Texas A&M Transportation Institute
Proving Ground

Texas A&M Transportation Institute
3135 TAMU
College Station, TX 77843-3135

979-845-6375
Fax: 979-845-6107
http://tti.tamu.edu/crashtesting

TECHNICAL MEMORANDUM

Contract No.: **T4541**
Test Report No.: **TM No. 605311**
Project Name: **Pendulum Testing on Composite Blockouts Raised on Steel Posts**
Sponsor: **Roadside Safety Pooled Fund**

DATE: **February 15, 2017**

TO: **Ali Hangul, P.E.**
Tennessee Department of Transportation

COPY TO: Epifania Davila / Erlinda Olivarez, TTI RDO
D. L. Bullard, Jr., Head, Roadside Safety & Physical Security Systems
Rebecca Heck, TTI Roadside Safety & Physical Security Systems

FROM: **Chiara Silvestri Dobrovolny**, Ph.D., Associate Research Scientist,
Texas A&M Transportation Institute

PREPARED BY: **Wanda L. Menges**, Research Specialist, TTI Proving Ground
Darrell L. Kuhn, P.E., Research Specialist, TTI Proving Ground
Chiara Silvestri Dobrovolny, Ph.D., Associate Research Scientist,
Texas A&M Transportation Institute

FOR MORE INFORMATION:
Name: Chiara Silvestri Dobrovolny
Phone: 979-845-8971
Email: c-silvestri@tti.tamu.edu

SUMMARY REPORT:

DISCLAIMER

The contents of this report reflect the views of the authors who are solely responsible for the facts and accuracy of the data, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Roadside Safety Pooled Fund, The Texas A&M University System, or Texas A&M Transportation Institute. This report does not constitute a standard, specification, or regulation. In addition, the above listed agencies assume no liability for its contents or use thereof. The names of specific products or manufacturers listed herein do not imply endorsement of those products or manufacturers. The results reported herein apply only to the article being tested. The test was performed according to TTI Proving Ground quality procedures and according to Quality System Procedure (QSP) 5.4.20.

INTRODUCTION

With recent changes/clarifications about the appropriate height for W-beam guardrail, there are many existing locations identified where rail height is below the recommended height. Pavement overlays create additional locations where this occurs. Raising the blockout on the post is a safe, low-cost means to adjust the rail height; however, there are still some unknowns regarding how the rail system would perform when using composite blockouts.

The purpose of this research was to analyze W-beam rail performance when blockouts are raised on the posts as a method of adjusting rail height. Specifically, this research evaluated wood post/composite blockout and steel post/wood blockout systems. The outcome of this study complements the existing guidelines regarding the procedure of raising blockout mounting height on steel and wood posts to achieve the recommended rail height for a W-beam guardrail. Constructability issues related to raising blockouts were addressed throughout this research study.

The information compiled from this research enables the Departments of Transportation to decide whether raising blockouts on the posts can be chosen as a safe, low cost means to adjust rail height when it is below the recommended value, without compromising the rail system performance.

PENDULUM FACILITY

Pendulum tests were conducted to determine the dynamic impact performance of a raised blockout on a steel guardrail post. The tests were performed at TTI's Proving Ground Pendulum Facility. The tests were designed such that the pendulum bogie impacted the face of a W-beam back-up mounted to the traffic face of the raised blockout at an angle of 90 degrees (normal) to what would be the direction of travel and at a target speed of 20 mi/h. The centerline of the pendulum's nose impacted each test article at a height of 29½ inches above grade. Testing was performed in accordance with the procedures presented in Appendix A.

The first series of pendulum testing (tests P1-P5) was performed on May 6, 2016. Weather conditions at the time of testing were as follows: Wind speed: 1-2 mi/h; wind direction: 253-346 degrees with respect to the pendulum bogie; temperature: 72-84°F; relative humidity: 37-62 percent.

The second series of pendulum testing (P6-P7) was performed on June 16, 2016. Weather conditions at the time of testing were as follows: Wind speed: 8-10 mi/h; wind direction: 169 degrees with respect to the pendulum bogie; temperature: 85-92°F; relative humidity: 58-77 percent.

The third series of pendulum testing (P8-P9) was performed on September 28, 2016. Weather conditions at the time of testing were as follows: Wind speed: 1 mi/h; wind direction: 346 degrees with respect to the pendulum bogie; temperature: 73-79°F; relative humidity: 57-72 percent.

TEST ARTICLE DESIGN AND CONSTRUCTION

The steel guardrail posts were standard galvanized 72-inch long W6×8.5 shapes (PWE01), some with bolt hole modifications as noted below.

In three of the first five tests (Test Nos. P2, P4, and P5), standard pressure treated and routered wood blockouts measuring 14-inches × 7⅞-inches × 6-inches (PDB-01b) were used. In the other two tests (P1 and P3), plastic King Block™ blockouts from Trinity Highway Products were used. A W-Beam backup plate (RWB01a) was secured to the traffic face of each blockout with one 10-inch long guardrail bolt and recessed nut (FBB03 & FBB).

For Test Nos. 605311-P6 through P8, the plastic blockouts from Mondo Polymer Technologies, Inc. were used. A W-Beam backup plate (RWB01a) was secured to the traffic face of each blockout with one 10-inch long guardrail bolt and recessed nut (FBB03 & FBB).

In the final test (Test No. 605311-P9) a King Block™ from Trinity Highway Products was used. A W-Beam backup plate (RWB01a) was secured to the traffic face of each blockout with one 10-inch long guardrail bolt and recessed nut (FBB03 & FBB).

In tests where the blockouts were raised 4 inches, an additional $^{13}/_{16}$–inch diameter hole was located in one flange of the post, 3 inches below the top and 1⅛ inches from the web centerline.

New components were used for each test, and each post was secured in compacted (pneumatically tamped) soil meeting grading B of AASHTO standard specification M147-65(2004) "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses." The soil was compacted to 95% of Standard Proctor Density following ASTM D698. Table 1 summarizes the tests performed.

Table 1. Summary of Performed Tests.

Test No.	Blockout Type	Blockout Raised on Post (inches)
P1	King Block™	-
P2	Wood	-
P3	King Block™	4
P4	Wood	4
P5	Wood	4
P6	Mondo™ Plastic Block	-
P7	Mondo™ Plastic Block	4
P8	Mondo™ Plastic Block	4
P9	King Block™	4

<u>TEST NO. 605311-P1 – Plastic King™ Block A at Standard Height</u>

For Test P1, a 72-inch long steel post (PWE01) with a King Block™ blockout was installed such that the top of the post was 32 inches above grade and the embedment depth was 40 inches The King Block™ blockout was installed at its standard height relative to the top of the post, which positioned the top of the W-beam back-up plate 31 inches above grade. The centerline of the pendulum's nose impacted the object-beam backup plate at a height of 29½ inches above grade. Details are provided in Sheet 1 of 6 in Appendix B1.

The pendulum contacted the blockout while traveling at an impact speed of 20.0 mi/h. At 0.003 s after impact, the post began to deflect toward the field side, and the top edge of the guardrail back-up plate began to climb up and over the blockout. At 0.063 s, the post began to rotate counterclockwise, and at 0.068 s, the blockout began to ride up the face of the post. The post was leaning toward the field side at 15 degrees and had a maximum displacement of 11 inches measured at the top of the post at 0.085 s, after which the blockout began to rotate about the post to 90 degrees and eventually fractured at approximately 0.125 s. The nose of the pendulum lost contact with the post and blockout at 0.150 s, and the pendulum was traveling at 11.0 mi/h. The skid plate of the pendulum contacted the guardrail back-up plate and blockout at 0.190 s.

The post was pushed downstream through the soil 5⅜ inches at ground level, with a 1-inch gap on the field side. The post was leaning 30 degrees downstream. The blockout fractured horizontally near the center. Maximum dynamic deflection during the test was 11.0 inches.

The 50-ms average longitudinal acceleration was -5.9 g, maximum 50-ms average force was 11.4 kips, and energy was 380 kip-inch. These values and other pertinent information from the test are summarized in Table C1 of Attachment C.

Before Test After Test

Figure 1. Plastic King™ Block A at Standard Height before and after Test No. 605311-P1.

TEST NO. 605311-P2 – Wood Block A at Standard Height

For Test P2, a 72-inch long steel post (PWE01) with a wood PDB-01b blockout was installed such that the top of the post was 32 inches above grade, and the top of the W-beam back-up plate was 31 inches above grade. The post was installed to a depth of 40 inches. The centerline of the pendulum's nose impacted the W-beam backup plate at a height of 29½ inches above grade. Details are provided in Sheet 4 of 6 in Appendix B1.

The pendulum contacted the blockout while traveling at an impact speed of 21.5 mi/h. At 0.004 s after impact, the post began to deflect toward the field side, and at 0.005 s, the top edge of the guardrail back-up plate began to climb up and over the blockout. At 0.136 s, the post was leaning toward the field side at 29 degrees and had a maximum displacement of 19 inches measured at the top of the post. The nose of the pendulum lost contact with the post and blockout at 0.180 s, and the pendulum was traveling at 9.1 mi/h. The pendulum nose lost contact with the backup plate at 0.200 s and the blockout was intact and did not rotate about the post. The skid plate of the pendulum contacted the guardrail and blockout at 0.269 s.

The post was pushed toward the field side through the soil 5⅜ inches at ground level, with a 1-inch gap on the field side. The post was leaning 25 degrees downstream. As shown in Figure 1, the blockout remained intact. Maximum dynamic deflection during the test was 19.0 inches.

The 50-ms average longitudinal acceleration was -6.5 g, maximum 50-ms average force was 12.8 kips, and energy was 488 kip-inch. These values and other pertinent information from the test are summarized in Table C2 of Attachment C.

Before Test After Test

Figure 2. Wood Block A at Standard Height before and after Test No. 605311-P2.

TEST NO. 605311-P3 – Plastic King Block™ B Raised 4-inches

For Test P3, a 72-inch long steel post (PWE01) with a King Block TM blockout was installed such that the top of the post was 28 inches above grade, and the top of the W-beam back-up plate was 31 inches above grade. The post was installed to a depth of 44 inches. The centerline of the pendulum's nose impacted the W-beam backup plate at a height of 29½ inches above grade. Details are provided in Sheet 2 of 6 in Appendix B1.

The pendulum contacted the blockout while traveling at an impact speed of 19.9 mi/h. At 0.003 s after impact, the post began to deflect toward the field side, and at 0.005 s, the top edge of the guardrail back-up plate began to climb up and over the blockout. At 0.056 s, the blockout began to ride up the face of the post and rotate counterclockwise, and by 0.074 s, the blockout had rotated 90 degrees counterclockwise. The post was leaning toward the field side at 10.5 degrees and had a maximum displacement of 10½ inches measured at the top of the post at 0.094 s. The blockout fractured horizontally at 0.097 s, the upper part of the blockout remained attached to the guardrail back-up plate, and the lower portion remained attached to the post. At the time of the blockout fracture, the post was still leaning toward the field side at 10.5 degrees, and was twisted counterclockwise approximately 20 degrees with the blockout rotated 90 degrees from its original position to the face of the post. The nose of the pendulum lost contact with the post and blockout at 0.120 s, and the pendulum was traveling at 12.3 mi/h. The skid plate of the pendulum contacted the lower portion of the blockout at 0.182 s.

The post was pushed toward the field side through the soil 4 inches at ground level, with a 1-inch gap on the field side. The post was leaning 15 degrees toward the field side. The blockout was fractured horizontally just above the center of the blockout, with the upper portion remaining attached to the guardrail back-up plate, and the lower portion remaining attached to the post (see Figure 2). Maximum dynamic deflection during the test was 10.5 inches.

The 50-ms average longitudinal acceleration was -5.0 g, maximum 50-ms average force was 9.8 kips, and energy was 310 kip-inch. These values and other pertinent information from the test are summarized in Table C3 of Attachment C.

Before Test After Test

Figure 3. Plastic King™ Block B Raised 4 inches before and after Test No. 605311-P3.

TEST NO. 605311-P4 – Wood Block B Raised 4-inches

For Test P4, a 72-inch long steel post (PWE01) with a wood PDB-01b blockout was installed such that the top of the post was 28 inches above grade, and the top of the W-beam back-up plate was 31 inches above grade. The post was installed to a depth of 44 inches. The centerline of the pendulum's nose impacted the W-beam backup plate at a height of 29½ inches above grade. Details are provided in Sheet 5 of 6 in Appendix B1.

The pendulum contacted the blockout while traveling at an impact speed of 19.7 mi/h. At 0.003 s after impact, the post began to deflect toward the field side, and at 0.014 s, the top edge of the guardrail back-up plate began to climb up and over the blockout. At 0.060 s, the post and blockout began to rotate counterclockwise. The post was leaning toward the field side at 17 degrees, and had a maximum displacement of 11 inches, measured at the top of the post, at 0.085 s. At 0.089 s, the blockout began to splinter and the post was leaning toward the field side at 16.5 degrees, and was twisted counterclockwise approximately 30 degrees. By 0.120 s, the blockout had rotated 90 degrees counterclockwise from its original position on the face of the post. The nose of the pendulum lost contact with the post and blockout at 0.130 s, and the pendulum was traveling at 11.3 mi/h. The skid plate of the pendulum contacted the lower portion of the blockout at 0.192 s.

Figure 4 shows the post pushed toward the field side through the soil 4 inches at ground level, with a ⅝-inch gap on the field side. The upper portion of the post was rotated 90 degrees counterclockwise. The blockout rotated on the post but remained attached to the post. Maximum dynamic deflection during the test was 11.0 inches.

The 50-ms average longitudinal acceleration was -6.0 g, maximum 50-ms average force was 11.6 kips, and energy was 369 kip-inch. These values and other pertinent information from the test are summarized in Table C4 of Attachment C.

Before Test After Test

Figure 4. Wood Block B Raised 4 inches before and after Test No. 605311-P4.

<u>TEST NO. 605311-P5 – Wood Block B Raised 4-inches</u>

Test P5 was a repeat of test P4 for validation purposes, in which a 72-inch long steel post (PWE01) with a wood PDB-01b blockout was installed such that the top of the post was 28 inches above grade, and the top of the W-beam back-up plate was 31 inches above grade. The post was installed to a depth of 44 inches. The centerline of the pendulum's nose impacted the W-beam backup plate at a height of 29½ inches above grade. Details are provided in Sheet 5 of 6 in Appendix B1.

The pendulum contacted the blockout while traveling at an impact speed of 19.7 mi/h. At 0.003 s after impact, the post began to deflect toward the field side, and at 0.020 s, the top edge of the guardrail back-up plate began to climb up and over the blockout. At 0.078 s, the blockout began to rotate away from the post. The post was leaning toward the field side at 32 degrees and had a maximum displacement of 19 inches measured at the top of the post at 0.142 s. The nose of the pendulum lost contact with the post and blockout at 0.190 s, and the pendulum was traveling at 8.1 mi/h. At this point, the post was leaning toward the field side at 27.5 degrees and was twisted approximately 20 degrees counterclockwise. The blockout remained attached to the face of the post but was twisted approximately 30 degrees clockwise. The skid plate of the pendulum contacted the lower portion of the backup plate at 0.250 s, and the blockout began to fracture at 0.342 s from a direct secondary impact on the blockout itself.

Figure 5 shows the blockout fractured upon impact with the skid plate of the pendulum, but the larger portion remained attached to the post. Maximum dynamic deflection during the test was 19.0 inches.

The 50-ms average longitudinal acceleration was -6.1 g, maximum 50-ms average force was 11.9 kips, and energy was 405 kip-inch. These values and other pertinent information from the test are summarized in Table C5 of Attachment C.

Before Test After Test

Figure 5. Wood Block B Raised 4 inches before and after Test No. 605311-P5.

TEST NO. 605311-P6 – Mondo Plastic Block at Standard Height

For Test P6, a 72-inch long steel post (PWE01) with an 8-inch deep Mondo #GB14SH2 blockout was installed such that the top of the post was 32 inches above grade, and the top of the W-beam was 31 inches above grade. A 10-inch long bolt was used to attach the blockout to the post. The post was installed to a depth of 40 inches. The centerline of the pendulum's nose impacted the W-beam backup plate at a height of 29½ inches above grade. Details are provided in Sheet 1 of 6 in Appendix B2.

The pendulum contacted the blockout while traveling at an impact speed of 19.8 mi/h. At 0.001 s after impact, the post began to deflect toward the field side, and at 0.009 s, the top edge of the guardrail back-up plate began to climb up and over the blockout. At 0.045 s, the blockout began to rotate counterclockwise. The blockout began to detach from the post at 0.065 s. At 0.071 s, the blockout was 90 degrees to its original position, and the post was twisted approximated 20 degrees. The post was leaning toward the field side at 13 degrees and had a maximum displacement of 10.0 inches measured at the top of the post at 0.106 s. At 0.108 s, the blockout abruptly released around the face flange of the post, but did not fracture and remained bolted to the post. The nose of the pendulum lost contact with the post and blockout at 0.155 s, and the pendulum was traveling at 11.0 mi/h.

Figure 6 shows the blockout rotated almost 180 degrees, but it remained attached to the post. The post deflected toward the field side through the soil 3.0 inches at grade. Maximum dynamic deflection during the test was 9.5 inches.

The 50-ms average longitudinal acceleration was -5.5 g, maximum 50-ms average force was 10.7 kips, and energy was 377 kip-inch. These values and other pertinent information from the test are summarized in Table C6 of Attachment C.

Before Test After Test

Figure 6. Mondo™ Plastic Block at Standard Height before and after Test No. 605311-P6.

<u>TEST NO. 605311-P7 – Mondo Plastic Block Raised 4-inches</u>

For Test P7, a 72-inch long steel post (PDE01) with an 8-inch deep Mondo #GB14SH2 blockout was installed such that the top of the post was 28 inches above grade, and the top of the W-beam was 31 inches above grade. A 10-inch long bolt was used to attach the blockout to the post. The post was installed to a depth of 44 inches. The centerline of the pendulum's nose impacted the W-beam backup plate at a height of 29½ inches above grade. Details are provided in Sheet 3 of 6 in Appendix B2.

The pendulum contacted the blockout while traveling at an impact speed of 19.8 mi/h. At 0.003 s after impact, the post began to deflect toward the field side, and at 0.007 s, the blockout began to rotate clockwise over the top of the post. At 0.048 s, the upper section of the post began to rotate counterclockwise. The post was leaning toward the field side at 7 degrees and had a maximum displacement of 5.5 inches measured at the top of the post at 0.057 s. The blockout began to rotate and separate on the face of the post at 0.060 s, and the backup plate detached from the blockout and post at 0.063 s. At 0.068 s, the blockout was 90 degrees to its original position, and the post was twisted approximated 10 degrees. At 0.070 s, the blockout abruptly released around the face flange of the post, but did not fracture and remained bolted to the post. The nose of the pendulum lost contact with the post and blockout at 0.145 s, and the pendulum was traveling at 13.5 mi/h. The skid plate of the pendulum contacted the lower portion of the blockout at 0.164 s.

Figure 7 shows the blockout rotated almost 180 degrees, but it remained attached to the post. The post deflected through the soil 3.75 inches at grade. Maximum dynamic deflection during the test was 6.0 inches.

The 50-ms average longitudinal acceleration was -4.8 g, maximum 50-ms average force was 9.3 kips, and energy was 310 kip-inch. These values and other pertinent information from the test are summarized in Table C7 of Attachment C.

Before Test After Test

Figure 7. Mondo Plastic Block Raised 4 inches before and after Test No. 605311-P7.

TEST NO. 605311-P8 – Mondo Plastic Block Raised 4-inches

For Test P8, a 72-inch long steel post (PDE01) with an 8-inch deep Mondo #GB14SH2 blockout was installed such that the top of the post was 28 inches above grade, and the top of the W-beam was 31 inches above grade. A 10-inch long bolt was used. The post was installed to a depth of 44 inches. The centerline of the pendulum's nose impacted the W-beam backup plate at a height of 29½ inches above grade. Details are provided in Sheet 3 of 6 in Appendix B3.

The pendulum contacted the blockout while traveling at an impact speed of 18.7 mi/h. At 0.002 s after impact, the post began to deflect toward the field side, and at 0.006 s, the blockout began to rotate clockwise over the top of the post. At 0.018 s, the blockout began to rotate counterclockwise. The post began to rotate counterclockwise at 0.042 s, and the bolt pulled through the backup plate slot at 0.058. The post had a maximum displacement of 5.3 inches measured at the top of the post at 0.060 s. At 0.064 s, the blockout abruptly released around the face flange of the post, but did not fracture and remained bolted to the post. At 0.066 s, the blockout was 90 degrees to its original position, and the post was twisted approximated 10 degrees. The backup plate detached from the blockout and post at 0.110 s. At 0.185 s, the blockout separated from the face of the post as it was impacted by the pendulum skid plate. The nose of the pendulum lost contact with the post and blockout at 0.250 s, and the pendulum was traveling at 12.1 mi/h.

Figure 8 shows the blockout, backup plate, and bolt separated from the post. The post deflected through the soil 1.5 inches at grade. Maximum dynamic deflection during the test was 6.5 inches.

The 50-ms average longitudinal acceleration was -4.6 g, maximum 50-ms average force was 8.2 kips, and energy was 280 kip-inch. These values and other pertinent information from the test are summarized in Table C8 of Attachment C.

Before Test After Test

Figure 8. Mondo Plastic Block Raised 4 inches before and after Test No. 605311-P8.

TEST NO. 605311-P9 – Plastic King Block™ B Raised 4-inches

For Test P9, a 72-inch long steel post (PDE01) with a King Block™ blockout was installed such that the top of the post was 28 inches above grade, and the top of the W-beam was 31 inches above grade. A 10-inch long bolt was used to attach the blockout to the post. The post was installed to a depth of 44 inches. The centerline of the pendulum's nose impacted the W-beam backup plate at a height of 29½ inches above grade. Details are provided in Sheet 6 of 6 in Appendix B3.

The pendulum contacted the blockout while traveling at an impact speed of 18.6 mi/h. At 0.003 s after impact, the post began to deflect toward the field side, and at 0.005 s, the top of the backup plate rode over the top of the blockout. At 0.009 s, the lower edge of the backup plate pulled away from the blockout, and at 0.016 s, the bottom edge of the blockout began to rotate away from the post. The post and blockout began to rotate counterclockwise at 0.038 s, and the bolt pulled through the backup plate slot at 0.056. At 0.058 s, the blockout began to rotate counterclockwise off of the post's flange. The blockout was 90 degrees to its original position, and the post was twisted counterclockwise approximately 30 degrees at 0.062 s. By 0.067 s, the blockout had rotated 90 degrees on the face of the post. The post had a maximum displacement of 6.3 inches measured at the top of the post at 0.075 s. The blockout fractured near the top at 0.077 s. The backup plate detached from the blockout at 0.110 s. The nose of the pendulum lost contact with the post and blockout at 0.255 s, and the pendulum was traveling at 11.4 mi/h. The blockout separated from the post at 0.265 s

Figure 9 shows the blockout, backup plate, and bolt separated from the post. The post deflected through the soil 1.7 inches at grade. The soil that had been pushed out by the post fell back into the post hole and final displacement was not attainable. Maximum dynamic deflection during the test was 8.0 inches.

The 50-ms average longitudinal acceleration was -4.0 g, maximum 50-ms average force was 8.0 kips, and energy was 255 kip-inch. These values and other pertinent information from the test are summarized in Table C9 of Attachment C.

Before Test After Test

Figure 9. King Block Raised 4 inches before and after Test No. 605311-P9.

SUMMARY AND CONCLUSIONS

Figures 9 and 10 summarize force-displacement and the energy-time plots from the performed tests. These plots are grouped by blockout type in Figures 11 and 12.

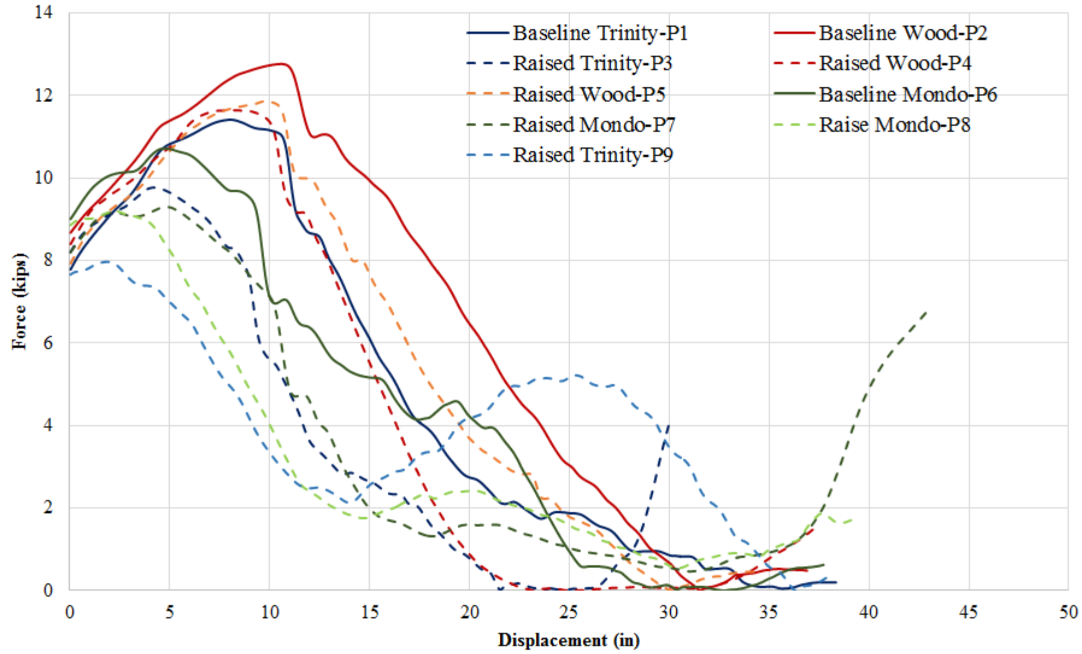


Figure 10. Force-Displacement histories for the performed tests.

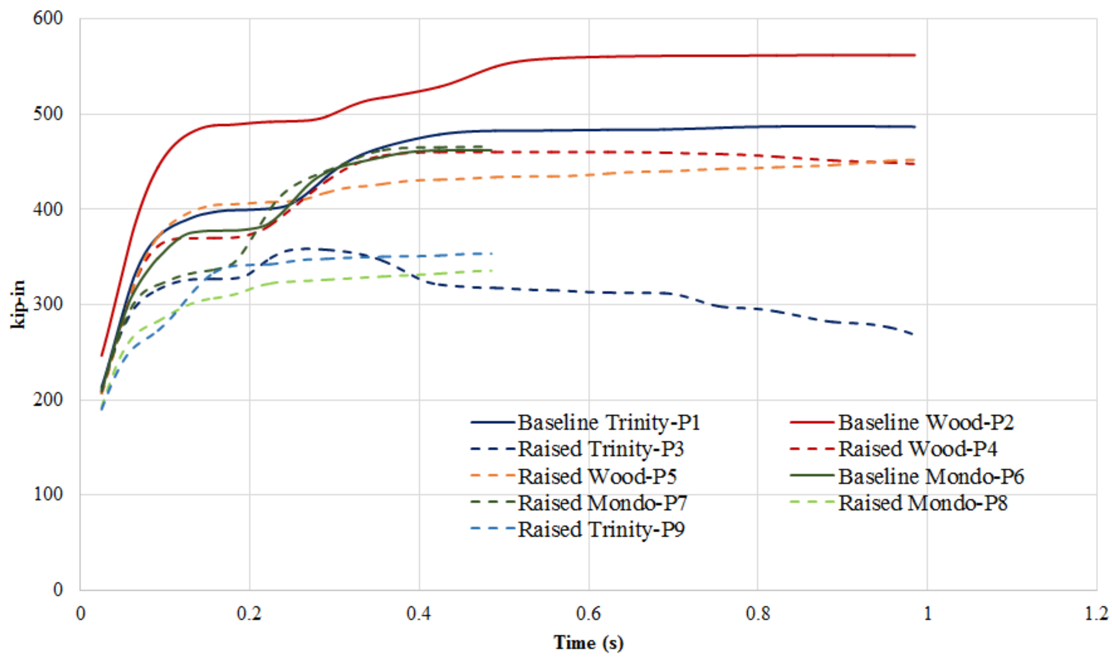
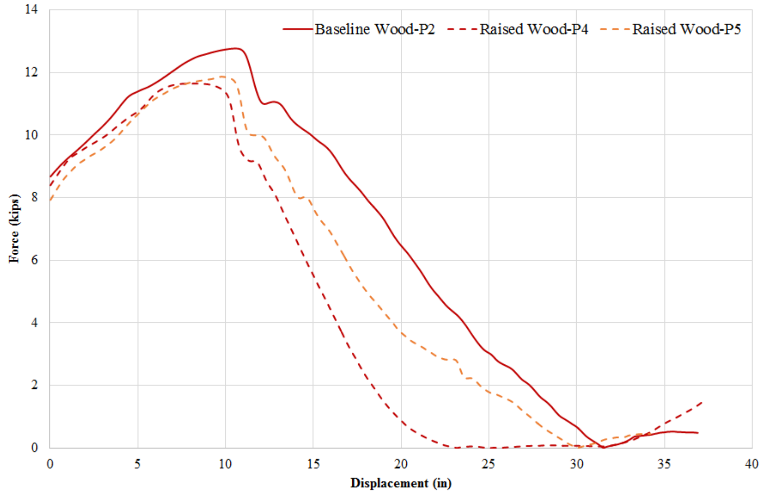
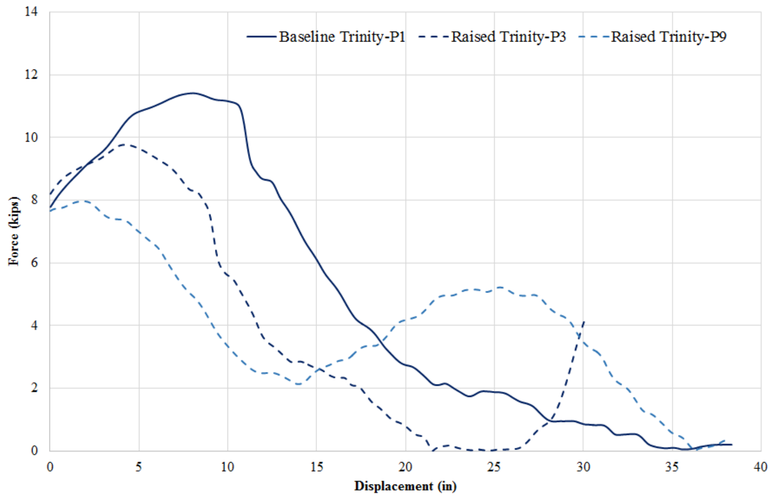


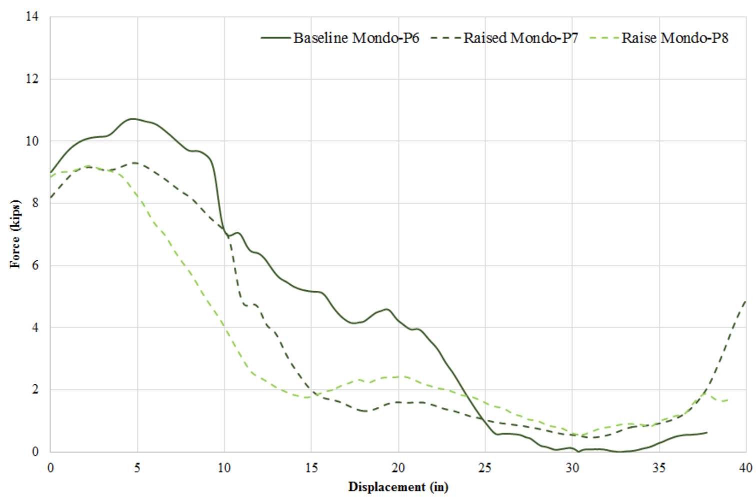
Figure 11. Energy-Time histories for the performed tests.



(a) Wood blockouts

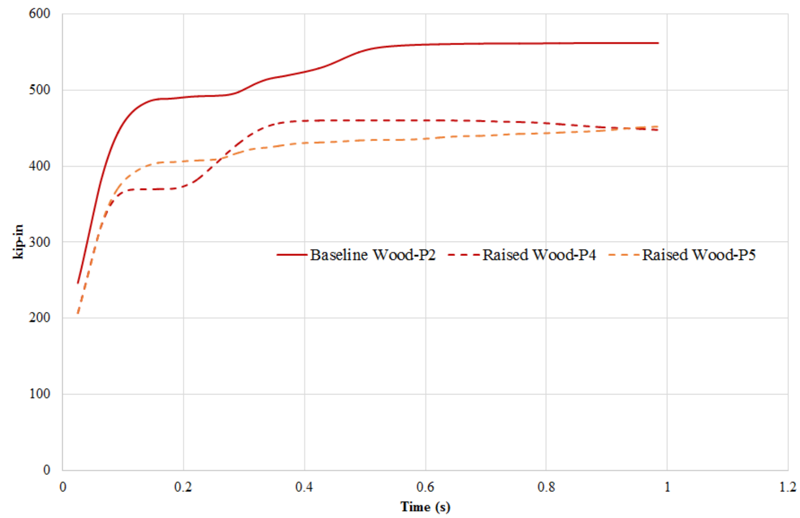


(b) King™ Block blockouts

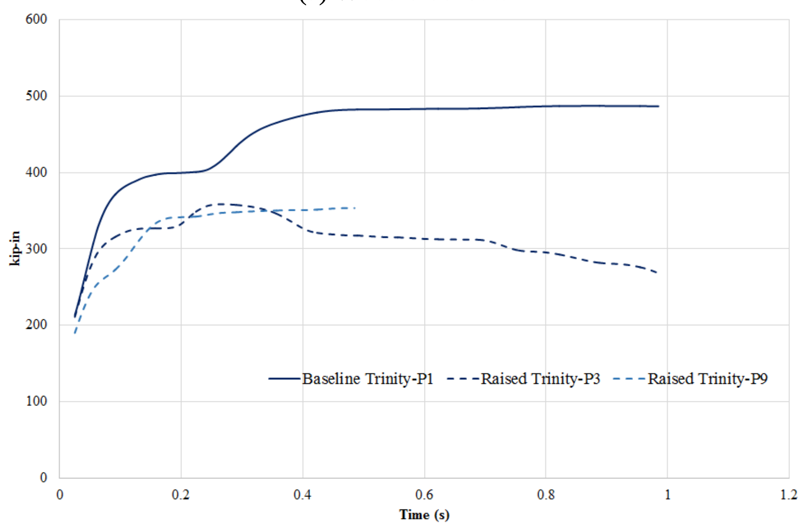


(c) Mondo™ Plastic blockouts

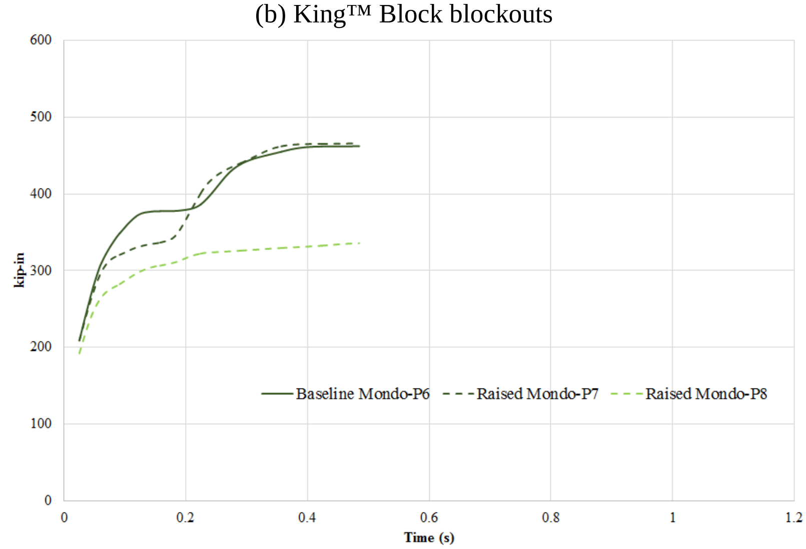
Figure 12. Force-Displacement histories categorized by blockout type.



(a) Wood blockouts



(b) King™ Block blockouts

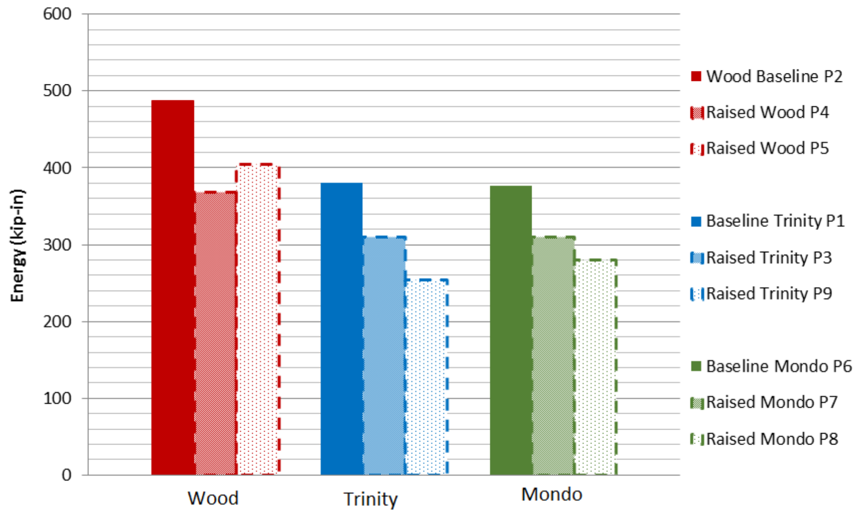


(c) Mondo™ Plastic blockouts

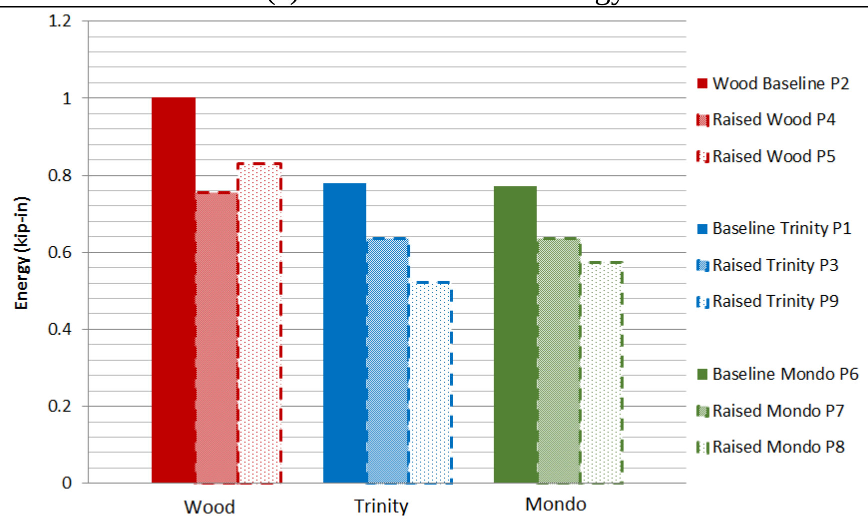
Figure 13. Energy-Time histories categorized by blockout type.

From the comparison of the energy plots, it appears that the system with wood blockouts was able to absorb more energy during the impact event in comparison to the systems which used proprietary composite blockouts (Figure 11) – this was true during the impact in the baseline condition (when blockout was not raised on post), and in the case where blockouts were raised on posts. The wood blockouts remained attached to the post and were not fractured as a consequence of the first impact from the pendulum nose. A summary table is reported below (Table 2).

Table 2. Absorbed Energy.



(a) Actual Absorbed Energy



(b) Normalized Absorbed Energy to the Wood Baseline Test

In each test, the composite blockout had sufficient strength to develop the capacity of the steel guardrail post. If the raised composite blockout fractured or detached, this behavior occurred after the post had twisted more than 90 degrees out of plane with the guardrail and in some cases was related to a secondary impact from the pendulum as it swung back after the initial impact event. If a guardrail post is laterally loaded to the point it twists 90 degrees or more as it bends and deflects, it is likely that the guardrail has detached from the blockout and the effective offset distance has been reduced. Fracture of the blockout at this time is not likely to affect the outcome of the impact event.

Table 3 summarizes testing results in terms of maximum displacement and maximum 50-ms average acceleration.

Table 3. Summary of Results.

	Maximum Displacement (inches)	Time at Maximum Displacement (s)	Maximum 50-ms Average Acceleration (g)	Time at Max 50-ms Average Acceleration (s)
P1 – Baseline Trinity	11	0.085	-5.9	0.051
P2 – Baseline Wood	19	0.136	-6.5	0.058
P3 – Trinity Raised (4")	10.5	0.094	-5.0	0.039
P4 – Wood Raised (4")	11	0.085	-6.0	0.053
P5 – Wood Raised (4")	19	0.142	-6.1	0.059
P6 – Baseline Mondo	10	0.106	-5.5	0.040
P7 – Mondo Raised (4")	5.5	0.063	-4.8	0.40
P8 – Mondo Raised (4")	5.3	0.060	-4.6	0.101
P9 – King Raised (4")	6.3	0.075	-4.0	0.088

As a result of the pendulum tests on raised blockouts reported herein, the Roadside Safety Pooled Fund has decided to fund an additional project to full-scale crash test a complete guardrail installation with blockouts raised on posts. Conducting a full-scale crash test with a 2270P (pickup truck) vehicle should provide a better understanding of the performance of blockouts when raised on posts.

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. One accelerometer is mounted at the rear of the bogie to measure longitudinal acceleration levels, the other is side-mounted at the CG of the bogey. The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Accelerometer data is compared after capture to ensure lack of anomalies that could affect test results.

The electronic signals from the accelerometers were amplified and transmitted to a base station by means of constant bandwidth FM/FM telemetry radio link for recording. 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.

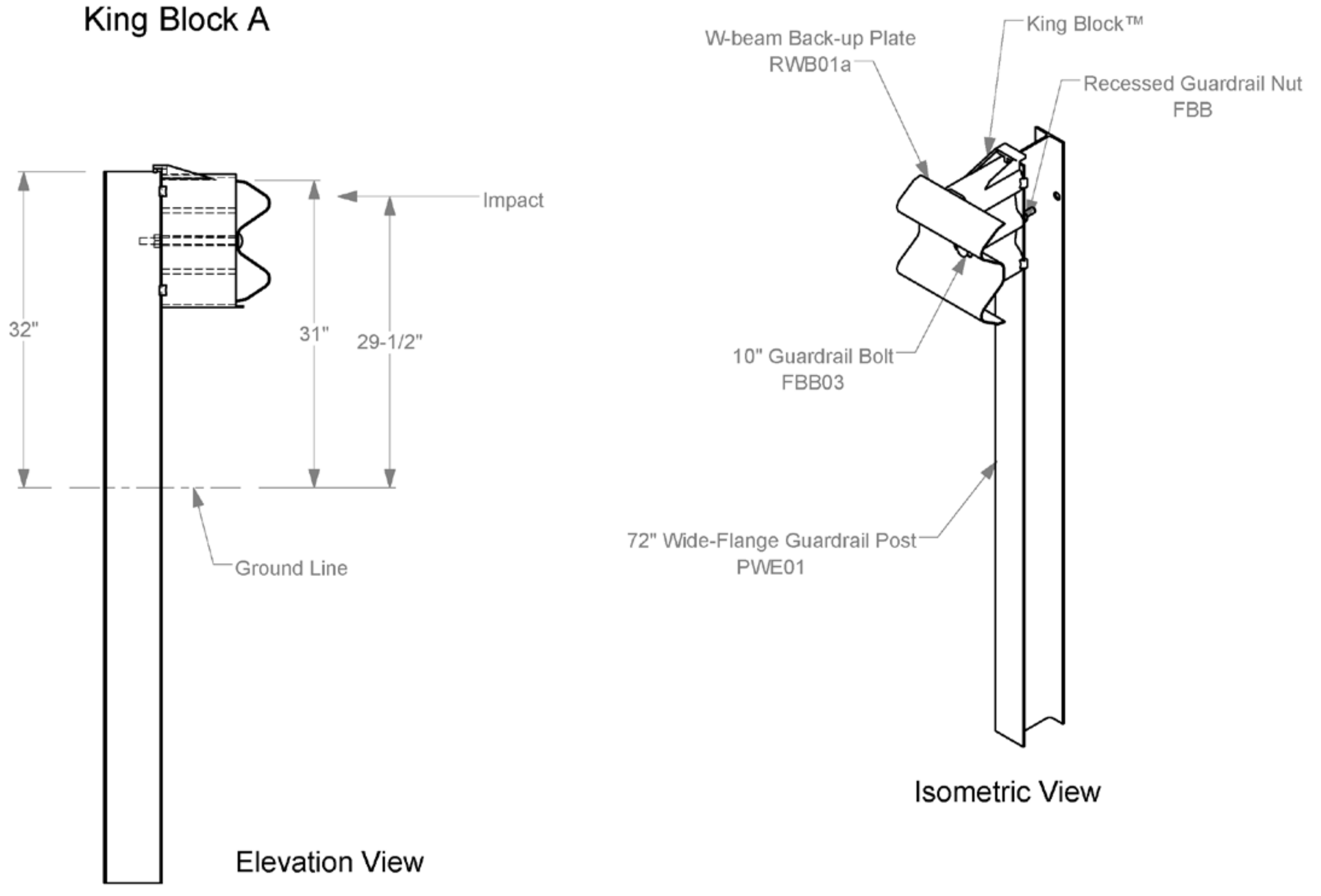
The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto TEAC® instrumentation data recorder. After the test, the data are played back from the TEAC® recorder and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer 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. TRAP 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 digital video files from this high-speed camera were analyzed on a computer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital video camera and still cameras were used to document the bogie nose and the test article before and after the test.

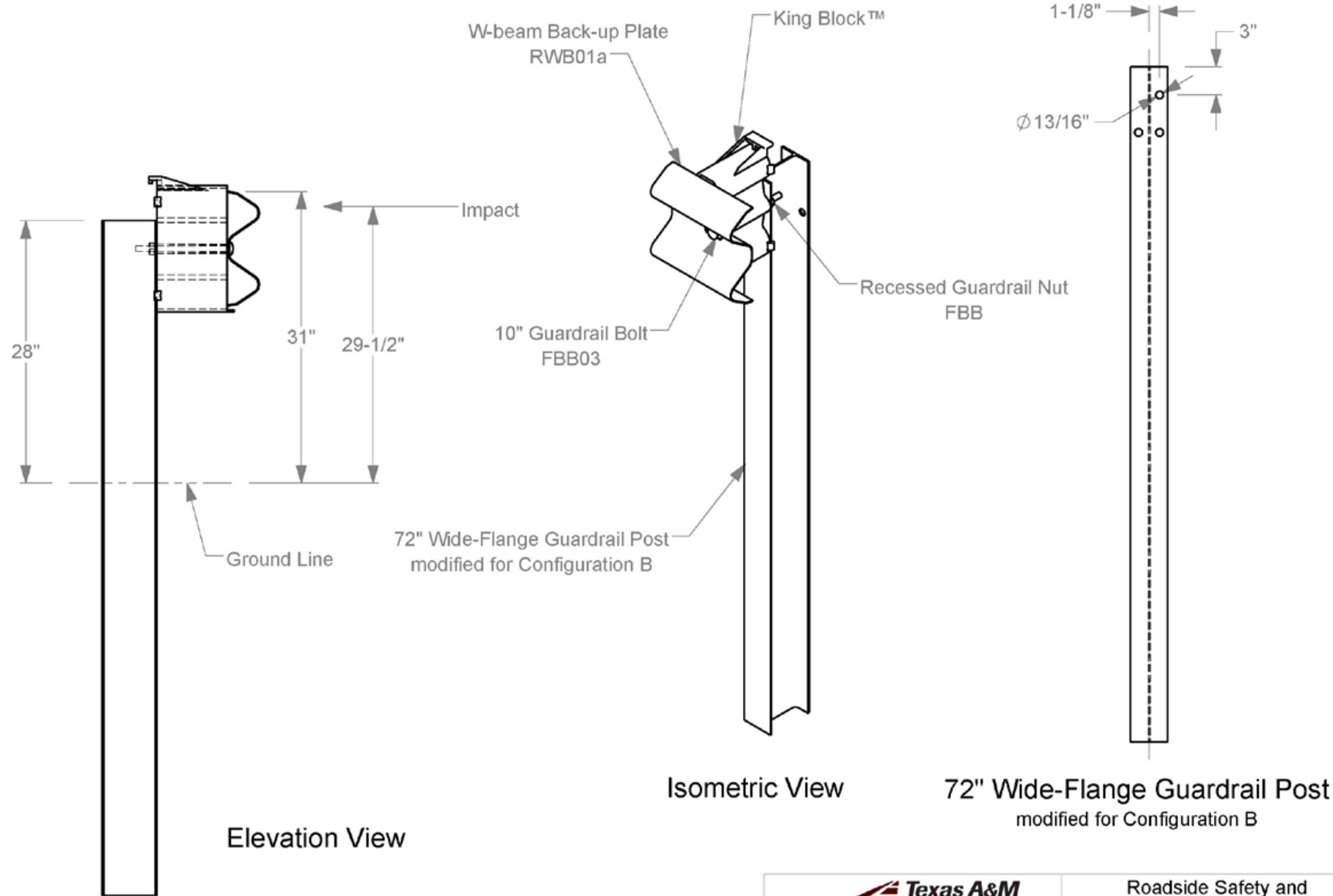
King Block A



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division Proving Ground -
Project 605311-P	Raised Composite Blockouts
Drawn By GES	Scale 1:15 · Sheet 1 of 6 · King Block A
Approved by Chiara Dobrovolny	Date: 2016-05-02

T:\1-ProjectFiles\605311 - Raised Blockouts - Chiara\Drafting\605311-P Drawing

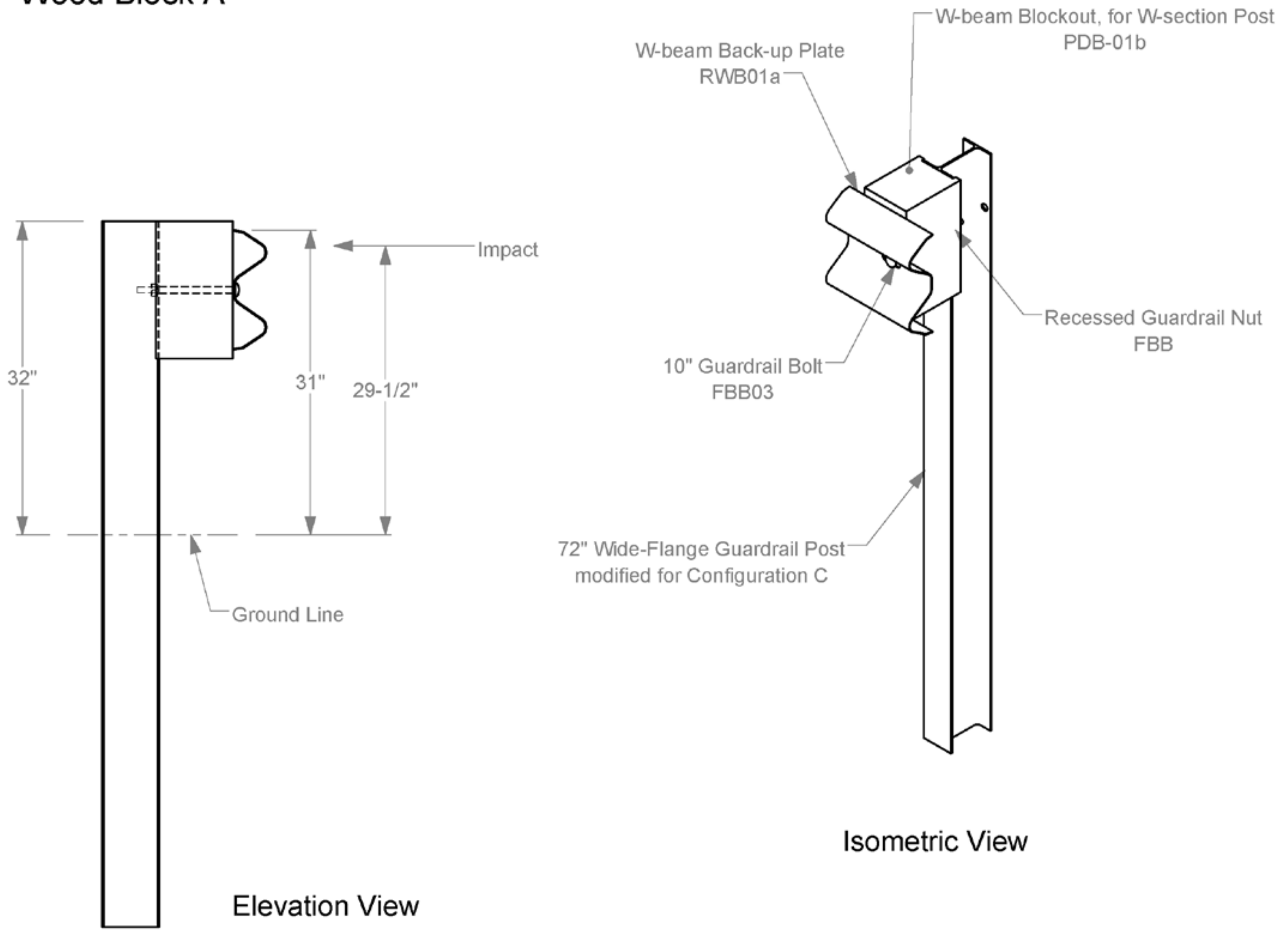
King Block B



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 605311-P	Raised Composite Blockouts		2016-05-02
Drawn By GES	Scale 1:15	Sheet 2 of 6	King Block B

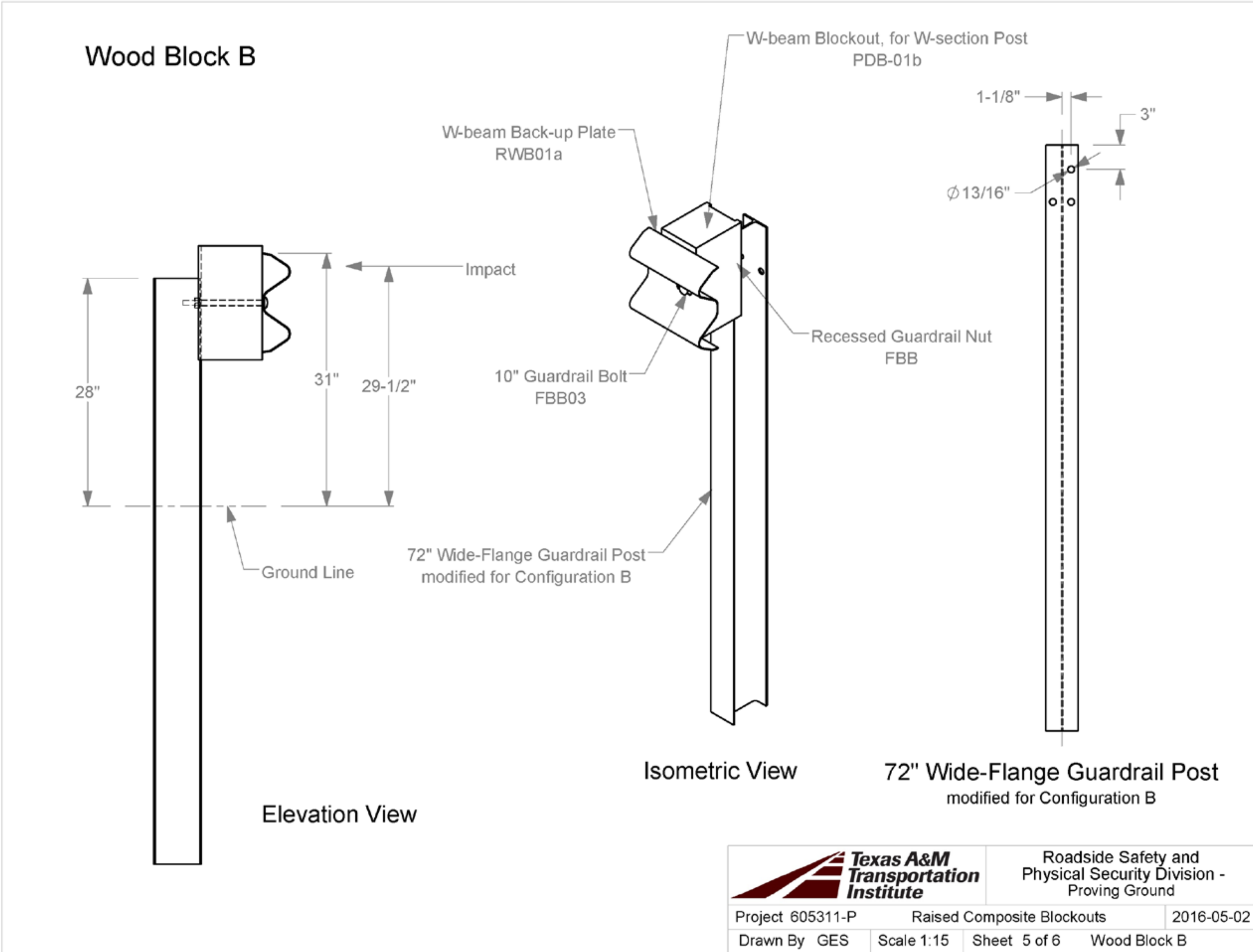
T:\1-ProjectFiles\605311 - Raised Blockouts - Chiara\Drafting\605311-P Drawing

Wood Block A



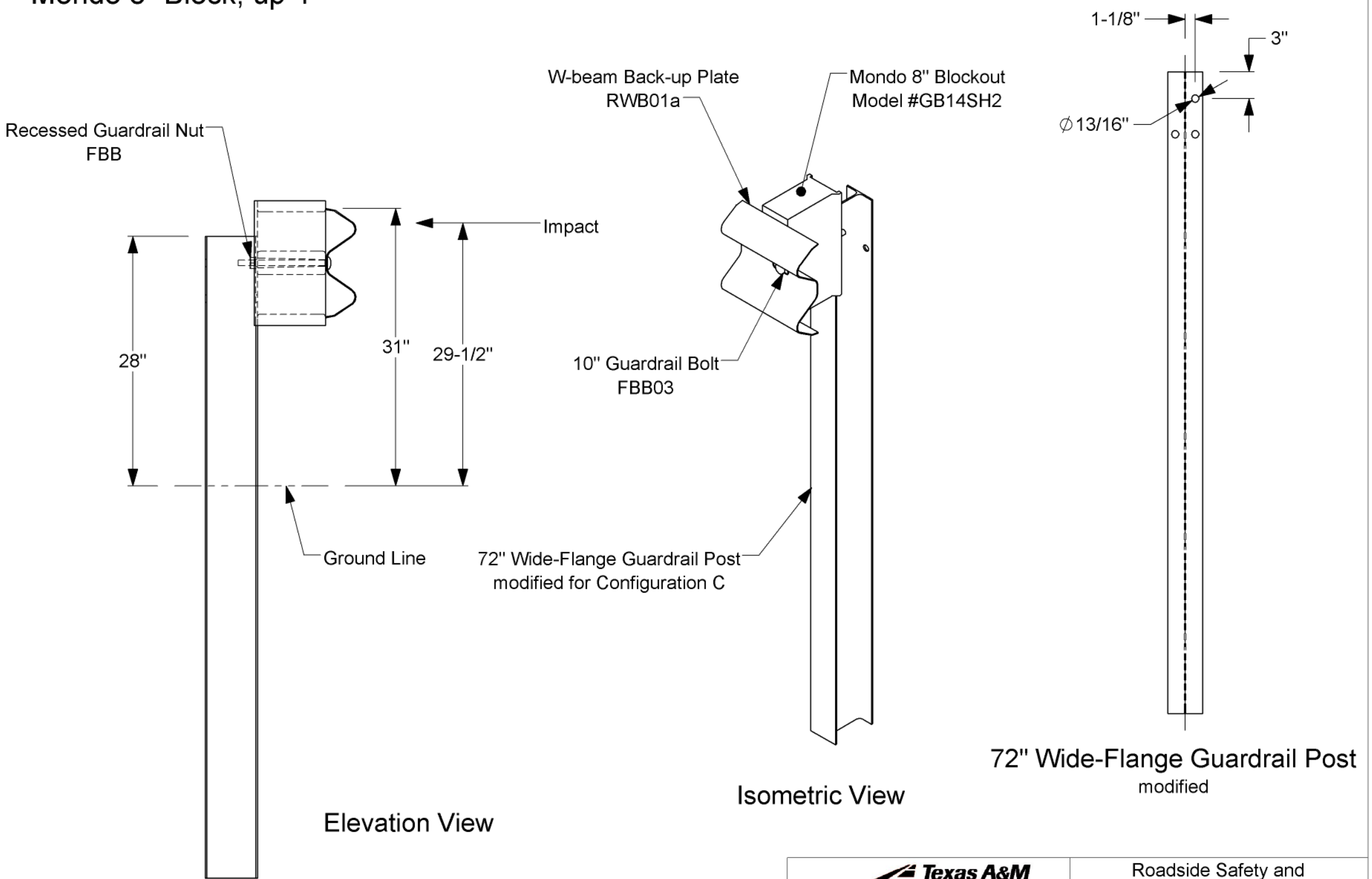
Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 605311-P	Raised Composite Blockouts		2016-05-02
Drawn By GES	Scale 1:15	Sheet 4 of 6	Wood Block A

T:\1-ProjectFiles\605311 - Raised Blockouts - Chiara\Drafting\605311-P Drawing



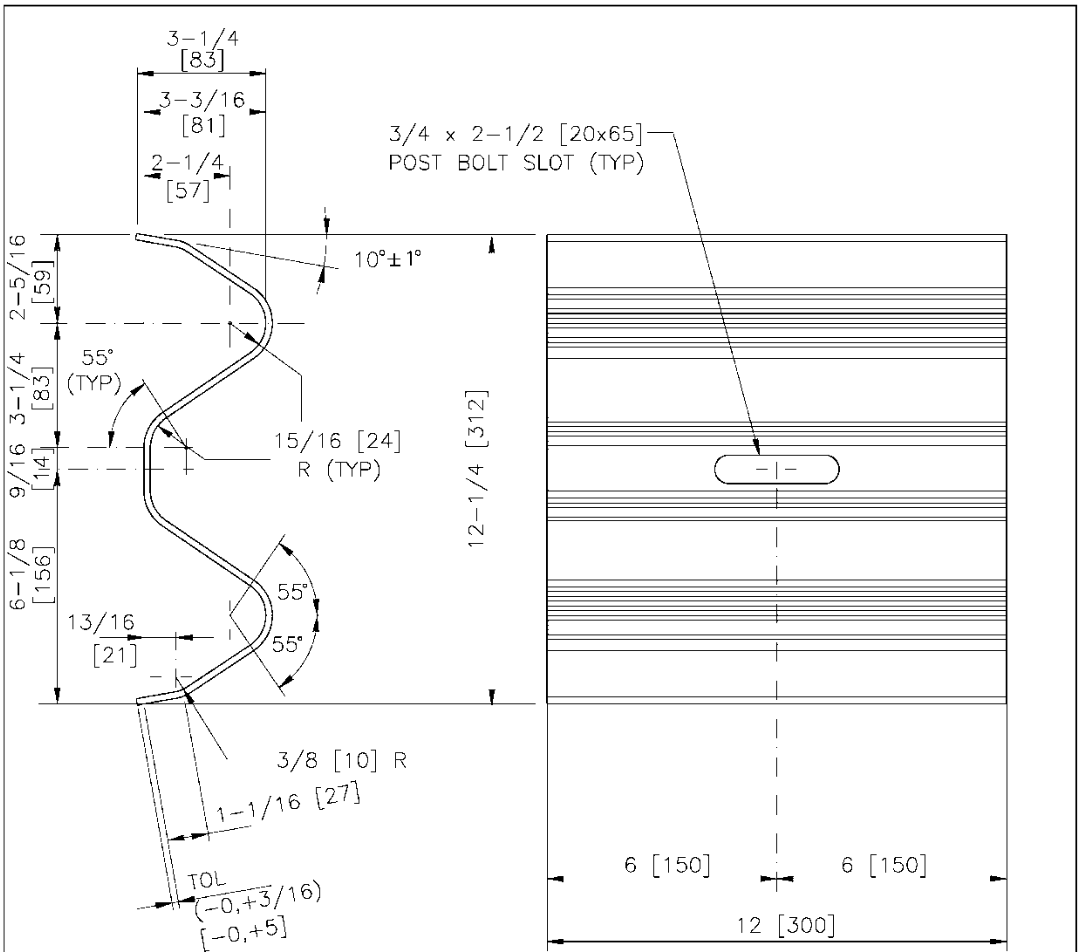
T:\1-ProjectFiles\605311 - Raised Blockouts - Chiara\Drafting\605311-P Drawing

Mondo 8" Block, up 4"



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project 605311 P8-	Raised Composite Blockouts		2016-09-06
Drawn By GES	Scale 1:15	Sheet 2 of 4	Mondo 8" Block, up 4"

T:\1-ProjectFiles\605311 - Raised Blockouts - Chiara\605311 P8-P13\Drafting\605311-P8- Drawing



DESIGNATOR	BASE METAL THICKNESS
RWB01a	12 GAGE [2.77]
RWB01b	10 GAGE [3.43]

1994

W-BEAM BACK-UP PLATE

RWB01a-b

SHEET NO.	DATE:
1 of 2	6/09/2005

SPECIFICATIONS

Back-up plates shall conform to the current requirements of AASHTO M 180. The section shall be manufactured from sheets with a nominal width of 19 inches [483 mm]. RWB01a shall conform to AASHTO M 180 Class A, and RWB01b shall conform to Class B. Corrosion protection shall be either Type II (galvanized) or Type IV (corrosion-resistant steel). Type IV material shall conform to ASTM A 588/A 588 M and shall not be galvanized, painted or otherwise coated.

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

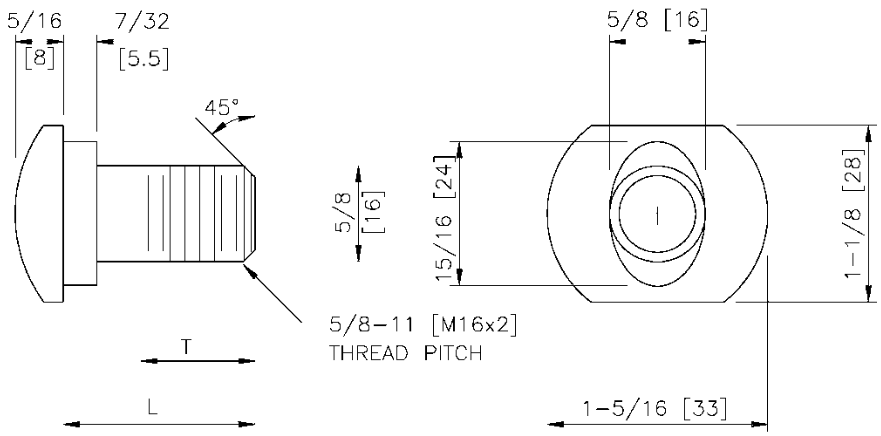
INTENDED USE

This back-up plate is placed behind W-beam guardrail elements (RWM02a-b) at intermediate steel posts (non-splice posts) in the SGR04a W-beam guardrail.

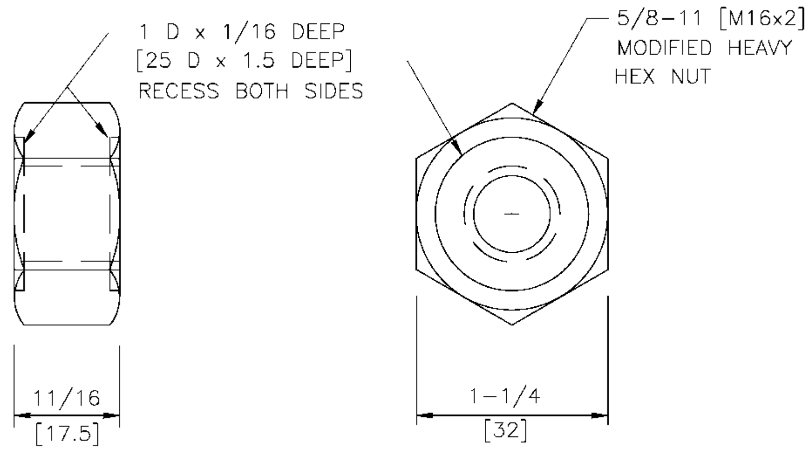
W-BEAM BACK-UP PLATE

RWB01a-b	
SHEET NO.	DATE
2 of 2	7/06/2005

NOTES:
1. ALL FILLETS SHALL HAVE A MINIMUM RADIUS OF 1/16 [2].
2. IF THE BOLT EXTENDS MORE THAN 1/4 [6] FROM THE NUT THE BOLT SHOULD BE TRIMMED BACK.



DESIGNATOR	L	T (MIN)
FBB01	1-1/4 [35]	1-1/8 [30]
FBB02	2 [50]	1-3/4 [45]
FBB03	10 [255]	4 [100]
FBB04	18 [460]	4 [100]
FBB05	25 [640]	4 [100]



1976

GUARDRAIL BOLT AND RECESSED NUT

FBB01-05

SHEET NO.	DATE:
1 of 2	6/30/2005

SPECIFICATIONS

The geometry and material specifications for this oval shoulder button-headed bolt and hex nut are found in AASHTO M 180. The bolt shall have 5/8-11 [M16x2] threads as defined in ANSI B1.1 [ANSI B1.13M] for Class 2A [6g] tolerances. Bolt material shall conform to ASTM A307 Grade A [ASTM F 568M Class 4.6], with a tensile strength of 60 ksi [400 MPa] and yield strength of 36 ksi [240 MPa]. Material for corrosion-resistant bolts shall conform to ASTM A325 Type 3 [ASTM F 568M Class 8.8.3], with tensile strength of 120 ksi [830 MPa] and yield strength of 92 ksi [660 MPa]. This bolt material has corrosion resistance comparable to ASTM A588 steels. Metric zinc-coated bolt heads shall be marked as specified in ASTM F 568 Section 9 with the symbol "4.6."

Nuts shall have ANSI B1.1 Class 2B [ANSI B1.13M Class 6h] 5/8-11 [M16x2] threads. The geometry of the nuts, with the exception of the recess shown in the drawing, shall conform to ANSI B18.2.2 [ANSI B18.2.4.1M Style 1] for zinc-coated hex nuts (shown in drawing) and ANSI B18.2.2 [ANSI B18.2.4.6M] for heavy hex corrosion-resistant nuts (not shown in drawing). Material for zinc-coated nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade A [AASHTO M 291M (ASTM A 563M) Class 5], and material for corrosion-resistant nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade C3 [AASHTO M 291M (ASTM A 563M) Class 8S3].

When zinc-coated bolts and nuts are required, the coating shall conform to either AASHTO M 232 (ASTM A 153/A 153M) for Class C or AASHTO M 298 (ASTM B 695) for Class 50. Zinc-coated nuts shall be tapped over-size as specified in AASHTO M 291 (ASTM A 563) [AASHTO M 291M (ASTM A 563M)], except that a diametrical allowance of 0.020 inch [0.510 mm] shall be used instead of 0.016 inches [0.420 mm].

Designator	Stress Area of Threaded Bolt Shank (in^2 [mm^2])	Min. Bolt Tensile Strength (kips [kN])
FBB01-05	0.226 [157.0]	13.6 [62.8]

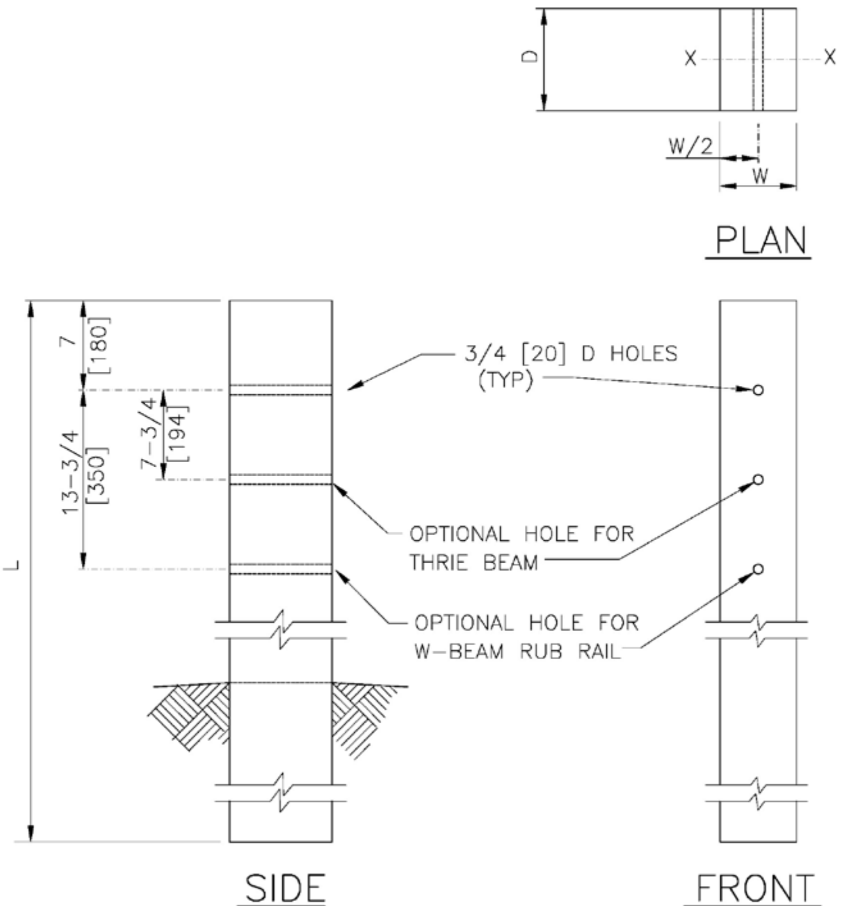
Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

These bolts and nuts are used in numerous guardrail and median barrier designs.

GUARDRAIL BOLT AND RECESSED NUT

FBB01-05	
SHEET NO.	DATE
2 of 2	6/30/2005



DESIGNATOR	L	W	D
PDE01	64 [1625]	6 [150]	7-7/8 [200]
PDE02	72 [1830]	6 [150]	7-7/8 [200]
PDE03	78 [1980]	6 [150]	7-7/8 [200]
PDE04	81 [2060]	6 [150]	7-7/8 [200]
PDE05	72 [1830]	7-7/8 [200]	7-7/8 [200]
PDE06	78 [1980]	7-7/8 [200]	7-7/8 [200]
PDE07	72 [1830]	9-7/8 [250]	9-7/8 [250]
PDE08	78 [1980]	9-7/8 [250]	9-7/8 [250]

1994

TIMBER GUARDRAIL POST

PDE01-08

SHEET NO.	DATE:
1 of 2	6/28/2005

SPECIFICATIONS

Posts shall be made of timber with a stress grade of at least 1160 psi [8 MPa]. Stress grading shall be in accordance with the rules of the West Coast Lumber Inspection Bureau, Southern Pine Inspection Bureau, or other appropriate timber association. Timber for posts shall be either rough-sawn (unplaned) or S4S (surfaced four sides) with nominal dimensions indicated. The size tolerance of posts in the direction parallel to the axis of the bolt holes shall not be more than ± ¼ inch [6 mm]. Only one type of surface finish shall be used for posts and blockouts in any one continuous length of guardrail.

All timber shall receive a preservation treatment in accordance with AASHTO M 133 after all end cuts are made and holes are drilled.

Inertial properties shown below are based on the nominal dimensions shown.

Designator	Area in^2 [10^3 mm^2]	I_x in^4 [10^6 mm^4]	I_y in^4 [10^6 mm^4]	S_x in^3 [10^3 mm^3]	S_y in^3 [10^3 mm^3]
PDE01-02	46.5 [30]	240.2 [100]	134.5 [56]	61.0 [1000]	45.8 [750]
PDE03-04	62.0 [40]	319.5 [133]	319.5 [133]	81.3 [1333]	81.3 [1333]
PDE05-06	77.5 [50]	624.6 [260]	401.2 [167]	127.1 [2083]	101.7 [1667]
PDE07-08	97.6 [63]	783.2 [326]	783.2 [326]	158.9 [2604]	158.9 [2604]

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

These posts are used in a variety of strong-post W-beam and thrie-beam systems, including the SGR04b, SGR04c, and SGR09c guardrails and the SGM04b and SGM09c median barriers.

TIMBER GUARDRAIL POST

PDE01-08

SHEET NO.	DATE
2 of 2	7/06/2005

ATTACHMENT C. TEST SUMMARIES

Table C1. Summary of Results for Pendulum Test No. 605311-P1.

0.000 s

0.070 s

0.140 s

0.210 s

General Information

Test Agency .... Texas A&M Transportation Institute
Test No. 605311-P1
Date 2016-05-06

Test Article

Type ....Blockout on Steel Post at Standard Height
Name .... King Block™
Installation Height
Top of Post ....32 inches above grade
Top of Guardrail Back-up Plate ....31 inches above grade
Impact Height ....29½ inches above grade
Material of Key Element ....King Block™ attached to 72-inch long steel post installed to depth of 40 inches

Soil Type .... AASHTO M147-65(2004), grading B Standard Soil

Test Vehicle

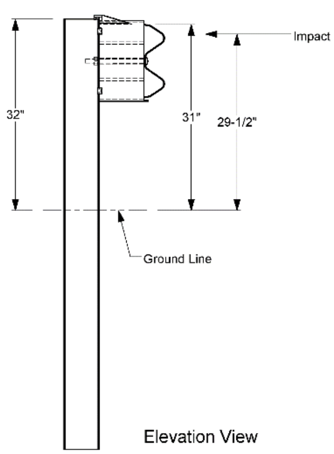
Type .... Bogie
Designation .... Pendulum
Test Inertia Mass....................1960 lb

Impact Conditions

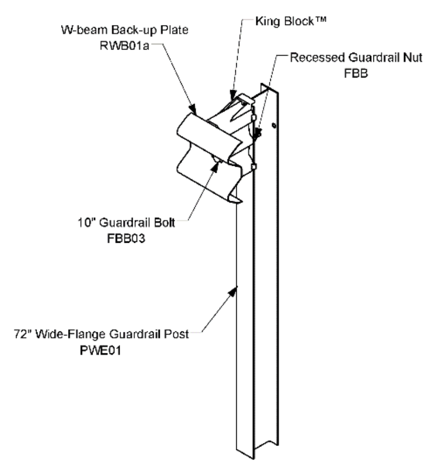
Speed....................20.0 mi/h
Angle....................90 deg

Maximum Dynamic Displacement.................... 11.0 inches
Energy .... 380 kip-inch
50-ms Average Acceleration.................... -5.9 g
50-ms Average Force .... 11.4 kips
Maximum Change in Velocity ....12.7 ft/s

King Block A



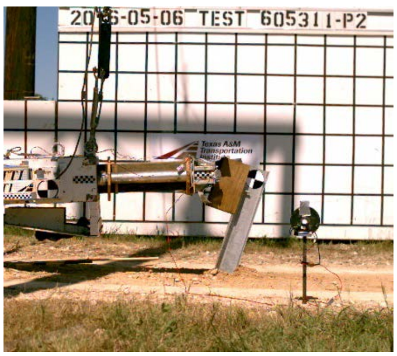
Elevation View



Isometric View

Table C2. Summary of Results for Pendulum Test No. 605311-P2.

0.000 s



0.070 s

0.140 s

0.210 s

General Information

Test Agency .... Texas A&M Transportation Institute
Test No. 605311-P2
Date 2016-05-06

Test Article

Type ....Blockout on Steel Post at Standard Height
Name .... PDB-01b Wood Blockout
Installation Height
Top of Post ....32 inches above grade
Top of Guardrail Back-up Plate ....31 inches above grade
Impact Height ....29½ inches above grade
Material of Key Element .... PDB-01b Wood Blockout
attached to 72-inch long steel post installed
to depth of 40 inches

Soil Type .... AASHTO M147-65(2004), grading B
Standard Soil

Test Vehicle

Type .... Bogie
Designation .... Pendulum
Test Inertia Mass...1960 lb

Impact Conditions

Speed...21.5 mi/h
Angle...90 deg

Maximum Dynamic Displacement....................... 19.0 inches
Energy .... 488 kip-inch
50-ms Average Acceleration... -6.5 g
50-ms Average Force .... 12.8 kips
Maximum Change in Velocity ....15.3 ft/s

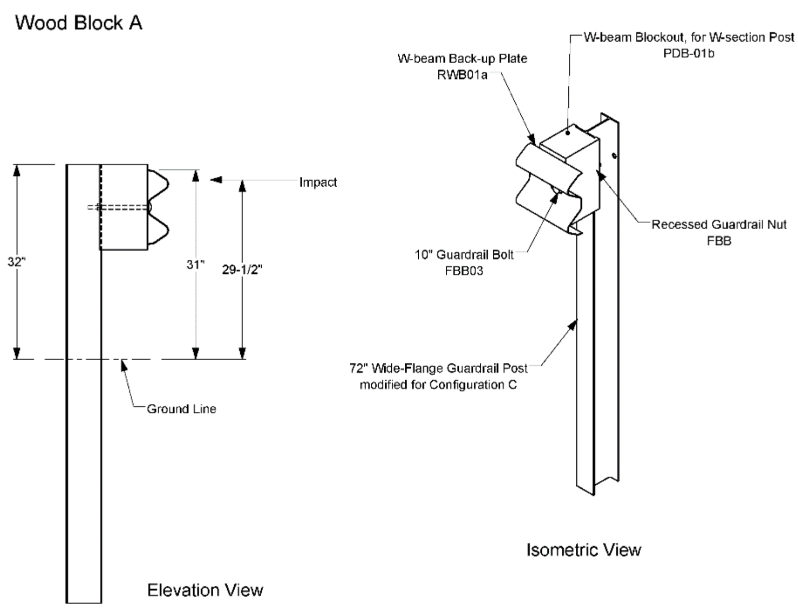
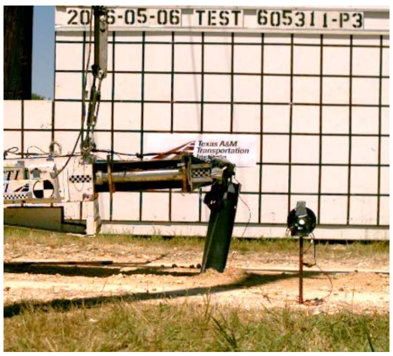


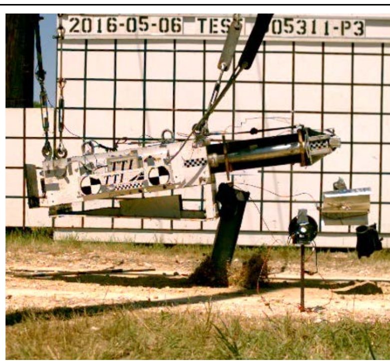
Table C3. Summary of Results for Pendulum Test No. 605311-P3.

0.000 s



0.070 s

0.140 s



0.210 s

General Information

Test Agency .... Texas A&M Transportation Institute
Test No. 605311-P3
Date 2016-05-06

Test Article

Type .... Blockout on Steel Post Raised 4 inches
Name .... King Block™
Installation Height
  Top of Post .... 28 inches above grade
  Top of Guardrail Back-up Plate .... 31 inches above grade
Impact Height .... 29½ inches above grade
Material of Key Element .... King Block™ attached to 72-inch long steel post installed to depth of 44 inches

Soil Type .... AASHTO M147-65(2004), grading B Standard Soil

Test Vehicle

Type .... Bogie
Designation .... Pendulum
Test Inertia Mass .... 1960 lb

Impact Conditions

Speed .... 19.9 mi/h
Angle .... 90 deg

Maximum Dynamic Displacement .... 10.5 inches
Energy .... 310 kip-inch
50-ms Average Acceleration .... -5.0 g
50-ms Average Force .... 9.8 kips
Maximum Change in Velocity .... 10.5 ft/s

King Block B

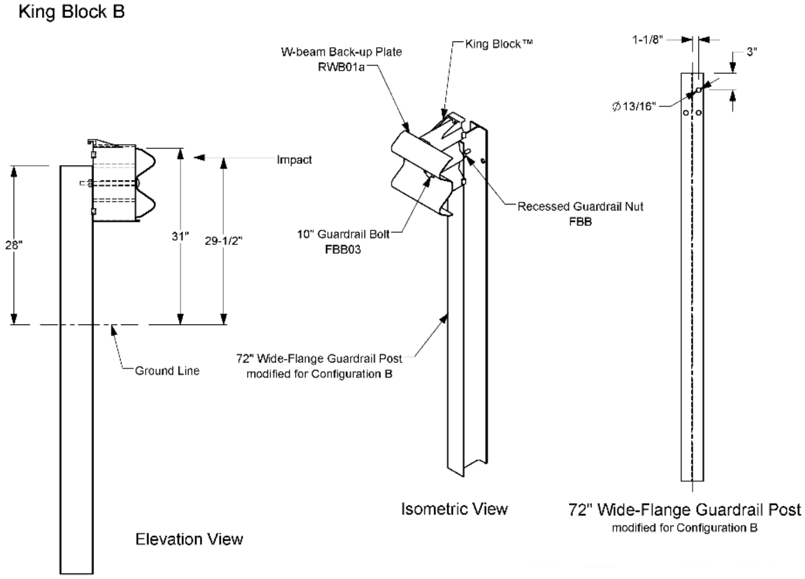
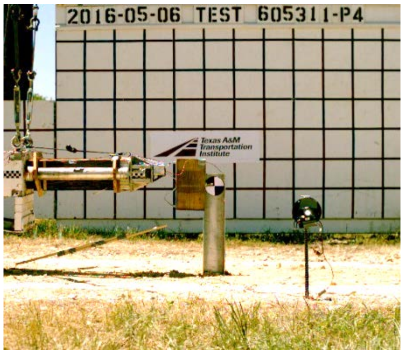
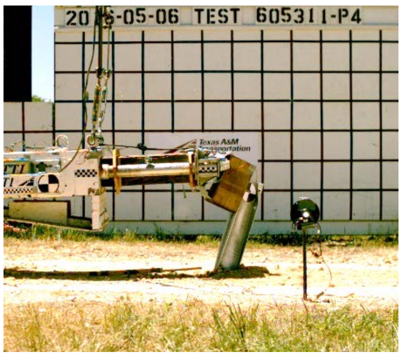


Table C4. Summary of Results for Pendulum Test No. 605311-P4.



0.000 s



0.070 s

0.140 s

0.210 s

General Information
- Test Agency .... Texas A&M Transportation Institute
- Test No. 605311-P4
- Date 2016-05-06

Test Article
- Type .... Blockout on Steel Post Raised 4 inches
- Name .... PDB-01b Wood Blockout
- Installation Height
  - Top of Post ....28 inches above grade
  - Top of Guardrail Back-up Plate ....31 inches above grade
- Impact Height ....29½ inches above grade
- Material of Key Element .... PDB-01b Wood Blockout attached to 72-inch long steel post installed to depth of 44 inches

Soil Type .... AASHTO M147-65(2004), grading B Standard Soil

Test Vehicle
- Type .... Bogie
- Designation .... Pendulum
- Test Inertia Mass..1960 lb

Impact Conditions
- Speed...19.7 mi/h
- Angle...90 deg

Maximum Dynamic Displacement....................... 11.0 inches

Energy .... 369 kip-inch

50-ms Average Acceleration.. -6.0 g

50-ms Average Force .... 11.6 kips

Maximum Change in Velocity ....11.9 ft/s

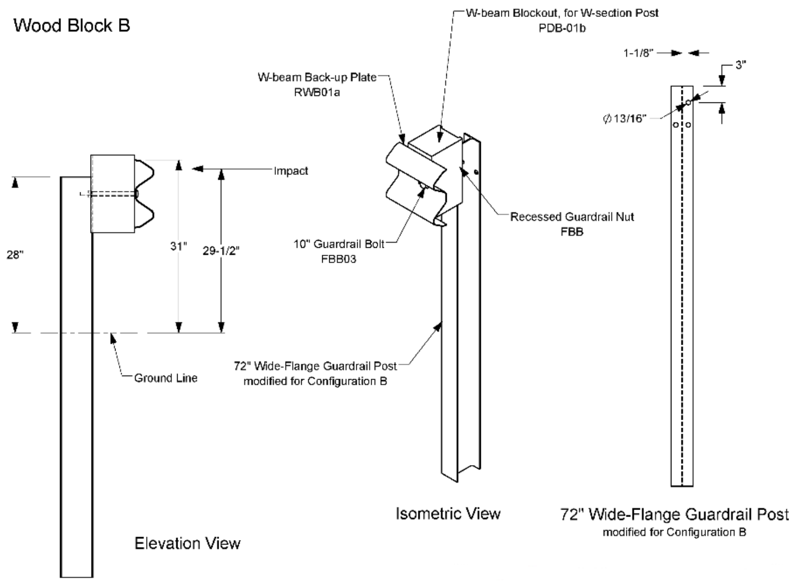
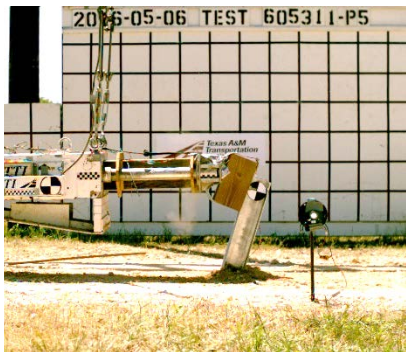
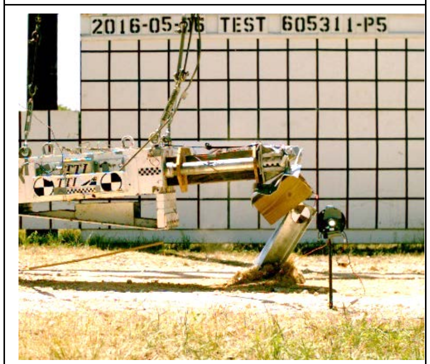


Table C5. Summary of Results for Pendulum Test No. 605311-P5.

0.000 s



0.070 s



0.140 s

0.210 s

General Information

Test Agency .... Texas A&M Transportation Institute
Test No. 605311-P5
Date 2016-05-06

Test Article

Type .... Blockout on Steel Post Raised 4 inches
Name .... PDB-01b Wood Blockout
Installation Height
Top of Post ....28 inches above grade
Top of Guardrail Back-up Plate ....31 inches above grade
Impact Height ....29½ inches above grade
Material of Key Element .... PDB-01b Wood Blockout attached to 72-inch long steel post installed to depth of 44 inches

Soil Type .... AASHTO M147-65(2004), grading B Standard Soil

Test Vehicle

Type .... Bogie
Designation .... Pendulum
Test Inertia Mass..1960 lb

Impact Conditions

Speed...19.7 mi/h
Angle...90 deg

Maximum Dynamic Displacement....................... 19.0 inches
Energy .... 405 kip-inch
50-ms Average Acceleration.. -6.1 g
50-ms Average Force... 11.9 kips
Maximum Change in Velocity ....17.0 ft/s

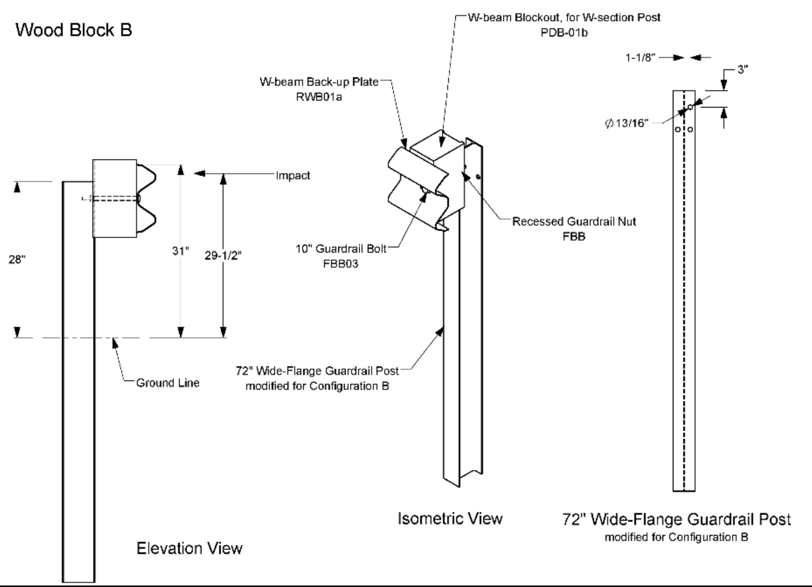
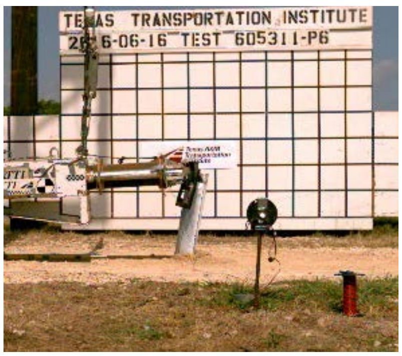
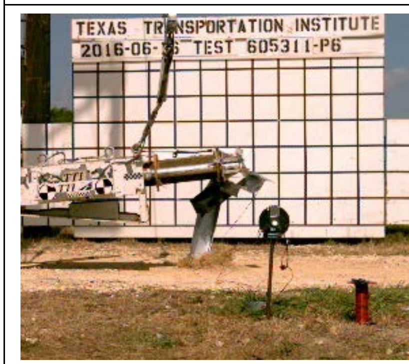


Table C6. Summary of Results for Pendulum Test No. 605311-P6.

0.000 s



0.070 s



0.140 s

0.210 s

General Information	
Test Agency	Texas A&M Transportation Institute
Test No.	605311-P6
Date	2016-06-16
Test Article	
Type	Mondo Blockout on Steel Post Raised 4 inches
Name	PDB-01b Wood Blockout
Installation Height	
Top of Post	28 inches above grade
Top of Guardrail Back-up Plate	31 inches above grade
Impact Height	29½ inches above grade
Material of Key Element	Mondo 8-inch Composite Block attached to 72-inch long steel post installed to depth of 44 inches
Soil Type	AASHTO M147-65(2004), grading B Standard Soil
Test Vehicle	
Type	Bogie
Designation	Pendulum
Test Inertia Mass	1750 lb
Impact Conditions	
Speed	19.7 mi/h
Angle	90 deg
Maximum Dynamic Displacement	9.5 inches
Energy	377 kip-inch
50-ms Average Acceleration	-5.5 g
50-ms Average Force	10.7 kips
Maximum Change in Velocity	16.8 ft/s

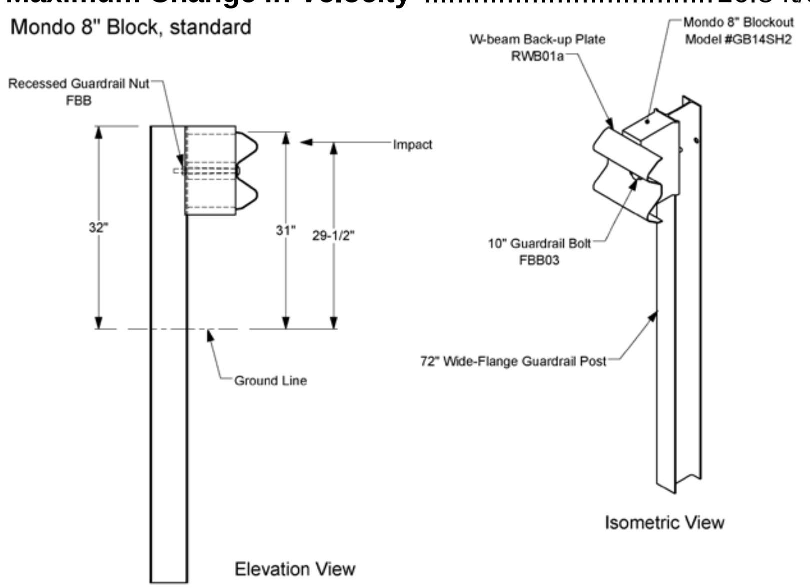
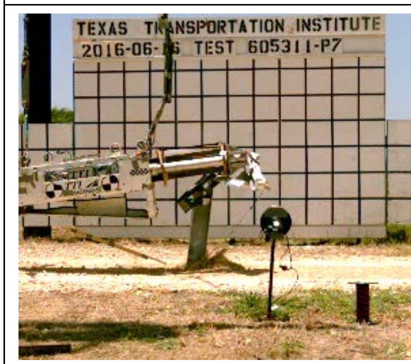
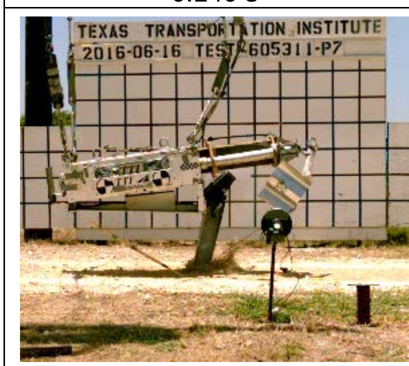


Table C7. Summary of Results for Pendulum Test No. 605311-P7.

0.000 s


0.070 s


0.140 s


0.210 s

General Information
Test Agency .... Texas A&M Transportation Institute
Test No. 605311-P7
Date 2016-06-16

Test Article
Type .... Blockout on Steel Post Raised 4 inches
Name .... Mondo Composite Blockout
Installation Height
Top of Post ....32 inches above grade
Top of Guardrail Back-up Plate ....29 inches above grade
Impact Height ....27½ inches above grade
Material of Key Element ....Mondo 8-inch Composite Block attached to 72-inch long steel post installed to depth of 44 inches

Soil Type .... AASHTO M147-65(2004), grading B Standard Soil

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

Impact Conditions
Speed..19.8 mi/h
Angle..90 deg

Maximum Dynamic Displacement......................... 6.0 inches
Energy .... 310 kip-inch
50-ms Average Acceleration.. -4.8 g
50-ms Average Force .... 9.3 kips
Maximum Change in Velocity ....9.2 ft/s

Mondo 8" Block, up 4"

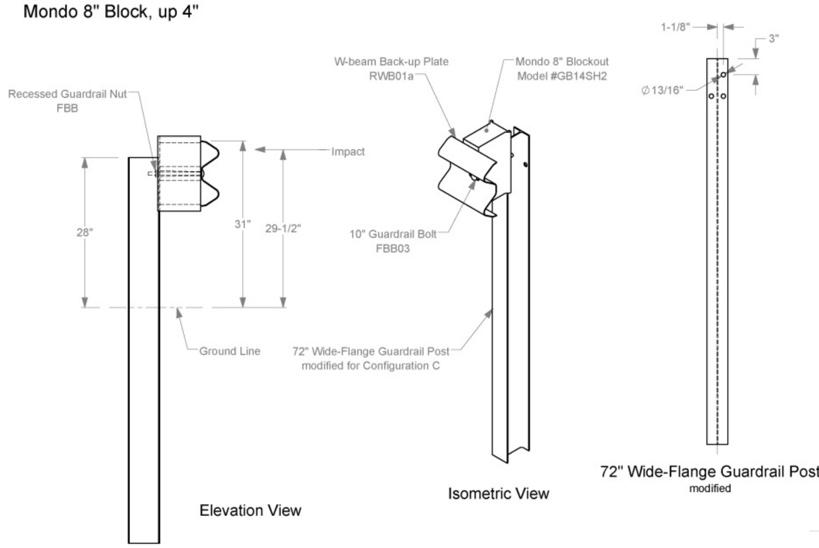


Table C8. Summary of Results for Pendulum Test No. 605311-P8.

0.000 s


0.090 s


0.180 s


0.270 s

General Information

Test Agency .... Texas A&M Transportation Institute
Test No. 605311-P8
Date 2016-09-28

Test Article

Type .... Blockout on Steel Post Raised 4 inches
Name .... Mondo Composite Blockout
Installation Height
Top of Post .... 28 inches above grade
Top of Guardrail Back-up Plate .... 31 inches above grade
Impact Height .... 29½ inches above grade
Material of Key Element .... Mondo 8-inch Composite Block attached to 72-inch long steel post installed to depth of 44 inches

Soil Type .... AASHTO M147-65(2004), grading B Standard Soil

Test Vehicle

Type .... Bogie
Designation .... Pendulum
Test Inertia Mass .... 2010 lb

Impact Conditions

Speed .... 18.7 mi/h
Angle .... 90 deg

Maximum Dynamic Displacement .... 6.5 inches
Energy .... 280 kip-inch
50-ms Average Acceleration .... -4.6 g
50-ms Average Force .... 9.2 kips
Maximum Change in Velocity .... 9.7 ft/s

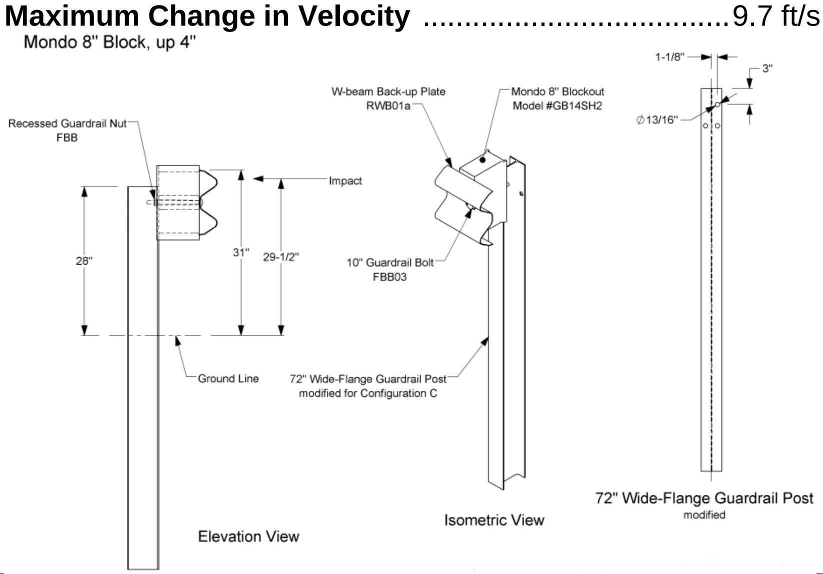


Table C9. Summary of Results for Pendulum Test No. 605311-P9.

0.000 s

0.090 s

0.180 s

0.270 s

General Information

Test Agency .... Texas A&M Transportation Institute
Test No. 605311-P9
Date 2016-09-28

Test Article

Type .... Blockout on Steel Post Raised 4 inches
Name ....King Block
Installation Height
Top of Post ....28 inches above grade
Top of Guardrail Back-up Plate ....31 inches above grade
Impact Height ....29½ inches above grade
Material of Key Element .... King 8-inch Composite Block attached to 72-inch long steel post installed to depth of 44 inches

Soil Type .... AASHTO M147-65(2004), grading B Standard Soil

Test Vehicle

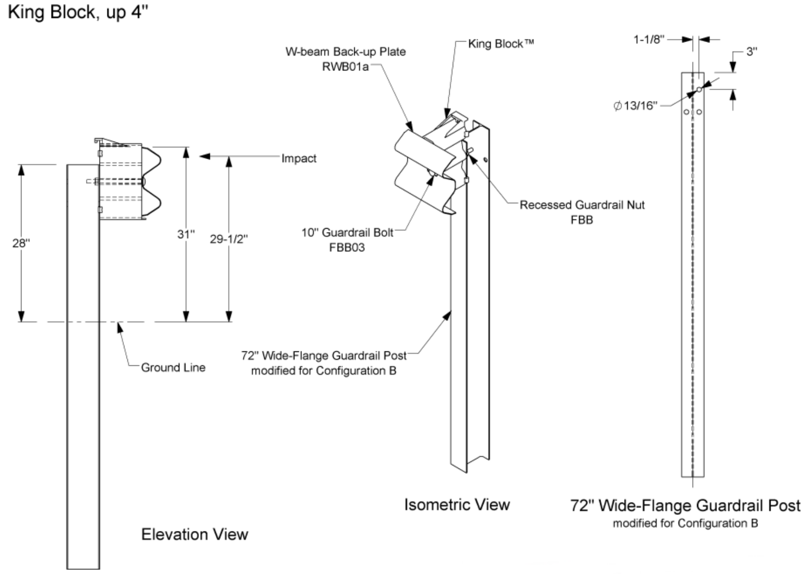
Type .... Bogie
Designation .... Pendulum
Test Inertia Mass..2010 lb

Impact Conditions

Speed..18.6 mi/h
Angle..90 deg

Maximum Dynamic Displacement......................... 8.0 inches
Energy .... 255 kip-inch
50-ms Average Acceleration.. -4.0 g
50-ms Average Force .... 8.0 kips
Maximum Change in Velocity ....10.6 ft/s

King Block, up 4"



ATTACHMENT D. ACCELERATION AND FORCE TRACES

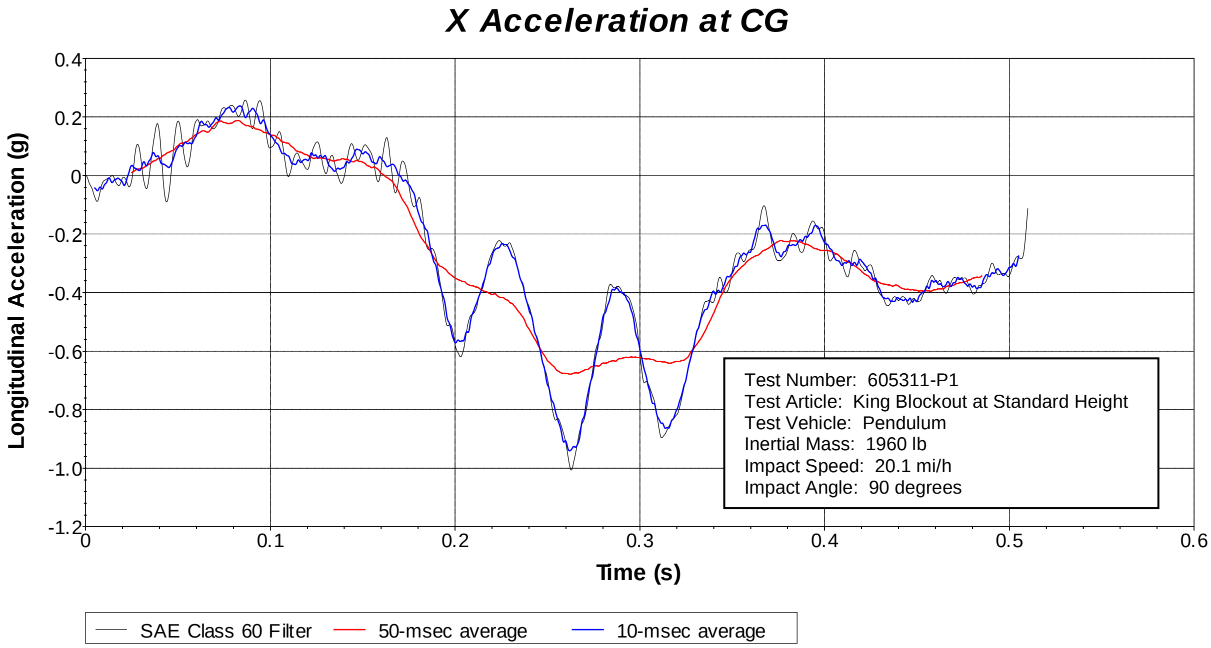


Figure D1. Accelerometer Trace for test 605311-P1.

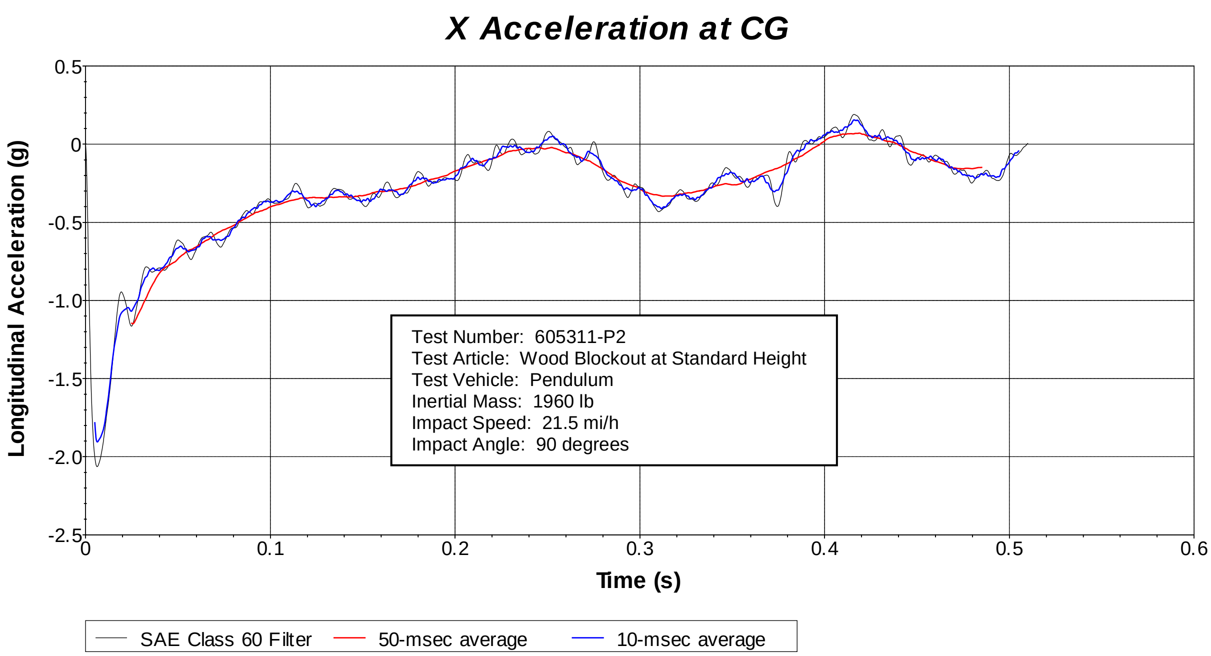


Figure D2. Accelerometer Trace for test 605311-P2.

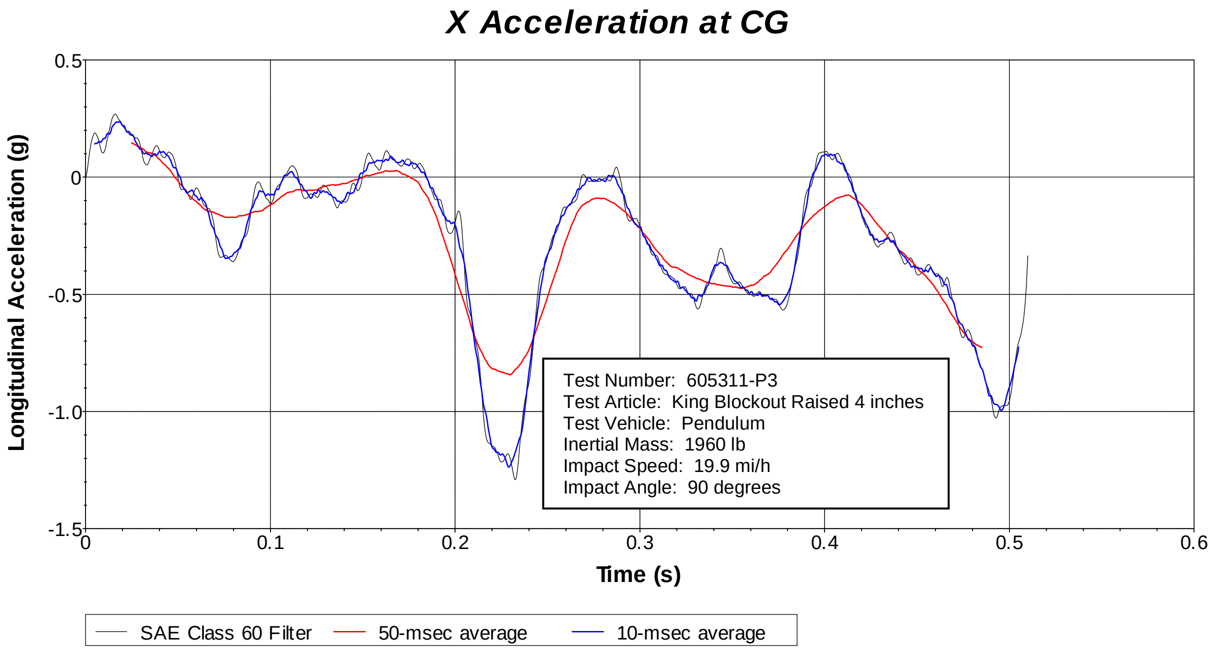


Figure D3. Accelerometer Trace for test 605311-P3.

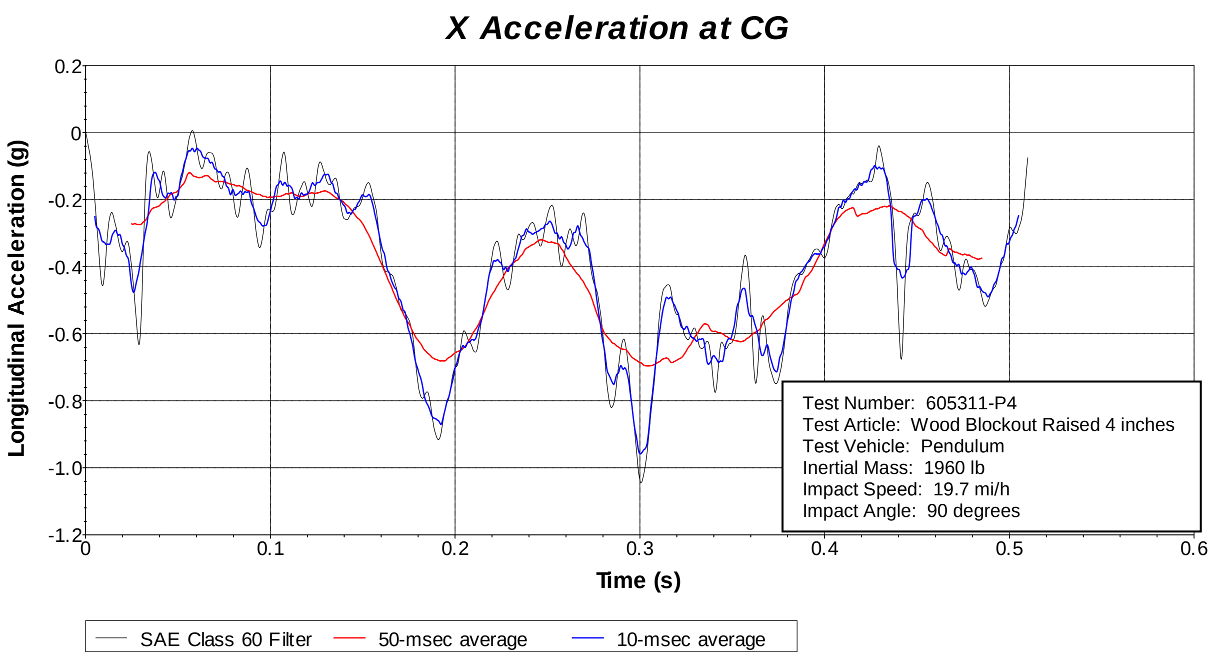


Figure D4. Accelerometer Trace for test 605311-P4.

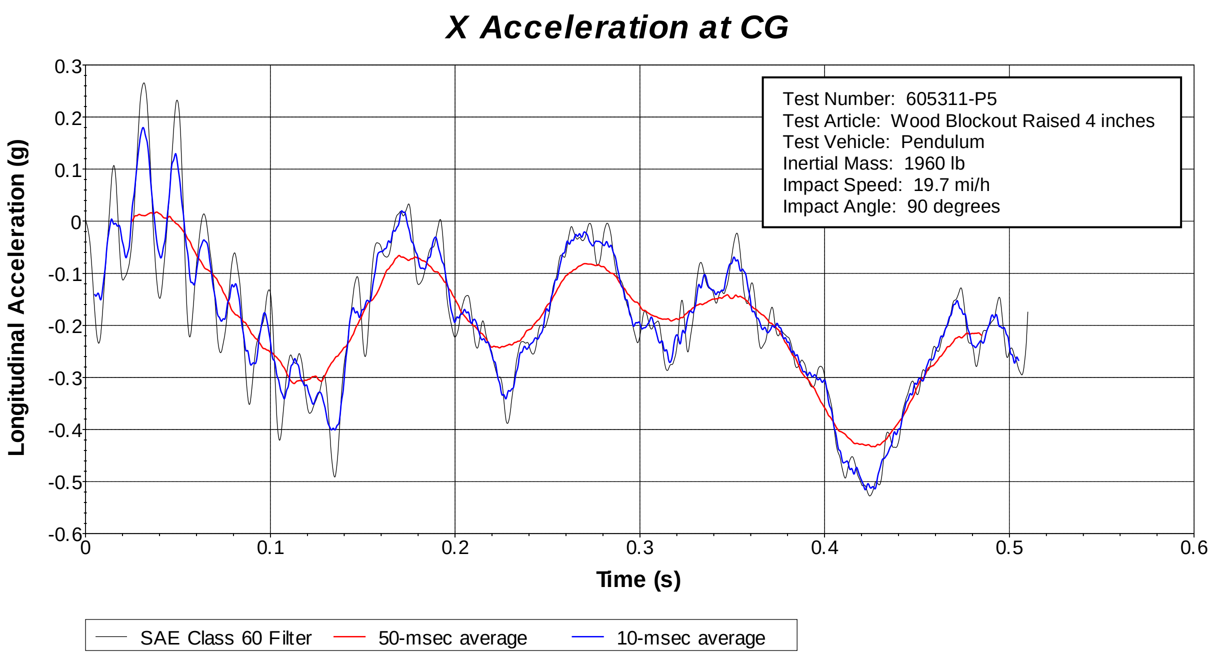


Figure D5. Accelerometer Trace for test 605311-P5.

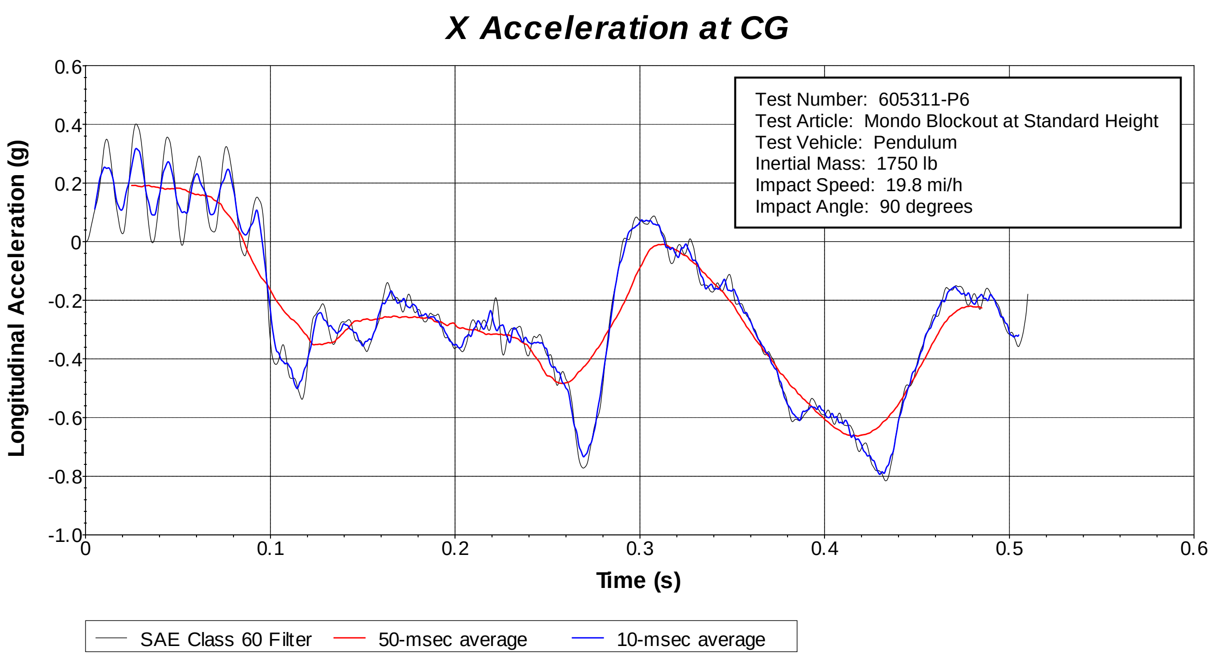


Figure D6. Accelerometer Trace for test 605311-P6.

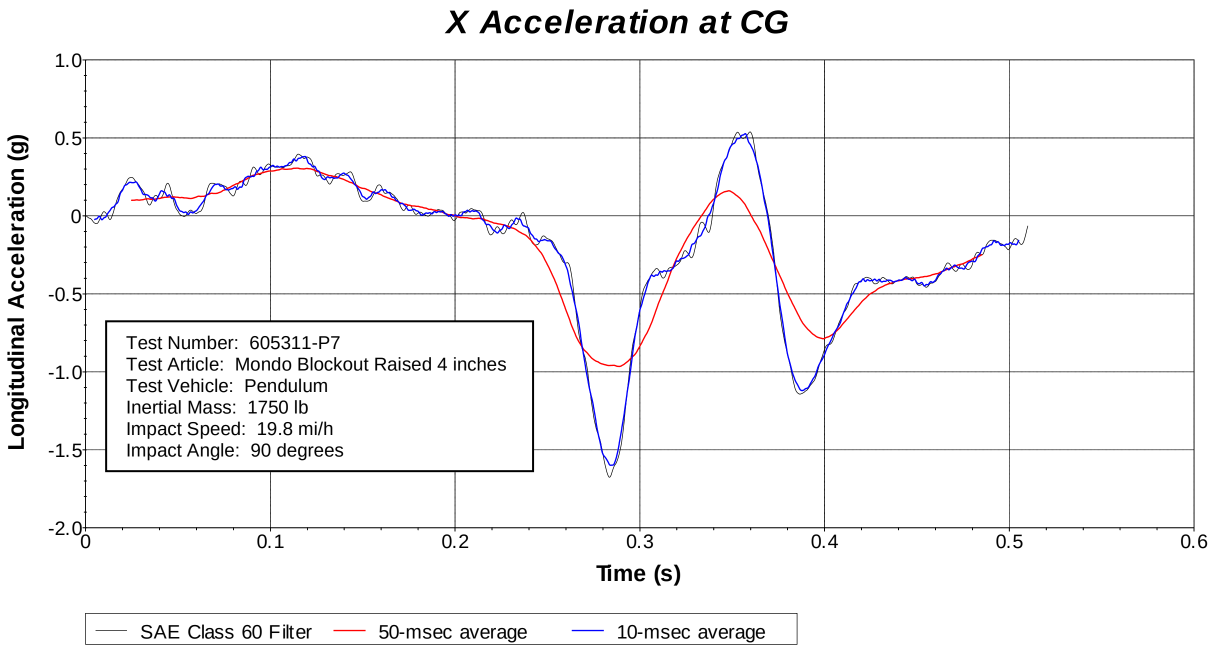


Figure D7. Accelerometer Trace for test 605311-P7.

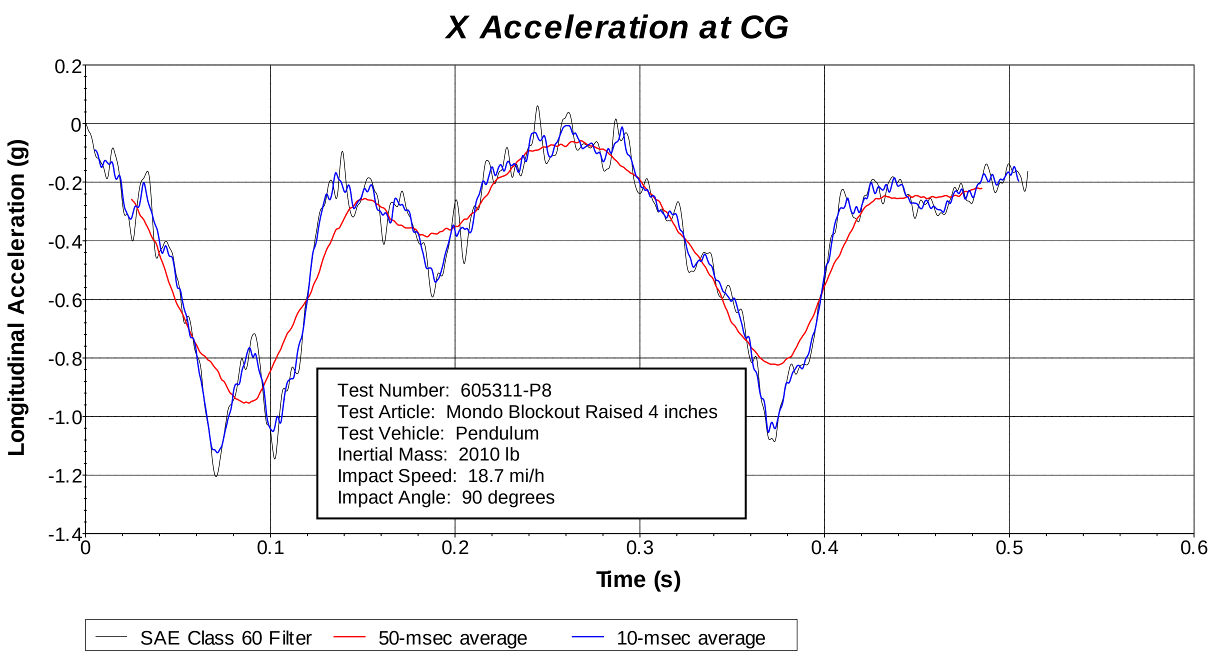


Figure D8. Accelerometer Trace for test 605311-P8.

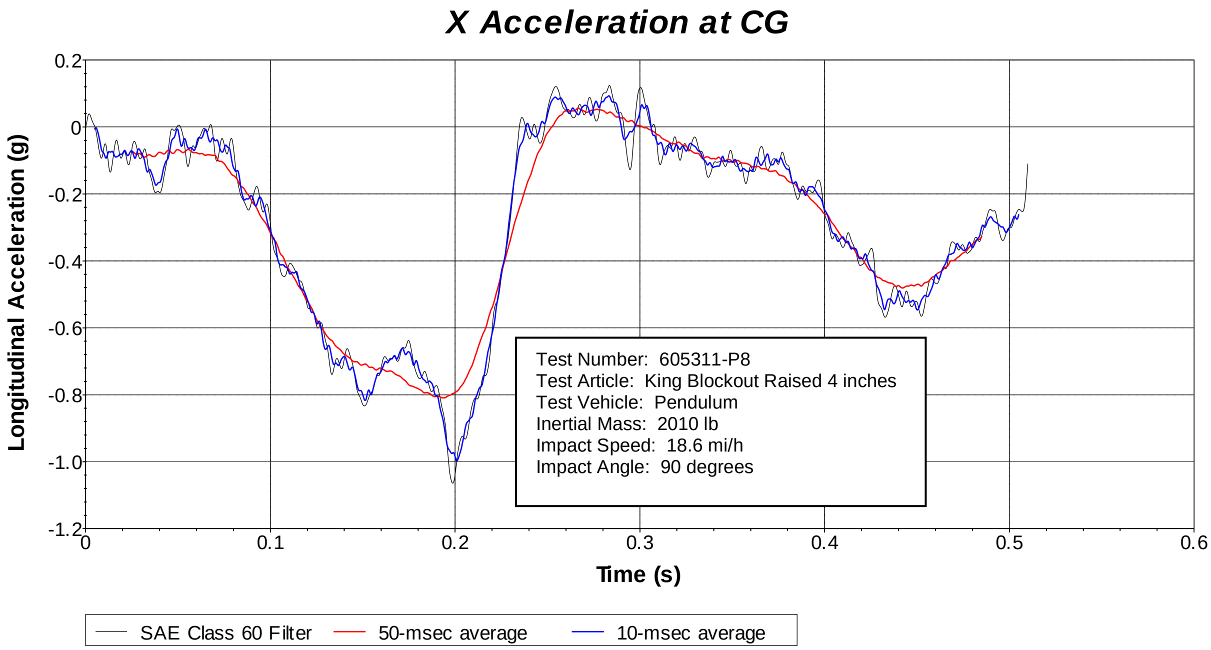


Figure D9. Accelerometer Trace for test 605311-P9.