weather conditions at the time of testing were as follows: Wind speed: 3-6 mi/h; wind direction: 157-190 degrees with respect to the pendulum bogie; temperature: 84-95 ºF; relative humidity: 39-73 percent.

PENDULUM FACILITY

The raised 8-inch wood blockout on wood posts embedded in soil was tested at Texas A&M Transportation Institute (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. A sweeper plate, constructed of steel angles and a steel plate, is attached to the body of the pendulum with a ground clearance of 6 inches to replicate roughly an automobile's undercarriage. The pendulum impacts the raised 8-inch wood blockout on wood posts embedded in soil at a target speed of 22 mi/h and at a height of 21-25 inches above the ground. A brief description of the procedures is presented in Appendix A.

TEST ARTICLE DESIGN AND CONSTRUCTION

Many beam guardrail sites have recently been found to have rail heights below the DOT/FHWA recommendations due to recent changes and clarifications regarding appropriate height for beam guardrail and/or additional pavement overlay(s). An economical solution to raising guardrail heights is to raise the existing blockouts to achieve the recommended beam heights.

Four tests were conducted to determine the wooden post's dynamic performance, each test varying the direction and height of impact energy imparted by the pendulum bogie at TTI's Proving Ground Pendulum Facility.

Test P1 - Perpendicular Impact

For Test P1, a 72-inch long modified wooden post (PDE02) with a blockout (PDB01a) was installed such that the top of the post was 28 inches above grade, and the top of the blockout was 32 inches above grade. The post was buried to a depth of 44 inches and secured with pneumatically tamped soil. A W-beam in the form of a W-beam back-up plate (RWB01a) was attached to the post and blockout with an 18-inch guardrail bolt with recessed nut and flat washer through a drilled ¾-inch diameter hole 3 inches below the top of the post (centerline at 25 inches above grade). Test P1 was designed such that the pendulum bogie impacted the face of the W-beam back-up plate at 90^{o} (normal) to what would be the direction of travel, at a target speed of 20 mi/h, and at a height of 29½ inches above grade. Detailed drawings are provided in Attachment B and photographs are shown in Figure 1.

Test P2 - Perpendicular Impact

Test P2 was a repeat of Test P1, with the same test installation setup and same conditions.

Figure 1. Test setup for Tests P1 and P2.

<u>Test P3 – Longitudinal Pull</u>

Test P3 was a pull/jerk test in the longitudinal direction (in the direction of traffic) wherein the test article was yanked by the pendulum bogie at a height of 25 inches above grade. Similar to Test P1, a 72-inch long modified wooden post (PDE02) with a blockout (PDB01a) was installed such that the top of the post was 28 inches above grade, and the top of the blockout was 32 inches above grade. The post was buried to a depth of 44 inches and secured with pneumatically tamped soil.

An 8 ft-6 inch long standard 12 guage W-beam guardrail was attached to the wooden post and blockout with an 18-inch guardrail bolt with recessed nut and flat washer through a drilled ¾-inch diameter hole 3 inches below the top of the post (centerline at 25 inches above grade). Near the test post, the W-beam featured eight ¾-inch diameter holes through which the pendulum cable jerk bracket was attached with ⅝-inch × 2-inch bolts and recessed nuts.

The far end of the W-beam guardrail was supported by a W6×9 anchor post installed in a 6-inch × 8-inch × 6-ft deep steel tubular sleeve embedded in tamped soil. Two 3×3×½-inch angle ground struts connected (welded) the post to a steel baseplate, which was bolted to a reinforced concrete foundation. The guardrail's bolting slot on this end was cut such that it extended to the end of the rail forming a horizontal elongated "U". A standard 1¼-inch guardrail bolt and recessed nut were installed to simply support this end of the Guardrail.

Test P3 was designed such that the pendulum bogie jerked the guardrail and wooden post in a longitudinal direction and at a height of 25 inches above grade. Detailed drawings are provided in Attachment B, and photographs of the completed installation area shown Figure 2.

<u>Test P4 – Longitudinal Pull</u>

Test P4 was a pull/jerk test in the longitudinal direction (in the direction of traffic) similar to Test P3 except that the test article was yanked by the pendulum bogie at a height of 21 inches above grade (vs. 25 inches). Similar to the previous tests, a 72-inch long modified wooden post (PDE02) with a blockout (PDB01a) was installed such that the top of the post was 28 inches above grade. The post was buried to a depth of 44 inches and secured with pneumatically tamped soil. However in Test P4, the top of the blockout was also 28 inches above grade and flush with the top of the post, and the guardrail and blockout were bolted to the post with an 18-inch guardrail bolt with recessed nut and flat washer through a drilled ¾-inch diameter hole 7 inches below the top of the post (centerline at 21 inches above grade). Anchor post installation was similar to Test P3 except that the guardrail bolt was 4 inches lower to provide for a level guardrail. Detailed drawings are provided in Attachment B, and photographs are shown in Figure 3.

Figure 2. Test setup for Test P3.

Figure 3. Test setup for Test P4.

TEST RESULTS

<u>Test P1- Perpendicular Impact</u>

The pendulum bogie impacted the raised 8-inch wood blockout mounted at 32 inches on a wood post embedded in soil at an impact speed of 19.9 mi/h. At approximately 0.038 s, the W-beam backup plate compressed and the wood post began to deflect toward the field side. By 0.143 s, the post contacted the ground, and at 0.178 s, the pendulum lost contact with the blockout and post traveling at an exit speed of 14.7 mi/h. As the pendulum bogie continued forward, the bottom of the post rotated upward and contacted the rear of the pendulum bogie.

The wood post fractured approximately 12 inches below ground level and the upper section pulled out of the ground. The blockout remained attached to the post. A ½-inch gap was measured from the lower edge of the blockout to the post, as shown in Figure 4.

Longitudinal occupant impact velocity was 8.5 ft/s, and longitudinal ridedown acceleration was 0.7 G. The maximum longitudinal 50-msec average acceleration was -3.7 G. Maximum 10-ms average force was 15.8 kips, and maximum kinetic energy was 12.04 ft-kips. Maximum change in velocity was 7.6 ft/s. A summary of results is provided in Table C1, and accelerometer graphs are shown in Attachment D, Figures D1 and D2.

Figure 4. Post and Blockout after Test P1.

<u>Test P2 – Perpendicular Impact</u>

The pendulum bogie impacted the raised 8-inch wood blockout mounted at 32 inches on a wood post embedded in soil at an impact speed of 20.0 mi/h. At approximately 0.042 s, the W-beam backup plate compressed and the wood post began to deflect toward the field side. By 0.133 s, the post contacted the ground, and at 0.184 s, the pendulum lost contact with the blockout and post traveling at an exit speed of 16.9 mi/h. As the pendulum bogie continued forward, the bottom of the post rotated upward and contacted the rear of the pendulum bogie.

The wood post fractured approximately 7 inches below ground level and the upper section pulled out of the ground. The blockout remained attached to the post and rotated slightly on the post, as shown in Figure 5.

Longitudinal occupant impact velocity was 6.9 ft/s, and longitudinal ridedown acceleration was 0.9 G. The maximum longitudinal 50-msec average acceleration was -3.7 G. Maximum 10-ms average force was 11.0 kips, and maximum kinetic energy was 8.26 ft-kips. Maximum change in velocity was 4.5 ft/s. A summary of results is provided in Table C2, and accelerometer graphs are shown in Attachment D, Figures D3 and D4.

Figure 5. Post and Blockout after Test P2.

<u>Test P3 – Longitudinal Pull</u>

The pendulum bogie pulled the raised 8-inch wood blockout mounted at 31 inches on a wood post embedded in soil at a speed of 14.8 mi/h. At approximately 0.033 s, the wood post began to split and at 0.041 s, the guardrail separated from the post. The wood blockout and rail separated from the post at 0.067 s, and by 0.123 s, the wood blockout and rail contacted the ground.

The wood post split longitudinally. The blockout remained attached to the rail, as shown in Figure 6.

Longitudinal occupant impact velocity was 4.6 ft/s, and longitudinal ridedown acceleration was 0.4 G. The maximum longitudinal 50-msec average acceleration was -1.4 G. Maximum 10-ms average force was 8.9 kips, and maximum kinetic energy was 3.71 ft-kips. A summary of results is provided in Table C3, and accelerometer graphs are shown in Attachment D, Figures D5 and D6.

Figure 6. Post and Blockout after Test P3.

<u>Test P4- Longitudinal Pull</u>

The pendulum bogie pulled the standard 8-inch wood blockout mounted at 27 inches on a wood post embedded in soil at a speed of 15.4 mi/h. At approximately 0.033 s, the wood post began to split where the bolt connects the guardrail, and at 0.054 s, the post split at a second location to the side of the first split. The wood blockout and bolt pulled away from the post at 0.069 , and then began to rotate toward the ground at 0.117 s. At 0.314 s, the blockout contacted the ground.

The wood post split longitudinally. The bolt pulled out of the rail, but remained attached to the blockout, as shown in Figure 7.

Longitudinal occupant impact velocity was 3.9 ft/s, and longitudinal ridedown acceleration was 0.4 G. The maximum longitudinal 50-msec average acceleration was -1.8 G. Maximum 10-ms average force was 8.6 kips, and maximum kinetic energy was 3.54 ft-kips. A summary of results is provided in Table C4, and accelerometer graphs are shown in Attachment D, Figures D7 and D8.

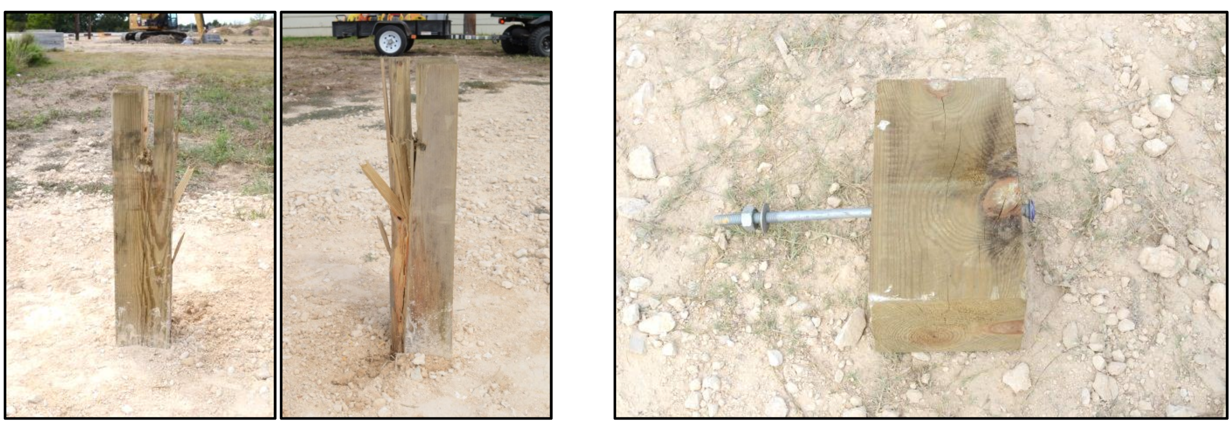


Figure 7. Post and Blockout after Test P4.

ATTACHMENT A. 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.

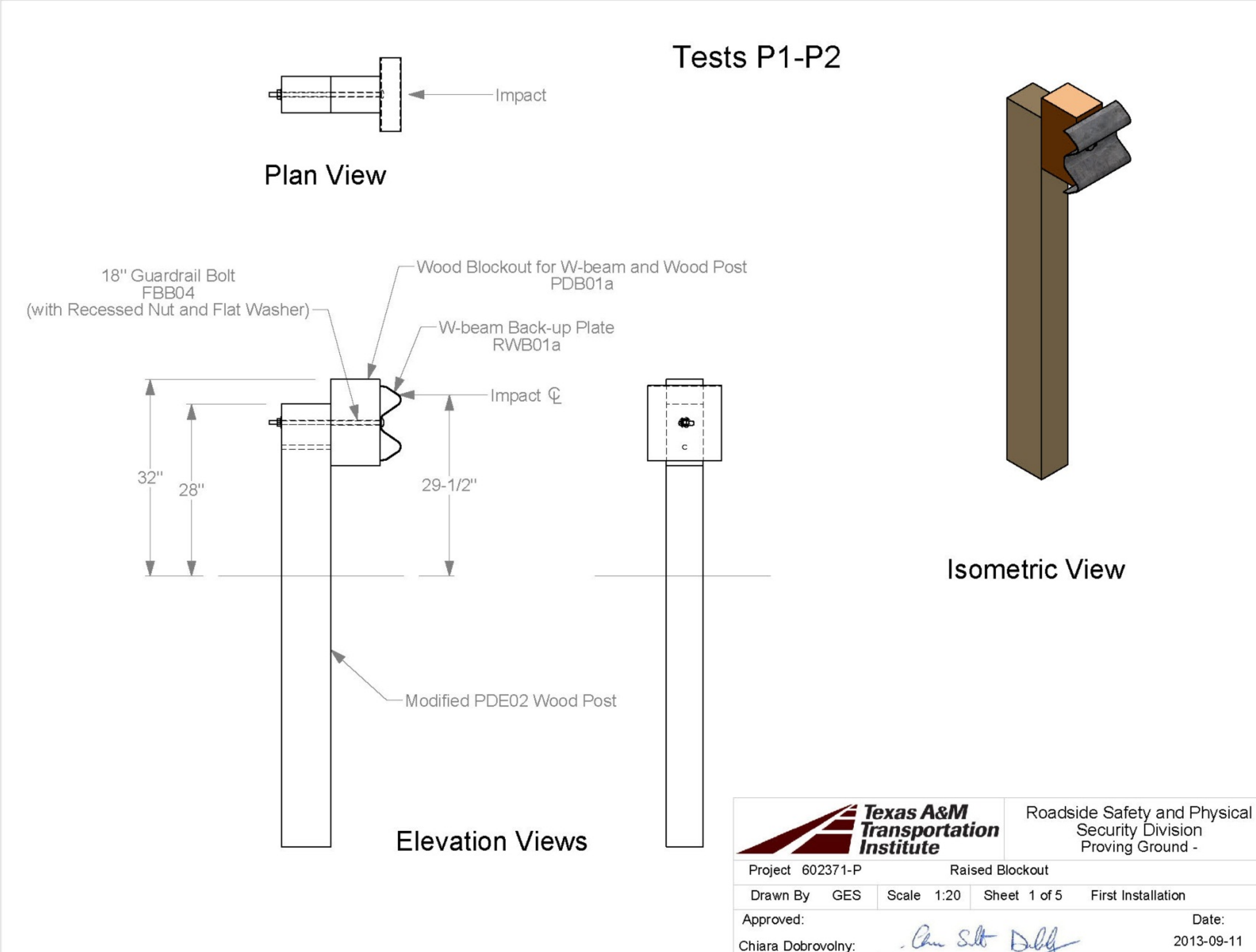
The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto TEAC® instrumentation data recorder. After the test, the data are played back from the TEAC® recorder and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer 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 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. 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

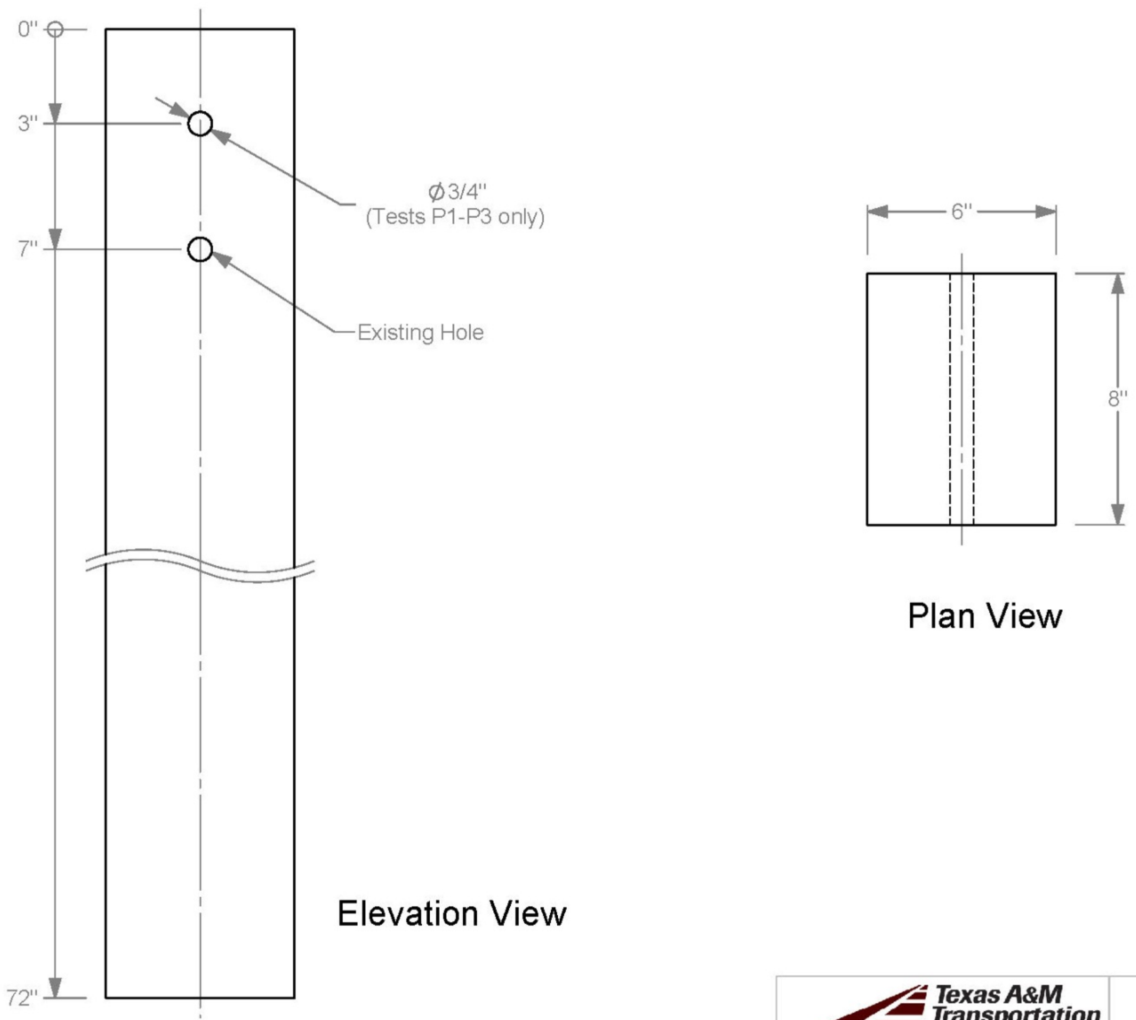
A high-speed digital camera, positioned perpendicular to the path of the bogie and the test article, was used to record the collision period. The film from this high-speed camera was analyzed on a computer to observe phenomena occurring during the collision and to obtain time-event, displacement, and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

ATTACHMENT B. DETAILS OF TEST ARTICLES



T:\2013-2014\602371-Raised Blockout\Drafting\602371-P Drawing , as tested

Post Details



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project 602371-P	Raised Blockout	2013-09-11
Drawn By GES	Scale 1:5	Sheet 2 of 5 Post Details

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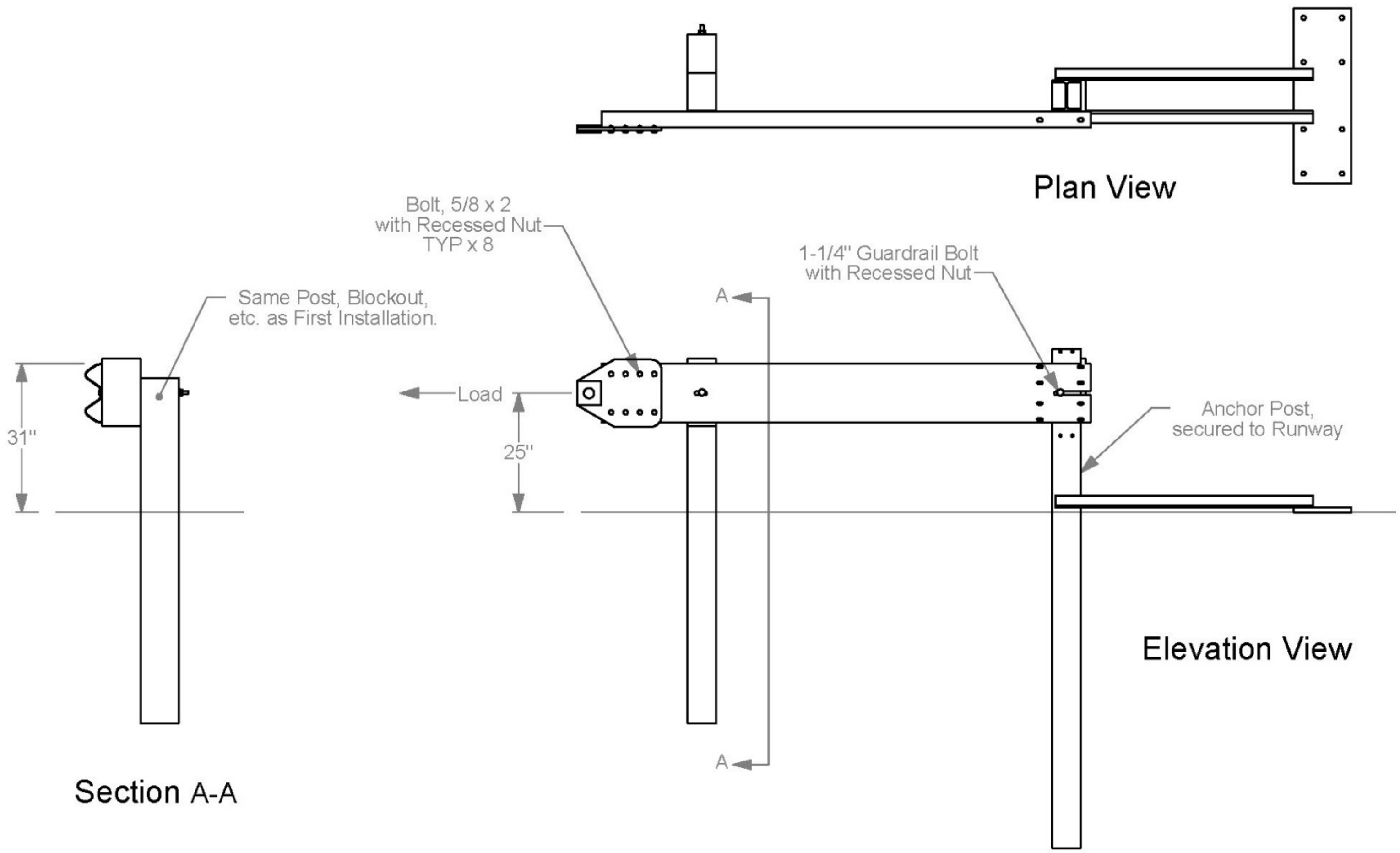
Test P3
Pull Test



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project 602371-P	Raised Blockout		2013-09-11
Drawn By GES	Scale 1:30	Sheet 3 of 5	Second Installation

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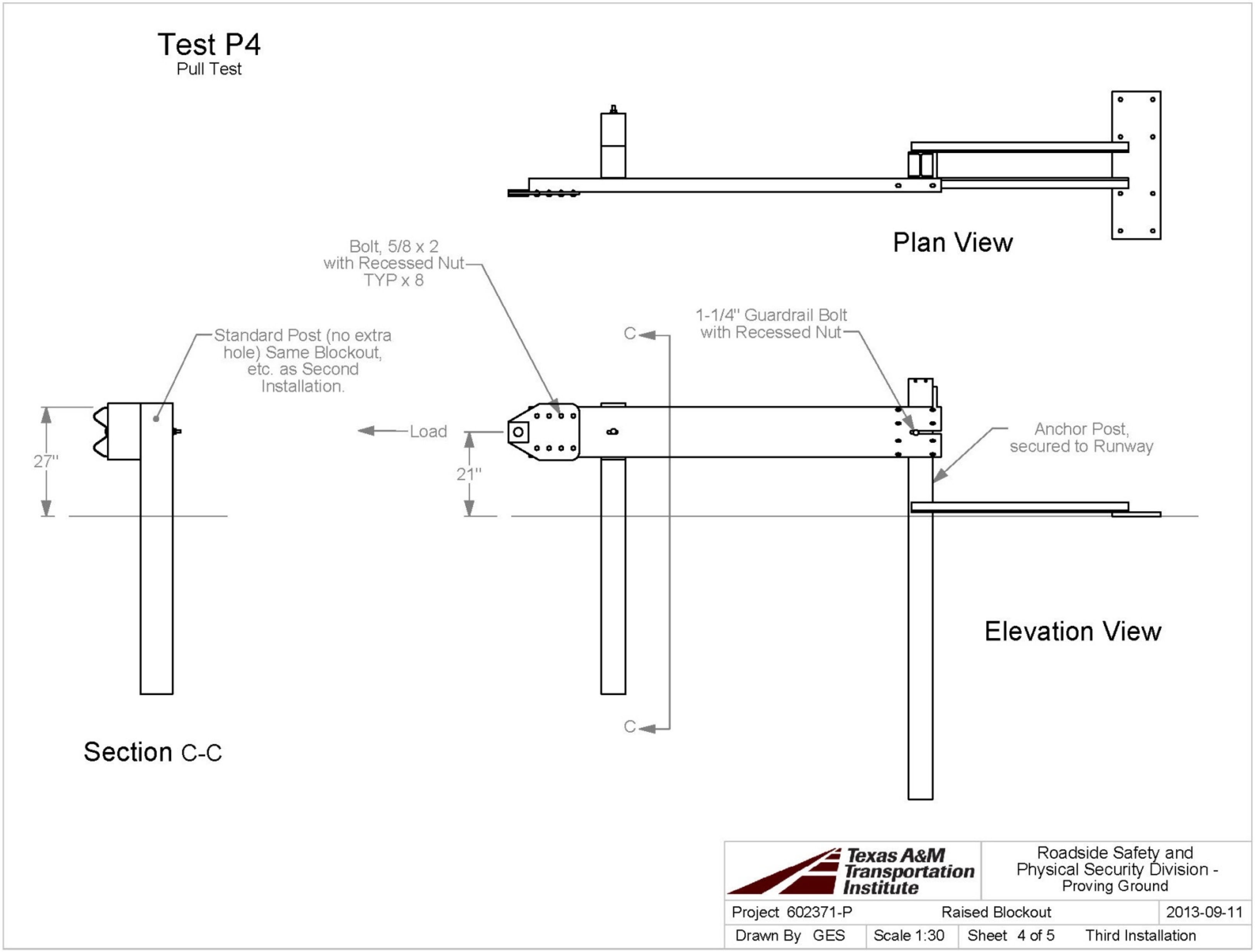

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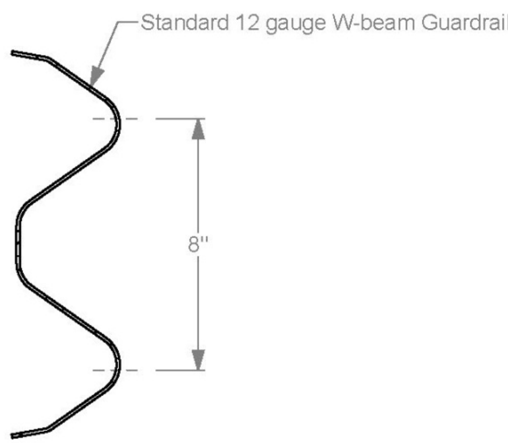
Rail Details
Pull Test

Elevation View



Section B-B
Scale 1 : 5

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project 602371-P	Raised Blockout	2013-09-11
Drawn By GES	Scale 1:15	Sheet 5 of 5 Rail Details

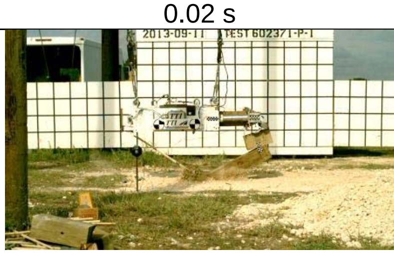
T:\2013-2014\602371-Raised Blockout\Drafting\602371-P Drawing , as tested

ATTACHMENT C. TESTING SUMMARIES

Table C1. Summary of results for pendulum test 602371- P1.

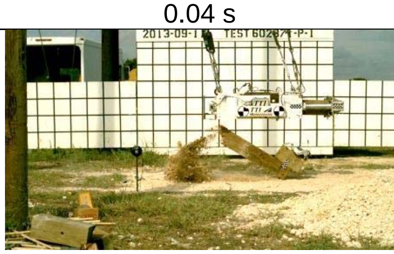
0.000 s

0.02 s



0.03 s

0.04 s



0.05 s

0.06 s

General Information

Test Agency	Texas A&M Transportation Institute
Test No.	602371- P1
Date	2013-09-11
Test Article	
Type	Wood Blockout
Name	Raised 8-inch Wood Blockout
Installation Height	32 inches
Material of Key Element	8-inch Wood Blockout on Wood Post embedded in Soil
Soil Type	Standard Soil
Test Vehicle	
Type	Bogie
Designation	Pendulum
Test Inertia Mass	1750 lb
Impact Conditions	
Speed	19.9 mi/h
Angle	90 deg
Occupant Risk Values	
Longitudinal Occupant Impact Velocity	8.5 ft/s
Longitudinal Ridedown Acceleration	0.7 G
Maximum Change in Velocity	7.6 ft/s
Maximum 10-ms Force	15.8 kips
Maximum Kinetic Energy	12.04 ft-kips

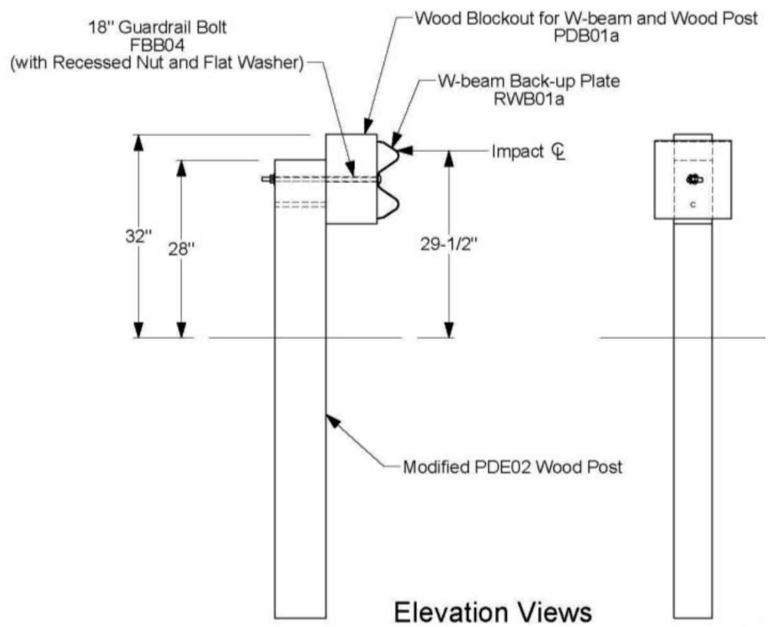


Table C2. Summary of results for pendulum test 602371- P2.

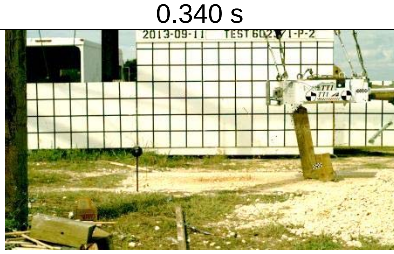
0.000 s

0.085 s

0.170 s

0.255 s

0.340 s



0.425 s

General Information

Test Agency .... Texas A&M Transportation Institute
Test No. 602371- P2
Date 2013-09-11

Test Article

Type .... Wood Blockout
Name .... Raised 8-inch Wood Blockout
Installation Height .... 32 inches
Material of Key Element.................. 8-inch Wood Blockout on Wood Post embedded in Soil

Soil Type .... Standard Soil

Test Vehicle

Type .... Bogie
Designation .... Pendulum
Test Inertia Mass .... 1750 lb

Impact Conditions

Speed .... 20.0 mi/h
Angle .... 90 deg

Occupant Risk Values

Longitudinal Occupant Impact Velocity .... 6.9 ft/s
Longitudinal Ridedown Acceleration .... 0.9 G

Maximum Change in Velocity .... 4.5 ft/s
Maximum 10-ms Force .... 11.0 kips
Maximum Kinetic Energy .... 8.26 ft-kips

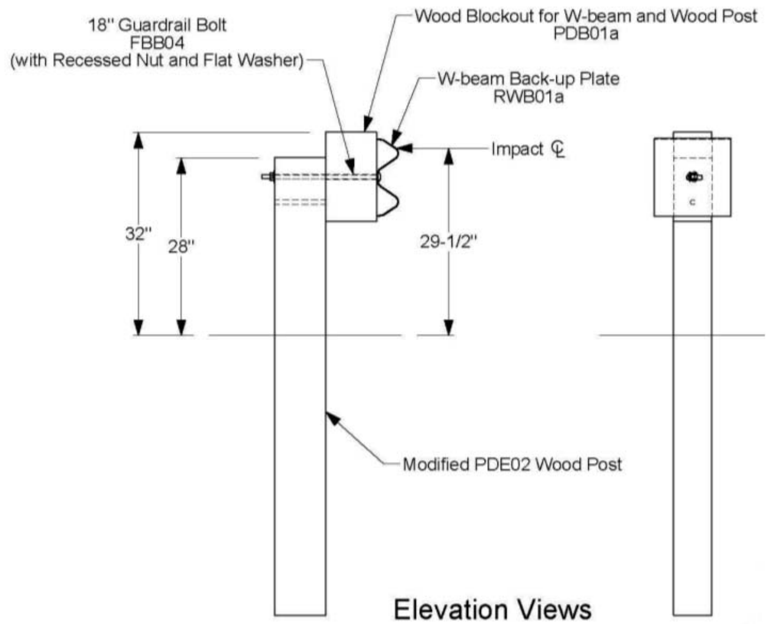
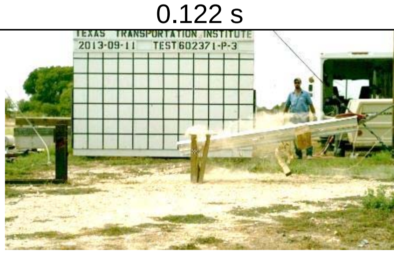


Table C3. Summary of results for pendulum test 602371- P3.

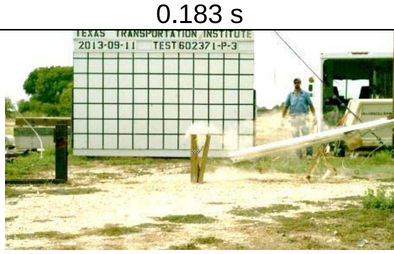
0.000 s

0.061 s

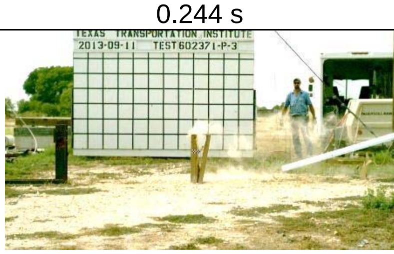
0.122 s



0.183 s



0.244 s



0.305 s

General Information
- Test Agency .... Texas A&M Transportation Institute
- Test No. 602371- P3
- Date 2013-09-11

Test Article
- Type .... Wood Blockout
- Name .... Raised 8-inch Wood Blockout
- Installation Height .... 31 inches
- Material of Key Element .... 8-inch Wood Blockout on Wood Post embedded in Soil

Soil Type .... Standard Soil

Test Vehicle
- Type .... Bogie
- Designation .... Pendulum
- Test Inertia Mass .... 2062 lb

Impact Conditions
- Speed (pull) .... 14.8 mi/h
- Angle .... 90 deg

Occupant Risk Values
- Longitudinal Occupant Impact Velocity .... 4.6 ft/s
- Longitudinal Ridedown Acceleration .... 0.4 G

Maximum 10-ms Force .... 8.9 kips

Maximum Kinetic Energy .... 3.71 ft-kips

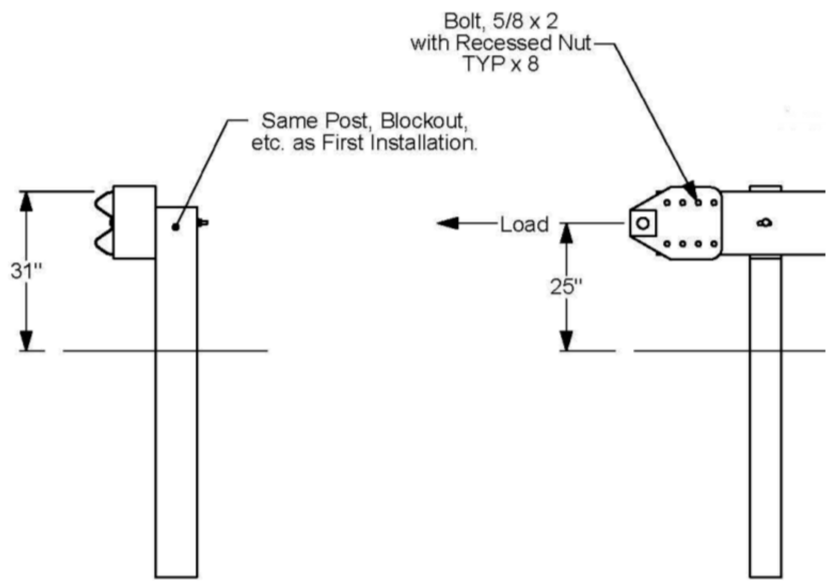


Table C4. Summary of results for pendulum test 602371- P4.

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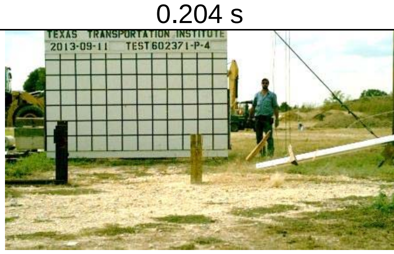
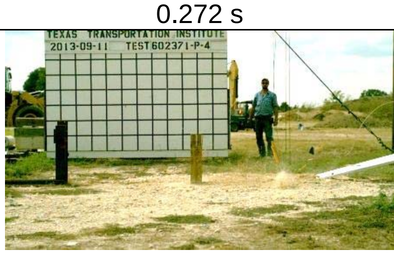
0.068 s

0.136 s

0.204 s



0.272 s



0.340 s

General Information
Test Agency .... Texas A&M Transportation Institute
Test No. 602371- P4
Date 2013-09-11

Test Article
Type .... Wood Blockout
Name .... 8-inch Wood Blockout
Installation Height .... 27 inches
Material of Key Element .... 8-inch Wood Blockout on Wood Post embedded in Soil

Soil Type .... Standard Soil

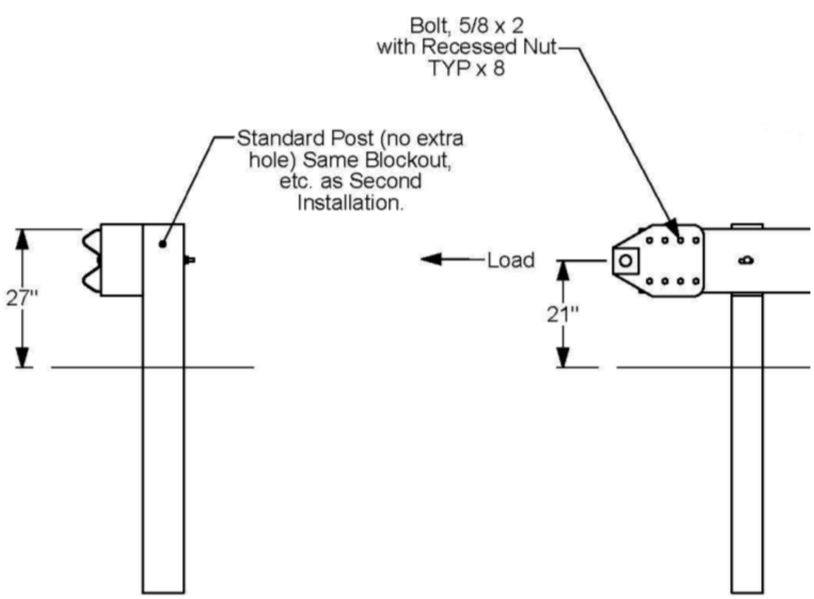
Test Vehicle
Type .... Bogie
Designation .... Pendulum
Test Inertia Mass .... 2062 lb

Impact Conditions
Speed (pull) .... 15.4 mi/h
Angle .... 90 deg

Occupant Risk Values
Longitudinal Occupant Impact Velocity .... 3.9 ft/s
Longitudinal Ridedown Acceleration .... 0.4 G

Maximum 10-ms Force .... 8.6 kips

Maximum Kinetic Energy .... 3.54 ft-kips



ATTACHMENT D. ACCELERATION AND FORCE TRACES

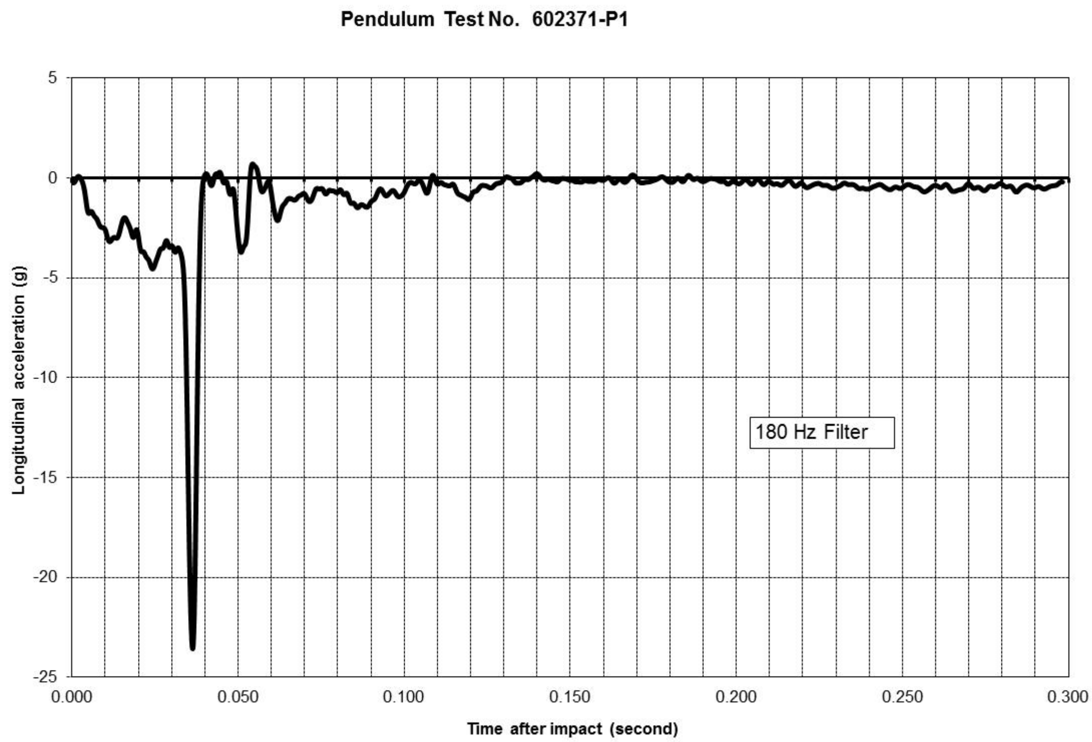


Figure D1. Accelerometer trace for test 602371-P1.

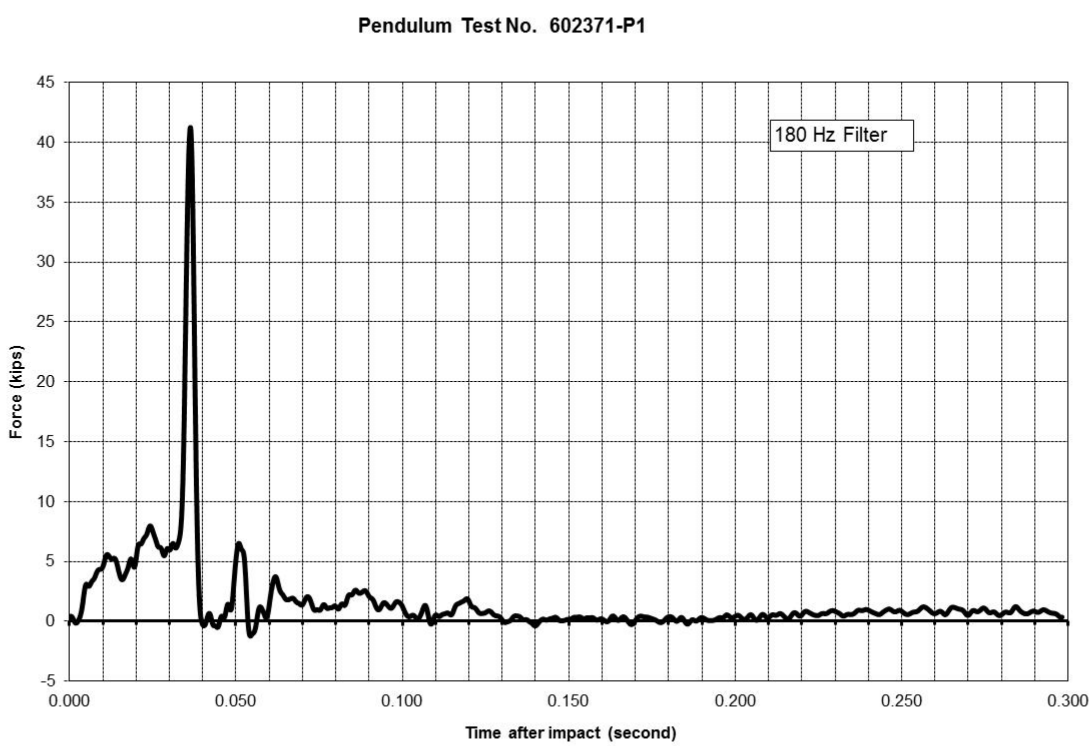


Figure D2. Force trace for test 602371-P1.

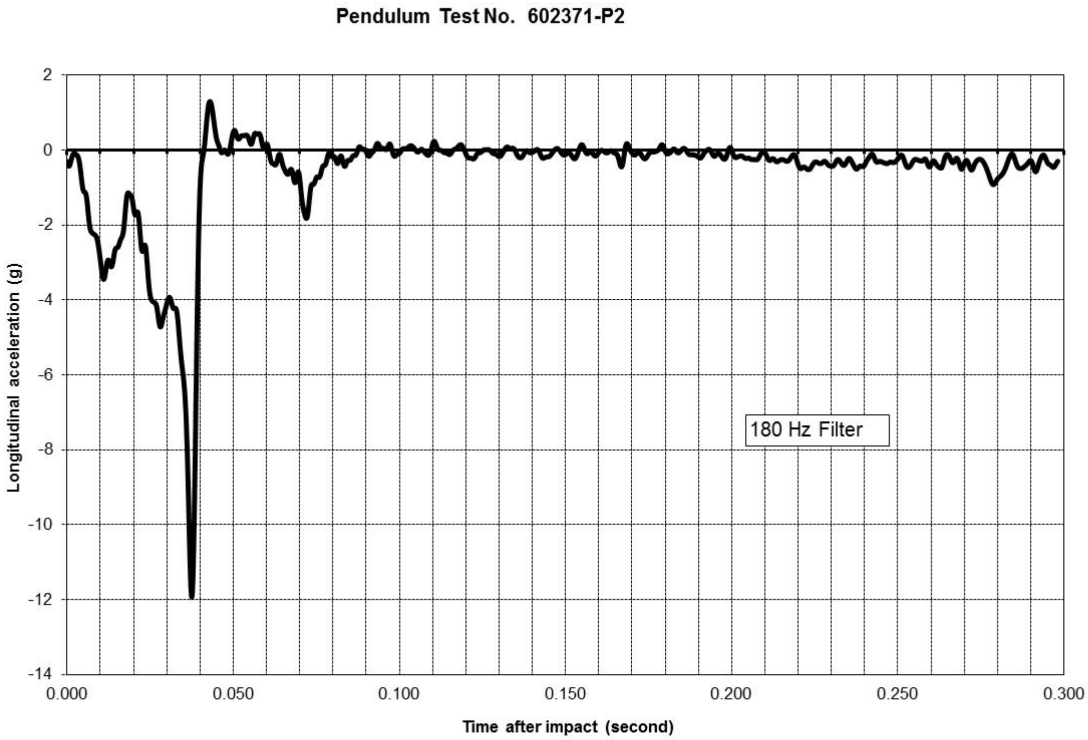


Figure D3. Accelerometer trace for test 602371-P2.

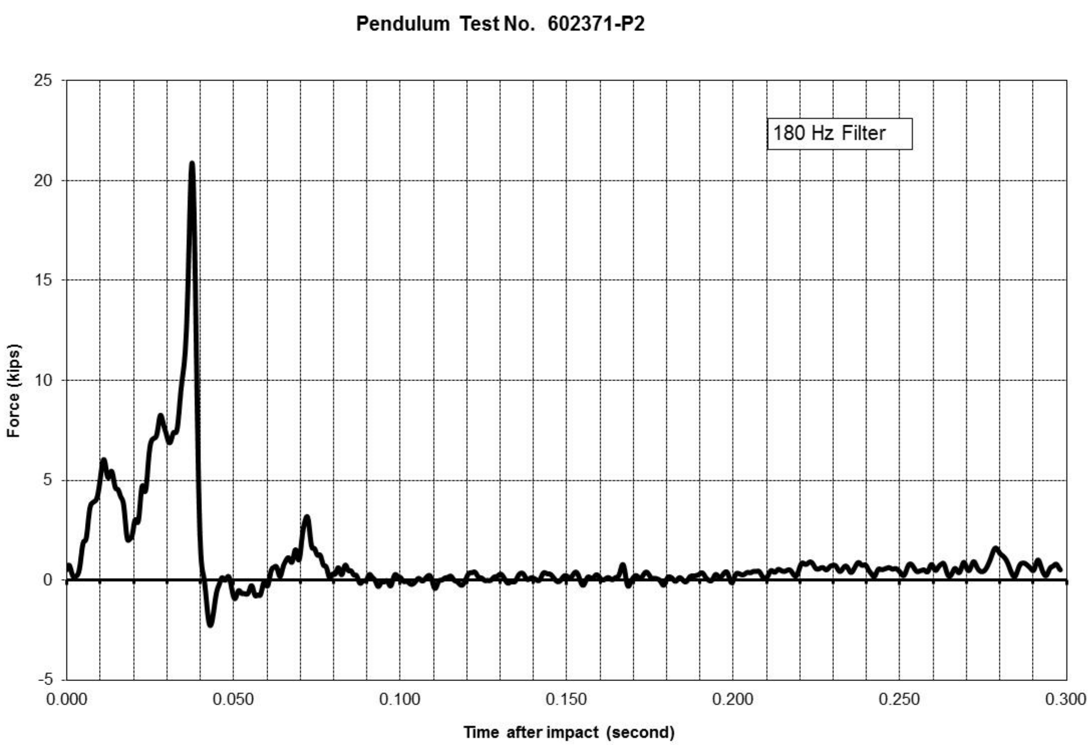


Figure D4. Force trace for test 602371-P2.

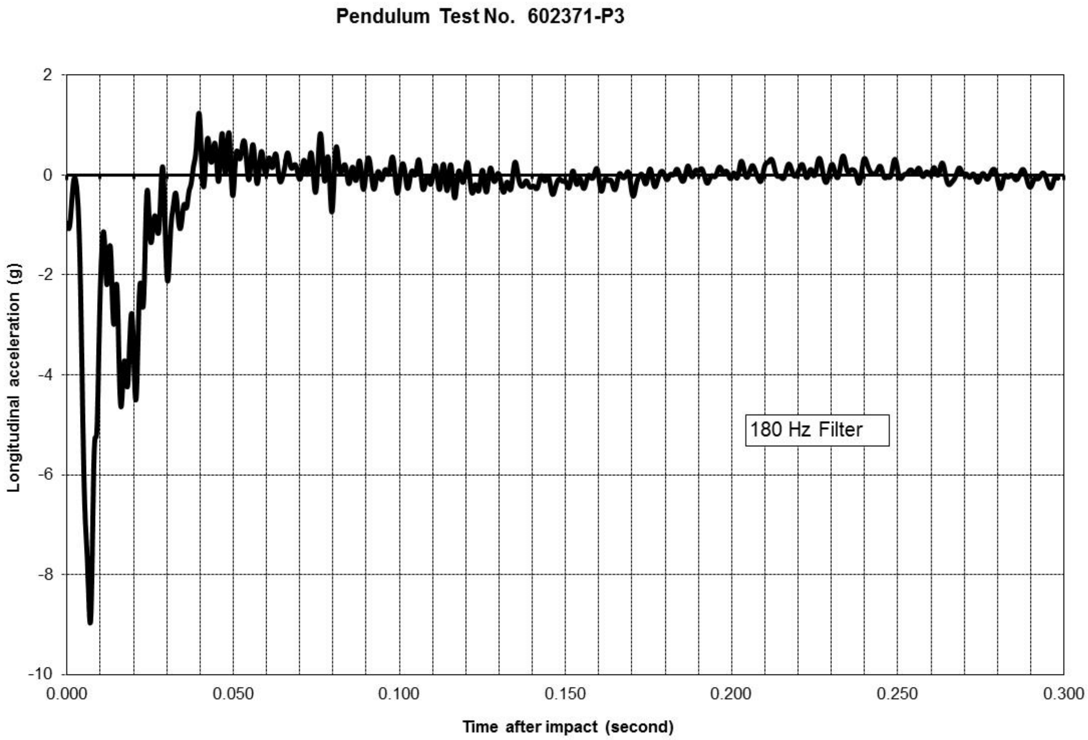


Figure D5. Accelerometer trace for test 602371-P3.

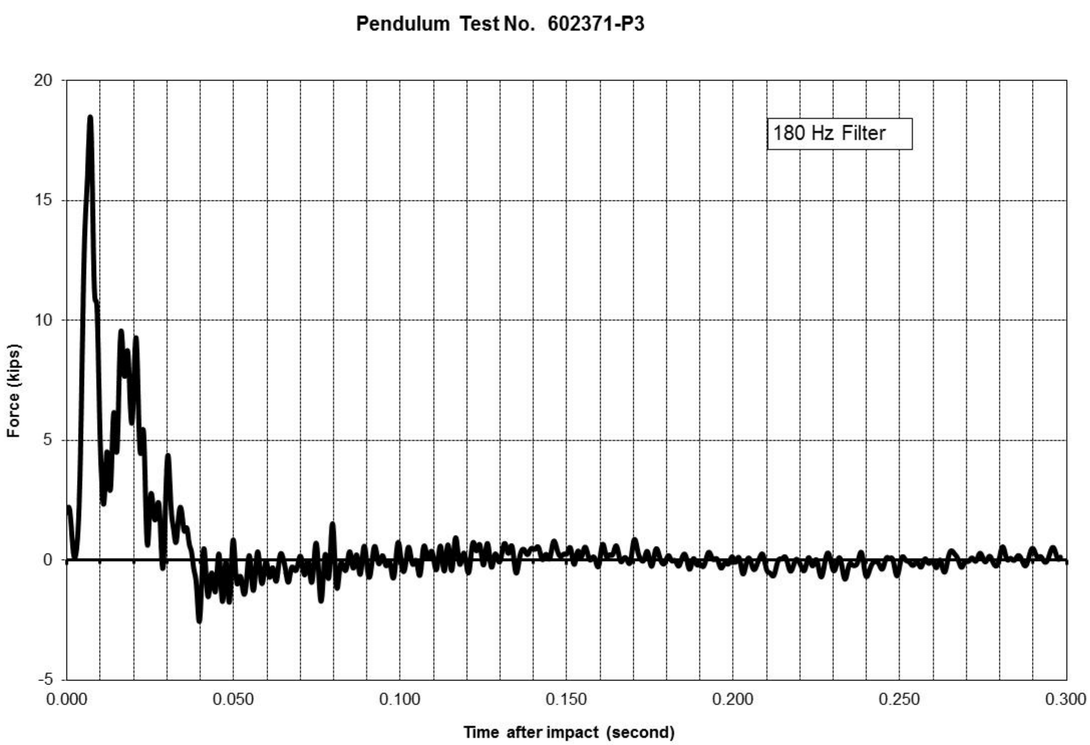


Figure D6. Force trace for test 602371-P3.

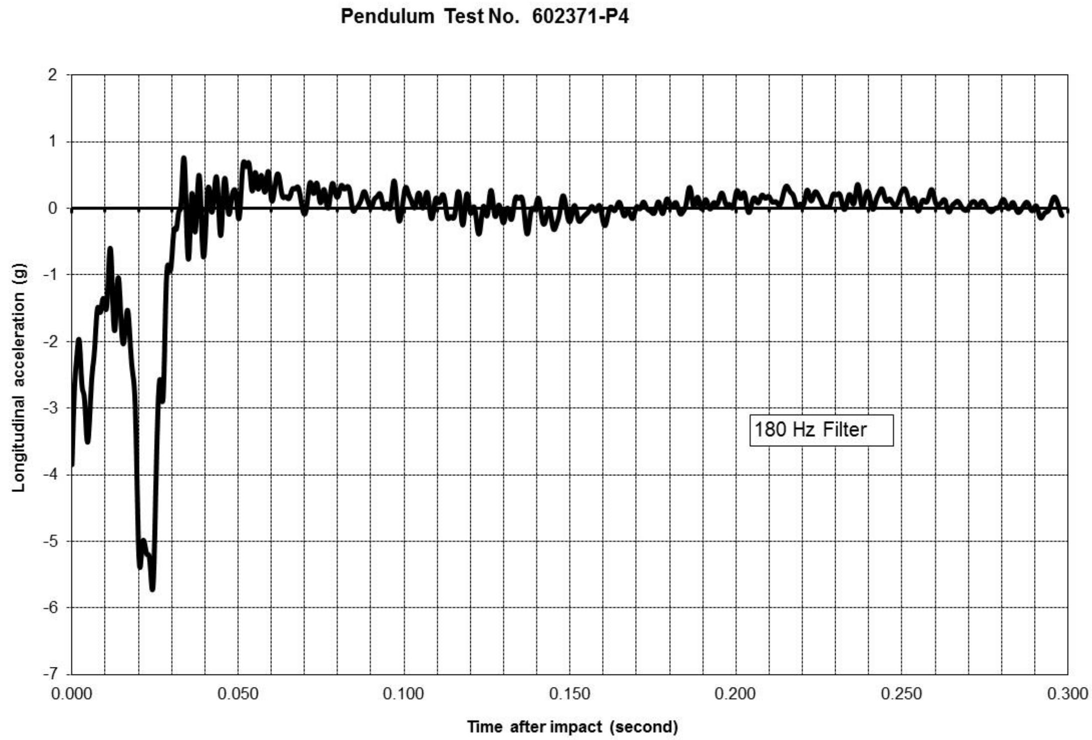


Figure D7. Accelerometer trace for test 602371-P4.

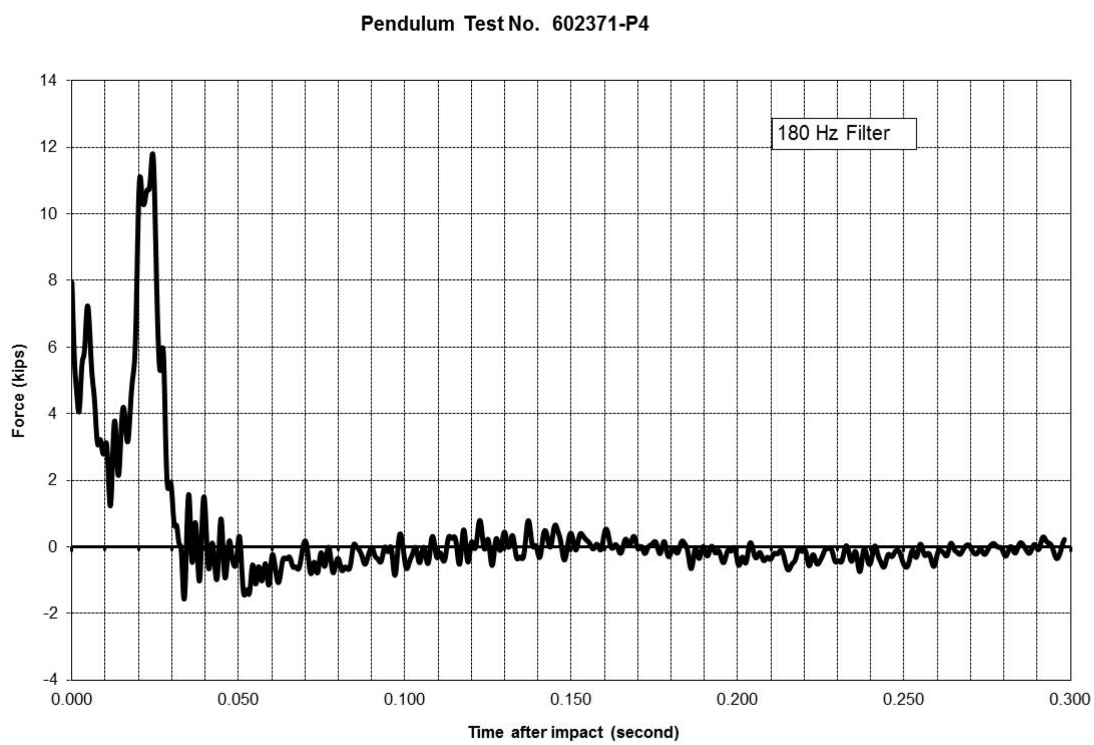


Figure D8. Force trace for test 602371-P4.