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Dynamic Impact Testing of Wood Posts for the Midwest Guardrail System Placed Adjacent to a 2H:1V Fill Slope

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DYNAMIC IMPACT TESTING OF WOOD POSTS FOR THE MIDWEST GUARDRAIL SYSTEM (MGS) PLACED ADJACENT TO A 2H:1V FILL SLOPE

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16. Abstract (Limit: 200 words)

A stiffened version of the Midwest Guardrail System (MGS) with steel posts has been developed for use adjacent to 2H:1V roadside slopes. However, many members of the Midwest States Pooled Fund Program utilize wood posts. Therefore, it was requested to determine a wood post alternative to the steel posts utilized in the MGS adjacent to a 2H:1V slope.

Dynamic impact testing was conducted on 6-in. x 8-in. (152-mm x 203-mm) wood posts and W6x9 (W152x13.4) steel posts with varying lengths and embedment depths when installed at the slope breakpoint of a 2H:1V slope. A total of seven bogie tests were performed - five tests on wood posts and two tests on steel posts. The posts were embedded in strong soil conforming to AASHTO Grade B for all tests. For each bogie test, acceleration data was used to determine the force vs. deflection and energy vs. deflection characteristics of the various post installations. Post-soil interaction forces and energy dissipation characteristics of the wood posts were compared to those for the steel posts used in the original design of the MGS adjacent to a 2H:1V slope. From these comparisons, a recommended post length was selected for the wood post alternative to the steel post in the MGS adjacent to a steep slope. A 7.5-ft (2.3-m) long, 6-in. x 8-in. (152-mm x 203-mm) wood post with a 58-in. (1,473-mm) embedment depth was found to provide the best possible performance and the closest correlation with the 9-ft (2.7-m) long, steel post. As such, this wood post was recommended as an alternative for the 9-ft (2.7-m) long, W6x9 (W152x13.4) steel post utilized in the MGS placed adjacent to a 2H:1V slope.

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UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

The Independent Approving Authority (IAA) for the data contained herein was Scott K. Rosenbaugh, Research Associate Engineer.

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1 INTRODUCTION

1.1 Background

A modified version of the Midwest Guardrail System (MGS) was developed for use adjacent to steep roadside slopes [1-2]. This design incorporated 9-ft (2.74-m) long, W6x9 (W152x13.4) steel posts spaced on 75-in. (1,905-mm) centers and installed at the slope breakpoint of a 2H:1V slope. The top mounting height of the MGS was 31 in. (787 mm). This system was successfully crash tested according to the safety performance evaluation criteria found in the *Manual for Assessing Safety Hardware* (MASH) [3].

Many Midwest States Regional Pooled Fund members use predominately wood posts in their guardrail systems. Therefore, a follow-on research study was funded to determine the appropriate size and length of a wood post to serve as a substitute for the 9-ft (2.74-m) long, W6x9 (W152x13.4) steel post used within the MGS placed adjacent to 2H:1V fill slopes.

1.2 Objective

The objective of this research project was to determine the dynamic properties and post-soil interaction for 6-in. x 8-in. (152-mm x 203-mm) wood posts of various lengths and embedment depths when installed at the slope breakpoint of a 2H:1V fill slope. The dynamic test results were used to determine the appropriate size and length of a wood post to be used as an alternative to the 9-ft (2.74-m) long, W6x9 (W152x13.4) steel post used within the MGS placed adjacent to 2H:1V fill slopes.

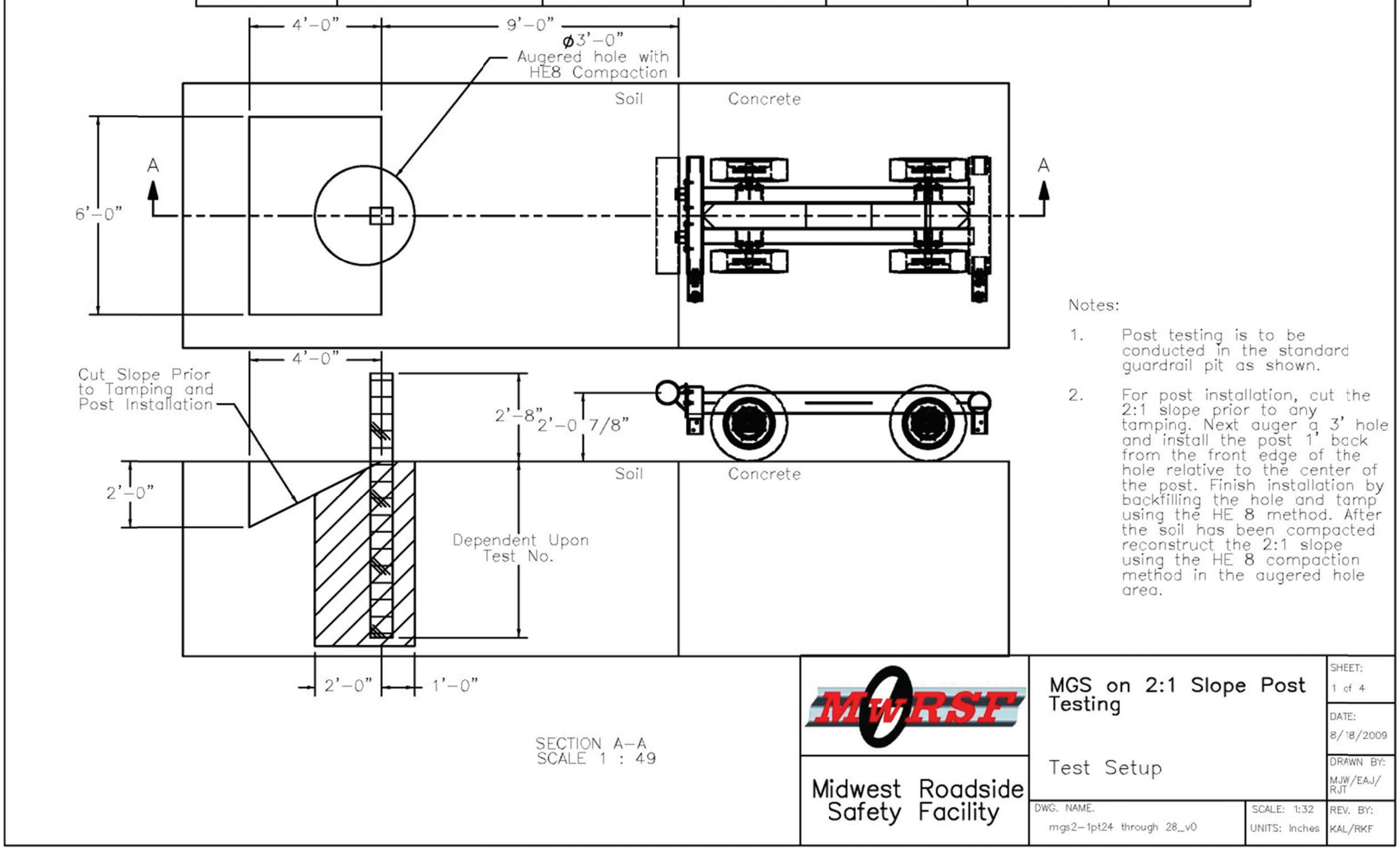
2 SCOPE OF PHYSICAL TESTING

2.1 Purpose

In prior research studies, MwRSF conducted numerous dynamic bogie tests of W6x9 (W152x13.4) steel posts and 6-in. x 8-in. (152-mm x 203-mm) wood posts. However, no such tests have been conducted on 6-in. x 8-in. (152-mm x 203-mm) wood posts placed adjacent to a 2H:1V fill slope. Therefore, a series of bogie tests were undertaken to determine the dynamic properties of 6-in. x 8-in. (152-mm x 203-mm) wood posts installed at the slope breakpoint of a 2H:1V slope. In addition, two tests of W6x9 (W152x13.4) steel posts, similar to those used in the original design and testing of the MGS adjacent to 2H:1V slopes, were conducted and used for comparison purposes.

2.2 Scope

The research objective was achieved by performing a total of seven dynamic bogie tests on posts placed adjacent to a 2H:1V fill slope. Five bogie tests were performed with 6-in. x 8-in. (152-mm x 203-mm) wood posts with lengths varying from 7.5 ft to 8 ft (2.29 m to 2.44 m) and with embedment depths ranging between 58 and 64 in. (1,473 and 1,626 mm). Two bogie tests were performed with 9-ft (2.74-m) long, W6x9 (W152x13.4) steel posts with an embedment depth of 76 in. (1,930 mm). A crusher run coarse aggregate material consisting of gravel and crushed limestone was used for filling the excavated pit area. The soil conformed to AASHTO standard specifications for "Materials for Aggregate and Soil Aggregate Sub-base, Base, and Surface Courses," designation M 147-65 (1990), grading B, as recommended by MASH [3]. The soil characteristics for each test are shown in Appendix A. The post was installed in the soil using 3-ft (914-mm) holes that were back-filled with fully compacted 8-in. (203-mm) lifts. The center of the post was installed at the slope breakpoint of the 2H:1V slope, as shown in Figure 1.



Test No.	Post Type	Test Quantity	Load Height	Bogie No.	Estimated Bogie Weight (lbs)	Bogie Speed (mph)
MGS221pt-24	Southern Yellow Pine 6"x8"x8'	1	24 7/8"	3	1860	15
MGS221pt-25	Southern Yellow Pine 6"x8"x7.5'	1	24 7/8"	3	1860	15
MGS221pt-26	Southern Yellow Pine 6"x8"x7.5'	1	24 7/8"	3	1860	15
MGS221pt-27	W6x9 9' Long	1	24 7/8"	3	1860	15
MGS221pt-28	W6x9 9' Long	1	24 7/8"	3	1860	15

Figure 1. Typical Test Setup

The target impact conditions for all tests were a speed of 15 mph (24 km/h) and an angle of 0 degrees, creating a classical "head-on" or full frontal impact and strong-axis bending. The posts were impacted 632 mm 24 7/8 in. (632 mm) above the groundline perpendicular to the face of the post. This impact height was chosen since it represented the center rail height of the MGS. The testing matrix is shown in Table 1, and the typical test setup is shown in Figure 1. Note that test no. MGS221PT-22 was conducted with the post and slope installed in an 8-ft long by 5-ft wide (2.44-m long by 1.52-m wide) soil pit. After reviewing the results of test no. MGS221PT-22, the researchers were concerned that the limited size of the testing pit was adversely affecting the post-soil interaction forces. Consequently, the remaining tests were conducted in a standard guardrail testing pit that was modified in order to conduct the post testing, as shown in Figure 1.

The wood posts were southern yellow pine (SYP) wood sections with nominal dimensions of 6-in. x 8-in. (152-mm x 203-mm). Cross-sectional dimensions, moisture content, weight, and ring density of the posts were recorded and are shown in Table 2. Cross-sectional measurements and moisture content were taken at both ends of the post and at groundline. The moisture content was measured with a pin-type moisture meter [4]. Due to differences in moisture contents, densities, and dimensions, each wood post had a different recorded weight. Since post imperfections can affect the strength of the wood post, the imperfections found in the wood posts were recorded and are shown in Appendix B. Material specifications, mill certifications, and certificates of conformity for both the steel and wood posts are shown in Appendix C.

Table 1. Dynamic Post Testing Matrix

Test No.	Post			Soil Type	Embedment Depth in. (mm)	Target Impact Velocity mph (km/h)	Bending Axis
	Type	Size in. x in. (mm x mm)	Length ft (m)				
MGS221PT-22	Wood (SYP)	6x8 (152x203)	8 (2.44)	AASHTO Grade B	64 (1,626)	15 (24)	Strong
MGS221PT-23	Wood (SYP)	6x8 (152x203)	8 (2.44)	AASHTO Grade B	64 (1,626)	15 (24)	Strong
MGS221PT-24	Wood (SYP)	6x8 (152x203)	8 (2.44)	AASHTO Grade B	64 (1,626)	15 (24)	Strong
MGS221PT-25	Wood (SYP)	6x8 (152x203)	7.5 (2.29)	AASHTO Grade B	58 (1,473)	15 (24)	Strong
MGS221PT-26	Wood (SYP)	6x8 (152x203)	7.5 (2.29)	AASHTO Grade B	58 (1,473)	15 (24)	Strong
MGS221PT-27	Steel	W6x9 (W152x13.4)	9 (2.74)	AASHTO Grade B	76 (1,930)	15 (24)	Strong
MGS221PT-28	Steel	W6x9 (W152x13.4)	9 (2.74)	AASHTO Grade B	76 (1,930)	15 (24)	Strong

Table 2. Wood Post Details

Test No.	Post Dimensions in. x in. (mm x mm)			Post Length in. (mm)	Moisture Content (%)			Weight lb (kg)	Ring Density rings/in. (rings/cm)
	At Top	At Groundline	At Bottom		At Top	At Groundline	At Bottom		
MGS221PT-22	5⅞x8 (149x203)	6x8⅛ (152x206)	6x8 (152x203)	96 (2438)	11	15	14	99 (44.9)	4 (1.6)
MGS221PT-23	5 15/16x8 (151x203)	5 15/16x7 15/16 (151x202)	6x8 (152x203)	96½ (2451)	13	11	13	83.8 (38.0)	2.5 (1.0)
MGS221PT-24	6 x 8 (152x203)	6 x 8 1/16 (152x205)	6 x 8 (152x203)	96½ (2451)	17	17	17	101 (45.8)	12 (4.7)
MGS221PT-25	5⅞ x 8 (149x203)	6 x 8⅛ (152x206)	6 x 8 1/16 (152x205)	90 (2286)	13	15	14	112 (50.8)	9 (3.5)
MGS221PT-26	6 x 8 (152x203)	6 x 8 (152x203)	6 x 8⅛ (152x206)	90 (2286)	14	17	16	100.4 (45.5)	6.3 (2.5)

3 TEST CONDITIONS

3.1 Test Facility

Physical testing of the various posts was conducted at the MwRSF testing facility, which is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport. The facility is approximately 5 miles (8 km) northwest from the University of Nebraska-Lincoln's city campus.

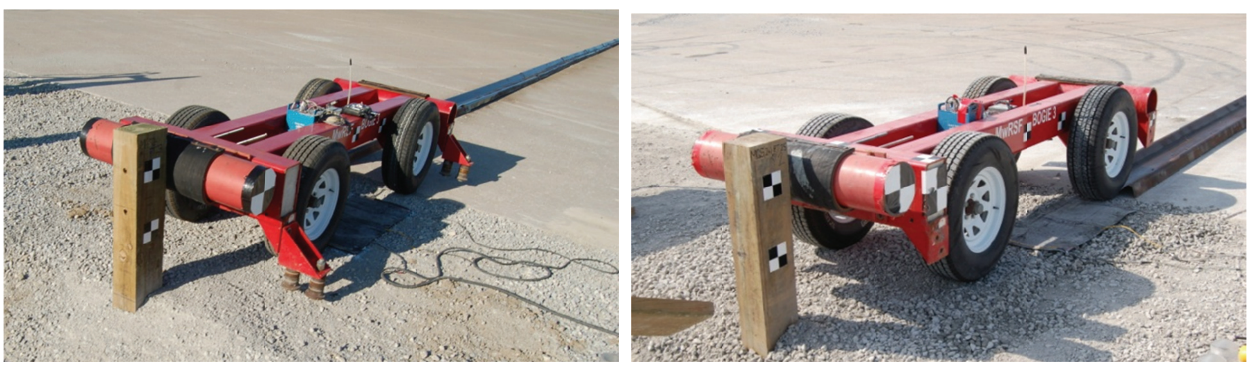
3.2 Equipment and Instrumentation

Equipment and instrumentation utilized to collect and record data during the dynamic bogie tests included a bogie, accelerometers, pressure tape switches, high-speed and standard speed digital video, and still cameras.

3.2.1 Bogie

A rigid frame bogie was used to impact the posts. A variable height, detachable impact head was used in the testing. The bogie head was constructed of 8-in. (203-mm) diameter, ½-in. (13-mm) thick standard steel pipe, with ¾-in. (19-mm) neoprene belting wrapped around the pipe to prevent local damage to the post from the impact. The impact head was bolted to the bogie vehicle, creating a rigid frame with an impact height of 24⅞ in. (632 mm). The bogie with the impact head for test no. MGS221PT-22 is shown in Figure 2, and the bogie for test no. MGS221PT-23 and MGS221PT-24 through MGS221PT-28 is shown in Figure 3(a) and Figure 3(b), respectively. For test nos. MGS221PT-22, MGS221PT-23, and MGS221PT-24 through MGS221PT-28, the weight of the bogie with the addition of the mountable impact head and accelerometers was 1,815 lb, 1,845 lb, and 1,757 lb (823 kg, 837 kg, and 797 kg), respectively. The weight variance was due to the different accelerometers used during each crash test and for test nos. MGS221PT-24 through MGS221PT-28, the guidance track bearings were removed from the bogie.

Figure 2. Rigid Frame Bogie on Guidance Track



(a) (b)

Figure 3. Rigid Frame Bogie on Corrugated Beam Guidance Track (a) with Guidance Bearing and (b) without Guidance Bearings

For test no. MGS221PT-22, a pickup truck with a reverse cable tow system was used to propel the bogie to a target impact speed of 15 mph (24 km/h). When the bogie approached the end of the guidance system, it was released from the tow cable, allowing it to be free rolling when it impacted the post. A remote braking system was installed on the bogie allowing it to be brought safely to rest after the test.

Test nos. MGS221PT-23 through MGS221PT-28 were conducted using a steel corrugated beam guardrail to guide the tire of the bogie vehicle. A pickup truck was used to push the bogie vehicle to a target impact speed of 15 mph (24 km/h). After reaching the target velocity, the push vehicle braked allowing the bogie to be free rolling as it came off the track.

3.2.2 Accelerometers

Three environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometers were mounted on the bogie vehicle near its center of gravity. The initial velocity and the accelerometer data were used to determine the force, velocity, displacement, and energy absorbed by the post during the impact. Although the accelerometer was located at the center of gravity of the bogie and measured the acceleration of the bogie's center of gravity, this data was used to approximate the post-soil forces at the point of impact using Newton's Second Law.

One triaxial piezoresistive accelerometer system, Model EDR-3, was manufactured by IST of Okemos, Michigan. The EDR-3 was configured with 256 kB of RAM, a range of ±200 g's, a sample rate of 3,200 Hz, and a 1,120 Hz low-pass filter. The "DynaMax 1 (DM-1)" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data. This system was used for test nos. MGS221PT-22 through MGS221PT-28.

The second accelerometer system was a triaxial piezoresistive accelerometer system, Model EDR-4 6DOF-500/1200, manufactured by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-4 6DOF-500/1200 was configured with 24 MB of RAM, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,677 Hz anti-aliasing filter. The "EDR4COM" and "DynaMax Suite" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data. This system was used for test nos. MGS221PT-22 and MGS22-PT-24 through MGS221PT-28.

The third accelerometer system was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The accelerometers were configured and controlled using a system developed and manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data. This system was used for test nos. MGS221PT-23 through MGS221PT-28.

3.2.3 Pressure Tape Switches

Three pressure tape switches, spaced at approximately 18-in. (457-mm) intervals and placed near the end of the bogie track, were used to determine the speed of the bogie before the impact. As either the right-front or the left-front tire of the bogie passed over each tape switch, a strobe light was fired sending an electronic timing signal to the data acquisition system. The system recorded the signals and the time each occurred. The speed was then calculated using the spacing between the sensors and the time between the signals. Strobe lights and high-speed video analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

3.2.4 Digital Cameras

One AOS VITcam high-speed digital video camera and two JVC digital video cameras were used to document each test. The AOS high-speed camera had a frame rate of 500 frames per second and the JVC digital video cameras had a frame rate of 29.97 frames per second. The cameras were placed laterally from the post, with a view perpendicular to the bogie's direction of travel. A Nikon D50 digital still camera was also used to document pre- and post-test conditions for all tests.

3.3 End of Test Determination

When the impact head initially contacts the test article, the force exerted by the surrogate test vehicle is directly perpendicular. However, as the post rotates, the surrogate test vehicle's orientation and path moves further from perpendicular. This introduces two sources of error: (1) the contact force between the impact head and the post has a vertical component and (2) the impact head slides upward along the test article. Therefore, only the initial portion of the accelerometer trace may be used since variations in the data become significant as the system rotates and the surrogate test vehicle overrides the system. For this reason, the end of the test needed to be defined.

Guidelines were established to define the end of test time using the high-speed digital video of the crash test. The first occurrence of any one of the following three events was used to determine the end of the test: (1) the test article fractures; (2) the surrogate vehicle overrides/loses contact with the test article; or (3) a maximum post rotation of 45 degrees.

3.4 Data Processing

The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [5]. The pertinent acceleration signal was extracted from the bulk of the data signals. The processed acceleration data was then multiplied by the mass of the bogie to get the impact force using Newton's Second Law. Next, the acceleration trace was integrated to find the change in velocity versus time. Initial velocity of the bogie, calculated from the pressure tape switch data, was then used to determine the bogie velocity, and the calculated velocity trace was integrated to find the bogie's displacement. This displacement is also the displacement of the post. Combining the previous results, a force vs. deflection curve was plotted for each test. Finally, integration of the force vs. deflection curve provided the energy vs. deflection curve for each test.

One useful aspect of using accelerometer data was that it included influences of the post inertia on the reaction force. This was important as the mass of the post would affect barrier performance as well as test results.

4 COMPONENT TESTING RESULTS AND DISCUSSION

4.1 Results

The information desired from the bogie tests was the relation between the applied force and deflection of the post at the impact location. The accelerometer data for each test was processed in order to obtain acceleration, velocity, and deflection curves, as well as force vs. deflection and energy vs. deflection curves. The values described herein were calculated from the EDR-3 data curves. Although the various transducers produced similar results, the EDR-3 has historically provided accurate results, and it was the only accelerometer used in all tests. Test results for all transducers are provided in Appendix D.

4.1.1 Test No. MGS221PT-22 (64-in. Embedment Depth)

Test no. MGS221PT-22 was an impact of the bogie on the strong axis of a 6-in. x 8-in. x 96-in. (152-mm x 203-mm x 2,438-mm) wood post at a speed of 15.1 mph (24.3 km/h). The post was installed in an 8-ft long by 5-ft wide (2.44-m long by 1.52-m wide) soil pit at the slope breakpoint of a 2H:1V slope with an embedment depth of 64 in. (1,626 mm). Upon impact, the post began to rotate through the soil. The post rotated through the soil 4.7 in. (119 mm) before fracture which initiated approximately 0.018 seconds after impact. Fracture occurred approximately 24 in. (610 mm) below ground level. The maximum deflection of the post was 6.2 in. (157 mm) at the time of complete fracture.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 4. The force vs. deflection curve indicated an initial peak in the force level due to the inertial effects of the post and soil. After this inertial peak, there was a slight drop in load followed by an increase in load as the post rotated through the soil. The rotation of the post in the soil generated a peak force of 12.7 kips (56.3 kN) at 4.7 in. (119 mm) of deflection prior to fracture of the post. After this point, the force rapidly declined to zero as the post fractured below grade with very little soil deformation. The post had a maximum deflection of 6.2 in (157 mm) and absorbed 48.8 kip-in. (5.5 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 5.

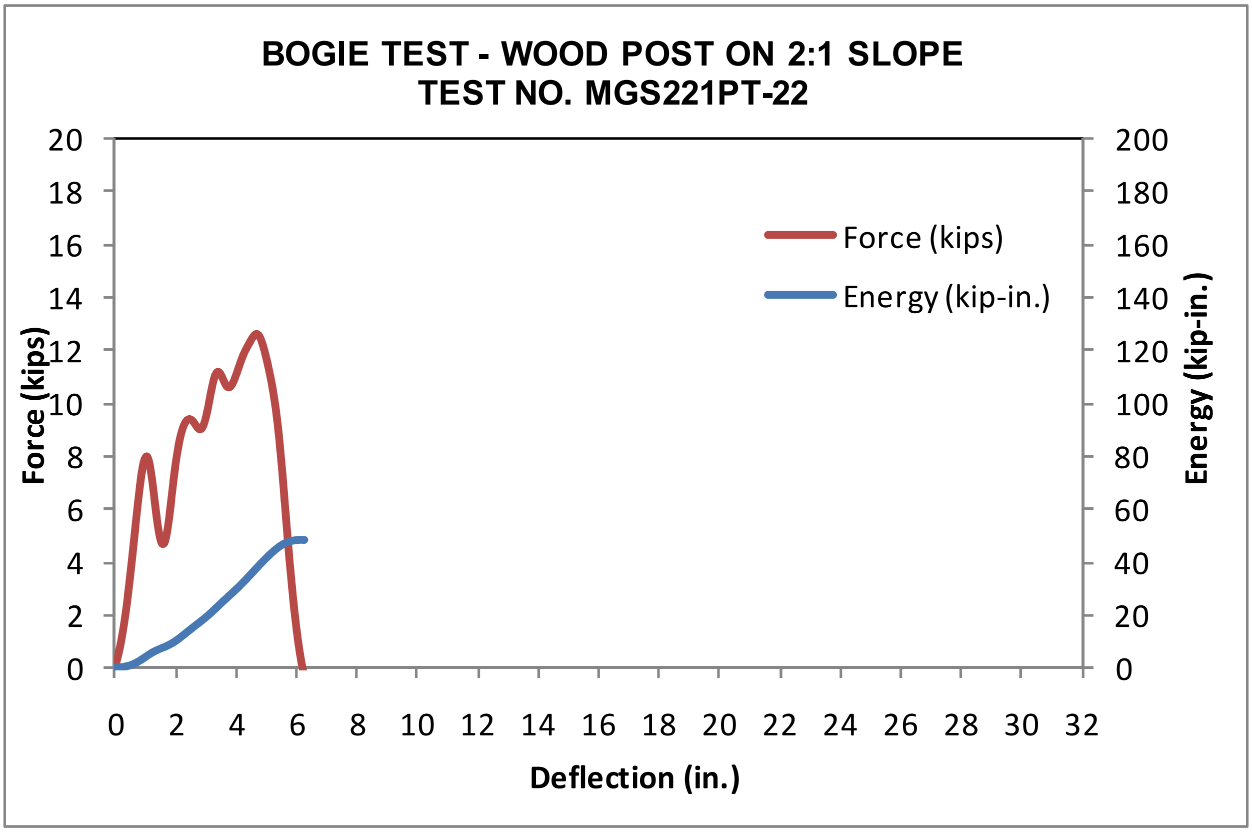


Figure 4. Force vs. Deflection and Energy vs. Deflection, Test No. MGS221PT-22

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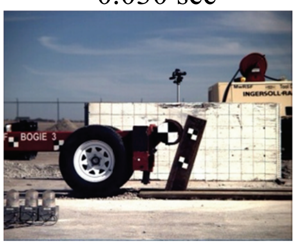

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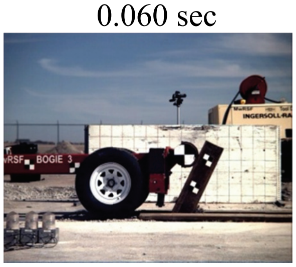

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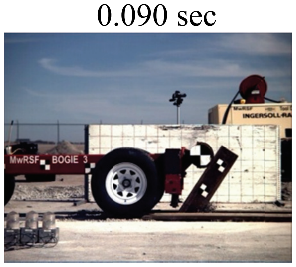

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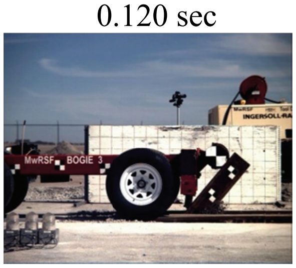

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Figure 5. Time Sequential and Post-Impact Photographs, Test No. MGS221PT-22

4.1.2 Test No. MGS221PT-23 (64-in. Embedment Depth)

Following test no. MGS221PT-22, the researchers were concerned that the limited size of the testing pit was adversely affecting the post-soil interaction forces. Consequently, the remaining tests were conducted in a standard guardrail testing pit that was modified in order to conduct the post testing. Test no. MGS221PT-23 was an impact of the bogie on the strong axis of a 6-in. x 8-in. x 96-in. (152-mm x 203-mm x 2,438-mm) wood post at a speed of 16.0 mph (25.7 km/h). The post was installed at the slope breakpoint of a 2H:1V slope with an embedment depth of 64 in. (1,626 mm). Upon impact, the post began to rotate through the soil. The post rotated through the soil 8.3 in. (211 mm) before fracture which initiated approximately 0.032 seconds after impact. Fracture occurred approximately 18 in. (457 mm) below ground level. The maximum deflection of the post was 9.8 in. (249 mm) at the time of complete fracture.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 6. The force vs. deflection curve indicated an initial peak in the force level due to the inertial effects of the post and soil. After this inertial peak, there was a slight drop in load followed by an increase in load as the post rotated through the soil. The rotation of the post in the soil generated a peak force of 11.2 kips (49.8 kN) at 8.3 in. (211 mm) of deflection. After this point, the force rapidly declined to zero as the post fractured with very little soil deformation. The post had a maximum deflection of 9.8 in (249 mm) and absorbed 75.0 kip-in. (8.5 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 7.

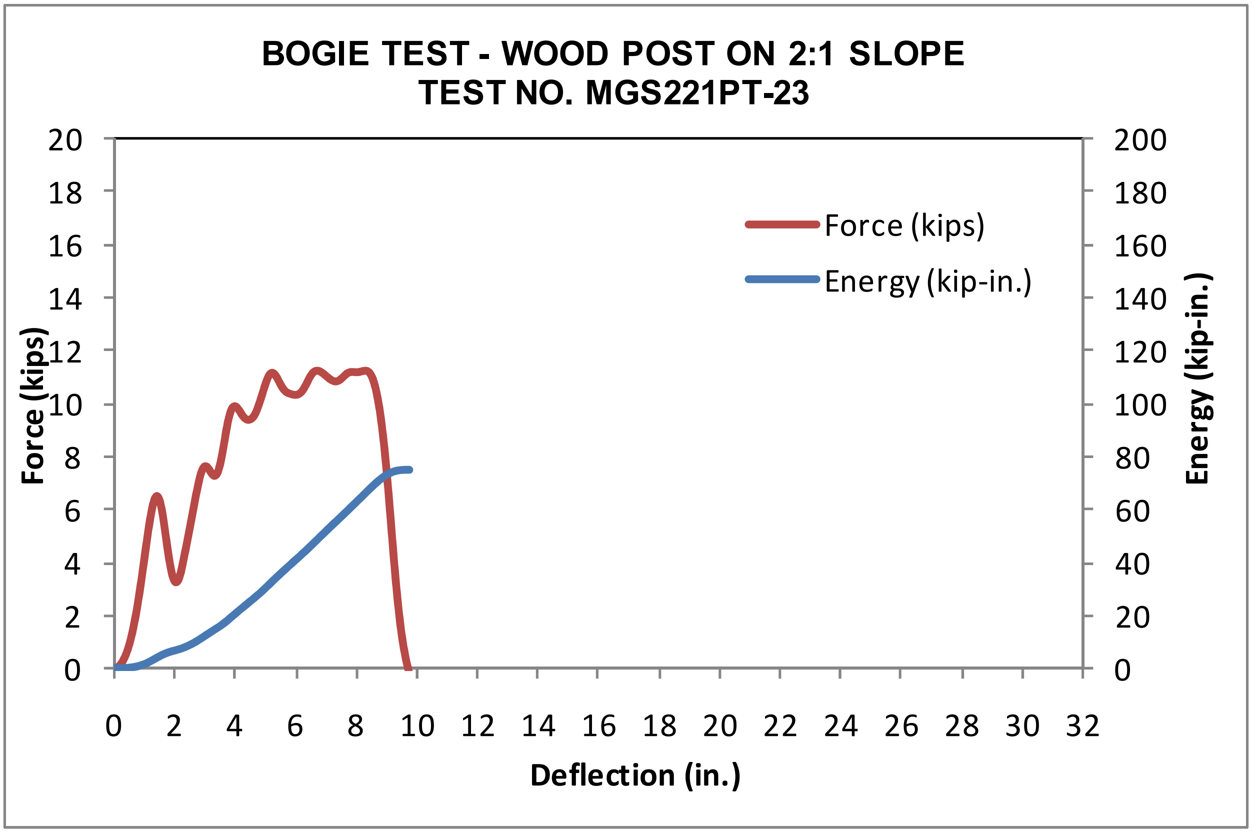

Figure 6. Force vs. Deflection and Energy vs. Deflection, Test No. MGS221PT-23

Figure 7. Time Sequential and Post-Impact Photographs, Test No. MGS221PT-23

4.1.3 Test No. MGS221PT-24 (64-in. Embedment Depth)

Test no. MGS221PT-24 was an impact of the bogie on the strong axis of a 6-in. x 8-in. x 96-in. (152-mm x 203-mm x 2,438-mm) wood post at a speed of 18.4 mph (29.6 km/h). The post was installed at the slope breakpoint of a 2H:1V slope with an embedment depth of 64 in. (1,626 mm). Upon impact, the post began to rotate through the soil. The post rotated through the soil 7.3 in. (185 mm) before fracture which initiated approximately 0.024 seconds after impact. Fracture occurred 14 in. (356 mm) below ground level at a knot on a side face of the post. The maximum deflection of the post was 9 in. (229 mm) at the time of complete fracture.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 8. The force vs. deflection curve indicated an initial peak in the force level due to the inertial effects of the post and soil. After this inertial peak, there was a slight drop in load followed by an increase in load as the post rotated through the soil. The rotation of the post in the soil generated a peak force of 17.4 kips (77.6 kN) at 7.3 in. (185 mm) of deflection. After this point, the force rapidly declined to zero as the post fractured with very little soil deformation. The post had a maximum deflection of 9.0 in (229 mm) and absorbed 103.4 kip-in. (11.7 kJ) of energy. Time-sequential photographs and post-impact photos are shown in Figure 9.

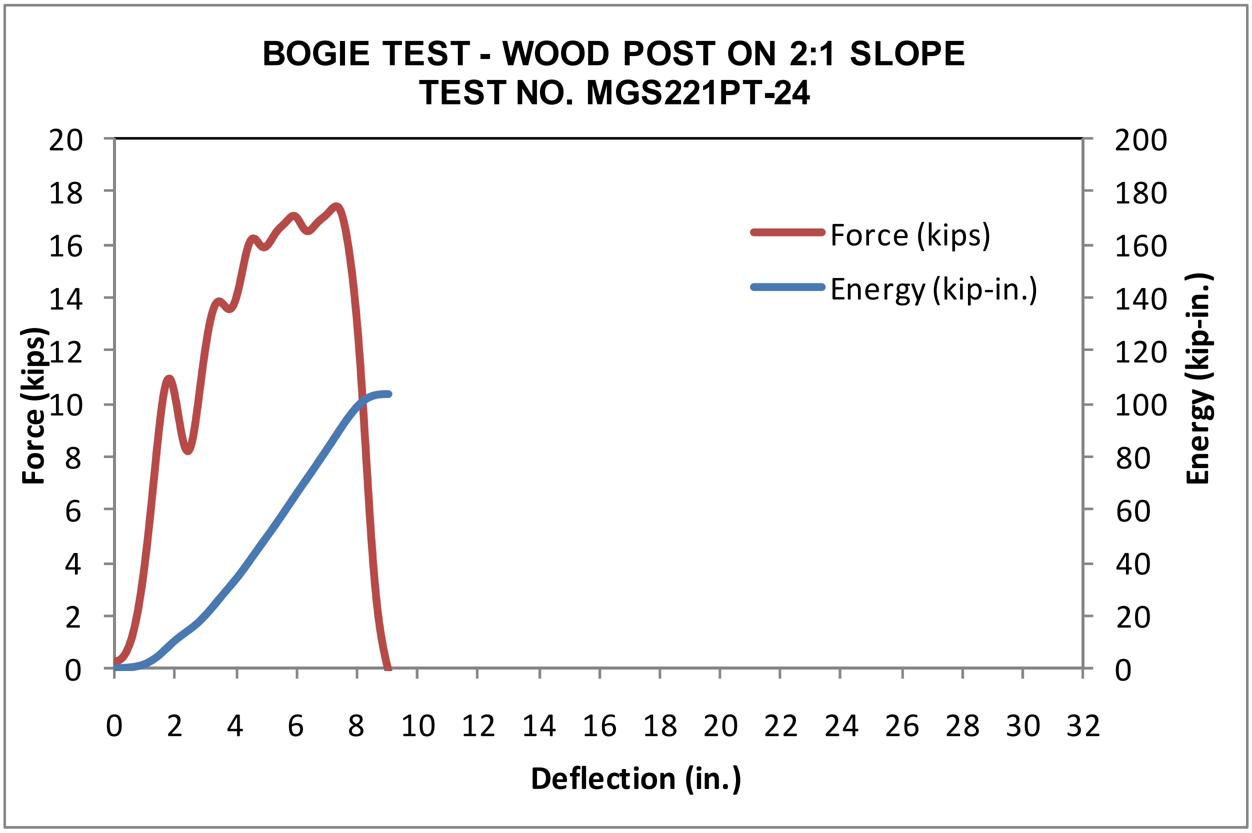

Figure 8. Force vs. Deflection and Energy vs. Deflection, Test No. MGS221PT-24

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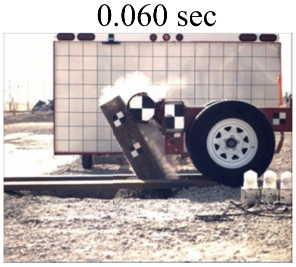

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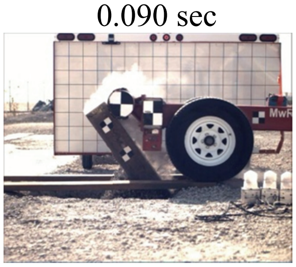

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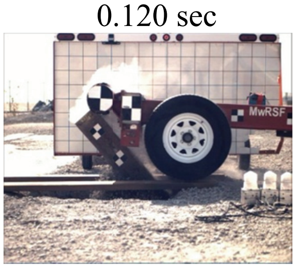

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Figure 9. Time Sequential and Post-Impact Photographs, Test No. MGS221PT-24

4.1.4 Test No. MGS221PT-25 (58-in. Embedment Depth)

Test no. MGS221PT-25 was an impact of the bogie on the strong axis of a 6-in. x 8-in. x 90-in. (152-mm x 203-mm x 2,286-mm) wood post at a speed of 15.1 mph (24.3 km/h). The post was installed at the slope breakpoint of a 2H:1V slope with an embedment depth of 58 in. (1,473 mm). Upon impact, the post began to rotate through the soil. The post rotated through the soil and showed no signs of fracturing. The bogie was brought to a stop and did not override the post. The maximum deflection of the post was 18.4 in. (467 mm).

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 10. The force vs. deflection curve indicated an initial peak in the force level due to the inertial effects of the post and soil. After this inertial peak, there was a slight drop in load followed by an increase in load as the post rotated through the soil. The rotation of the post in the soil generated a peak force of 12.1 kips (53.8 kN) at 4.9 in. (124 mm) of deflection. After the reaching the peak force level, the resistive force declined slightly through the maximum deflection of 18.4 in. (467 mm). The average force level for the test through 15 in. (381 mm) of deflection was 9.9 kips (44.1 kN). The post rotating in soil absorbed a total of 161.7 kip-in. (18.3 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 11.

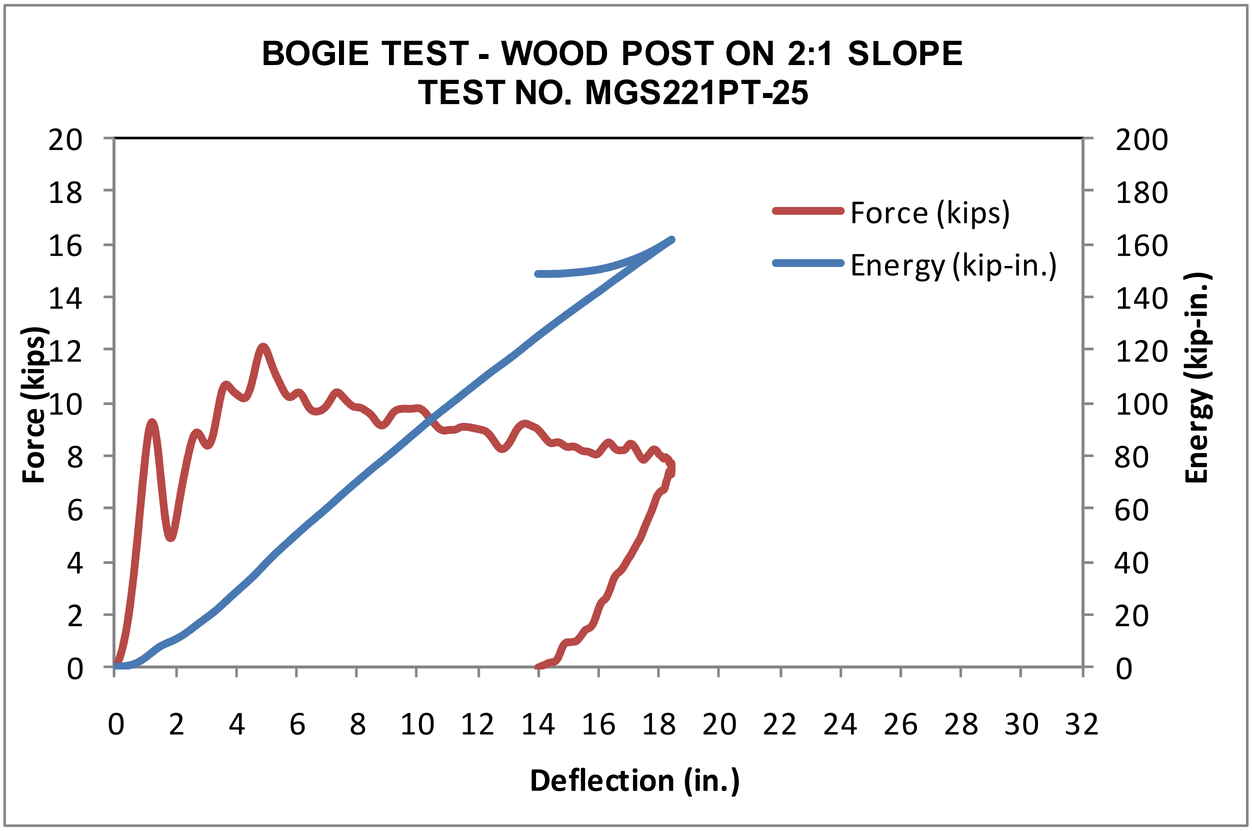
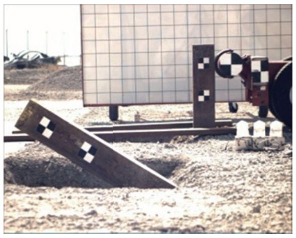


Figure 10. Force vs. Deflection and Energy vs. Deflection, Test No. MGS221PT-25



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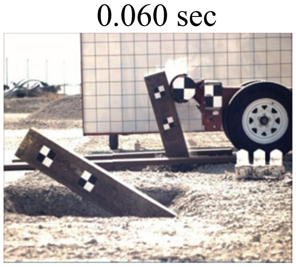

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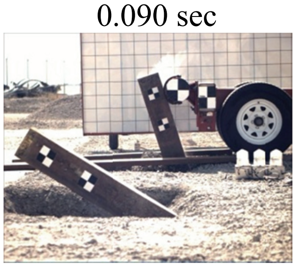

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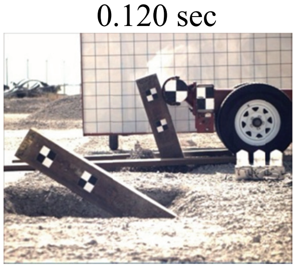

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Figure 11. Time Sequential and Post-Impact Photographs, Test No. MGS221PT-25

4.1.5 Test No. MGS221PT-26 (58-in. Embedment Depth)

Test no. MGS221PT-26 was an impact of the bogie on the strong axis of a 6-in. x 8-in. x 90-in. (152-mm x 203-mm x 2,286-mm) wood post at a speed of 16.0 mph (25.7 km/h). The post was installed at the slope breakpoint of a 2H:1V slope with an embedment depth of 58 in. (1,473 mm). Upon impact, the post began to rotate through the soil. The post rotated through the soil and the post did not fracture. Some splintering was observed along the edge of the post. The bogie was brought to a stop and did not override the post. The maximum deflection of the post was 15.1 in. (384 mm).

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 12. The force vs. deflection curve indicated an initial peak in the force level due to the inertial effects of the post and soil. After this inertial peak, there was a slight drop in load followed by an increase in load as the post rotated through the soil. The rotation of the post in the soil generated a peak force of 15.6 kips (69.4 kN) at 4.7 in. (119 mm) of deflection. After the reaching the peak force level, the resistive force declined slightly through the maximum deflection of 15.1 in. (384 mm). The average force level for the test through 15 in. (381 mm) of deflection was 11.3 kips (50.4 kN). The post rotating in soil absorbed a total of 180.9 kip-in. (20.4 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 13.

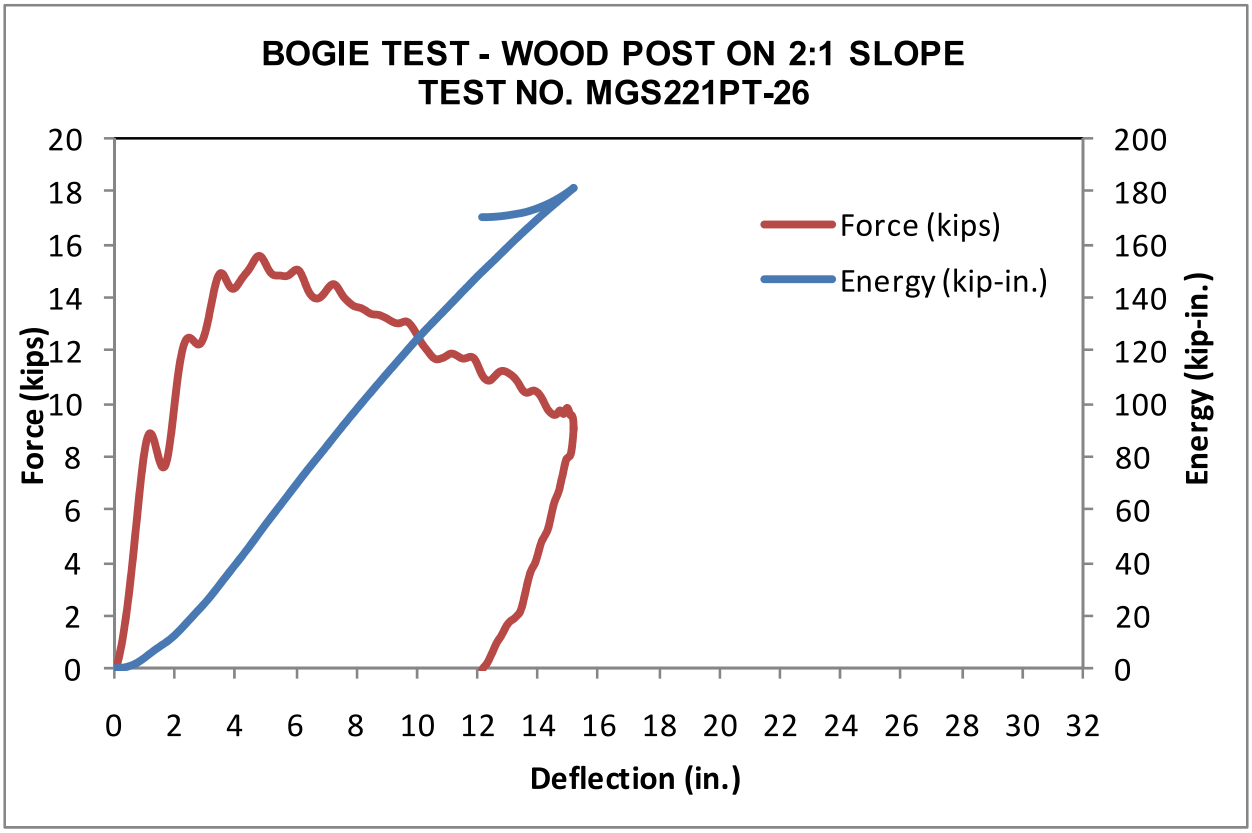
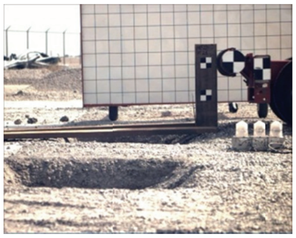


Figure 12. Force vs. Deflection and Energy vs. Deflection, Test No. MGS221PT-26



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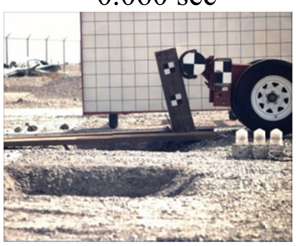

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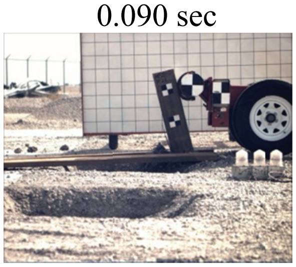

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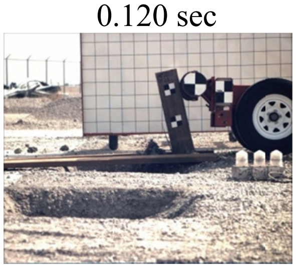

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Figure 13. Time Sequential and Post-Impact Photographs, Test No. MGS221PT-26

4.1.6 Test No. MGS221PT-27 (76-in. Embedment Depth)

Test no. MGS221PT-27 was an impact of the bogie on the strong axis of a W6x9 (W152x13.4) steel post at a speed of 13.7 mph (22.0 km/h). The 108-in. (2,743-mm) long post was installed at the slope breakpoint of a 2H:1V slope with an embedment depth of 76 in. (1,930 mm). Upon impact, the post began to rotate through the soil. As the post rotated through the soil, the post yielded about the strong axis. The bogie was brought to a stop and did not override the post. The maximum deflection of the post was 16.2 in. (411 mm).

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 14. The force vs. deflection curve indicated an initial peak in the force level due to the inertial effects of the post and soil. After this inertial peak, the load continued to increase as the post rotated through the soil. The rotation of the post in the soil generated a peak force of 13.2 kips (58.7 kN) at 2.4 in. (61 mm) of deflection. After the reaching the peak force level, the resistive force steadily declined through the maximum deflection of 16.2 in. (411 mm). The average force level for the test through 15 in. (381 mm) of deflection was 8.4 kips (37.2 kN). The post rotating in soil absorbed a total of 131.8 kip-in. (14.9 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 15.

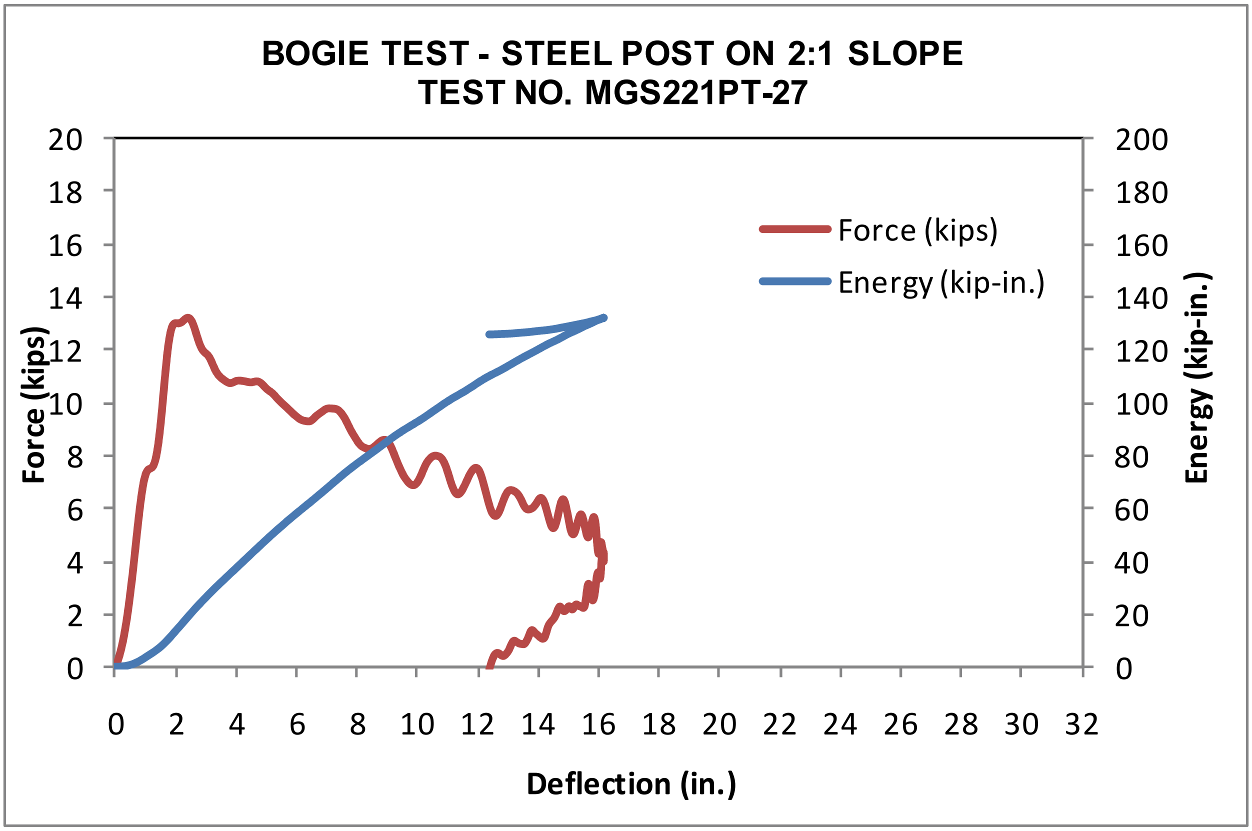
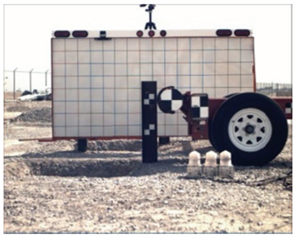


Figure 14. Force vs. Deflection and Energy vs. Deflection, Test No. MGS221PT-27



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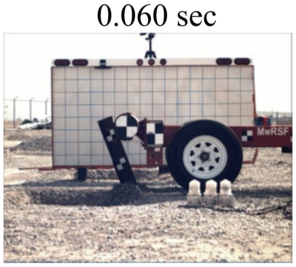

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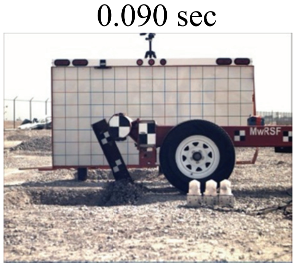

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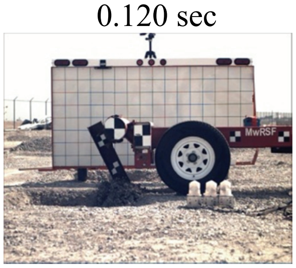

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Figure 15. Time Sequential and Post-Impact Photographs, Test No. MGS221PT-27

4.1.7 Test No. MGS221PT-28 (76-in. Embedment Depth)

Test no. MGS221PT-28 was an impact of the bogie on the strong axis of a W6x9 (W152x13.4) steel post at a speed of 16.4 mph (26.4 km/h). The 108-in. (2,743-mm) long post was installed at the slope breakpoint of a 2H:1V slope with an embedment depth of 76 in. (1,930 mm). Upon impact, the post began to rotate through the soil. As the post rotated through the soil, the post yielded about the strong axis. The bogie was brought to a stop and did not override the post. The maximum deflection of the post was 30.4 in. (772 mm) based on the acceleration data. Review of the high-speed digital video suggested that this deflection was larger than what was actually observed. The maximum deflection based on the high-speed digital video was approximately 23.8 in. (605 mm).The increased deflection determined by the bogie acceleration analysis can be explained due to potential error caused by inaccurate bogie impact speeds. Because the deflection is calculated from the area under the bogie velocity curve, inaccuracy in the bogie impact speed can increase the overall post deflection as the bogie velocity can take significantly more time to reach zero. However, in this testing the researchers were mainly concerned with the performance of the post through the first 15 in. (381 mm) of deflection and test nos. MGS221PT-28 and MGS221PT-27 compared well through 15 in. (381 mm) of deflection.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 16. The force vs. deflection curve indicated an initial peak in the force level due to the inertial effects of the post and soil. After this inertial peak, the load continued to increase as the post rotated through the soil. The rotation of the post in the soil generated a peak force of 13.0 kips (57.8 kN) at 2.3 in. (58 mm) of deflection. After the reaching the peak force level, the resistive force steadily declined through the maximum deflection of 30.4 in. (772 mm). The average force level for the test through 15 in. (381 mm) of deflection was 8.9

kips (39.6 kN). The average force level for the test through 20 in. (508 mm) of deflection was 8.0 kips (35.6 kN). The post rotating in soil absorbed a total of 189.8 kip-in. (21.5 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 17.

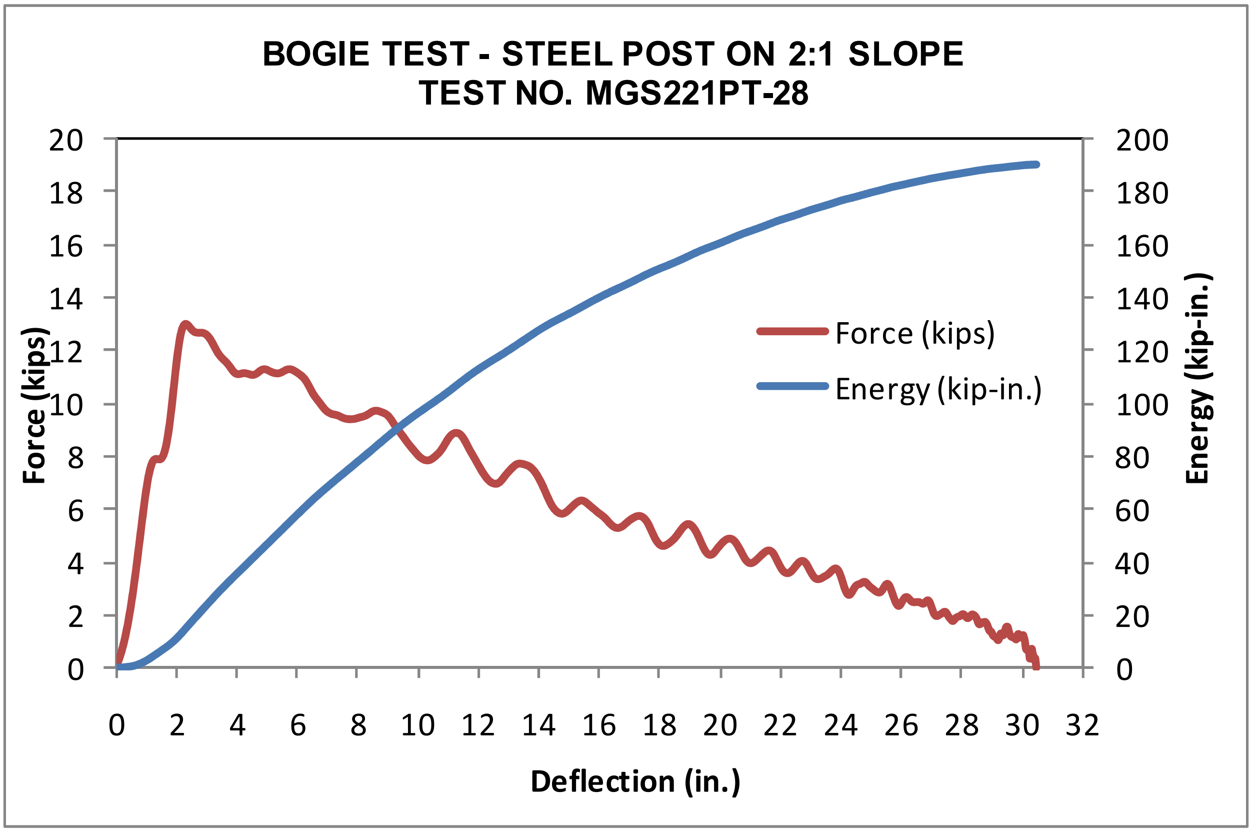

Figure 16. Force vs. Deflection and Energy vs. Deflection, Test No. MGS221PT-28

IMPACT

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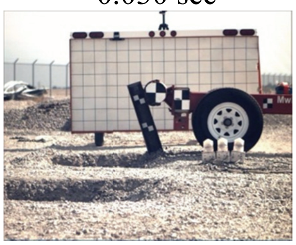

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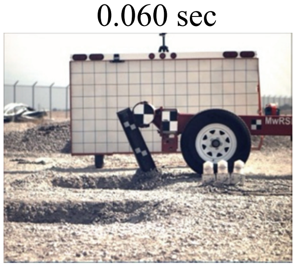

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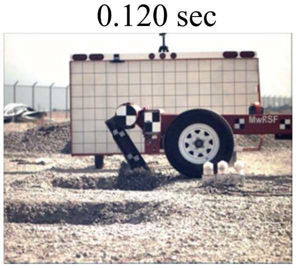

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Figure 17. Time Sequential and Post-Impact Photographs, Test No. MGS221PT-28

4.2 Discussion

Dynamic impact testing was performed on 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts of 7.5 and 8 ft (2.29 and 2.44 m) lengths and 9-ft (2.74-m) long, W6x9 (W152x13.4) steel posts placed at the break point of a 2H:1V fill slope. This testing program was used to evaluate the post-soil behavior and to select a wood post alternative for the 9-ft (2.74-m) long, W6x9 (W152x13.4) steel post utilized in the MGS placed adjacent to a steep fill slope. A summary of all bogie testing results is shown in Table 3. Force vs. deflection curves are shown in Figure 18, and energy vs. deflection curves are shown in Figure 19.

Review of the data from all seven impact tests found that the 7.5-ft (2.29-m) long, 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts provided the best alternative to the 9-ft (2.74-m) long, W6x9 (W152x13.4) steel posts. Three tests of 8-ft (2.44-m) long, 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts resulted in post fracture due to the post-soil forces exceeding the capacity of the wood post. The wood fracture prevented effective rotation of the post in the soil as well as resulted in insufficient energy absorption during the impact. Thus, the 8-ft (2.44-m) long, wood posts were deemed unsuitable for the MGS when installed adjacent to a 2H:1V fill slope.

In contrast, the 7.5-ft (2.29-m) long, 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts correlated reasonably well with the data obtained from the 9-ft (2.74-m) long, W6x9 (W152x13.4) steel post tests. The 7.5-ft (2.29-m) long posts did not fracture during impact but rather rotated through the soil. The average peak force for the two 7.5-ft (2.29-m) long, wood post tests was only 5.7 percent greater than the average peak force of the two W6x9 (W152x13.4) steel post tests. Similarly, the average total energy of the two 7.5-ft (2.29-m) long, wood post tests was only 6.5 percent greater than the average total energy of the two W6x9 (W152x13.4) steel post tests. The average force levels for the 7.5-ft (2.29-m) long, wood post tests were 23 percent greater through 15-in. (381-mm) of deflection than the values obtained from the steel post testing. Thus, the two 7.5-ft (2.29-m) long, wood posts compared very well with the steel posts in terms of peak force and total energy absorbed, while being slightly higher in terms of average force. It is not believed that the reasonably small differences observed between the 7.5-ft (2.29-m) long, wood post and the 9-ft (2.74-m) long, steel post would have any adverse effects on the performance of the MGS system. Based on this comparison, it is believed that the 7.5-ft (2.29-m) long, 6-in. x 8-in. (152-mm x 203-mm) SYP wood post provides a suitable alternative to the 9-ft (2.74-m) long, W6x9 (W152x13.4) steel post.

It should be noted that there is a significant difference in length between the original 9-ft (2.74-m) long, steel post and the 7.5-ft (2.29-m) long, wood post alternative. There are several reasons for the difference in length between the steel and wood posts. First, in the original development of the MGS installed on a 2H:1V fill slope [1-2], the 9-ft (2.74-m) long, steel post was conservatively chosen for the final design. During the original component testing program with posts of various lengths, there was very little difference observed between the performance of a 9-ft (2.74-m) long, W6x9 (W152x13.4) steel post as compared to an 8-ft (2.44-m) long, W6x9 (W152x13.4) steel post. Thus, if one considered the performance of the 8-ft (2.44-m) long, steel post to be similar to the 9-ft (2.74-m) long, steel post, then the difference between the length of the steel post and the wood post selected in this research is only 6 in. (152 mm). Second, the 6-in. x 8-in. (152-mm x 203-mm) SYP wood post has as significantly different profile as it moves through the soil as compared to the W6x9 (W152x13.4) steel post. This difference in the shape of the post section could potentially affect the post-soil interaction forces. Finally, the reduced embedment of the wood post ensured that the wood post would rotate in the soil rather than fracture. The lack of fracture is critical to the performance of the wood post. If post-soil resistance forces exceed the capacity of a wood post, the post fractures and ceases to dissipate energy during an impact. Conversely, when post-soil interaction forces exceed the capacity of a steel post, the steel post yield and deforms. This deformation of the steel post continues to dissipate energy.

As a final remark, the post-soil interaction forces observed in this study appear to be significantly higher than those found in the original development of the MGS installed on a 2H:1V fill slope [1-2]. This result was not entirely unexpected as MwRSF's post installation procedures have been updated as part of the implementation of the test guidelines set forth in the *Manual for Assessing Safety Hardware* (MASH) [3]. As part of MASH, test facilities are now required to follow more consistent guidelines for installation of test articles in soil in order to ensure a minimum post-soil resistance. MASH adheres to the general philosophy that testing of longitudinal barriers in stiff soil results in higher impact and barrier loads, increased occupant risk values, and increased propensity for rail rupture, pocketing, and snag. In order to ensure compliance with the soil strength criteria, MwRSF has implemented procedures to install posts with consistent lift depths and full-compaction of the soil around the post. The improved installation method provided a consistent means to maintain soil loads above the loads specified in MASH, but the soil resistance loads have increased over what had been historically observed in previous studies. While this increase in soil loads was consistent with evaluation of general longitudinal barriers in MASH, it can cause some confusion when comparing data from previous testing of soil-based systems and components.

It is not believed that the increased soil resistance observed in the evaluation of the posts in this study should prevent their use in the MGS system installed on a 2H:1V fill slope. Several full-scale crash tests have been performed on both wood and steel post versions of the MGS system using the revised post installation method, and the results have shown that the MGS performed very well. These studies include the MGS with W6x9 (152x13.4) steel posts installed on a wire-faced, rock gabion or MSE wall at the slope breakpoint of a 3H:1V fill slope [6] and the MGS with white pine wood posts [7].

Table 3. Dynamic Testing Results

Test No.	Post Type			Embedment Depth in. (mm)	Impact Velocity mph (m/s)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
	Material	Size in. x in. (mm x mm)	Length ft (m)			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
MGS221PT-22	Wood (SYP)	6x8 (152x203)	8 (2.44)	64 (1,626)	15.1 (6.7)	12.7 (56.5)	4.7 (119)	NA	NA	48.8 (5.5)	6.2 (157)	Post Fracture
MGS221PT-23	Wood (SYP)	6x8 (152x203)	8 (2.44)	64 (1,626)	16.0 (7.2)	11.2 (49.8)	8.3 (211)	NA	NA	75.0 (8.5)	9.8 (249)	Post Fracture
MGS221PT-24	Wood (SYP)	6x8 (152x203)	8 (2.44)	64 (1,626)	18. 5 (8.3)	17.4 (77.4)	7.3 (185)	NA	NA	103.4 (11.7)	9.0 (229)	Post Fracture
MGS221PT-25	Wood (SYP)	6x8 (152x203)	7.5 (2.29)	58 (1,473)	15.12 (6.76)	12.1 (53.8)	4.9 (124)	9.9 (44.1)	NA	161.7 (18.3)	18.4 (467)	Rotation in Soil
MGS221PT-26	Wood (SYP)	6x8 (152x203)	7.5 (2.29)	58 (1,473)	16.0 (7.2)	15.6 (69.4)	4.7 (119)	11.3 (50.4)	NA	180.9 (20.4)	15.1 (384)	Rotation in Soil
MGS221PT-27	Steel	W6x9 (W152x13.4)	9 (2.74)	76 (1,930)	13.7 (6.1)	13.2 (58.7)	2.4 (61)	8.4 (37.2)	NA	131.8 (14.9)	16.2 (411)	Rotation in Soil & Post Yielding
MGS221PT-28	Steel	W6x9 (W152x13.4)	9 (2.74)	76 (1,930)	16.4 (7.3)	13.0 (57.8)	2.3 (58)	8.9 (39.6)	8.0 (35.6)	189.8 (21.4)	30.4 (772)	Rotation in Soil & Post Yielding

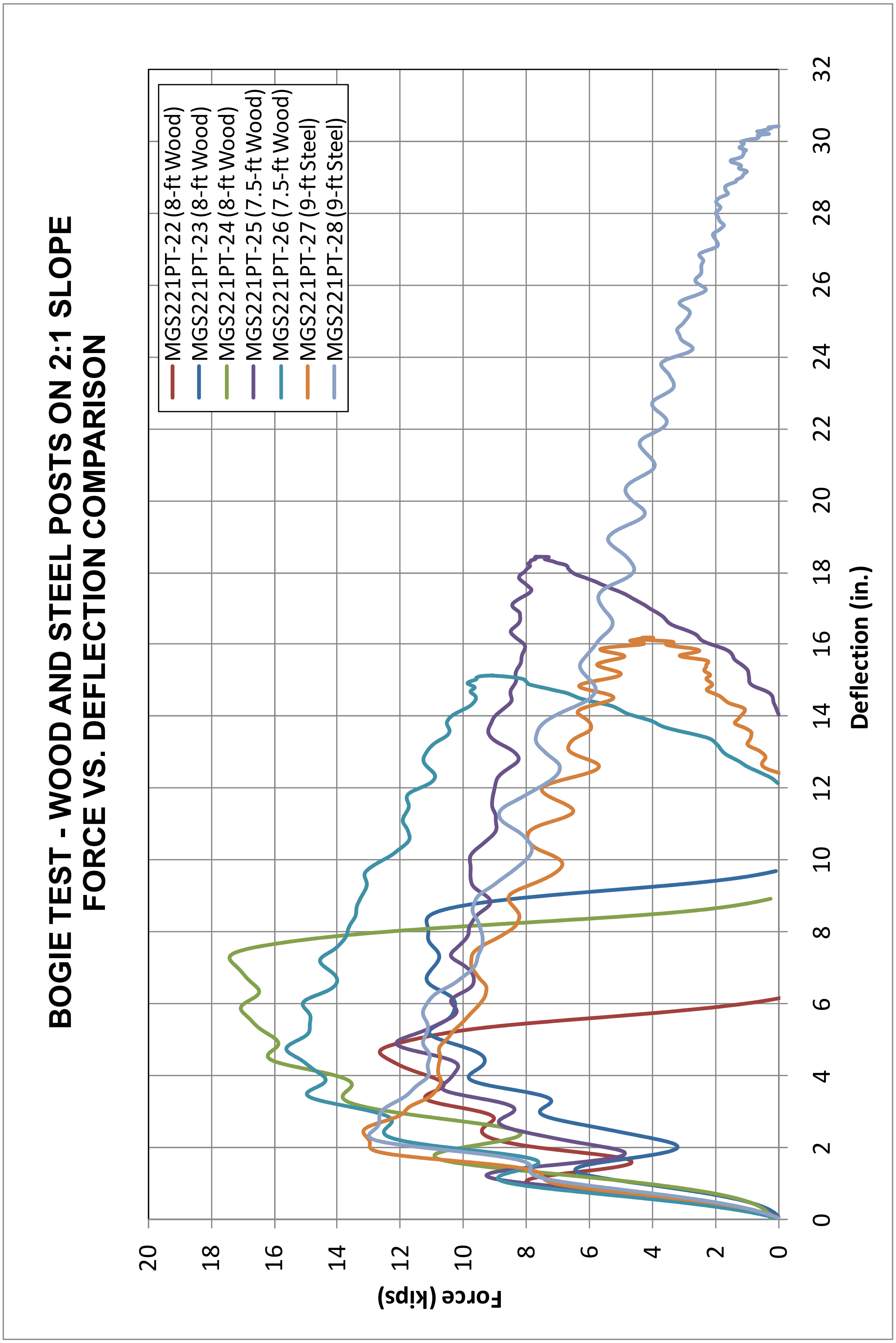

Figure 18. Force vs. Deflection Comparison Plot, All Bogie Tests

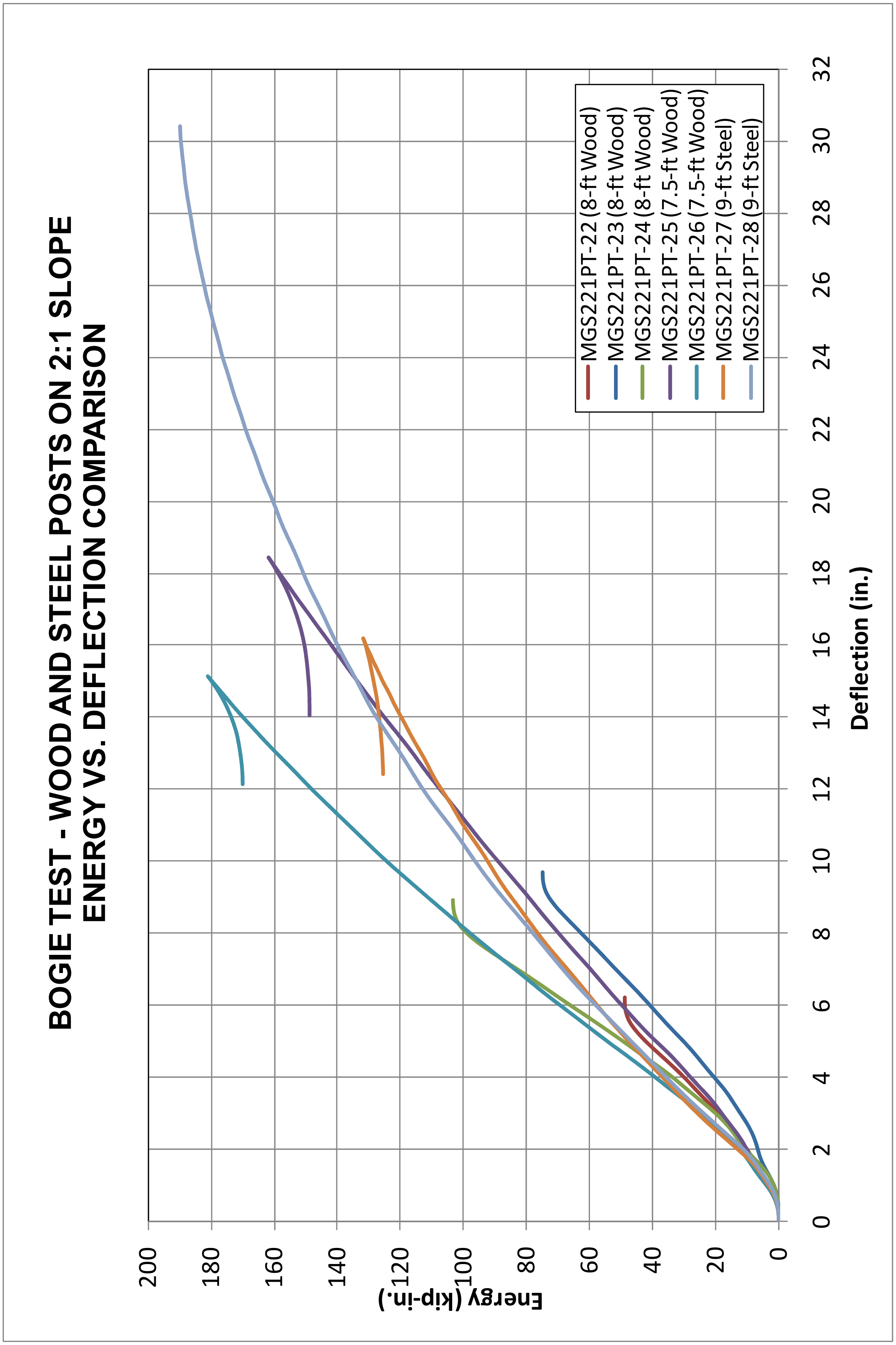

Figure 19. Energy vs. Deflection Comparison Plot, All Bogie Tests

5 SUMMARY AND CONCLUSIONS

The objective of the study described herein was to evaluate a suitable wood post alternative for use in the MGS system installed adjacent to a 2H:1V fill slope. In order to complete this objective, a series of seven bogie tests were conducted on 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts of 7.5 and 8 ft (2.29 and 2.44 m) lengths and 9-ft (2.74-m) long, W6x9 (W152x13.4) steel posts placed at the break point of a 2H:1V fill slope. The results from these tests were evaluated and compared. The results found that the 7.5-ft (2.29-m) long, 6-in. x 8-in. (152-mm x 203-mm) SYP wood post provided the best possible performance and the closest correlation to the 9-ft (2.74-m) long, W6x9 (W152x13.4) steel post used in the original design. Thus, it is recommend that the MGS system may be installed adjacent to a 2H:1V fill slope with either 9-ft (2.74-m) long, W6x9 (W152x13.4) steel posts or 7.5-ft (2.29-m) long, 6-in. x 8-in. (152-mm x 203-mm) SYP wood posts.

6 REFERENCES

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2. Dey, G., Faller, R.K., Hascall, J.A., Bielenberg, R.W., Polivka, K.A., and Molacek, K., *Dynamic Impact Testing of W152x13.4 (W6x9) Steel Posts on a 2:1 Slope*, Final Report to the Midwest States Regional Pooled Fund Program, Transportation Research Report No. TRP-03-165-07, Project No. SPR-3(017)-Year 15, Project Code: RPFP-05-09, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, March 23, 2007.

3. *Manual for Assessing Safety Hardware (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

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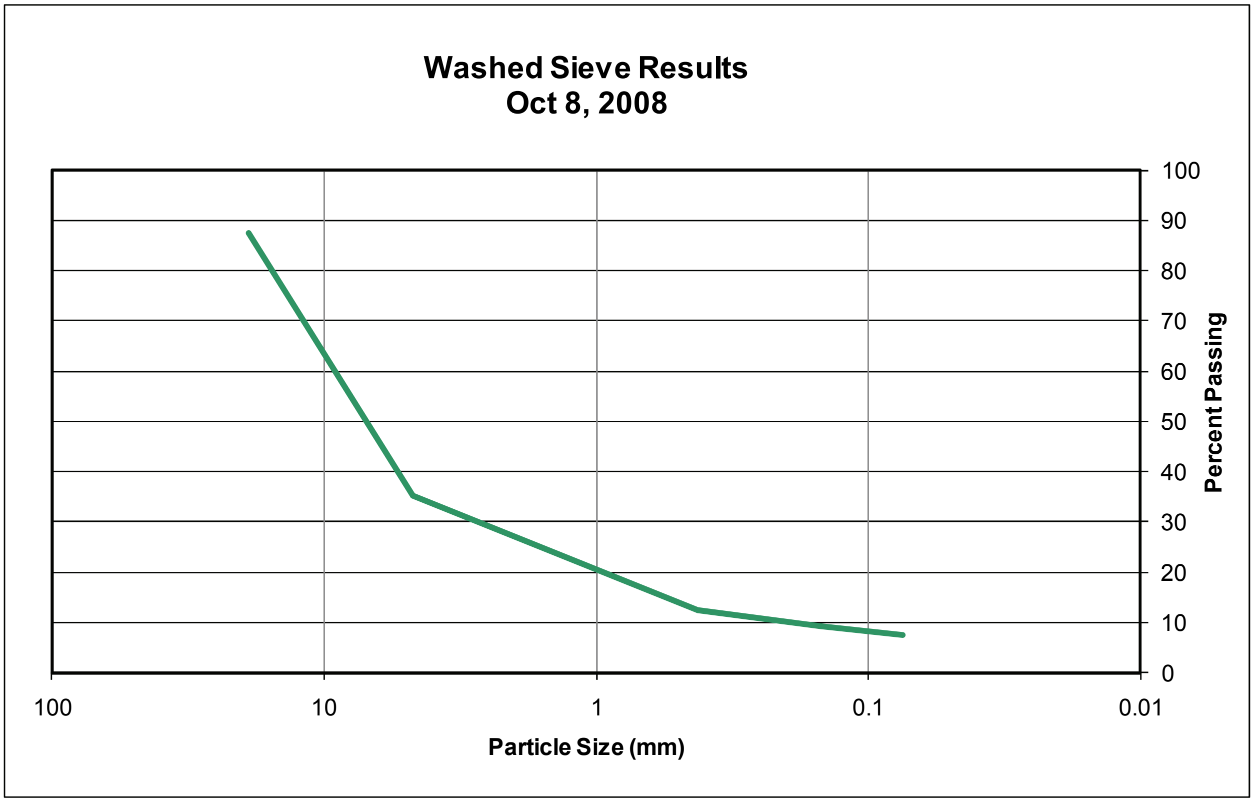
7. Stolle, C.J., Lechtenberg, K.A., Faller, R.K., Rosenbaugh, S.K., Sicking, D.L., and Reid, J.D., *Evaluation of the Midwest Guardrail System (MGS) with White Pine Wood Posts*, Draft Report to the Wisconsin Department of Transportation, MwRSF Research Report No. TRP-03-241-10, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, November 8, 2010.

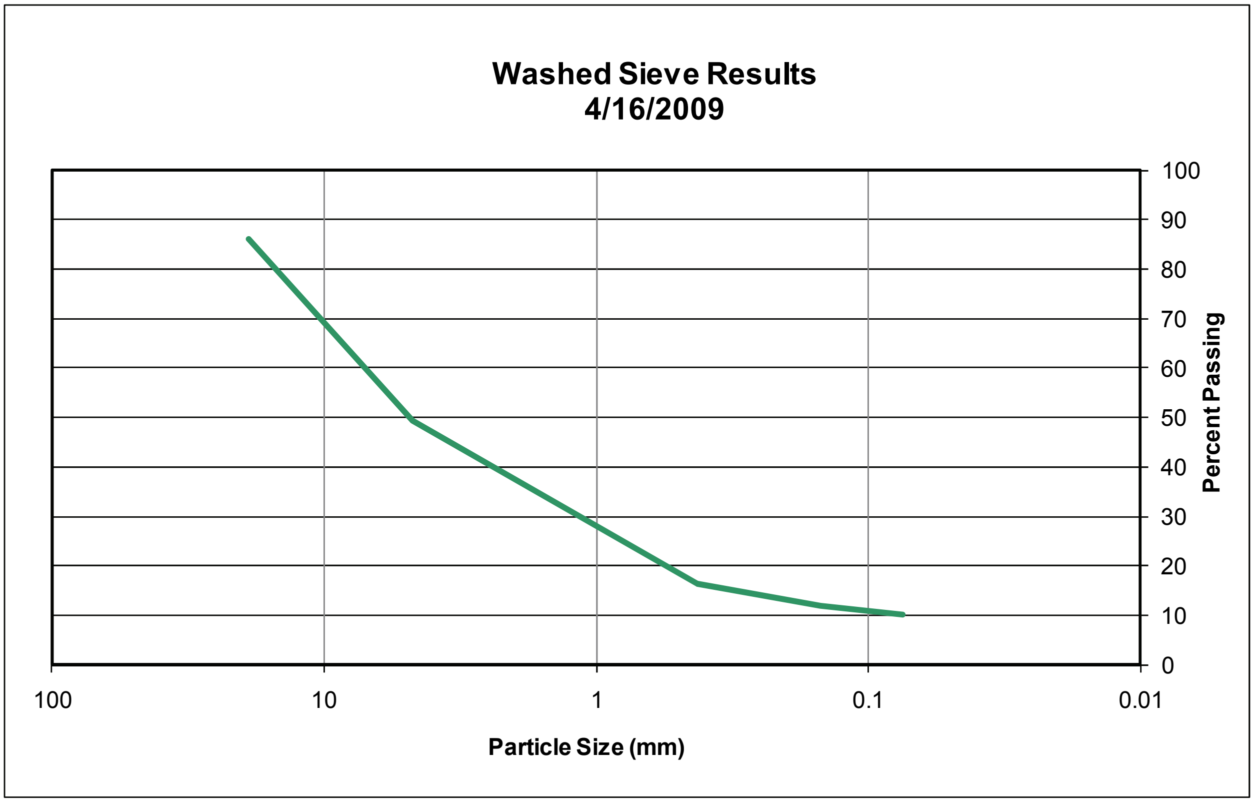
7 APPENDICES

Appendix A. Soil Characteristic Data



Soil Test #		10082008		Moisture Content %	-55.853
Wet Soil Test Weight (kg)		1.056			
Dry Soil Test Weight (kg)		2.392			
Date		10/8/2008			
Sieve Pan #	Sieve Opening (mm)	Pan Weight (kg)	Final Weight (kg)	Final Soil Weight (kg)	% passing
3 / 4	19.05	1.196	1.496	0.300	87.458
4	4.75	1.068	2.320	1.252	35.117
40	0.425	0.822	1.364	0.542	12.458
100	0.15	0.762	0.842	0.080	9.114
200	0.075	0.716	0.752	0.036	7.609
Loss		0.182			

Figure A-1. Soil Characteristic Data, Test No. MGS221PT-22



Soil Test #		4162009		Moisture Content %	#DIV/0!
Wet Soil Test Weight (kg)					
Dry Soil Test Weight (kg)		1.488			
Date		4/16/2009			
Sieve Pan #	Sieve Opening (mm)	Pan Weight (kg)	Final Weight (kg)	Final Soil Weight (kg)	% passing
3 / 4	19.05	1.196	1.402	0.206	86.156
4	4.75	1.068	1.618	0.550	49.194
40	0.425	0.822	1.310	0.488	16.398
100	0.15	0.762	0.826	0.064	12.097
200	0.075	0.716	0.744	0.028	10.215
Loss		0.152			

Figure A-2. Soil Characteristic Data, Test No. MGS221PT-23

Soil Test #		8132009		Moisture Content %	#VALUE!
Wet Soil Test Weight (kg)		N/A			
Dry Soil Test Weight (kg)		4.226			
Date		8/13/2009			
Sieve Pan #	Sieve Opening (mm)	Pan Weight (kg)	Final Weight (kg)	Final Soil Weight (kg)	% passing
3 / 4	19.05	1.196	1.938	0.742	82.442
4	4.75	1.068	2.876	1.808	39.659
40	0.425	0.822	1.866	1.044	14.955
100	0.15	0.762	0.904	0.142	11.595
200	0.075	0.716	0.790	0.074	9.844
Loss		0.416			

Figure A-3. Soil Characteristic Data, Test Nos. MGS221PT-24 through MGS221PT-28

Appendix B. Post Imperfections

Documentation of the wood post imperfections, including knots and splits, for each wood post used during the dynamic tests contained in this research report are provided in the table in this appendix.

Table B-1. Wood Post Imperfection Details

Test No.	Knots			Splits		
	Diameter in.	Face	Distance from Groundline[1] in.	Size in.	Face	Distance from Groundline[1] in.
MGS221PT-22	1	Right	4	NA	NA	NA
	1¾	Right	-11¾			
	1	Left	-11¾			
	1¼	Back	-12¾			
MGS221PT-23	1½	Right	9½	NA	NA	NA
	2¾	Back	7¼			
	1¼	Back	10½			
	1½	Left	9¾			
MGS221PT-24	2½	Left	8	NA	NA	NA
	2	Left	-14			
MGS221PT-25	2	Right	17	NA	NA	NA
	½	Right	-11			
	½	Right	-1½			
	½	Right	-10½			
	½	Right	-10			
	½	Left	1			
	1	Left	1			
	½	Left	11			
	½	Left	-12½			
	1	Left	-12½			
	½	Left	-13			
	¾	Back	13½			
	½	Back	-13			
MGS221PT-26	1	Back	-15½	¼	Right	3¼ to -8
	¼	Left	1¼	½	Front	12½
	1	Left	-15	⅛	Front	-8¾
	⅝	Right	1	¼	Back	Entire length
	1	Right	-15	3/16	Front	-3½

[1] Upward from groundline is positive and below groundline is negative.

Appendix C. Material Specifications

Aug 17 09 11:54a   Attn: Jim 402-472-9464

PERMA-TREAT OF ILLINOIS, INC.

1800 PERMA-TREAT DRIVE, P.O. BOX 99
MARION, IL 62959
PH# 800.572.7384 FAX# 618.993.8680

This is to certify that the guardrail material has been treated and inspected according to the Iowa Department of Transportation Specification requirements and IM 462.

This material has been processed from Rough Sawn #1 Southern Yellow Pine.

Company: Midwest Fence/Guardrail Systems

Bill of Lading: 23389

Quantity	Description	Charge #	Date of Treatment	QC Name	Treatment	MC prior to treatment
60	6x8x7 2 Hole Post	4027-08	7/30/09	Martin	.60 CCA-C	20%
160	6x8x6 1 Hole Post	3987-09	7/7/09	Martin	.60 CCA-C	20%
90	6x8x6 1 Hole Post	4034-09	8/3/09	Martin	.60 CCA-C	20%
216	6x8x18 2 Hole Blocks	3939-09	6/12/09	Martin	.60 CCA-C	20%
72	6x8x18 2 Hole Blocks	4035-09	8/3/09	Martin	.60 CCA-C	20%
32	6x8x8	3871-09	5-5-09	Martin	.60 CCA-C	20%
				Martin	.60 CCA-C	20%
				Martin	.60 CCA-C	20%
				Martin	.60 CCA-C	20%
				Martin	.60 CCA-C	20%
				Martin	.60 CCA-C	20%
				Martin	.60 CCA-C	20%

Perma-Treat of Illinois, Inc

By: [signature]

Title: President

Date: 8-17-09

NOTARIZED

Sworn to and described
Before me this 17 day of
August 2009.

By: [signature]

Official Seal

OFFICIAL SEAL
ROSE M. SCHUMAKER
Notary Public, State of Illinois
My Commission Expires 03/20/13

Figure C-1. 6-in. x 8-in. Wood Post Certificate of Conformance

CERTIFIED MATERIAL TEST REPORT

CHAPARRAL

CHAPARRAL STEEL
300 Ward Rd.
Midlothian, TX
76065-9651
(972) 775-8241

Bill To:
STEEL AND PIPE SUPPLY
P.O. BOX 1688
MANHATTAN KS
66502 US

Ship To: 2
STEEL AND PIPE SUPPLY
1050 FORT GIBSON ROAD
CATOOSA OK
US

Order Date:06/01/2006
PO No:45/74258
Mill Order No:3153490
Load No:1037572
Manifest No:1757157

SPECIFICATIONS	SIZE	GRADE	LENGTH	PRODUCT
ASTM A6-05a. A992-04a. A572-04	W 6 X 9# / W150 X 13.5	992/572-50	50 FT / 15.24 M	WF BEAMS

HEAT NO: 22344410

CHEMICAL ANALYSIS

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Al	Nb	CE
.09	.83	.004	.019	.20	.37	.13	.10	.030	.010	.001	.005	.014	.29

PHYSICAL PROPERTIES

Yield Strength KSI	Yield Strength MPa	Tensile Strength KSI	Tensile Strength MPa	Specimen Area Sq In	Specimen Area Sq cm	Elongation %	Gage Length		Bend Test Dia.	Bend Test Result	ROA %
60.0	413.7	74.8	515.7	0.249	1.61	23.4	8 In	200 mm			
57.7	397.8	73.0	503.3	0.252	1.63	23.3	8 In	200 mm			

Remarks

Material meets requirements of ASTM A992

received 4/28/09

All manufacturing processes of this product, including electric arc melting and continuous casting, occurred in the U.S.A.
CMTR complies with DIN EN 10204 3.1.B

"I hereby certify that the contents of this report are correct and accurate. All tests and operations performed by this material manufacturer or its sub-contractors, when applicable, are in compliance with the requirements of the material spe

Signed: [signature] Date: Jun. 26, 2006
Tom L. Harrington: Quality Assurance Manager

Signed: ____________ Date: ____________
Notary Public (If applicable)

Page: 1 of 1

Figure C-2. W6x9 Steel Post Material Specifications

Appendix D. Bogie Test Results

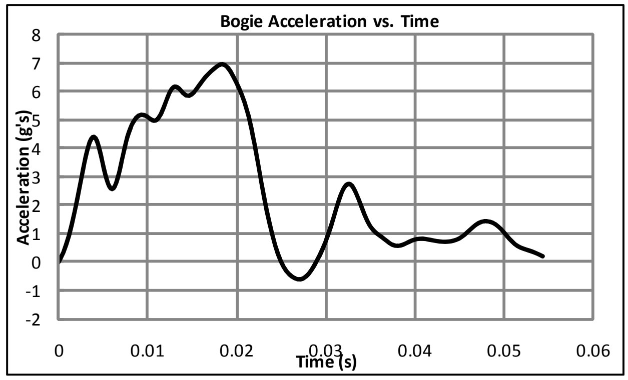
The results of the recorded data from each accelerometer on every dynamic bogie test are provided in the summary sheets found in this appendix. Summary sheets include acceleration, velocity, and deflection versus time plots as well as force vs. deflection and energy vs. deflection plots.

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	MGS 2:1 Wood Post Bogie Testing	
Test Number:	MGS2-1pt22	
Test Date:	6-Mar-2009	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	SYP	
Post Size:	6"x8"	152x203
Post Length:	96 in.	243.8 cm
Embedment Depth:	64 in.	162.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	10082008	
Moisture Content:	4	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.08 mph (22.1 fps)	6.74 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1815 lbs	823.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS 6 - fujinon 50 - 32'-8.75" perp.	

Test Results Summary		
Max. Deflection:	6.2	in.
Peak Force:	12.7	k
Initial Linear Stiffness:	7.4	k/in.
Total Energy:	48.8	k-in.



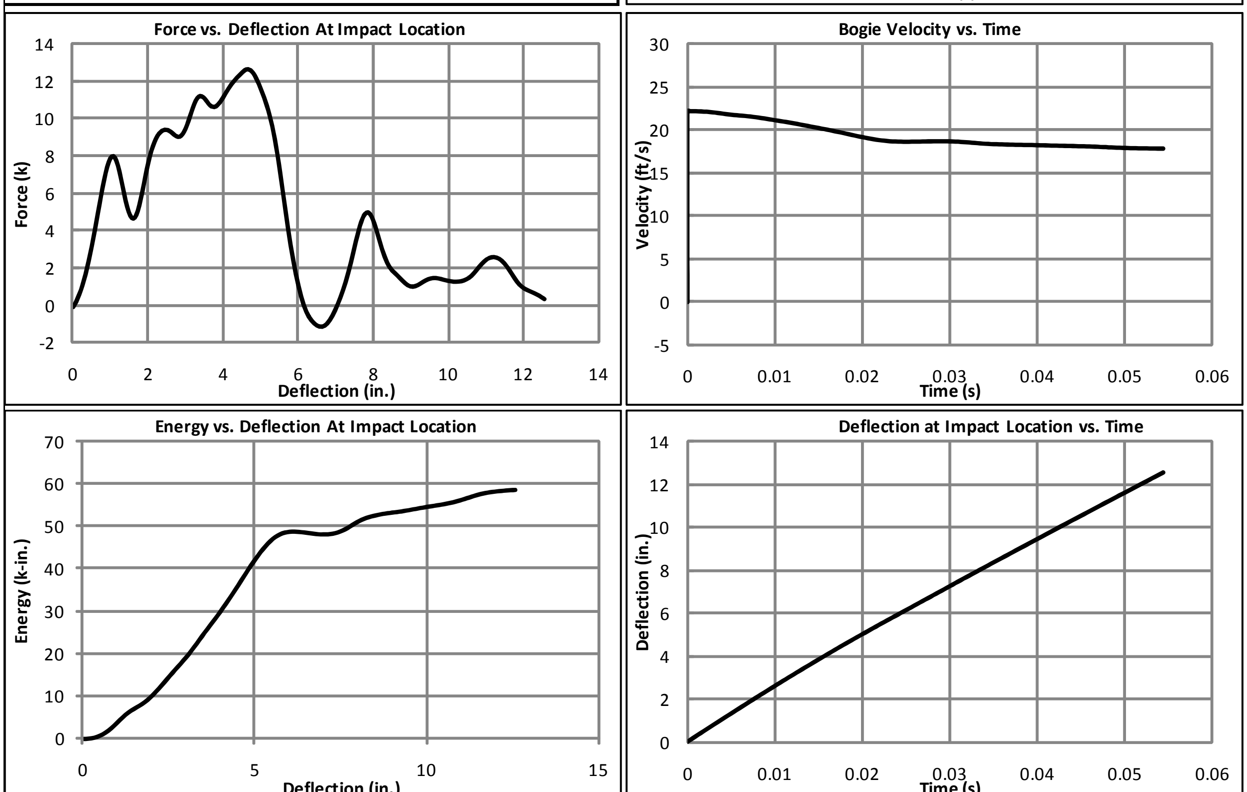


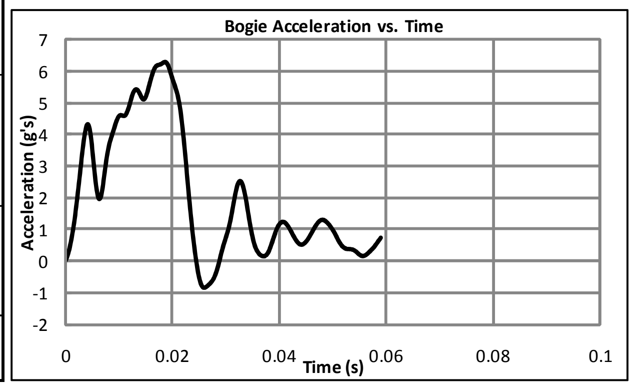
Figure D-1. Results of Test No. MGS221PT-22 (EDR-3)

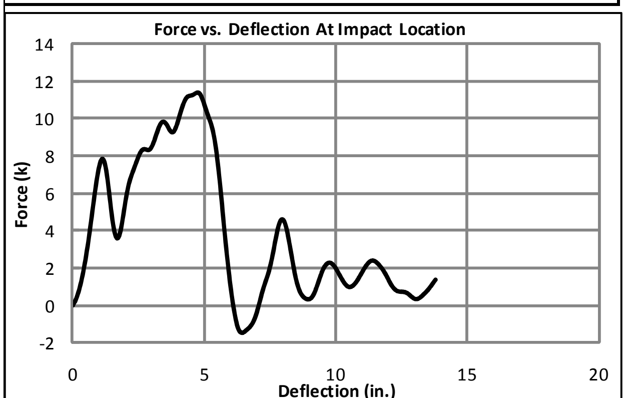
MIDWEST ROADSIDE SAFETY FACILITY

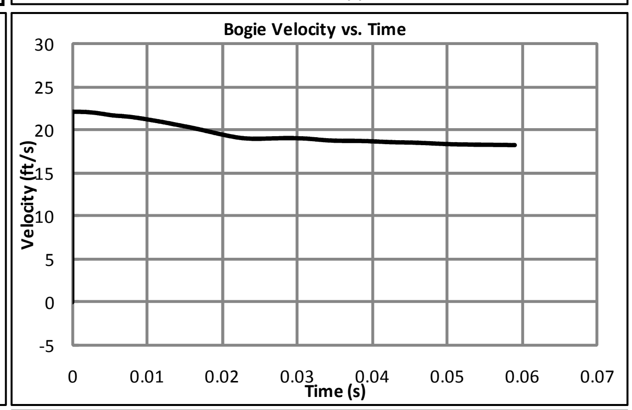
Bogie Test Summary

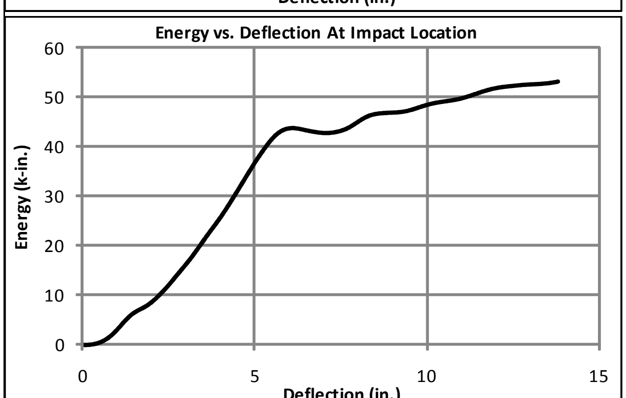
Test Information	MGS 2:1 Wood Post Bogie Testing	
Test Number:	MGS2-1pt22	
Test Date:	6-Mar-2009	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	SYP	
Post Size:	6"x8"	152x203
Post Length:	96 in.	243.8 cm
Embedment Depth:	64 in.	162.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	10082008	
Moisture Content:	4	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.08 mph (22.1 fps)	6.74 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1815 lbs	823.3 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS 6 - fujinon 50 - 32'-8.75" perp.	

Test Results Summary		
Max. Deflection:	6.1	in.
Peak Force:	11.4	k
Initial Linear Stiffness:	7.0	k/in.
Total Energy:	43.7	k-in.









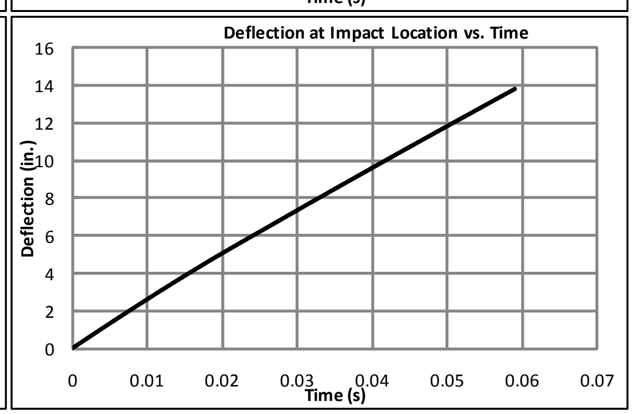


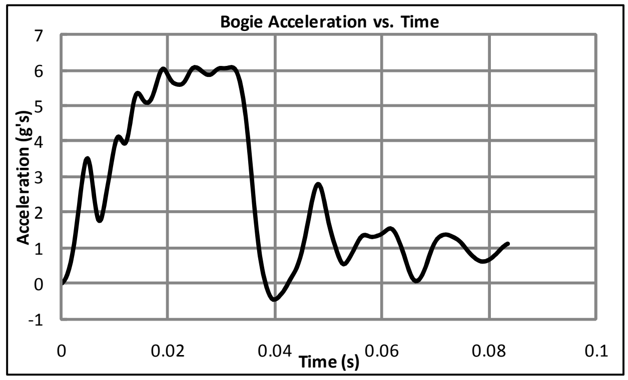
Figure D-2. Results of Test No. MGS221PT-22 (EDR-4)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	MGS on 2:1 slope post test	
Test Number:	MGS221PT-23	
Test Date:	24-Jul-2009	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	6x8 SYP	
Post Size:	6x8 SYP	152x203
Post Length:	96.5 in.	245.1 cm
Embedment Depth:	64 in.	162.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	4162009	
Moisture Content:	2.59	
Compaction Method:	HE8 in 3' hole on 2:1 slope in guardrail pit	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.99 mph (23.5 fps)	7.15 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1844.97 lbs	836.9 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-6, 24-70 @35, Perpendicular - 262"	

Test Results Summary		
Max. Deflection:	9.8	in.
Peak Force:	11.2	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	75.0	k-in.



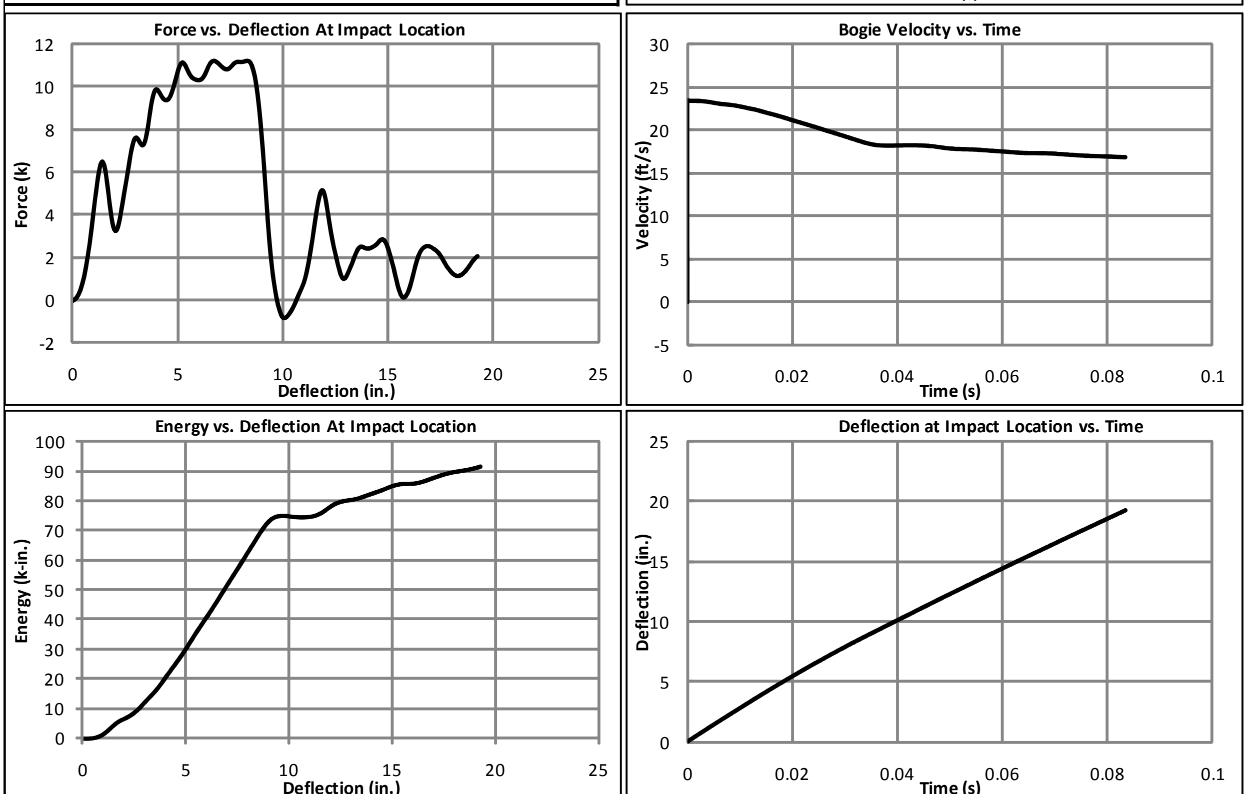


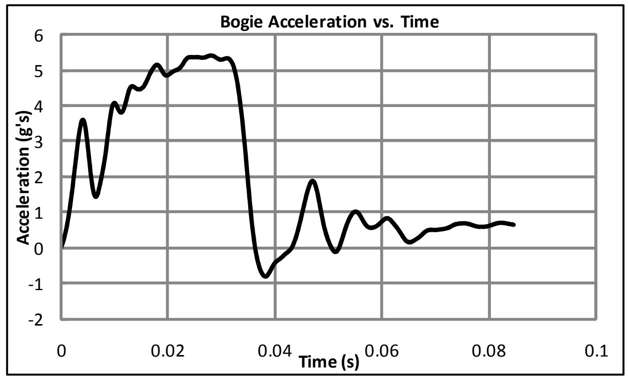
Figure D-3. Results of Test No. MGS221PT-23 (EDR-3)

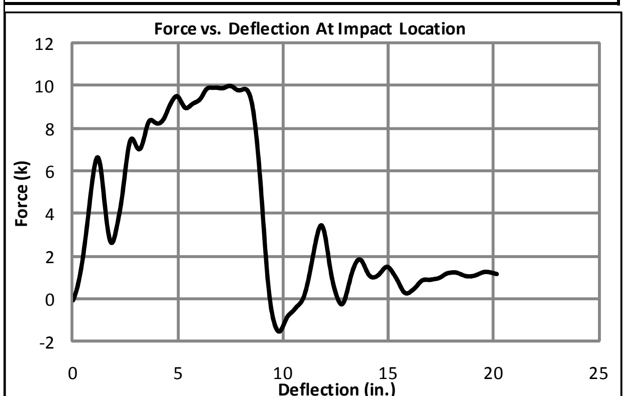
MIDWEST ROADSIDE SAFETY FACILITY

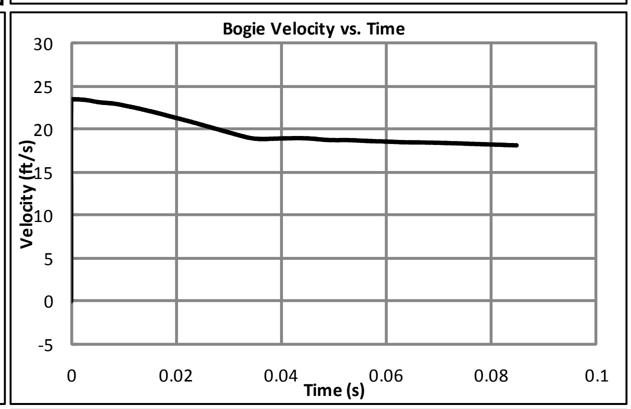
Bogie Test Summary

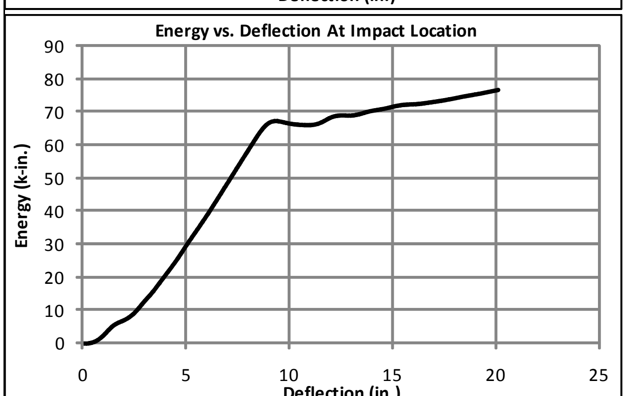
Test Information	MGS on 2:1 slope post test	
Test Number:	MGS221PT-23	
Test Date:	24-Jul-2009	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	6x8 SYP	
Post Size:	6x8 SYP	W150x18
Post Length:	96.5 in.	245.1 cm
Embedment Depth:	64 in.	162.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	4162009	
Moisture Content:	2.59	
Compaction Method:	HE8 in 3' hole on 2:1 slope in guardrail pit	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.99 mph (23.5 fps)	7.15 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1844.97 lbs	836.9 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-6, 24-70 @35, Perpendicular - 262"	

Test Results Summary		
Max. Deflection:	9.4	in.
Peak Force:	10.0	k
Initial Linear Stiffness:	5.6	k/in.
Total Energy:	67.2	k-in.









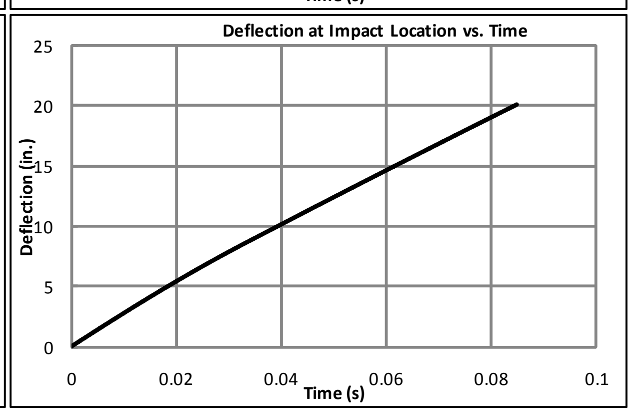


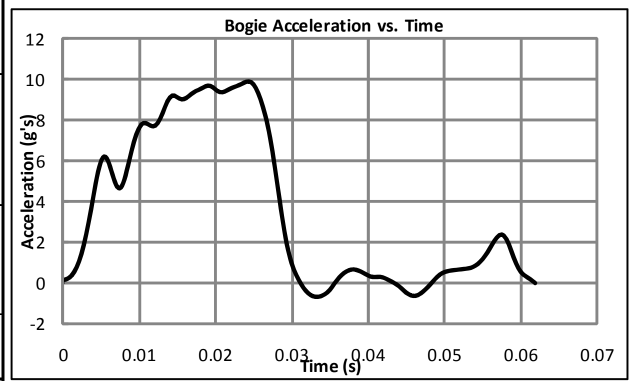
Figure D-4. Results of Test No. MGS221PT-23 (DTS)

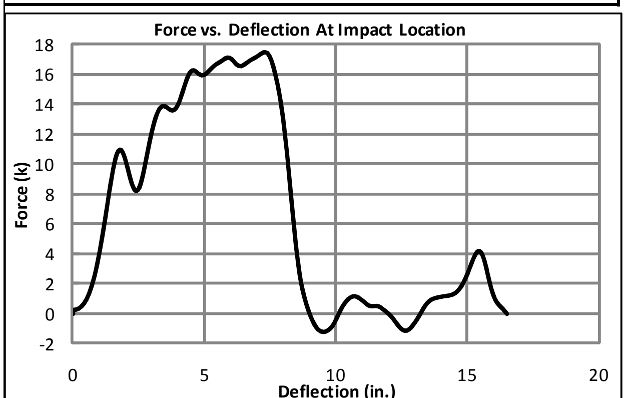
MIDWEST ROADSIDE SAFETY FACILITY

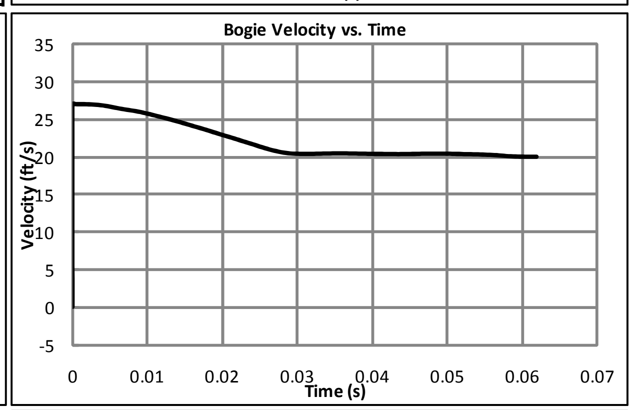
Bogie Test Summary

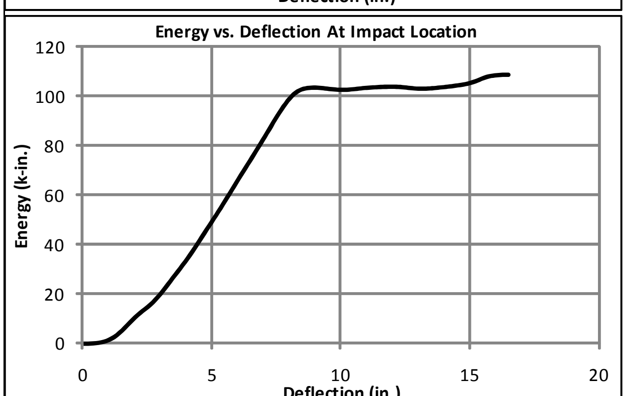
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-24	
Test Date:	17-Sep-2009	
Failure Type:	Post Fracture (some rotation)	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	96.5 in.	245.1 cm
Embedment Depth:	64 in.	162.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.024	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	18.45 mph (27.1 fps)	8.25 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	9.0	in.
Peak Force:	17.4	k
Initial Linear Stiffness:	6.4	k/in.
Total Energy:	103.4	k-in.









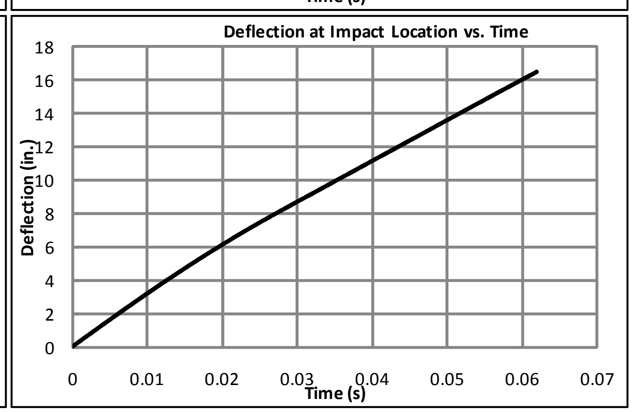


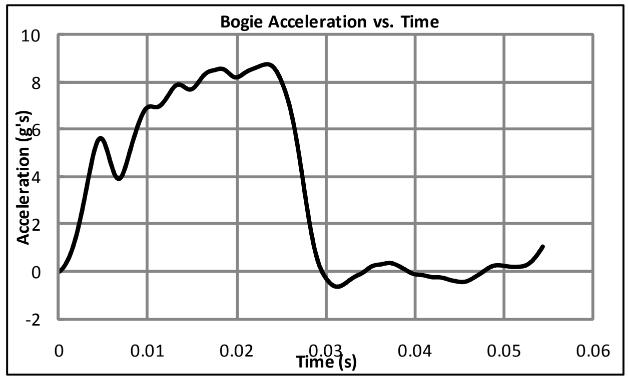
Figure D-5. Results of Test No. MGS221PT-24 (EDR-3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-24	
Test Date:	17-Sep-2009	
Failure Type:	Post Fracture (some rotation)	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	96.5 in.	245.1 cm
Embedment Depth:	64 in.	162.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.024	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	18.45 mph (27.1 fps)	8.25 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	8.7	in.
Peak Force:	15.4	k
Initial Linear Stiffness:	7.0	k/in.
Total Energy:	91.5	k-in.



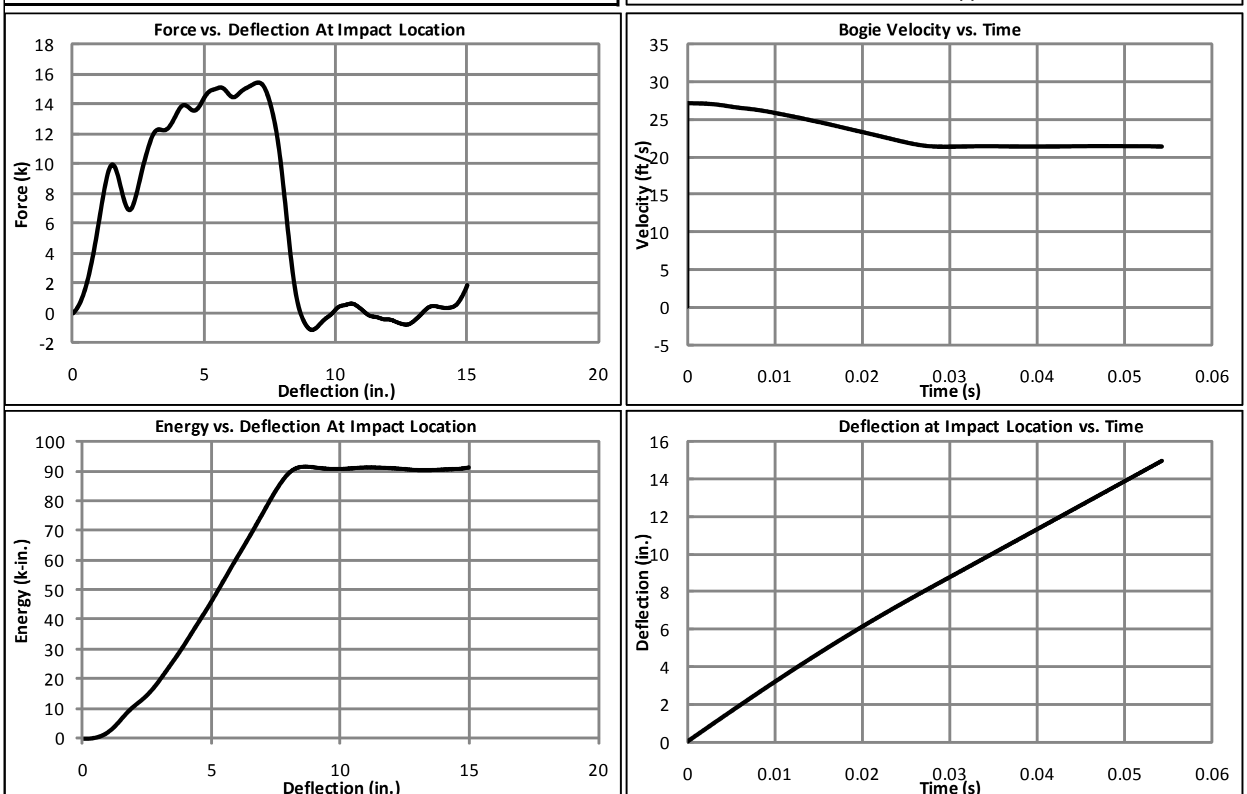


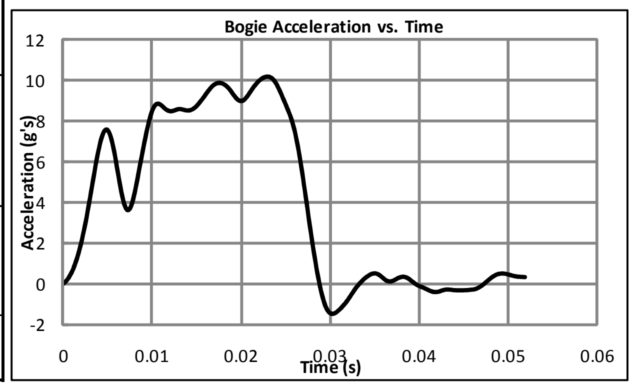
Figure D-6. Results of Test No. MGS221PT-24 (EDR-4)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-24	
Test Date:	17-Sep-2009	
Failure Type:	Post Fracture (some rotation)	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	96.5 in.	245.1 cm
Embedment Depth:	64 in.	162.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.024	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	18.45 mph (27.1 fps)	8.25 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	8.3	in.
Peak Force:	17.9	k
Initial Linear Stiffness:	8.9	k/in.
Total Energy:	101.6	k-in.



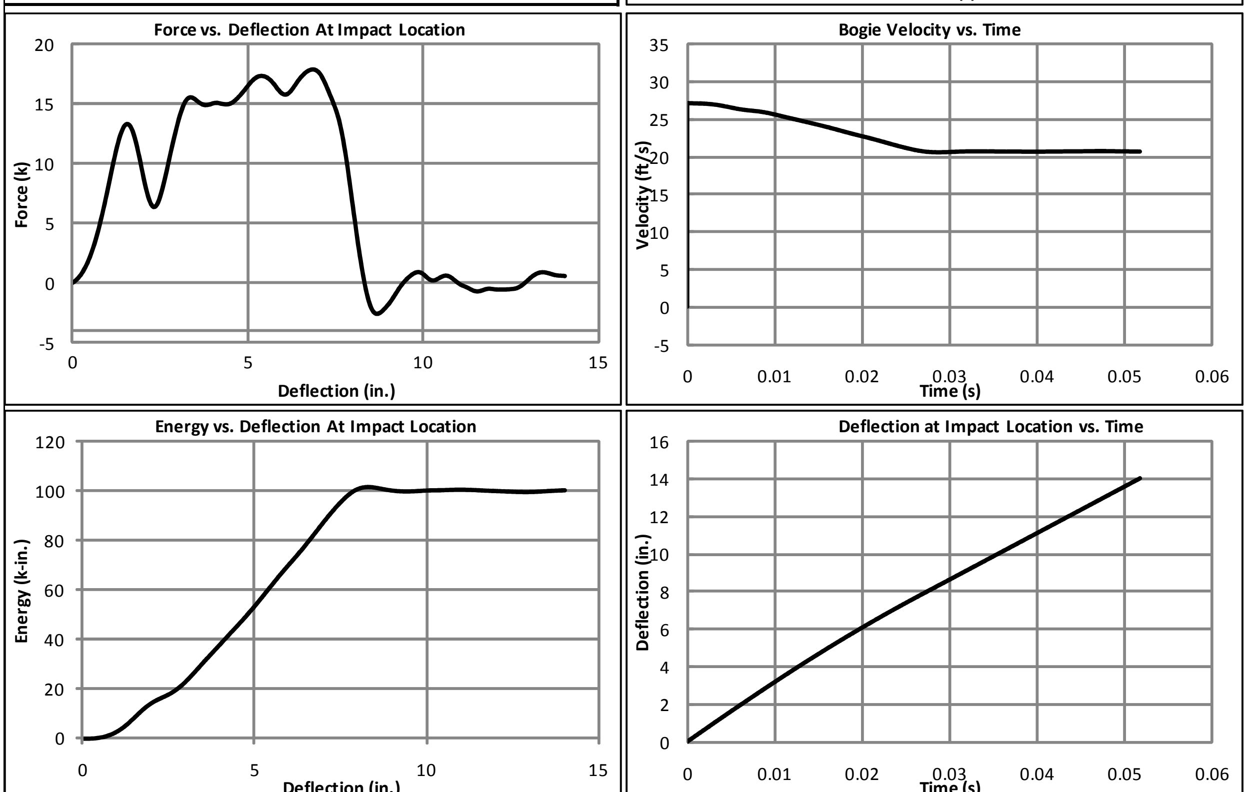


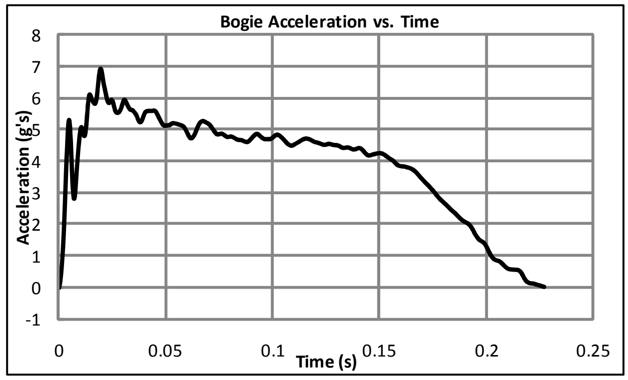
Figure D-7. Results of Test No. MGS221PT-24 (DTS)

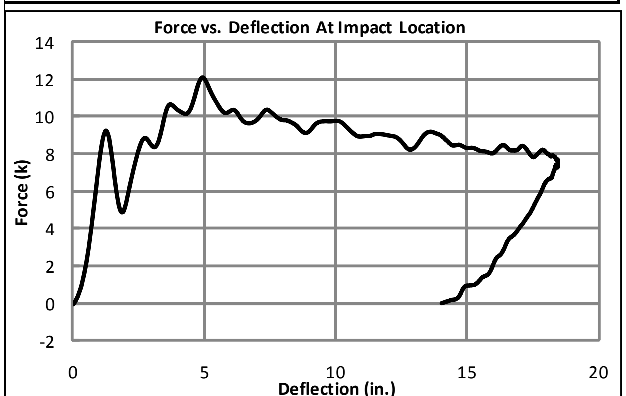
MIDWEST ROADSIDE SAFETY FACILITY

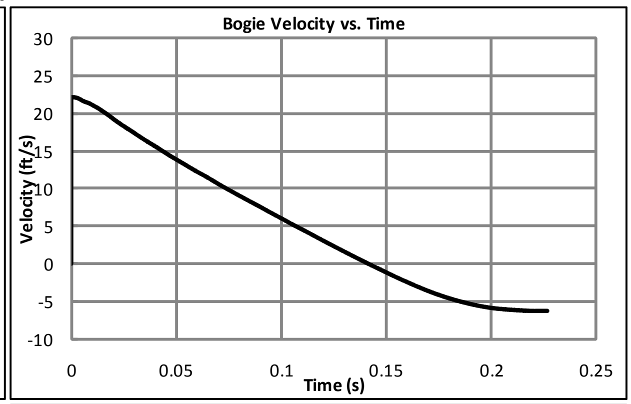
Bogie Test Summary

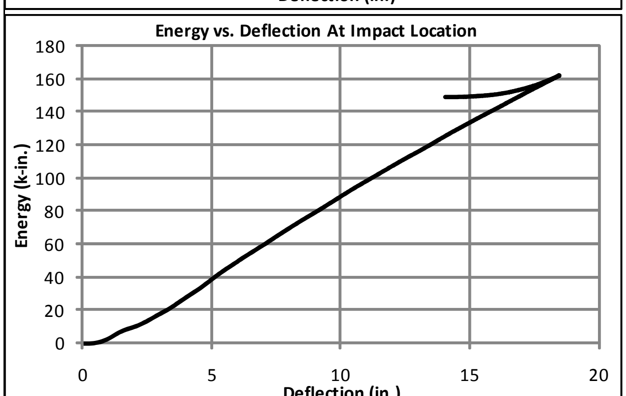
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-25	
Test Date:	17-Sep-2009	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	90 in.	228.6 cm
Embedment Depth:	58 in.	147.3 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.02	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.12 mph (22.2 fps)	6.76 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	18.4	in.
Peak Force:	12.1	k
Initial Linear Stiffness:	2.5	k/in.
Total Energy:	161.7	k-in.









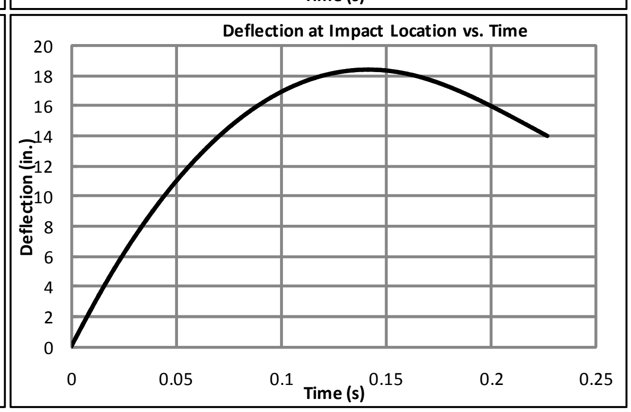


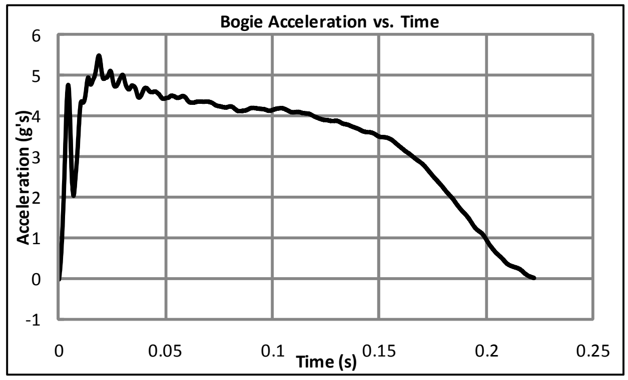
Figure D-8. Results of Test No. MGS221PT-25 (EDR-3)

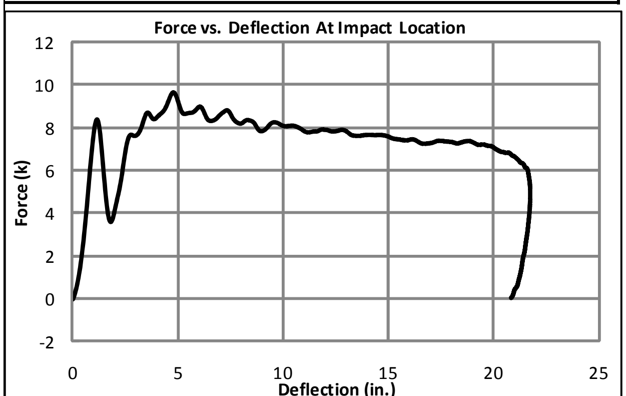
MIDWEST ROADSIDE SAFETY FACILITY

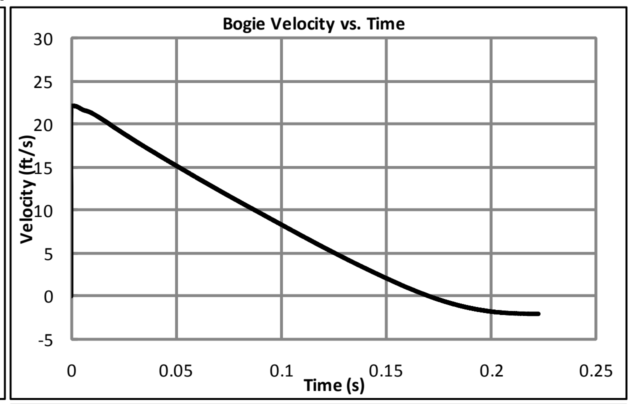
Bogie Test Summary

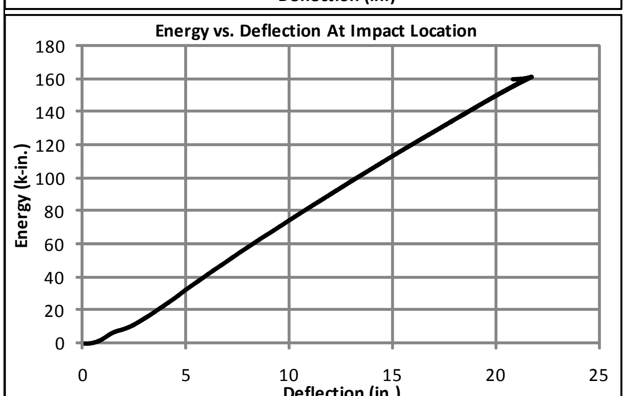
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-25	
Test Date:	17-Sep-2009	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	90 in.	228.6 cm
Embedment Depth:	58 in.	147.3 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.02	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.12 mph (22.2 fps)	6.76 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	21.7	in.
Peak Force:	9.6	k
Initial Linear Stiffness:	7.7	k/in.
Total Energy:	161.4	k-in.









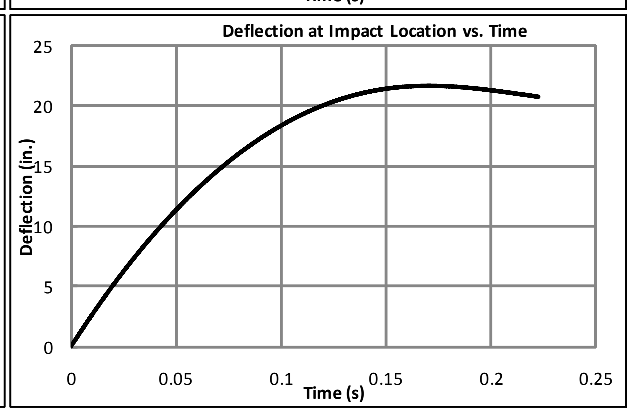


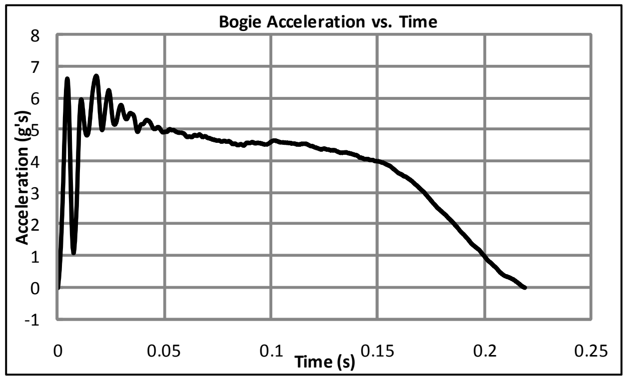
Figure D-9. Results of Test No. MGS221PT-25 (EDR-4)

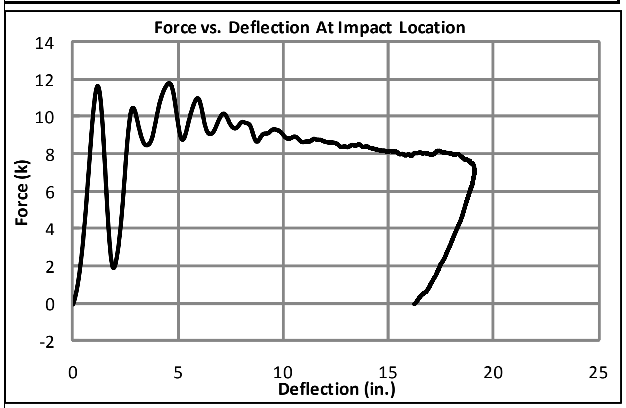
MIDWEST ROADSIDE SAFETY FACILITY

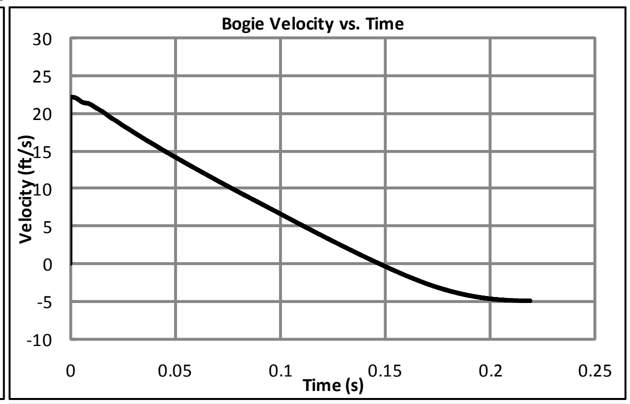
Bogie Test Summary

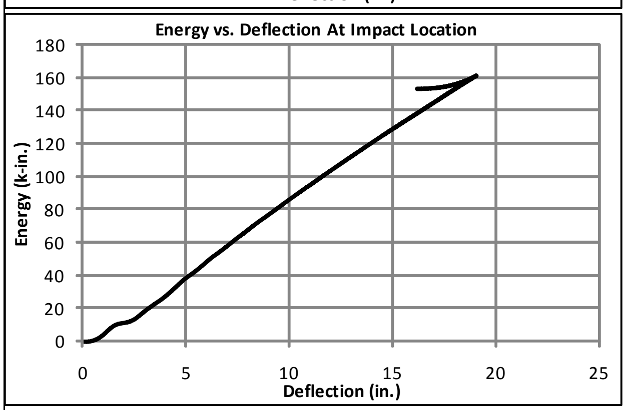
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-25	
Test Date:	17-Sep-2009	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	90 in.	228.6 cm
Embedment Depth:	58 in.	147.3 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.02	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.12 mph (22.2 fps)	6.76 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	19.1	in.
Peak Force:	11.8	k
Initial Linear Stiffness:	10.0	k/in.
Total Energy:	161.4	k-in.









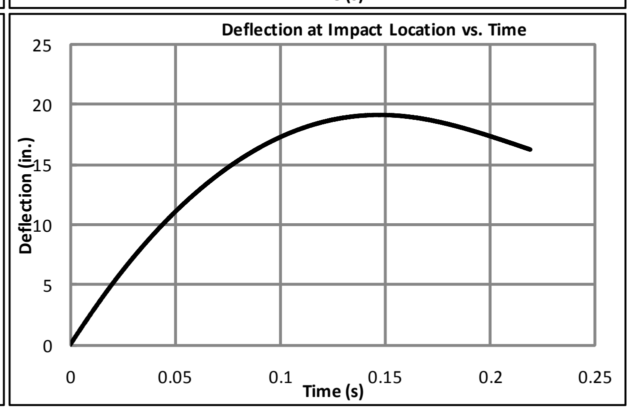


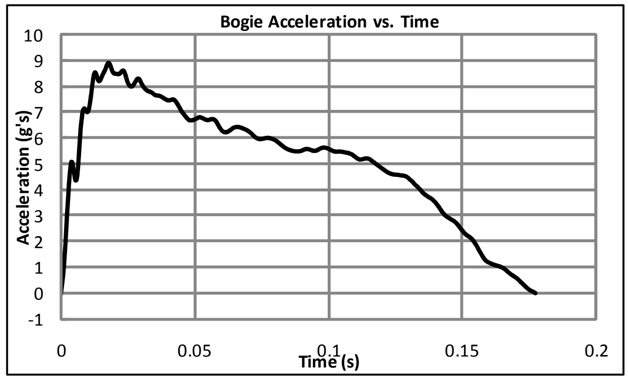
Figure D-10. Results of Test No. MGS221PT-25 (DTS)

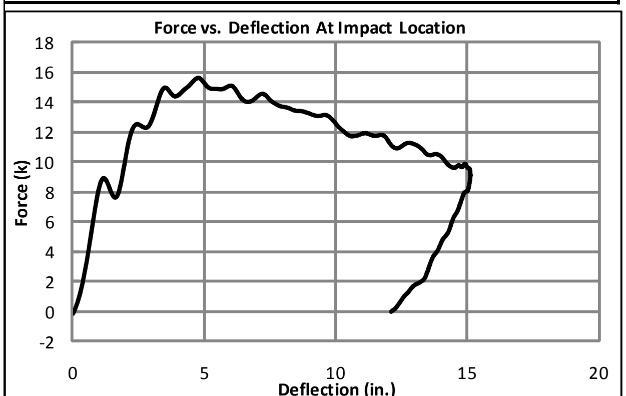
MIDWEST ROADSIDE SAFETY FACILITY

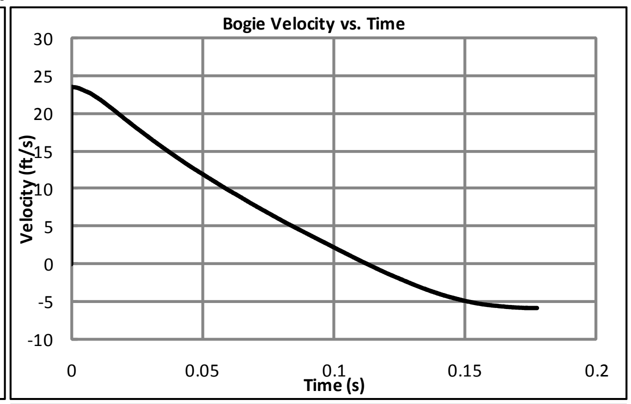
Bogie Test Summary

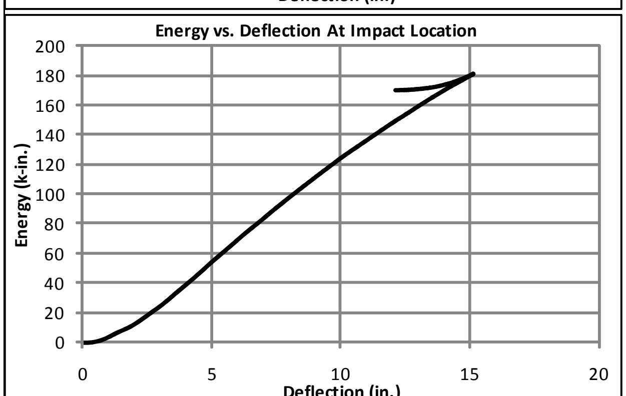
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-26	
Test Date:	17-Sep-2009	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	90 in.	228.6 cm
Embedment Depth:	58 in.	147.3 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.026	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.99 mph (23.5 fps)	7.15 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	15.1	in.
Peak Force:	15.6	k
Initial Linear Stiffness:	3.3	k/in.
Total Energy:	180.9	k-in.









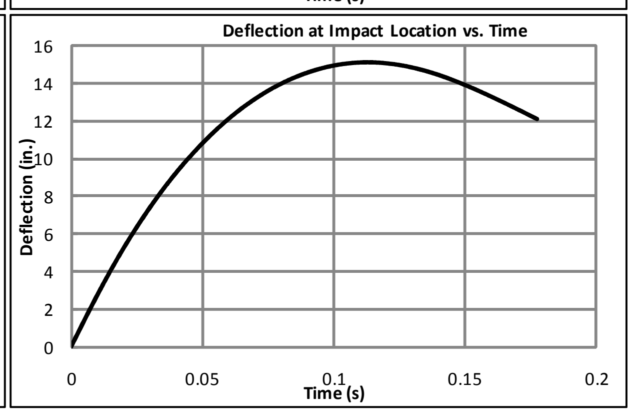


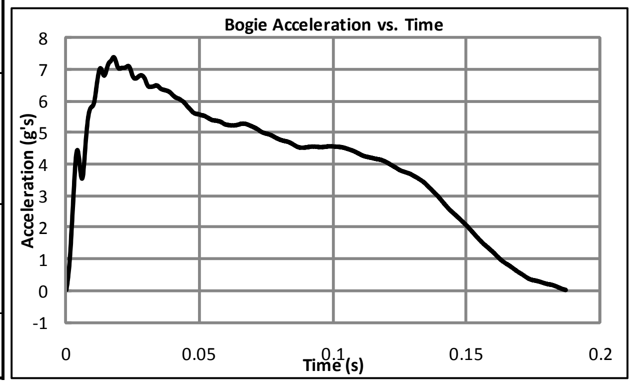
Figure D-11. Results of Test No. MGS221PT-26 (EDR-3)

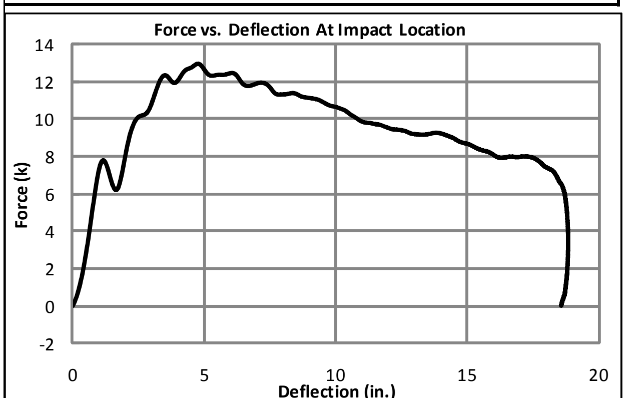
MIDWEST ROADSIDE SAFETY FACILITY

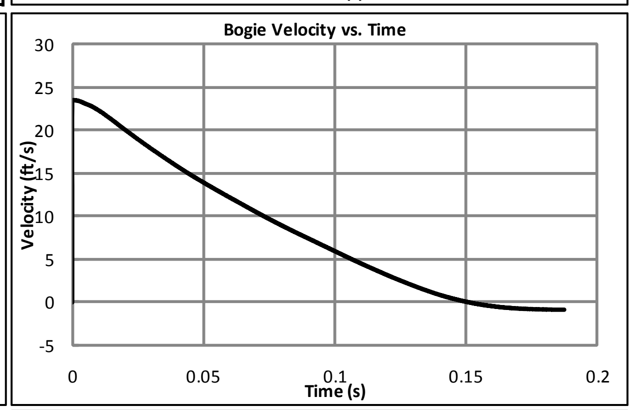
Bogie Test Summary

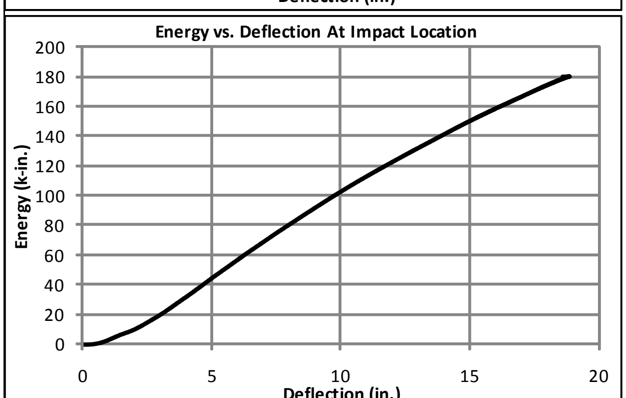
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-26	
Test Date:	17-Sep-2009	
Failure Type:	Post rotation in soil	
Post Properties		
Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	90 in.	228.6 cm
Embedment Depth:	58 in.	147.3 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.026	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.99 mph (23.5 fps)	7.15 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	18.8	in.
Peak Force:	13.0	k
Initial Linear Stiffness:	7.3	k/in.
Total Energy:	180.5	k-in.









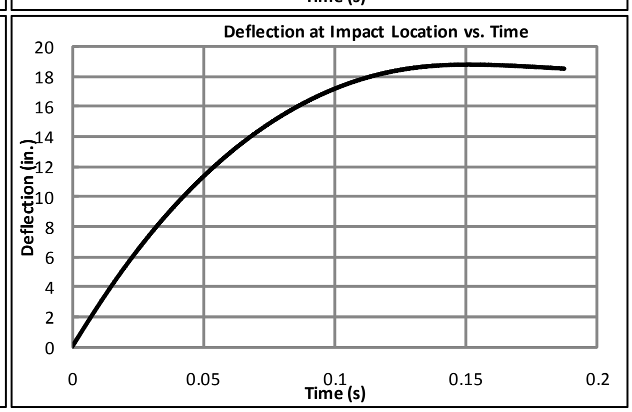


Figure D-12. Results of Test No. MGS221PT-26 (EDR-4)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information MGS 2:1 Slope Post Testing

Test Number:	MGS221PT-26	
Test Date:	17-Sep-2009	
Failure Type:	Post rotation in soil	

Post Properties

Post Type:	SYP	
Post Size:	6x8	152x203
Post Length:	90 in.	228.6 cm
Embedment Depth:	58 in.	147.3 cm
Orientation:	Strong Axis	

Soil Properties

Gradation:	8132009
Moisture Content:	0.026
Compaction Method:	HE8
Soil Density, γd:	NA

Bogie Properties

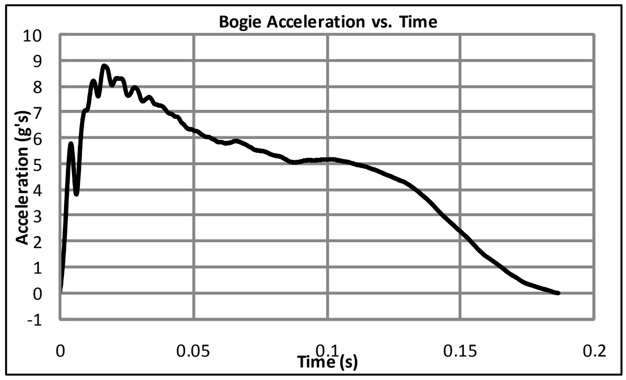
Impact Velocity:	15.99 mph (23.5 fps)	7.15 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg

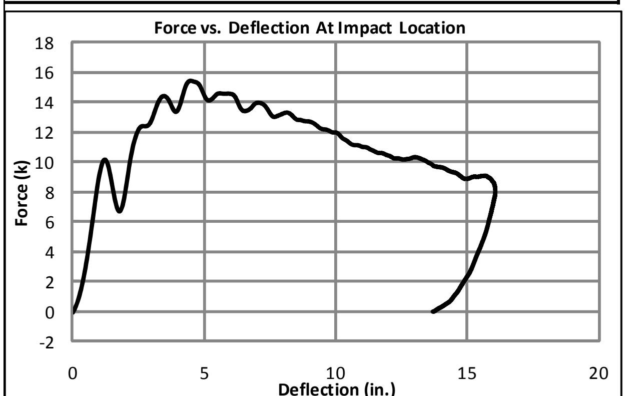
Data Acquired

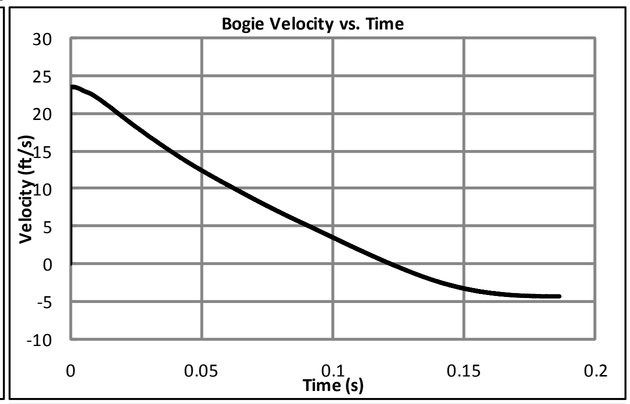
Acceleration Data:	DTS
Camera Data:	see field book

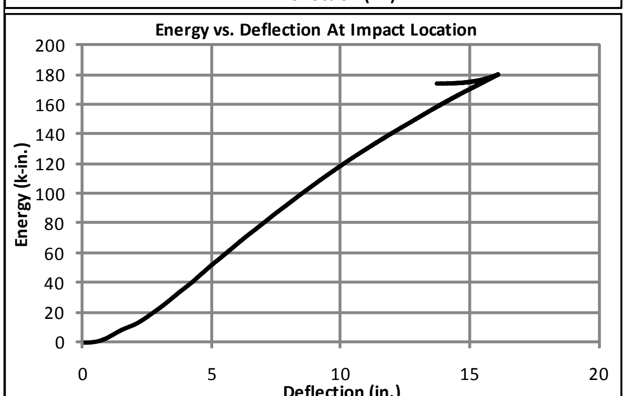
Test Results Summary

Max. Deflection:	16.1	in.
Peak Force:	15.4	k
Initial Linear Stiffness:	8.4	k/in.
Total Energy:	180.5	k-in.









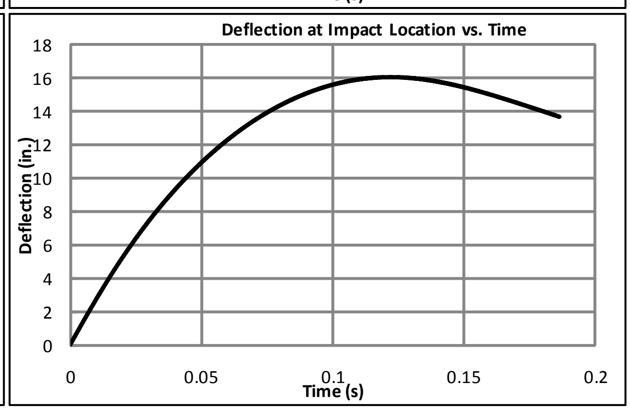


Figure D-13. Results of Test No. MGS221PT-26 (DTS)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information — MGS 2:1 Slope Post Testing

Test Number:	MGS221PT-27	
Test Date:	18-Sep-2009	
Failure Type:	Post rotation in soil and yielding	

Post Properties

Post Type:	Steel	
Post Size:	W6x9	W152x13.5
Post Length:	108.125 in.	274.6 cm
Embedment Depth:	76 in.	193 cm
Orientation:	Strong Axis	

Soil Properties

Gradation:	8132009
Moisture Content:	0.033
Compaction Method:	HE8
Soil Density, γd:	NA

Bogie Properties

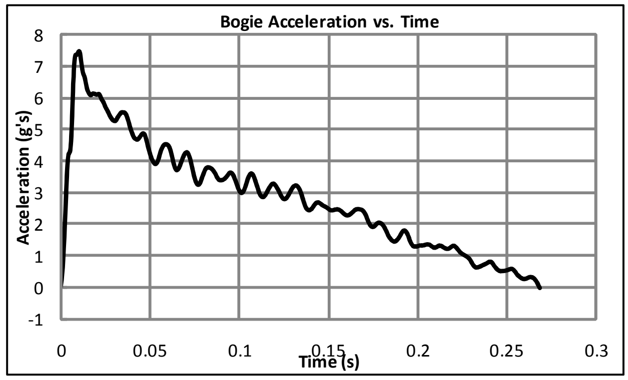
Impact Velocity:	13.67 mph (20 fps)	6.11 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg

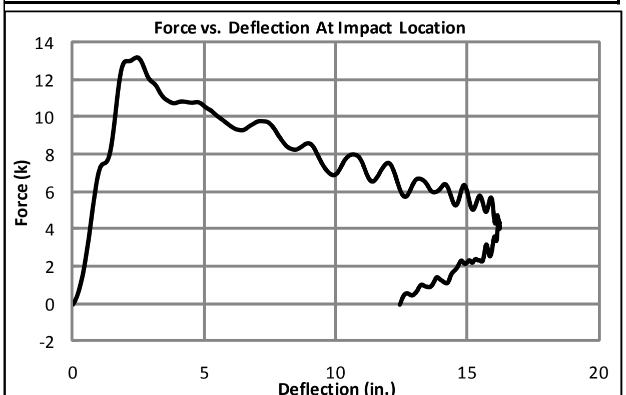
Data Acquired

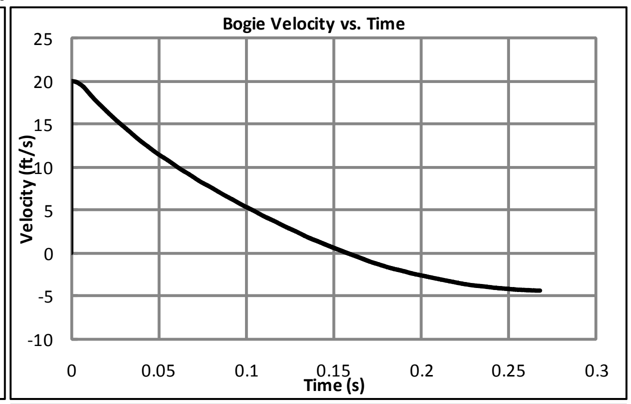
Acceleration Data:	EDR-3
Camera Data:	see field book

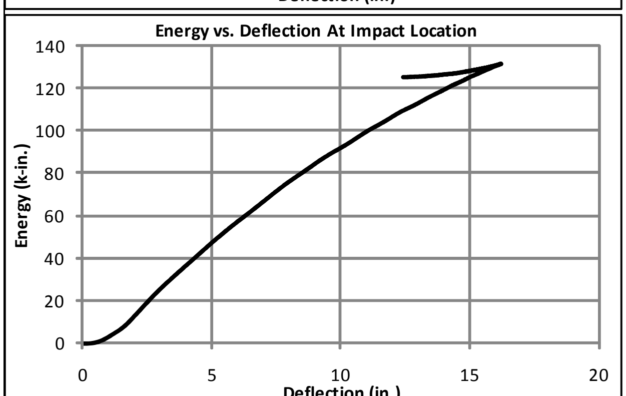
Test Results Summary

Max. Deflection:	16.2	in.
Peak Force:	13.2	k
Initial Linear Stiffness:	5.4	k/in.
Total Energy:	131.8	k-in.









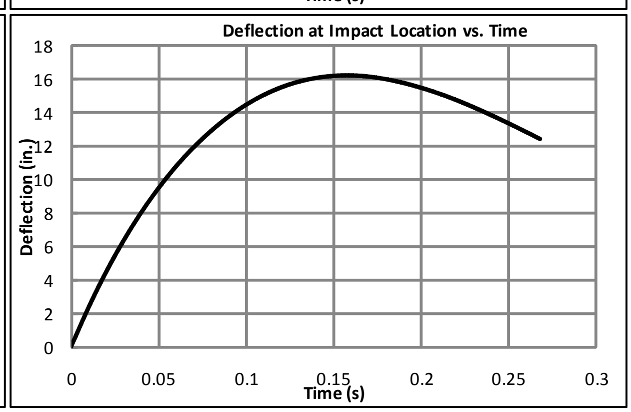


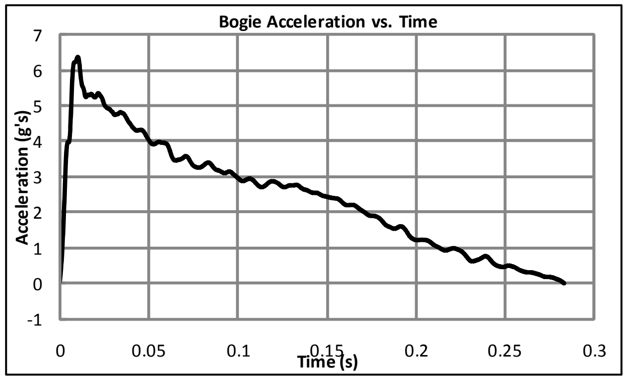
Figure D-14. Results of Test No. MGS221PT-27 (EDR-3)

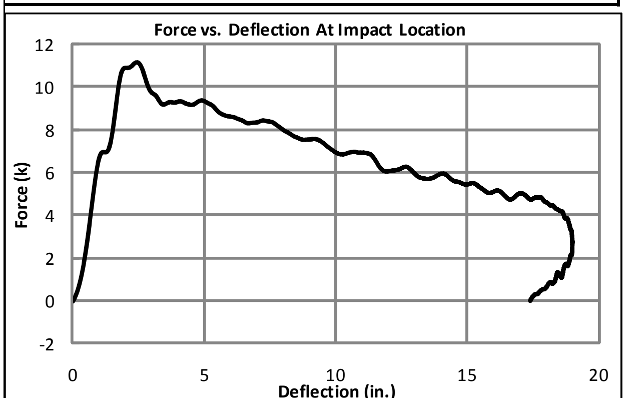
MIDWEST ROADSIDE SAFETY FACILITY

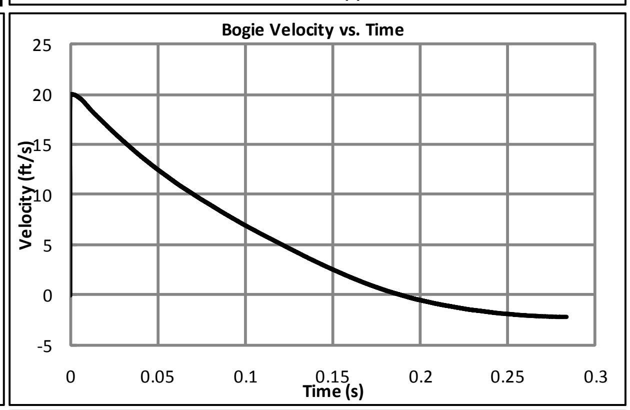
Bogie Test Summary

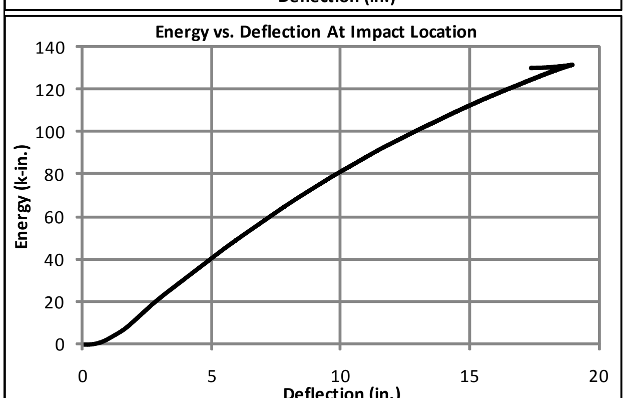
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-27	
Test Date:	18-Sep-2009	
Failure Type:	Post rotation in soil and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.5
Post Length:	108.125 in.	274.6 cm
Embedment Depth:	76 in.	193 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.033	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	13.67 mph (20 fps)	6.11 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	19.0	in.
Peak Force:	11.2	k
Initial Linear Stiffness:	6.8	k/in.
Total Energy:	131.6	k-in.









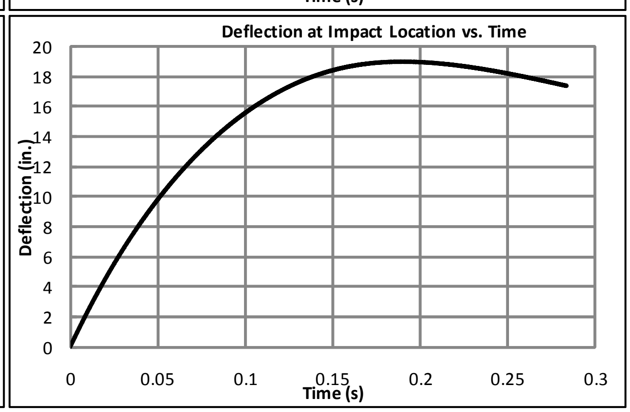


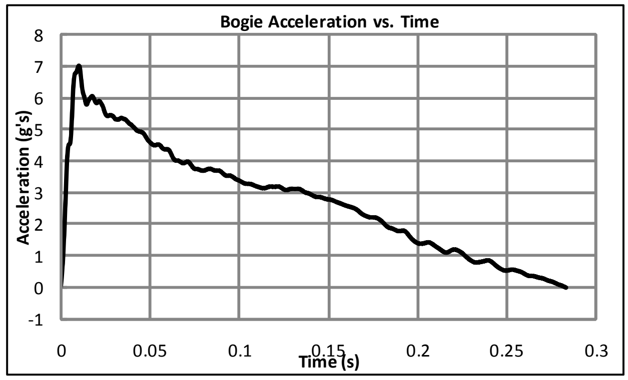
Figure D-15. Results of Test No. MGS221PT-27 (EDR-4)

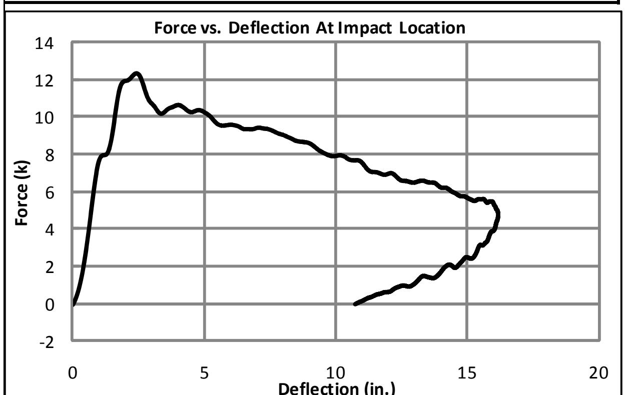
MIDWEST ROADSIDE SAFETY FACILITY

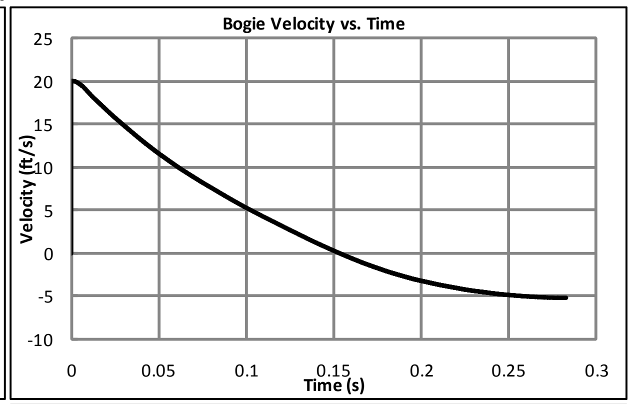
Bogie Test Summary

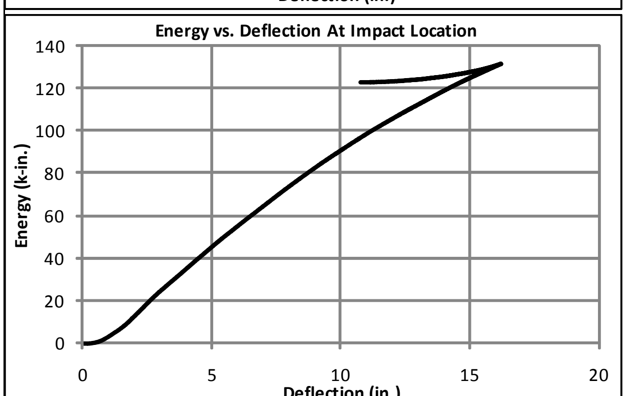
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-27	
Test Date:	18-Sep-2009	
Failure Type:	Post rotation in soil and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	152x203
Post Length:	108.125 in.	274.6 cm
Embedment Depth:	76 in.	193 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.033	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	13.67 mph (20 fps)	6.11 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	16.2	in.
Peak Force:	12.3	k
Initial Linear Stiffness:	5.1	k/in.
Total Energy:	131.6	k-in.









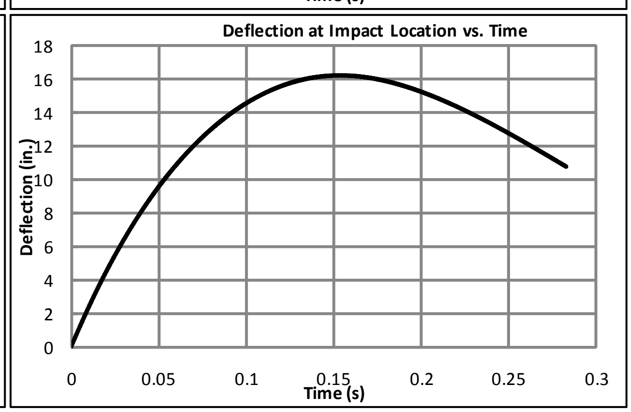


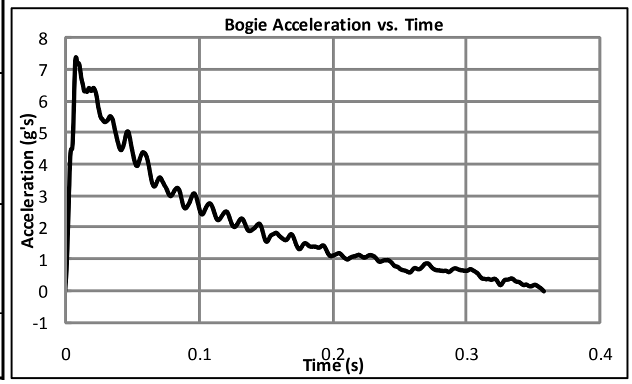
Figure D-16. Results of Test No. MGS221PT-27 (DTS)

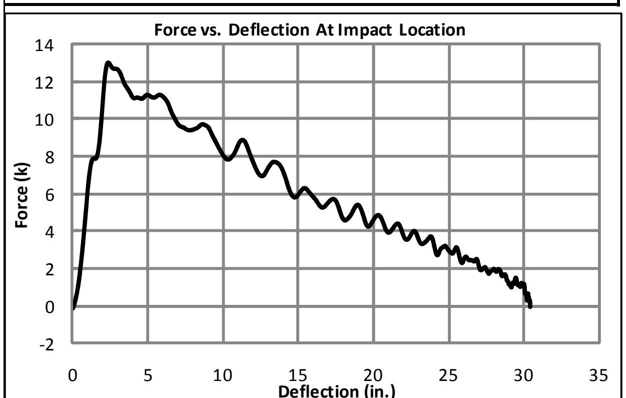
MIDWEST ROADSIDE SAFETY FACILITY

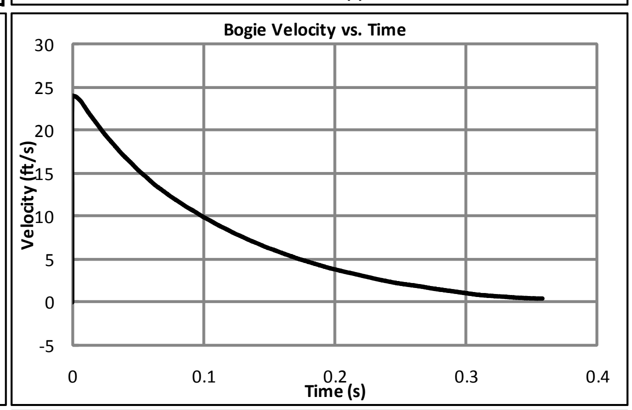
Bogie Test Summary

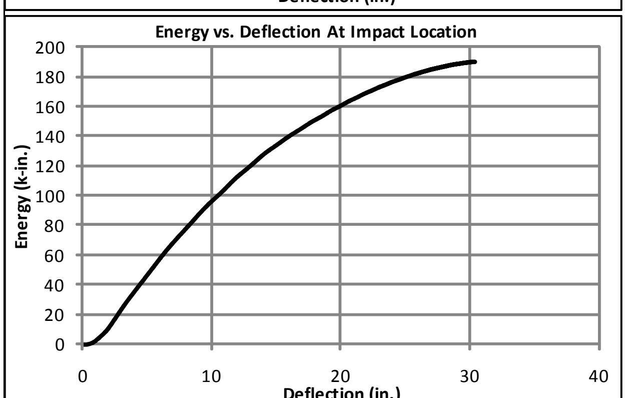
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-28	
Test Date:	18-Sep-2009	
Failure Type:	Post rotation in soil and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.5
Post Length:	108 in.	274.3 cm
Embedment Depth:	76 in.	193 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.033	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	16.4 mph (24 fps)	7.33 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	30.4	in.
Peak Force:	13.0	k
Initial Linear Stiffness:	5.6	k/in.
Total Energy:	189.8	k-in.









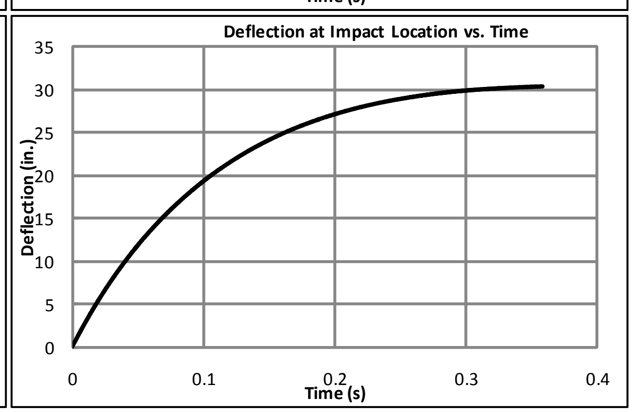


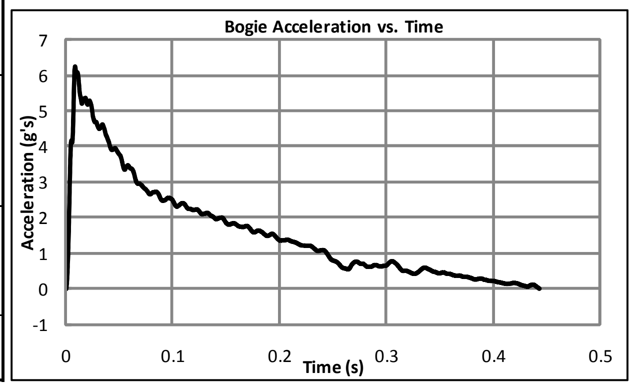
Figure D-17. Results of Test No. MGS221PT-28 (EDR-3)

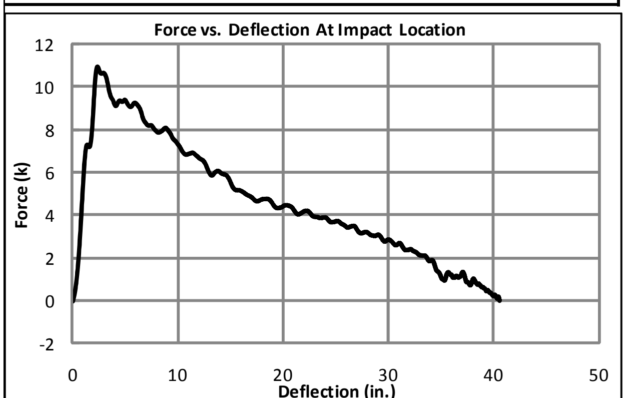
MIDWEST ROADSIDE SAFETY FACILITY

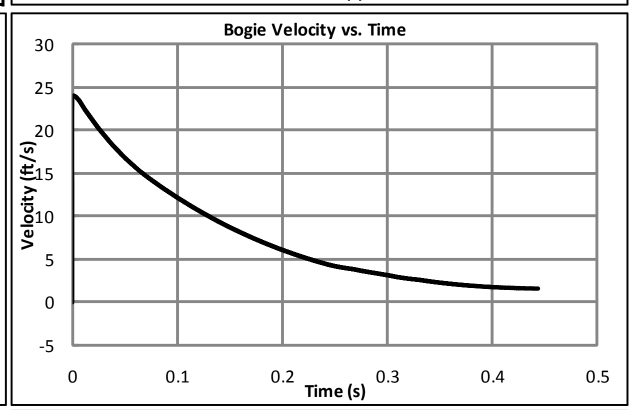
Bogie Test Summary

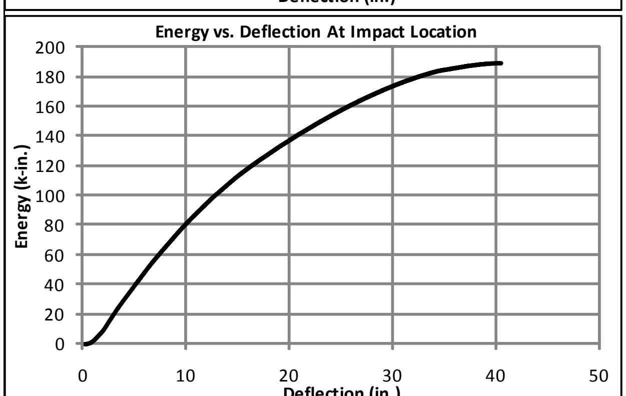
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-28	
Test Date:	18-Sep-2009	
Failure Type:	Post rotation in soil and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.5
Post Length:	108 in.	274.3 cm
Embedment Depth:	76 in.	193 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.033	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	16.4 mph (24 fps)	7.33 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	40.5	in.
Peak Force:	10.9	k
Initial Linear Stiffness:	5.8	k/in.
Total Energy:	188.9	k-in.









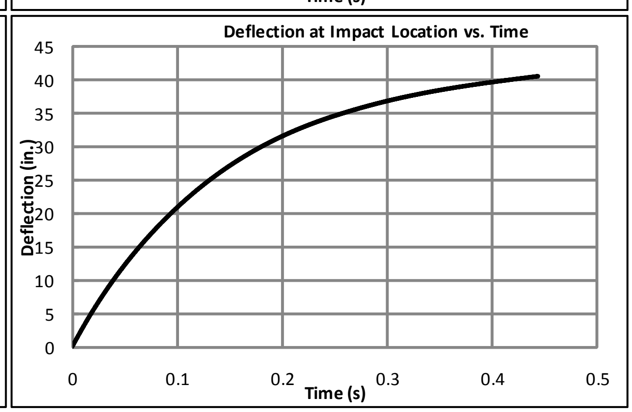


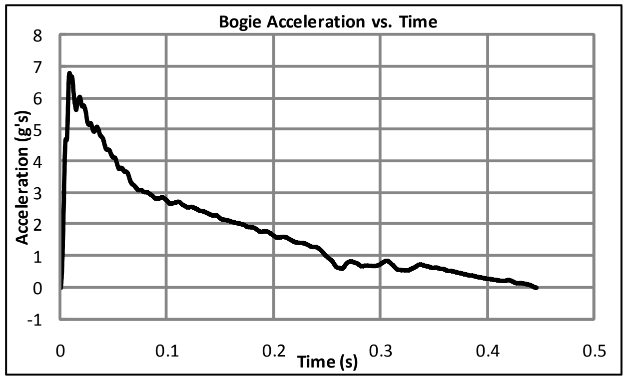
Figure D-18. Results of Test No. MGS221PT-28 (EDR-4)

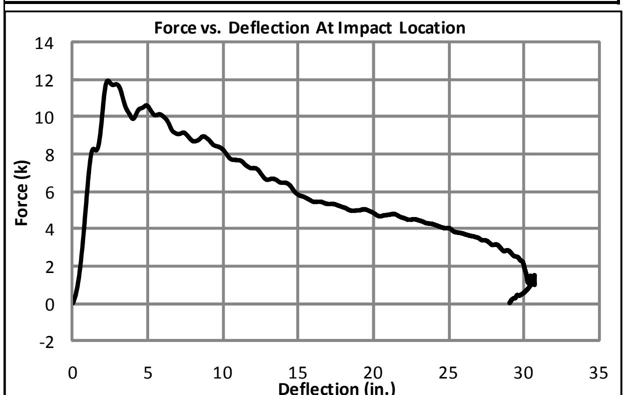
MIDWEST ROADSIDE SAFETY FACILITY

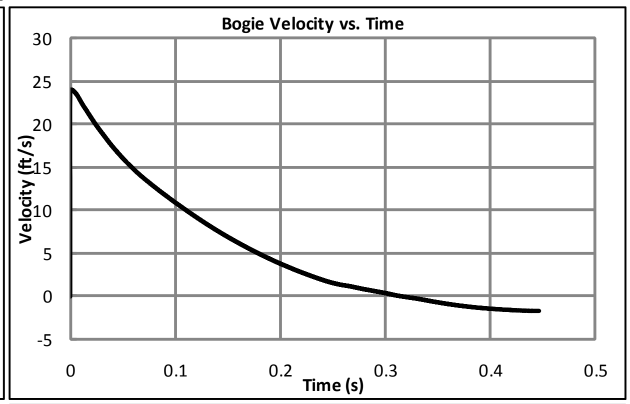
Bogie Test Summary

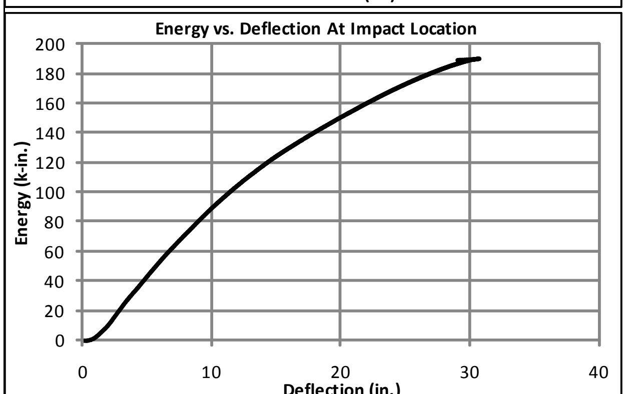
Test Information	MGS 2:1 Slope Post Testing	
Test Number:	MGS221PT-28	
Test Date:	18-Sep-2009	
Failure Type:	Post rotation in soil and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.5
Post Length:	108 in.	274.3 cm
Embedment Depth:	76 in.	193 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	8132009	
Moisture Content:	0.033	
Compaction Method:	HE8	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	16.4 mph (24 fps)	7.33 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1757 lbs	797 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	see field book	

Test Results Summary		
Max. Deflection:	30.7	in.
Peak Force:	11.9	k
Initial Linear Stiffness:	5.1	k/in.
Total Energy:	189.7	k-in.









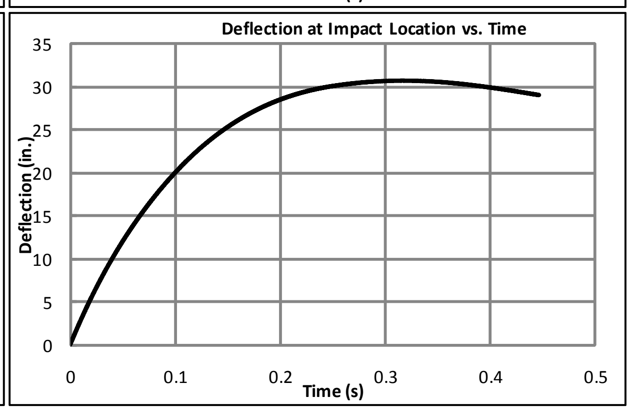


Figure D-19. Results of Test No. MGS221PT-28 (DTS)

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