INVESTIGATION AND DYNAMIC TESTING OF WOOD AND STEEL POSTS FOR MGS ON A WIRE-FACED, MSE WALL

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U.S. Department of Transportation
Federal Highway Administration

CTIP

Federal Lands Highway
Commitment to Excellence

CENTRAL FEDERAL LANDS HIGHWAY DIVISION
12300 WEST DAKOTA AVENUE
Lakewood, CO 80228

FOREWORD

The Federal Lands Highway Division (FLHD) designs and constructs numerous wire-faced, mechanically-stabilized (MSE) walls across the U.S. These MSE walls are utilized to support highways and roadways built on sloped terrain which may carry significant vehicular traffic. The FLHD designs and constructs vehicular barrier systems which are placed within the exterior region of MSE walls. This report contains the research results aimed at the development of economical and crashworthy barrier systems for placement on top of and near the exterior edge of MSE walls.

The objective for this study was to develop an economical barrier system for safely treating vertical drop-offs located at the outside edge of wire-faced, MSE walls. The new barrier system was to be capable of providing acceptable safety performance during high-speed, high-energy passenger car impacts, be easily maintained, and not impart unreasonable damage to the MSE wall system and was to be evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH).

The study included numerous design concepts, significant dynamic component testing to determine post type, length, and placement, and development of a non-blocked version of the MGS with steel posts placed at the slope break point of a 3H:1V fill slope. Full-scale crash testing was successfully used to evaluate the proposed design. TL-3 and TL-2 guidance was provided regarding the placement of a non-blocked, steel-post version of the MGS on wire-faced, MSE walls. The results from this study are recommended for use to update Central Federal Lands highway Division's (CFLHD) Standard Detail C255-50, dated August 18, 2008, regarding semi-rigid barriers installed on welded, wire-face, MSE walls.

F. David Zanetell, P.E., Director of Project Delivery
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Notice

Quality Assurance Statement

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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.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Mr. Robert Bielenberg, Research Associate Engineer

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16. Abstract
This study was performed to support the development of a non-blocked version of the Midwest Guardrail System (MGS) for use on wire-faced, MSE walls. The dynamic post-soil behavior for standard wood and steel posts placed in various soils with sloped and level terrain and using different installation methods was investigated. A total of twenty-six dynamic component tests were performed within four distinct rounds of testing - two tests conducted at 25 mph (40 km/h), twenty tests conducted at 20 mph (32 km/h), and four tests conducted at 15 mph (24 km/h). Dynamic testing was performed on 6-in. x 8-in. (152-mm x 203-mm) wood posts as well as on W6x8.5 (W152x12.6), W6x9 (W152x13.4), and W6x16 (W152x23.8) steel posts. The posts were embedded in strong soil conforming to AASHTO Grading B for all tests except one, in which the post was embedded in larger wall-facing limestone rock material. For each bogie test, force versus deflection and energy versus deflection curves were prepared. From this component testing program, a non-blocked version of the MGS with W-beam backup plates was recommended for installation, crash testing, and evaluation using 6-ft (1.8-m) long, W6x8.5 (W152x12.6) or W6x9 (W152x13.4) steel posts driven at the slope break point of a 3H:1V fill slope adjacent to and on top of an MSE wall.

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ROADSIDE SAFETY, WOOD POSTS, STEEL POSTS, GUARDRAIL POSTS, BOGIE TESTING, IMPACT TESTING, MSE WALL, WIRE-FACED, FILL SLOPE, AND MGS	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short ton (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE & PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	ac
km	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or “metric ton”)	1.103	short ton (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE & PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
AOS	AOS Technologies AG
ASTM	American Society for Testing and Materials
B.S.B.A.	Bachelor of Science in Business Administration
B.S.M.A.	Bachelor of Science in Management Accounting
CFL	Central Federal Lands
CFLHD	Central Federal Lands Highway Department
cm	centimeter
DM-1	DynaMax 1
DOT	Department of Transportation
DTS	Diversified Technical Systems, Incorporated
EDR	Event Data Recorder
E.I.T.	Engineer in Training
FHWA	Federal Highway Administration
FLHD	Federal Lands Highway Division
fps	feet per second
ft	foot
ft/s	feet per second
g	gram
h	hour
H	Horizontal
HE8	high-energy, 8 inch lift compaction method
hr	hour
Hz	Hertz
IAA	Independent Approving Authority
in.	inch
IST	Instrumented Sensor Technology, Incorporated
J	Joule
JVC	Victor Company of Japan, Limited
kB	kilobyte
kg	kilogram
kip-in	thousand pounds-force inches
kips	thousand pounds-force
kJ	kilojoules
km	kilometer
km/h	kilometer per hour
kN	kilonewton
lb	pound(s)
m	meter
m/s	meter per second
MASH	Manual for Assessing Safety Hardware
MB	megabyte

MGS	Midwest Guardrail System
mm	millimeter
mph	miles per hour
M.S.C.E.	Master of Science in Civil Engineering
MSE	Mechanically Stablized Earth
M.S.M.E.	Master of Science in Mechanical Engineering
MwRSF	Midwest Roadside Safety Facility
N	Newton
NA	not applicable
NCHRP	National Cooperative Highway Research Program
No.	Number
P.E.	Professional Engineer
Ph.D.	Doctor of Philosophy
RAM	random-access memory
s	second
SAE	Society of Automotive Engineers
sec	second
SIM	Sensor Input Module
SRAM	static random access memory
SYP	Southern Yellow Pine
TL	Test Level
U.S.	United States
V	Vertical
vs.	versus
‘	foot
“	inch
%	percent

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EXECUTIVE SUMMARY

Wire-faced, mechanically-stabilized earth (MSE) walls provide an economical method for constructing vertical structures for supporting roadways where local topography or high land costs preclude the use of conventional fill slopes. While an economical solution for slope stability, MSE walls create safety issues by producing deep vertical drop-offs adjacent to the roadway. For years, the Federal Lands Highway Division (FLHD) has designed and constructed a large number of MSE walls across the United States (U.S.). The accepted practice has been to install the face of conventional, wood-post W-beam guardrail nearly 10 ft (3.0 m) away from the exterior face of an MSE wall, when considering 2 ft (0.6 m) of level surface behind the posts, an adjacent 3H:1V fill slope, and a 2-ft (0.6-m) fill height. Thus, it became desirable to place the barrier systems closer to the exterior edge of the MSE wall. Unfortunately, no methods were currently available for anchoring these barriers at or near the exterior face.

The primary research objective for this study was to develop an economical barrier system for safely treating vertical drop-offs located at the outside edge of wire-faced, MSE walls. During high-speed, high-energy impacts with passenger vehicles, the new barrier system should not impart unreasonable damage to the MSE wall system. The new barrier system should be easily maintained without requiring extensive repairs to the MSE wall structure. Several design concepts were considered for a new barrier system positioned closer to the exterior edge of wire-faced, MSE walls. The standard MGS along with its design variations were also considered. The new or modified barrier system was to be evaluated according to the Test Level 3 (TL-3) safety performance criteria set forth in the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH).

For this study, the Midwest Guardrail System (MGS) was extensively reviewed and considered for use in shielding the vertical drop-offs associated for MSE walls. From a review, the MGS was shown to provide acceptable safety performance when used for shielding wide, transverse culvert structures as well as fill slopes as steep as 2H:1V.

Multiple design concepts were considered for treating vertical drop-offs at the exterior face of wire-faced, MSE wall. As part of the brainstorming and selection process, several factors were considered, including: (1) control of overall project costs; (2) environmental impacts; (3) use of an economical barrier system; (4) concerns for MSE wall damage; (5) use 3H:1V fill slope at the top outer edge of MSE wall; (6) use of beam and post barriers for aesthetics; (7) constructability, maintenance, and repair of barrier system; and (8) approximate dynamic deflection and assumed vehicle trajectory for high-speed, high-energy vehicular impacts into semi-rigid guardrail systems. After considering concerns for constructability and repair, those barrier systems with deeply-embedded reinforced concrete foundations in combination with tension elements were eliminated from further investigation and comparison. Later, five design concepts were subjected to a basic cost analysis and system comparison. Following this effort, the project team chose to further develop a non-blocked version of the MGS with the posts placed at the slope break point of a 3H:1V fill slope.

Dynamic component testing was utilized to determine the post-soil behavior of steel and wood posts embedded in compacted, soil materials used for constructing wire-faced, MSE walls as well as to evaluate the effects of sloped terrain and different installation methods. Twenty-six dynamic tests were performed to evaluate the propensity for MSE wall damage, select post length, and determine post material and section. Following the post testing program, a non-blocked version of the MGS was recommended for evaluation within a crash testing program using: (1) steel W-beam backup plates; (2) 6-ft (1.8-m) long posts manufactured from either W6x8.5 (W152x12.6) or W6x9 (W152x13.4) steel sections; (3) posts driven at the slope break point of a 3H:1V fill slope adjacent to and on top of a wire-faced, MSE wall; and (4) posts installed using a 40-in. (1,016-mm) embedment depth. All other MGS features were maintained, including, rail splices at mid-span locations, 31-in. (787-mm) top mounting height, and 75-in. (1,905-mm) post spacing.

A full-size, MGS and MSE wall system was constructed for testing and evaluation. The non-blocked MGS was constructed with the back side of the steel posts positioned approximately 2 ft – 9 in. (0.84 m) away from the inside edge of the wall facing fill or 5 ft – 9 in. (1.75 m) away from the outer edge of the wire-faced, MSE wall. The modified MGS system was crash tested successfully using the 1100C small car and 2270P pickup truck vehicles according to the Test Level 3 (TL-3) safety performance guidelines provided in MASH. In both crash tests, no damage was observed in the MSE wall system. As a result of the extensive dynamic component testing and full-scale vehicle crash testing programs, the non-blocked MGS was recommended for use with wire-faced, MSE walls when placed at the slope break point of a 3H:1V fill slope. The modified MGS reduces the required width of the MSE wall, thus resulting in decreased construction costs.

For this research study, the test results and findings are contained in two different reports. The first report contains the design review of the MGS, design considerations, a summary of the dynamic component testing program, details for the MGS and MSE wall systems, the MASH full-scale crash testing requirements, results from the two full-scale crash tests, as well as a project summary, overall conclusions, and recommendations. This report (TRP-03-235-11) is entitled, "*Development of an Economical Guardrail System for Use on Wire-Faced, MSE Walls*." The second report contains the procedures utilized for the dynamic bogie testing program, results from the 26 dynamic post tests, as well as a post testing summary with conclusions and recommendations specific to the component testing program. This report (TRP-03-231-11) is entitled, "*Investigation and Dynamic Component Testing of Wood and Steel Posts for MGS on a Wire-Faced, MSE Wall*."

Following the completion of the research program noted above, MwRSF researchers also determined the minimum lateral barrier offset for wire-faced MSE wall systems which utilize a 3H:1V fill slope. For non-blocked MGS systems, the back side of steel posts are recommended to be placed a minimum of 1 ft (0.30 m) away from the inside edge of the wall facing fill or 4 ft (1.22 m) away from the outer edge of the MSE wall, whichever results in the largest lateral offset between the post and exterior wall face. For this recommendation, the minimum lateral offset between the rail face and outer edge of the MSE wall would be 4 ft – 9 ¼ in. (1.45 m). For varying thickness of select wall backfill and different widths for the 3H:1V fill slope, three different configurations were prepared to demonstrate the recommended guidance regarding the minimum lateral offset for the steel posts, as shown in Figures ES-1 through ES-3. This design guidance is suitable for use under both TL-2 and TL-3 roadside applications.

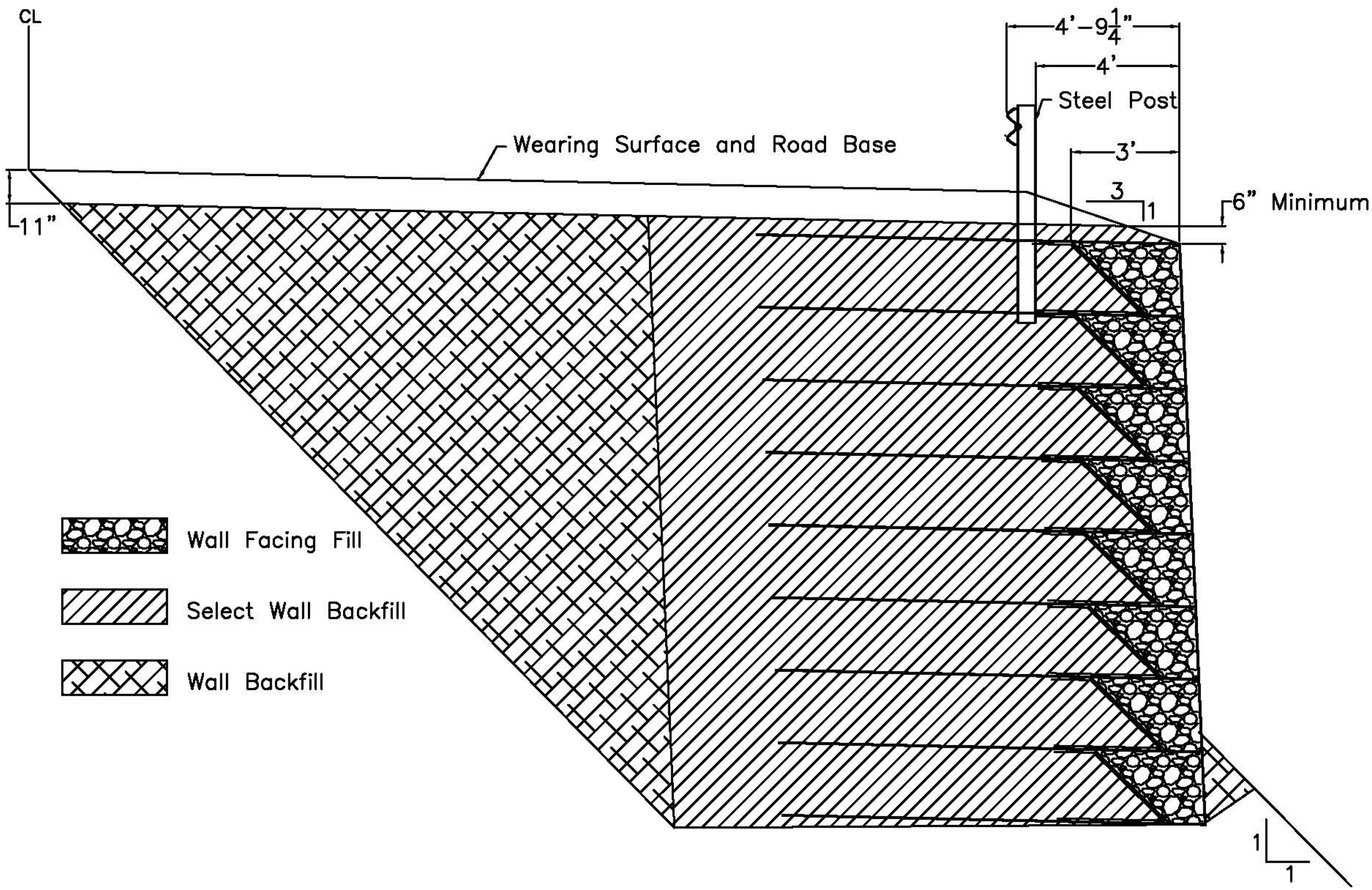


Figure ES-1. Schematic. Non-Blocked, Steel-Post MGS Centered at Slope Break Point with Minimum Lateral Offset.

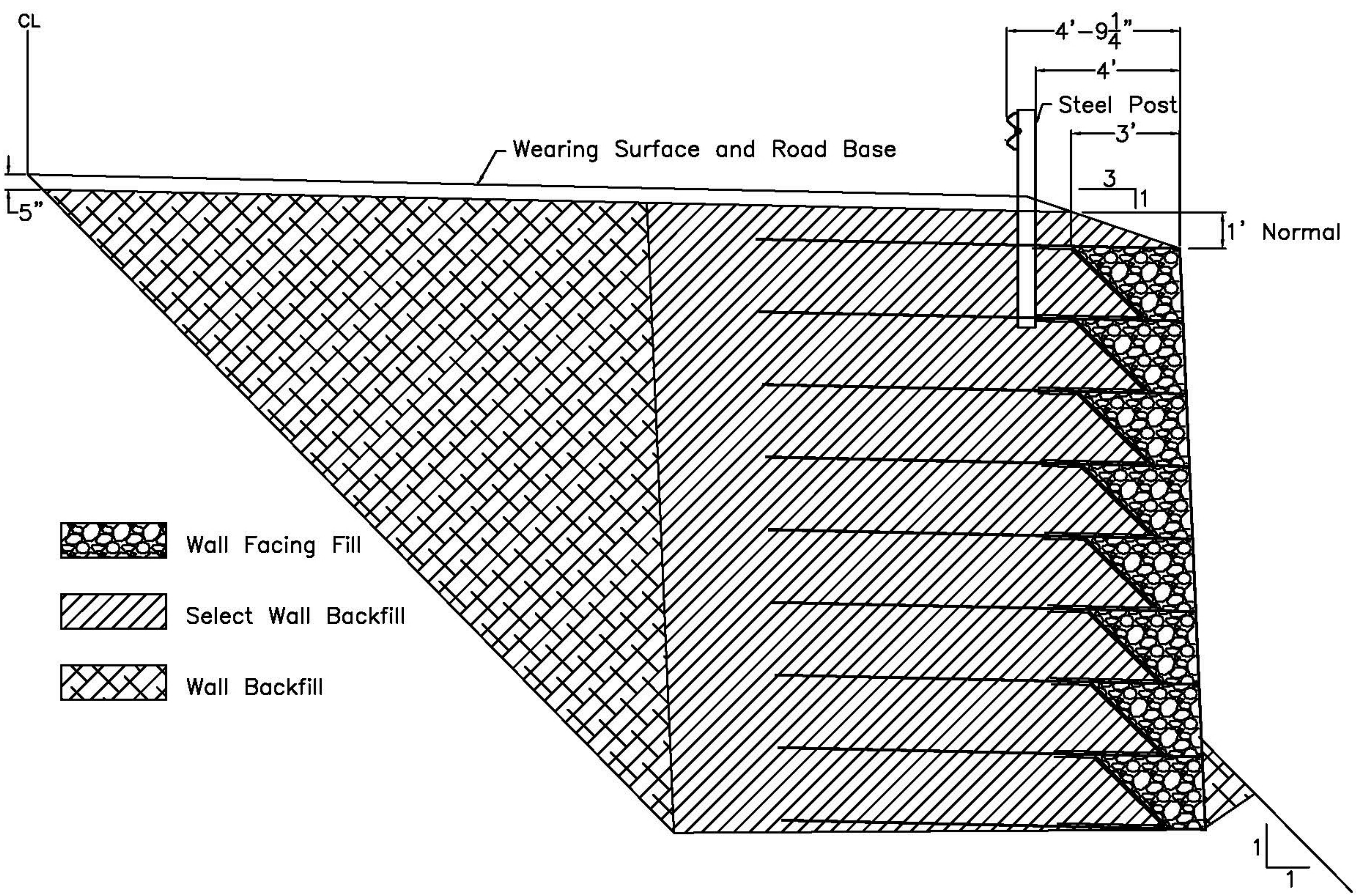


Figure ES-2. Schematic. Non-Blocked, Steel-Post MGS Centered at Slope Break Point with Minimum Lateral Offset.

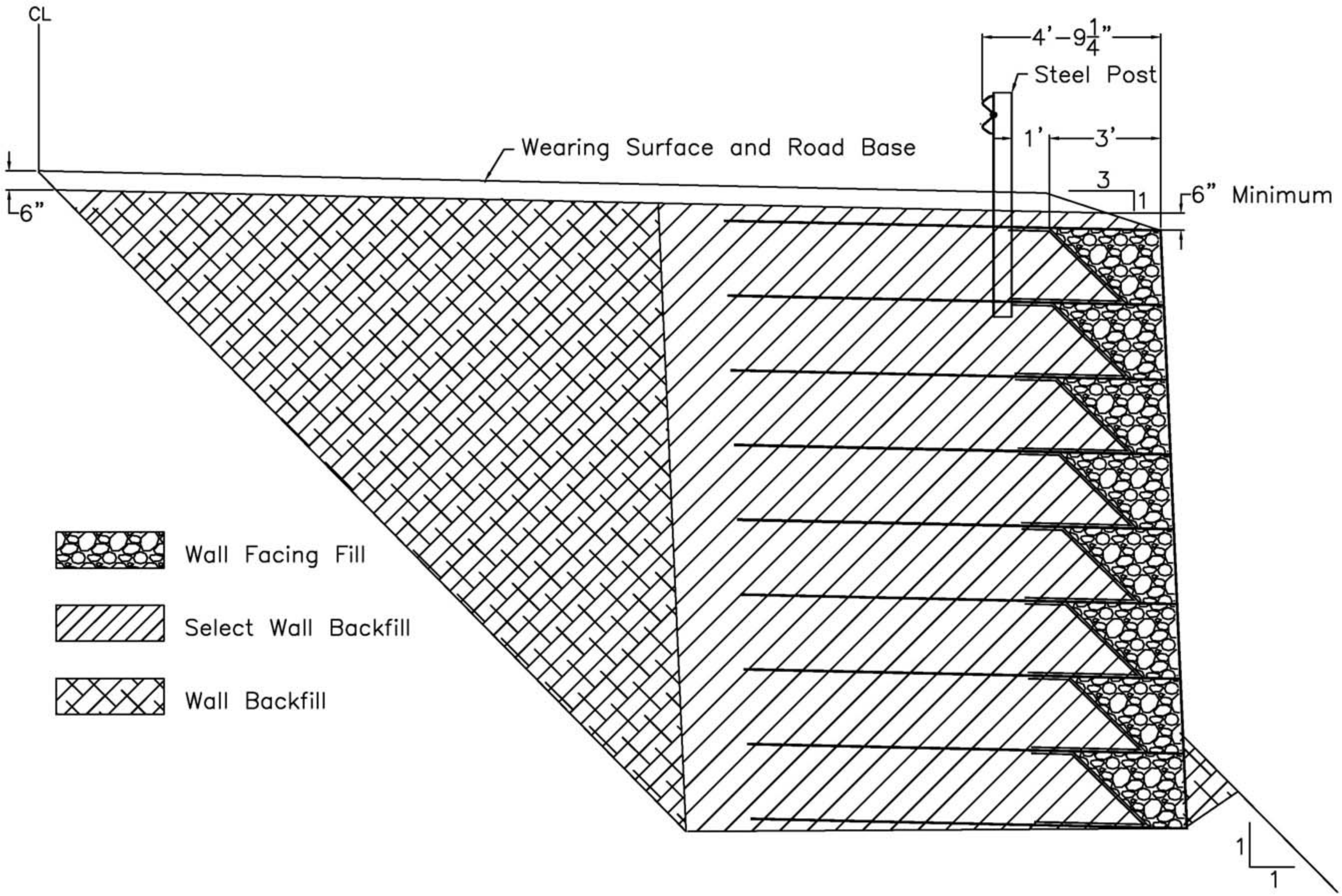


Figure ES-3. Schematic. Non-Blocked, Steel-Post MGS with Minimum Lateral Offset.

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

In 2007, the Federal Highway Administration (FHWA) and the Midwest Roadside Safety Facility (MwRSF) began an effort to develop an economical, longitudinal barrier system for placement on a wire-faced, MSE wall. As part of this system development, it was deemed necessary to evaluate the effect that varying soil gradations, terrain slopes, embedment depths, installation methods, and post material types had on guardrail post performance, including lateral stiffness, strength, and energy dissipation. Therefore, an extensive dynamic testing program was conducted to study and evaluate these parameters.

1.2 OBJECTIVE

The objective of this research project was to determine the dynamic post-soil behavior for standard wood and steel posts placed in various soils with sloped and level terrain and using different installation methods. This study utilized a 24⅞-in. (632-mm) impact height, which is the center height of the rail for the Midwest Guardrail System (MGS), and various post embedment depths. Once completed, the test results can be used: (1) for comparison to those results obtained from prior dynamic testing studies of standard posts placed in compacted soil; (2) to determine the correct barrier placement, embedment depth, and fill material for the MGS installed on a wire-faced, MSE wall; and (3) to provide dynamic test data for modeling post-soil behavior within BARRIER VII computer simulations of vehicle-to-barrier impacts. [1,2]

1.3 RESEARCH APPROACH

Four rounds of dynamic testing were performed to achieve the research objective. For the first round of dynamic testing, wood posts were embedded in various soils and impacted at different impact speeds. The soil material was placed using moderate compaction, as used in previous testing efforts of W6x9 (W152x13.4) steel posts. For the second round of testing, both steel and wood posts were evaluated when embedded in strong soil conforming to AASHTO designation M147-65 (1990) Grading B, as described in the National Cooperative Highway Research Program (NCHRP) Report No. 350. [3] The soil material was placed using a high-energy compaction method with 6-in. (152-mm) lifts (HE6). These tests were performed to compare the dynamic behavior and post-soil resistance for wood and steel posts installed in dense, strong soils. For the third round of testing, both steel and wood posts were installed at the slope break point of a 3H:1V fill slope. The majority of posts were installed using a high-energy, 8-in. (203-mm) lift compaction method (HE8) combined with back-filled and tamped soil surrounding each post. However, one post was installed using the driven method. These tests were used to evaluate the affect that slope and installation method had on post rotation, stiffness, and strength. The fourth round of testing was used to confirm the dynamic behavior of a steel post driven at the slope breakpoint of a 3H:1V fill slope located on an actual wire-faced, MSE wall.

CHAPTER 2. LITERATURE REVIEW

2.1 PRIOR WOOD POST TESTING

Numerous testing and evaluation studies have been performed on 6-in. x 8-in. (152-mm x 203-mm) southern yellow pine (SYP) wood guardrail posts embedded in soil as well as placed in rigid frame foundations. In 2007, Hascall et al. reviewed and summarized the previous post studies completed from 1960 through 2004. [4] However, no prior research studies were found that involved the dynamic component testing of 6-in. x 8-in. (152-mm x 203-mm) wood posts using a 24⅞-in. (632-mm) impact height, a 40-in. (1,016-mm) embedment depth, and placed in soil conforming to AASHTO designation M147-65 (1990) Grading B, as described in the National Cooperative Highway Research Program (NCHRP) Report No. 350. [3]

In Hascall et al., two tests were conducted on 6-in. x 8-in. (152-mm x 203-mm) wood posts with a 24⅞ in. (632-mm) impact height. The wood posts were embedded 37 in. (940 mm) and 40 in. (1,016 mm) in test nos. RWP-1 and RWP-2, respectively. Both posts were embedded in strong soil conforming to AASHTO Grading B and impacted by a bogie vehicle at an angle of 0 degrees, creating a classical “head-on” or full frontal impact and strong-axis bending. Test results are summarized in Table 1 and shown graphically in Figures 1 and 2.

Since only one dynamic component test was conducted on a 6-in. x 8-in. (152-mm x 203-mm) SYP wood post with a 40-in. (1,016-mm) embedment depth and a 24⅞-in. (632-mm) impact height, additional testing was deemed necessary to verify the performance of wood posts placed in strong soil, other soils, and on fill slopes.

Table 1. Test Results for 6-in. x 8-in. SYP Wood Posts.[4]

Test No.	Embedment Depth in. (mm)	Impact Speed mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
RWP-1	37 (940)	25.9 (41.7)	20.2 (89.9)	2.0 (50)	8.6 (38.0)	8.4 (37.5)	250.6 (28.3)	42.5 (1,080)	Rotation in Soil
RWP-2	40 (1,016)	25.2 (40.6)	17.5 (77.9)	2.1 (52)	11.3 (50.1)	11.8 (52.4)	362.9 (41.0)	37.6 (956)	Rotation in Soil

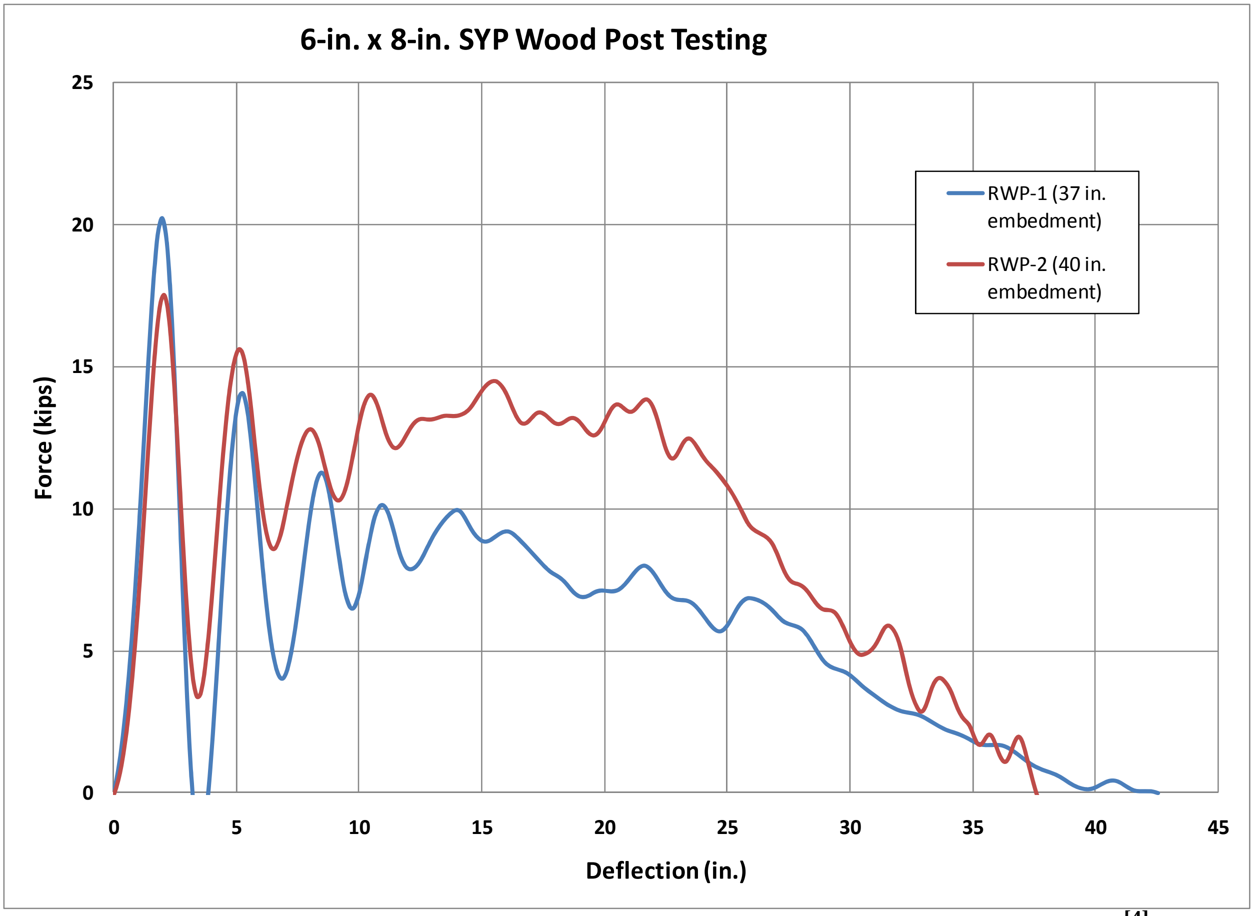


Figure 1. Graph. Force vs. Deflection, 6-in. x 8-in. SYP Wood Post Testing.[4]

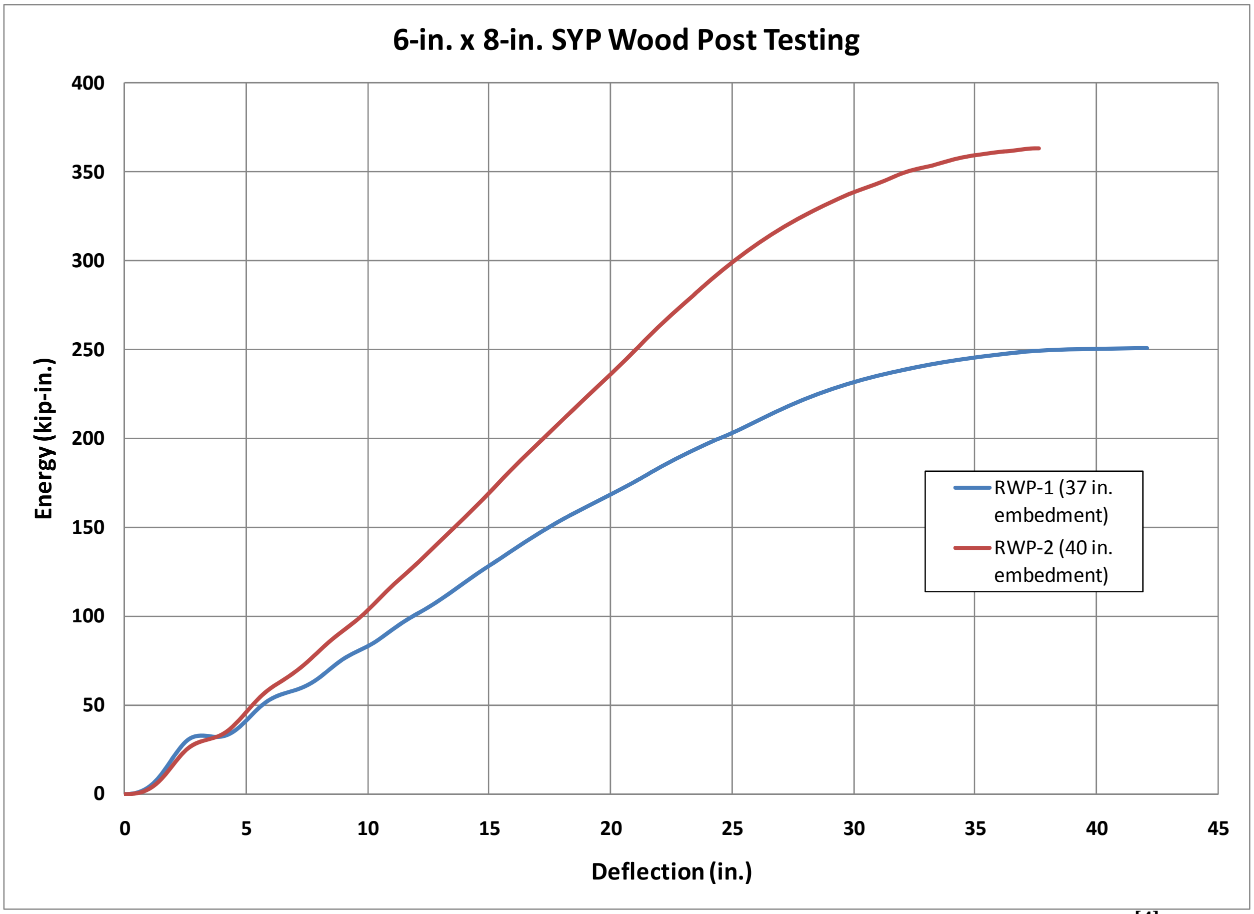


Figure 2. Graph. Energy vs. Deflection, 6-in. x 8-in. SYP Wood Post Testing.[4]

2.2 PRIOR STEEL POST TESTING

In 2003, Kuipers et al. evaluated the dynamic soil resistance of W6x16 (W152x23.8) steel posts embedded in strong soil with embedment depths of 40 in. (1,016 mm).[5] The posts were impacted at a height of 24⅞ in. (632 mm) and at an angle of 0 degrees, creating a classical "head-on" or full frontal impact and strong-axis bending. Test results are summarized in Table 2 and shown graphically in Figures 3 and 4.

In 2007, Dey et al. conducted four tests on W6x9 (W152x13.4) steel posts installed on flat terrain with strong soil conforming to AASHTO Grading B with a 40-in. (1,016-mm) embedment depth.[6] All four posts were impacted at a height of 24⅞ in. (632 mm). The target impact speeds were 15 mph (24.1 km/h) for test nos. MGS2-1B18 and MGS2-1B19 and 20 mph (32.2 km/h) for test nos. MGS2-1B20 and MGS2-1B21. All tests were conducted at an angle of 0 degrees, creating a classical "head-on" or full frontal impact and strong-axis bending. Test results are summarized in Table 3 and shown graphically in Figures 5 and 6.

Table 2. Test Results for W6x16 Steel Posts.[5]

Test No.	Embedment Depth in. (mm)	Impact Velocity mph (km/h)	Peak Force		Maximum Deflection in. (mm)	Total Energy kip-in. (kJ)	Failure Type
			Deflection in. (mm)	Force kips (kN)			
NPGB-2	40 (1,016)	21.0 (33.8)	2.2 (556)	8.3 (36.8)	45.4 (1,153)	258.0 (29.2)	Rotation in Soil
NPGB-4	40 (1,016)	20.0 (32.2)	2.2 (556)	11.9 (52.8)	43.0 (1,092)	257.9 (29.1)	Rotation in Soil
NPGB-9	40 (1,016)	20.8 (33.4)	2.2 (548)	13.1 (58.0)	48.1 (1,222)	258.1 (29.2)	Rotation & Post Yielding
NPGB-10	40 (1,016)	21.5 (34.6)	2.4 (597)	14.1 (62.9)	46.7 (1,186)	281.2 (31.8)	Rotation & Post Yielding

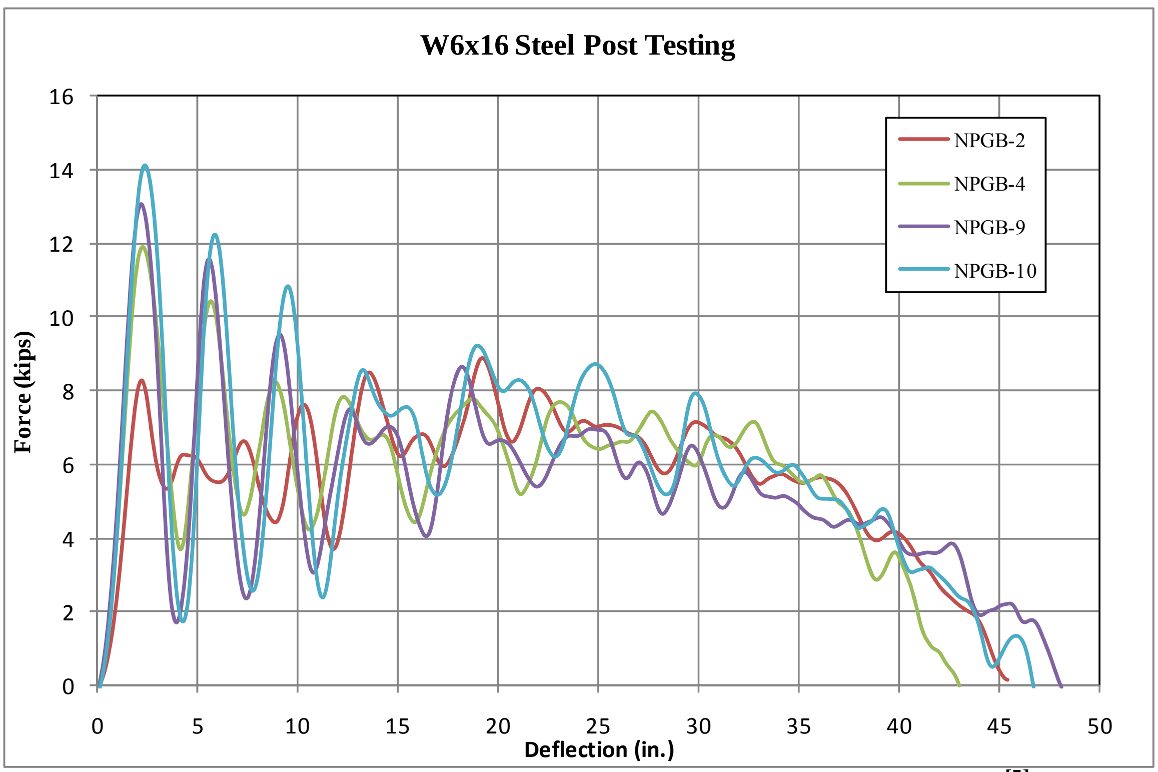


Figure 3. Graph. Force vs. Deflection, W6x16 Steel Post Testing.[5]

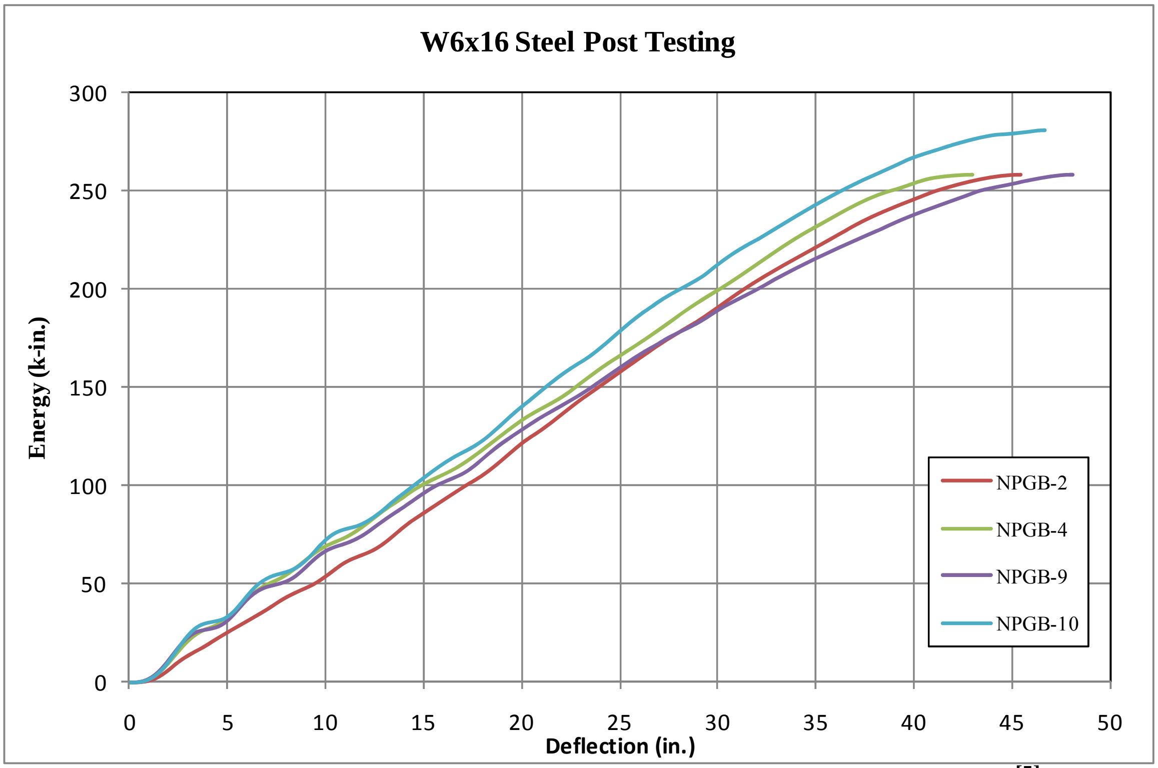


Figure 4. Graph. Energy vs. Deflection, W6x16 Steel Post Testing.[5]

Table 3. Test Results of W6x9 Steel Posts.[6]

Test No.	Embedment Depth in. (mm)	Impact Velocity mph (km/h)	Peak Force		Maximum Deflection in. (mm)	Total Energy kip-in. (kJ)	Failure Type
			Deflection in. (mm)	Force kips (kN)			
MGS2-1B18	40 (1,016)	15.4 (24.8)	20.2 (513)	9.1 (40.7)	21.7 (550)	152.9 (17.3)	Rotation in Soil
MGS2-1B19	40 (1,016)	15.9 (25.6)	19.3 (490)	8.7 (38.8)	24.7 (628)	163.2 (18.4)	Rotation in Soil
MGS2-1B20	40 (1,016)	19.3 (31.1)	1.5 (38)	10.0 (41.8)	34.3 (871)	235.3 (26.6)	Rotation in Soil
MGS2-1B21	40 (1,016)	19.8 (31.9)	2.0 (51)	9.8 (43.5)	37.5 (953)	213.4 (24.1)	Rotation in Soil

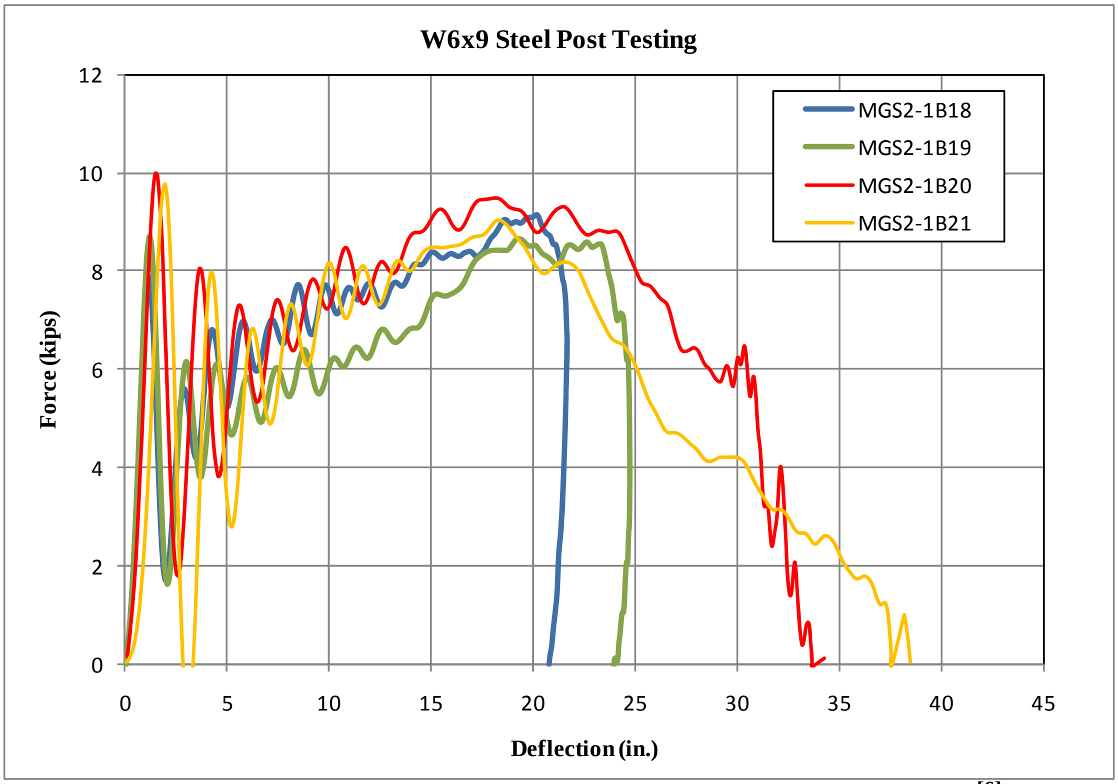


Figure 5. Graph. Force vs. Deflection, W6x9 Steel Post Testing.[6]

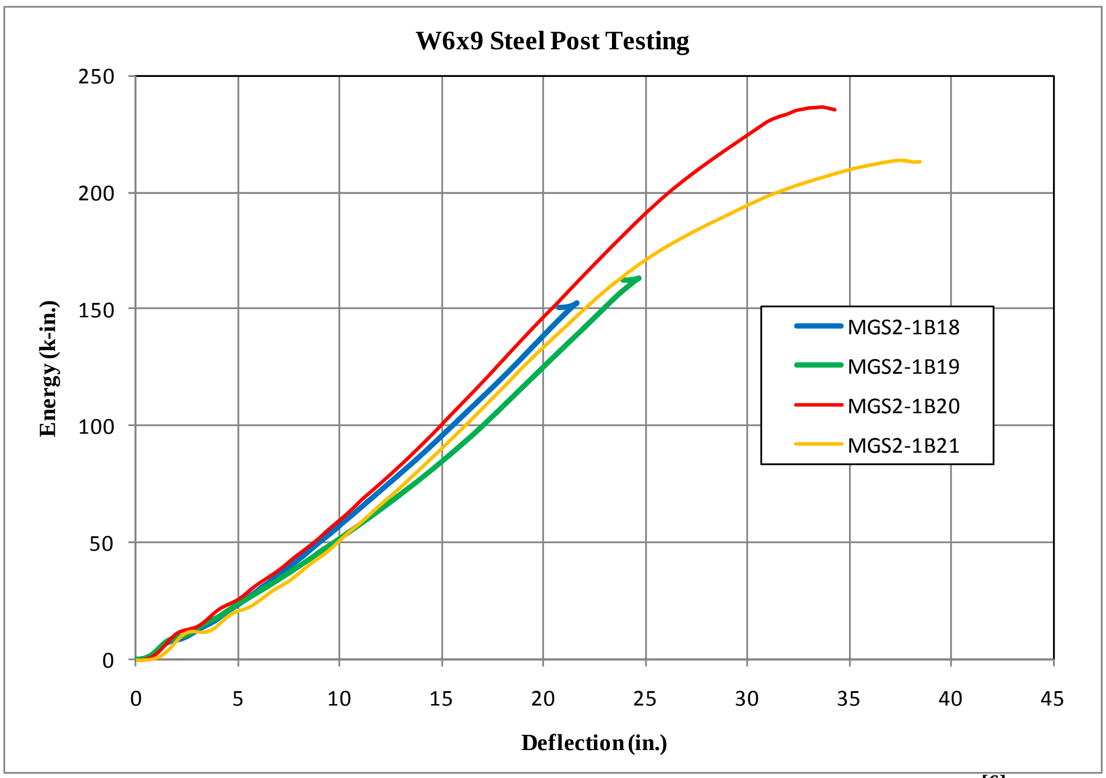


Figure 6. Graph. Energy vs. Deflection, W6x9 Steel Post Testing.[6]

CHAPTER 3. TEST CONDITIONS

3.1 TEST FACILITY

Physical testing of the various posts was conducted at the MwRSF outdoor 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

Various types of equipment and instrumentation were utilized to conduct, collect, and record data for the dynamic post 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 using 8-in. (203-mm) diameter, ½-in. (13-mm) thick standard steel pipe, with ¾-in. (19-mm) neoprene belting wrapped around the pipe. The neoprene material was used to prevent the impact head from causing local damage to the post and to prevent large spikes in acceleration. The impact head was bolted to the bogie vehicle, creating a rigid frame with an impact height of 24⅞ in. (632 mm). The bogie and attached impact head are shown in Figure 7. The weight of the bogie with the addition of the mountable impact head varied for the tests. The bogie vehicle weight for each test is shown on the individual test summaries provided in Appendix A.

For test nos. GWB-1 through GWB-15, GWR4-1, and GWR5-1 through GWR5-4, a pickup truck with a reverse cable tow system was used to propel the bogie to the target impact speed. When the bogie reached 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, thus allowing it to be brought safely to rest after the test. This setup is shown in Figure 7.

Test nos. GWBR5-1 through GWBR5-6 were conducted using a steel corrugated B-beam guardrail to guide the left-side tires of the bogie, as shown in Figure 8. The B-beam is also along the targeted impact angle. A pickup truck is used to push the bogie to the required impact velocity. As the bogie reaches the end of the guide track, the pickup truck releases and allows the bogie to be "free wheeling" as it exits the guide track and impacts the test article. A remote braking system was installed on the bogie allowing it to be brought safely to rest after the test.

Figure 7. Photo. Rigid Frame Bogie on Pipe Guide Track System.

Figure 8. Photo. Rigid Frame Bogie on Corrugated Beam.

3.2.2 Accelerometers

For each test, two accelerometers were mounted on the bogie vehicle near its center of gravity to measure the acceleration in the longitudinal direction.

The first accelerometer, Model EDR-3, was a triaxial piezoresistive accelerometer system 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 analyzed and plot the accelerometer data.

For test nos. GWB-1 through GWB-5 and GWBR5-1 through GWBR5-6, the second 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.

For test nos. GWB-6 through GWB-14, GWR4-1, and GWR5-1 through GWR5-4, the second accelerometer 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.

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 impact. As the 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. For test nos. GWB-1 through GWB-15, GWR4-1, and GWR5-1 through GWR5-4, the right-front tire was used to trigger the tape switches. For test nos. GWBR5-1 through GWBR5-6, the left-front tire was used to trigger the tape switches.

3.2.4 Digital Cameras

One AOS VITcam high-speed digital video camera and two JVC digital video cameras were used to document test nos. GWB-1 through GWB-4, GWB-6 through GWB-11, and GWB-13 through GWB-15. One AOS X-PRI high-speed digital video camera and 2 JVC digital video cameras were used to document test nos. GWB-5, GWB-12, GWR4-1, and GWBR-2 through GWBR-6. One AOS X-PRI high-speed digital video camera and 1 JVC digital video camera were used to document test nos. GWR5-1 through GWR5-4. Two AOS X-PRI high-speed digital video cameras and two JVC digital video cameras were used to document test nos. GWBR5-1 through GWBR5-6. The AOS high-speed cameras had frame rates of 500 frames per second and the JVC digital video cameras had frame rates of 29.97 frames per second. All 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 contacted the test article, the force exerted by the surrogate test vehicle was 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

Initially the electronic accelerometer data was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications. [7] 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 deflection, which is also the deflection 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.

3.5 RESULTS

The information desired from the bogie tests was the relation between the applied force and deflection of the post at the impact location. This data was then used to find total energy (the area under the force vs. deflection curve) dissipated during each test.

Although the acceleration data was applied to the impact location, the data came from the center of gravity of the bogie. Error was added to the data since the bogie was not perfectly rigid and sustained vibrations. The bogie may have also rotated during impact, causing differences in accelerations between the bogie center of mass and the bogie impact head. While these issues may affect the data, the data was still valid. Filtering procedures were applied to the data to smooth out vibrations, and the rotations of the bogie during the tests were minor. Significant pitch angles did develop late in some tests as the bogie overrode the post; however, these occurred after the post-bogie interaction of interest. One useful aspect of using accelerometer data was that it included influences of the post inertia on reaction force. This influence was important as the mass of the post would affect barrier performance as well as test results.

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 transducers used produced similar results, the EDR-3 has historically provided accurate results, and was the only accelerometer used in all tests. Test results for all transducers are provided in Appendix A.

CHAPTER 4. ROUND 1 DYNAMIC TESTING – POST, SOIL, & SPEED VARIATION

4.1 PURPOSE

Physical testing of components is an important aspect of any design process. The researcher is able to gain practical insights for both component and system behavior using this tool. As discussed in Chapter 2, only limited testing had been conducted on 6-in. x 8-in. (152-mm x 203-mm) wood posts installed in soil with a 40-in. (1,016-mm) embedment depth and a 24⅞-in. (632-mm) impact height. Therefore, additional bogie tests were undertaken to determine force vs. deflection and energy vs. deflection properties of the 6-in. x 8-in. (152-mm x 203-mm) wood posts embedded 40 in. (1,016 mm) in soil and impacted at a height of 24⅞ in. (632 mm).

4.2 SCOPE

For the first round of dynamic testing, a total of eleven tests, nos. GWB-1 through GWB-11, were conducted on standard wood guardrail posts. The posts were embedded 40 in. (1,016 mm) in various soils and impacted 24⅞ in. (632 mm) above the ground line. The target impact speeds varied between 15 mph (24 km/h) and 25 mph (40 km/h). All posts were impacted at an angle of 0 degrees, creating a classical “head-on” or full frontal impact and strong-axis bending. The testing matrix is shown in Table 4, and the test setup is shown in Figure 9.

The posts were southern yellow pine (SYP) wood sections with nominal dimensions of 6 in. x 8 in. x 72 in. (152 mm x 203 mm x 1,829 mm), as shown in Figure 10. Cross-sectional dimensions, moisture content, weight, and ring density of the posts were recorded, as shown in Table 5. Cross-sectional measurements were taken at both ends of the post. The moisture content for each post was measured at 16 in. (406 mm) above the ground line, at the ground line, and at 20 in. (508 mm) below the ground line with a pin-type moisture meter. [8] Due to differences in moisture contents, densities, and dimensions, each wood post had a different recorded weight. Although the details of the posts were not recorded for all tests, none of the posts fractured. Thus, variations in post properties did not significantly affect test results.

A compacted, coarse, crushed limestone material meeting Grading B of AASHTO M147-95 (1990) was utilized for all tests except test no. GWB-5. For test no. GWB-5, the soil was a mixture of 2-in. (51-mm) to 4-in. (102-mm) limestone, or wall-facing rock. This mixture was a combination of two mixes from Martin Marietta materials that were blended and sieved on site.

The results of test nos. GWB-1 through GWB-4 displayed significant differences from the results of test nos. RWP-1 and RWP-2, which were discussed previously in Chapter 2. Thus, a different mixture of strong soil, designated “X”, was used for test no. GWB-6. Although both mixtures of soil met the AASHTO Grading B strong soil criteria, soil “X” had fewer fines than the soil used in test nos. GWB-1 through GWB-4 and GWB-7 through GWB-11, which was referred to as soil “Y”. Both soils were compacted using a pneumatic tamper and had similar moisture contents. Soil specifications are shown in Appendix A.

Table 4. Round 1 Dynamic Post Testing Matrix.

Test No.	Post		Soil Gradation	Embedment Depth in. (mm)	Target Impact Velocity mph (km/h)	Bending Axis
	Type (Species)	Size in. (mm)				
GWB-1	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - Y	40 (1,016)	20 (32)	Strong
GWB-2	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - Y	40 (1,016)	20 (32)	Strong
GWB-3	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - Y	40 (1,016)	15 (24)	Strong
GWB-4	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - Y	40 (1,016)	15 (24)	Strong
GWB-5	Wood (SYP)	6x8 (152x203)	2- to 4-in. Limestone	40 (1,016)	20 (32)	Strong
GWB-6	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - X	40 (1,016)	20 (32)	Strong
GWB-7	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - Y	40 (1,016)	20 (32)	Strong
GWB-8	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - Y	40 (1,016)	15 (24)	Strong
GWB-9	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - Y	40 (1,016)	15 (24)	Strong
GWB-10	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - Y	40 (1,016)	25 (40)	Strong
GWB-11	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (strong soil) - Y	40 (1,016)	25 (40)	Strong

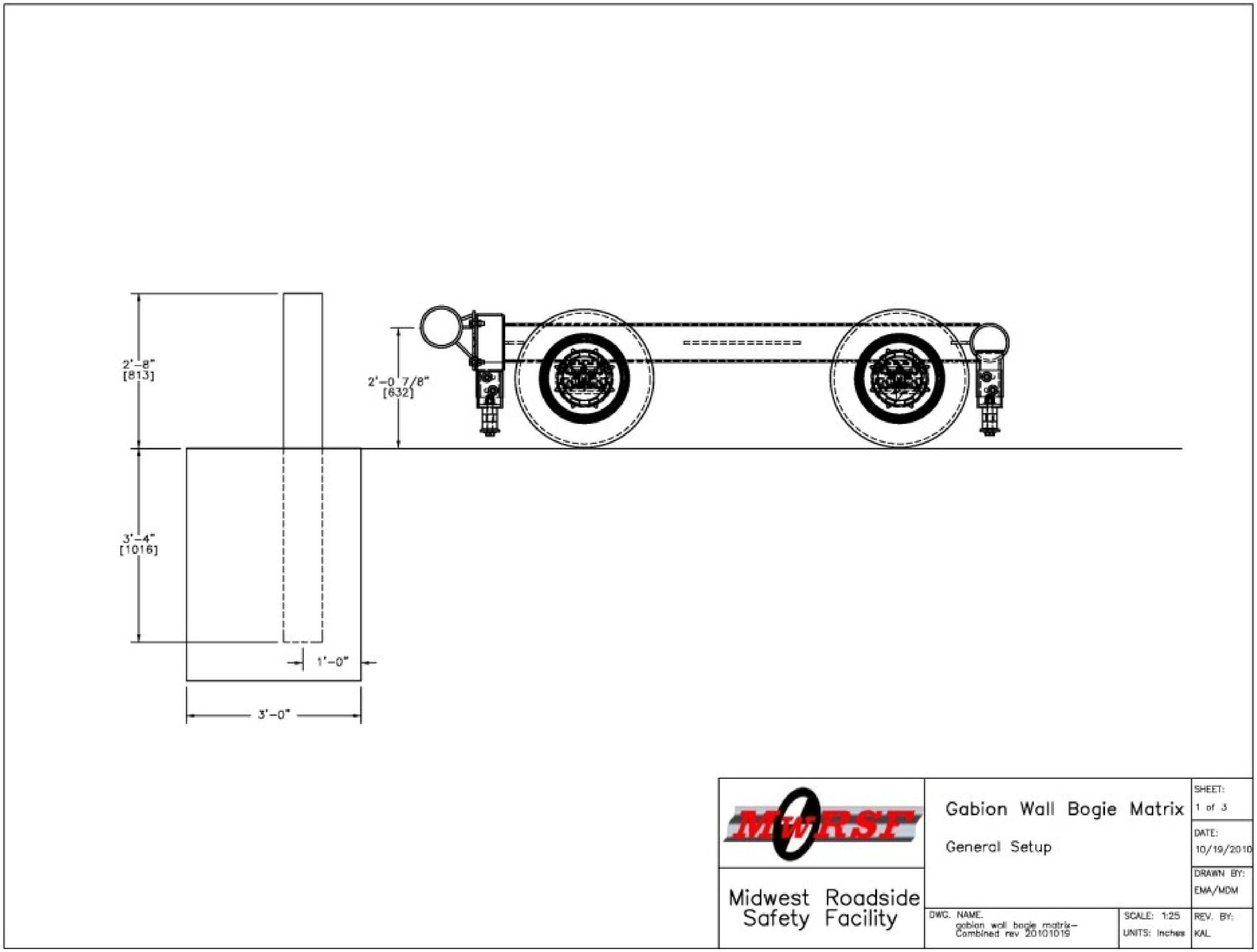
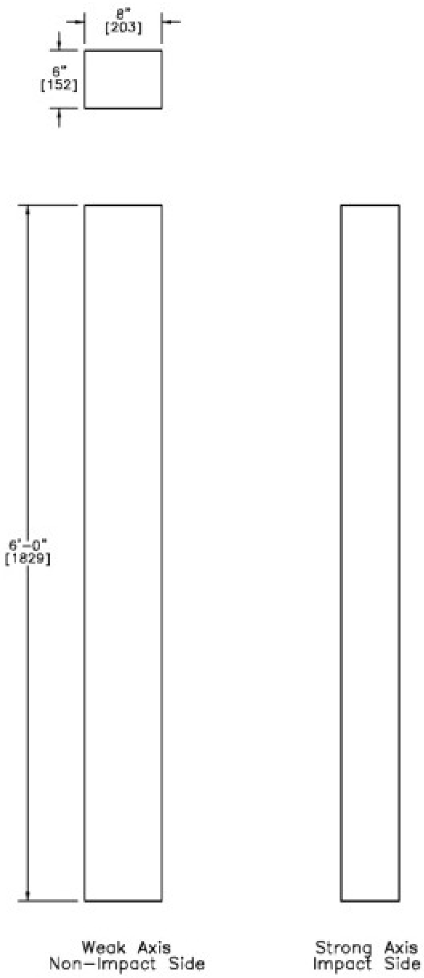


Figure 9. Schematic. Round 1 Test Setup.



AASHTO Grading B, Soil X and Soil Y				
Sieve	% Pass	Gr. A	Gr. B	Sieve
4"	100	100	100	AASHTO Grading B
3"	75-100	100	100	
#4	30-75	25-55	30-60	
#200	0-15	2-8	5-20	

2"-4" Lime Stone		
Sieve	% Pass	Clean Rock made up of 2 mixes from Martin Marietta Sieved on Site
4"	100	
2"	0-5	

NOTES: (1) Post is made of Southern Yellow Pine with no knots.
(2) Both Soil X and Soil Y met AASHTO Grading B criteria.
(3) Soil X has more fines.

MwRSF Midwest Roadside Safety Facility	Gabion Wall Bogie Matrix Post and Soil Specifications	SHEET: 2 of 3 DATE: 10/19/2010 DRAWN BY: EMA/MDM
	DWG. NAME. gabion wall bogie matrix-Combined rev 20101019 / SCALE: 1:15 UNITS: Inches	REV. BY: KAL

Figure 10. Schematic. Round 1 Post and Soil Specifications.

Test No.	Target Speed		Impact Height (inches)	Embedment Depth (inches)	Embedment Material	Impact Axis
	mph	ft/s				
GWB-1	20	29.3	24.875	40	AASHTO Grading B – "Y"	Strong
GWB-2	20	29.3	24.875	40	AASHTO Grading B – "Y"	Strong
GWB-3	15	22.0	24.875	40	AASHTO Grading B – "Y"	Strong
GWB-4	15	22.0	24.875	40	AASHTO Grading B– "Y"	Strong
GWB-5	20	29.3	24.875	40	2"–4" Limestone	Strong
GWB-6	20	29.3	24.875	40	AASHTO Grading B – "X"	Strong
GWB-7	20	29.3	24.875	40	AASHTO Grading B – "Y"	Strong
GWB-8	15	22.0	24.875	40	AASHTO Grading B – "Y"	Strong
GWB-9	15	22.0	24.875	40	AASHTO Grading B – "Y"	Strong
GWB-10	25	36.7	24.875	40	AASHTO Grading B – "Y"	Strong
GWB-11	25	36.7	24.875	40	AASHTO Grading B – "Y"	Strong

Midwest Roadside Safety Facility

Gabion Wall Bogie Matrix

Testing Matrix

SHEET: 3 of 3
DATE: 10/19/2010
DRAWN BY: EMA/MDM
DWG. NAME: gabion wall bogie matrix–Combined rev 20101019
SCALE: None
UNITS: Inches
REV. BY: KAL

Figure 11. Schematic. Round 1 Testing Matrix and Soil Materials.

Table 5. Round 1 Wood Post Details.

Test No.	Post Dimensions in. (mm)		Moisture Content (%)			Weight lb (kg)	Ring Density rings/in. (rings/mm)
	@ Top	@ Bottom	16 in. (406 mm) Above Ground Line	Ground Line	20 in. (508 mm) Below Ground Line		
GWB-5	6 x 8-1/4 (152 x 210)	6 x 8-1/4 (152 x 210)	14	22	13	68.8 (31.2)	3 (0.12)
GWB-8	6-3/8 x 8 (162 x 203)	6-3/8 x 8 (162 x 203)	17	18	15	76 (34.5)	9-10 (0.35-0.39)
GWB-9	6 x 7-7/8 (152 x 200)	6 x 7-7/8 (152 x 200)	18	19	19	61.8 (28.0)	5 (0.20)
GWB-10	5-7/8 x 7-7/8 (149 x 200)	5-7/8 x 7-3/4 (149 x 197)	14	15	15	84.2 (38.2)	16 (0.63)
GWB-11	6 x 8 (152 x 203)	6 x 7-7/8 (152 x 200)	16	16	16	84.2 (38.2)	6 (0.24)

4.3 ROUND 1 RESULTS

The accelerometer data for each test was processed in a manner discussed in Section 3.6. Individual results are provided in Appendix A for all accelerometers used for each test.

4.3.1 Test No. GWB-1

During test no. GWB-1, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 20.7 mph (33.3 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil and showed no signs of fracturing. The bogie overrode the post at 0.180 seconds after impact. The maximum deflection of the post was 48.5 in. (1,233 mm), as measured at the center height of the head.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 12. Initially, inertial effects resulted in a peak force of 9.7 kips (43.0 kN) over the first few inches of deflection. After the initial peak, the resistive force remained relatively constant at approximately 5.5 kips (24.5 kN) through a deflection of 35 in. (889 mm). The force then subsided through the remaining 13.5 in. (343 mm) of deflection. The post rotating in soil absorbed a total of 220.0 kip-in. (25.1 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 13.

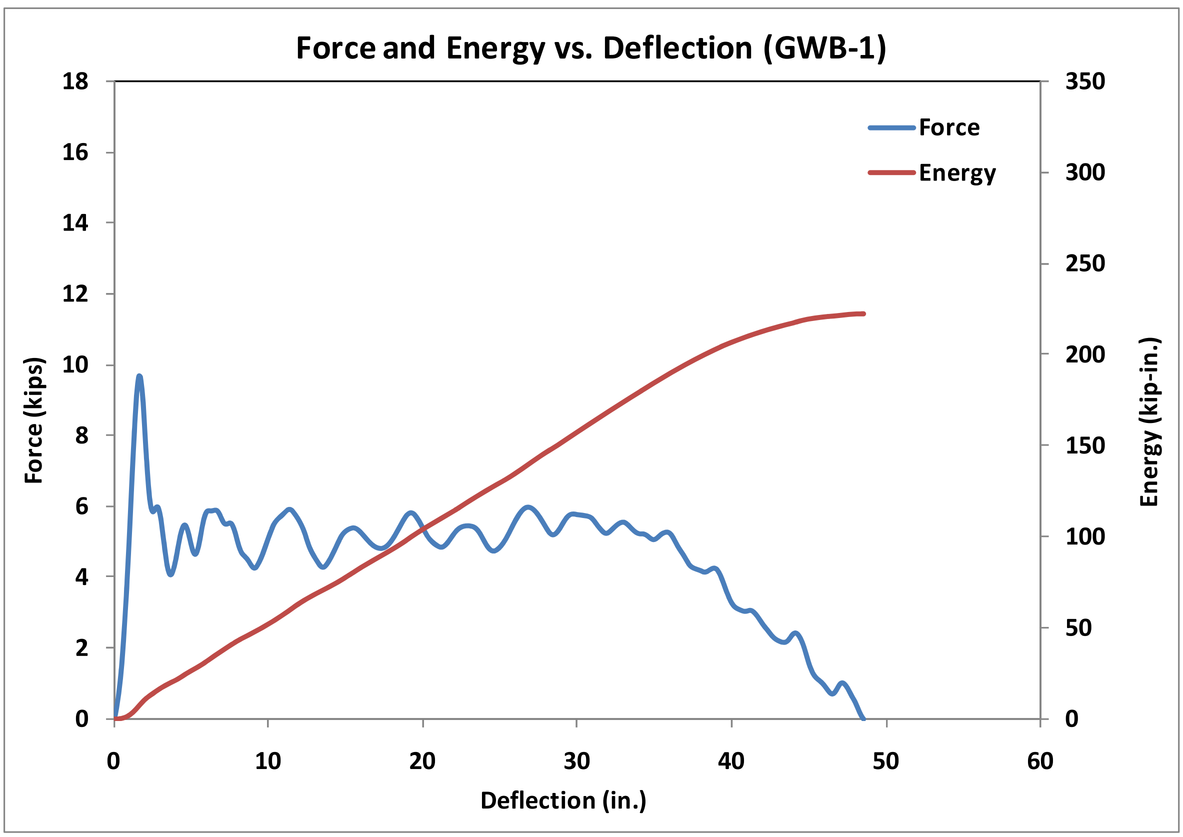
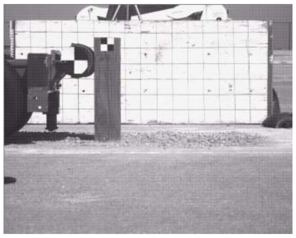
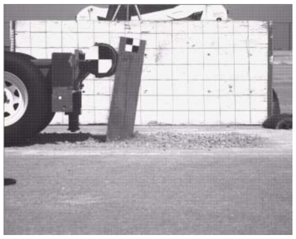


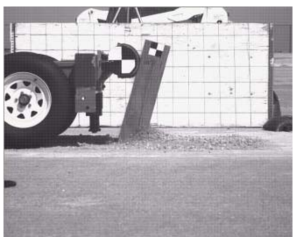
Figure 12. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-1.



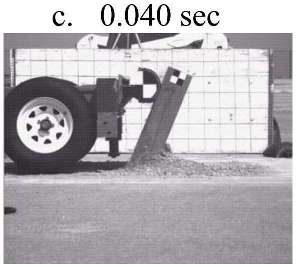
a. IMPACT



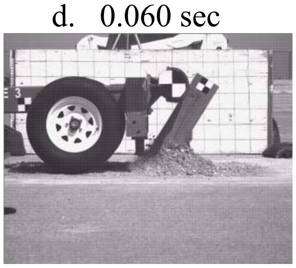
b. 0.020 sec



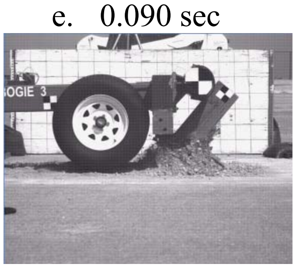
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front

Figure 13. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-1.

4.3.2 Test No. GWB-2

During test no. GWB-2, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 19.8 mph (31.9 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil and showed no signs of fracturing. The bogie overrode the post at 0.188 seconds after impact at a maximum deflection of 45.9 in. (1,165 mm), as measured at the center height of the head.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 14. Initially, inertial effects resulted in a peak force of 12.3 kips (54.9 kN) over the first few inches of deflection. After the initial peak, the force steadily declined from approximately 8 kips (36 kN) to 0 kips (0 kN) between deflections of 10 in. (254 mm) and 45.9 in. (1,165 mm), respectively. The post rotating in soil absorbed a total of 205.0 kip-in. (23.2 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 15.

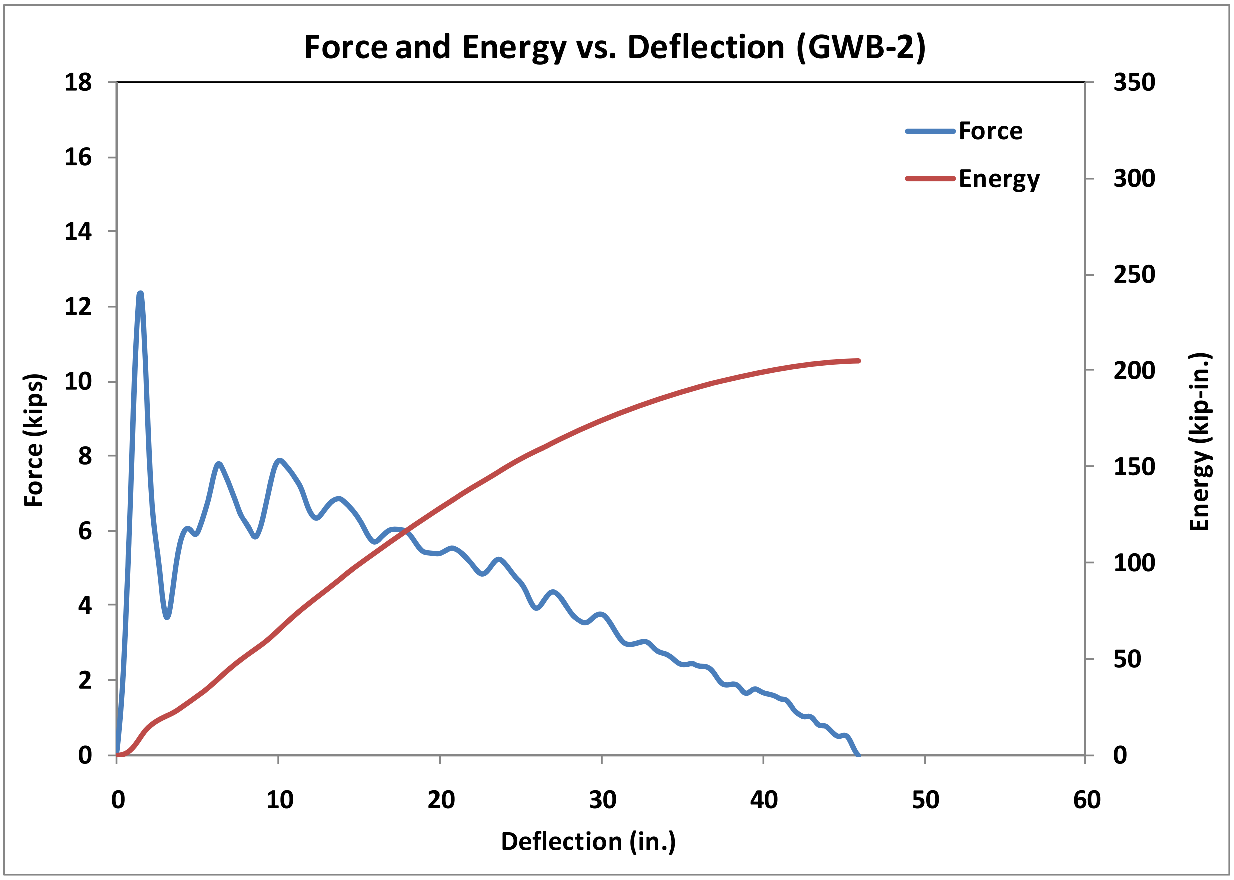
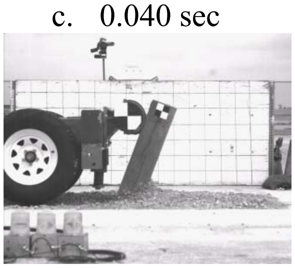


Figure 14. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-2.

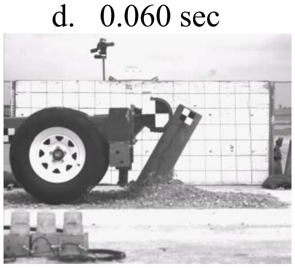
a. Impact

b. 0.020 sec

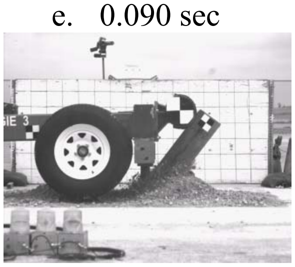
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Rear Quarter View

Figure 15. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-2.

4.3.3 Test No. GWB-3

During test no. GWB-3, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 15.1 mph (24.4 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil and showed no signs of fracturing. The maximum deflection of the post was 52.8 in. (1,341 mm), as measured at the center height of the head. The bogie impact head lost contact with the post after 0.345 seconds, and the bogie overrode the post. The bogie vehicle came to rest with its back end directly over the top of the rotated post.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 16. Inertial effects resulted in a peak force of 8.3 kips (36.9 kN) over the first few inches of deflection. After the initial peak, the force steadily declined from approximately 5 kips (22 kN) to 4 kips (18 kN) over a deflection of 28 in. (711 mm). The resistive forces decreased to nearly zero at a deflection of 41 in. (1,041 mm) but remained until the bogie overrode the post. The post rotating in soil absorbed a total of 141.9 kip-in. (16.0 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 17.

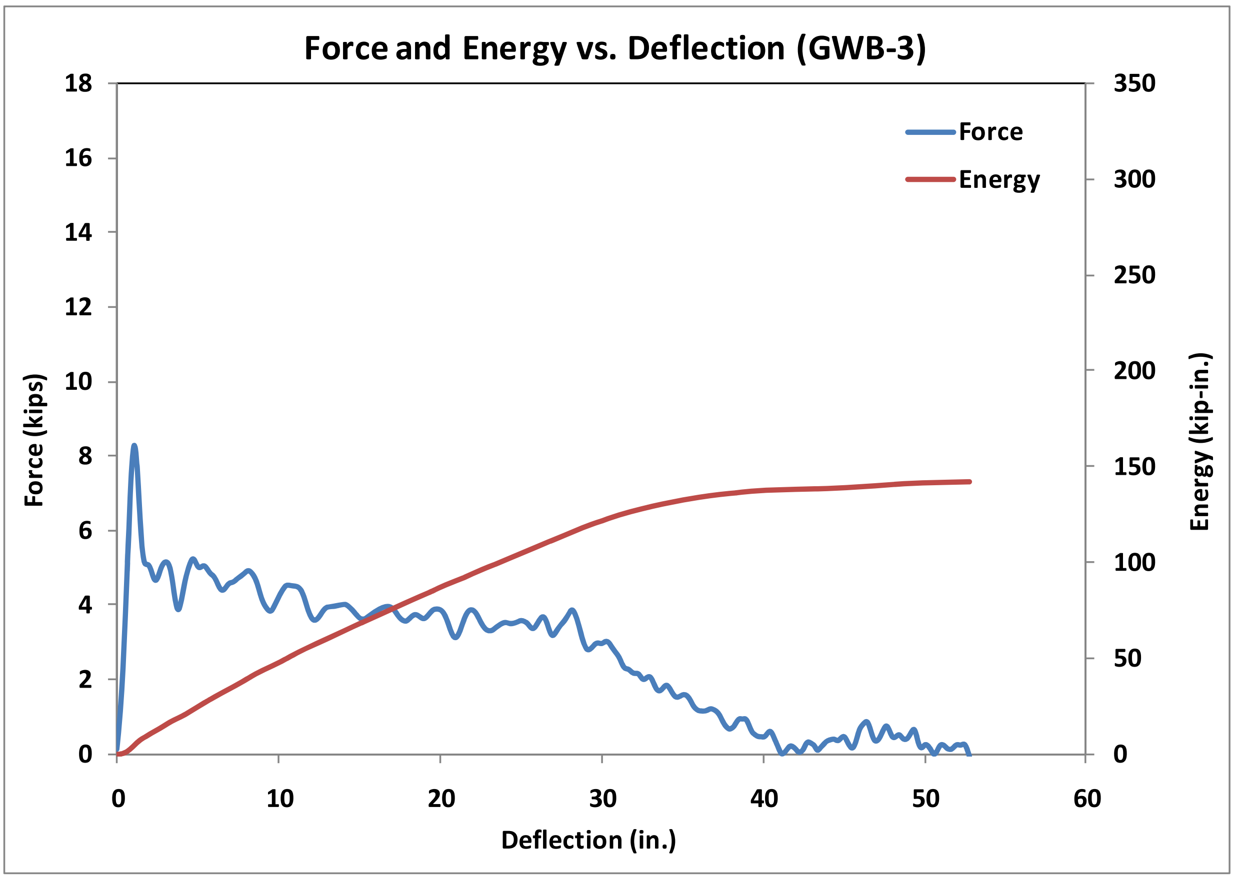


Figure 16. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-3.

a. Impact

b. 0.020 sec

c. 0.040 sec

d. 0.060 sec

e. 0.090 sec

f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Rear Quarter View

Figure 17. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-3.

4.3.4 Test No. GWB-4

During test no. GWB-4, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 14.3 mph (23.1 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil and showed no signs of fracturing. The bogie overrode the post at 0.287 seconds after impact. The maximum deflection of the post was 44.9 in. (1,140 mm), as measured at the center height of the head.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 18. Inertial effects resulted in a peak force of 10.2 kips (45.2 kN) over the first few inches of deflection. After the initial peak, the resistive force remained between approximately 4.5 kips (20.0 kN) and 3.0 kips (13.3 kN) through 30 in. (762 mm) of deflection. The force then steadily decreased to zero at 44.9 in. (1,140 mm) of deflection. The post rotating in soil absorbed a total of 129.3 kip-in. (14.6 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 19.

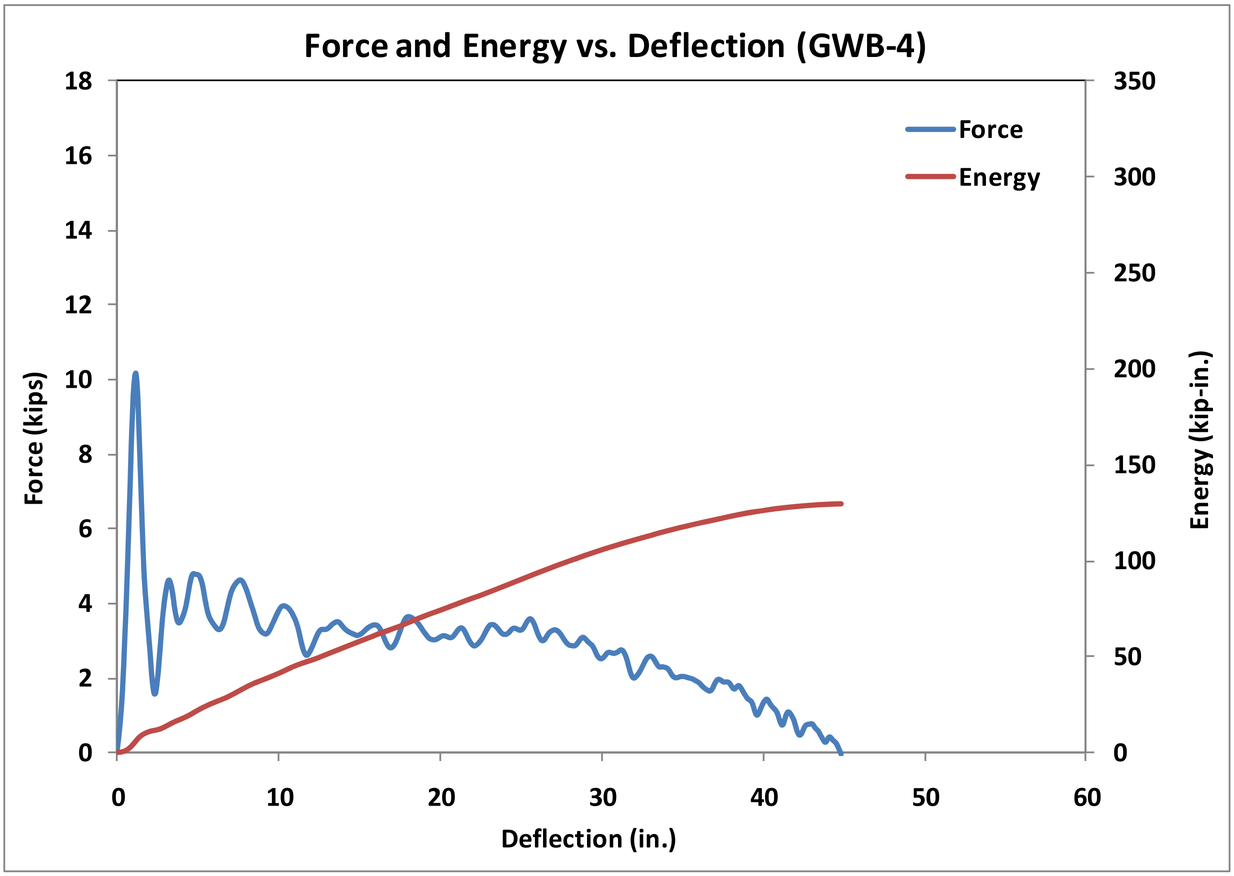
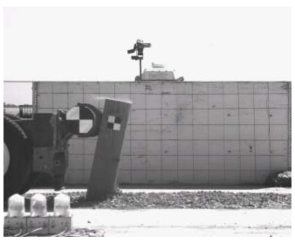


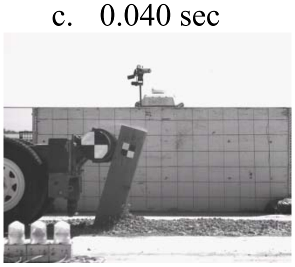
Figure 18. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-4.

a. Impact

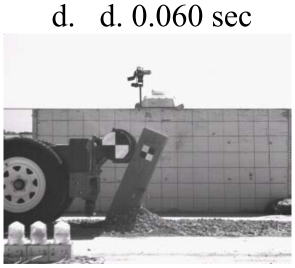
b. 0.020 sec



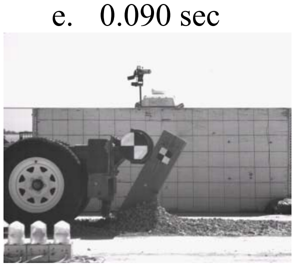
c. 0.040 sec



d. d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front Quarter View

Figure 19. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-4.

4.3.5 Test No. GWB-5

During test no. GWB-5, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 19.7 mph (31.7 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the course aggregate and showed no signs of fracturing. The bogie overrode the post at 0.192 seconds after impact. The maximum deflection of the post was 56.2 in. (1,428 mm), as measured at the center height of the head.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 20. Inertial effects resulted in a peak force of 8.4 kips (37.4 kN) during the first few inches of deflection. After the initial peak, the force varied between approximately 5 kips (22 kN) and 1 kip (4 kN). The post rotating in soil absorbed a total of 126.3 kip-in. (14.3 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 21.

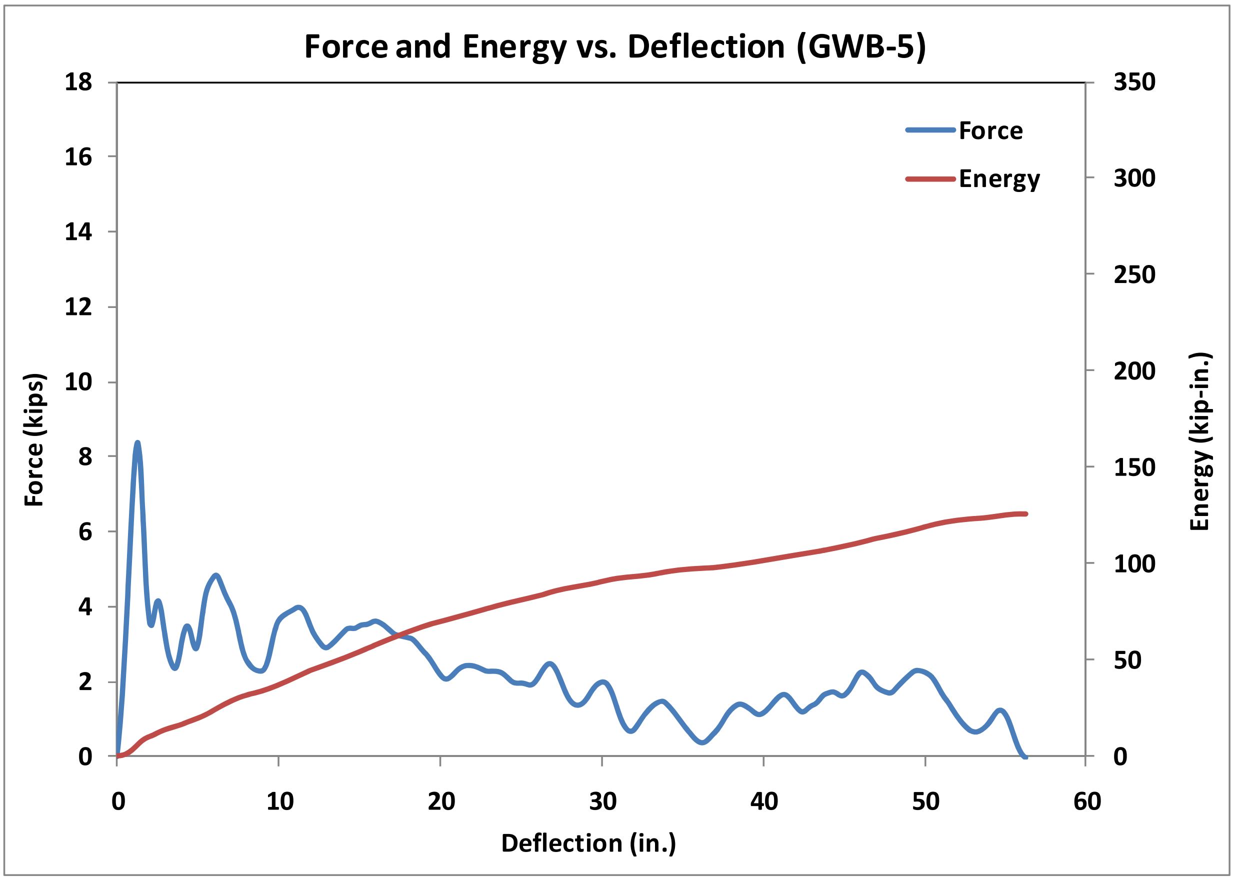
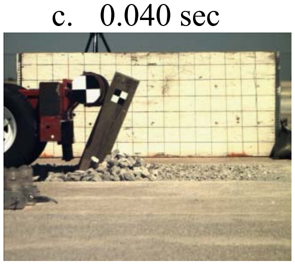


Figure 20. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-5.

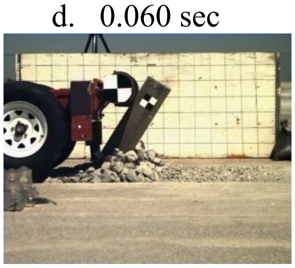
a. Impact

b. 0.020 sec

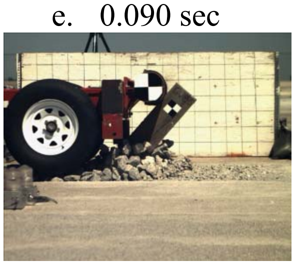
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front View

Figure 21. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-5.

4.3.6 Test No. GWB-6

During test no. GWB-6, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 19.6 mph (31.5 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil and showed no signs of fracturing. The bogie overrode the post at 0.158 seconds after impact. The maximum deflection of the post was 40.5 in. (1,029 mm), as measured at the center height of the head.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 22. Inertial effects resulted in a peak force of 8.7 kips (38.9 kN) during the first few inches of deflection. After the initial peak, the resistive force was approximately 7 kips (31 kN) through 15 in. (381 mm) of deflection. Then, the force steadily decreased to zero at a deflection of 40.5 in. (1,029 mm). The post rotating in soil absorbed a total of 177.3 kip-in. (20.0 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 23.

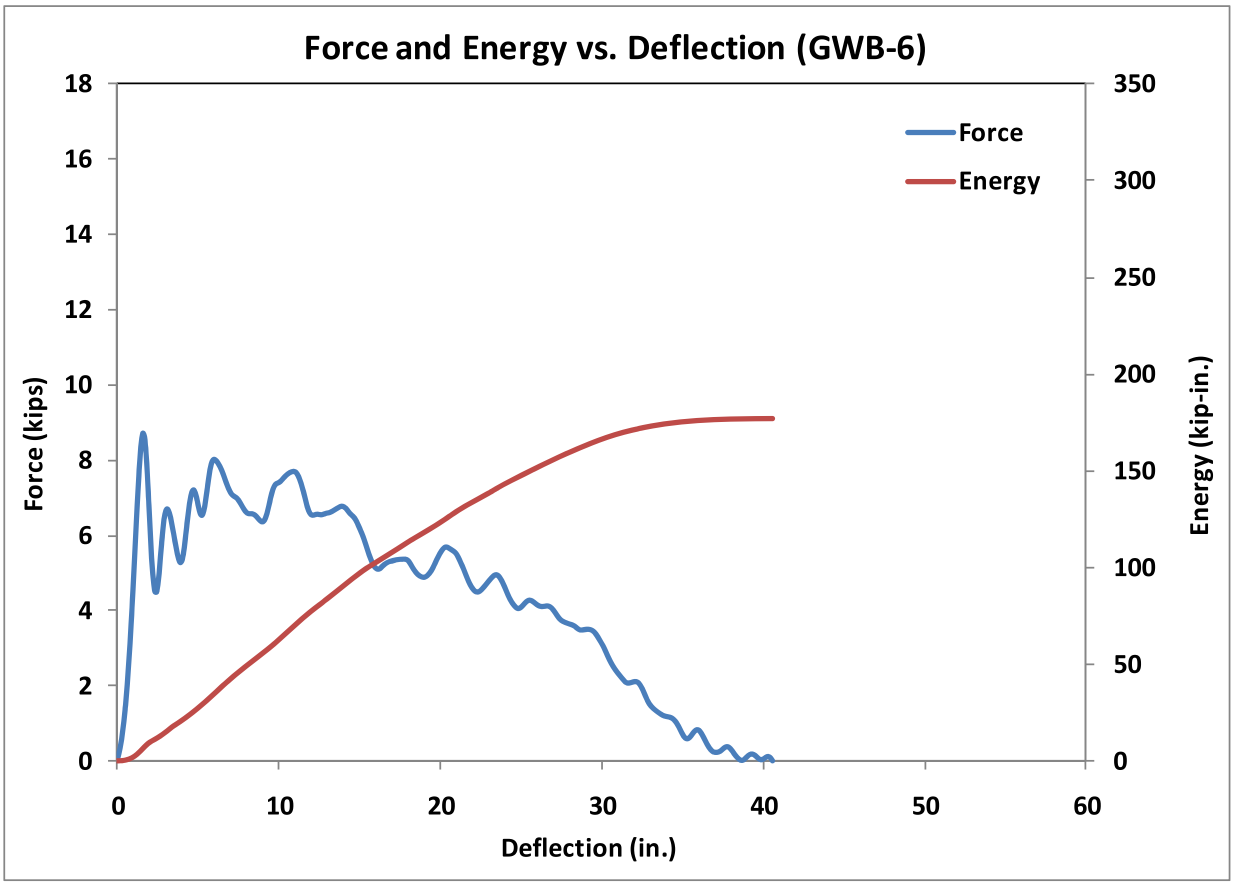
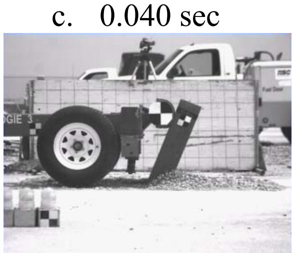


Figure 22. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-6.

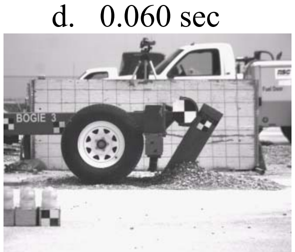
a. Impact

b. 0.020 sec

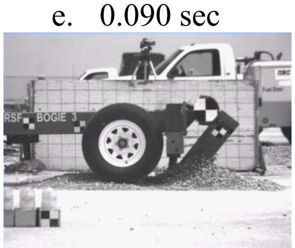
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side View

h. Post After Impact – Side View

Figure 23. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-6.

4.3.7 Test No. GWB-7

During test no. GWB-7, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 19.0 mph (30.6 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil and showed no signs of fracturing. The bogie overrode the post at 0.177 seconds after impact. The maximum deflection of the post was 40.8 in. (1,036 mm), as measured at the center height of the head.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 24. Inertial effects resulted in a peak force of 8.6 kips (38.0 kN) through the first few inches of deflection. After the initial peak, the force remained relatively constant at approximately 6 kips (27 kN) through 30 in. (762 mm) of deflection. The resistive force then decreased to zero at a deflection of 40.8 in. (1,036 mm). The post rotating in soil absorbed a total of 207.5 kip-in. (23.4 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 25

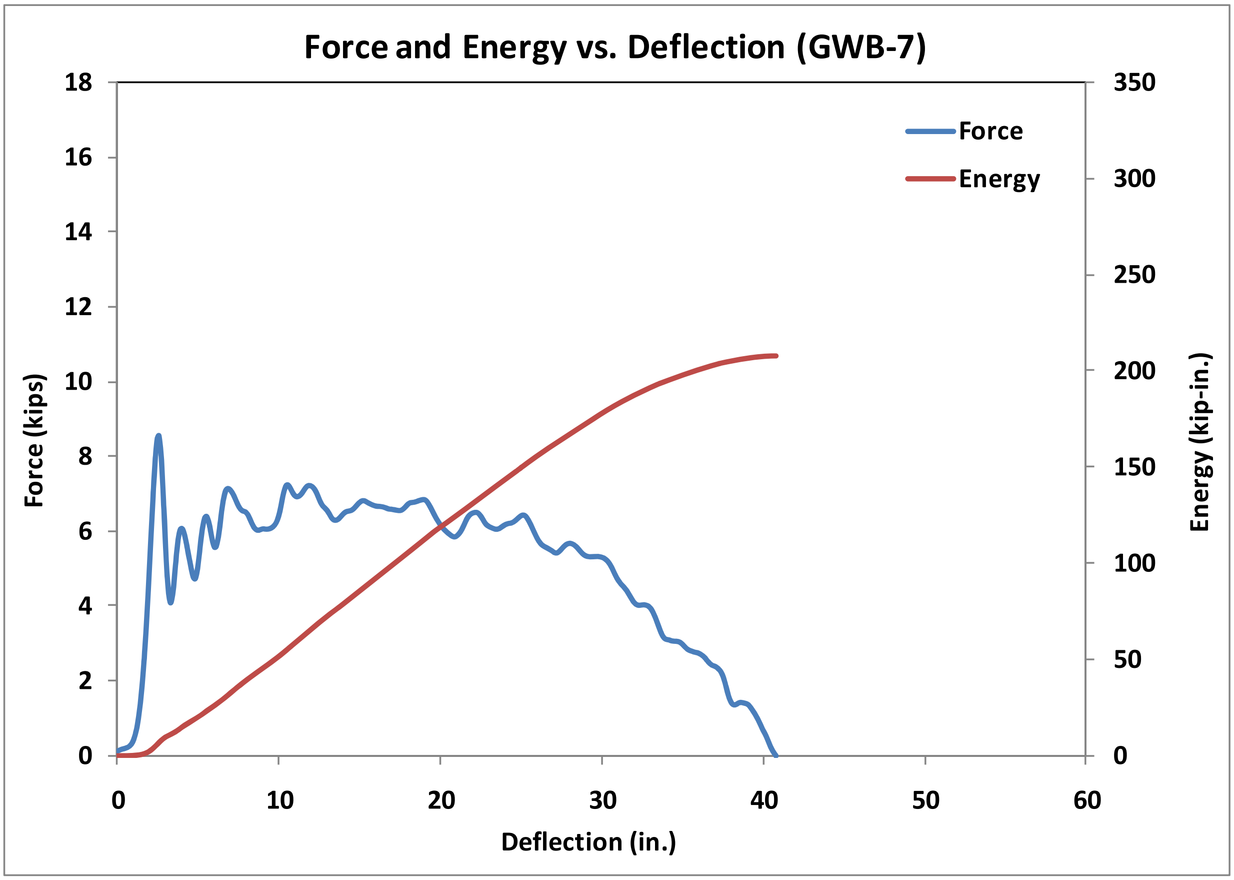
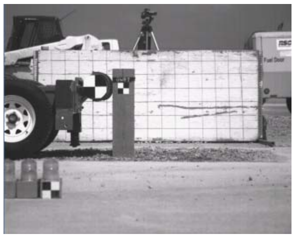
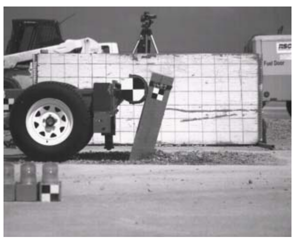


Figure 24. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-7.

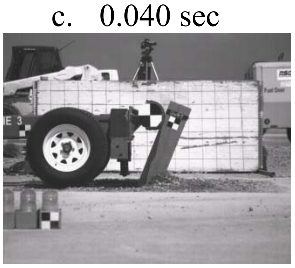


a. Impact

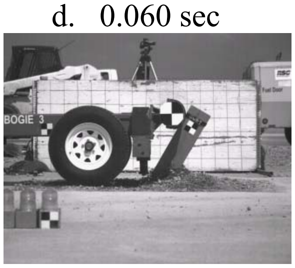
b. 0.020 sec



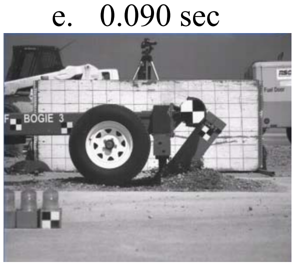
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Soil Displaced During Event on the Front Side of Post

Figure 25. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-7.

4.3.8 Test No. GWB-8

During test no. GWB-8, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 15.1 mph (24.3 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil to a maximum deflection of 43.3 in. (1,101 mm), as measured at the center height of the head, and showed no signs of fracturing. The bogie overrode the post at 0.270 seconds after impact. The bogie came to rest over the deflected post.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 26. Inertial effects resulted in a peak force of 8.7 kips (38.5 kN) through the first few inches of deflection. After the initial peak, the force remained relatively constant at approximately 4 kips (18 kN) through 30 in. (762 mm) of deflection. The post rotating in soil absorbed a total of 144.9 kip-in. (16.4 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 27.

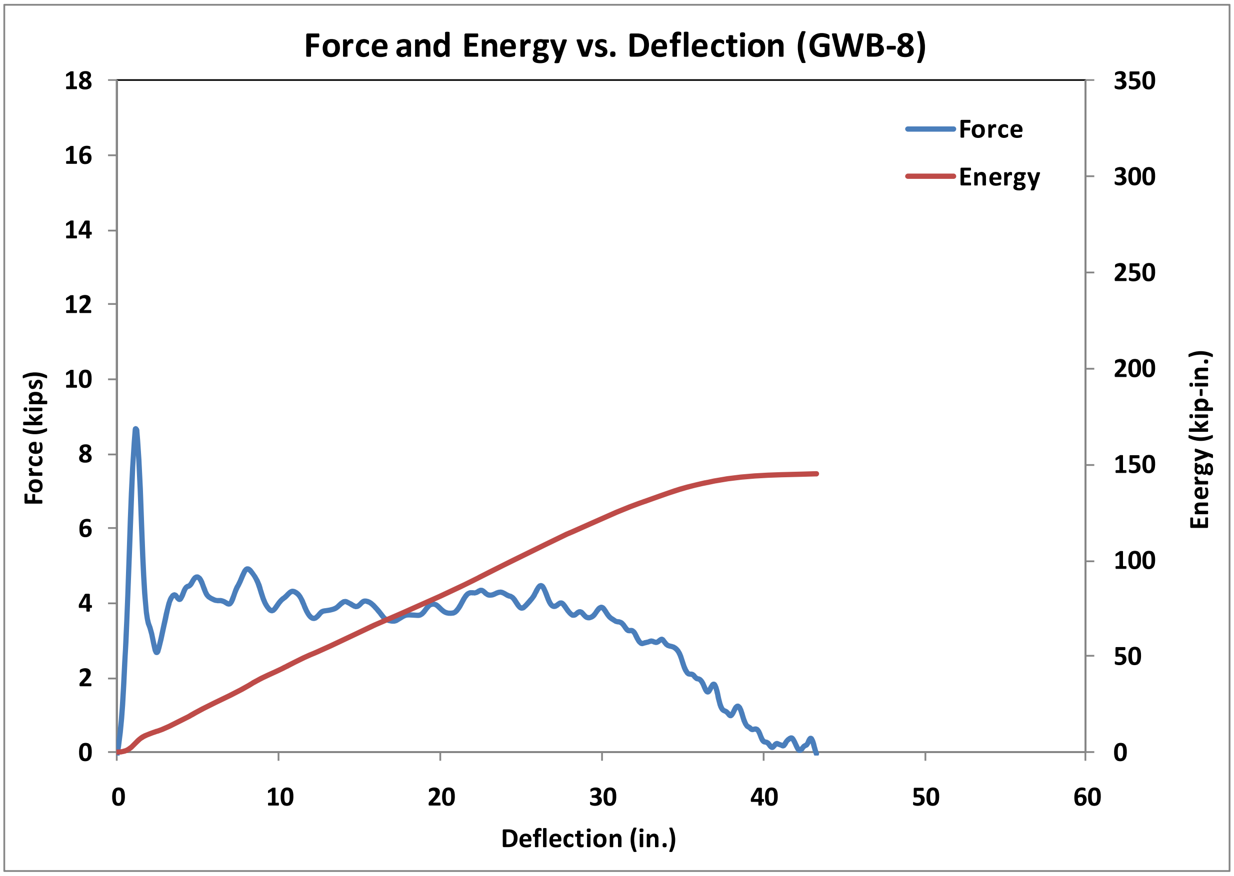
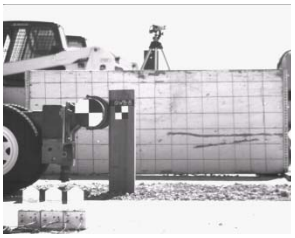
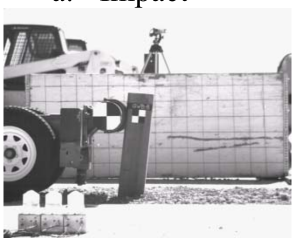


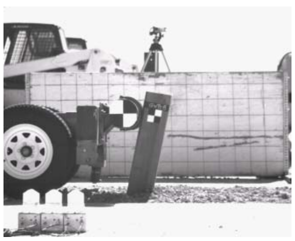
Figure 26. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-8.



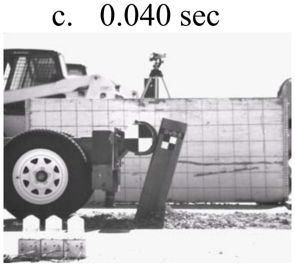
a. Impact



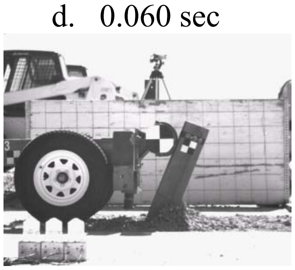
b. 0.020 sec



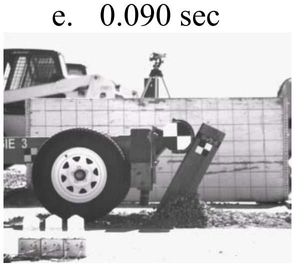
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Rear Quarter View

h. Post After Impact – Rear Quarter View

Figure 27. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-8.

4.3.9 Test No. GWB-9

During test no. GWB-9, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 14.5 mph (23.3 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil to a maximum deflection of 42.7 in. (1,084 mm), as measured at the center height of the head, and showed no signs of fracturing. The bogie impact head lost contact with the post after at 0.258 seconds when the bogie overrode the post. The bogie came to a stop over the deflected post.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 28. Inertial effects resulted in a peak force of 6.6 kips (29.4 kN) through the first few inches of deflection. After the initial peak, the force remained relatively constant at approximately 3.5 kips (15.6 kN) through 30 in. (762 mm) of deflection, then it decreased to zero at the maximum deflection of 42.7 in. (1,084 mm). The post rotating in soil absorbed a total of 127.7 kip-in. (14.4 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 29.

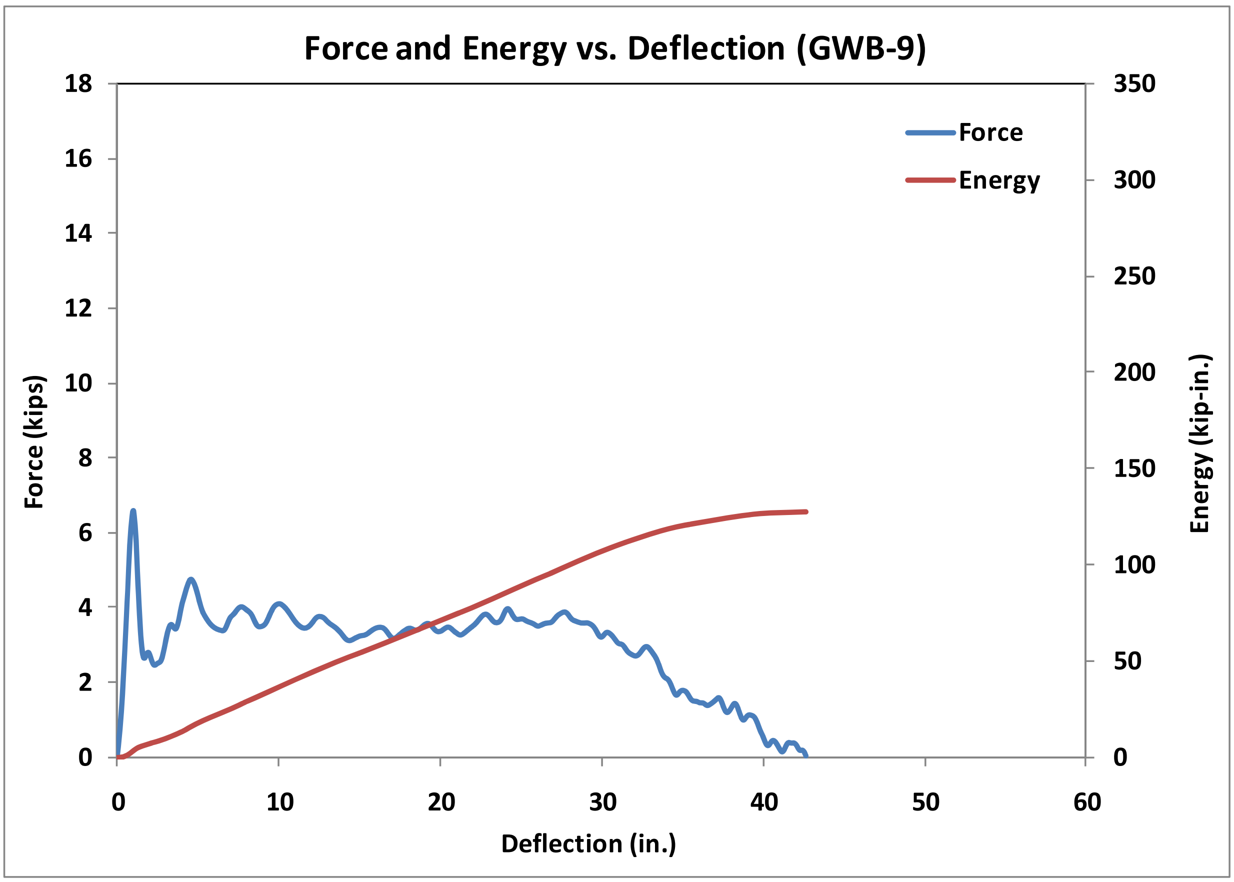
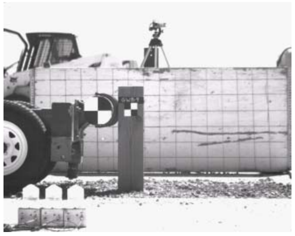
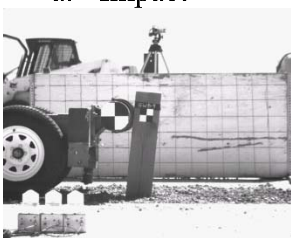
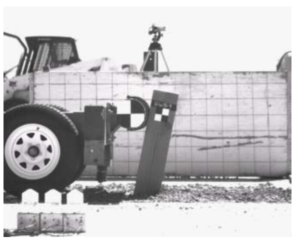
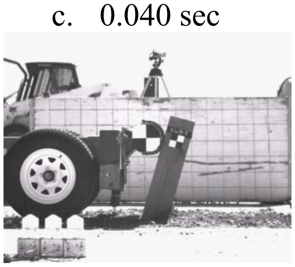


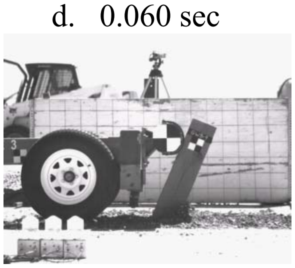
Figure 28. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-9.

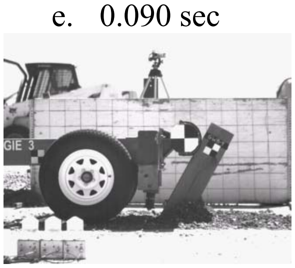

a. Impact


b. 0.020 sec


c. 0.040 sec


d. 0.060 sec


e. 0.090 sec


f. 0.120 sec


g. Post After Impact – Rear View

h. Post After Impact – Side View

Figure 29. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-9.

4.3.10 Test No. GWB-10

During test no. GWB-10, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 24.7 mph (39.8 km/h) and at an orientation causing strong-axis bending in the post. During the test, one of the strobes did not fire. Therefore, the velocity of the tow vehicle was used for the velocity of the bogie. The post rotated through the soil and showed no signs of fracturing. The bogie overrode the post at 0.126 seconds after impact. The maximum dynamic deflection was 45.5 in. (1,155 mm), as measured at the center height of the head.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 30. Inertial effects resulted in a peak force of 14.6 kips (64.9 kN) through the first few inches of deflection. After the initial peak, the force remained relatively constant at approximately 5 kips (22 kN) over 30 in. (762 mm) of deflection. The force then decreased to zero at a deflection of 45.5 in. (1,156 mm). The post rotating in soil absorbed a total of 223.5 kip-in. (25.3 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 31.

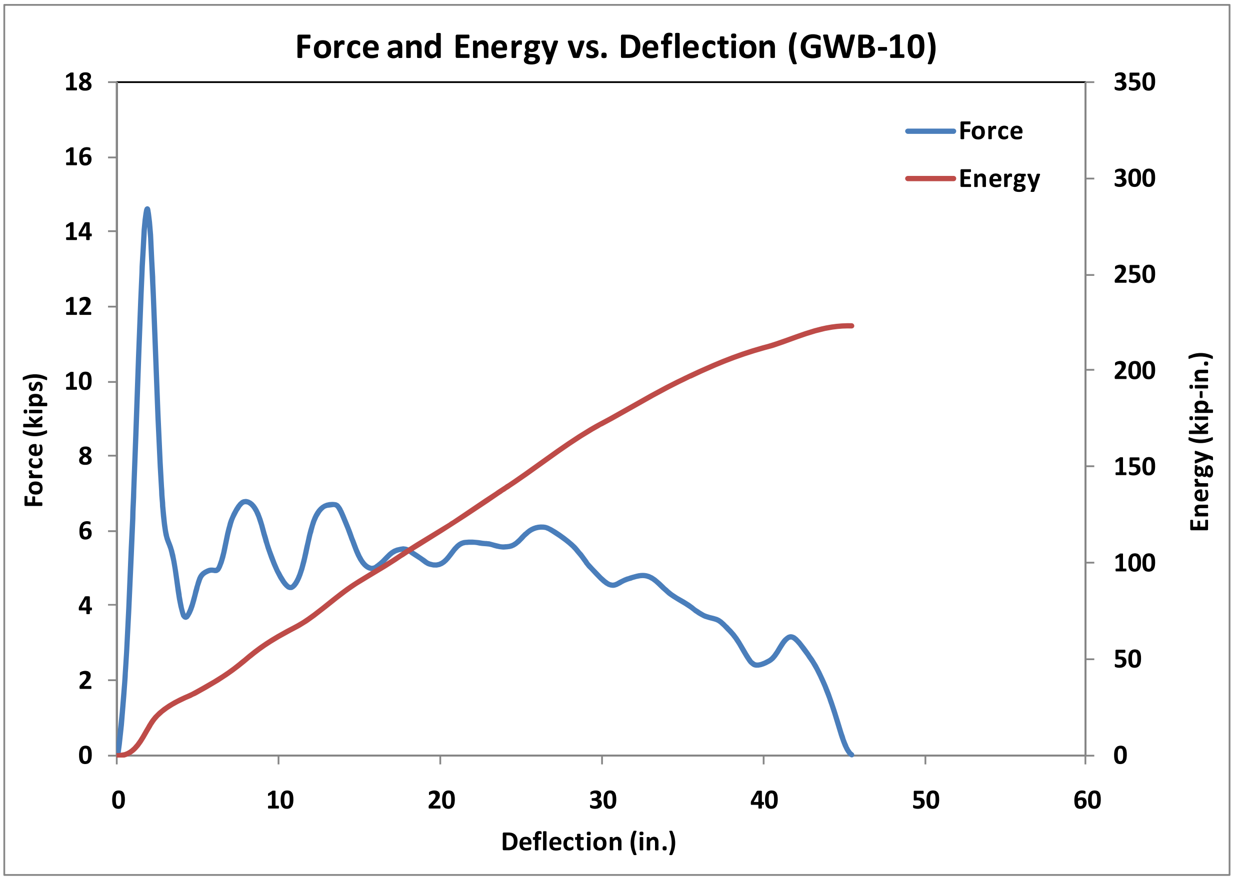
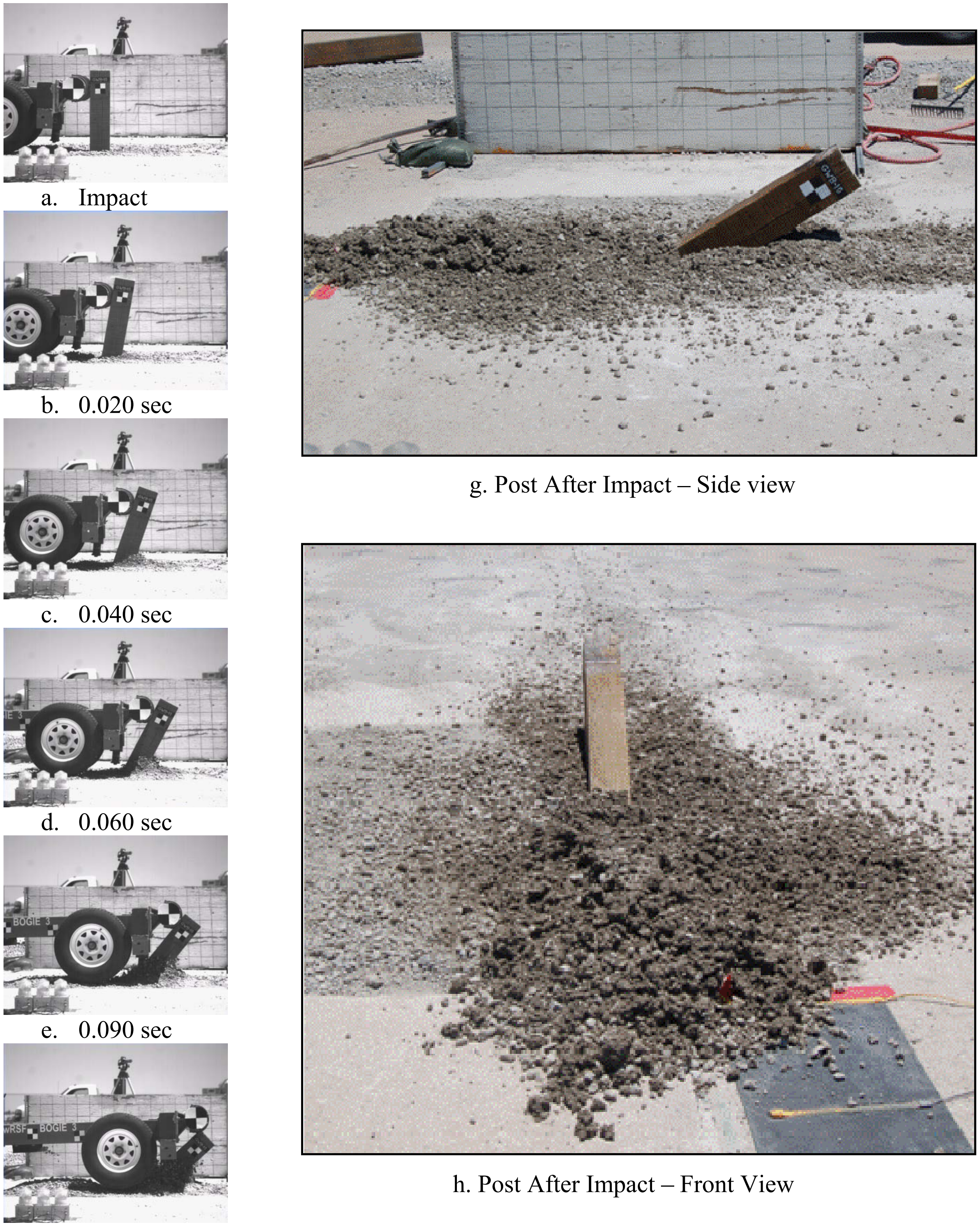


Figure 30. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-10.



a. Impact

b. 0.020 sec

c. 0.040 sec

d. 0.060 sec

e. 0.090 sec

f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front View

Figure 31. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-10.

4.3.11 Test No. GWB-11

During test no. GWB-11, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 24.7 mph (39.8 km/h) and at an orientation causing strong-axis bending in the post. During the test, one of the strobes did not fire. Therefore, the velocity of the tow vehicle was used as the velocity of the bogie. The post rotated through the soil and showed no signs of fracturing. The bogie overrode the post at 0.129 seconds after impact. The maximum dynamic deflection was 45.8 in. (1,164 mm), as measured at the center height of the head.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 32. Inertial effects resulted in a peak force of 14.8 kips (65.8 kN) through the first few inches of deflection. After the initial peak, the force remained relatively constant at approximately 6 kips (27 kN) through 30 in (762 mm) of deflection. The force then decreased to zero at a deflection of 45.8 in. (1,164 mm). The post rotating in soil absorbed a total of 233.5 kip-in. (26.4 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 33.

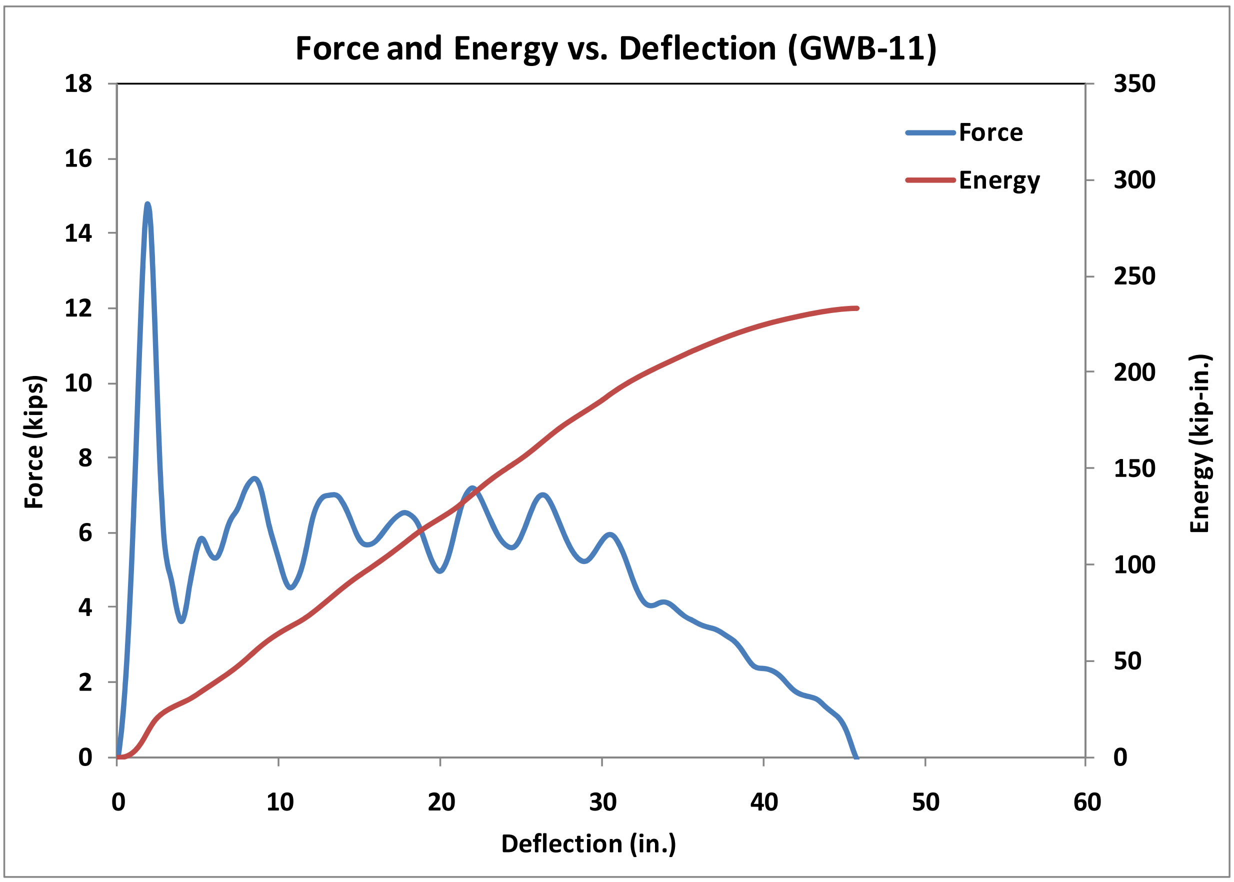
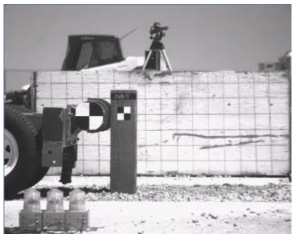


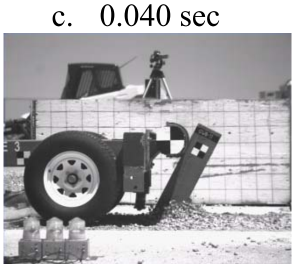
Figure 32. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-11.



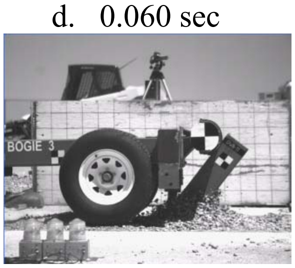
a. Impact

b. 0.020 sec

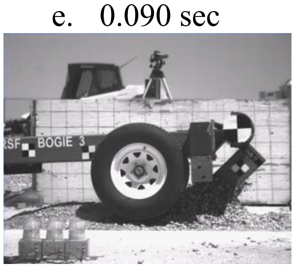
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Rear Quarter View

h. Post After Impact – Front Quarter View

Figure 33. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-11.

4.4 ROUND 1 DISCUSSION

The data from the first round of dynamic testing was summarized by impact speed. The grouped data can provide insights into the resistive force and energy absorption properties of the 6-in. x 8-in. (152-mm x 203-mm) wood post at the three different impact speeds.

4.4.1 25 mph (40 km/h) Dynamic Tests

Test nos. GWB-10 and GWB-11 were conducted with target impact speeds of 25 mph (40 km/h). The two tests are summarized in Table 6. The force vs. deflection and energy vs. deflection curves are shown in Figure 34. Both tests produced similar results. Peak forces of approximately 15 kips (67 kN) occurred in at deflections of 1.9 in. (48 mm) followed by average forces of approximately 6 kips (27 kN) through deflections of 20 in. (508 mm). Slightly more energy was absorbed in test no. GWB-11, but the difference was less than 5 percent.

4.4.2 20 mph (32 km/h) Dynamic Tests

Test nos. GWB-1, GWB-2, and GWB-5 through GWB-7 were conducted with target impact speeds of 20 mph (32 km/h). Test no. GWB-5 was conducted in 2-in. to 4-in. (51-mm to 102-mm) limestone rock, while the others were conducted in strong soil conforming to the AASHTO Grading B strong soil criteria. The five tests are summarized in Table 7. The force vs. deflection and energy vs. deflection curves are shown in Figure 35.

The four strong soil tests produced similar results. Initial peak forces ranged from 8.6 kips (38.0 kN) to 12.3 kips (54.9 kN). The shape of the force vs. deflections curves were similar and each post provided constant resistive forces between 5.2 kips (23.1 kN) and 6.4 kips (27.5 kN) for the first 20 in. (508 mm) of deflection. The total absorbed energies from these four tests ranged from 177.3 kip-in. (20.0 kJ) to 222.0 kip-in. (25.1 kJ).

The result of test no. GWB-5 demonstrated that the 2-in. to 4-in. (51-mm to 102-mm) limestone provided significantly lower force levels than the strong soil. In fact, resistive forces generated during test no. GWB-5 were approximately 40 percent less than observed in the other four tests conducted at the same speed. The energy absorbed during test no. GWB-5 was approximately 38 percent less than the energy absorbed during the AASHTO Grading B strong soil tests.

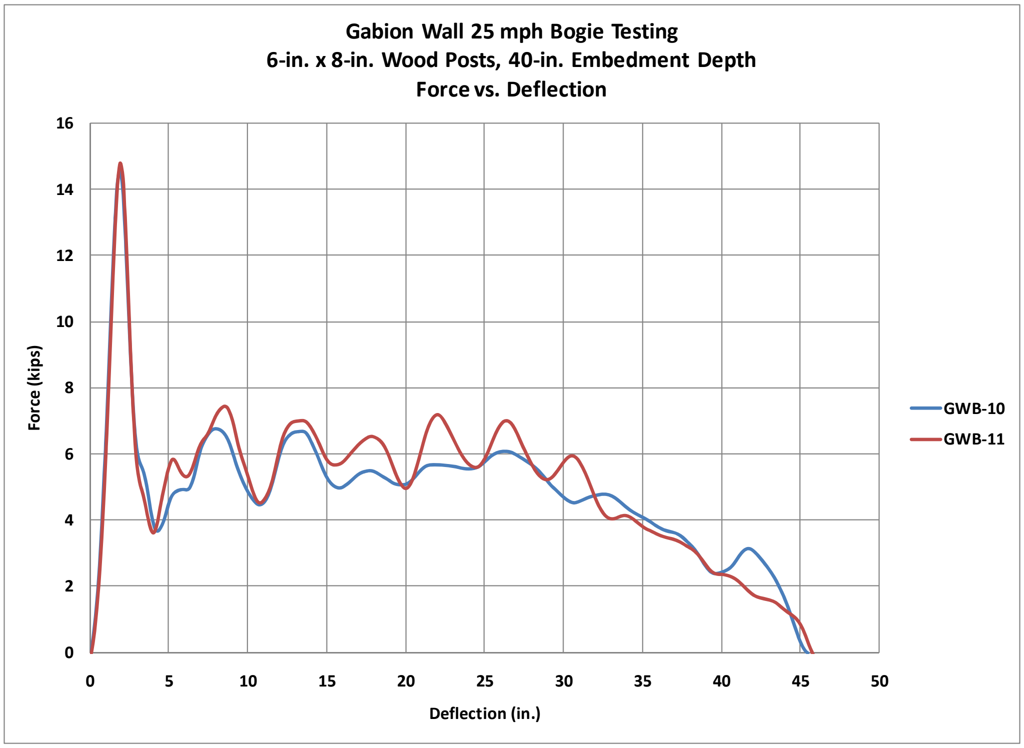
4.4.3 15 mph (24 km/h) Dynamic Tests

Test nos. GWB-3, GWB-4, GWB-8, and GWB-9 were conducted with target impact speeds of 15 mph (24 km/h). The tests are summarized in Table 8. The force vs. deflection and energy vs. deflection curves are shown in Figure 36.

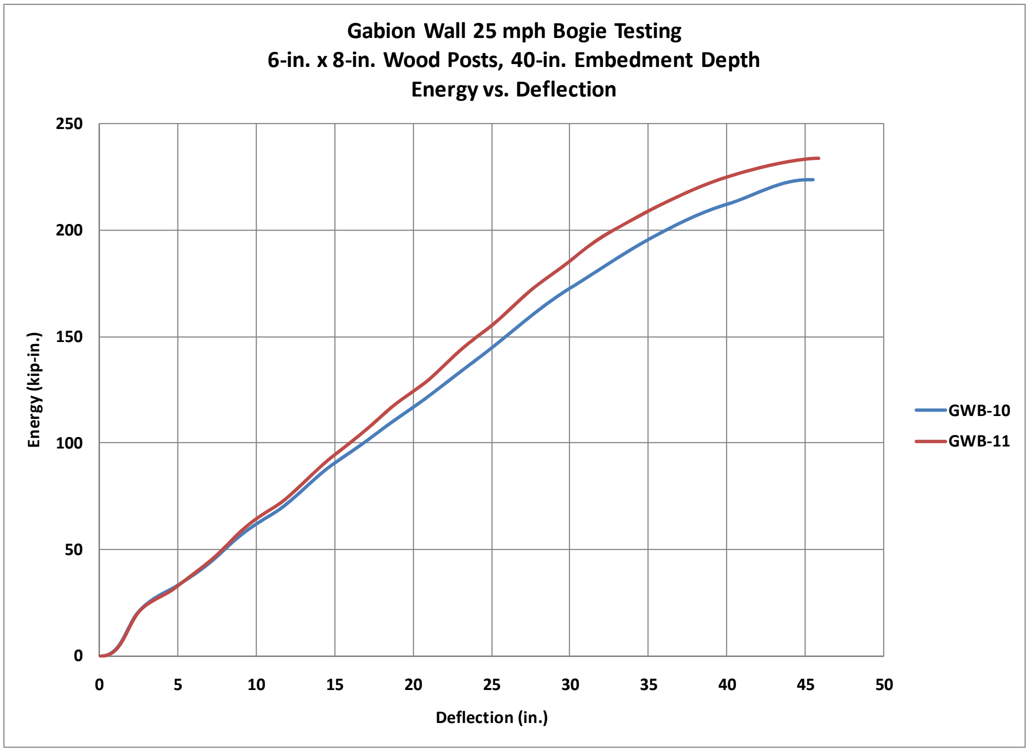
The force vs. deflection curves for all four tests maintained forces of approximately 4 kips (18 kN) through deflections of 20 in. (508 mm) before decreasing to 0 kips (0 kN) at deflections of 42.7 in. (1,085 mm) to 52.8 in. (1,341 mm). The amount of energy absorbed was also similar, ranging from 127.7 to 144.9 kip-in. (14.4 to 16.4 kJ). The bogie came to rest on top of the posts in test nos. GWB-8 and GWB-9 and just downstream of the posts during test nos. GWB-3 and GWB-4.

Table 6. Test Summary - 6-in. x 8-in. (152-mm x 203-mm) Wood Posts with 40-in. (1,016-mm) Embedment Depth at 25 mph.

Test No.	Soil Gradation	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
GWB-10	AASHTO Grading B (strong soil) - Y	24.7 (39.8)	14.6 (64.9)	1.9 (48)	6.0 (26.9)	5.8 (26.0)	223.5 (25.3)	45.5 (1,155)	Rotation in Soil
GWB-11	AASHTO Grading B (strong soil) - Y	24.7 (39.8)	14.8 (65.8)	1.9 (48)	6.3 (28.0)	6.2 (27.6)	233.5 (26.4)	45.8 (1,164)	Rotation in Soil
Average		24.7 (39.8)	14.7 (65.3)	1.9 (48)	6.2 (27.5)	6.0 (26.8)	228.5 (25.8)	45.6 (1,159)	



a. Force vs. Deflection



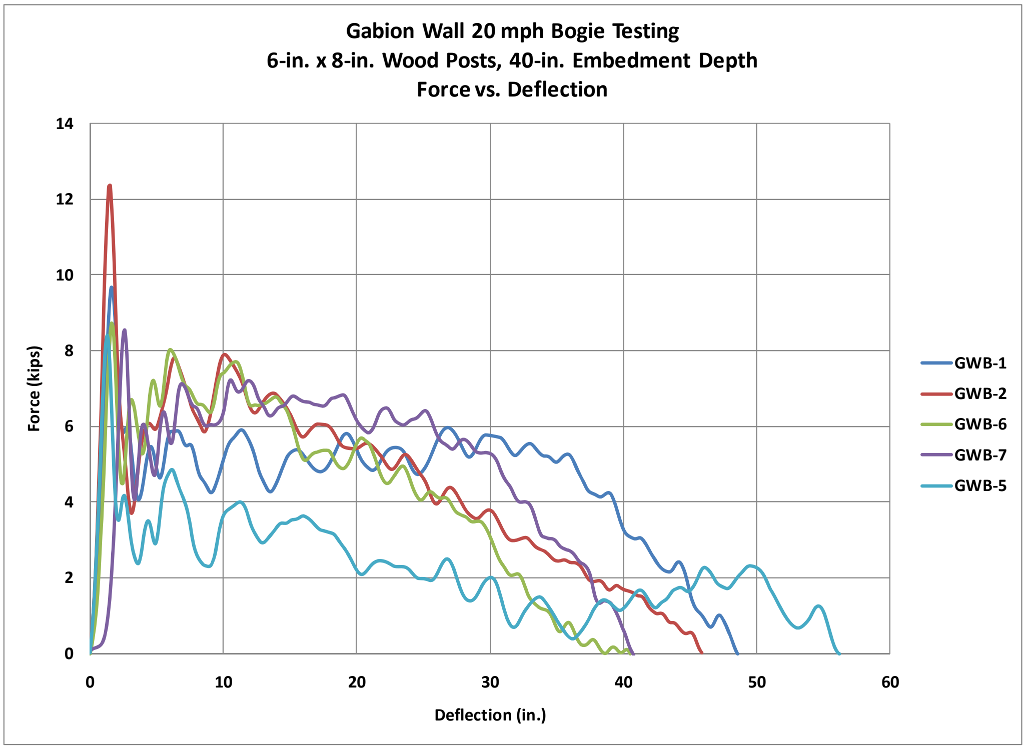
b. Energy vs. Deflection

Figure 34. Graph. Force vs. Deflection and Energy vs. Deflection, Round 1 Testing – 25 mph.

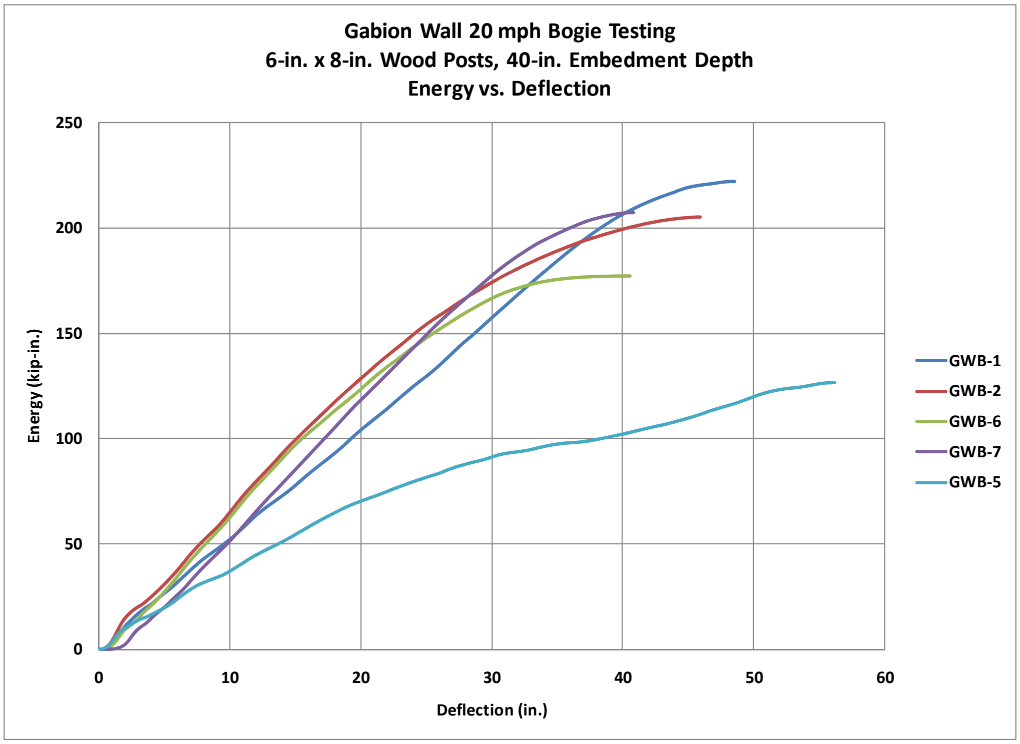
Table 7. Test Summary - 6-in. x 8-in. (152-mm x 203-mm) Wood Posts with 40-in. (1,016-mm) Embedment Depth at 20 mph.

Test No.	Soil Gradation	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
GWB-1	AASHTO Grading B (strong soil) - Y	20.7 (33.3)	9.7 (43.0)	1.6 (40)	5.2 (23.1)	5.2 (23.1)	222.0 (25.1)	48.5 (1,233)	Rotation in Soil
GWB-2	AASHTO Grading B (strong soil) - Y	19.8 (31.8)	12.3 (54.9)	1.5 (39)	6.6 (29.5)	6.4 (28.6)	205.0 (23.2)	45.9 (1,165)	Rotation in Soil
GWB-6	AASHTO Grading B (strong soil) - X	19.6 (31.5)	8.7 (38.9)	1.6 (41)	6.5 (28.8)	6.2 (27.5)	177.3 (20.0)	40.5 (1,029)	Rotation in Soil
GWB-7	AASHTO Grading B (strong soil) - Y	19.0 (30.6)	8.6 (38.0)	2.6 (66)	5.7 (25.3)	5.9 (26.4)	207.5 (23.4)	40.8 (1,036)	Rotation in Soil
Average		19.8 (31.8)	9.8 (43.7)	1.8 (46)	6.0 (26.7)	5.9 (26.4)	202.9 (22.9)	43.9 (1,116)	
GWB-5*	2- to 4-in. Dia. Limestone	19.7 (31.7)	8.4 (37.3)	1.3 (33)	3.6 (16.1)	3.5 (15.6)	126.3 (14.3)	56.2 (1,428)	Rotation in Soil

*Embedded in 2-4-in. limestone – not included in average of strong soil tests



a. Force vs. Deflection

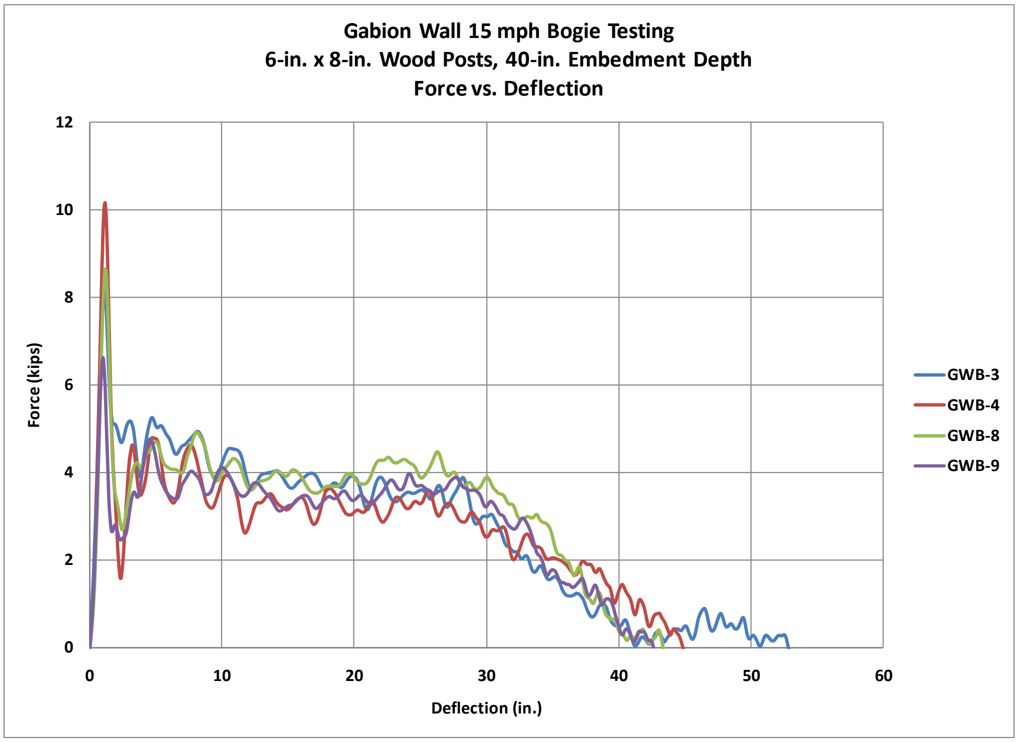


b. Energy vs. Deflection

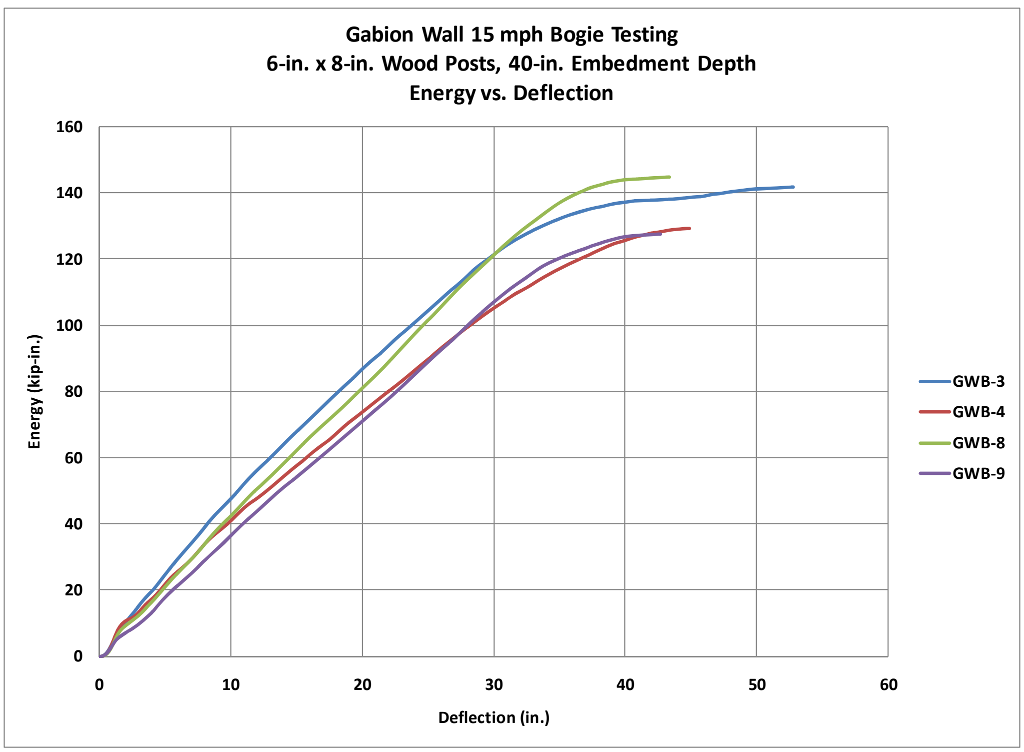
Figure 35. Graph. Force vs. Deflection and Energy vs. Deflection, Round 1 Testing – 20 mph.

Table 8. Test Summary - 6-in. x 8-in.(152-mm x 203-mm) Wood Posts with 40-in. (1,016-mm) Embedment Depth at 15 mph.

Test No.	Soil Gradation	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
GWB-3	AASHTO Grading B (strong soil) - Y	15.1 (24.4)	8.3 (36.9)	1.1 (27)	4.5 (20.1)	4.3 (19.3)	141.9 (16.0)	52.8 (1,341)	Rotation in Soil
GWB-4	AASHTO Grading B (strong soil) - Y	14.3 (23.1)	10.2 (45.2)	1.2 (30)	3.8 (17.1)	3.7 (16.4)	129.3 (14.6)	44.9 (1,140)	Rotation in Soil
GWB-8	AASHTO Grading B (strong soil) - Y	15.1 (24.3)	8.7 (38.5)	1.2 (29)	4.1 (18.5)	4.1 (18.0)	144.9 (16.4)	43.3 (1,101)	Rotation in Soil
GWB-9	AASHTO Grading B (strong soil) - Y	14.5 (23.3)	6.6 (29.4)	1.0 (26)	3.6 (16.1)	3.6 (15.8)	127.7 (14.4)	42.7 (1,085)	Rotation in Soil
Average		14.8 (23.8)	8.4 (37.5)	1.1 (28)	4.0 (17.9)	3.9 (17.4)	136.0 (15.4)	45.9 (1,166)	



a. Force vs. Deflection



b. Energy vs. Deflection

Figure 36. Graph. Force vs. Deflection and Energy vs. Deflection, Round 1 Testing – 15 mph.

4.4.4 Comparison of Results Between Impact Speeds

When comparing the averaged results for each impact speed, two observations should be noted. First, there appeared to be a direct relationship between impact velocity and peak force. Increases in the impact velocity resulted in an increase in the peak force. However, this relation was expected; since, the peak forces occurred within the first couple inches of deflection. The force spike that occurs at the beginning of a test is largely a result of the inertia of the post and the momentum transfer within the impact event. Thus, the magnitude of the inertia spike is increased as the impact velocity is increased since the bogie has more momentum to transfer to the post at a faster rate.

Second, the average forces increased when impact speeds increased from 15 to 20 mph (24 to 32 km/h), but no substantial difference was observed between 20 and 25 mph (32 km/h and 40 km/h). The average force over 15 and 20 inches (381 and 508 mm) of deflection was increased by approximately 50 percent when the impact velocity increased from 15 to 20 mph (24 to 32 km/h). However, these average forces were increased by less than 5 percent when the impact velocity was increase from 20 to 25 mph (32 km/h to 40 km/h). Further testing would be required to determine if this phenomenon was the result of the soil inertia, the dynamic properties of the soil, or some other cause.

4.5 COMPARISON TO PREVIOUS W6X9 (W152X13.4) STEEL POST TESTING

After the first round of dynamic testing, the results of the 6-in. x 8-in. (152-mm x 203-mm) wood post testing were compared to previous testing of W6x9 (W152x13.4) steel posts conducted in AASHTO Grading B strong soil with embedment depths of 40 in. (1,016 mm) [5-6]. The results from the previous tests, nos. MGS2-1B18 through MGS2-1B21, may have slightly different values in this report than published by Dey et al. due to an improved method of filtering the raw electronic data. [6] The new analysis method was used for all test results presented in this report.

4.5.1 Comparison of 20 mph (32 km/h) Tests

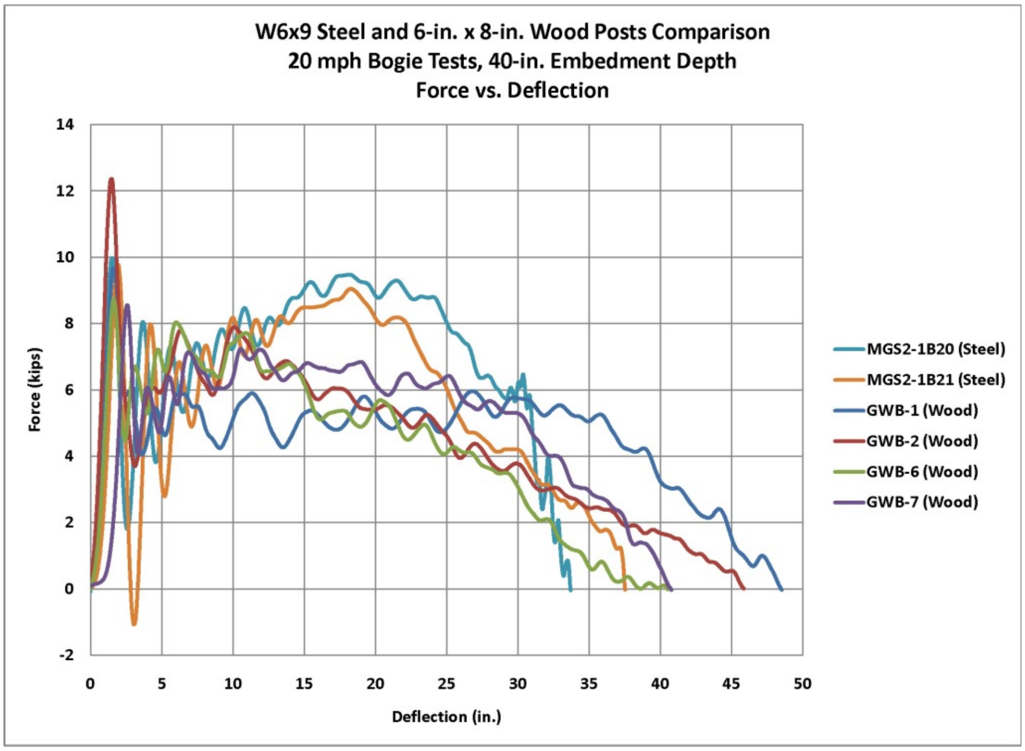
Results from the four 6-in. x 8-in. (152-mm x 203-mm) wood post bogie tests conducted at speeds of 20 mph (32 km/h) were compared to the results of two W6x9 (W152x13.4) steel post tests conducted at 20 mph (32 km/h). The tests are summarized in Table 9. The force vs. deflection and energy vs. deflection curves are shown in Figure 37. The shape and magnitude of the force vs. deflection curves were similar between the two post types. However, the steel W6x9 (W152x13.4) posts provided 20 to 30 percent higher resistive forces between 15 and 25 in. (381 and 635 mm) of deflection. Consequently, the steel posts absorbed more energy toward the end of the tests, but the total energy absorbed was similar for all tests. Thus, the steel W6x9 (W152x13.4) posts and the 6-in. x 8-in. (152-mm x 203-mm) wood posts were deemed to have comparable overall post-soil resistive characteristics when impacted at 20 mph (32 km/h). However, it should be noted that the W6x9 (W152x13.4) steel posts buckled just below ground line, thus preventing direct comparison of soil-only resistive forces.

4.5.2 Comparison of 15 mph (24 km/h) Tests

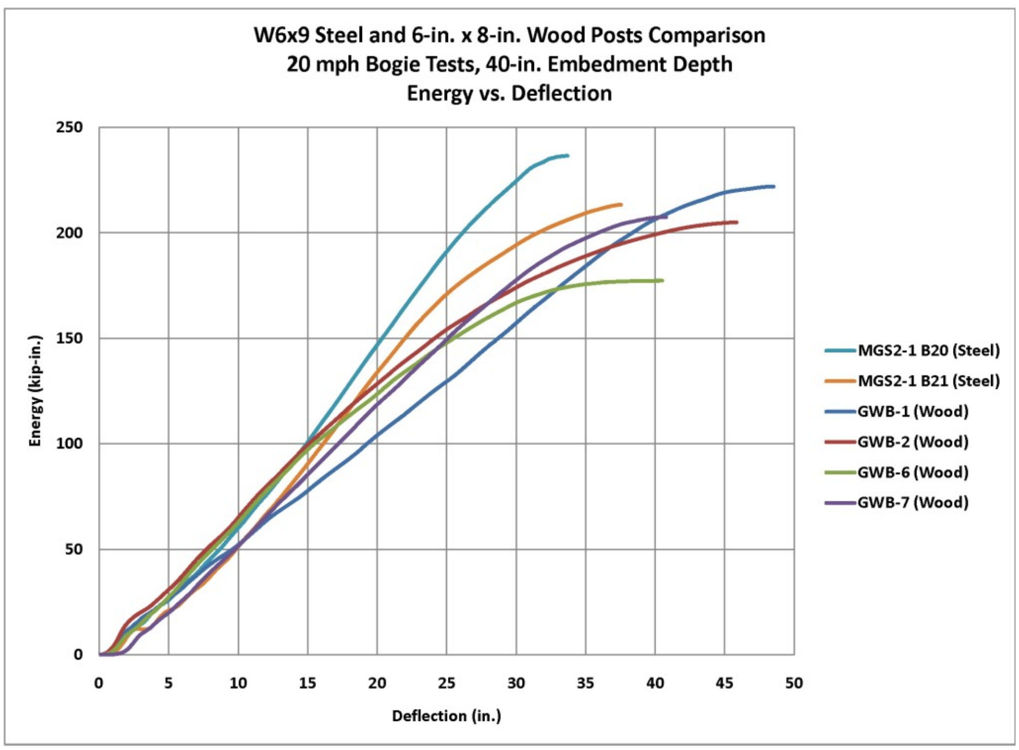
Results from the four 6-in. x 8-in. (152-mm x 203-mm) wood post bogie tests conducted at speeds of 15 mph (24 km/h) were compared to the results of two W6x9 (W152x13.4) steel post tests conducted at 15 mph (24 km/h) The tests are summarized in Table 10. Force vs. deflection and energy vs. deflection curves are shown in Figure 38. The initial stiffness of the posts was similar, but the behavior of the steel and wood posts differed greatly after the initial inertial spike. The forces were much higher for the steel post, thus stopping the bogie in a shorter distance. Note the W6x9 (W152x13.4) steel posts did not buckle during these tests. Thus, the post-soil resistances for the wood and steel posts did not compare well during testing with impact speeds of 15 mph (24 km/h).

Table 9. Round 1 Testing Results - W6x9 (W152x13.4) Steel Posts vs. 6-in. x 8-in. (152-mm x 203-mm) Wood Posts with 40-in. Embedment Depth at 20 mph.

Test No.	Soil Gradation	Impact Velocity	Peak Force		Average Force		Total Energy	Maximum Deflection	Failure Type
			Force	Deflection	@ 15 in.	@ 20 in.			
		mph (km/h)	kips (kN)	in. (mm)	kips (kN)	kips (kN)	kip-in. (kJ)	in. (mm)	
6-in. x 8-in. (152-mm x 203-mm) SYP Wood Posts									
GWB-1	AASHTO Grading B (strong soil) - Y	20.7 (33.3)	9.7 (43.0)	1.6 (40)	5.2 (23.1)	5.2 (23.1)	222.0 (25.1)	48.5 (1,233)	Rotation in Soil
GWB-2	AASHTO Grading B (strong soil) - Y	19.8 (31.8)	12.3 (54.9)	1.5 (39)	6.6 (29.5)	6.4 (28.6)	205.0 (23.2)	45.9 (1,165)	Rotation in Soil
GWB-6	AASHTO Grading B (strong soil) - X	19.6 (31.5)	8.7 (38.9)	1.6 (41)	6.5 (28.8)	6.2 (27.5)	177.3 (20.0)	40.5 (1,029)	Rotation in Soil
GWB-7	AASHTO Grading B (strong soil) - Y	19.0 (30.6)	8.6 (38.0)	2.6 (66)	5.7 (25.3)	5.9 (26.4)	207.5 (23.4)	40.8 (1,036)	Rotation in Soil
Average		19.8 (31.8)	9.8 (43.7)	1.8 (47)	6.0 (26.7)	5.9 (26.4)	202.9 (22.9)	43.9 (1,116)	
W6x9 (W152x13.4) Steel Posts									
MGS2-1B20	AASHTO Grading B Strong Soil	19.3 (31.1)	10.0 (44.4)	1.5 (38)	6.7 (29.8)	7.3 (32.6)	236.5 (26.7)	33.7 (856)	Rotation in Soil
MGS2-1B21	AASHTO Grading B Strong Soil	19.8 (31.8)	9.8 (43.5)	2.0 (50)	6.0 (26.8)	6.7 (29.8)	213.4 (24.1)	37.5 (953)	Rotation in Soil
Average		19.6 (31.5)	9.9 (43.9)	1.7 (44)	6.4 (28.3)	7.0 (31.2)	224.9 (25.4)	35.6 (905)	



a. Force vs. Deflection

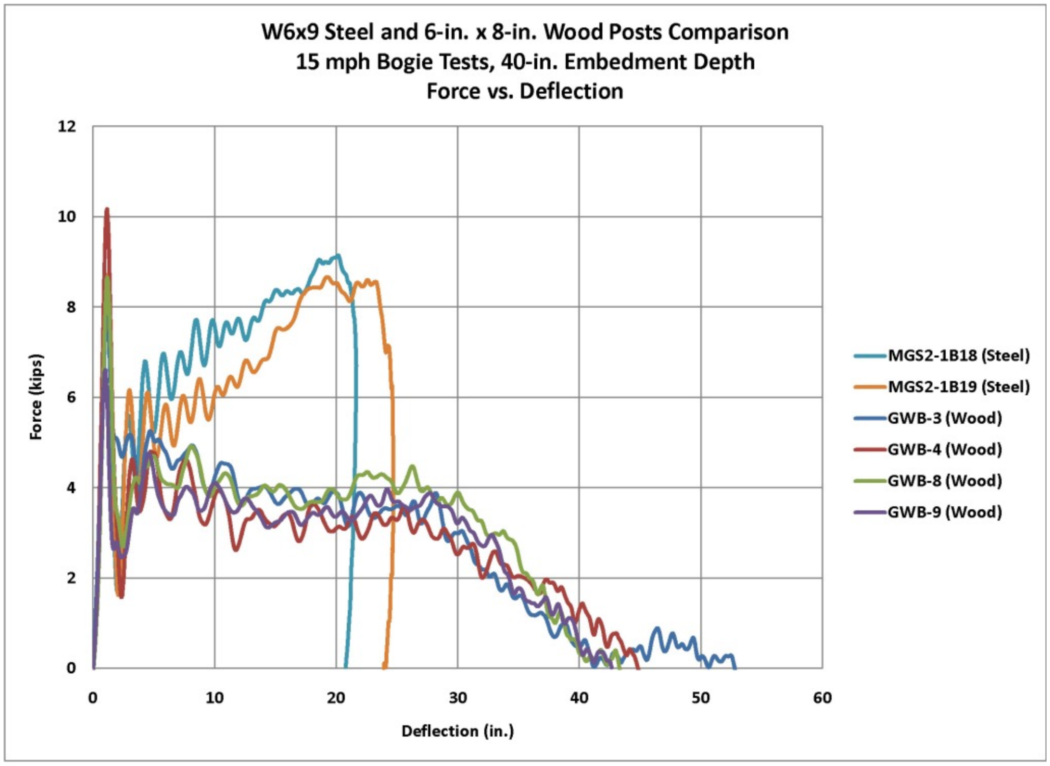


b. Energy vs. Deflection

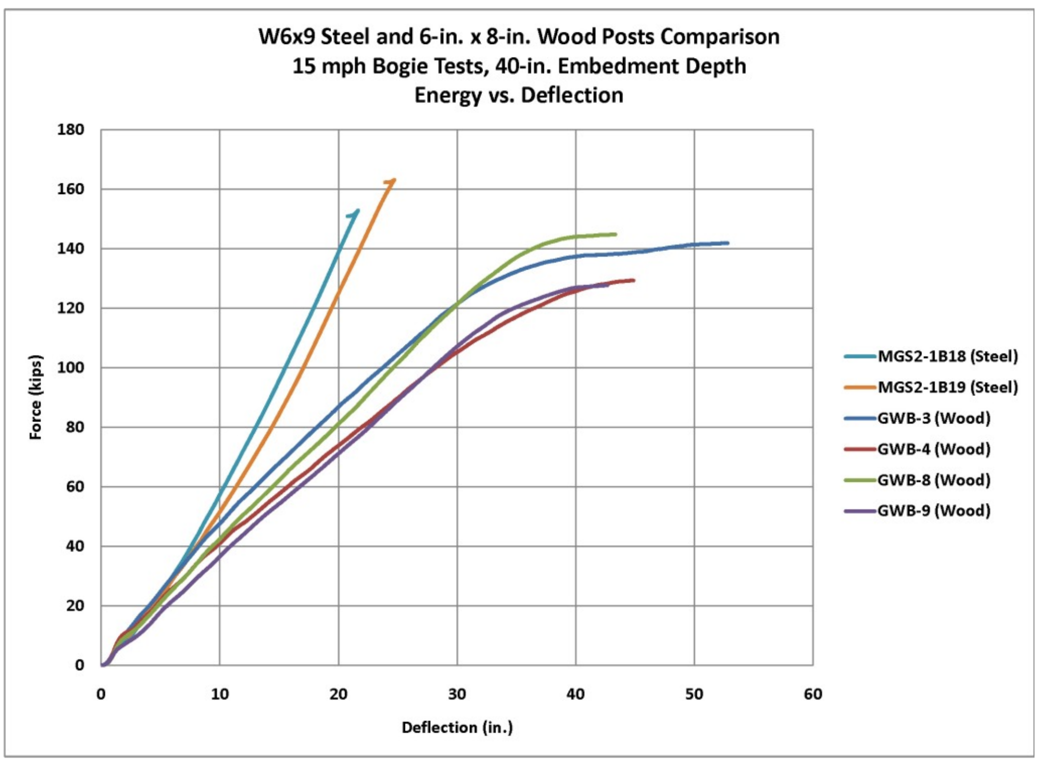
Figure 37. Graph. Force vs. Deflection and Energy vs. Deflection of Wood and Steel Post Comparison at 20 mph.

Table 10. Round 1 Testing Results - W6x9 (W152x13.4) Steel Posts vs. 6-in. x 8-in. (152-mm x 203-mm) Wood Posts with 40-in. Embedment Depth at 15 mph.

Test No.	Soil Gradation	Impact Velocity	Peak Force		Average Force		Total Energy	Maximum Deflection	Failure Type
			Force	Deflection	@ 15 in.	@ 20 in.			
		mph (km/h)	kips (kN)	in. (mm)	kips (kN)	kips (kN)	kip-in. (kJ)	in. (mm)	
Wood (SYP) 6-in. x 8-in. (152-mm x 203-mm) Posts									
GWB-3	AASHTO Grading B (strong soil) - Y	15.1 (24.4)	8.3 (36.9)	1.1 (27)	4.5 (20.1)	4.3 (19.3)	141.9 (16.0)	52.8 (1,341)	Rotation in Soil
GWB-4	AASHTO Grading B (strong soil) - Y	14.3 (23.1)	10.2 (45.2)	1.2 (30)	3.8 (17.1)	3.7 (16.4)	129.3 (14.6)	44.9 (1,140)	Rotation in Soil
GWB-8	AASHTO Grading B (strong soil) - Y	15.1 (24.3)	8.7 (38.5)	1.2 (29)	4.1 (18.5)	4.1 (18.0)	144.9 (16.4)	43.3 (1,101)	Rotation in Soil
GWB-9	AASHTO Grading B (strong soil) - Y	14.5 (23.3)	6.6 (29.4)	1.0 (26)	3.6 (16.1)	3.6 (15.8)	127.7 (14.4)	42.7 (1,085)	Rotation in Soil
Average		14.8 (23.8)	8.4 (37.5)	1.1 (28)	4.0 (16.1)	3.9 (17.4)	136.0 (15.4)	45.9 (1,166)	
Steel W6x9 (W152x13.4) Posts									
MGS2-1B18	NCHRP 350 Strong Soil	15.4 (24.8)	9.1 (40.7)	20.2 (512)	6.4 (28.3)	6.9 (30.8)	152.9 (17.3)	21.7 (550)	Rotation in Soil
MGS2-1B19	NCHRP 350 Strong Soil	15.9 (25.6)	8.7 (38.8)	1.2 (31)	5.6 (25.0)	6.2 (27.8)	163.2 (18.4)	24.7 (628)	Rotation in Soil
Average		15.6 (25.2)	8.9 (39.7)	10.7 (272)	6.0 (26.7)	6.6 (29.3)	158.1 (17.9)	23.2 (589)	



a. Force vs. Deflection



b. Energy vs. Deflection

Figure 38. Graph. Energy vs. Deflection of Wood and Steel Post Comparison at 15 mph.

4.6 ROUND 1 CONCLUSIONS

The first round of dynamic testing demonstrated that wood posts placed in strong soil produced lower than expected post-soil resistive forces, and the results were inconsistent with previous wood post testing. [4] Following test nos. GWB-1 through GWB-4, a different soil mixture, soil "X", was used instead of the "Y" mixture used in the first four tests. Both mixtures met the requirements for AASHTO Grading B strong soil, but soil "X" had fewer fines. However, both soil mixtures produced similar results. Thus, the post-soil behavior in all of the dynamic tests of wood posts may have been influenced by inconsistent soil compaction. The test results still provided information on the dynamic behavior of the SYP wood posts in soil, which could be compared to the results from W6x9 (W152x13.4) steel post testing. Therefore, the data was deemed useful in designing guardrail systems for use on a wire-faced, MSE wall.

Test nos. GWB-1 through GWB-11 provided consistent post-soil data for the 6-in. x 8-in. (152-mm x 203-mm) wood posts at each impact speed. No posts fractured or showed signs of fracturing, thus the SYP wood posts had sufficient bending strength for the observed force levels generated in the soil. However, the observed post-soil resistances were lower than expected. Further testing in stiffer/more compact soil is necessary to evaluate the post strength.

Comparison of the test results for the 6-in. x 8-in. (152-mm x 203-mm) wood posts and W6x9 (W152x13.4) steel posts was inconclusive, assuming that the wood and steel posts have comparable post-soil behavior. The tests at 20 mph (32 km/h) produced similar force vs. deflection curves and absorbed similar amounts of energy even though the steel posts developed significantly greater resistive forces between 15 and 25 in. (381 and 635 mm) of deflection. However, the steel posts generated much greater resistive forces than the wood posts in the tests conducted at 15 mph (24 km/h). Test no. GWB-5 demonstrated that the MSE wall-facing limestone rock produced lower resistive forces and absorbed less energy than the posts placed in standard strong soil.

Following the completion of the first round of dynamic testing, two items required further investigation. First, the ability for 6-in. x 8-in. (152-mm x 203-mm) wood posts to replace W6x9 (W152x13.4) steel posts was uncertain. The force vs. deflection behavior for both post types was similar for certain conditions, but significantly different for others. The W6x9 (W152x13.4) steel posts used in previous testing deformed plastically, thus it was difficult to use in comparisons with different post-soil resistances. Second, the inconsistent compaction of the soil may have influenced the results observed in the first round of testing. The performance of the wood posts embedded in a stiffer, stronger, more compacted soil remains unknown. Thus, additional dynamic bogie tests are recommended.

CHAPTER 5. ROUND 2 DYNAMIC TESTING – POSTS ON FLAT TERRAIN

5.1 PURPOSE

The first round of dynamic testing provided insight into the effects of impact velocity and soil gradation on the resistance of a post rotating through soil. When the results of these wood post tests were compared to previously conducted steel post bogie tests, the overall characteristics were similar for both post types. But, discrepancies in force magnitudes at certain deflections also occurred. It was unclear whether these differences were the result of the different post types, differing soil gradations, or compaction methods. Therefore, the soil resistance for both wood and steel posts was further investigated under identical circumstances.

The *Manual for Assessing Safety Hardware* (MASH) identifies strong, stiff soils as the critical soil type (over weaker soils) when evaluating a longitudinal guardrail system's safety performance. [9] Thus, it was desired to evaluate the post-soil behavior in a very stiff soil. Similar to the first round of dynamic testing, a soil satisfying the AASHTO Grading B strong soil criteria was utilized. However, a high-energy compaction method was utilized for the second round of dynamic testing. This newer compaction method resulted in both a more consistent, stiff soil having greater density.

Previously, dynamic testing of W6x9 (W152x13.4) steel posts revealed plastic bending and soil displacement. [6] It was desired to limit these deformations since the current round of testing was aimed to quantify the soil resistance, not the strength of the posts themselves. Therefore, W6x16 (W152x23.8) steel posts were selected in place of the standard W6x9 (W152x13.4) steel posts in order to provide the posts with additional strength and resistance to plastic deformations. The two cross-sections have the same depth and flange width, so the soil resistance on either post would be the same.

5.2 SCOPE

For the second round of dynamic testing, a total of four tests were conducted. Test nos. GWB-12 and GWB-13 were conducted on W6x16 (W152x23.8) steel posts, and test nos. GWB-14 and GWB-15 were conducted on 6-in. x 8-in. (152-mm x 203-mm) wood posts. Both post types were embedded 40 in. (1,016 mm) in a well compacted AASHTO Grading B strong soil and impacted 24⅞ in. (632 mm) above the groundline. The target impact speed was 20 mph (32 km/h) for all four tests. The test matrix is shown in Table 11, and details of the two wood posts are shown in Table 12.

Table 11. Round 2 Dynamic Testing Matrix.

Test No.	Post		Soil Type	Embedment Depth in. (mm)	Target Impact Velocity mph (km/h)	Bending Axis
	Type	Size in. (mm)				
GWB-12	Steel	W6x16 (W152x23.8)	AASHTO Grading B (Strong Soil)	40 (1,016)	20 (32)	Strong
GWB-13	Steel	W6x16 (W152x23.8)	AASHTO Grading B (Strong Soil)	40 (1,016)	20 (32)	Strong
GWB-14	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (Strong Soil)	40 (1,016)	20 (32)	Strong
GWB-15	Wood (SYP)	6x8 (152x203)	AASHTO Grading B (Strong Soil)	40 (1,016)	20 (32)	Strong

Table 12. Round 2 Wood Post Details.

Test No.	Post Dimensions in. (mm)		Moisture Content (%)			Weight lb (kg)	Ring Density rings/in. (rings/cm)
	@ Top	@ Bottom	16 in. (406 mm) Above Ground Line	Ground Line	20 in. (508 mm) Below Ground Line		
GWB-14	6 x 8-1/4 (152 x 210)	6 x 8-1/4 (152 x 210)	13	13	14	68.8 (31.2)	3 (1.18)
GWB-15	6 x 8 (152 x 203)	6 x 7-7/8 (152 x 200)	13	13	12	81.6 (37.0)	5 (1.97)

5.3 ROUND 2 RESULTS

The accelerometer data for each test was processed in a manner discussed in Section 3.6. Individual test results are provided in Appendix A for all accelerometers used for each test.

5.3.1 Test No. GWB-12

During test no. GWB-12, the bogie impacted the W6x16 (W152x23.8) steel post at a speed of 19.0 mph (30.6 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil to a maximum deflection of 33.8 in. (860 mm) and showed no signs of yielding or buckling. The bogie impact head lost contact with the post after 0.200 seconds, and the bogie overrode the post.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 39. The resistive force quickly increased to around 12 kips (53 kN) and remained relatively constant through a deflection of 11 in. (279 mm). After this plateau, the force steadily decreased until reaching zero at a deflection of 33.8 in. (860 mm). The maximum resistive force was 12.8 kips (57.1 kN), and the post rotating in soil absorbed a total of 236.1 kip-in. (26.7 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 40.

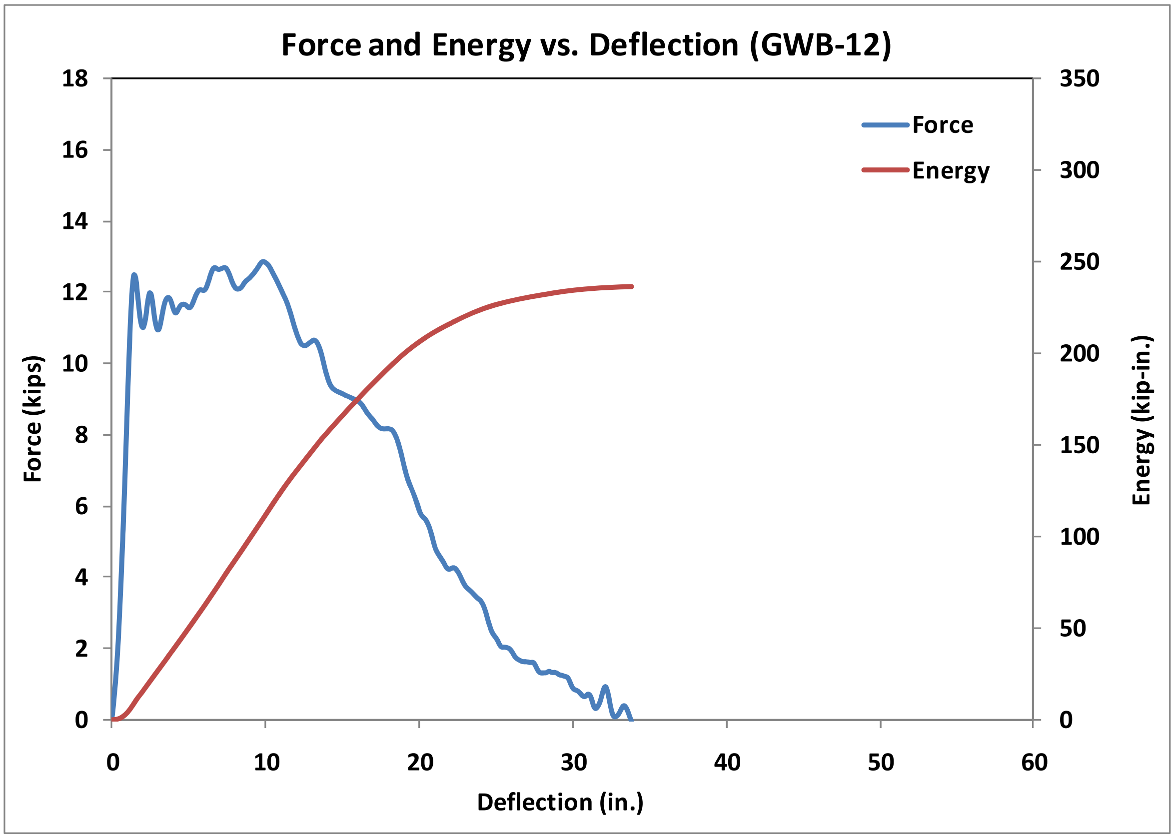
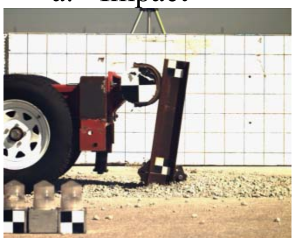


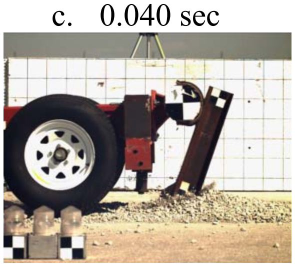
Figure 39. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-12.

a. Impact

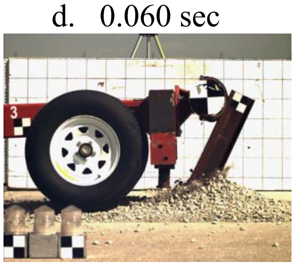


b. 0.020 sec

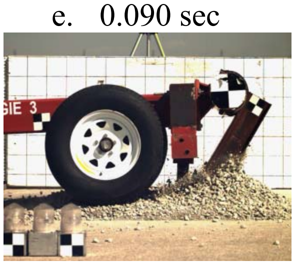
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front Quarter View

Figure 40. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-12.

5.3.2 Test No. GWB-13

During test no. GWB-13, the bogie impacted the W6x16 (W152x23.8) steel post at a speed of 19.2 mph (30.8 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil to a maximum deflection of 31.3 in. (795 mm) and showed no signs of yielding or buckling. The bogie impact head lost contact with the post after 0.186 seconds, and the bogie overrode the post.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 41. Similar to test no. GWB-12, the resistive force quickly increased to approximately 12 kips (53 kN) and stayed relatively constant for a deflection of 10 in. (254 mm). After this plateau, the force steadily decreased until reaching zero at a deflection of 31.3 in. (795 mm). The maximum resistive force was 12.8 kips (57.1 kN), and the post rotating in soil absorbed a total of 247.7 kip-in. (28.0 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 42.

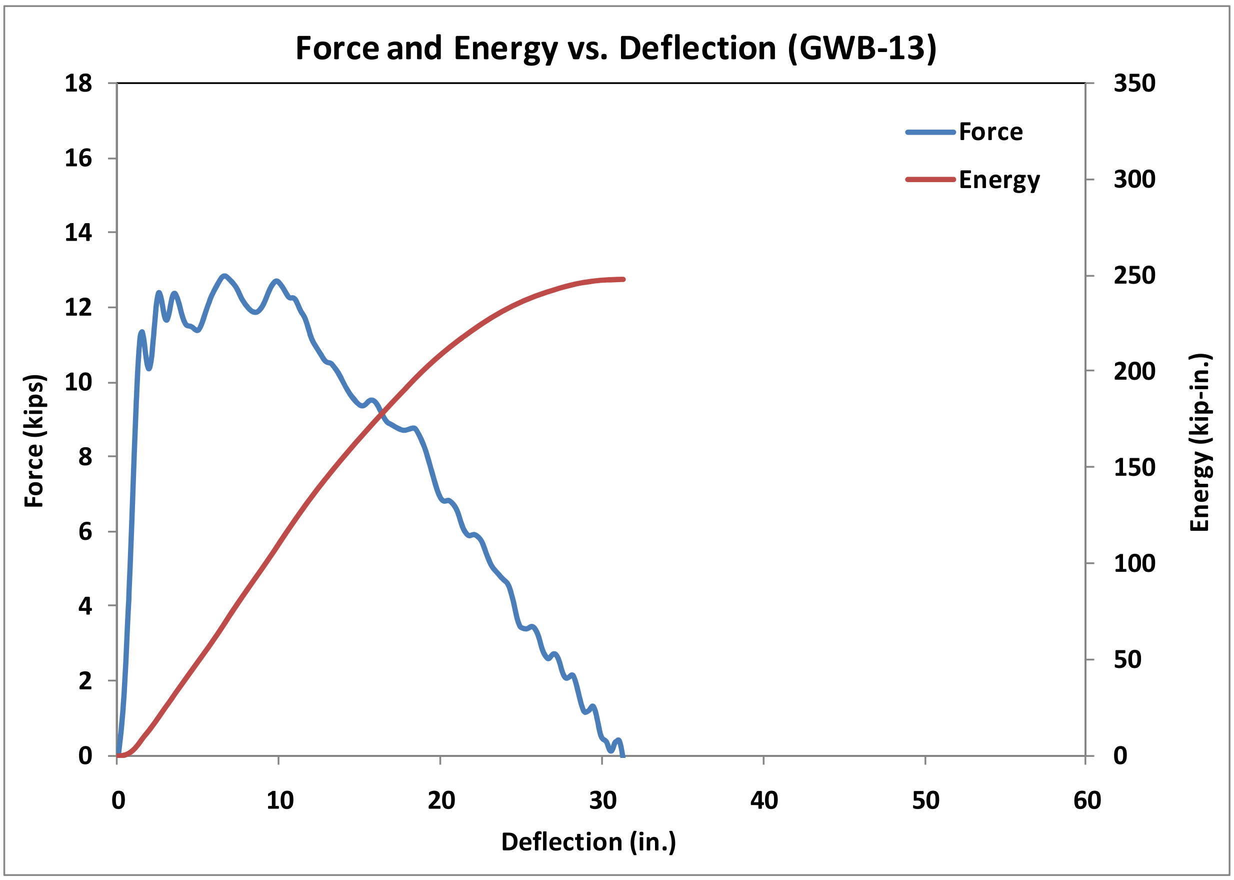
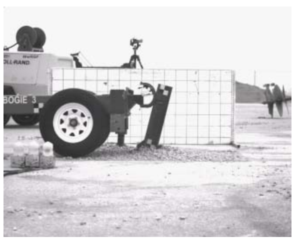


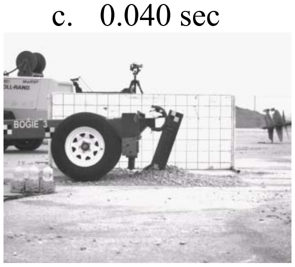
Figure 41. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-13.

a. Impact

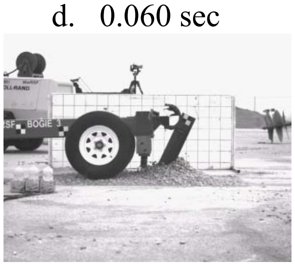
b. 0.020 sec



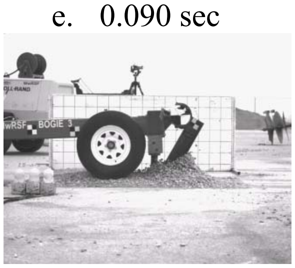
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front Quarter View

Figure 42. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-13.

5.3.3 Test No. GWB-14

During test no. GWB-14, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 19.3 mph (31.0 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil and showed no signs of fracturing. The bogie impact head lost contact with the post after 0.171 seconds, and the bogie overrode the post.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 43. The resistive force quickly increased to a maximum of 14.6 kips (65.0 kN) and then maintained an average force of 13 kips (58 kN) through a deflection of approximately 11 in. (279 mm). The force then steadily decreased to zero at a deflection of 31.7 in. (805 mm). The post rotating in soil absorbed a total of 232.0 kip-in. (26.2 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 44.

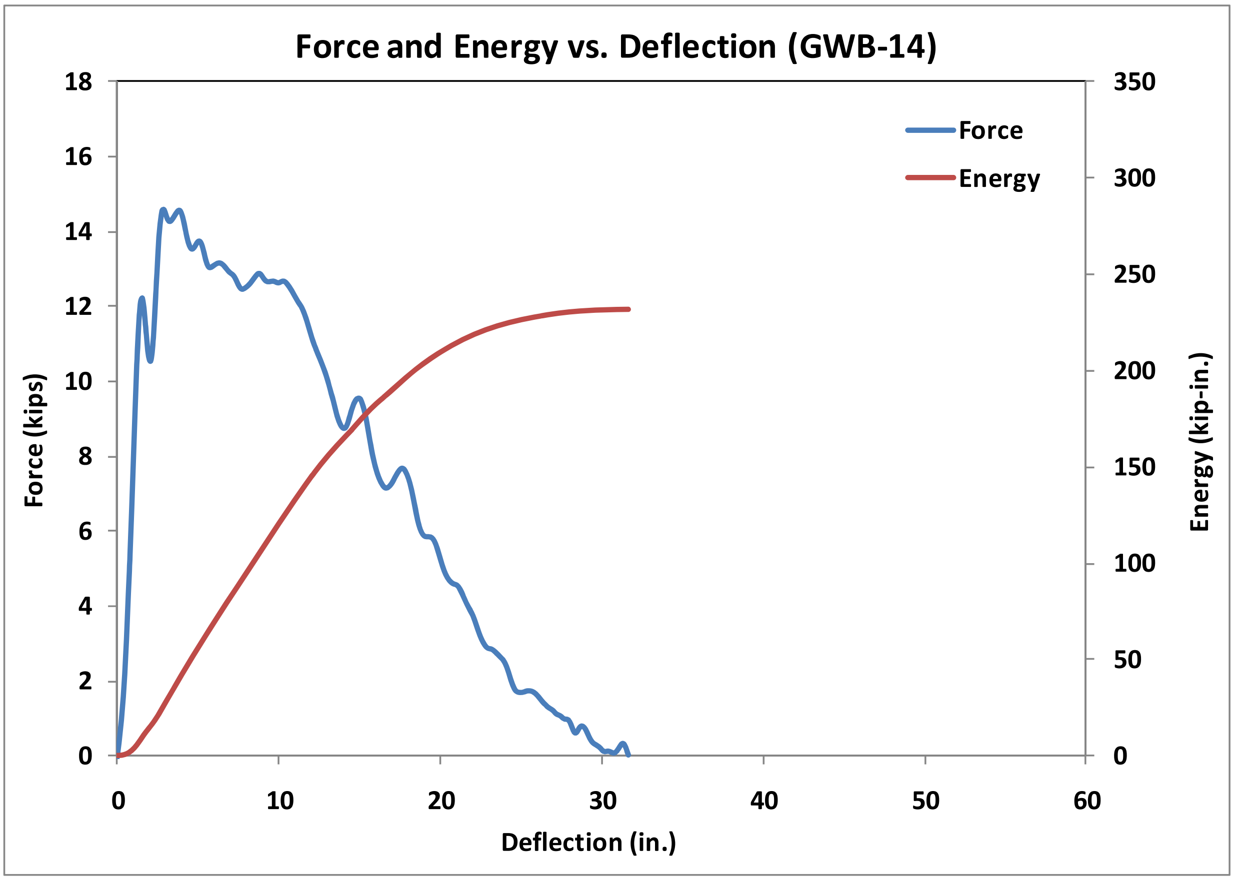
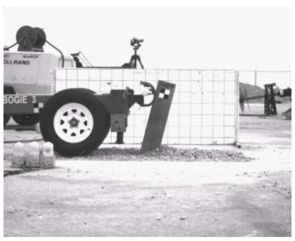


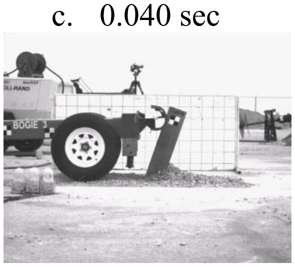
Figure 43. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-14.

a. Impact

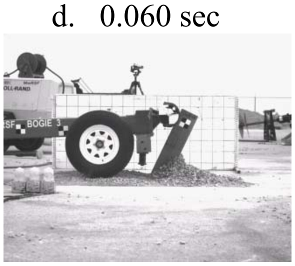
b. 0.020 sec



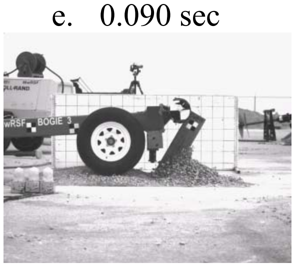
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front View

Figure 44. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-14.

5.3.4 Test No. GWB-15

During test no. GWB-15, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 19.6 mph (31.6 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil and showed no signs of fracturing. The bogie impact head lost contact with the post after 0.142 seconds, and the bogie overrode the post.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 45. The resistive force quickly increased to a maximum of 13.5 kips (60.2 kN) and remained relatively constant through a deflection of 11 in. (279 mm). The force then steadily decreased until reaching zero at a deflection of 30.0 in. (761 mm). The post rotating in soil absorbed a total of 225.6 kip-in. (25.5 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 46.

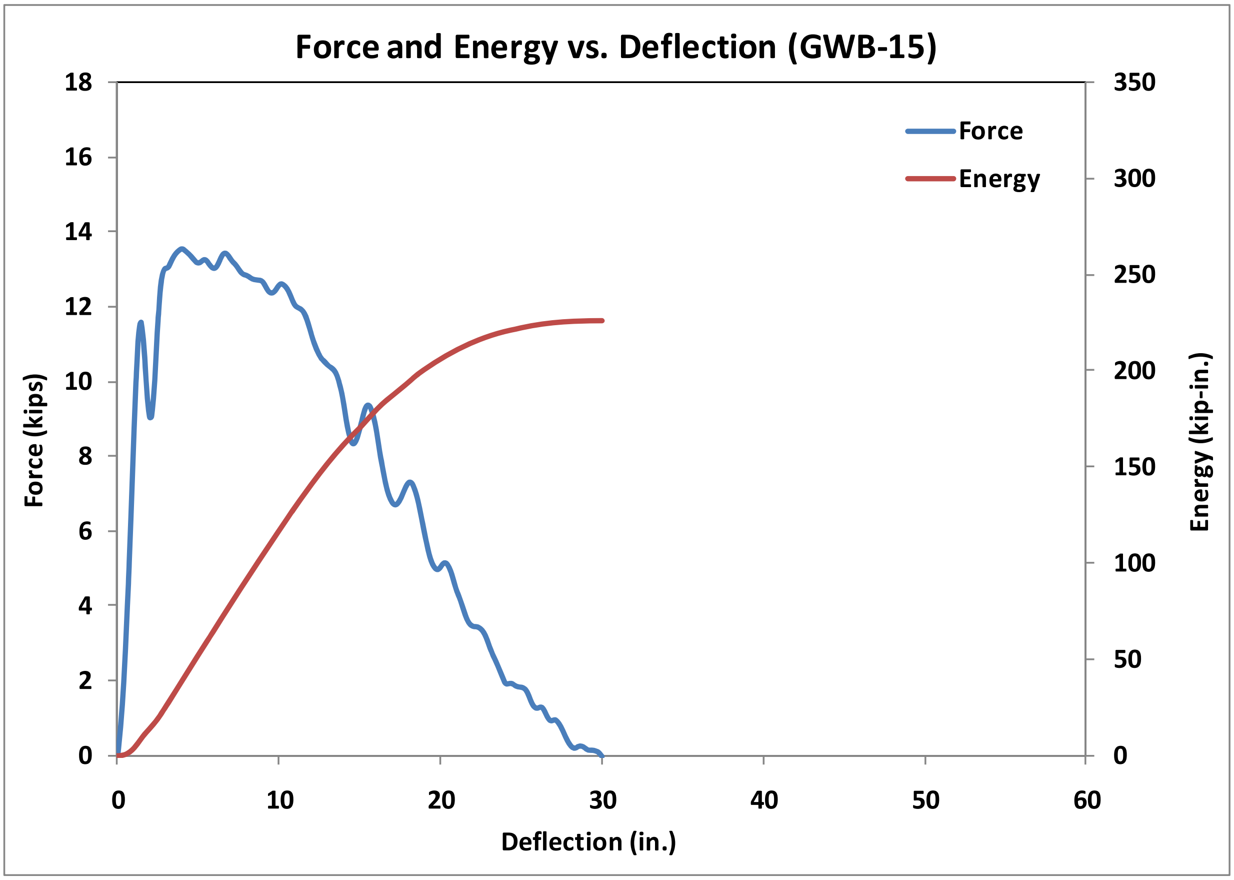
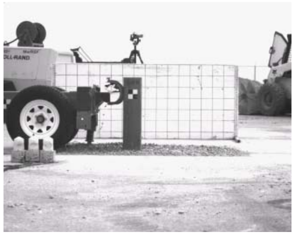
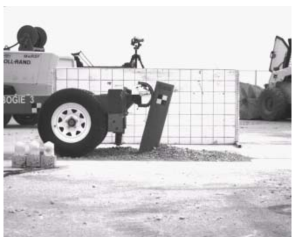


Figure 45. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWB-15.

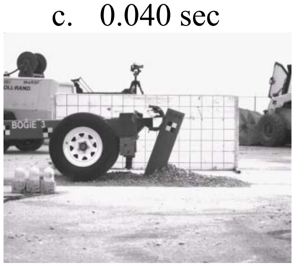


a. Impact

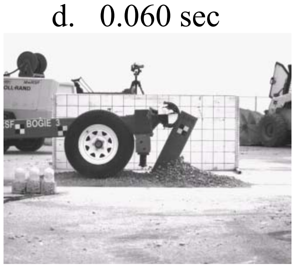
b. 0.020 sec



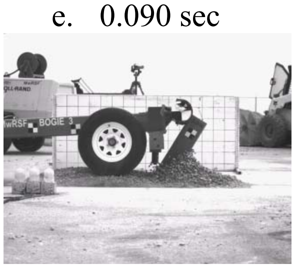
c. 0.040 sec



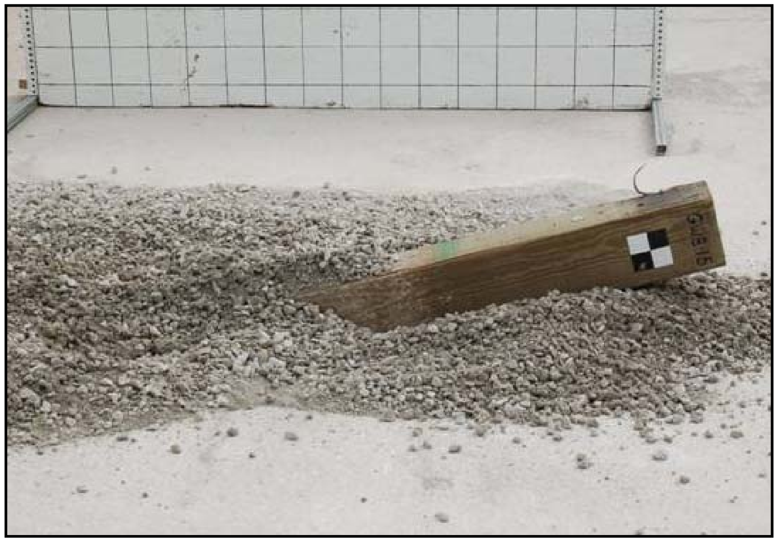
d. 0.060 sec



e. 0.090 sec



f. 0.120 sec



g. Post After Impact – Side view

h. Post After Impact – Front View

Figure 46. Photo. Time Sequential and Post-Impact Photographs, Test No. GWB-15.

5.4 ROUND 2 DISCUSSION AND CONCLUSIONS

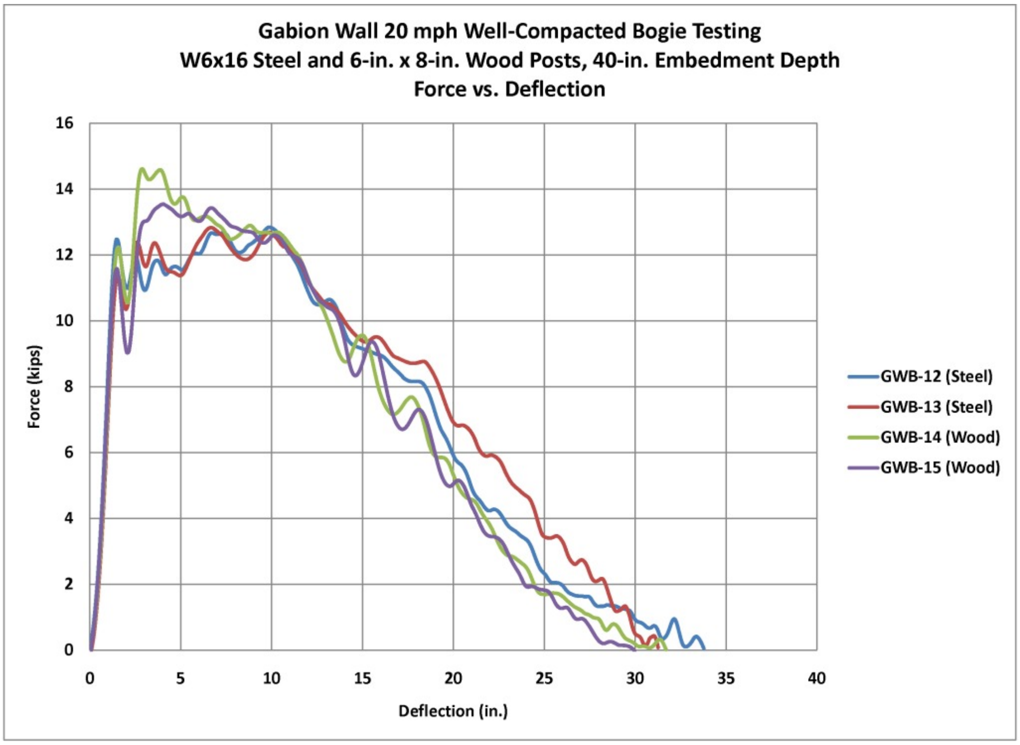
Test nos. GWB-12 and GWB-13 were performed with W6x16 (W152x23.8) steel posts, while test nos. GWB-14 and GWB-15 were performed with 6-in. x 8-in. (152-mm x 203-mm) wood posts. A summary of the second round of bogie testing is shown in Table 13, and force vs. deflection and energy vs. deflection curves are shown in Figure 47. The force vs. deflection curves for all four tests were similar in both shape and magnitude, but the forces in the wood posts were slightly higher between deflections of 3 and 7 in. (76 and 178 mm). The energy vs. deflection curves for both post types were very similar, and almost overlapped for the first 20 in. (508 mm) of deflection. The total absorbed energies were also similar, ranging from 225.6 k-in. to 247.7 k-in. (25.5 kJ to 28.0 kJ).

The second round of dynamic testing indicated that the soil resistances for 6-in. x 8-in. (152-mm x 203-mm) wood posts and a W6x16 (W152x23.8) steel posts are similar when tested in heavily-compacted soil meeting the AASHTO Grading B requirements. Since a W6x9 (W152x13.4) steel post has the same depth and flange width as a W6x16 (W152x23.8) post, the soil resistance for a W6x9 (W152x13.4) post is expected to be similar as well. This evidence supports the common assumption that 6-in. x 8-in. (152-mm x 203-mm) wood posts and W6x9 (W152x13.4) steel posts provide equivalent resistances for guardrail systems.

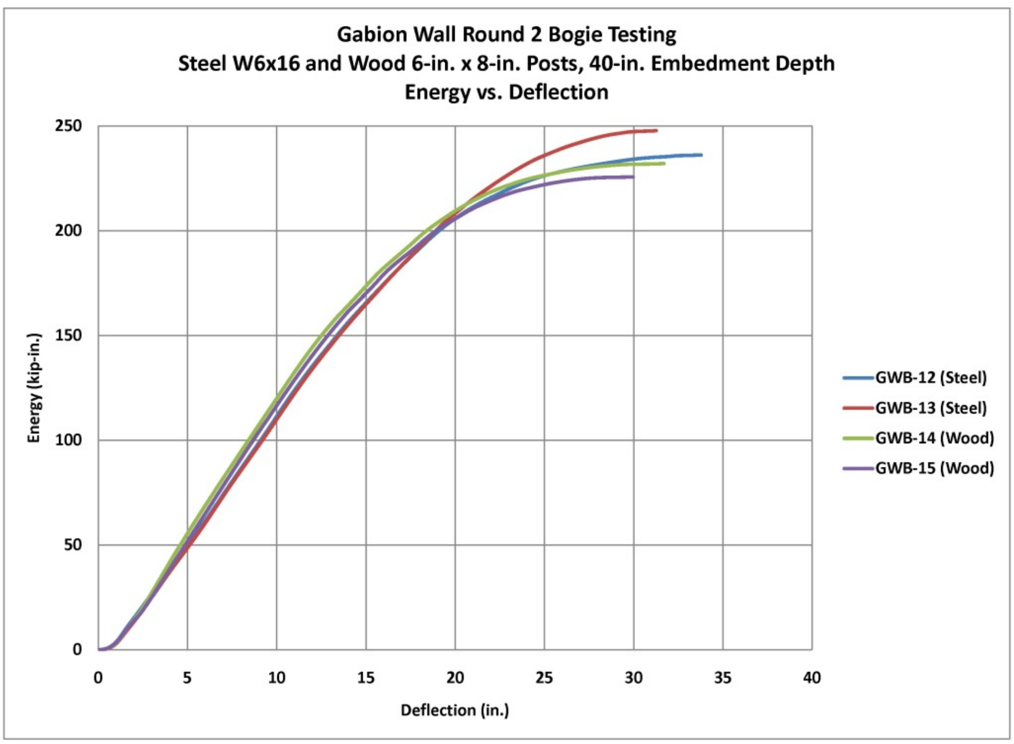
All tests comprising Round 2 were conducted in the same soil pit, used the same soil batch/gradation, and were installed with the same compaction equipment. Further, the heavily-compacted soil is believed to provide a critical condition for testing and evaluating longitudinal guardrail systems. Thus, the results from the Round 2 dynamic testing were believed to be more appropriate for comparing the dynamic performance of wood and steel posts.

Table 13. Round 2 Testing Results - W6x16 Steel Posts v.s 6-in. x 8-in. Wood Posts with 40-in. Embedment Depth at 20 mph.

Test No.	Impact Velocity	Peak Force		Average Force		Total Energy	Maximum Deflection	Failure Type
		Force	Deflection	@ 15 in.	@ 20 in.			
	mph (km/h)	kips (kN)	in. (mm)	kips (kN)	kips (kN)	kip-in. (kJ)	in. (mm)	
W6x16 (W152x23.8) Steel Posts								
GWB-12	19.0 (30.6)	12.8 (57.1)	9.9 (251)	11.0 (49.1)	10.3 (45.8)	236.1 (26.7)	33.8 (860)	Rotation in Soil
GWB-13	19.2 (30.8)	12.8 (57.1)	6.6 (169)	11.0 (48.9)	10.4 (46.3)	247.7 (28.0)	31.3 (795)	Rotation in Soil
Average	19.1 (30.7)	12.8 (57.1)	8.3 (210)	11.0 (49.0)	10.4 (46.1)	241.9 (27.3)	32.6 (828)	
6-in. x 8-in. (152-mm x 203-mm) SYP Wood Posts								
GWB-14	19.3 (31.0)	14.6 (65.0)	2.9 (74)	11.6 (51.5)	10.5 (46.6)	232.0 (26.2)	31.7 (805)	Rotation in Soil
GWB-15	19.6 (31.6)	13.5 (60.2)	4.0 (102)	11.3 (50.5)	10.3 (45.8)	225.6 (25.5)	30.0 (761)	Rotation in Soil
Average	19.5 (31.3)	14.1 (62.6)	3.5 (88)	11.5 (51.0)	10.4 (46.2)	228.8 (25.8)	30.8 (783)	



a. Force vs. Deflection



b. Energy vs. Deflection

Figure 47. Graph. Force vs. Deflection and Energy vs. Deflection, Round 2 Testing at 20 mph and Well-Compacted.

CHAPTER 6. ROUND 3 DYNAMIC TESTING – POSTS ON 3H:1V SLOPE

6.1 PURPOSE

The second round of dynamic testing demonstrated that the soil resistance of standard W6x16 (W152x23.8) steel and 6-in. x 8-in. (152-mm x 203-mm) wood posts in strong soil were similar when evaluated in flat terrain. However, the installation of guardrail systems adjacent to a wire-faced, MSE wall would likely result in the posts being installed on a fill slope and within the wire mesh reinforcement. Preliminary designs indicated that a 3H:1V fill slope would be placed on top of and adjacent to the outer edge of the MSE wall. Thus, the dynamic post-soil behavior of posts placed at the slope breakpoint of a 3H:1V fill slope was investigated.

It was anticipated that the loss of back-fill material due to the slope would result in lower post-soil resistance as compared to that observed for a post installed on flat terrain. However, the magnitude of the force reduction was unknown. Therefore, the third round of testing began with a post length of 7 ft (2.1 m) and an embedment depth of 52 in. (1,321 mm), and dimensions were modified as the testing progressed. Recall, the previous rounds of bogie testing and the MGS utilized a 6-ft (1.8-m) long, steel post with a 40-in. (1,016-mm) embedment depth.

It was also desired to investigate the effects of different post installation methods. The posts for the previous bogie tests had been installed by having a hole augered, positioning the post in the hole, backfilling the soil in 8-in. (203-mm) lifts (HE8), and tamping the soil around the post with heavy compaction method. For comparison, test no. GWR5-1 utilized a steel post that was driven into soil at the slope break point of an already compacted 3H:1V fill slope.

6.2 SCOPE

For the third round of dynamic testing, a total of eight tests were initially planned. Test nos. GWR4-1 through GWR4-4 were to be conducted with 6-in. x 8-in. (152-mm x 203-mm) wood posts, while test nos. GWR5-1 through GWR5-2 and GWR5-3 through GWR5-4 were to be conducted with W6x9 (W152x13.4) and W6x8.5 (W152x12.6) steel posts, respectively, as shown in Table 14. All eight tests were intended to evaluate the post-soil resistance for a post placed at the slope break point of a 3H:1V fill slope, as shown in Figure 48.

Test no. GWR4-1 was conducted on a 6-in. x 8-in. (152-mm x 203-mm) wood post. Test nos. GWR4-2 through GWR4-4 were not performed due to the failure observed in test no. GWR4-1. Details of the wood post used in test no. GWR4-1 are shown in Table 15.

Test nos. GWR5-1 and GWR5-2 were W6x9 (W152x13.4) steel posts, and test nos. GWR5-3 and GWR5-4 were W6x8.5 (W152x12.6) steel posts. For all tests, the posts were impacted 24⅞ in. (632 mm) above the ground line at a target impact speed of 20 mph (32 km/h). For test no. GWR5-1, the post was driven into the compacted soil. All of the posts were positioned at the slope break point of a 3H:1V fill slope at various embedment depths, as shown in Table 14. A highly-compacted, AASHTO Grading B strong soil was used for all tests.

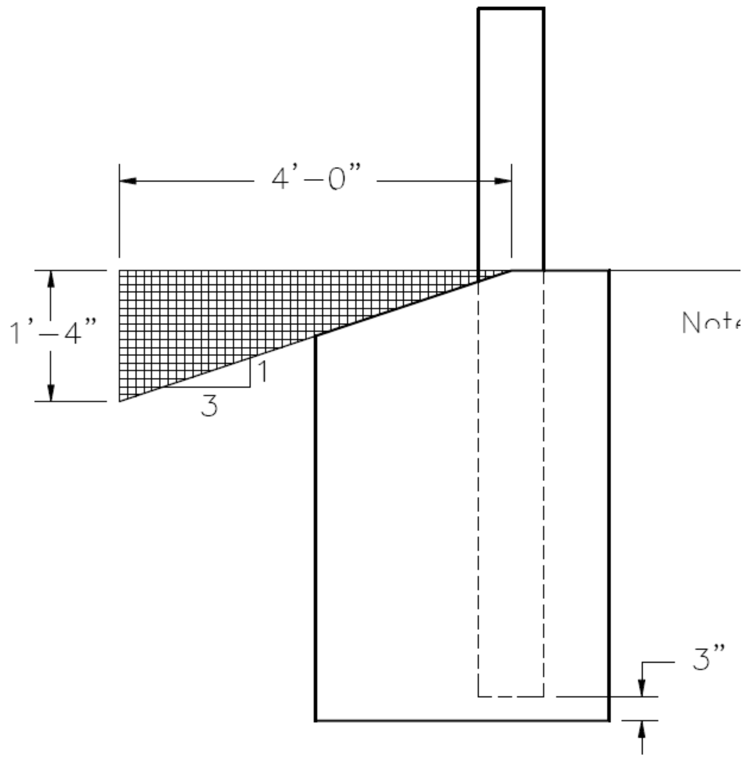
Table 14. Round 3 Dynamic Testing Matrix with Posts at 3H:1V Slope Break Point.

Test No.	Post			Soil Type	Embedment Depth in. (mm)	Target Impact Velocity mph (km/h)	Bending Axis
	Type	Size in. (mm)	Length in. (mm)				
GWR4-1	Wood (SYP)	6x8 (152x203)	84 (2,134)	AASHTO Grading B (strong soil)	52 (1,321)	20 (32)	Strong
GWR4-2 [1]	Wood (SYP)	6x8 (152x203)	84 (2,134)	AASHTO Grading B (strong soil)	52 (1,321)	20 (32)	Strong
GWR4-3 [1]	Wood (SYP)	6x8 (152x203)	96 (2,438)	AASHTO Grading B (strong soil)	64 (1,626)	20 (32)	Strong
GWR4-4 [1]	Wood (SYP)	6x8 (152x203)	96 (2,438)	AASHTO Grading B (strong soil)	64 (1,626)	20 (32)	Strong
GWR5-1 [2]	Steel	W6x9 (W152x13.4)	84 (2,134)	AASHTO Grading B (strong soil)	52 (1,321)	20 (32)	Strong
GWR5-2	Steel	W6x9 (W152x13.4)	84 (2,134)	AASHTO Grading B (strong soil)	52 (1,321)	20 (32)	Strong
GWR5-3	Steel	W6x8.5 (W152x12.6)	78 (1,981)	AASHTO Grading B (strong soil)	46 (1,168)	20 (32)	Strong
GWR5-4	Steel	W6x8.5 (W152x12.6)	72 (1,829)	AASHTO Grading B (strong soil)	40 (1,016)	20 (32)	Strong

[1] Tests were not conducted.
[2] Post driven.

Table 15. Round 3 Wood Post Details.

Test No.	Post Dimensions in. (mm)		Moisture Content (%)			Weight lb (kg)	Ring Density rings/in. (rings/mm)
	@ Top	@ Bottom	16 in. (406 mm) Above Ground Line	Ground Line	20 in. (508 mm) Below Ground Line		
GWR4-1	6 x 8 (152 x 203)	6 x 8 (152 x 203)	13	16	14	88 (40)	NA (Variable)



a. Drawing Profile View

b. Test Profile View

Figure 48. Photo. Round 3 Test Setup on 3H:1V Fill Slope.

6.3 ROUND 3 RESULTS

The accelerometer data for each test was processed in a manner discussed in Section 3.6. Individual test results are provided in Appendix A for all accelerometers used for each test.

6.3.1 Test No. GWR4-1

During test no. GWR4-1, the bogie impacted the 6-in. x 8-in. (152-mm x 203-mm) wood post at a speed of 20.5 mph (33.1 km/h) and at an orientation causing strong-axis bending in the post. The post deflected 1.5 in. (38 mm) before fracture was initiated approximately 0.004 seconds after impact. Fracture occurred 18 in. (457 mm) below ground level at a knot on a side face of the post. The maximum deflection was 4.1 in. (104 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 49. The resistive force reached a peak of 11.1 kips (49.5 kN) when the post fractured. At the time of peak resistive force, the energy reached 8.1 kip-in. (0.9 kJ). After fracturing, the post continued to apply small resistive forces to the bogie, resulting in a total energy absorption of 21.0 kip-in. (2.4 kJ) at a deflection of 4.1 in. (104 mm). Time-sequential photographs and post-impact photographs are shown in Figure 50.

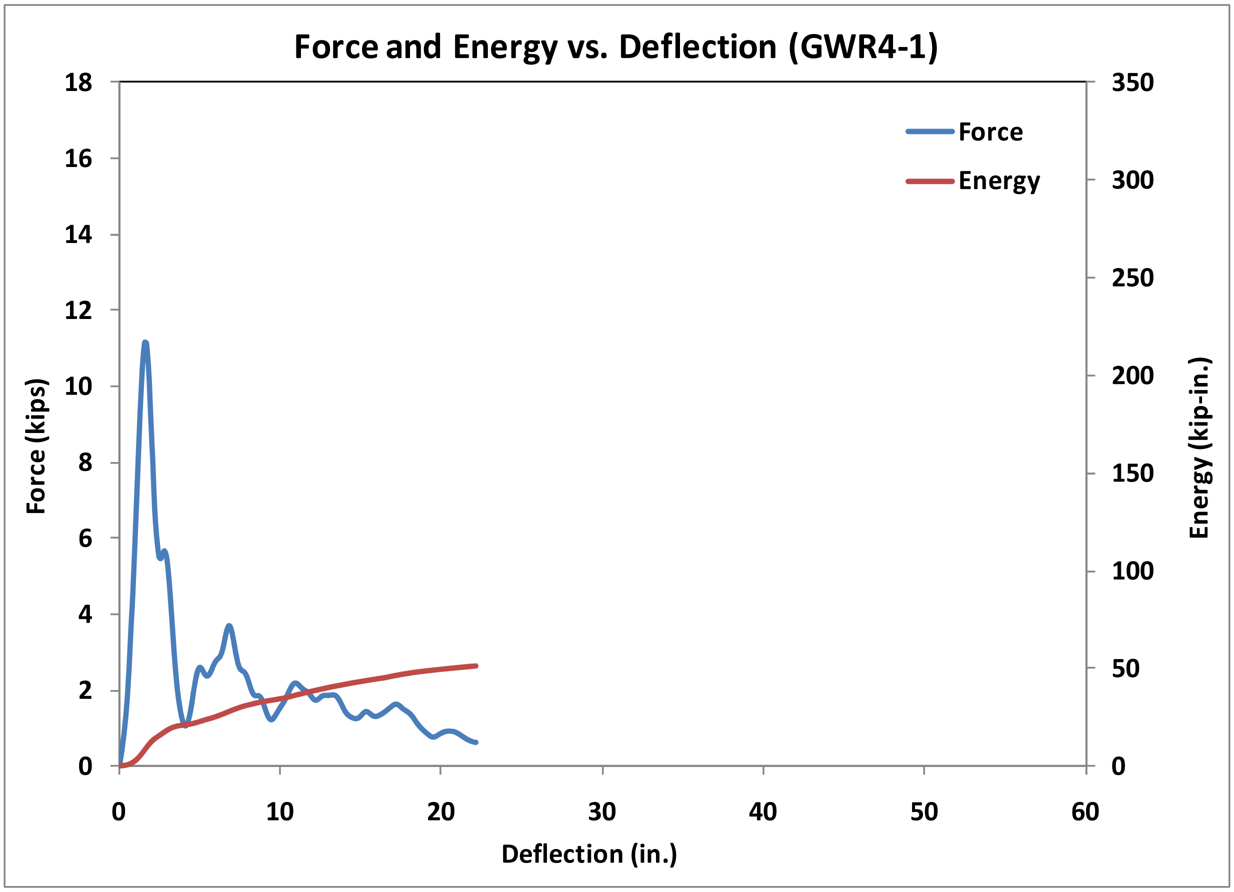
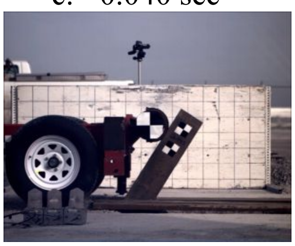


Figure 49. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWR4-1.

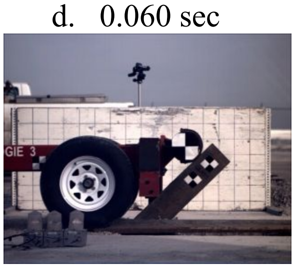
a. Impact

b. 0.020 sec

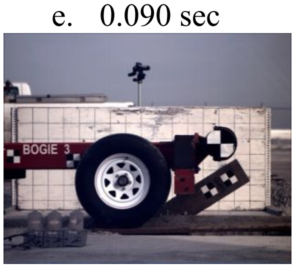
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Full View of Post After Impact

i. Close up of Post Fracture

Figure 50. Photo. Time Sequential and Post-Impact Photographs, Test No. GWR4-1.

6.3.2 Test No. GWR5-1

During test no. GWR5-1, the bogie impacted the W6x9 (W152x13.4) steel post at a speed of 20.0 mph (32.1 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 35.4 in. (900 mm). The twisting in the post appeared to occur after 18 in. (457 mm) of deflection.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 51. The resistive force quickly increased to a peak of 15.1 kip (67.2 kN), then steadily declined to zero at the maximum deflection of 35.4 in. (900 mm). The post rotating in soil absorbed a total of 237.4 kip-in. (26.8 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 52. It should be noted that due to technical difficulties, the EDR-4 accelerometer data acquired during test no. GWR5-1 was unusable for analysis.

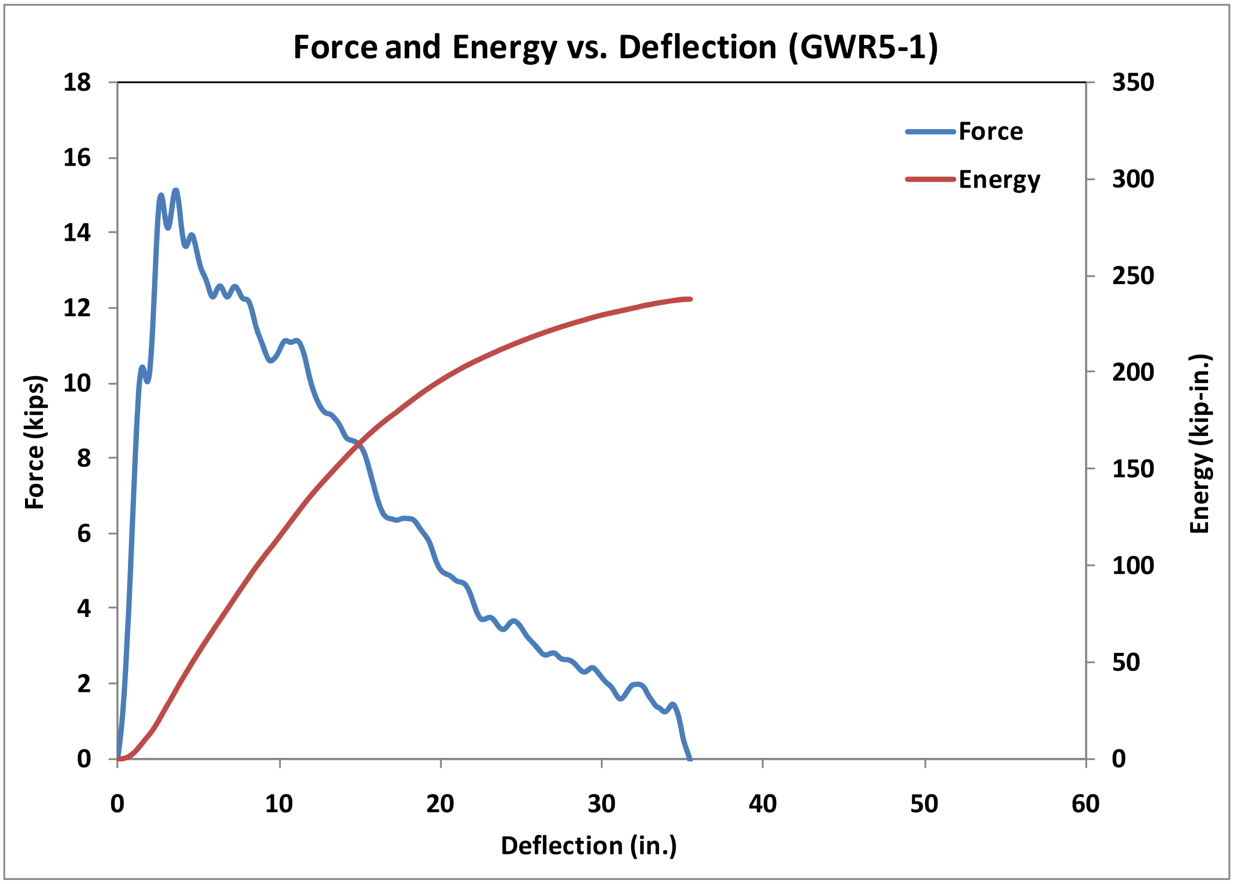
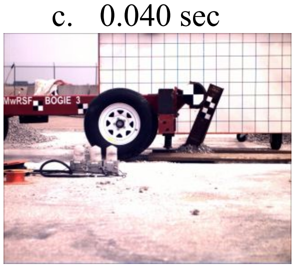


Figure 51. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWR5-1.

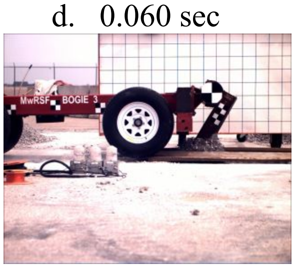
a. Impact

b. 0.020 sec

c. 0.040 sec



d. 0.060 sec



e. 0.090 sec

f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front View

i. Post After Impact – Removed, Showing Deformation

Figure 52. Photo. Time Sequential and Post-Impact Photographs, Test No. GWR5-1.

6.3.3 Test No. GWR5-2

During test no. GWR5-2, the bogie impacted the W6x9 (W152x13.4) steel post at a speed of 20.8 mph (33.5 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 33.2 in. (844 mm) when the bogie overrode the post at 0.142 seconds after impact. The twisting in the post began at 20 in. (508 mm) of deflection.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 53. The resistive force quickly increased to a peak of 15.6 kips (69.5 kN) and then steadily declined to zero at the maximum deflection of 33.2 in. (844 mm). The post rotating in soil absorbed a total of 251.2 kip-in. (28.4 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 54.

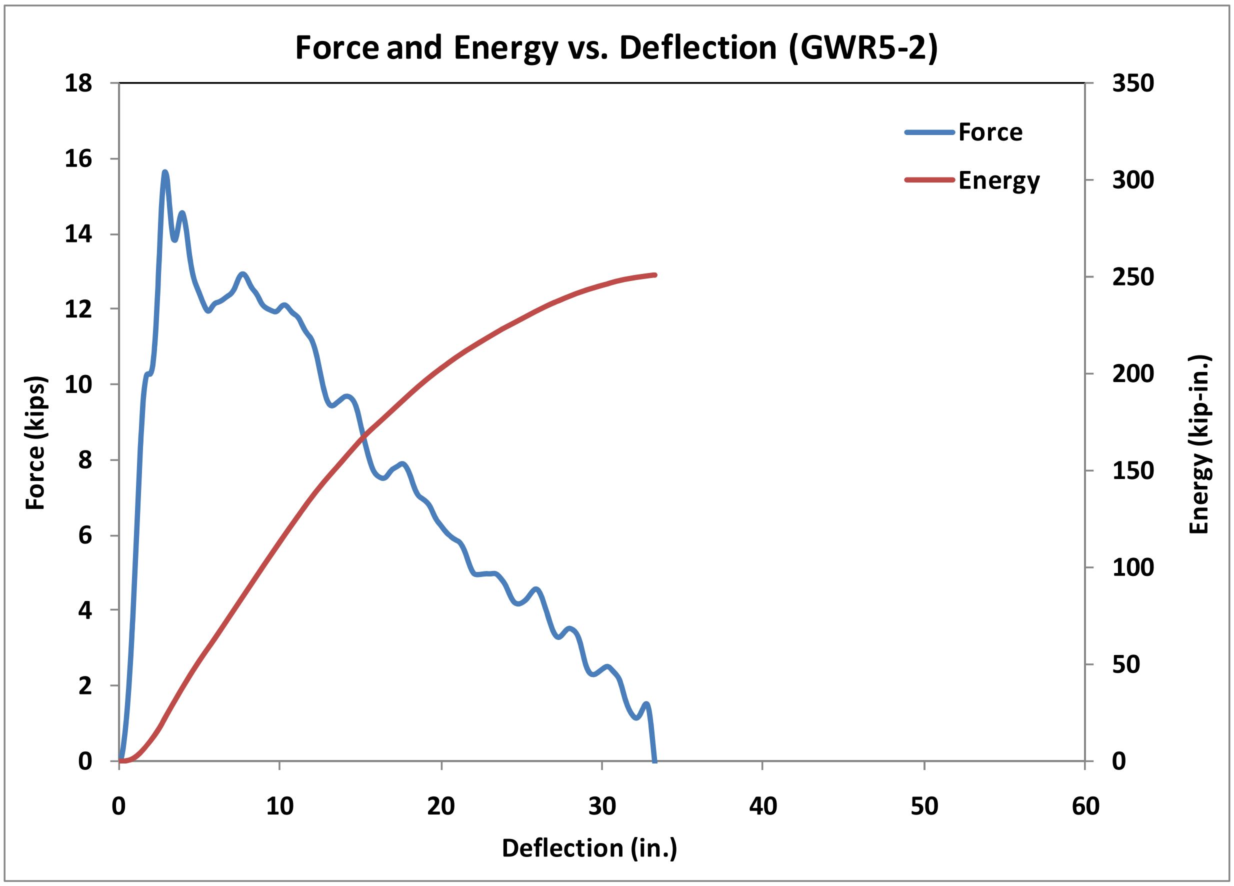
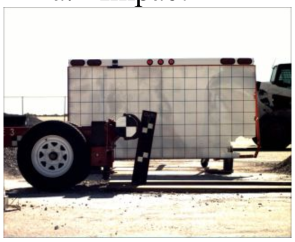


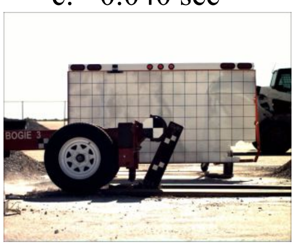
Figure 53. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWR5-2.

a. Impact

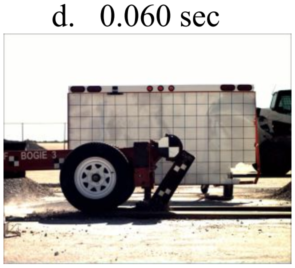


b. 0.020 sec

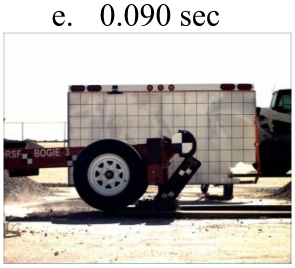
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Front View

h. Post After Impact – Side view

i. Post After Impact – Removed, Showing Deformation

Figure 54. Photo. Time Sequential and Post-Impact Photographs, Test No. GWR5-2.

6.3.4 Test No. GWR5-3

During test no. GWB5-3, the bogie impacted the W6x8.5 (W152x12.6) steel post at a speed of 19.9 mph (32.0 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 34.8 in. (883 mm) when the bogie overrode the post at 0.152 seconds after impact. The twisting in the post occured after 18 in. (457 mm) of deflection.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 55. The resistive force quickly increased to a peak of 14.7 kips (65.6 kN), then steadily declined until reaching zero at the maximum deflection of 34.8 in. (883 mm). The post rotating in soil absorbed a total of 221.5 kip-in. (25.0 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 56.

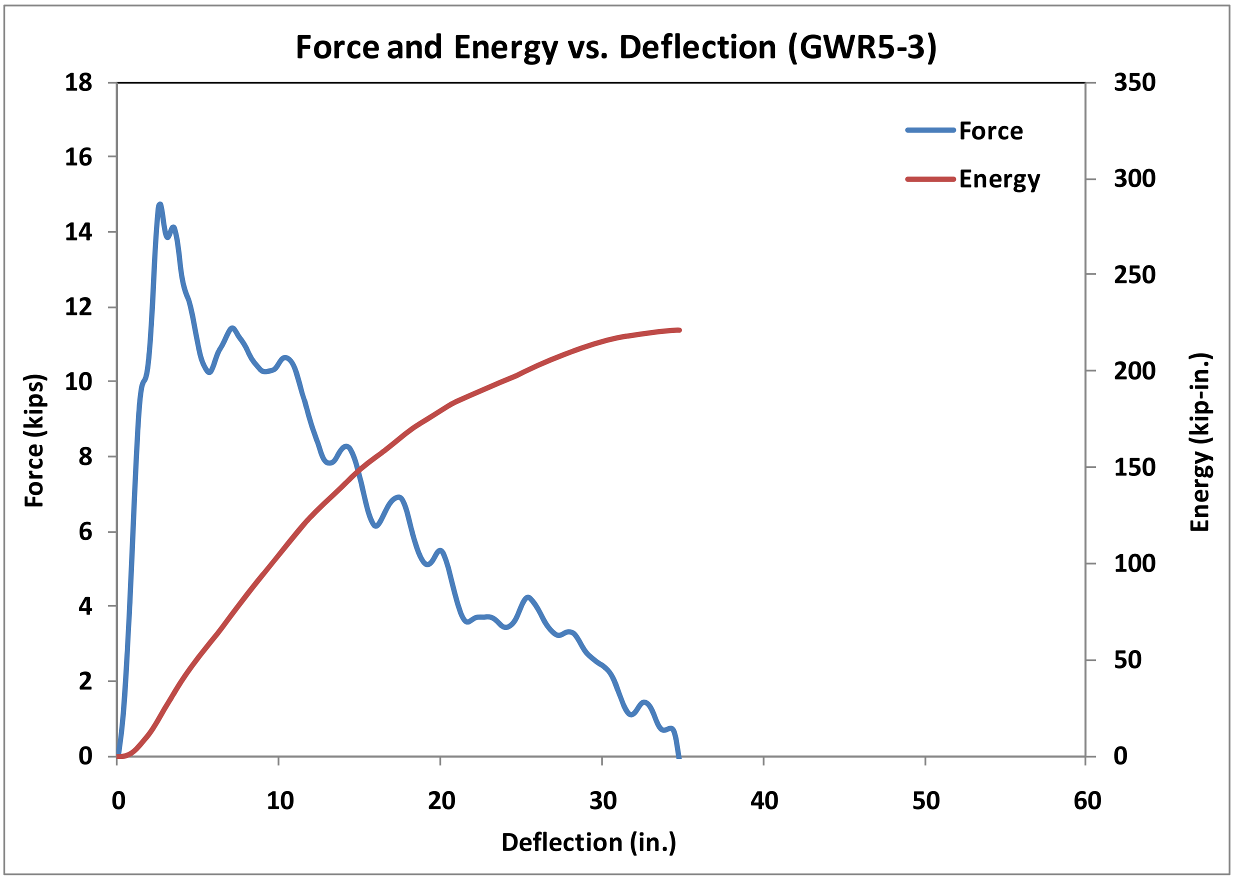
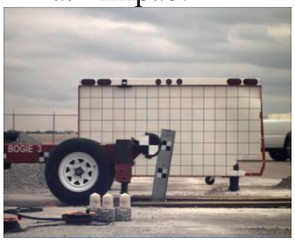


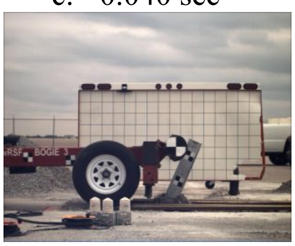
Figure 55. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWR5-3.

a. Impact

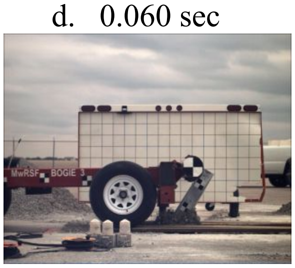


b. 0.020 sec

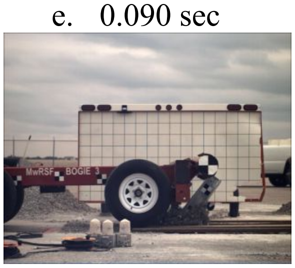
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front View

i. Post After Impact – Removed, Showing Deformation

Figure 56. Photo. Time Sequential and Post-Impact Photographs, Test No. GWR5-3.

6.3.5 Test No. GWR5-4

During test no. GWB5-4, the bogie impacted the W6x8.5 (W152x12.6) steel post at a speed of 20.6 mph (33.2 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 34.5 in. (877 mm) when the bogie overrode the post at 0.143 seconds after impact. The twisting in the post began at 20 in. (508 mm) of deflection.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 57. The load quickly increased to and peaked at 14.0 kips (62.1 kN) and then steadily declined until reaching zero at the maximum deflection of 34.5 in. (877 mm). The post rotating in soil absorbed a total of 237.1 kip-in. (26.8 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 58.

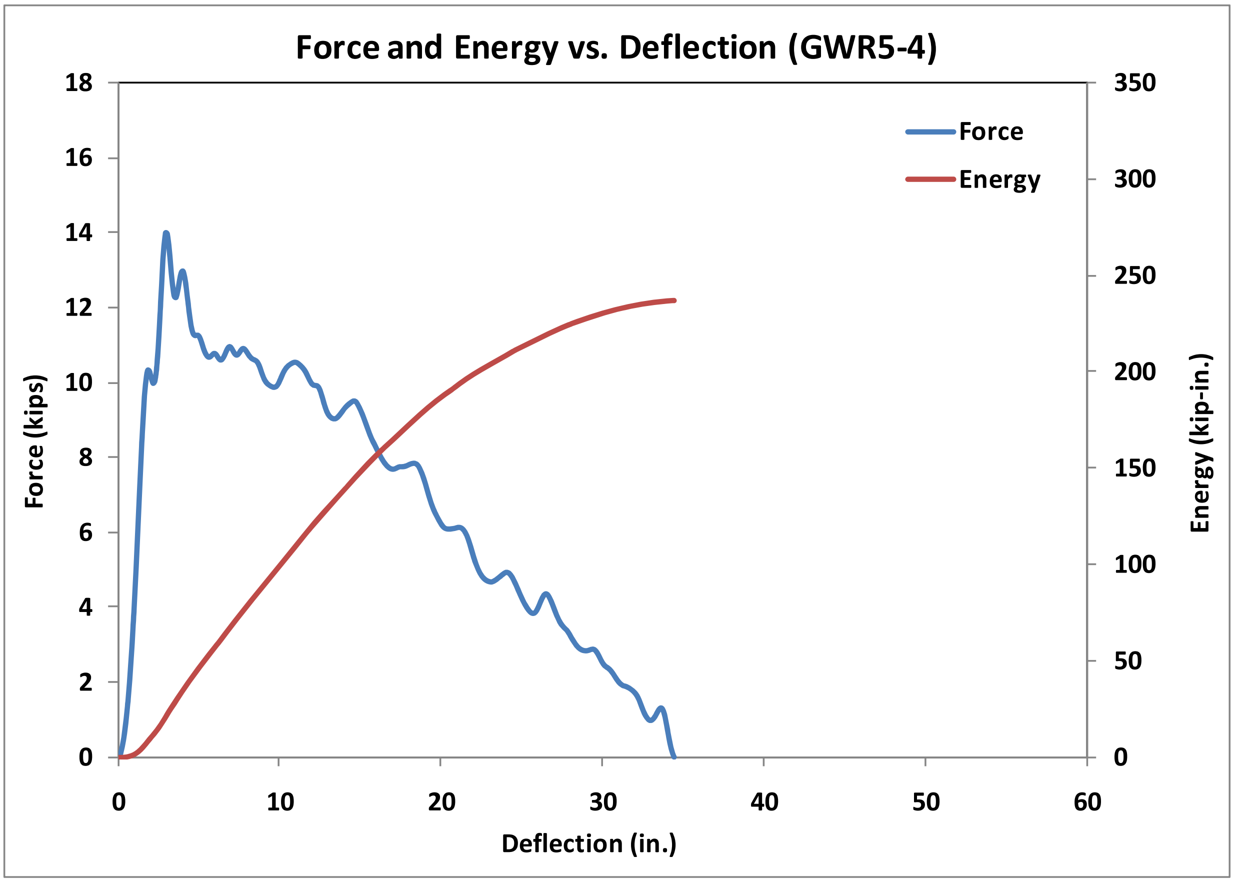
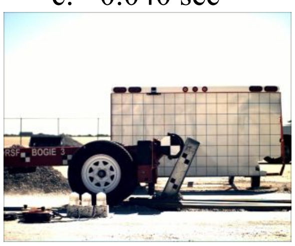


Figure 57. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWR5-4.

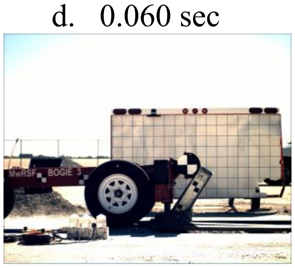
a. Impact

b. 0.020 sec

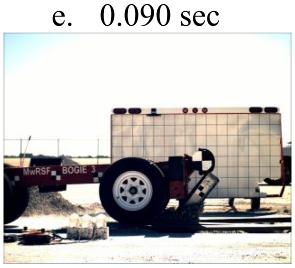
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Rear Quarter

i. Post After Impact – Removed, Showing Deformation

Figure 58. Photo. Time Sequential and Post-Impact Photographs, Test No. GWR5-4.

6.4 ROUND 3 DISCUSSION AND CONCLUSIONS

A summary of the third round of dynamic testing is shown in Table 16, and force vs. deflection and energy vs. deflection curves are shown in Figure 59. A discussion of the third round of dynamic testing was summarized by post material.

6.4.1 Round 3 Wood Post Tests

Round 3 testing was originally comprised of four wood post dynamic tests. However, only one of four planned tests was conducted. During test no. GWR4-1, the post fractured very early in the test and provided very little energy absorption. This tendency was also recognized in another MwRSF project where 6-in. x 8-in. (152-mm x 203-mm) wood posts embedded greater than 40 in. (1,016 mm) in well-compacted, strong soil continuously fractured during component testing. [10] At the time, it was reasoned that the wood post performance could be improved by increasing the post's cross section, reducing the post's embedment depth, or by using a stronger wood species. However, the remaining three wood post tests were temporarily aborted, and steel posts were selected for the design of the barrier system due to their ease of placement in the wire-faced, MSE wall.

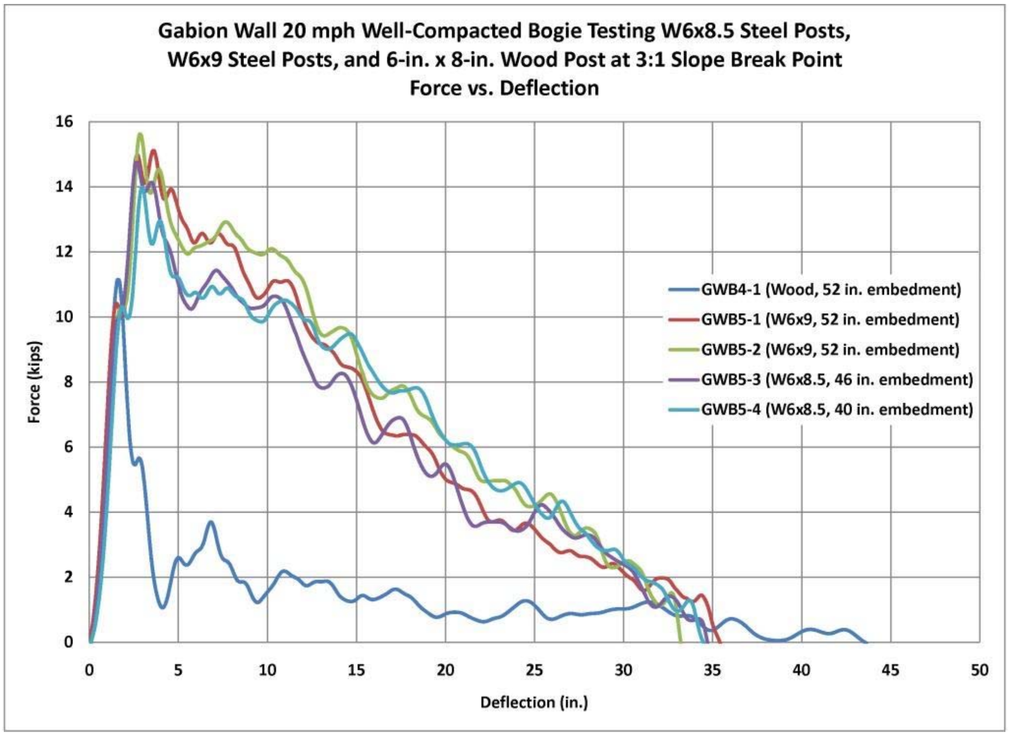
6.4.2 Round 3 Steel Post Tests

Test nos. GWBR5-1 and GWBR5-2 were performed with W6x9 (W152x13.4) steel posts, and test nos. GWBR5-3 and GWBR5-4 were performed with W6x8.5 (W152x12.6) steel posts. These two posts have very similar cross sections and have been used interchangeably in actual guardrail installations. The force vs. displacement curves for all four tests on the 3H:1V fill slope were very similar in shape and magnitude. In fact, there was very little reduction in resistance as the embedment depth was reduced from 52 in. to 40 in. (1,321 mm to 1,016 mm), as shown in Figure 59. This was an unexpected result, but it was explained by the plastic deformation found in the posts. The forces required to bend the posts should be nearly identical, so the resistive forces for all of the tests should be similar if the soil is strong enough to yield the posts.

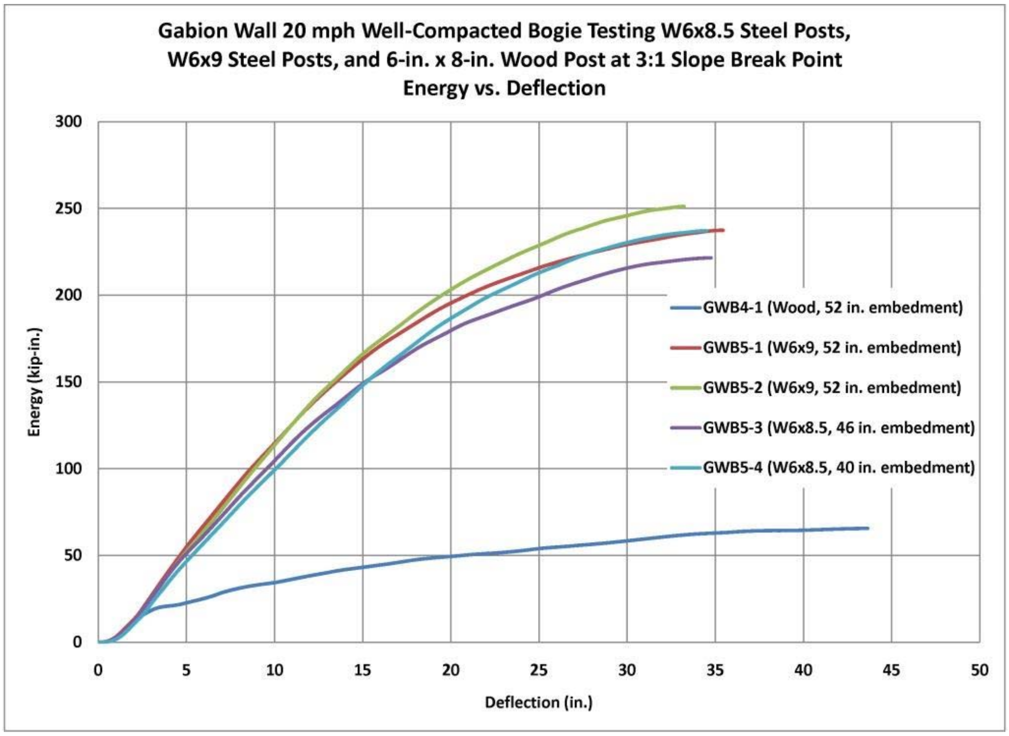
Table 16. Round 3 Testing Results - 6-in. x 8-in. Wood Posts vs. W6x9 and W6x8.5 Steel Posts at 20 mph with Varying Embedment Depths and Posts at 3H:1V Slope Break Point.

Test No.	Embedment Depth in. (mm)	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
6-in. x 8 in. (152-mm x 203-mm) SYP Wood Posts									
GWR4-1	52 (1,321)	20.5 (33.1)	11.1 (49.5)	1.6 (40)	NA	NA	21.0 (2.4)	4.1 (104)	Post Fracture
W6x9 (W152x13.4) Steel Posts									
GWR5-1 [1]	52 (1,321)	20.0 (32.1)	15.1 (67.2)	3.7 (93)	10.9 (48.4)	9.8 (43.5)	237.4 (26.8)	35.4 (900)	Soil Rotation & Post Yielding
GWR5-2	52 (1,321)	20.8 (33.4)	15.6 (69.5)	2.8 (72)	11.1 (49.3)	10.2 (45.2)	251.2 (28.4)	33.2 (844)	Soil Rotation & Post Yielding
W6x8.5 (W152x12.6) Steel Posts									
GWR5-3	46 (1,168)	19.9 (32.0)	14.7 (65.6)	2.7 (69)	9.9 (44.2)	9.0 (40.0)	221.5 (25.0)	34.8 (883)	Soil Rotation & Post Yielding
GWR5-4	40 (1,016)	20.6 (33.2)	14.0 (62.1)	2.9 (74)	9.9 (43.9)	9.3 (41.5)	237.1 (26.8)	34.5 (877)	Soil Rotation & Post Yielding

[1] Post driven.



a. Force vs. Deflection



b. Energy vs. Deflection

Figure 59. Graph. Force vs. Deflection and Energy vs. Deflection, Round 3 Testing – 20 mph and Well-Compacted.

CHAPTER 7. ROUND 4 DYNAMIC TESTING – POSTS ON MSE WALL

7.1 PURPOSE

The third round of dynamic testing evaluated guardrail posts installed in well-compacted strong soil and placed at the slope break point of a 3H:1V fill slope. However, posts installed on a wire-faced, MSE wall would extend through the compacted soil layer and into the steel wire mesh layers adjacent to the larger wall-facing rock. Recall from the first round of dynamic testing, the 2-in. to 4-in. (51-mm to 102-mm) wall-facing rock of a MSE wall provided much less post-soil resistance than observed for posts embedded in the standard AASHTO Grading B strong soil material. Thus, it was desired to evaluate the performance of steel posts installed on an actual wire-faced, MSE wall which contained the 3H:1V fill slope, heavily-compacted crushed limestone soil material, as well as the adjacent large wall-facing rocks within the outer steel mesh cages. Details for the MSE wall can be found in McGhee et al. [11]

7.2 SCOPE

For the fourth round of dynamic testing, six tests were conducted. The steel posts conformed to the W6x9 (W152x13.4) and W6x8.5 (W152x12.6) sections with various lengths and embedment depths, as shown in Table 17. The posts were impacted 24⅞ in. (632 mm) above the ground line at 20 mph (32 km/h). The posts were placed at the slope break point of a 3H:1V fill slope located on the top of the wire-faced, MSE wall, as shown in Figure 60. The MSE wall was constructed of steel wire cages filled with 2-in. to 4-in. (51-mm to 102-mm) wall-facing rock at the exterior edge. The soil material within the interior wire mesh layers and on top of the MSE wall was placed with a roller compactor using AASHTO Grading B strong soil material. To match common field installation methods, the posts were driven into position through the top soil layer and into the wire mesh layers found within the interior region of the MSE wall.

Table 17. Round 4 Dynamic Testing Matrix with Posts Driven into a Wire-Faced, MSE Wall.

Test No.	Post		Soil Description	Embedment Depth in. (mm)	Target Impact Velocity mph (km/h)	Bending Axis
	Size	Length in. (mm)				
GWBR5-1	W6x9 (W152x13.4)	84 (2,134)	Roller Compacted AASHTO Grading B Strong Soil	52 [1] (1,321)	20 (32)	Strong
GWBR5-2	W6x9 (W152x13.4)	78 (1,981)	Roller Compacted AASHTO Grading B Strong Soil	46 [1] (1,168)	20 (32)	Strong
GWBR5-3	W6x8.5 (W152x12.6)	72 (1,829)	Roller Compacted AASHTO Grading B Strong Soil	40 [1] (1,016)	20 (32)	Strong
GWBR5-4	W6x9 (W152x13.4)	84 (2,134)	Roller Compacted AASHTO Grading B Strong Soil	52 [1] (1,321)	20 (32)	Strong
GWBR5-5	W6x9 (W152x13.4)	78 (1,981)	Roller Compacted AASHTO Grading B Strong Soil	46 [1] (1,168)	20 (32)	Strong
GWBR5-6	W6x8.5 (W152x12.6)	72 (1,829)	Roller Compacted AASHTO Grading B Strong Soil	40 [1] (1,016)	20 (32)	Strong

[1] Post driven.

a. Post Locations

b. Impact Location

Figure 60. Photo. Round 4 Test Setup on Wire-Faced, MSE Wall with a 3H:1V Fill Slope.

7.3 ROUND 4 RESULTS

The accelerometer data for each test was processed in a manner discussed in Section 3.6. Individual test results are provided in Appendix A. Due to technical difficulties observed during test nos. GWBR5-1 through GWBR5-6, the accelerometer data from the DTS accelerometer was unusable. Therefore, only data from the EDR-3 accelerometer was available for these tests.

7.3.1 Test No. GWBR5-1

During test no. GWBR5-1, the bogie impacted the W6x9 (W152x13.4) steel post at a speed of 21.1 mph (34.0 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 28.5 in. (724 mm) before the bogie overrode the post at 0.104 seconds after impact. The twisting of the post did not appear to occur until the end of the test.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 61. The load quickly increased and peaked at 16.2 kips (72.0 kN) and then declined until a deflection of 20 in. (508 mm) where it remained near 4 kips (18 kN) to a deflection of 26 in. (660 mm). The force then declined until reaching zero at the maximum deflection of 28.5 in. (724 mm). The post rotating in soil absorbed a total of 211.0 k-in. (23.8 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 62.

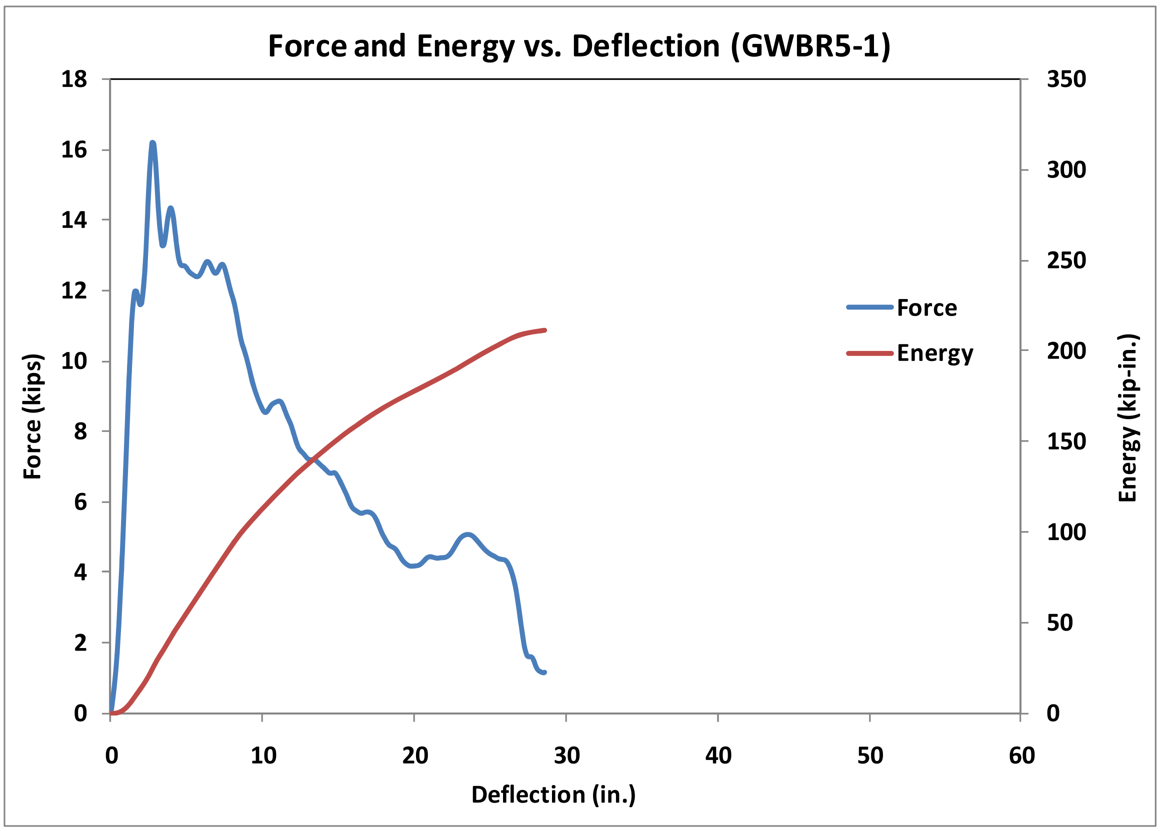
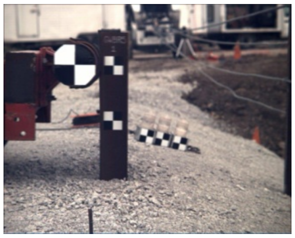
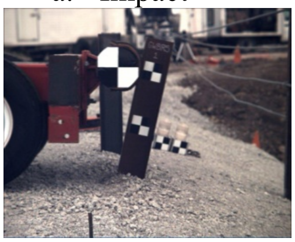
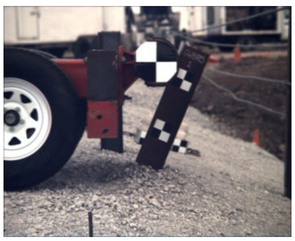
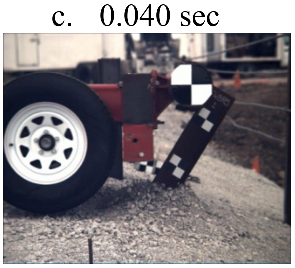


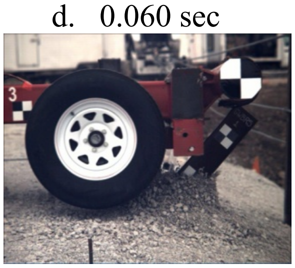
Figure 61. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWBR5-1.

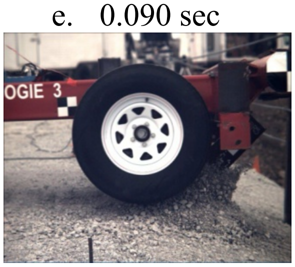

a. Impact


b. 0.020 sec


c. 0.040 sec


d. 0.060 sec


e. 0.090 sec



f. 0.120 sec


g. Post After Impact – Side view


h. Post After Impact – Front View


i. Post After Impact – Removed, Showing Deformation

Figure 62. Photo. Time Sequential and Post-Impact Photographs, Test No. GWBR5-1.

7.3.2 Test No. GWBR5-2

During test no. GWBR5-2, the bogie impacted the W6x9 (W152x13.4) steel post at a speed of 19.4 mph (31.2 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 35.0 in. (889 mm) before the bogie overrode the post at 0.188 seconds after impact. The post did not appear to twist until the end of the test.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 63. The load quickly increased and peaked at 15.1 kips (67.1 kN) and then steadily declined until reaching a force of approximately 2 kips (9 kN) before dropping sharply, reaching zero at the maximum deflection of 35.0 in. (889 mm). The post rotating in soil absorbed a total of 240.8 k-in. (27.2 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 64.

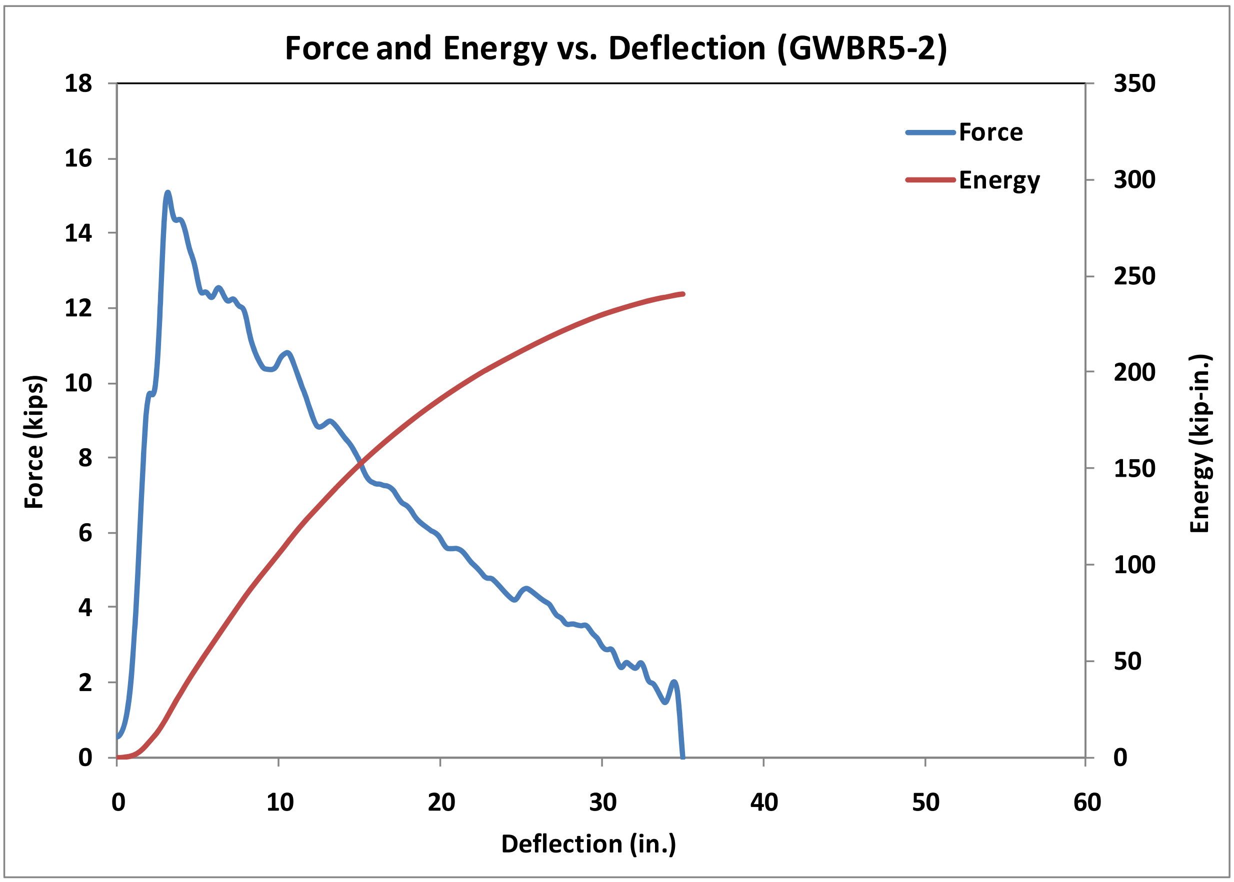
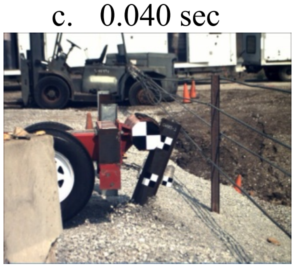


Figure 63. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWBR5-2.

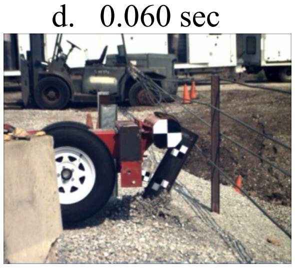
a. Impact

b. 0.020 sec

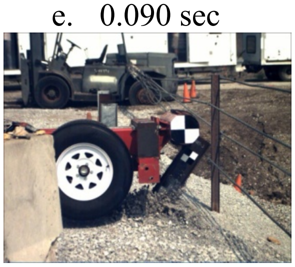
c. 0.040 sec



d. 0.060 sec



e. 0.090 sec



f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Front View

i. Post After Impact – Removed, Showing Deformation

Figure 64. Photo. Time Sequential and Post-Impact Photographs, Test No. GWBR5-2.

7.3.3 Test No. GWBR5-3

During test no. GWBR5-3, the bogie impacted the W6x8.5 (W152x12.6) steel post at a speed of 22.1 mph (35.6 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 43.7 in. (1,109 mm) before the bogie overrode the post at 0.19 seconds after impact. Post twisting appeared to occur near the end of the test.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 65. The load quickly increased and peaked at 13.3 kips (59.2 kN) and then steadily declined reaching zero at the maximum deflection of 43.7 in. (1,109 mm). The post rotating in soil absorbed a total of 305.4 k-in. (34.5 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 66.

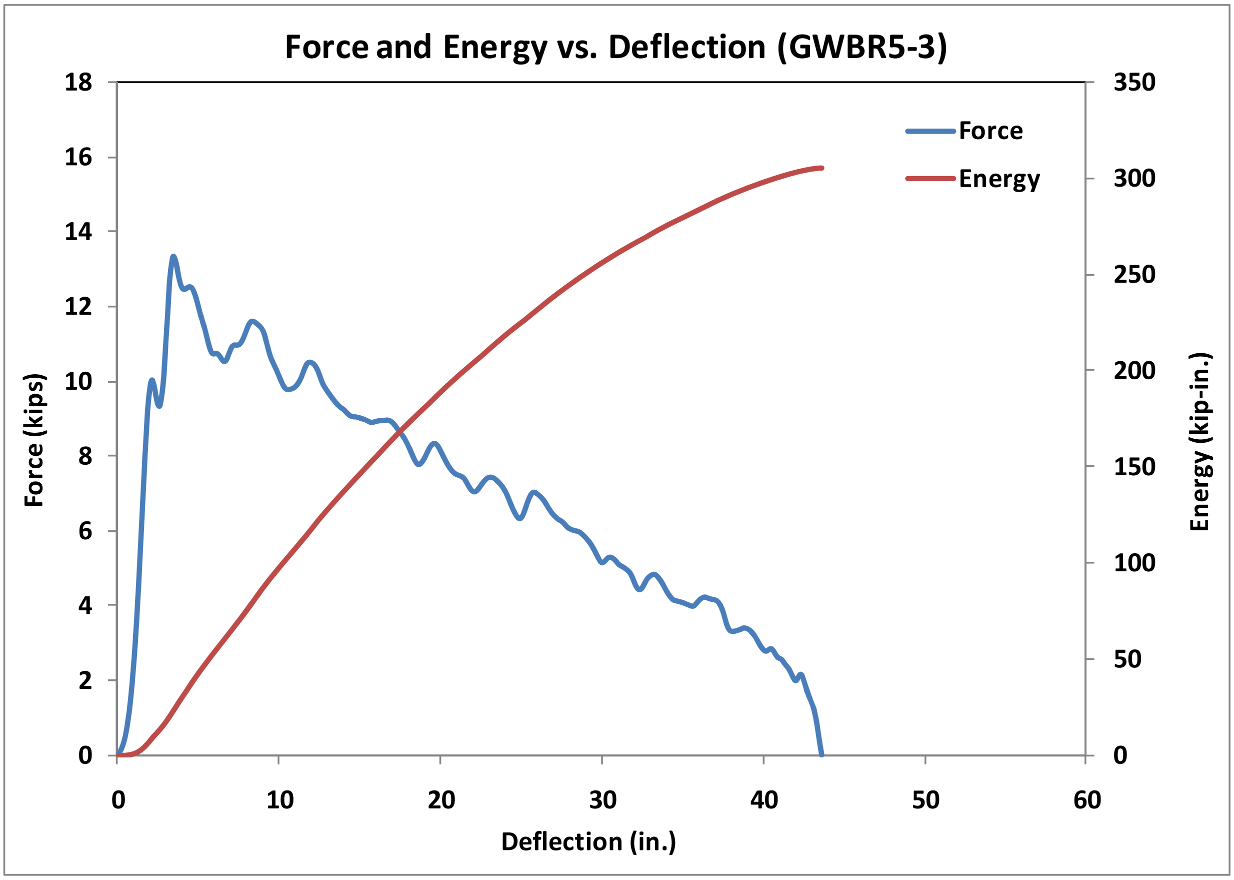
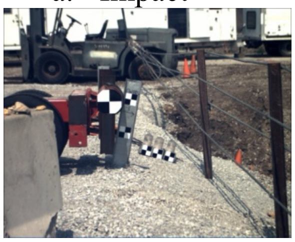
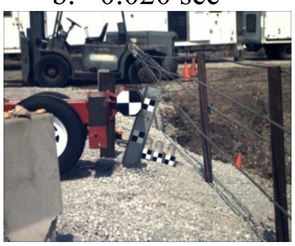


Figure 65. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWBR5-3.

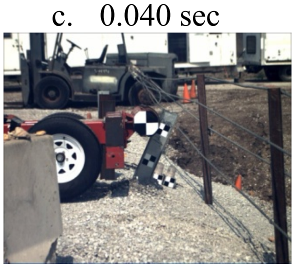
a. Impact



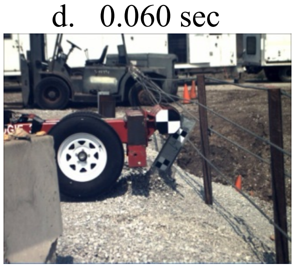
b. 0.020 sec



c. 0.040 sec



d. 0.060 sec



e. 0.090 sec

f. 0.120 sec

g. Post After Impact – Side view

h. Soil Displacement of Post After Impact

i. Post After Impact – Removed, Showing Deformation

Figure 66. Photo. Time Sequential and Post-Impact Photographs, Test No. GWBR5-3.

7.3.4 Test No. GWBR5-4

During test no. GWBR5-4, the bogie impacted the W6x9 (W152x13.4) steel post at a speed of 22.3 mph (35.9 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 34.2 in. (869 mm) before the bogie overrode the post. Due to technical difficulties, no high-speed digital video was recorded. Therefore, the post override time was unavailable.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 67. The load quickly increased and peaked at 15.1 kips (67.1 kN) and then steadily declined until reaching the maximum deflection of 34.2 in. (869 mm). The post rotating in soil absorbed a total of 235.7 kip-in. (26.6 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 68.

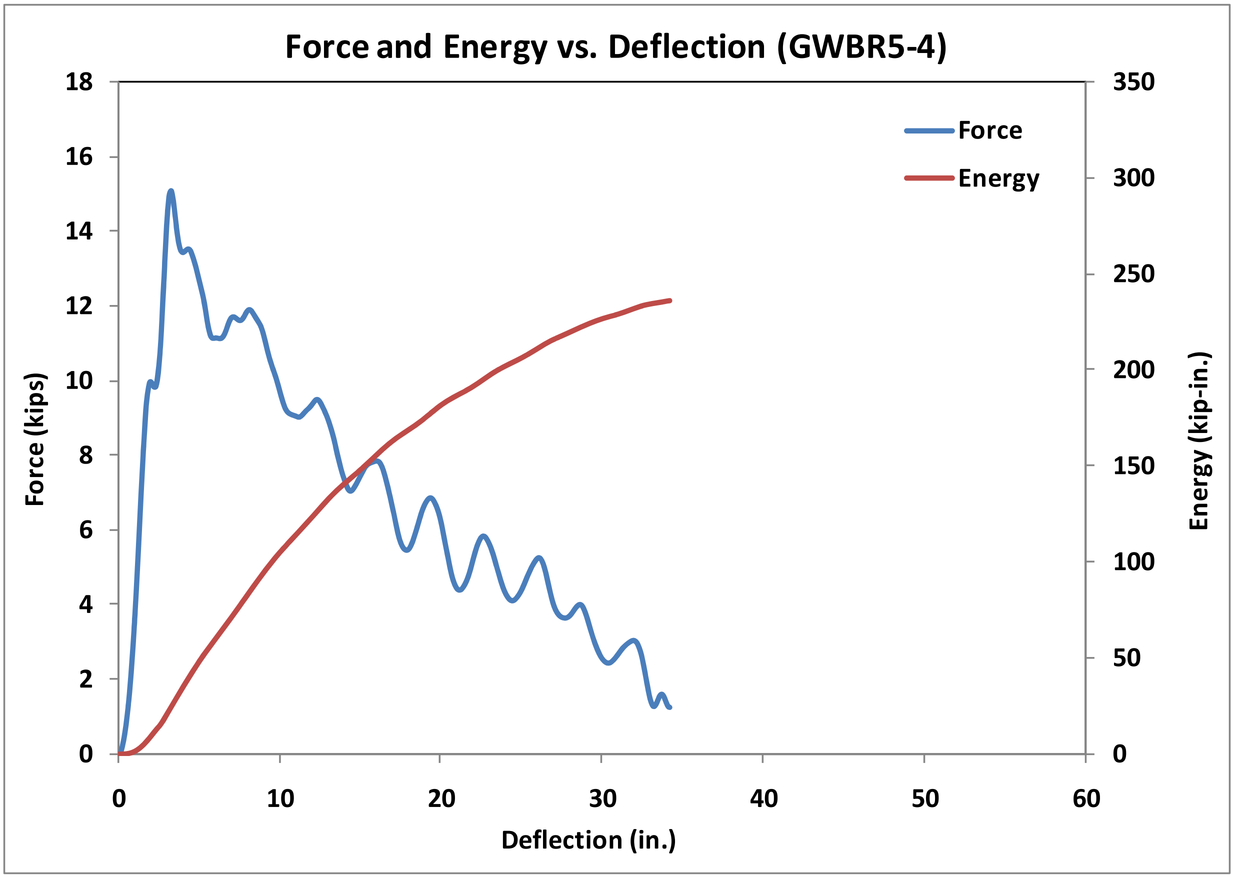
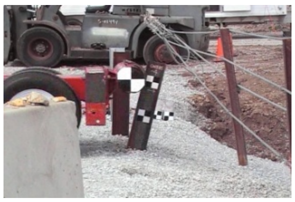


Figure 67. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWBR5-4.

a. Pre-Impact



b. ~0.035 sec

c. ~0.070 sec

d. ~0.104 sec

e. ~0.138 sec

f. ~0.172 sec

g. Post After Impact – Front View

h. Post After Impact – Displaced Soil

i. Post After Impact – Removed, Showing Deformation

Figure 68. Photo. Time Sequential and Post-Impact Photographs, Test No. GWBR5-4.

7.3.5 Test No. GWBR5-5

During test no. GWBR5-5, the bogie impacted the W6x9 (W152x13.4) steel post at a speed of 23.9 mph (38.5 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 38.5 in. (978 mm) before the bogie overrode the post at 0.118 seconds after impact. The twisting of the post did not appear to occur until the end of the test.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 69. The load quickly increased and peaked at 14.4 kips (64.0 kN) and then steadily declined until reaching the maximum deflection of 38.5 in. (978 mm). The post rotating in soil absorbed a total of 244.5 kip-in. (27.6 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 70.

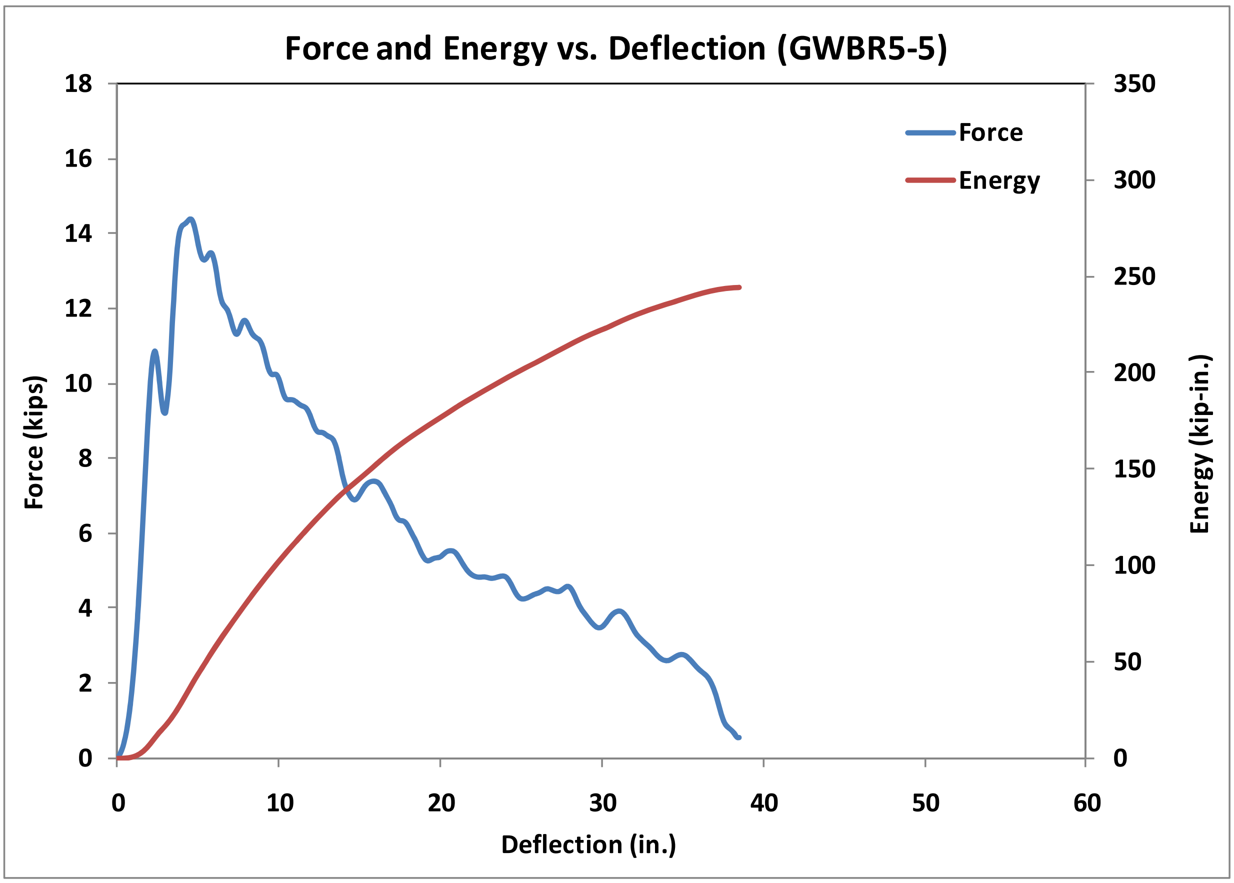
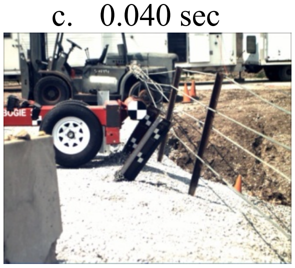


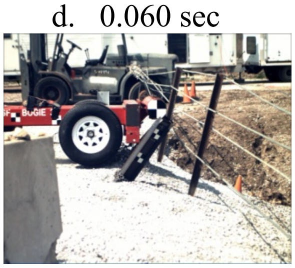
Figure 69. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWBR5-5.


a. Impact


b. 0.020 sec


c. 0.040 sec


d. 0.060 sec


e. 0.090 sec


f. 0.120 sec

g. Post After Impact – Front Quarter View


h. Post After Impact – Side view


i. Post After Impact – Removed, Showing Deformation

Figure 70. Photo. Time Sequential and Post-Impact Photographs, Test No. GWBR5-5.

7.3.6 Test No. GWBR5-6

During test no. GWBR5-6, the bogie impacted the W6x8.5 (W152x12.6) steel post at a speed of 22.9 mph (36.8 km/h) and at an orientation causing strong-axis bending in the post. The post rotated through the soil, twisted, and bent backward to a maximum deflection of 38.2 in. (969 mm) before the bogie overrode the post at 0.136 seconds after impact. Twisting of the post did not occur until the end of the test. Upon inspection of the post, the compression flange was found to be torn at the location of buckling and twisting, as shown in Figure 72.

Force vs. deflection and energy vs. deflection curves were created from the accelerometer data and are shown in Figure 71. The load quickly increased and peaked at 14.0 kips (62.2 kN) and then steadily declined until reaching zero at the maximum deflection of 38.2 in. (969 mm). The post rotating in soil absorbed a total of 251.7 kip-in. (28.4 kJ) of energy. Time-sequential photographs and post-impact photographs are shown in Figure 72.

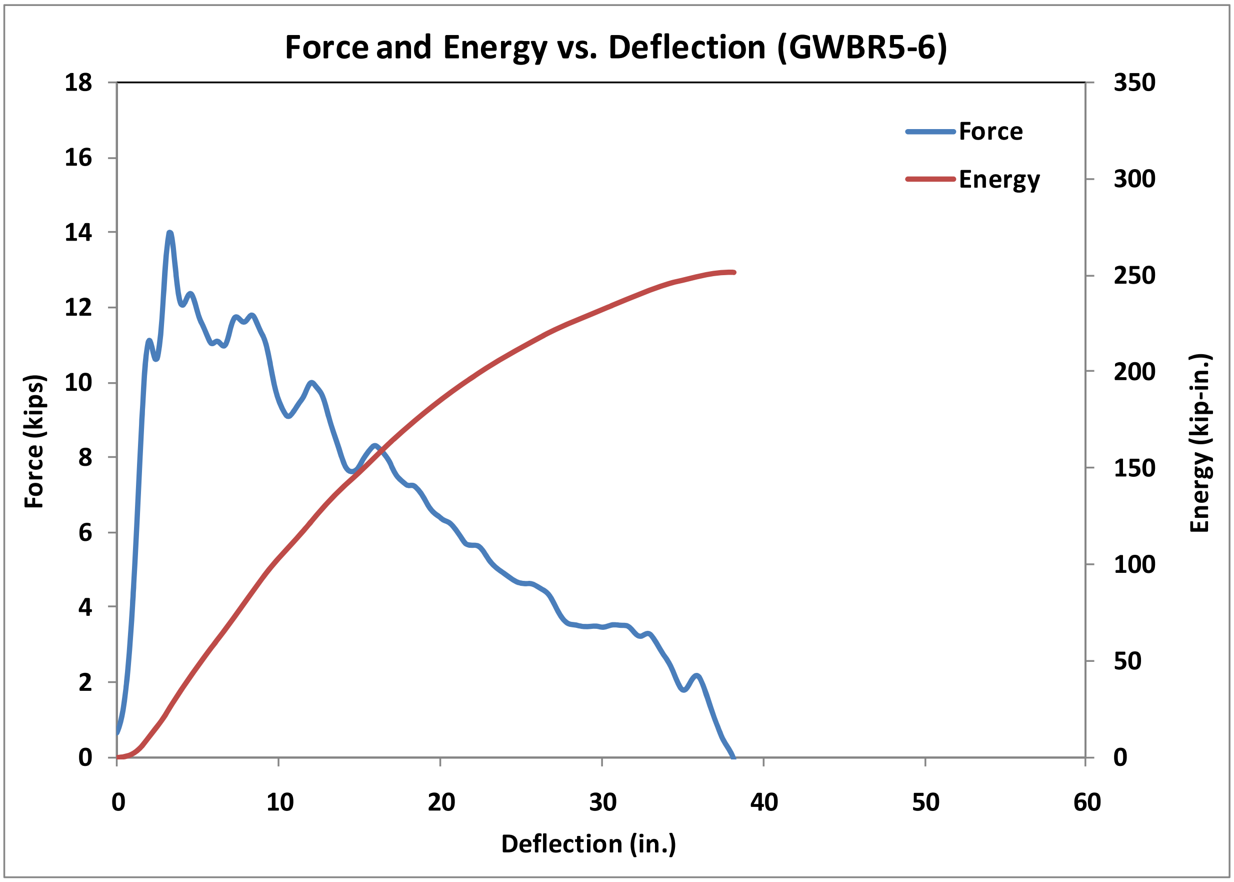
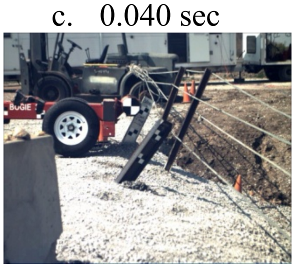


Figure 71. Graph. Force vs. Deflection and Energy vs. Deflection, Test No. GWBR5-6.

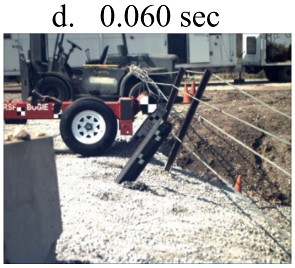
a. Impact

b. 0.020 sec

c. 0.040 sec



d. 0.060 sec



e. 0.090 sec

f. 0.120 sec

g. Post After Impact – Side view

h. Post After Impact – Side View Wide

i. Post After Impact – Removed, Showing Deformation

Figure 72. Photo. Time Sequential and Post-Impact Photographs, Test No. GWBR5-6.

7.4 ROUND 4 DISCUSSION AND CONCLUSIONS

Round 4 of dynamic testing consisted of two tests at three different embedment depths for a total of six tests. The test results from the fourth round of bogie testing are summarized in Table 18 and shown graphically in Figure 73. For these tests, the observed force vs. deflection response was similar in shape, magnitude, and duration. In fact, the calculated average forces at deflections of 15 and 20 in. (381 and 508 mm) varied by less than 5 percent. Therefore, the variation in embedment depth, ranging from 40 to 52 in. (1,016 to 1,321 mm), had limited effect on the post-soil resistance for the steel posts driven into the MSE wall system at the slope break point.

A linear correlation between embedment depth and peak force was found. As shown in Table 18, the peak force increased by approximately 1 kip (4.5 kN) for every 6 in. (152 mm) of additional embedment. These peak loads occurred at the beginning of the tests. Thus, the noted increase in peak load may have been attributed to the increased inertial resistance of the longer posts and additional soil that must be moved at impact.

Modest differences were observed in the maximum post deflections and total energy absorbed. As the embedment depth increased, the maximum post deflection decreased. As noted previously, the average forces for these tests were very similar. In addition, the posts with shallower embedment depths absorbed more energy than the posts with deeper embedment depths. A 12 in. (305 mm) increase in post embedment depth, ranging from 40 in. (1,016 mm) to 52 in. (1,321 mm), resulted in a 20 percent reduction in the total energy absorbed.

A reduction in maximum post deflection corresponded with an increase in post embedment depth, which can be attributed to the higher ‘average’ post-soil forces observed during testing. The posts with deeper embedment depths had more soil resistance to overcome as the post rotated. The increased soil resistance led to higher forces and stresses imparted to the posts as well as increased plastic deformations due to bending and lateral torsional buckling. For the shorter posts, less force was required to rotate the post through the soil.

Once the bogie testing was completed, the posts were pulled out of the soil so that the deformations could be compared to one another. The two galvanized W6x8.5 (W152x12.6) steel posts, which both used a 40-in. (1,016-mm) embedment depth, had decreased plastic deformations as compared to those observed for the four un-galvanized W6x9 (W152x13.4) steel posts installed with greater embedment depths. The deformed posts are depicted in Figure 74. The specific hinge locations for these steel posts installed with varying embedment depths are provided in Table 19. For the 52-in. (1,321-mm) embedment depth, the average hinge location was 42 in. (1,067 mm) below the top of the post. For the 46-in. (1,168-mm) embedment depth, the average hinge location was 40.25 in. (1,022 mm) below the top of the post. For the 40-in. (1,016-mm) embedment depth, the average hinge location was 40.5 in. (1,029 mm) below the top of the post. As a result, the hinge locations were found to be 1.5 in. (38 mm) lower for the posts with 52-in. (1,321-mm) embedment depths as compared to those posts which used 40-in. (1,016-mm) embedment depths, as noted in Table 19.

For the Round 3 dynamic bogie testing program, the steel posts were placed at the slope break point of a 3H:1V fill slope within a soil testing pit using two installation methods – the auger, backfill, and tamping method as well as the driven method. For the Round 4 dynamic bogie testing program, the steel posts were placed at the slope break point of a 3H:1V fill slope adjacent to and on top of the wire-faced, MSE wall system using the driven method. In addition to variations for the installation method and soil testing area, three embedment depths were evaluated – 40 in. (1,016 mm), 46 in. (1,168 mm), and 52 in. (1,321 mm). A summary of the test parameters and results is provided in Table 20.

The Round 3 and 4 test results were then compared to evaluate the affects of the posts installed at the slope break point of a 3H:1V fill slope in a soil testing pit versus on a wire-faced, MSE wall. The post testing results were graphically compared in terms of force versus deflection and energy versus deflection and as a function of embedment depth, as shown in Figures 75 through 77.

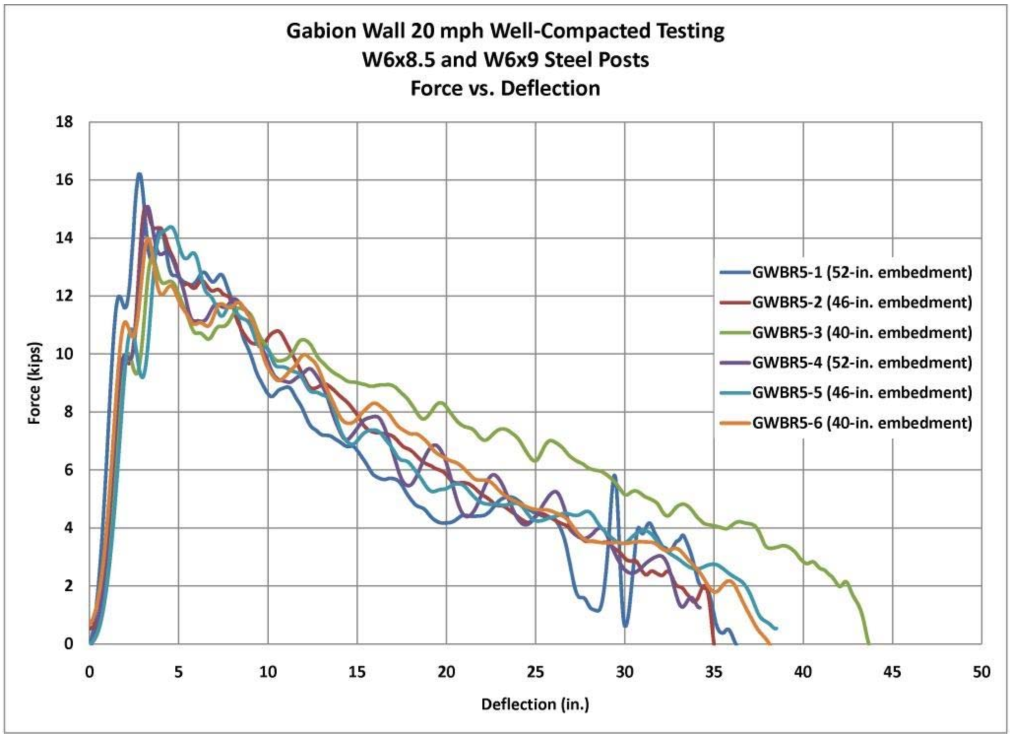
For the 40-in. (1,016-mm) embedment depth, the average force at both 15 in. (381 mm) and 20 in. (508 mm) of deflection was very similar for W6x8.5 (W152x12.6) steel posts either driven into the MSE wall or installed in a soil test pit with the auger, backfill, and tamping method. For tests nos. GWBR5-3, GWBR5-6, and GWR5-4, the energy dissipated through 20 in. (508 mm) of deflection was nearly identical, even when considering the different test locations and varied post installation methods, as shown in Figure 75.

For the 46-in. (1,168-mm) embedment depth, the average force at both 15 in. (381 mm) and 20 in. (508 mm) of deflection was also very similar for either W6x9 (W152x13.4) steel posts driven into the MSE wall or a W6x8.5 (W152x12.6) steel post installed in a soil test pit with the auger, backfill, and tamping method. For tests nos. GWBR5-2, GWBR5-5, and GWR5-3, the energy dissipated through 20 in. (508 mm) of deflection varied only modestly, even when considering the different test locations and varied post installation methods, as shown in Figure 76.

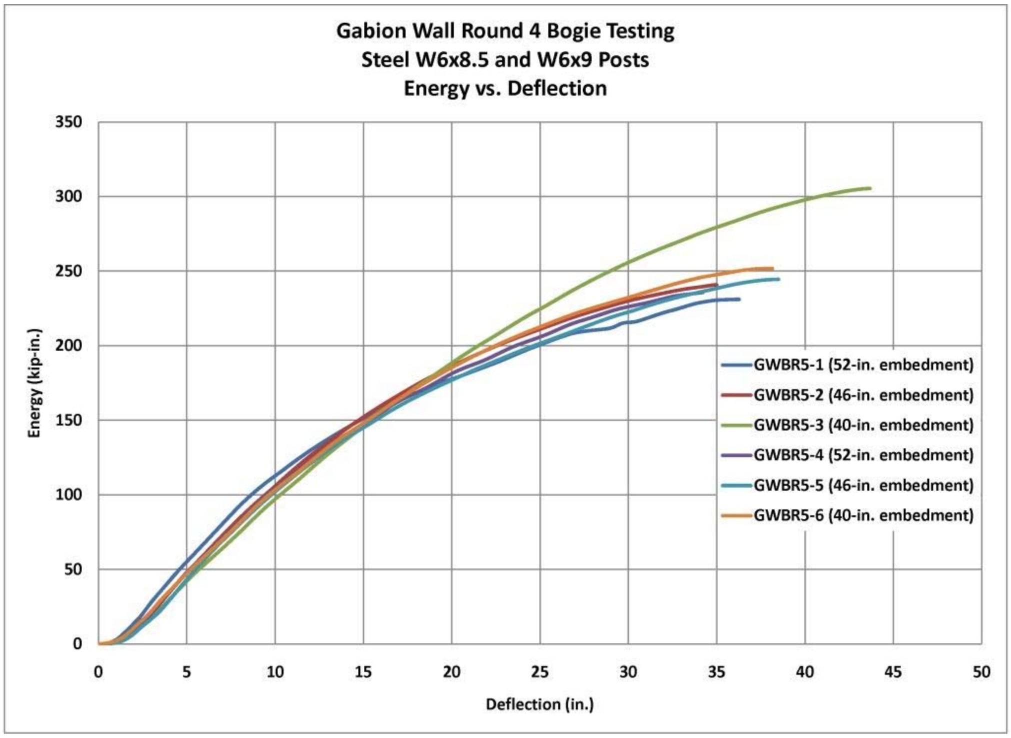
For the 52-in. (1,321-mm) embedment depth, the average force at both 15 in. (381 mm) and 20 in. (508 mm) of deflection for the W6x9 (W152x13.4) steel posts was lower for the two posts driven into the MSE wall as compared to the two posts installed in a soil test pit – one driven and another placed with the auger, backfill, and tamping method. For tests nos. GWBR5-1, GWBR5-4, GWR5-1, and GWR5-2, the energy dissipated through 20 in. (508 mm) of deflection was more varied and correlated more with test location, as shown in Figure 77. At 20 in. (508 mm) of deflection, the two posts driven into the MSE wall dissipated less energy than the two posts installed in the soil testing pit - one driven and another placed with the auger, backfill, and tamping method.

Table 18. Round 4 Testing Results – W6x9 Steel Posts vs. W6x8.5 Steel Posts with Varying Embedment Depths and Posts Driven at 3H:1V Slope Break Point.

Test No.	Embedment Depth in. (mm)	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)	Failure Type
			Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)			
W6x9 (W152x13.4) Steel Posts, 52-in. (1,321-mm) Embedment Depth									
GWBR5-1	52 (1,321)	21.1 (34.0)	16.2 (72.0)	2.7 (70)	10.1 (44.9)	8.9 (39.6)	211.0 (23.8)	28.5 (724)	Soil Rotation, Post Yielding
GWBR5-4	52 (1,321)	22.3 (35.9)	15.1 (67.1)	3.3 (83)	9.9 (43.8)	9.1 (40.4)	235.7 (26.6)	34.2 (869)	Soil Rotation, Post Yielding
Average	52 (1,321)	21.7 (34.9)	15.6 (69.6)	3.0 (77)	10.0 (44.4)	9.0 (40.0)	223.4 (25.2)	31.4 (797)	
W6x9 (W152x13.4) Steel Posts, 46-in. (1,168-mm) Embedment Depth									
GWBR5-2	46 (1,168)	19.4 (31.2)	15.1 (67.1)	3.2 (80)	10.2 (45.2)	9.3 (41.5)	240.8 (27.2)	35.0 (889)	Soil Rotation, Post Yielding
GWBR5-5	46 (1,168)	23.9 (38.5)	14.4 (64.0)	4.5 (115)	9.7 (43.1)	8.9 (39.4)	244.5 (27.6)	38.5 (978)	Soil Rotation, Post Yielding
Average	46 (1,168)	21.6 (34.8)	14.7 (65.5)	3.8 (98)	9.9 (44.1)	9.1 (40.4)	242.7 (27.4)	36.7 (933)	
W6x8.5 (W152x12.6) Steel Posts, 40-in. (1,016-mm) Embedment Depth									
GWBR5-3	40 (1,016)	22.1 (35.6)	13.3 (59.2)	3.5 (89)	9.7 (43.3)	9.4 (41.9)	305.4 (34.5)	43.7 (1,109)	Soil Rotation, Post Yielding
GWBR5-6	40 (1,016)	22.9 (36.8)	14.0 (62.2)	3.2 (82)	9.9 (43.9)	9.3 (41.2)	251.7 (28.4)	38.2 (969)	Soil Rotation, Post Yielding
Average	40 (1,016)	22.5 (36.2)	13.6 (60.7)	3.4 (85)	9.8 (43.6)	9.3 (41.6)	278.6 (31.5)	40.9 (1,039)	



a. Force vs. Deflection



b. Energy vs. Deflection

Figure 73. Graph. Force vs. Deflection and Energy vs. Deflection, 20 mph and Well-Compacted Soil.

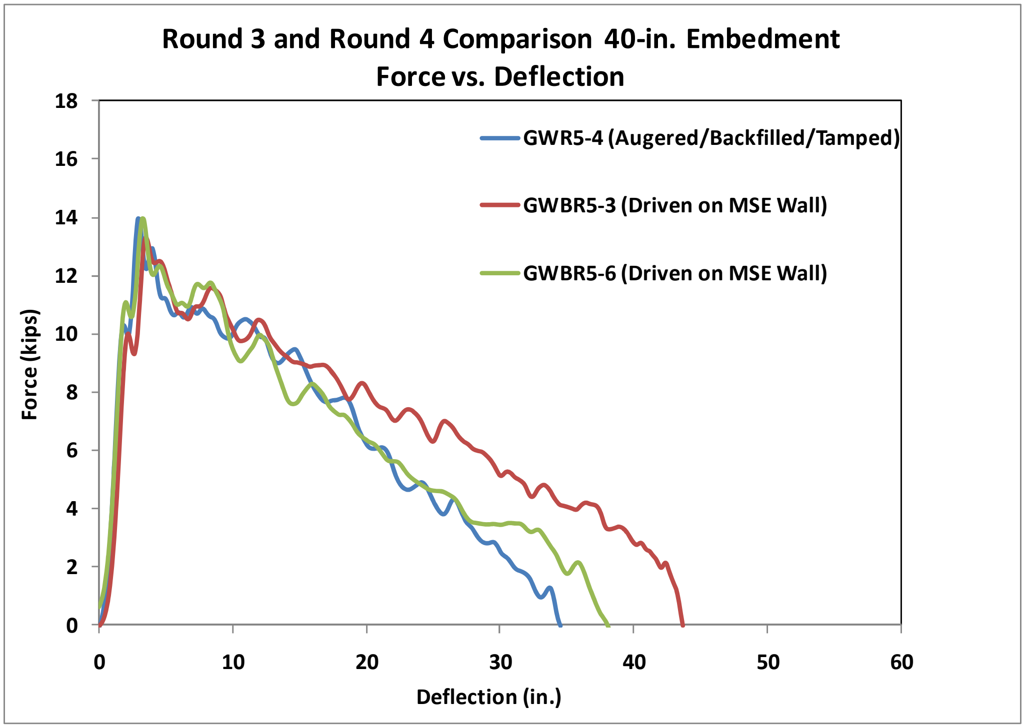
Figure 74. Photo. Post Damage – Round 4 (Ascending Left to Right).

Table 19. Hinge Points (From Top of Posts).

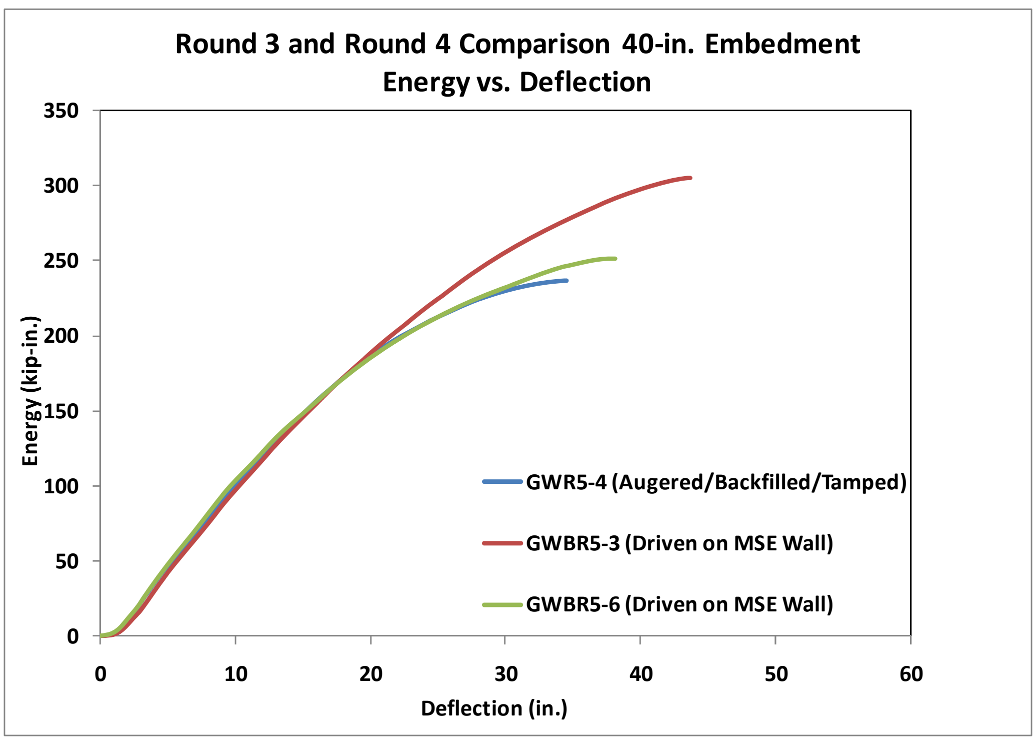
Post Length in. (mm)	Test No.	Hinge Location in. (mm)
52 (1,321)	GWBR-1	42 (1,067)
	GWBR-4	42 (1,067)
46 (1,168)	GWBR-2	40.5 (1,029)
	GWBR-5	40 (1,016)
40 (1,016)	GWBR-3	41 (1,041)
	GWBR-6	40 (1,016)

Table 20. Comparison of Round 3 Posts on 3H:1V Slope and Round 4 Posts on 3H:1V Slope Adjacent to MSE Wall.

Test No.	Installation Method	Post Type	Impact Velocity mph (km/h)	Peak Force		Average Force		Total Energy kip-in. (kJ)	Maximum Deflection in. (mm)
				Force kips (kN)	Deflection in. (mm)	@ 15 in. kips (kN)	@ 20 in. kips (kN)		
Steel Posts with 40-in. (1,016-mm) Embedment Depth									
GWBR5-3	Driven on MSE wall	W6x8.5 (W152x12.6)	22.1 (34.0)	13.3 (59.2)	3.5 (89)	9.7 (43.3)	9.4 (41.9)	305.4 (34.5)	43.7 (1,109)
GWBR5-6	Driven on MSE wall	W6x8.5 (W152x12.6)	22.3 (35.9)	14.0 (62.2)	3.2 (82)	9.9 (43.9)	9.3 (41.2)	251.7 (28.4)	38.2 (969)
GWR5-4	Augered hole Backfilled/Tamped	W6x8.5 (W152x12.6)	20.6 (33.2)	14.0 (62.1)	2.9 (74)	9.9 (43.9)	9.3 (41.5)	237.1 (26.8)	34.5 (877)
Average			21.6 (34.4)	13.8 (61.2)	3.2 (82)	9.8 (43.7)	9.3 (41.5)	264.7 (29.9)	38.8 (985)
Steel Posts with 46-in. (1,168-mm) Embedment Depth									
GWBR5-2	Driven on MSE wall	W6x9 (W152x13.4)	19.4 (31.2)	15.1 (67.1)	3.2 (80)	10.2 (45.2)	9.3 (41.5)	240.8 (27.2)	35.0 (889)
GWBR5-5	Driven on MSE wall	W6x9 (W152x13.4)	23.9 (38.5)	14.4 (64.0)	4.5 (115)	9.7 (43.1)	8.9 (39.4)	244.5 (27.6)	38.5 (978)
GWR5-3	Augered hole Backfilled/Tamped	W6x8.5 (W152x12.6)	19.9 (32.0)	14.7 (65.6)	2.7 (69)	9.9 (44.2)	9.0 (40.0)	221.5 (25.0)	34.8 (883)
Average			21.1 (33.9)	14.7 (65.6)	3.5 (88)	9.9 (44.2)	9.1 (40.3)	235.6 (26.6)	36.1 (917)
Steel Posts with 52-in. (1,321-mm) Embedment Depth									
GWBR5-1	Driven on MSE wall	W6x9 (W152x13.4)	21.2 (34.0)	16.2 (72.0)	2.7 (70)	10.1 (44.9)	8.9 (39.6)	211.0 (23.8)	28.5 (724)
GWBR5-4	Driven on MSE wall	W6x9 (W152x13.4)	22.3 (35.9)	15.1 (67.1)	3.3 (83)	9.9 (43.8)	9.1 (40.4)	235.7 (26.6)	34.2 (869)
GWR5-1	Driven in pit	W6x9 (W152x13.4)	20.0 (32.1)	15.1 (67.2)	3.7 (93)	10.9 (48.4)	9.8 (43.5)	237.4 (26.8)	35.4 (900)
GWR5-2	Augered hole Backfilled/Tamped	W6x9 (W152x13.4)	20.8 (33.4)	15.6 (69.5)	2.8 (72)	11.1 (49.3)	10.2 (45.2)	251.2 (28.4)	33.2 (844)
Average			21.1 (33.9)	15.5 (69.0)	3.1 (80)	10.5 (46.6)	9.5 (42.2)	233.8 (26.4)	32.8 (834)

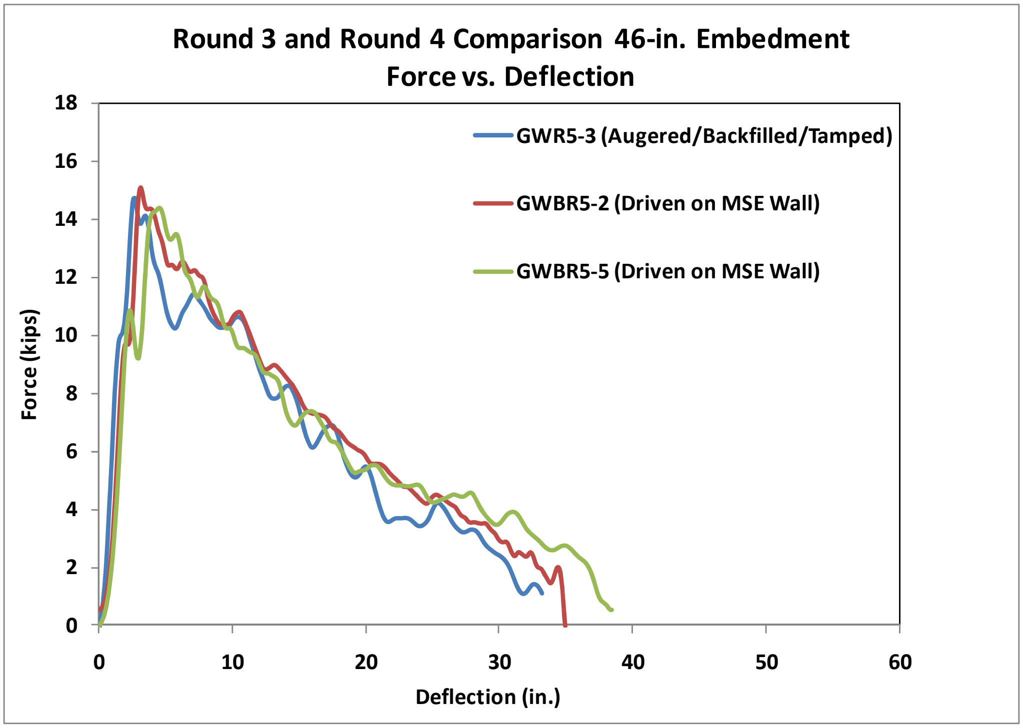


a. Force vs. Deflection

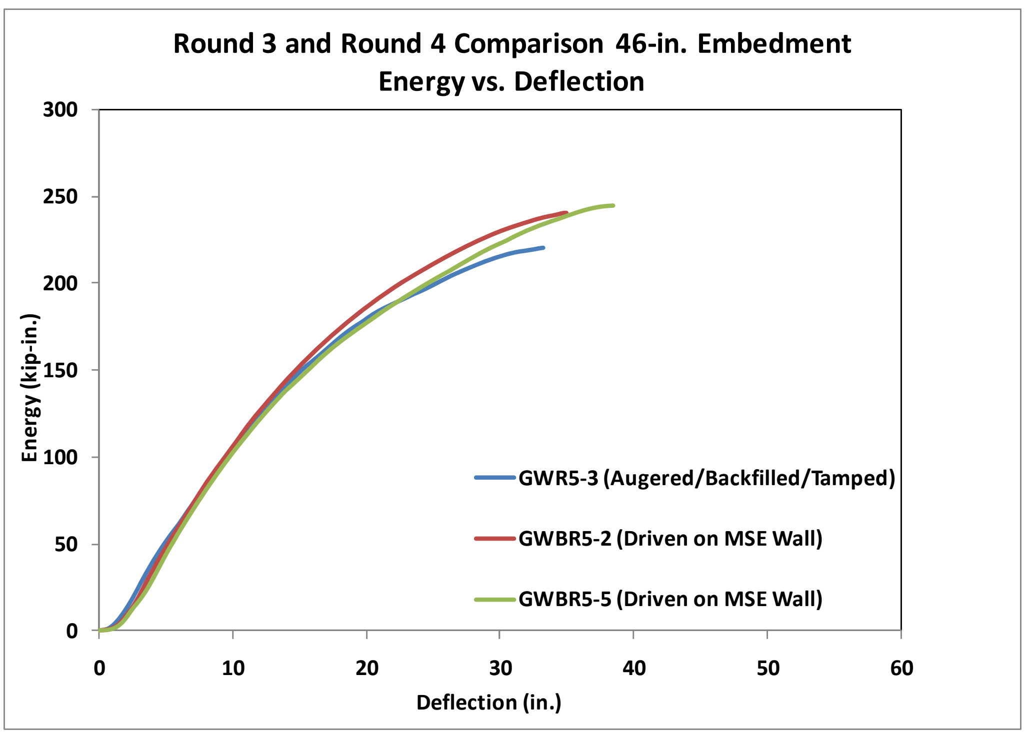


b. Energy vs. Deflection

Figure 75. Graph. Rounds 3 and 4 - Force vs. Deflection and Energy vs. Deflection (40-in. Embedment and 3H:1V Slope Break Point).

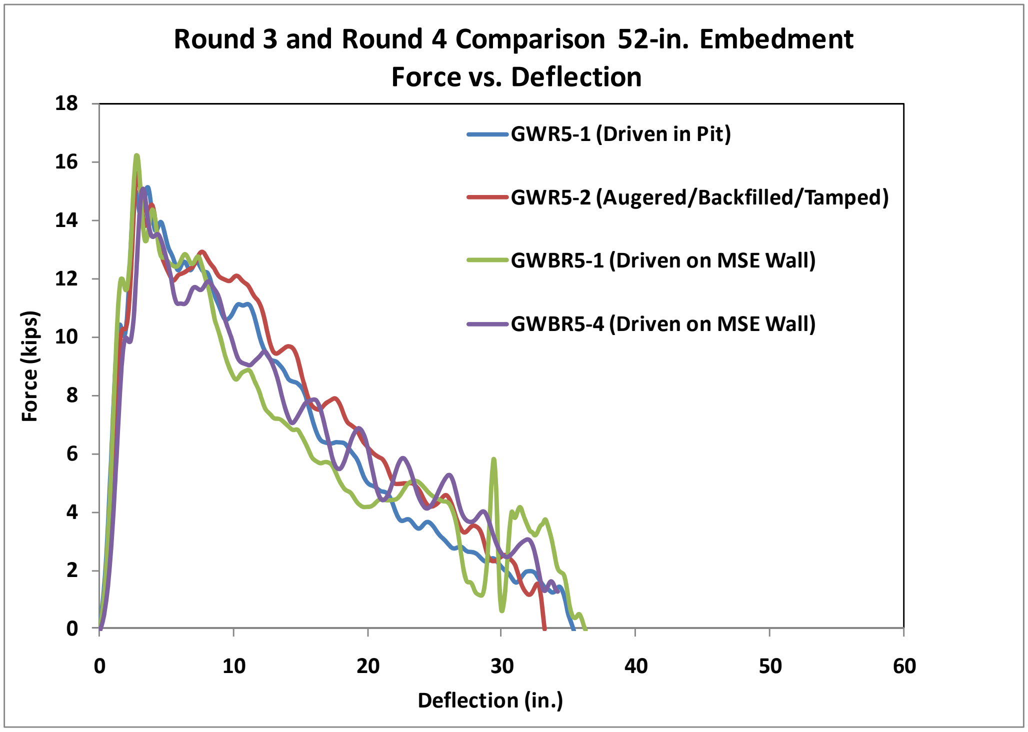


a. Force vs. Deflection

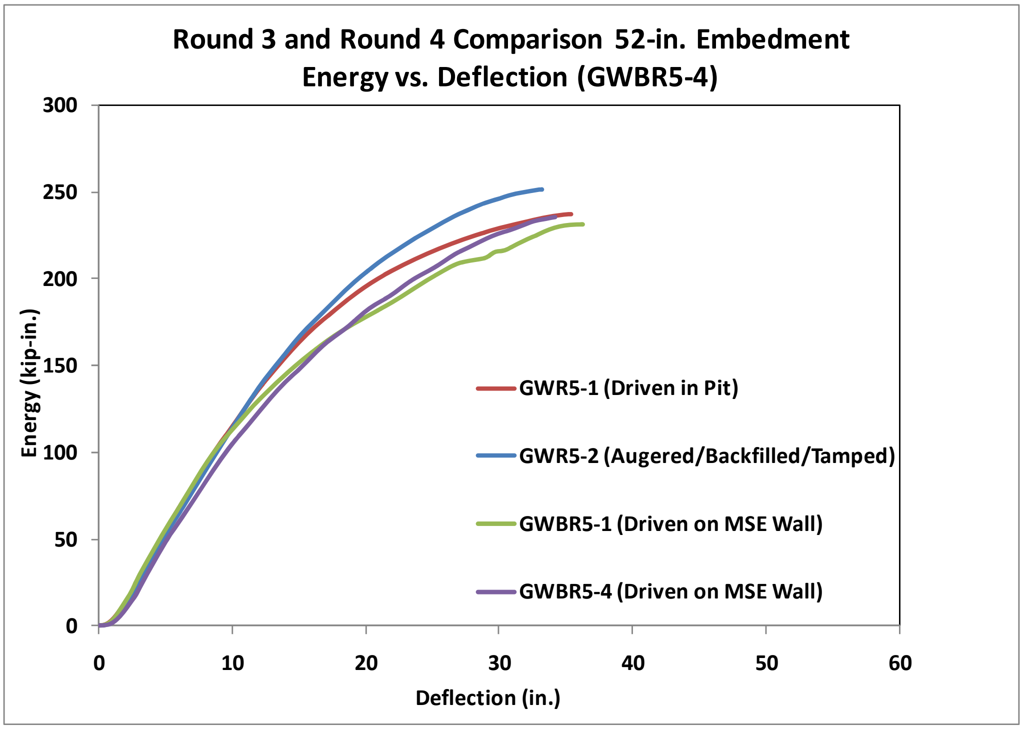


b. Energy vs. Deflection

Figure 76. Graph. Rounds 3 and 4 - Force vs. Deflection and Energy vs. Deflection (46-in. Embedment and 3H:1V Slope Break Point).



a. Force vs. Deflection



b. Energy vs. Deflection

Figure 77. Graph. Rounds 3 and 4 - and Energy vs. Deflection (52-in. Embedment and 3H:1V Slope Break Point).

CHAPTER 8. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

8.1 SUMMARY OF DYNAMIC TESTING

The first round of testing included 11 tests on 6-in. x 8-in. (152-mm x 203-mm) wood posts embedded 40 in. (1,016 mm) in different soils and impacted at various speeds. Two major conclusions came from this round of testing. First, the resistance to post rotation provided by the 2-in. to 4-in. (51-mm to 102-mm) wall-facing rock was dramatically less than that observed in standard strong soil, e.g., AASHTO Grading B. Thus, a standard MGS should not be configured with posts placed in larger wall-facing rock. In addition, it would seem extremely difficult, if not impossible, to place posts into the larger wall facing fill using the driven method. Second, testing at various impact speeds demonstrated an increase in force and energy absorbed with increases in impact velocity. A 50 percent increase in average force occurred when comparing the 20 mph (32 km/h) tests to the 15 mph (24 km/h) tests, but a minimal increase occurred between the 20 mph (32 km/h) and 25 mph (40 km/h) tests. Further testing would be required to determine whether this phenomenon was the result of the soil inertia, the dynamic properties of the soil, or some other unknown cause.

The second round of testing included two tests on 6-in. x 8-in. (152-mm x 203-mm) wood posts and two tests on W6x16 (W152x23.8) steel posts. A W6x16 (W152x23.8) steel section was used in lieu of a W6x9 (W152x13.4) steel section to determine the post-soil resistance of an embedded guardrail post since the heavier section had a similar flange width but decreased concerns for plastic deformations. All four posts were embedded 40 in. (1,016 mm) into a well-compacted, strong soil and impacted at 20 mph (32 km/h). The test results showed that the post-soil resistance for standard wood and steel posts was nearly identical. This finding supports the common, industry-wide assumption that the two post types provide equivalent post-soil resistance for guardrail systems.

The third round of testing involved five tests of wood and steel posts placed at the slope break point of a 3H:1V fill slope with various embedment depths, ranging between 40 in. and 52 in. (1,016 mm and 1,321 mm). A 6-in. x 8-in. (152-mm x 203-mm) wood post with a 52-in. (1,321-mm) post embedment depth was shown to fracture and thus could not provide the required energy absorption for an MGS post. The steel post tests resulted in similar resistances to post rotation regardless of the embedment depth due to plastic bending of the posts during all of the tests.

The fourth round of bogie testing utilized six bogie tests to evaluate standard steel posts placed on top of an actual MSE wall constructed to FHWA specifications. The posts were driven into a roller-compacted, strong soil at the slope break point of a 3H:1V fill slope adjacent to and on top of a wire-faced, MSE wall system. Multiple embedment depths, ranging from 40 in. to 52 in. (1,016 mm to 1,321 mm), were again evaluated. All of the tests resulted in force vs. deflection curves with similar shapes and magnitudes. However, the deeper embedment depths resulted in higher peak post-soil resistance but caused greater post bending and less post rotation. Deeper embedment depths caused the point of rotation (plastic bending hinge) to be farther below the ground line, thus resulting in a lower maximum deflection and decreased energy absorption. On the other hand, the shorter embedment depths allowed for more post rotation through the soil and less post bending, thus resulting in larger deflections and increased energy absorption.

8.2 RECOMMENDATIONS

The fourth round of testing demonstrated that standard steel posts, ranging between 6 and 7 ft (1.8 and 2.1 m) in length, provide similar post-soil behavior through the deflections of 15 to 20 in. (381 to 408 mm) or within the expected performance for typical W-beam guardrail systems. However, the 6-ft (1.8-m) long posts with a 40-in. (1,016-mm) embedment depth provided improved energy absorption as compared to the steel posts with embedment depths of 46 and 52 in. (1,168 and 1.321 mm). Therefore, it is recommended that a non-blocked version of the MGS with W-beam backup plates be installed with 6-ft (1.8-m) long steel posts driven at the slope break point of a 3H:1V fill slope adjacent to and on top of a wire-faced, MSE wall using either W6x8.5 (W152x12.6) or W6x9 (W152x13.4) steel sections.

During the second round of testing, the post-soil resistance provided by 6-ft (1.8-m) long, W6x16 (W152x23.8) steel and 6-ft (1.8-m) long, 6-in x 8-in. (152-mm x 203 mm) wood posts installed in level terrain was found to be very similar. Since the W6x8.5 (W152x12.6) and W6x9 (W152x13.4) steel sections have similar flange widths to the W6x16 (W152x23.8) steel section, it is believed that standard steel posts would also provide similar post-soil resistance to 6-in x 8-in. (152-mm x 203-mm) wood posts when installed in level terrain and using 6-ft (1.8-m) long sections. As such, it is the researcher's opinion that the standard MGS installed in level terrain would perform in an acceptable manner when supported by 6-in. x 8-in. (152-mm x 203-mm) wood posts using a 6 ft (1.8 m) length and a 40-in. (1,016-mm) embedment depth.

During the third round of testing, wood posts measuring 7 ft (2.1 m) long or greater were to be tested and evaluated when installed at the slope break point of a 3H:1V fill slope. Due to a failure observed in the first test within this series, the wood post test matrix was temporarily aborted. As a result, the dynamic post-soil behavior and an acceptable length for a 6-in x 8-in. (152-mm x 203 mm) wood post was not determined for MSE wall applications. Further bogie testing of wood posts installed at the slope break point of a 3H:1V fill slope is planned for a follow-on research and testing program to determine an acceptable post length. If that wood post testing program is successful, the implementation of wood posts into the barrier system may be hindered unless an acceptable post installation method is developed for MSE wall applications.

Wood posts have a much larger cross-sectional area as compared to standard steel guardrail posts. Thus, it may be difficult to install wood posts either with the driven method or by using the auger, backfill, and tamping method due to the compacted soil and steel wire mesh found within the upper surface of a wire-faced, MSE wall. Based on post-soil performance, reliability, and ease of installation, steel posts versus wood posts were recommended for use in the crash testing and evaluation program of a non-blocked, MGS installed on a wire-faced, MSE wall system.

CHAPTER 9. REFERENCES

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2. Powell, G.H., *Barrier VII: A Computer Program for Evaluation of Automobile Barrier Systems,* Report No. FHWA-RD-73-51, Department of Civil Engineering, University of California, Berkeley, California, April 1973.

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10. McGhee, M.D., Faller, R.K., Lechtenberg, K.A., Bielenberg, R.W., Reid, J.D., Sicking, D.L., *Dynamic Impact Testing of Wood Posts for the MGS on a 2:1 Slope*, Final Report to the Midwest States Regional Pooled Fund Program, MwRSF Research Report No. TRP-03-235-10, Project No. SPR-3(017)-Year 15, Project Code RPFP-05-09, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, December 16, 2010.

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Appendix A. Material Specifications

Certified Analysis

Trinity Highway Products, LLC
2548 N.E. 28th St.
Ft Worth, TX

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1104828
Customer PO: 2095
BOL Number: 26405
Document #: 1
Shipped To: NE
Use State: KS

As of: 2/2/09

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
634	545G	6'0 POST/DB:DDR	A-709			22479790	49,600	69,100	23.8	0.100	0.790	0.033	0.032	0.200	0.440	0.00	0.200	0.002	4
100	901G	12/FLARE/8 HOLE	M-180	A		583168	71,200	77,900	27.0	0.061	0.750	0.016	0.015	0.012	0.071	0.00	0.051	0.000	4

24 Posts purchased 3/24/09
002

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 2nd day of February, 2009
Notary Public:
Commission Expires:

RACHEL R. MEDINA
Notary Public
STATE OF TEXAS
My Comm. Exp. 07/19/2009

Trinity Highway Products, LLC
Certified By: Stefanie Englert
Quality Assurance

Figure 78. Photo. W6x8.5 (W152x12.6) Steel Posts, Material Specification.

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

CERTIFIED MATERIAL TEST REPORT

CHAPARRAL

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

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		Tensile Strength		Specimen Area		Elongation			Bend Test	ROA
KSI	MPa	KSI	MPa	Sq In	Sq cm	%	Gage Length		Dia. Result	%
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: Tom L. Harrington Date: Jun. 26, 2006
Tom L. Harrington: Quality Assurance Manager

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

Page: 1 of 1

Figure 79. Photo. W6x9 (W152x13.4) Steel Posts, Material Specification.

Certified Analysis

Trinity Highway Products, LLC
2548 N.E. 28th St.
Ft Worth, TX

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1104828
Customer PO: 2095
BOL Number: 26405
Document #: 1
Shipped To: NE
Use State: KS

As of: 2/2/09

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
634	545G	6'0 POST/DB:DDR	A-709			22479790	49,600	69,100	23.8	0.100	0.790	0.033	0.032	0.200	0.440	0.00	0.200	0.002	4
100	901G	12/FLARE/8 HOLE	M-180	A		583168	71,200	77,900	27.0	0.061	0.750	0.016	0.015	0.012	0.071	0.00	0.051	0.000	4

24 Posts purchased 3/24/09
002

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123, UNLESS OTHERWISE STATED.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 2nd day of February, 2009

Notary Public:
Commission Expires:

RACHEL R. MEDINA
Notary Public
STATE OF TEXAS
My Comm. Exp. 07/18/2009

Trinity Highway Products, LLC
Certified By: Stefanie Inglet
Quality Assurance

Figure 80. Photo. W6x16 (W152x23.8) Steel Posts, Material Specification.

Appendix B. Soil Sieve Data

The results of washed soil sieve passing tests from each batch of soil used for every dynamic bogie test are provided in the graphs found in this appendix. The graphs show the passing percentages for the soil.

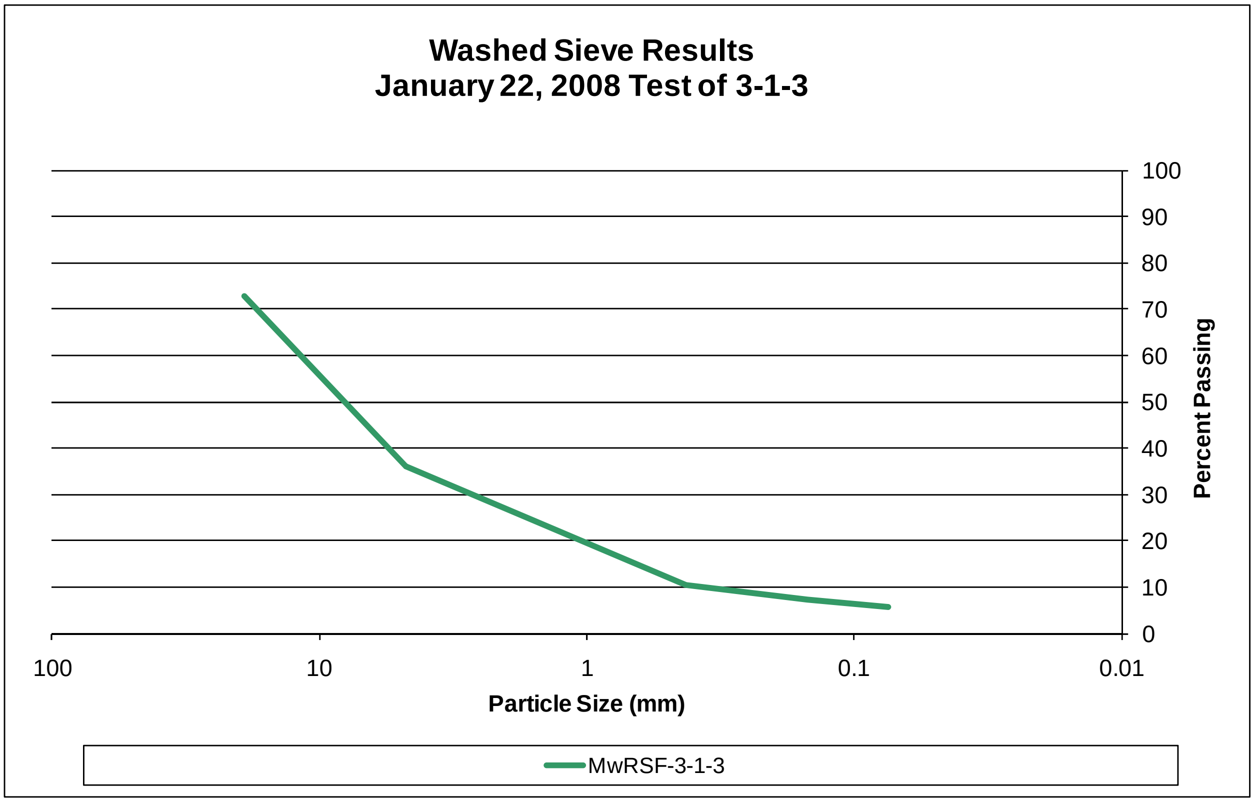


Figure 81. Graph. Sieve Results for Test No. GWB-1 through GWB-5.

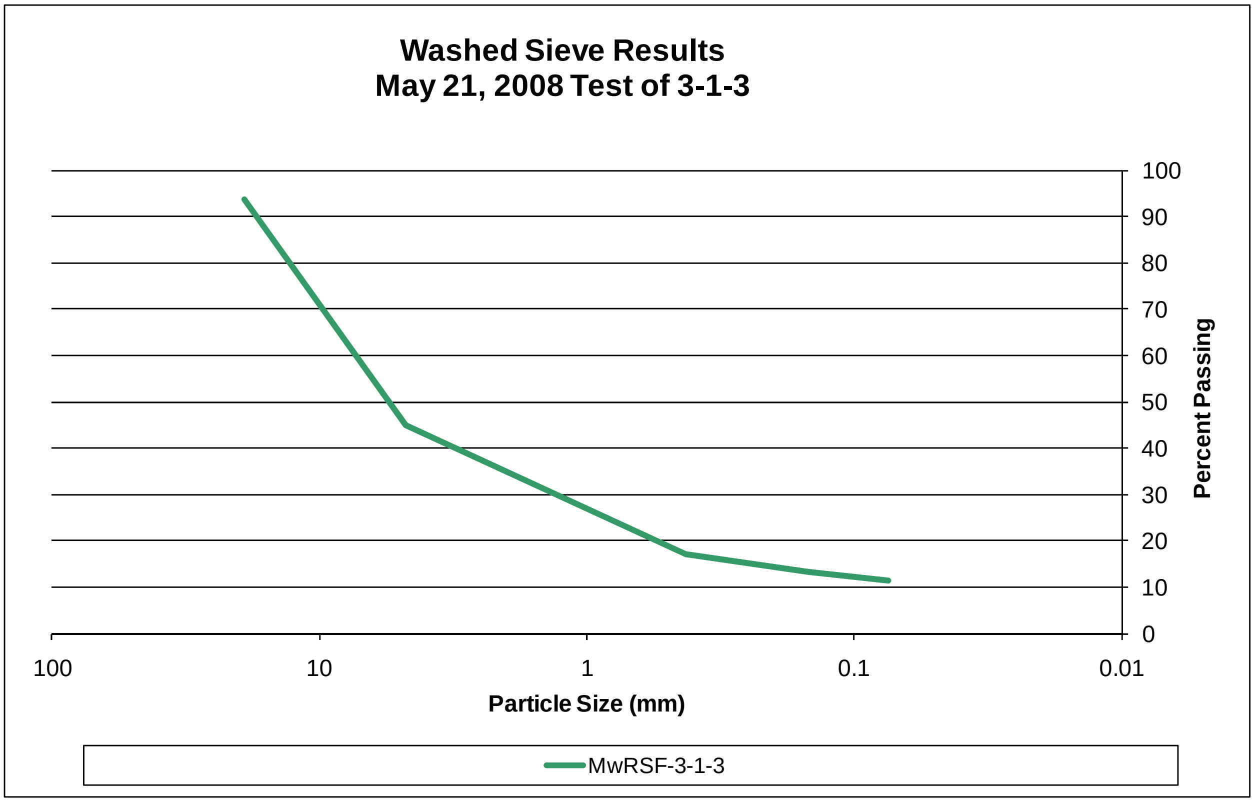


Figure 82. Graph. Sieve Results for Test No. GWB-6 through GWB-11.

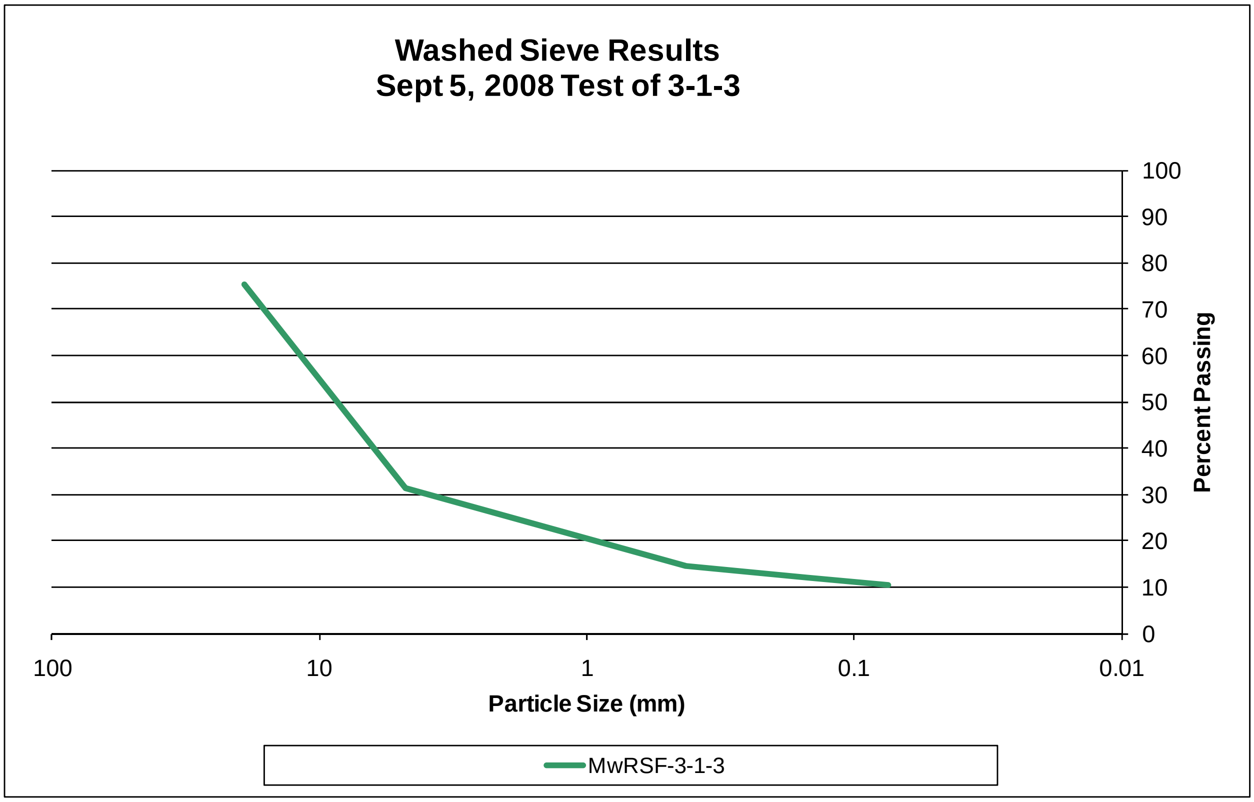


Figure 83. Graph. Sieve Results for Test No. GWB-12 through GWB-15.

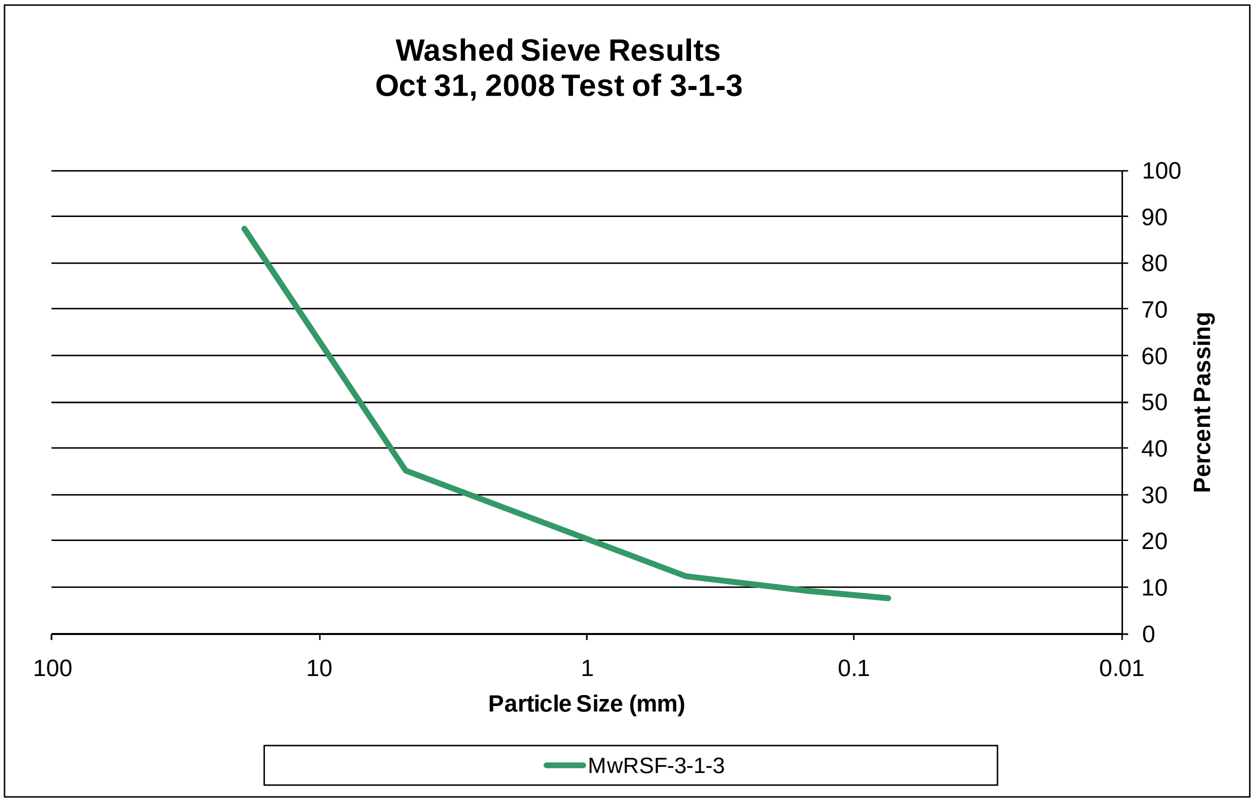


Figure 84. Graph. Sieve Results for Test No. GWR4-1.

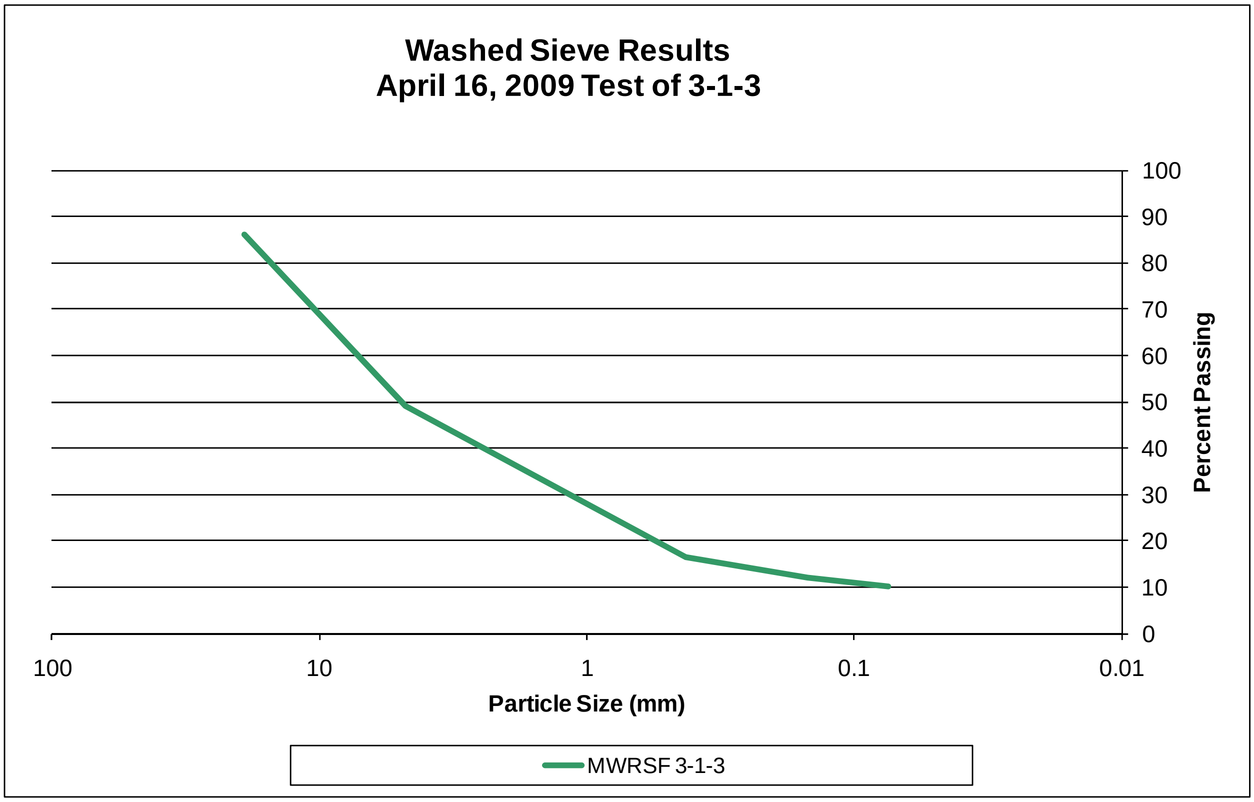


Figure 85. Graph. Sieve Results for Test No. GWR5-1 through GWR5-4.

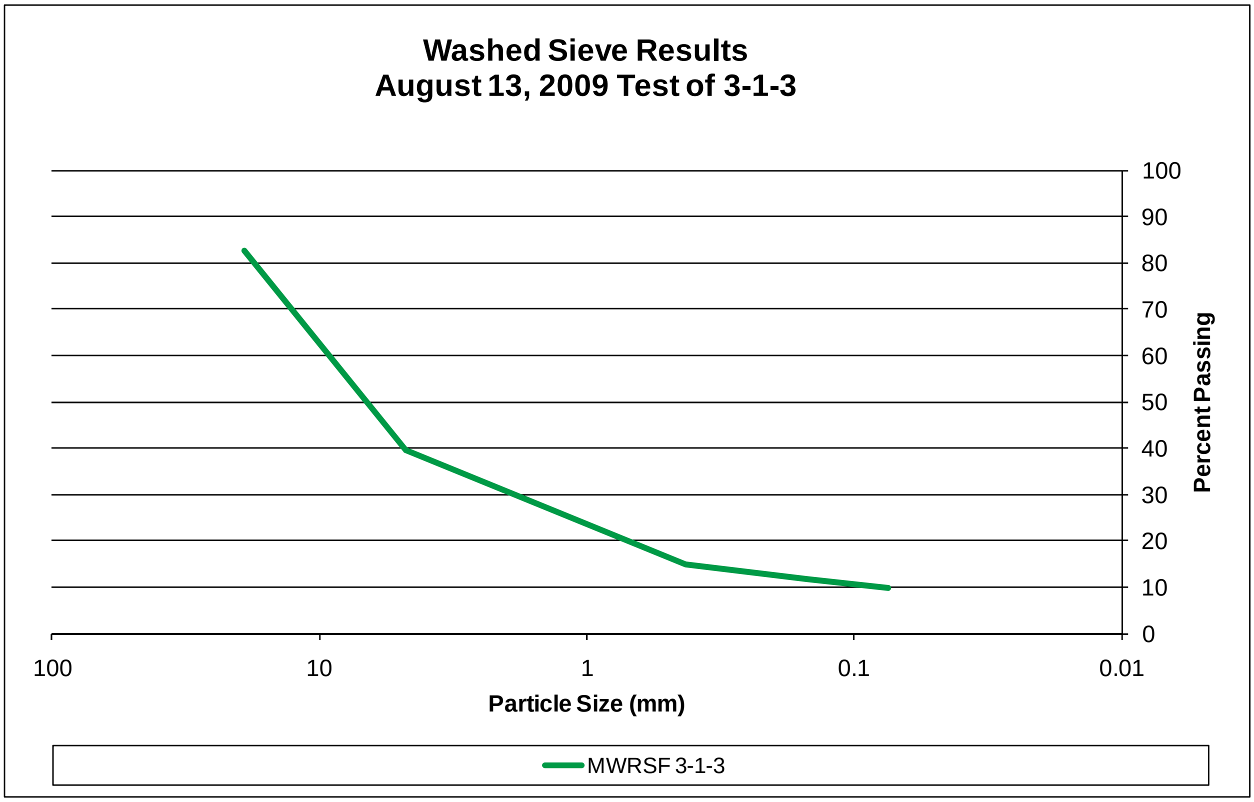


Figure 86. Graph. Sieve Results for Test No. GWBR5-1 through GWBR5-6.

Appendix C. Dynamic Test Results

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

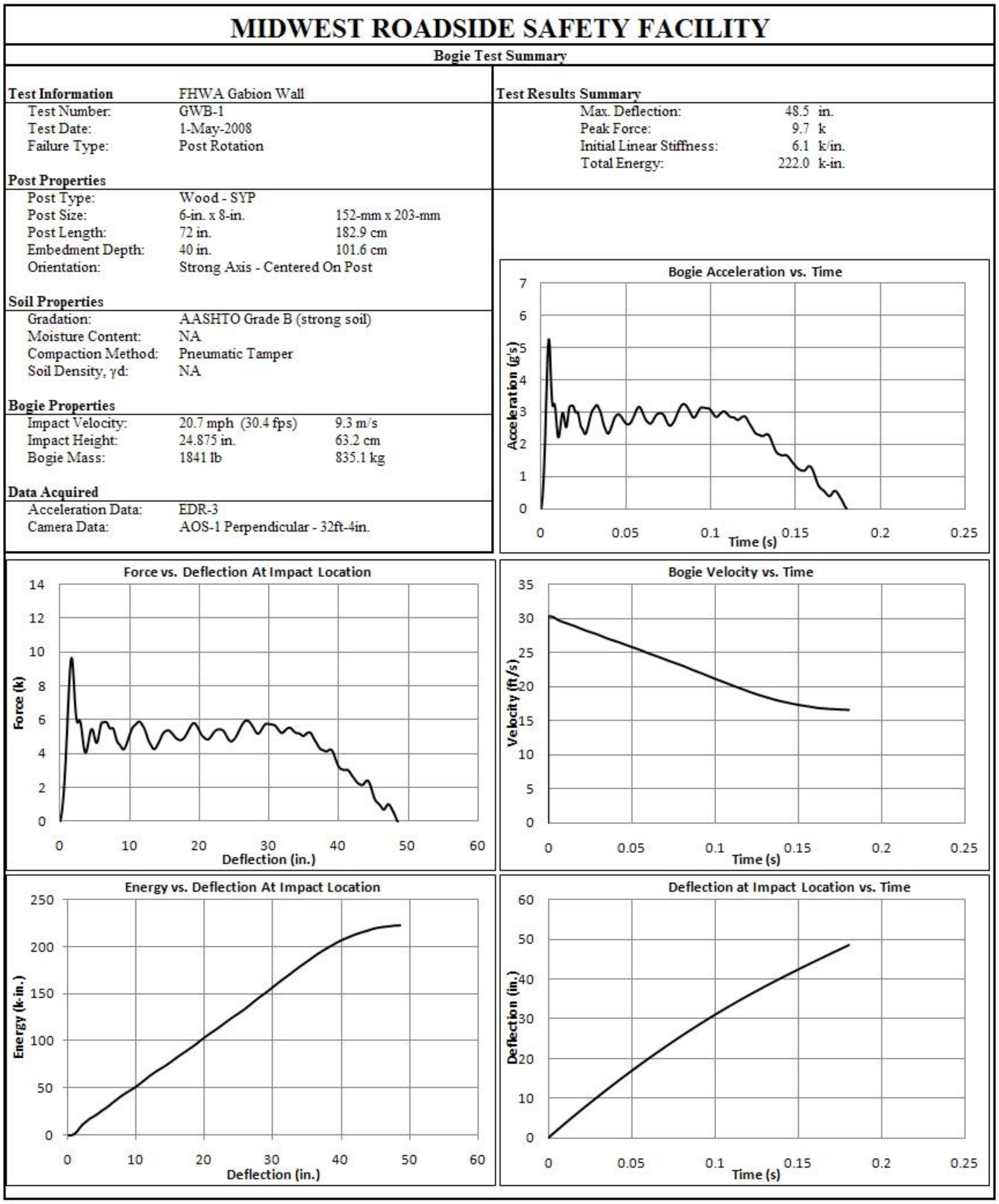


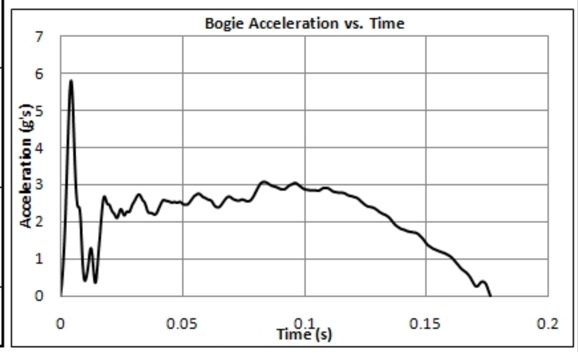
Figure 87. Graph. Test No. GWB-1 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-1	
Test Date:	1-May-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Wood - SYP	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	AASGTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pnuematic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	20.71 mph (30.4 fps)	9.26 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1841 lb	835.1 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-1 Perpendicular - 32ft-4in.	

Test Results Summary		
Max. Deflection:	49.7	in.
Peak Force:	10.7	k
Initial Linear Stiffness:	6.6	k/in.
Total Energy:	207.8	k-in.



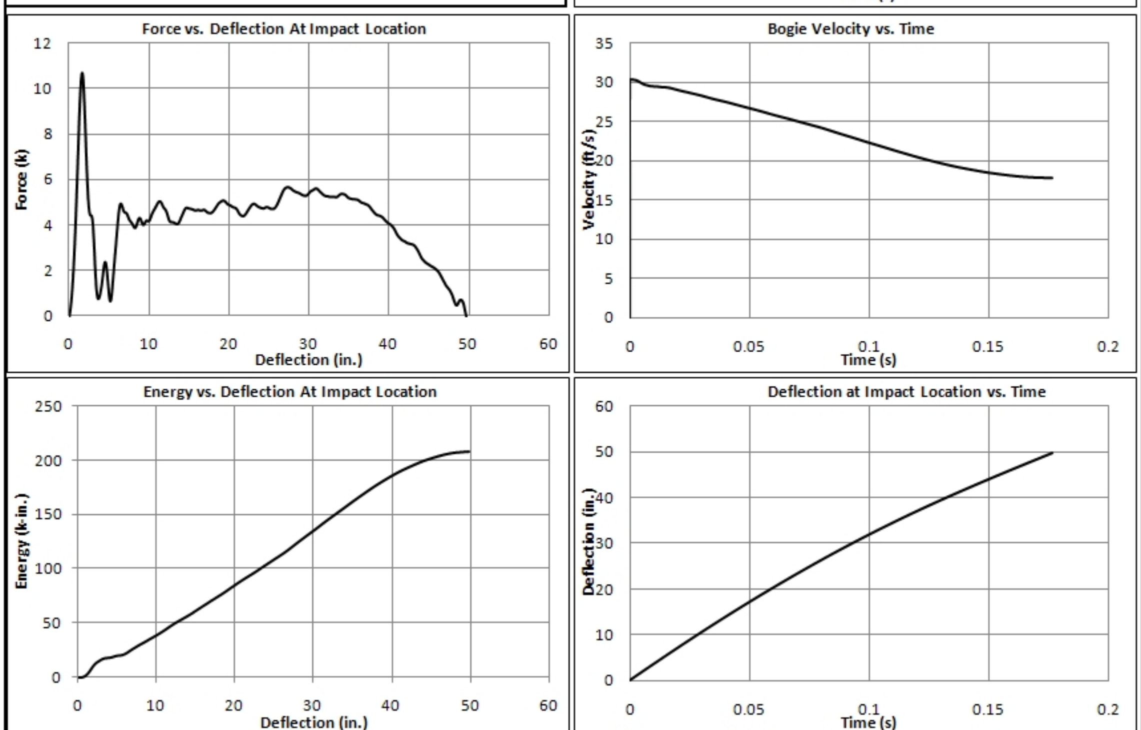


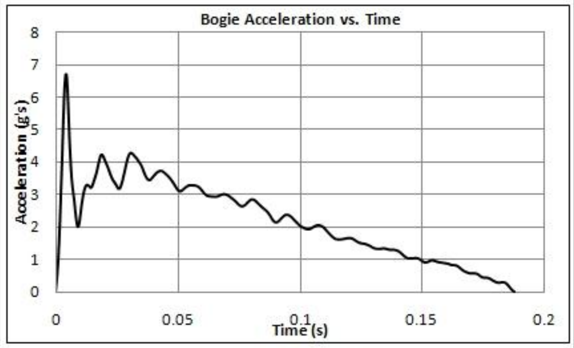
Figure 88. Graph. Test No. GWB-1 Results (DTS).

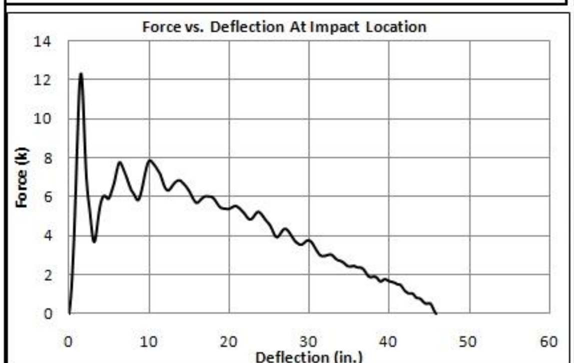
MIDWEST ROADSIDE SAFETY FACILITY

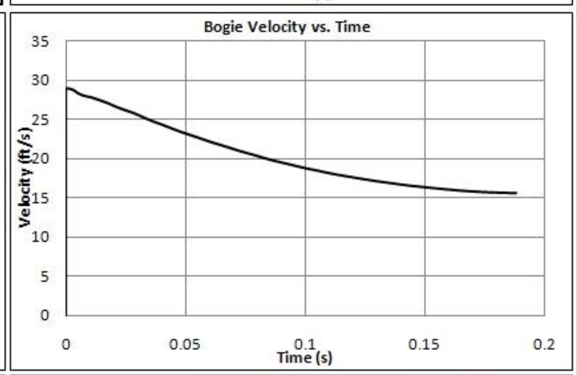
Bogie Test Summary

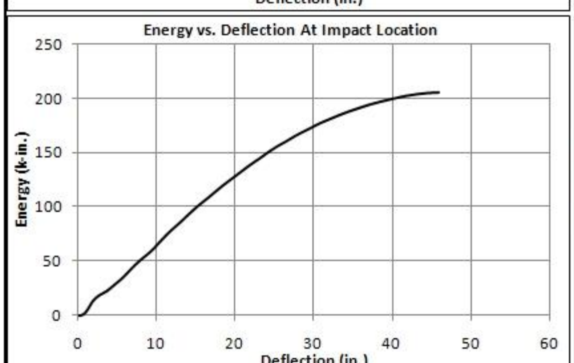
Test Information	FHWA Gabion Wall	
Test Number:	GWB-2	
Test Date:	7-May-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Wood - SYP	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.8 mph (29 fps)	8.9 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1841 lb	835.1 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-1 Perpendicular - 32ft-4in.	

Test Results Summary		
Max. Deflection:	45.9	in.
Peak Force:	12.3	k
Initial Linear Stiffness:	8.2	k/in.
Total Energy:	205.0	k-in.









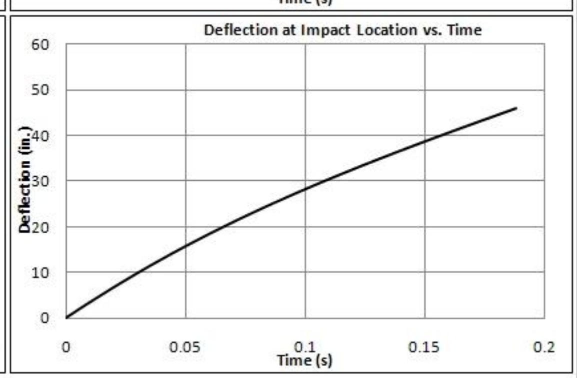


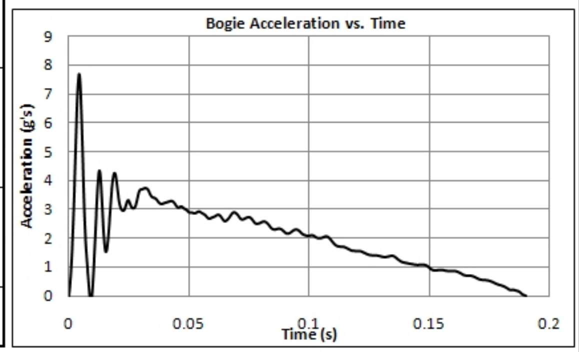
Figure 89.Graph. Test No. GWB-2 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-2	
Test Date:	7-May-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Wood - SYP	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	AASGTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pnuematic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.77 mph (29 fps)	8.84 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1841 lb	835.1 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-1 Perpendicular - 32ft-4in.	

Test Results Summary		
Max. Deflection:	48.1	in.
Peak Force:	14.2	k
Initial Linear Stiffness:	9.8	k/in.
Total Energy:	194.6	k-in.



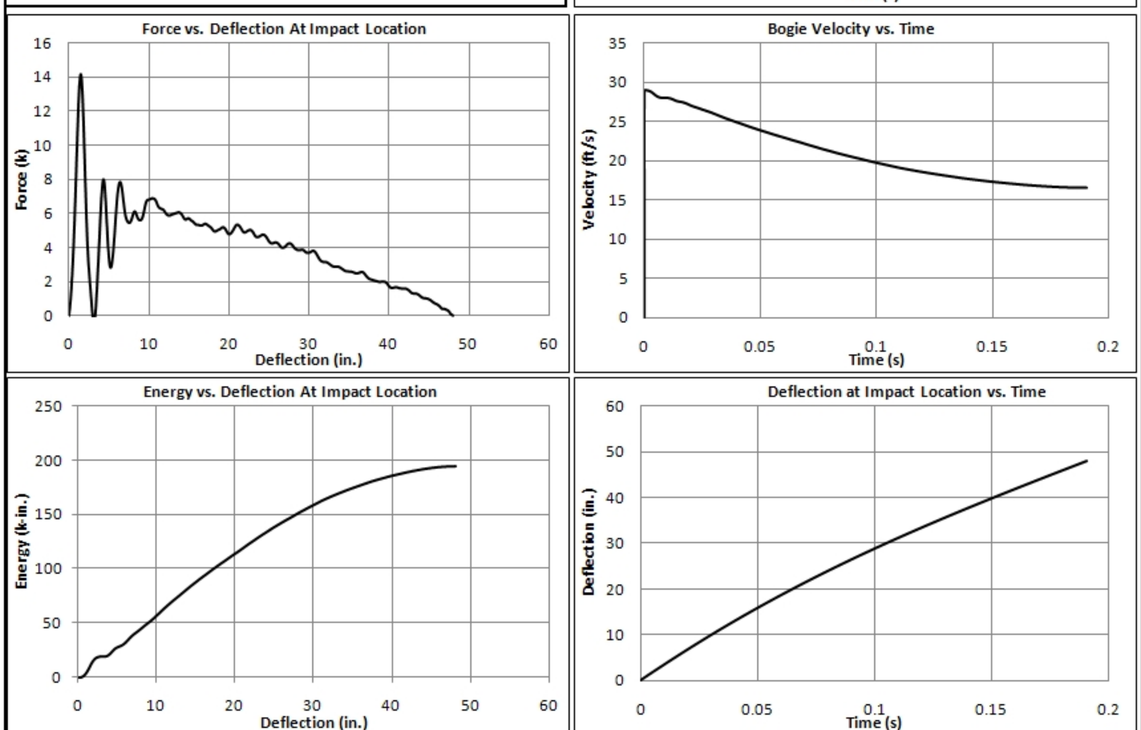
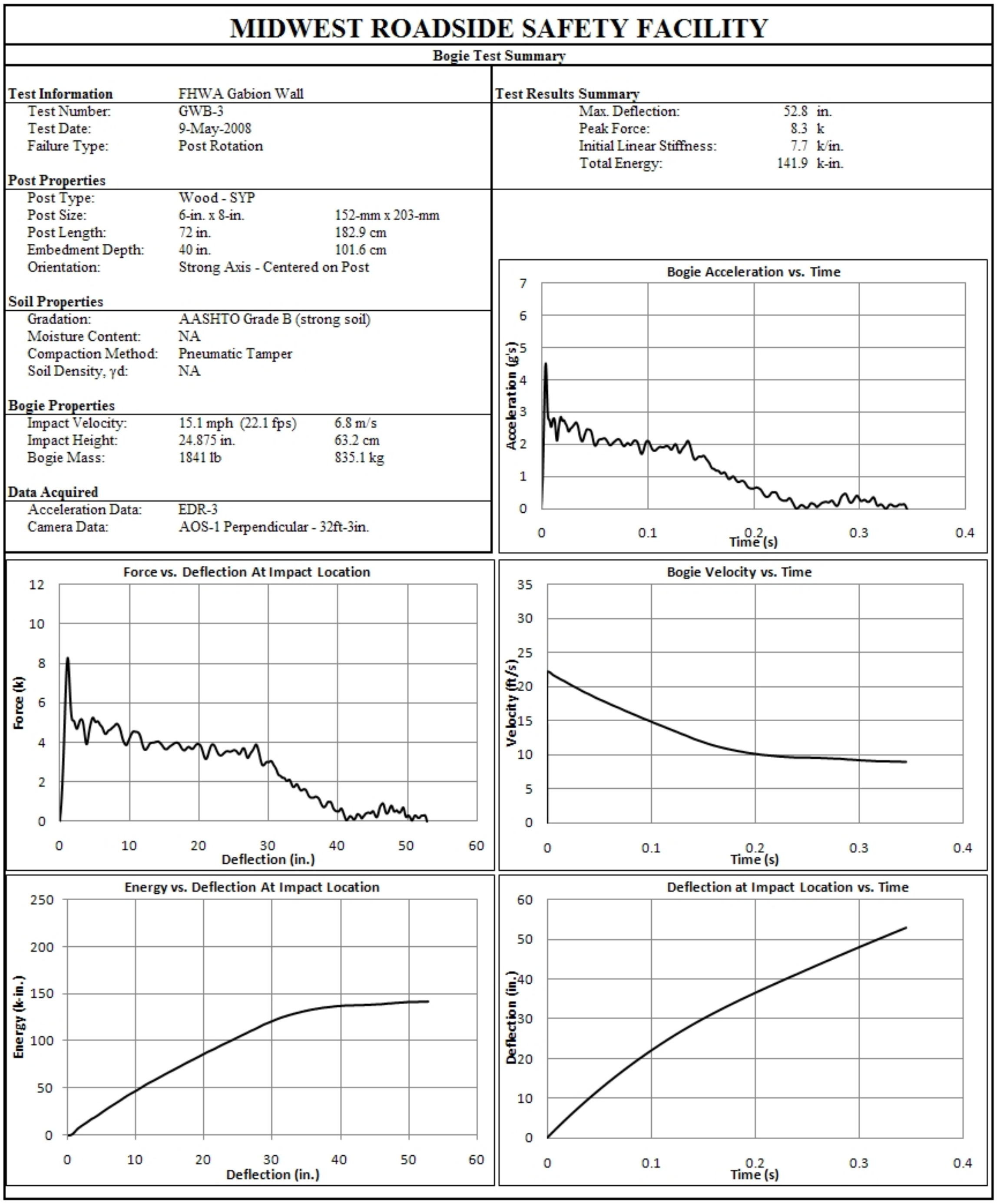


Figure 90. Graph. Test No. GWB-2 Results (DTS).


MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-3	
Test Date:	9-May-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Wood - SYP	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered on Post	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	15.1 mph (22.1 fps)	6.8 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1841 lb	835.1 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-1 Perpendicular - 32ft-3in.	

Test Results Summary		
Max. Deflection:	52.8	in.
Peak Force:	8.3	k
Initial Linear Stiffness:	7.7	k/in.
Total Energy:	141.9	k-in.

Figure 91. Graph. Test No. GWB-3 Results (EDR-3).

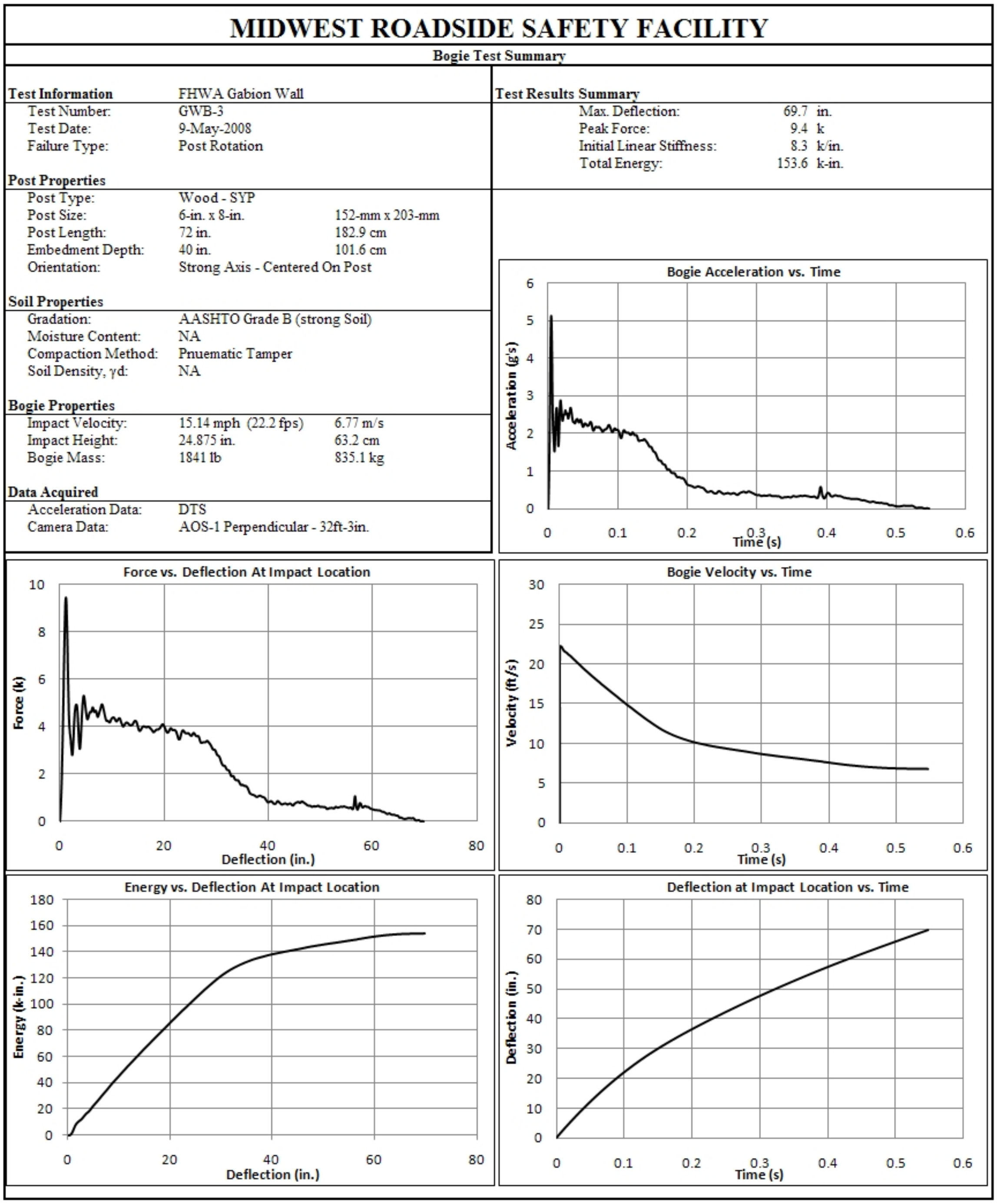


Figure 92. Graph. Test No. GWB-3 Results (DTS).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information FHWA Gabion Wall

Test Number:	GWB-4	
Test Date:	9-May-2008	
Failure Type:	Post Rotation	

Post Properties

Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered on Post	

Soil Properties

Gradation:	AASHTO Grade B (strong soil)
Moisture Content:	NA
Compaction Method:	Pneumatic Tamper
Soil Density, γd:	NA

Bogie Properties

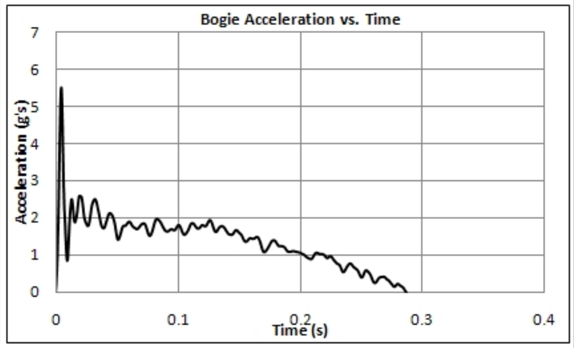
Impact Velocity:	14.3 mph (21 fps)	6.4 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1841 lb	835.1 kg

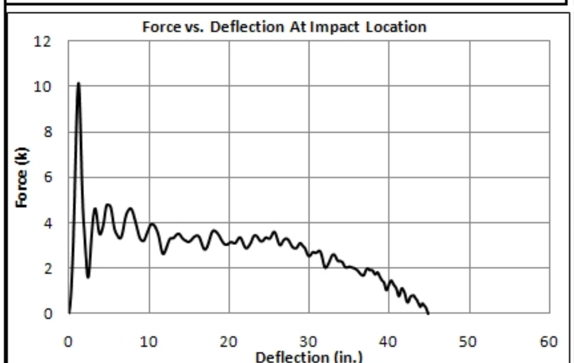
Data Acquired

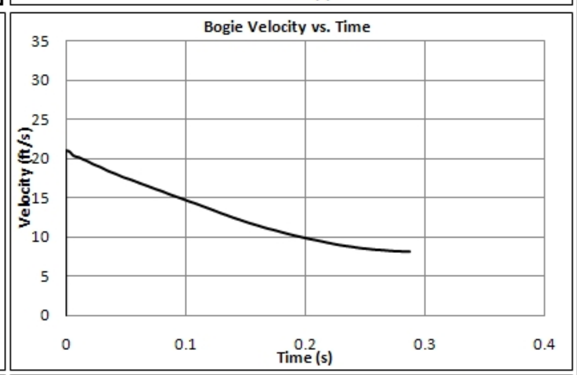
Acceleration Data:	EDR-3
Camera Data:	AOS-1 Perpendicular - 32ft-3in.

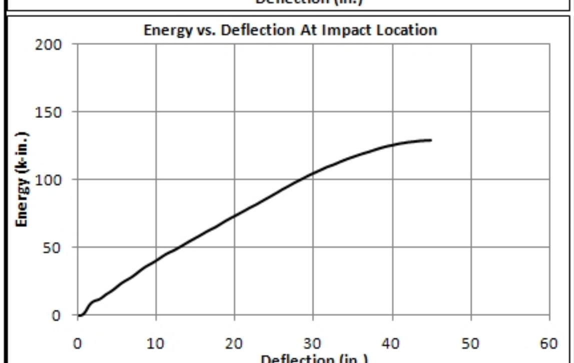
Test Results Summary

Max. Deflection:	44.9	in.
Peak Force:	10.2	k
Initial Linear Stiffness:	8.6	k/in.
Total Energy:	129.3	k-in.









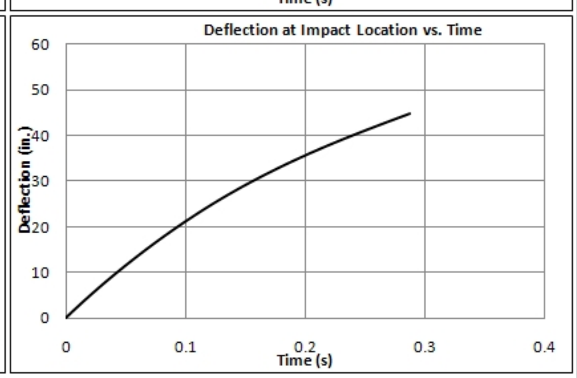


Figure 93. Graph. Test No. GWB-4 Results (EDR-3).

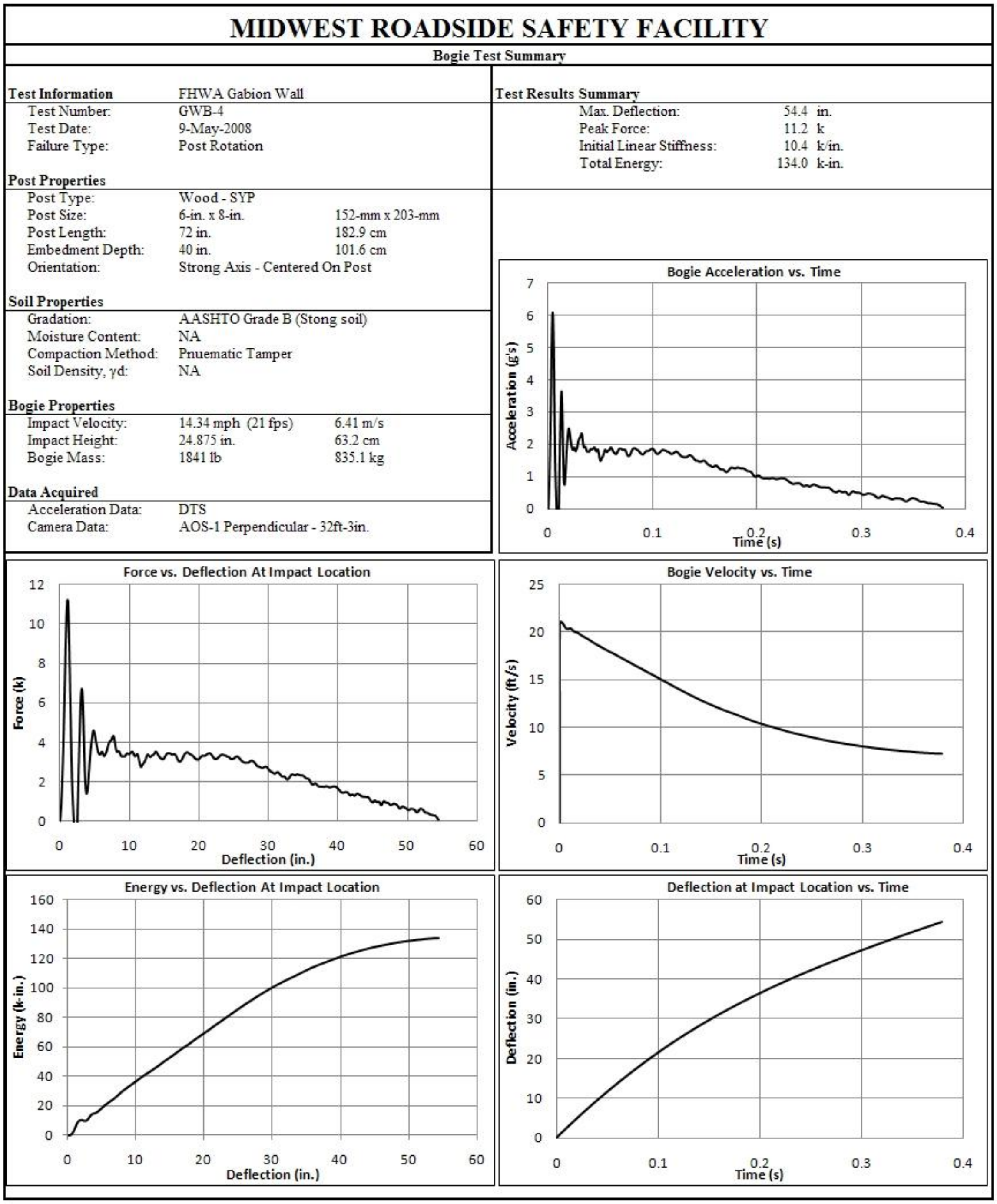


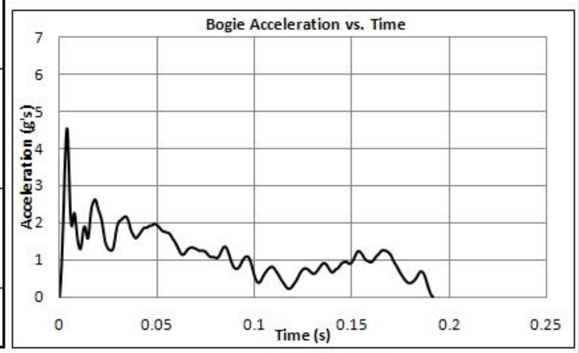
Figure 94. Graph. Test No. GWB-4 Results (DTS).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-5	
Test Date:	14-May-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Wood - SYP	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	2-in. to 4-in. Limestone Rock	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.7 mph (28.9 fps)	8.8 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1841 lb	835.1 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 32ft-3in.	

Test Results Summary		
Max. Deflection:	56.2	in.
Peak Force:	8.4	k
Initial Linear Stiffness:	6.5	k/in.
Total Energy:	126.3	k-in.



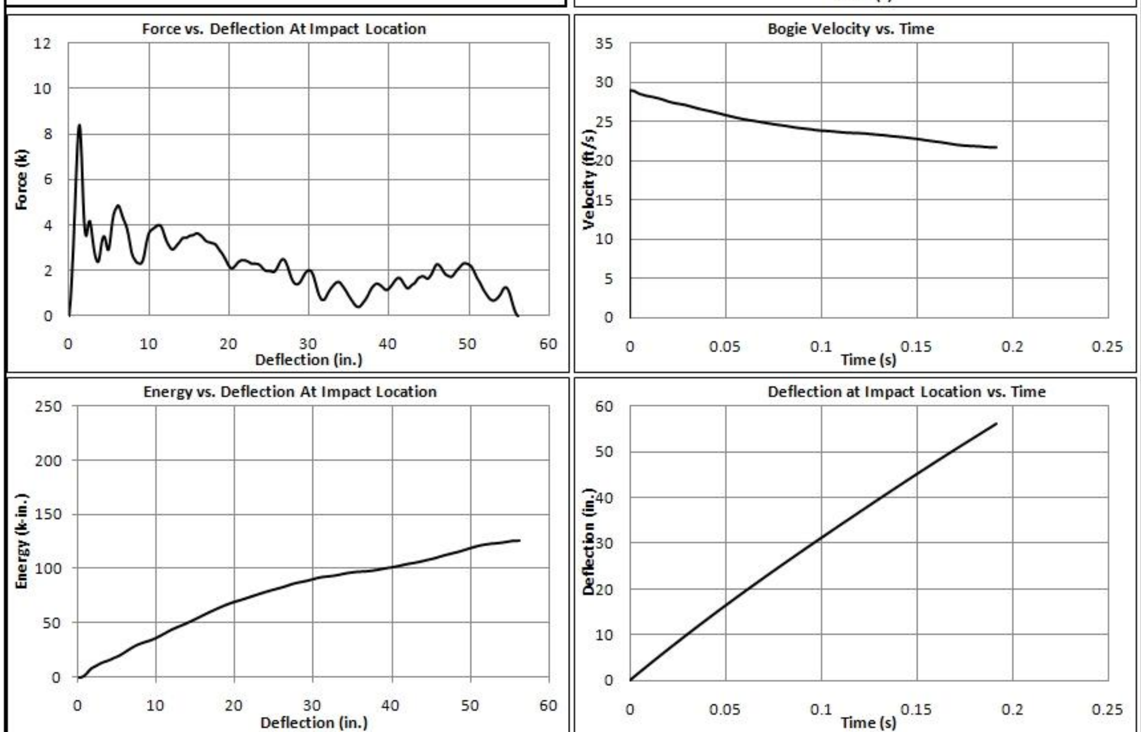


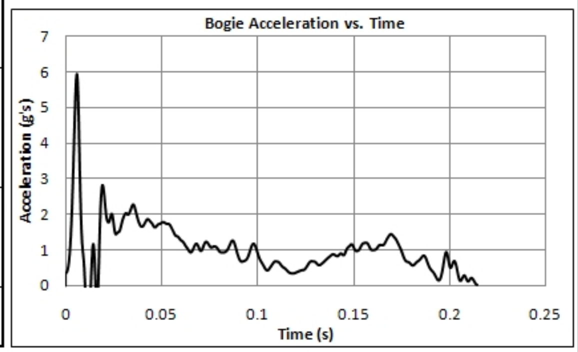
Figure 95. Graph. Test No. GWB-5 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-5	
Test Date:	14-May-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Wood - SYP	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	2-in. to 4-in. Limestone Rock	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.73 mph (28.9 fps)	8.82 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1841 lb	835.1 kg
Data Acquired		
Acceleration Data:	DTS	
Camera Data:	AOS-1 Perpendicular - 32ft-3in.	

Test Results Summary		
Max. Deflection:	63.3	in.
Peak Force:	10.9	k
Initial Linear Stiffness:	5.3	k/in.
Total Energy:	124.3	k-in.



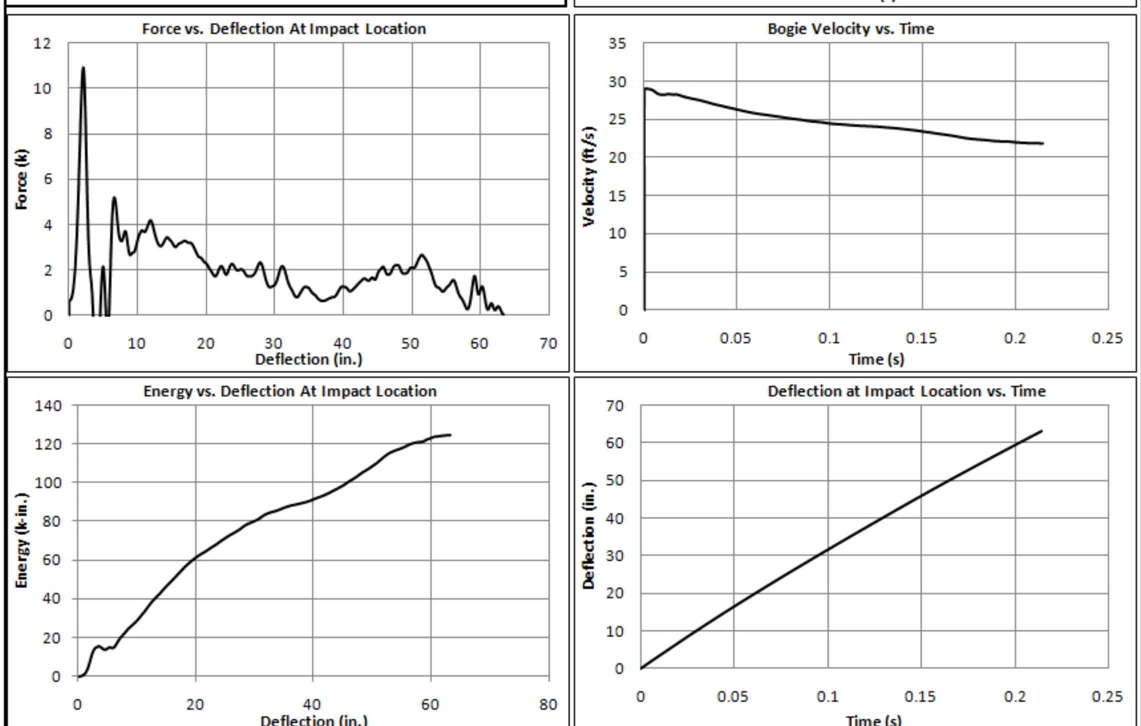


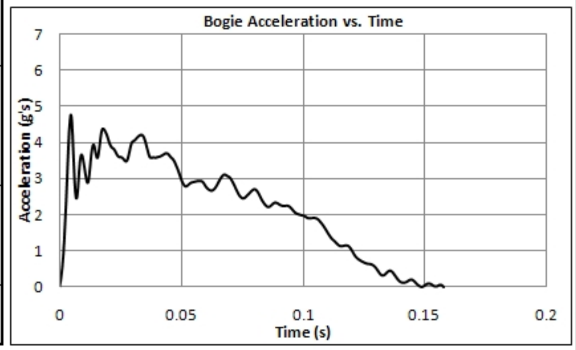
Figure 96. Graph. Test No. GWB-5 Results (DTS).

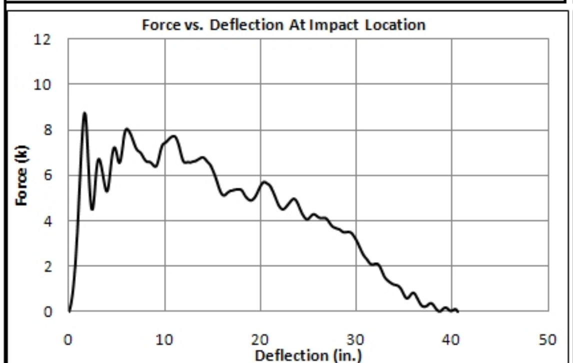
MIDWEST ROADSIDE SAFETY FACILITY

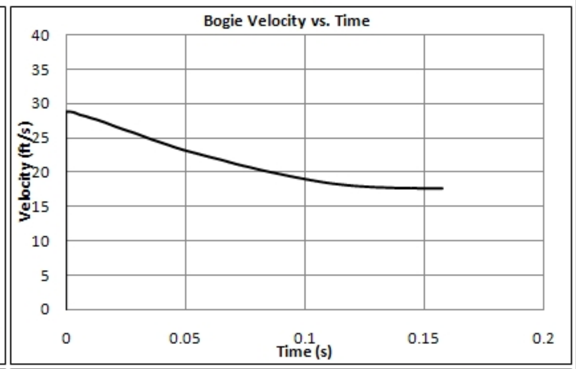
Bogie Test Summary

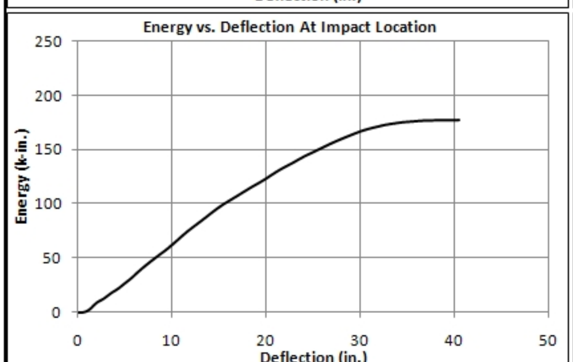
Test Information	FHWA Gabion Wall	
Test Number:	GWB-6	
Test Date:	4-Jun-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Wood - SYP	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.6 mph (28.7 fps)	8.8 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	40.5	in.
Peak Force:	8.7	k
Initial Linear Stiffness:	5.4	k/in.
Total Energy:	177.3	k-in.









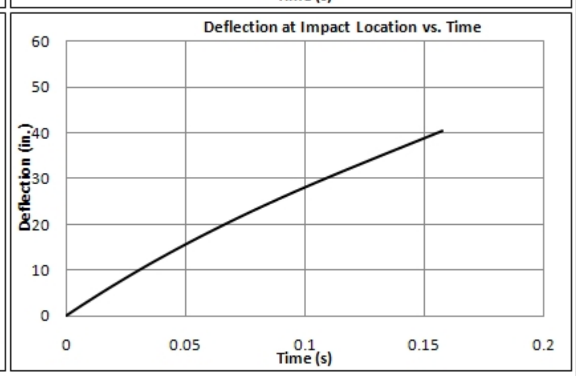


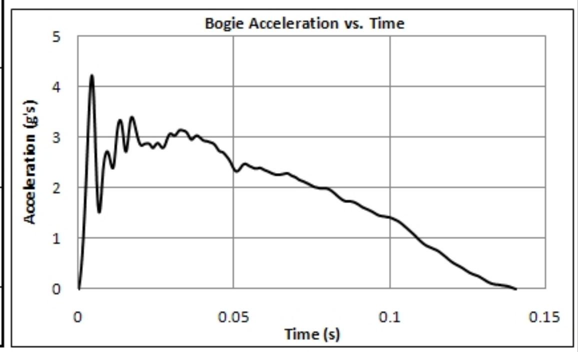
Figure 97. Graph. Test No. GWB-6 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-6	
Test Date:	4-Jun-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.6 mph (28.7 fps)	8.76 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	39.4	in.
Peak Force:	7.8	k
Initial Linear Stiffness:	5.4	k/in.
Total Energy:	142.6	k-in.



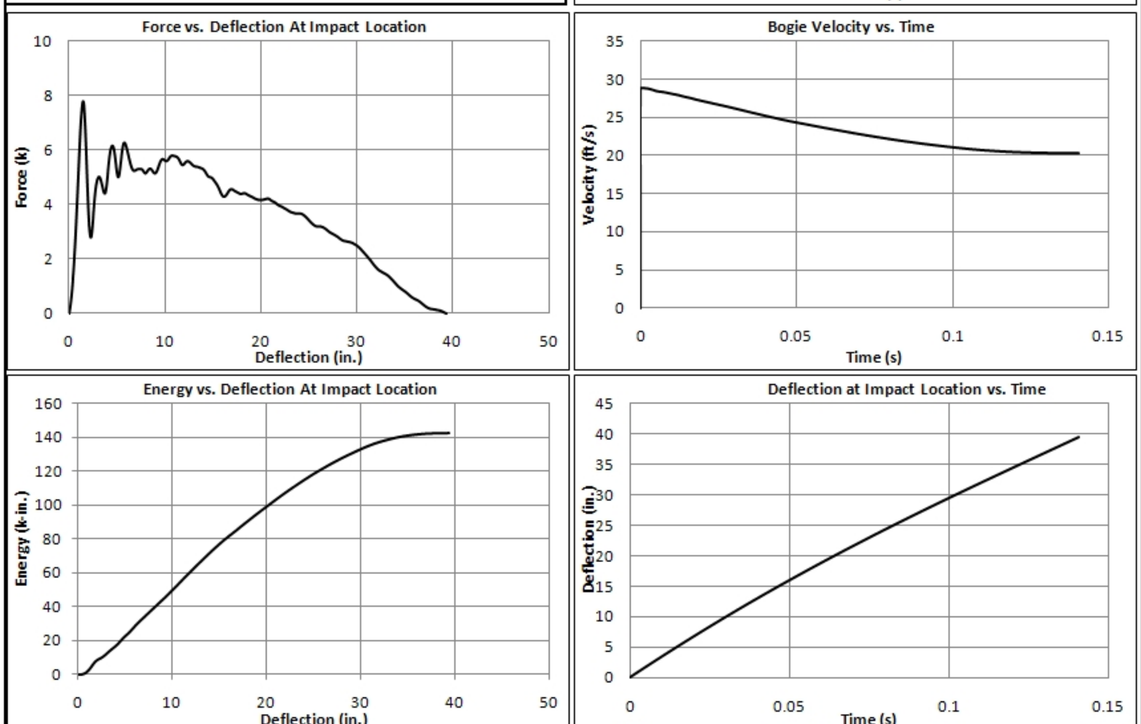


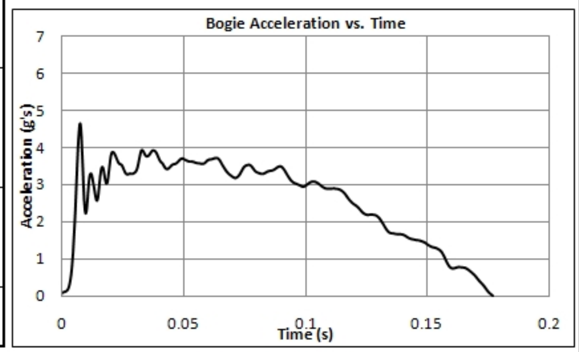
Figure 98. Graph. Test No. GWB-6 Results (EDR-4).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-7	
Test Date:	4-Jun-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Wood - SYP	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19 mph (27.9 fps)	8.5 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	40.8	in.
Peak Force:	8.6	k
Initial Linear Stiffness:	3.3	k/in.
Total Energy:	207.5	k-in.



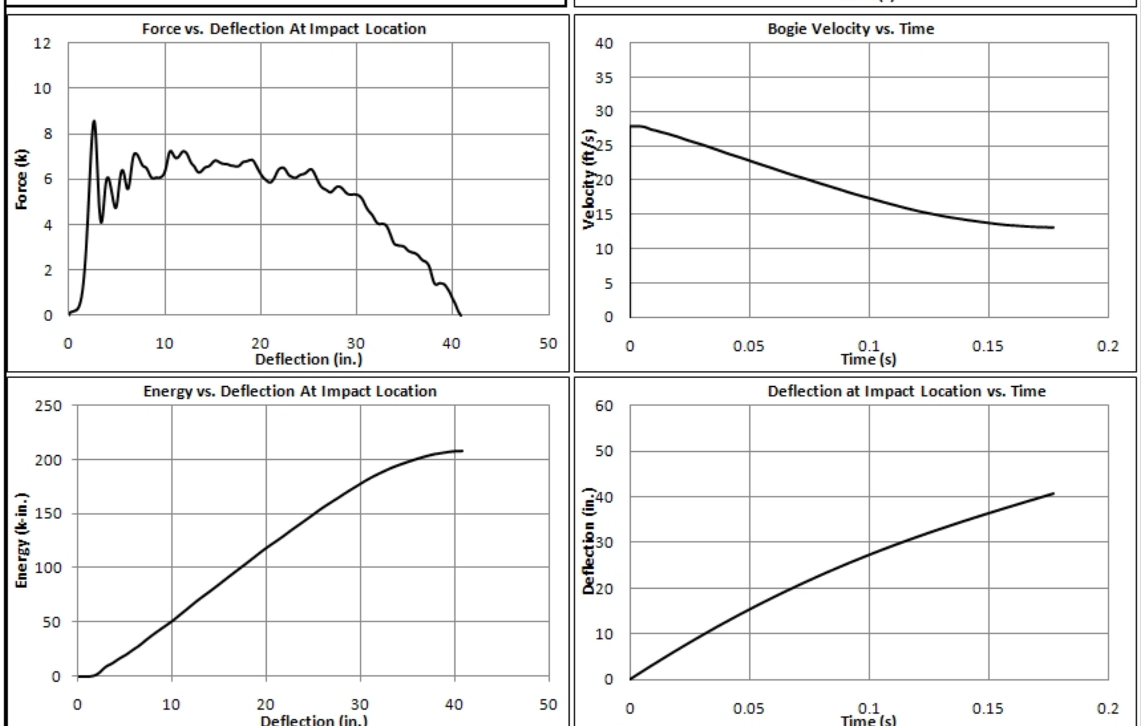


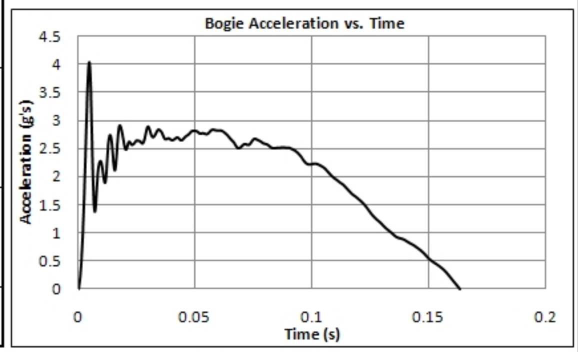
Figure 99. Graph. Test No. GWB-7 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-7	
Test Date:	4-Jun-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	18.99 mph (27.9 fps)	8.49 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	42.2	in.
Peak Force:	7.4	k
Initial Linear Stiffness:	5.0	k/in.
Total Energy:	164.0	k-in.



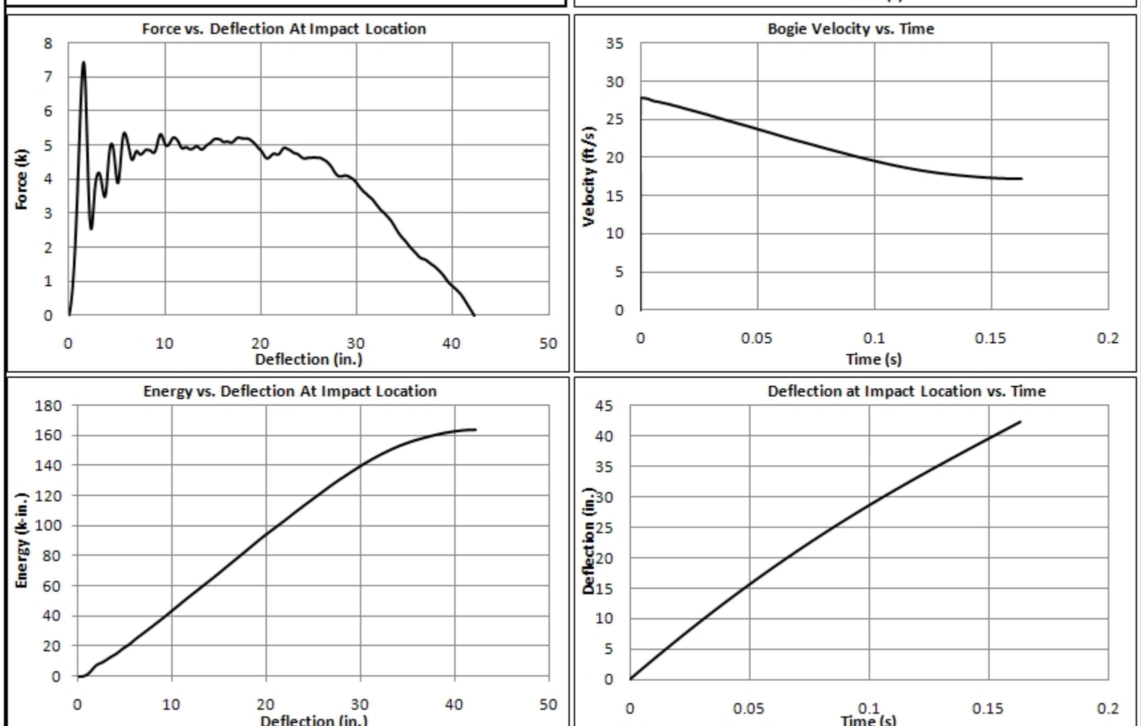


Figure 100. Graph. Test No. GWB-7 Results (EDR-4).

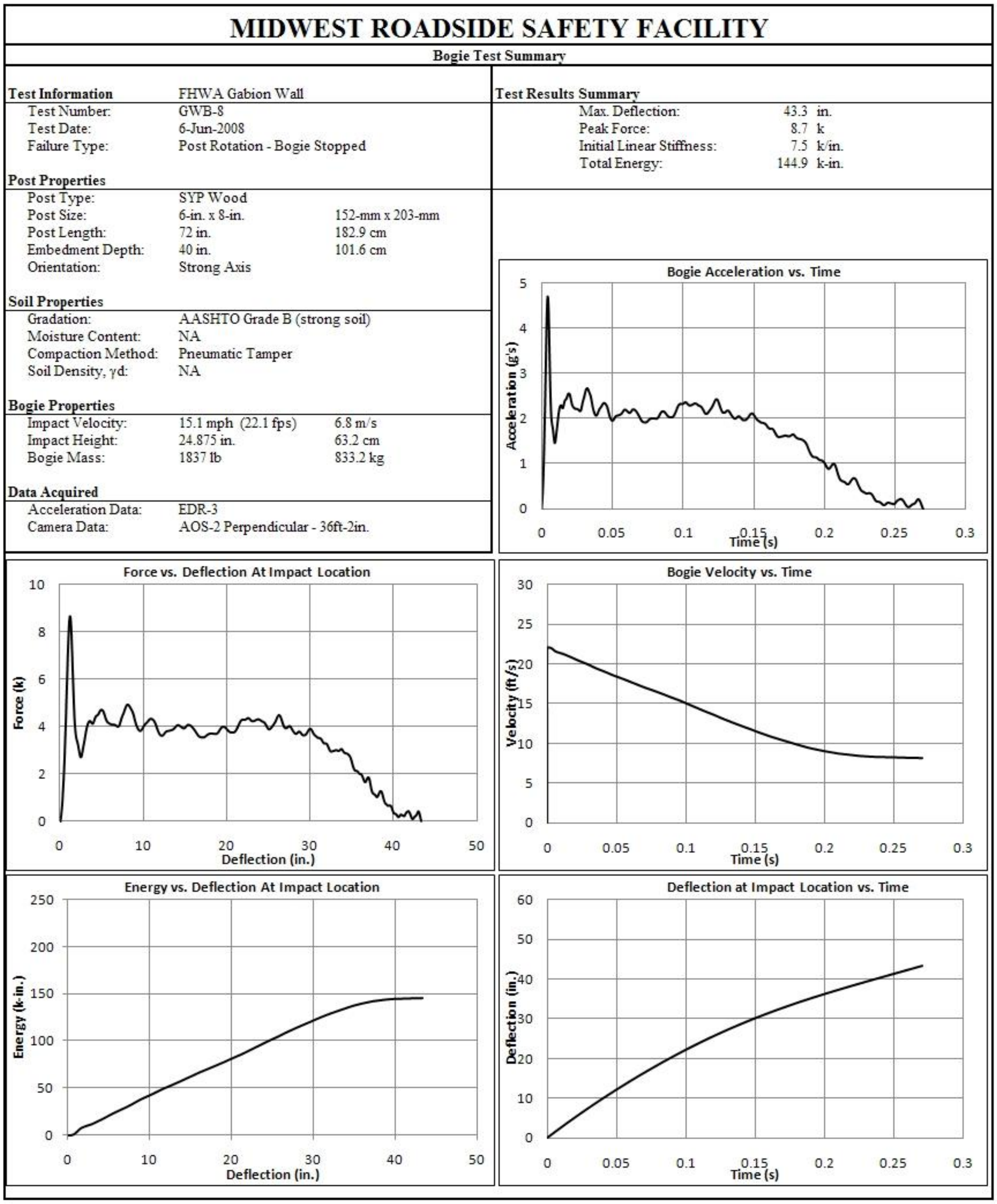


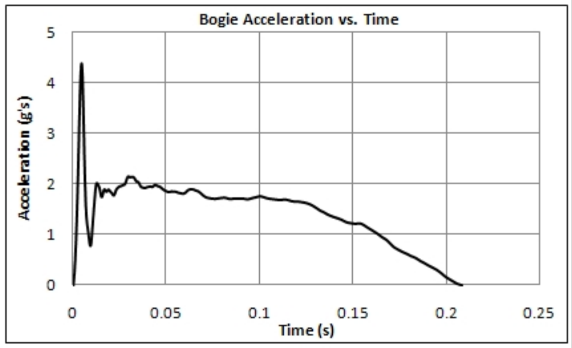
Figure 101. Graph. Test No. GWB-8 Results (EDR-3).

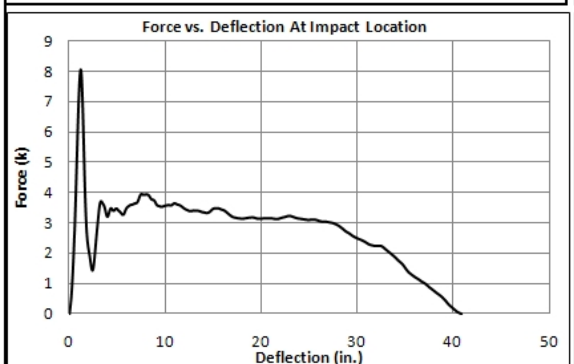
MIDWEST ROADSIDE SAFETY FACILITY

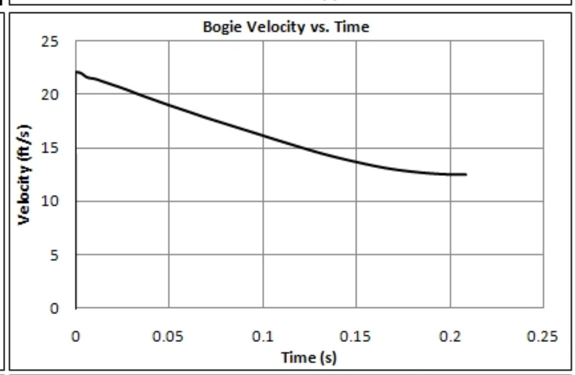
Bogie Test Summary

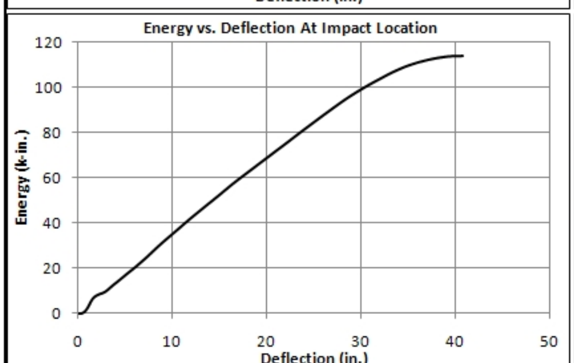
Test Information	FHWA Gabion Wall	
Test Number:	GWB-8	
Test Date:	6-Jun-2008	
Failure Type:	Post Rotation - Bogie Stopped	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
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:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	40.8	in.
Peak Force:	8.1	k
Initial Linear Stiffness:	6.8	k/in.
Total Energy:	113.8	k-in.









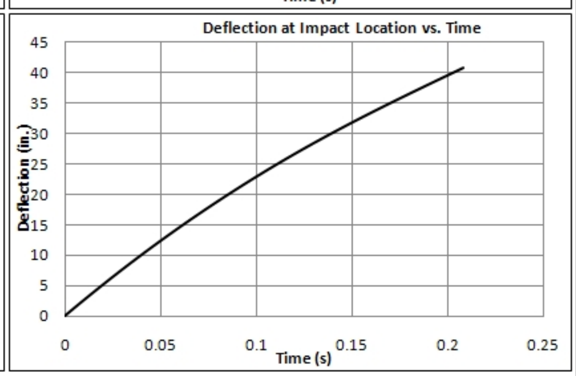


Figure 102. Graph. Test No. GWB-8 Results (EDR-4).

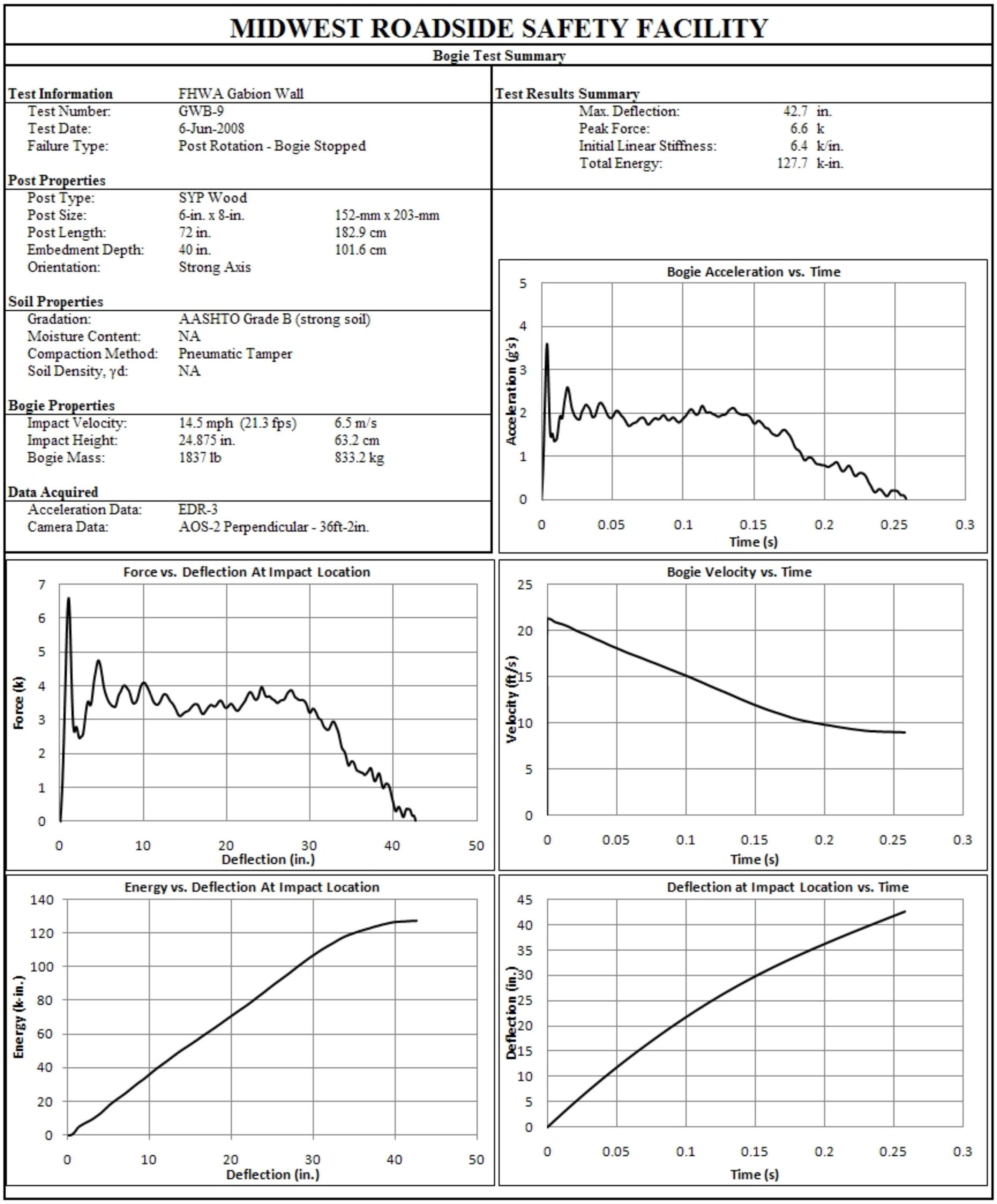


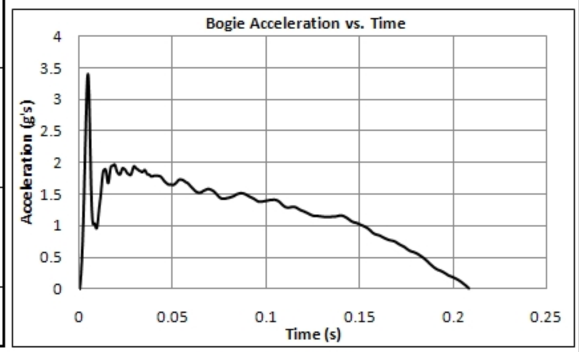
Figure 103. Graph. Test No. GWB-9 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-9	
Test Date:	6-Jun-2008	
Failure Type:	Post Rotation - Bogie Stopped	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	14.5 mph (21.3 fps)	6.48 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	40.6	in.
Peak Force:	6.3	k
Initial Linear Stiffness:	5.6	k/in.
Total Energy:	96.6	k-in.



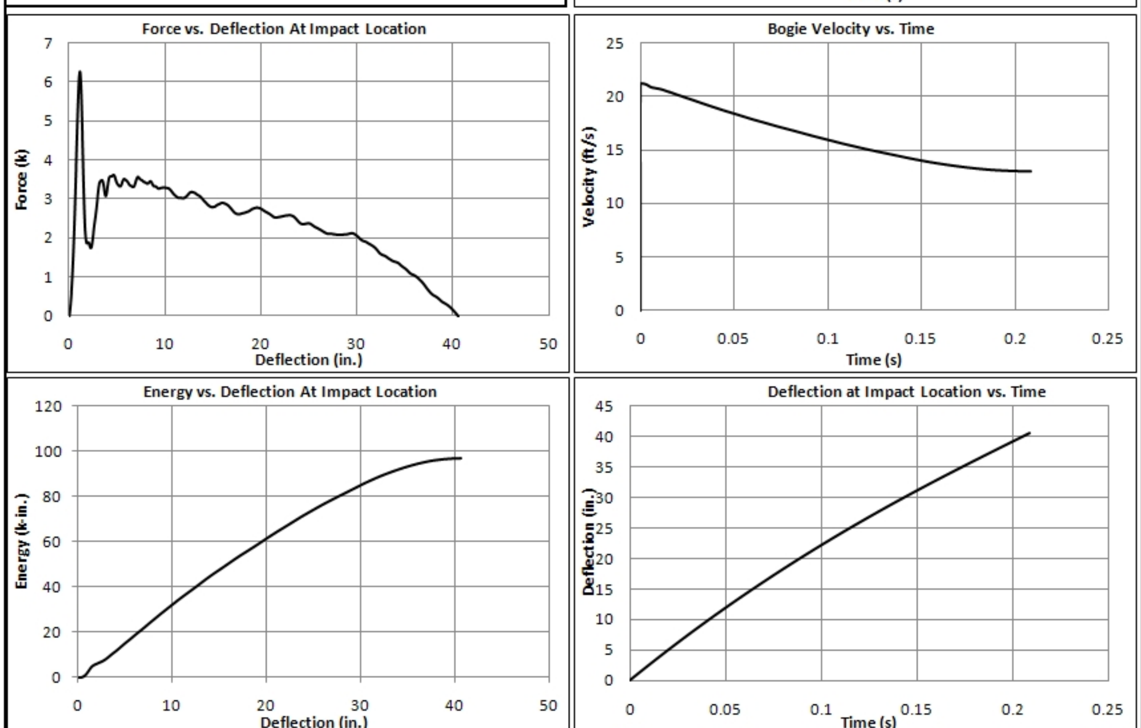


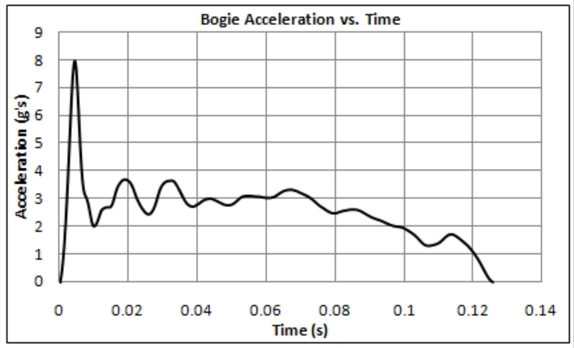
Figure 104. Graph. Test No. GWB-9 Results (EDR-4).

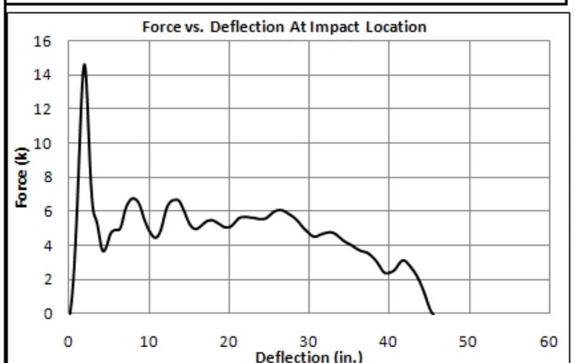
MIDWEST ROADSIDE SAFETY FACILITY

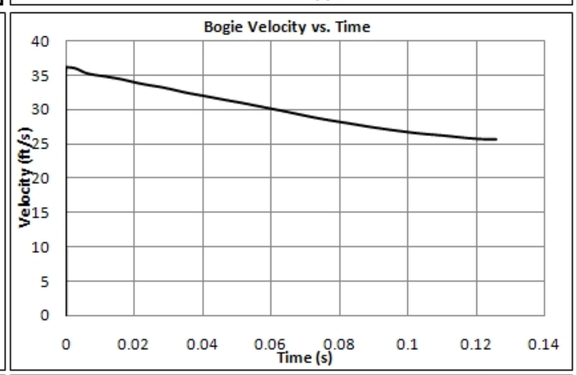
Bogie Test Summary

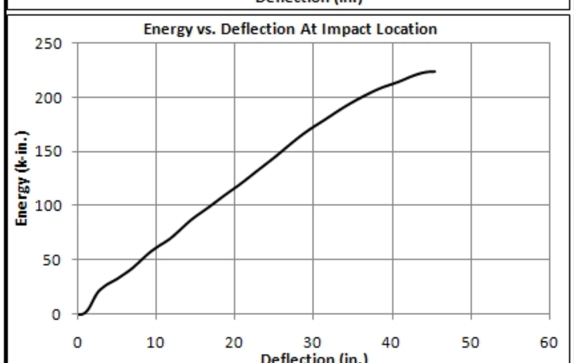
Test Information	FHWA Gabion Wall	
Test Number:	GWB-10	
Test Date:	6-Jun-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	24.7 mph (36.2 fps)	11 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	45.5	in.
Peak Force:	14.6	k
Initial Linear Stiffness:	7.7	k/in.
Total Energy:	223.5	k-in.









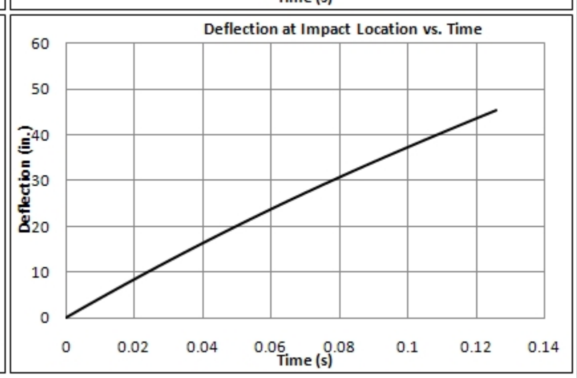


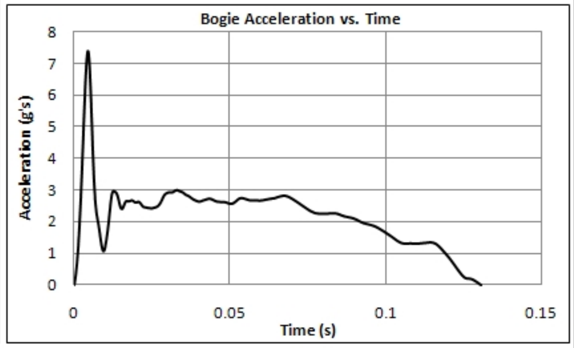
Figure 105. Graph. Test No. GWB-10 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-10	
Test Date:	6-Jun-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	24.7 mph (36.2 fps)	11.04 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	48.2	in.
Peak Force:	13.6	k
Initial Linear Stiffness:	7.1	k/in.
Total Energy:	200.3	k-in.



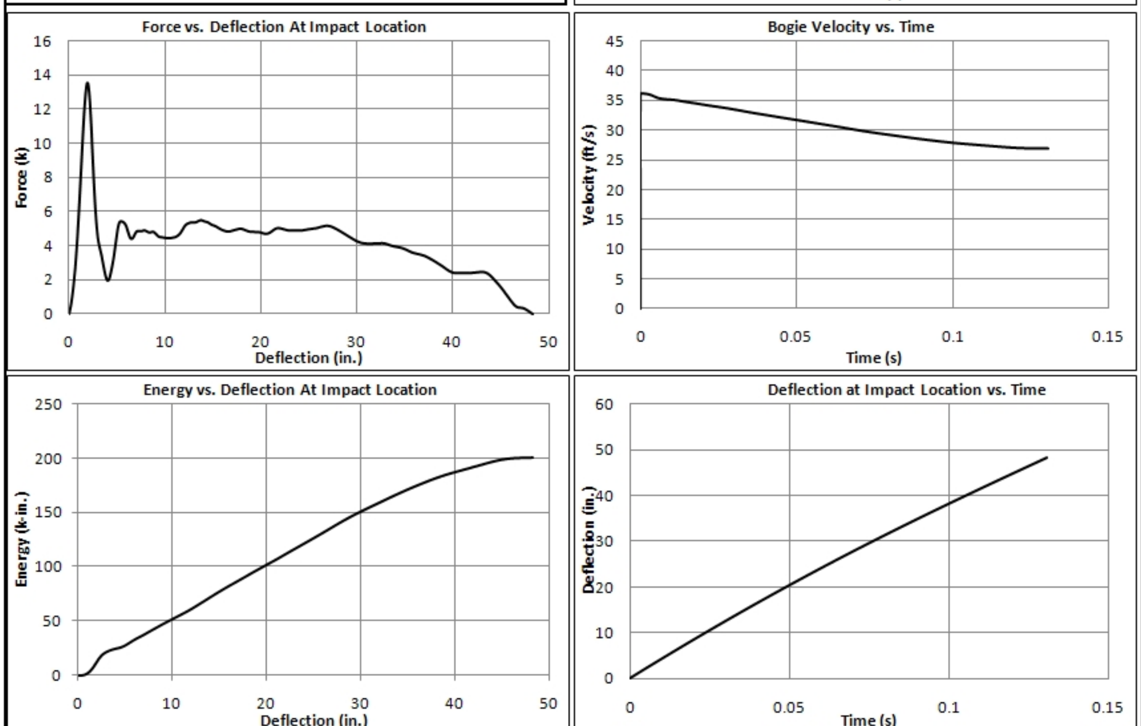


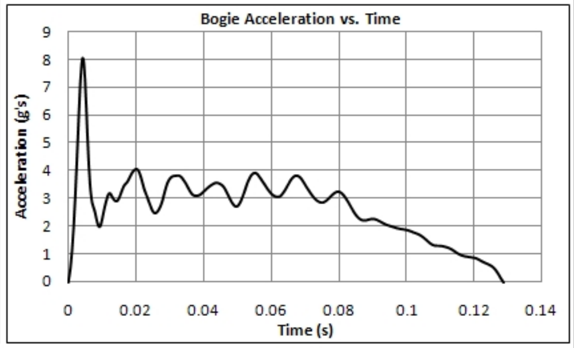
Figure 106. Graph. Test No. GWB-10 Results (EDR-4).

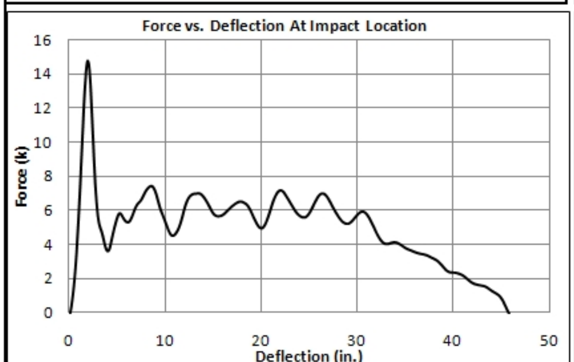
MIDWEST ROADSIDE SAFETY FACILITY

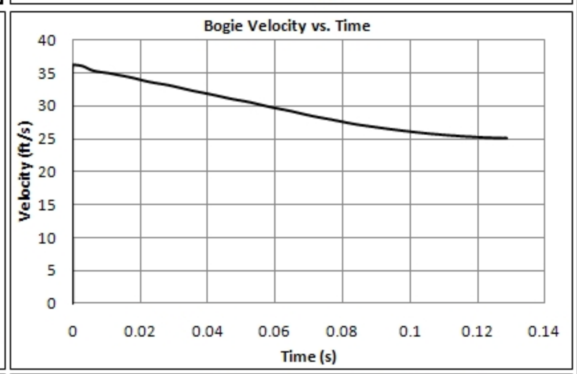
Bogie Test Summary

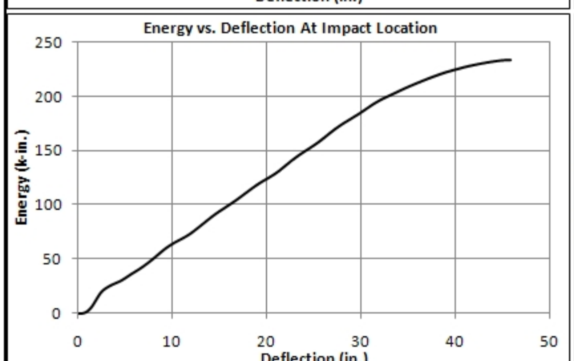
Test Information	FHWA Gabion Wall	
Test Number:	GWB-11	
Test Date:	6-Jun-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	24.7 mph (36.2 fps)	11 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	45.8	in.
Peak Force:	14.8	k
Initial Linear Stiffness:	7.8	k/in.
Total Energy:	233.5	k-in.









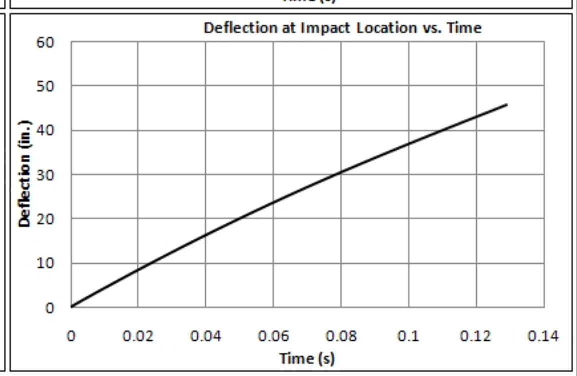


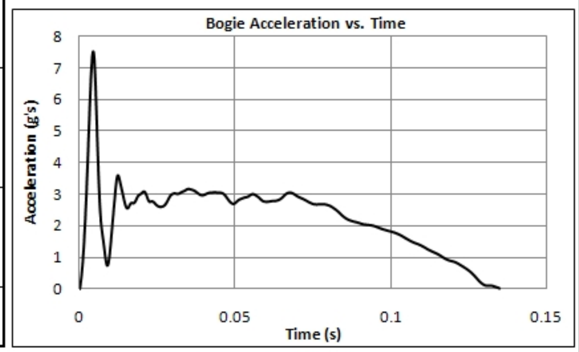
Figure 107. Graph. Test No. GWB-11 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-11	
Test Date:	6-Jun-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (storng soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	24.7 mph (36.2 fps)	11.04 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1837 lb	833.2 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-2 Perpendicular - 36ft-2in.	

Test Results Summary		
Max. Deflection:	49.0	in.
Peak Force:	13.8	k
Initial Linear Stiffness:	7.4	k/in.
Total Energy:	211.4	k-in.



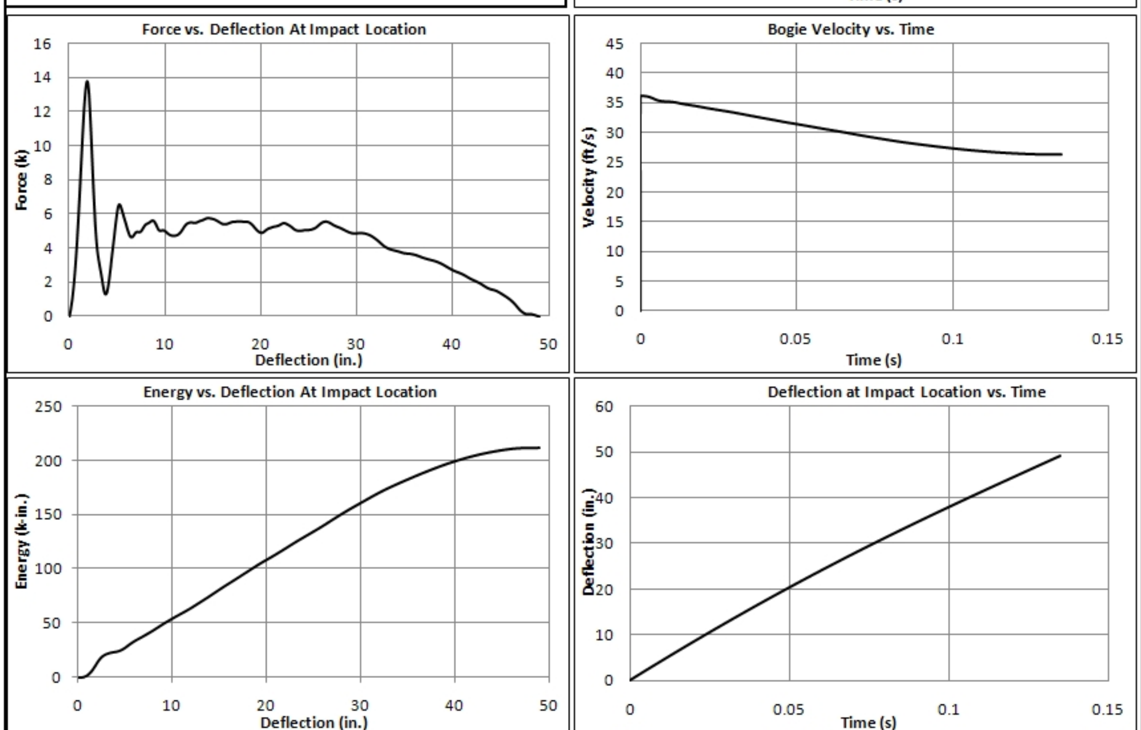


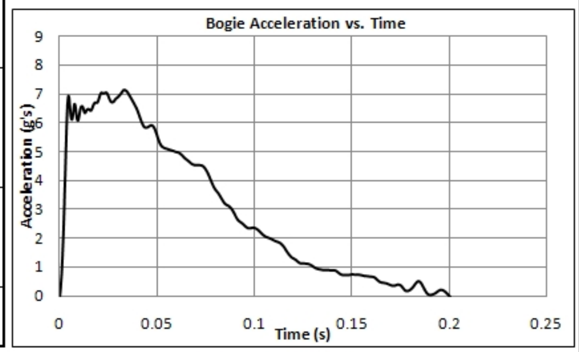
Figure 108. Graph. Test No. GWB-11 Results (EDR-4).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-12	
Test Date:	19-Sep-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Steel	
Post Size:	W6x16	W152x23.8
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19 mph (27.9 fps)	8.5 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1802 lb	817.4 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 34ft	

Test Results Summary		
Max. Deflection:	33.8	in.
Peak Force:	12.8	k
Initial Linear Stiffness:	8.6	k/in.
Total Energy:	236.1	k-in.



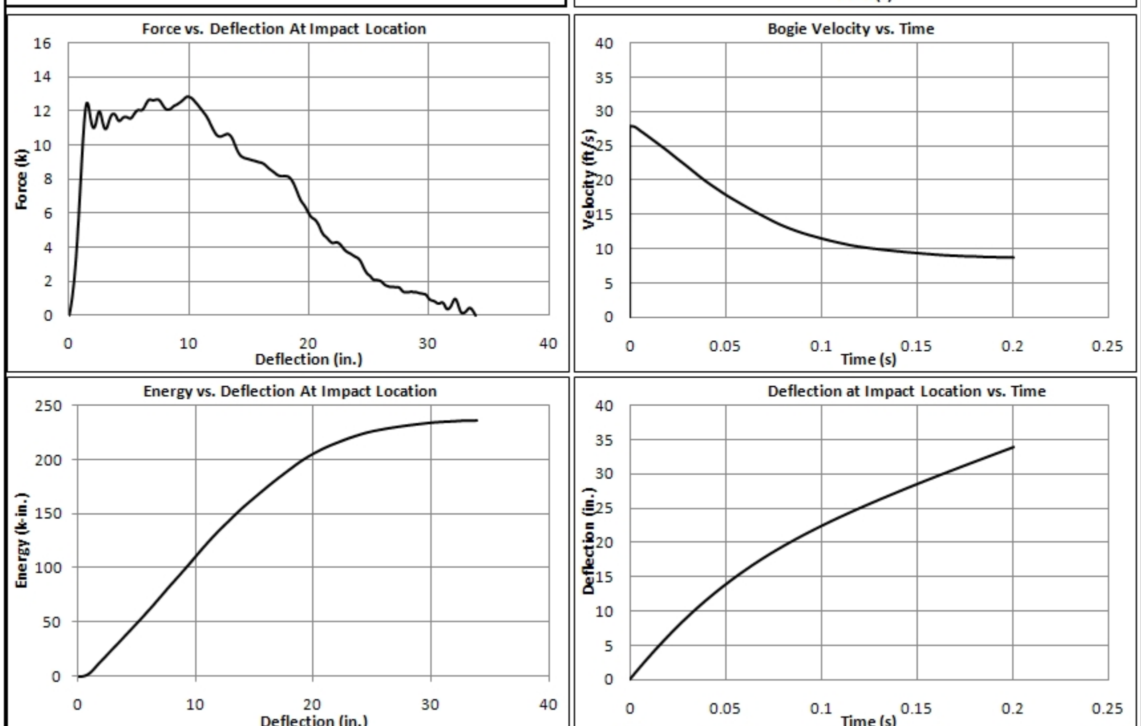


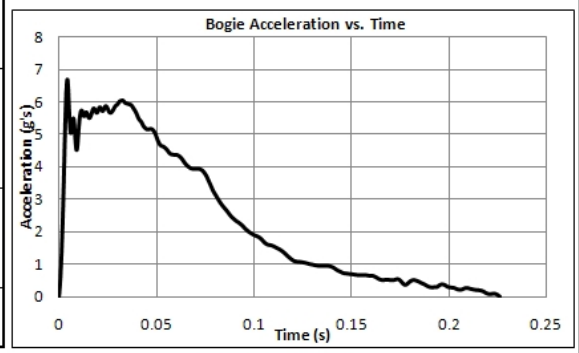
Figure 109. Graph. Test No. GWB-12 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-12	
Test Date:	19-Sep-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Steel	
Post Size:	W6x16	W152x23.8
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	18.99 mph (27.9 fps)	8.49 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1802 lb	817.4 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-5 Perpendicular - 34ft	

Test Results Summary		
Max. Deflection:	41.6	in.
Peak Force:	12.0	k
Initial Linear Stiffness:	8.4	k/in.
Total Energy:	221.0	k-in.



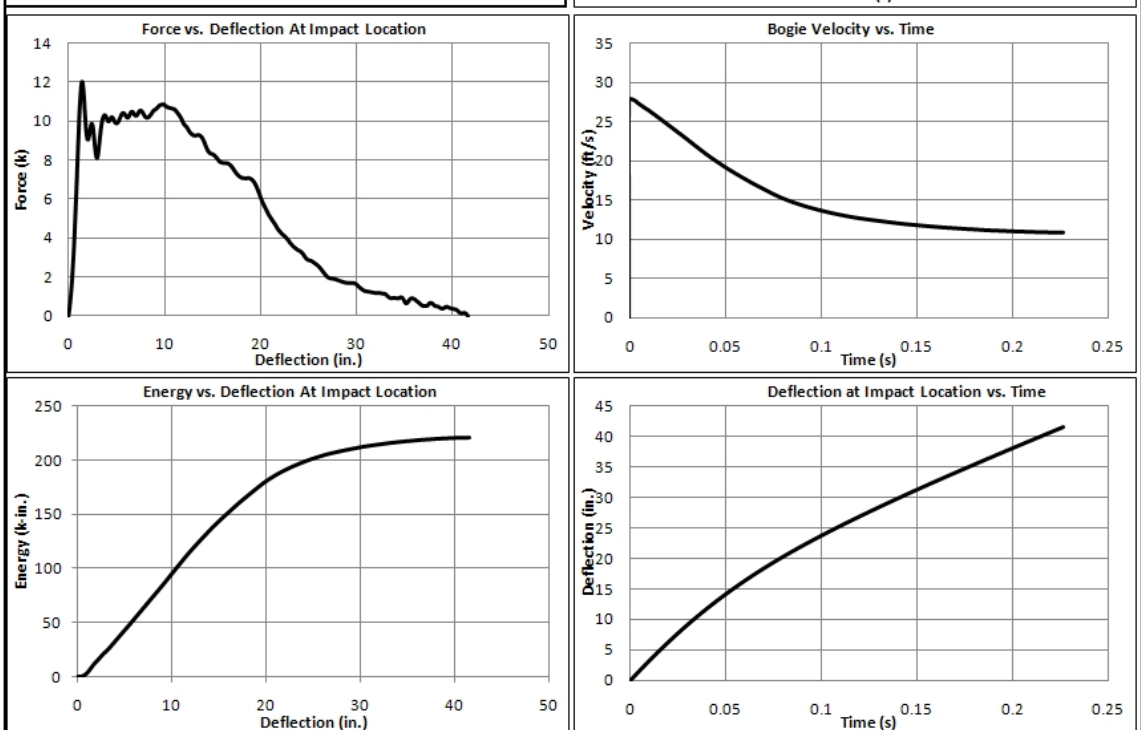


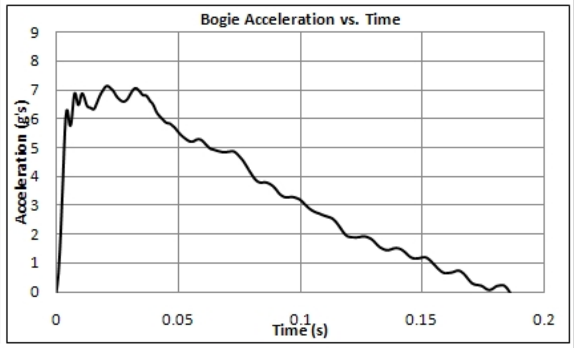
Figure 110. Graph. Test No. GWB-12 Results (EDR-4).

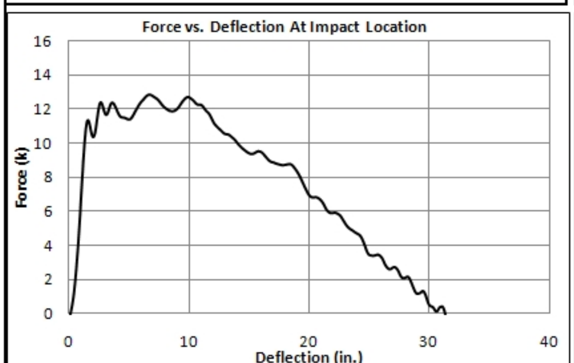
MIDWEST ROADSIDE SAFETY FACILITY

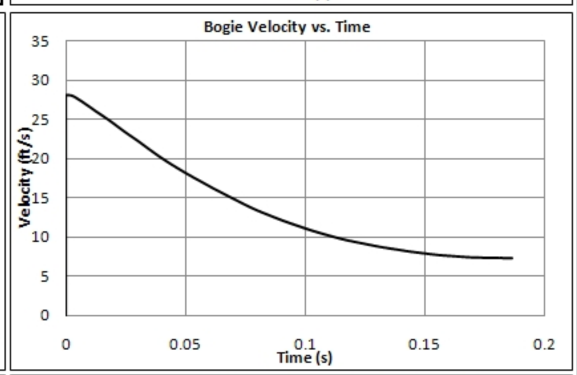
Bogie Test Summary

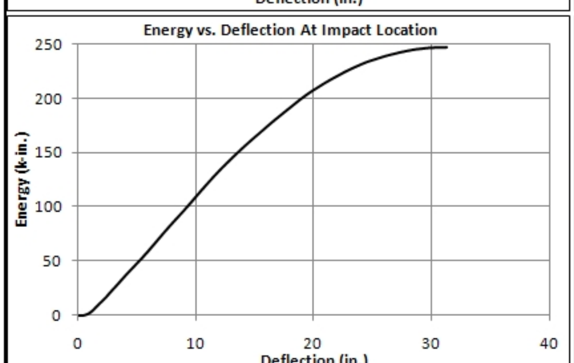
Test Information	FHWA Gabion Wall	
Test Number:	GWB-13	
Test Date:	6-Oct-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	Steel	
Post Size:	W6x16	W152x23.8
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.2 mph (28.2 fps)	8.6 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1802 lb	817.4 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 34ft	

Test Results Summary		
Max. Deflection:	31.3	in.
Peak Force:	12.8	k
Initial Linear Stiffness:	7.2	k/in.
Total Energy:	247.7	k-in.









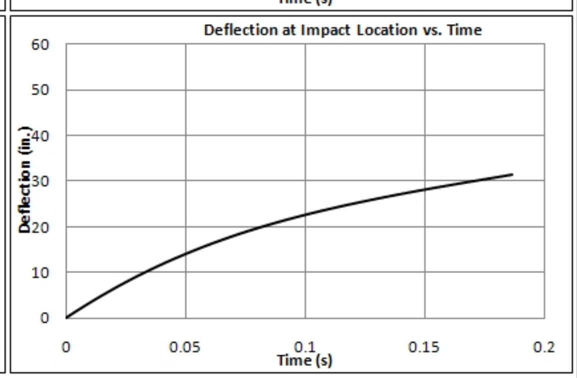


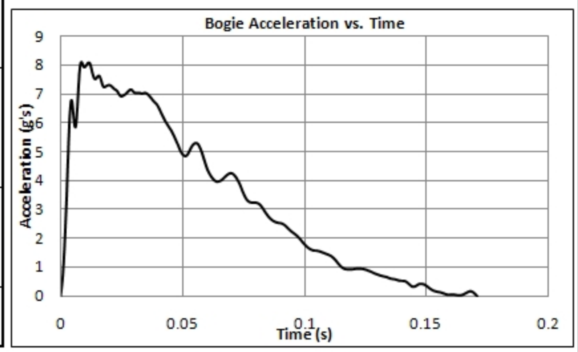
Figure 111. Graph. Test No. GWB-13 Results (EDR-3).

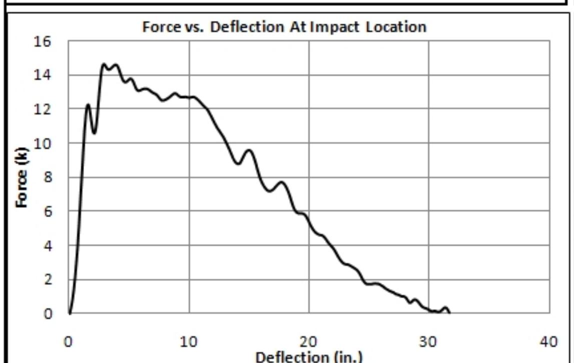
MIDWEST ROADSIDE SAFETY FACILITY

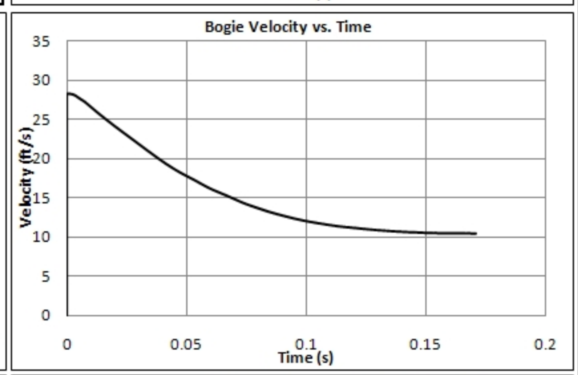
Bogie Test Summary

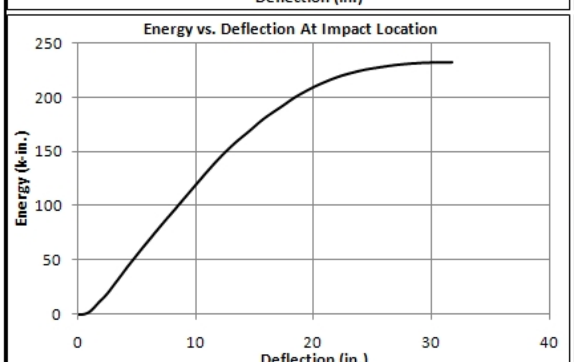
Test Information	FHWA Gabion Wall	
Test Number:	GWB-14	
Test Date:	6-Oct-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.3 mph (28.3 fps)	8.6 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1802 lb	817.4 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 34ft	

Test Results Summary		
Max. Deflection:	31.7	in.
Peak Force:	14.6	k
Initial Linear Stiffness:	5.0	k/in.
Total Energy:	232.0	k-in.









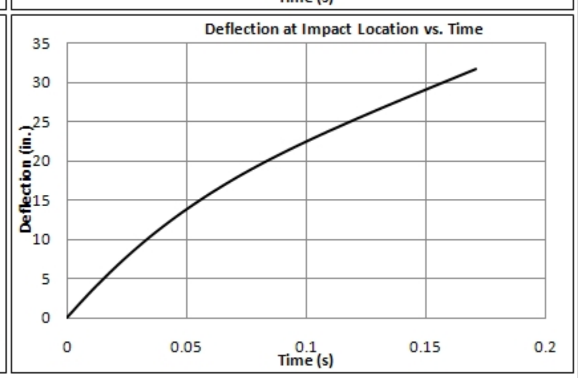


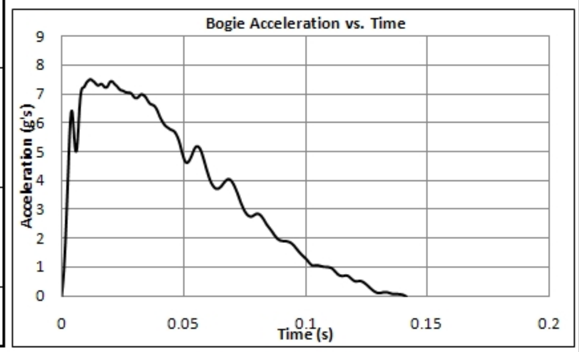
Figure 112. Graph. Test No. GWB-14 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	FHWA Gabion Wall	
Test Number:	GWB-15	
Test Date:	6-Oct-2008	
Failure Type:	Post Rotation	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Pneumatic Tamper	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	19.6 mph (28.7 fps)	8.8 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1802 lb	817.4 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 34ft	

Test Results Summary		
Max. Deflection:	30.0	in.
Peak Force:	13.5	k
Initial Linear Stiffness:	3.4	k/in.
Total Energy:	225.6	k-in.



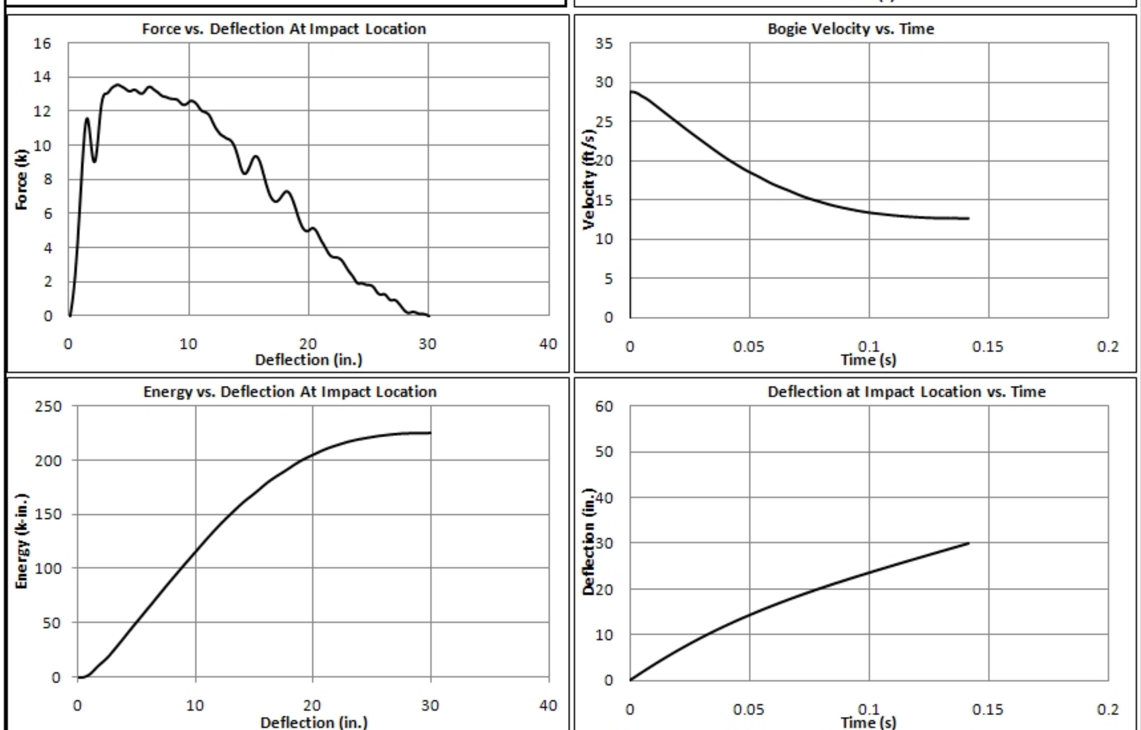


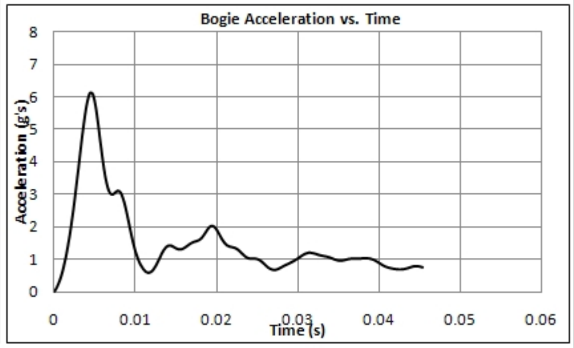
Figure 113. Graph. Test No. GWB-15 Results (EDR-3).

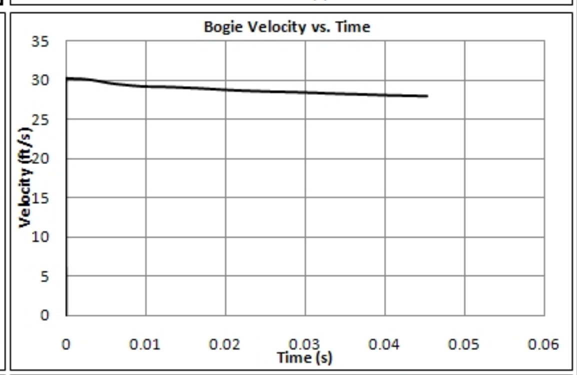
MIDWEST ROADSIDE SAFETY FACILITY

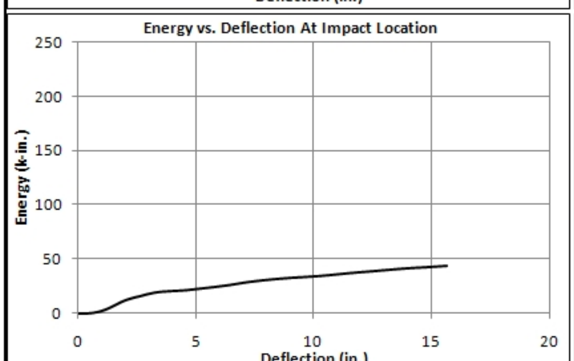
Bogie Test Summary

Test Information	Gabion Wall Post Testing	
Test Number:	GWR4-1	
Test Date:	25-Feb-2009	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	84 in.	213.4 cm
Embedment Depth:	52 in.	132.1 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	5.2%	
Compaction Method:	Pneumatic Tamper	
Back Slope	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	20.5 mph (30.1 fps)	9.2 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1816 lb	823.7 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-6 Perpendicular - 33ft	

Test Results Summary		
Max. Deflection:	4.1	in.
Peak Force:	11.1	k
Initial Linear Stiffness:	7.1	k/in.
Total Energy:	21.0	k-in.







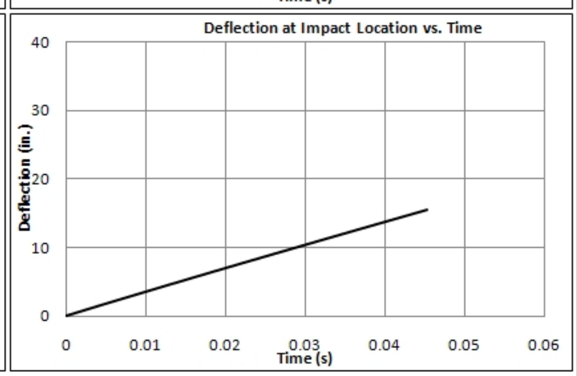


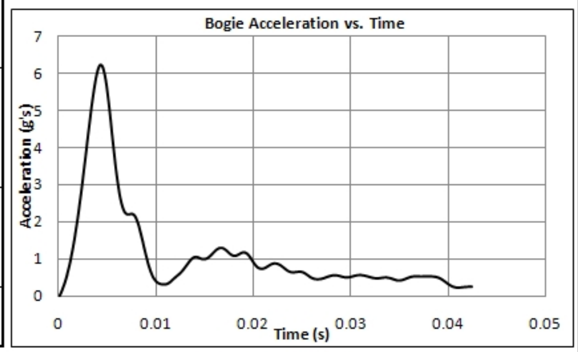
Figure 114. Graph. Test No. GWR4-1 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Gabion Wall Post Testing	
Test Number:	GWR4-1	
Test Date:	25-Feb-2009	
Failure Type:	Post Fracture	
Post Properties		
Post Type:	SYP Wood	
Post Size:	6-in. x 8-in.	152-mm x 203-mm
Post Length:	84 in.	213.4 cm
Embedment Depth:	52 in.	132.1 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	5.2%	
Compaction Method:	Pneumatic Tamper	
Terrain:	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	20.54 mph (30.1 fps)	9.18 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1816 lb	823.7 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-6 Perpendicular - 33ft	

Test Results Summary		
Max. Deflection:	3.8	in.
Peak Force:	11.3	k
Initial Linear Stiffness:	7.3	k/in.
Total Energy:	18.0	k-in.



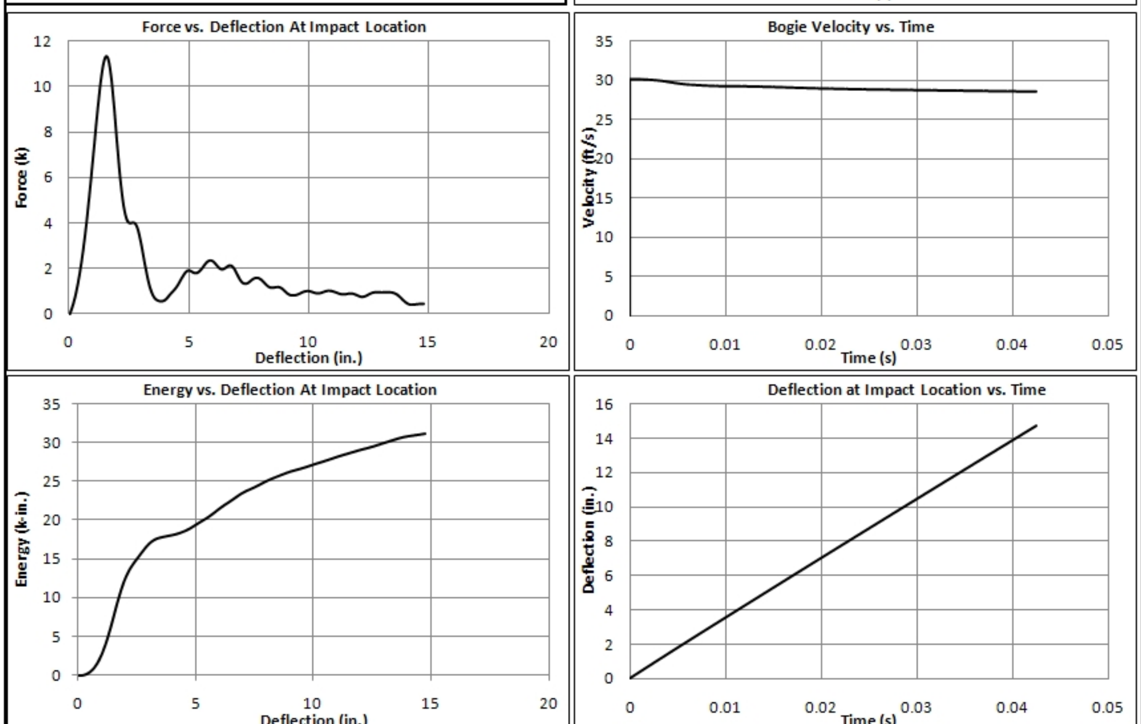


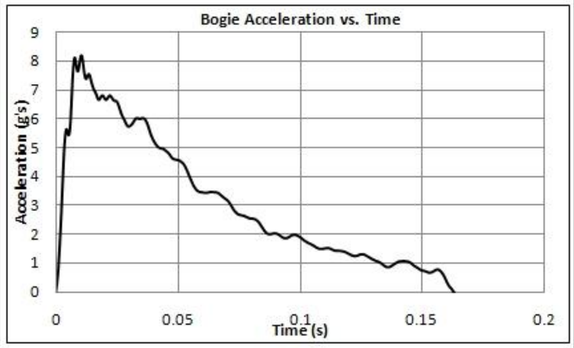
Figure 115. Graph. Test No. GWR4-1 Results (EDR-4).

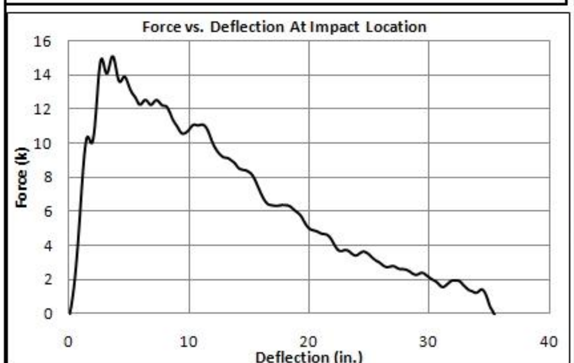
MIDWEST ROADSIDE SAFETY FACILITY

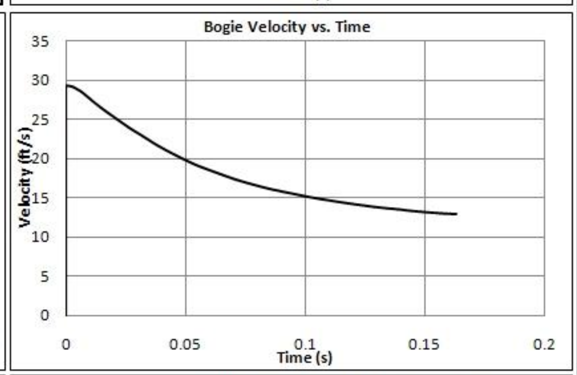
Bogie Test Summary

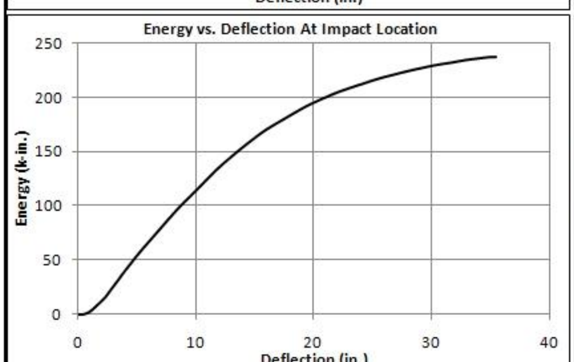
Test Information	Gabion Wall Post Testing	
Test Number:	GWR5-1	
Test Date:	17-Apr-2009	
Failure Type:	Lateral-Torsional Buckling of Post	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.4
Post Length:	84 in.	213.4 cm
Embedment Depth:	52 in.	132.1 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	NA	
Compaction Method:	Post driven into soil - Pneumatic Tamper	
Terrain:	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	19.98 mph (29.3 fps)	8.93 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1840 lb	834.6 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-6 Perpendicular - 32ft-7in.	

Test Results Summary		
Max. Deflection:	35.4	in.
Peak Force:	15.1	k
Initial Linear Stiffness:	5.5	k/in.
Total Energy:	237.4	k-in.









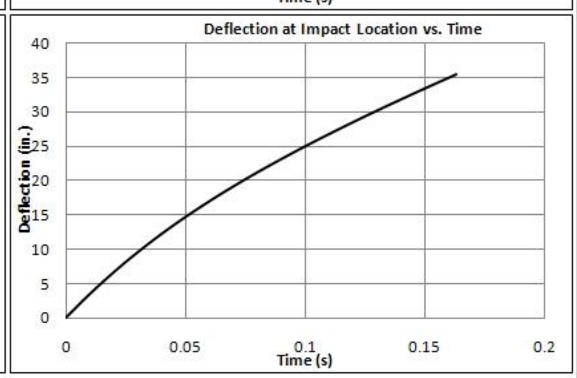


Figure 116. Graph. Test No. GWR5-1 Results (EDR-3).

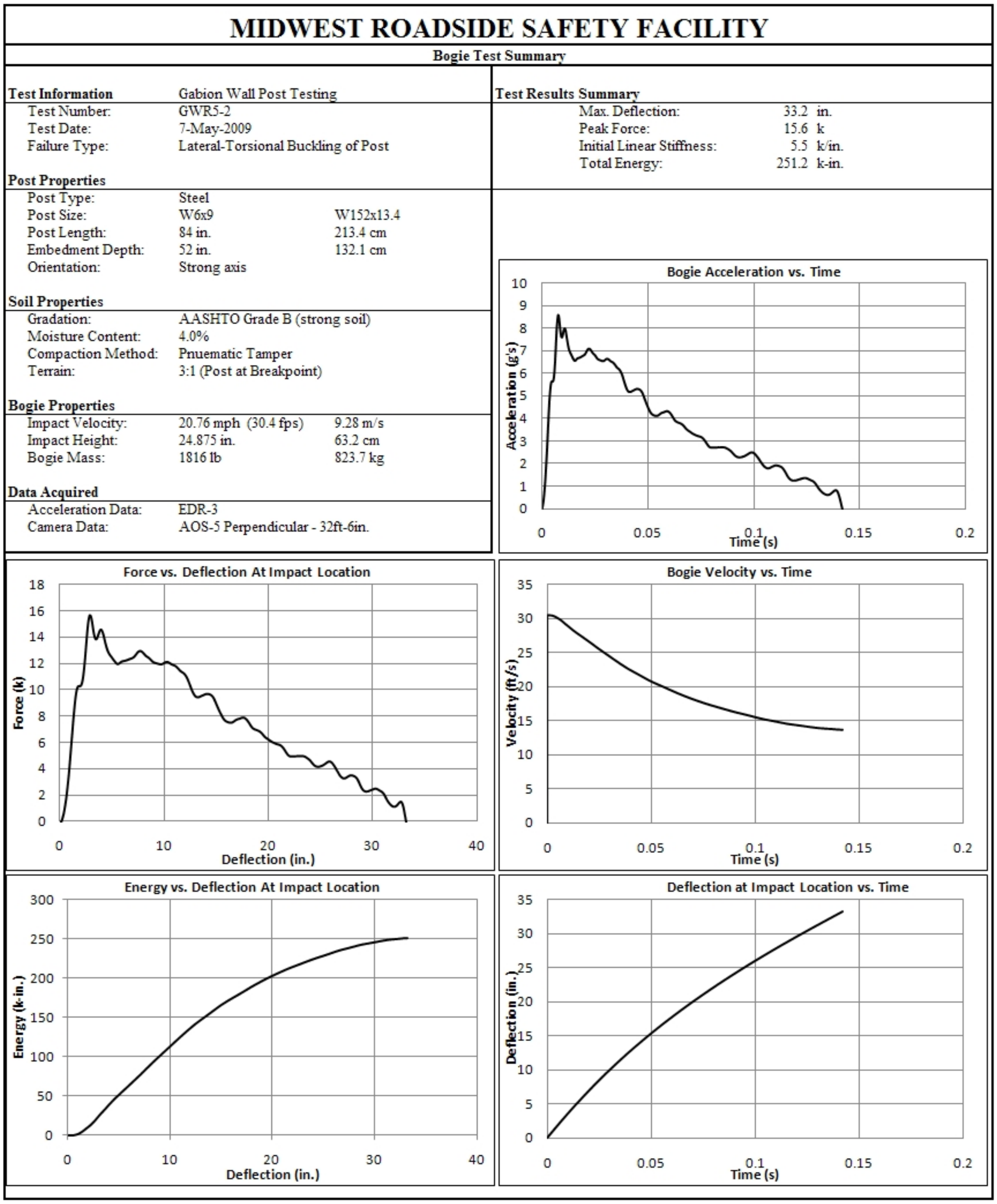


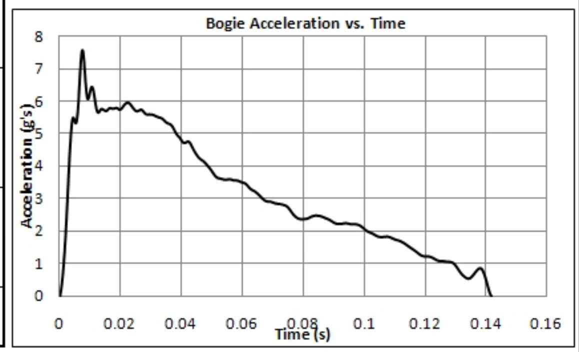
Figure 117. Graph. Test No. GWR5-2 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	W6x9 on 3:1 slope breakpoint	
Test Number:	GWR5-2	
Test Date:	7-May-2009	
Failure Type:	Lateral-Torsional Buckling of Post	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.4
Post Length:	84 in.	213.4 cm
Embedment Depth:	52 in.	132.1 cm
Orientation:	Strong axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	4.0%	
Compaction Method:	Pnuematic Tamper	
Terrain:	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	20.76 mph (30.4 fps)	9.28 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1816 lb	823.7 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-5 Perpendicular - 32ft-6in.	

Test Results Summary		
Max. Deflection:	35.8	in.
Peak Force:	13.7	k
Initial Linear Stiffness:	5.1	k/in.
Total Energy:	228.0	k-in.



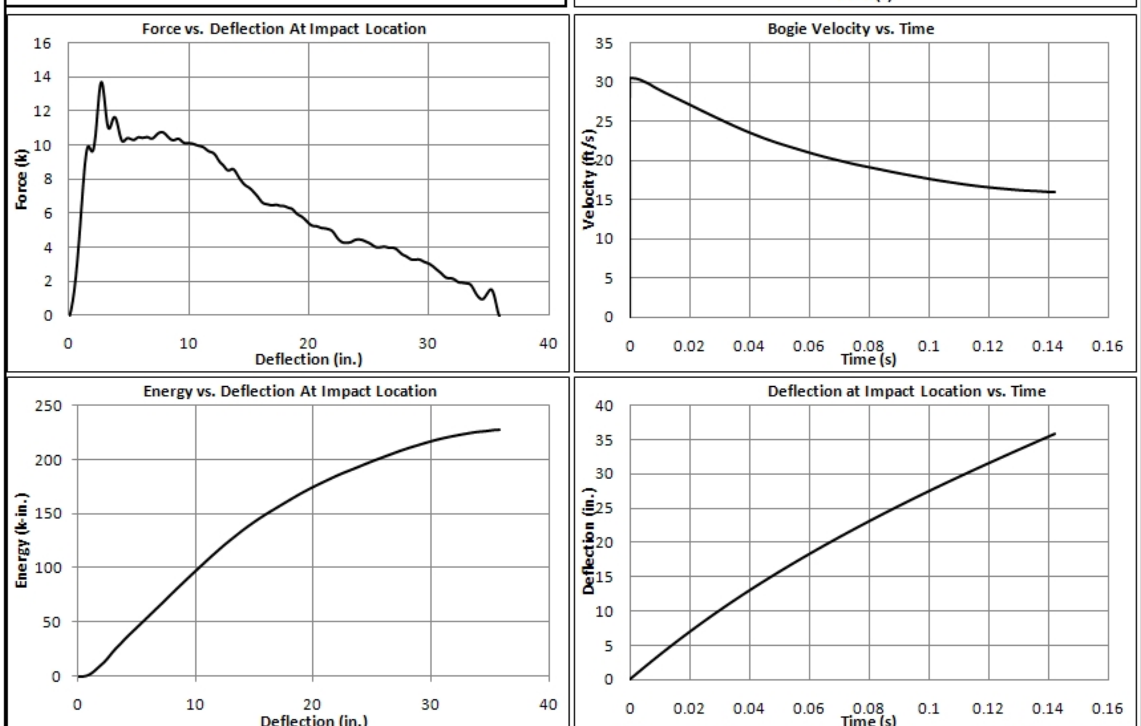


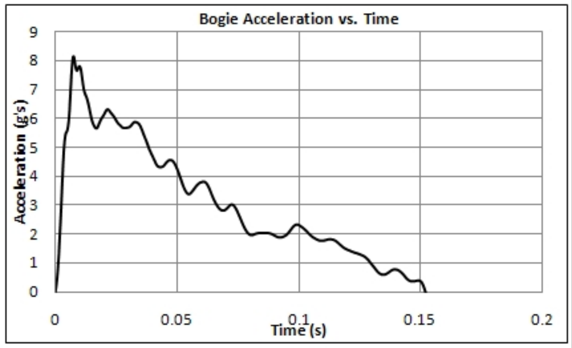
Figure 118. Graph. Test No. GWR5-2 Results (EDR-4).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Gabion Wall Post Testing	
Test Number:	GWR5-3	
Test Date:	12-May-2009	
Failure Type:	Lateral-Torsional Buckling of Post	
Post Properties		
Post Type:	Steel - Galvanized	
Post Size:	W6x8.5	W152x12.6
Post Length:	78 in.	198.1 cm
Embedment Depth:	46 in.	116.8 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	4.0%	
Compaction Method:	Pneumatic Tamper	
Terrain:	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	19.89 mph (29.2 fps)	8.89 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1812 lb	821.9 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-7 Perpendicular - 16ft-2in.	

Test Results Summary		
Max. Deflection:	34.8	in.
Peak Force:	14.7	k
Initial Linear Stiffness:	5.5	k/in.
Total Energy:	221.5	k-in.



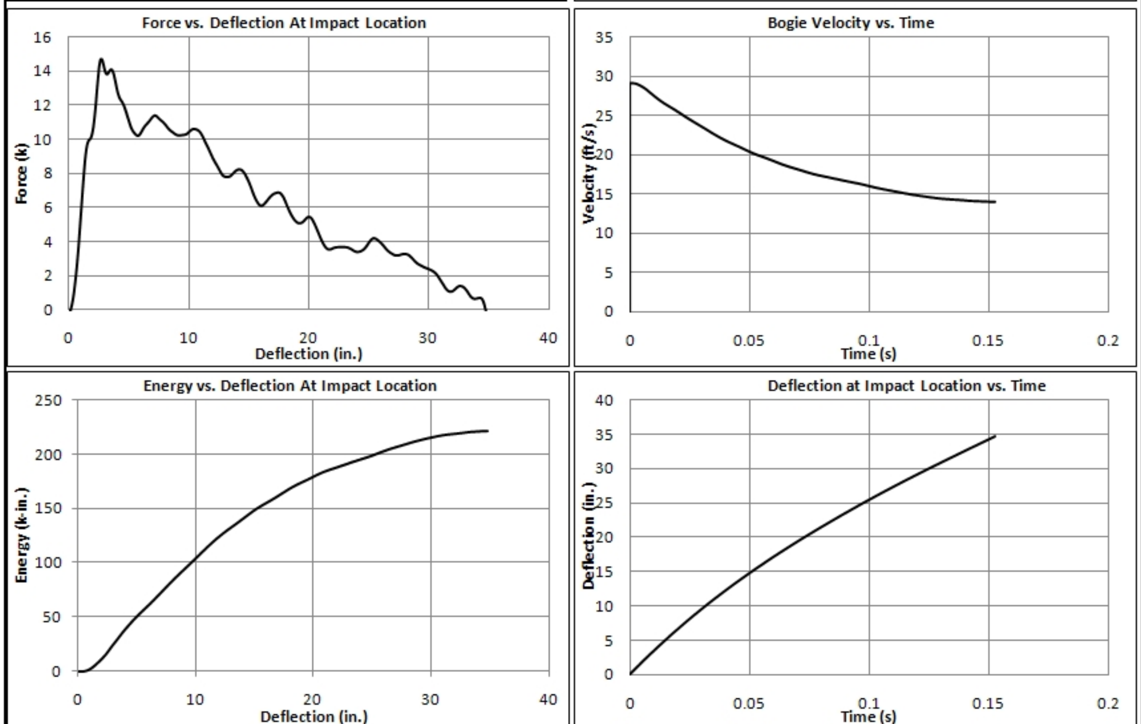


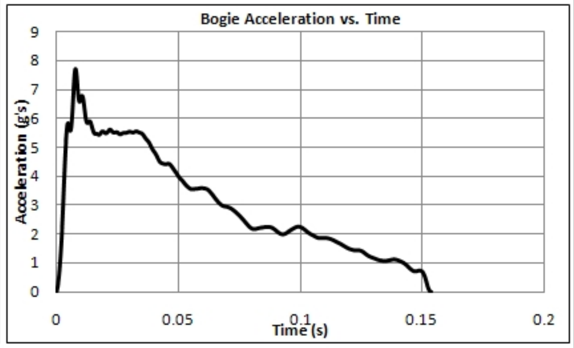
Figure 119. Graph. Test No. GWR5-3 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Gabion Wall Post Testing	
Test Number:	GWR5-3	
Test Date:	12-May-2009	
Failure Type:	Lateral-Torsional Buckling of Post	
Post Properties		
Post Type:	Steel - Galvanized	
Post Size:	W6x8.5	W152x12.6
Post Length:	78 in.	198.1 cm
Embedment Depth:	46 in.	116.8 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	4.0%	
Compaction Method:	Pnuematic Tamper	
Terrain:	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	19.89 mph (29.2 fps)	8.89 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1812 lb	821.9 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-7 Perpendicular - 16ft-2in.	

Test Results Summary		
Max. Deflection:	35.7	in.
Peak Force:	13.9	k
Initial Linear Stiffness:	5.1	k/in.
Total Energy:	220.2	k-in.



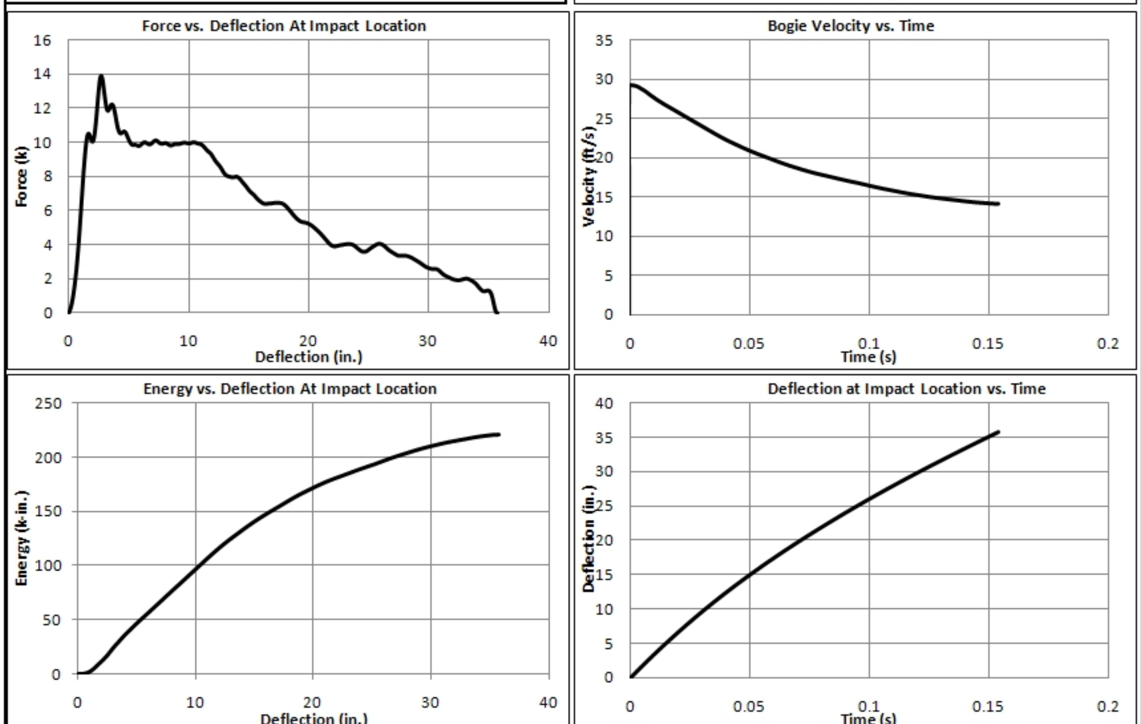


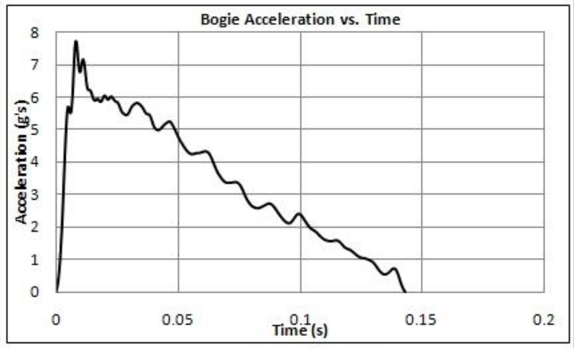
Figure 120. Graph. Test No. GWR5-3 Results (EDR-4).

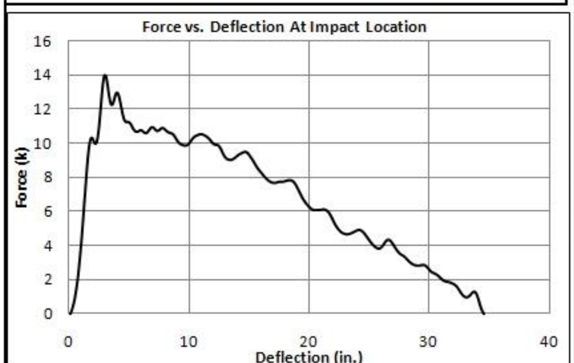
MIDWEST ROADSIDE SAFETY FACILITY

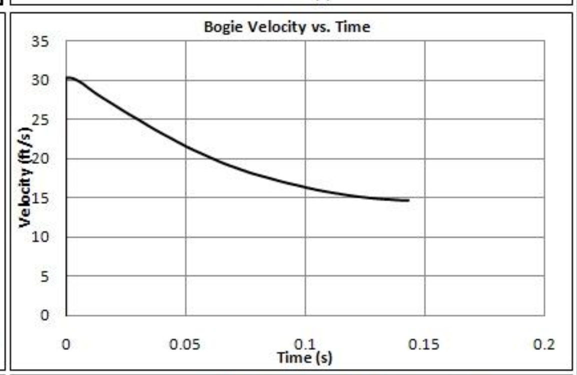
Bogie Test Summary

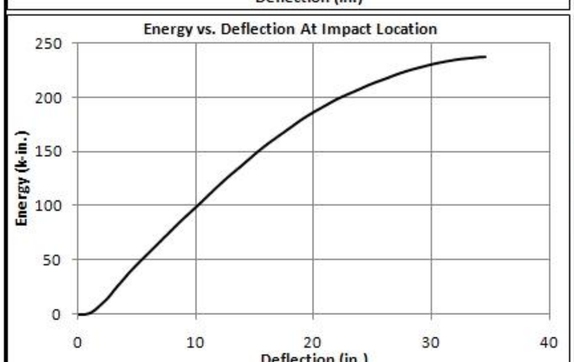
Test Information	Gabion Wall Post Testing	
Test Number:	GWR5-4	
Test Date:	19-May-2009	
Failure Type:	Lateral-Torsional Buckling of Post	
Post Properties		
Post Type:	Steel - Galvanized	
Post Size:	W6x8.5	W152x12.6
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	3.8%	
Compaction Method:	Pnuematic Tamper	
Slope	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	20.62 mph (30.2 fps)	9.22 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1812 lb	821.9 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-7 Perpendicular - 32ft-11.5in.	

Test Results Summary		
Max. Deflection:	34.5	in.
Peak Force:	14.0	k
Initial Linear Stiffness:	4.8	k/in.
Total Energy:	237.1	k-in.









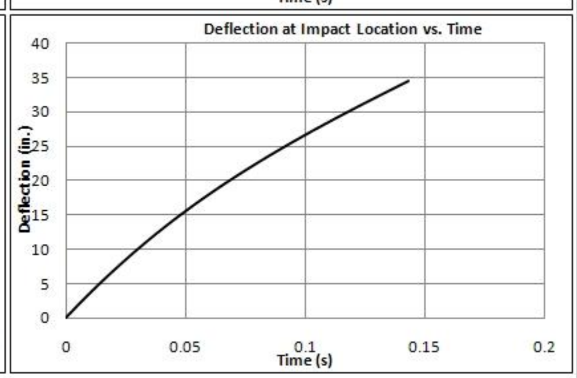


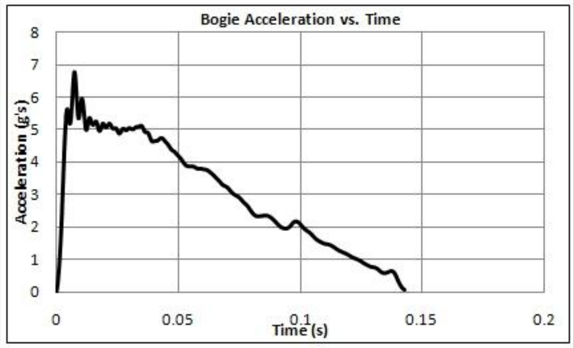
Figure 121. Graph. Test No. GWR5-4 Results (EDR-3).

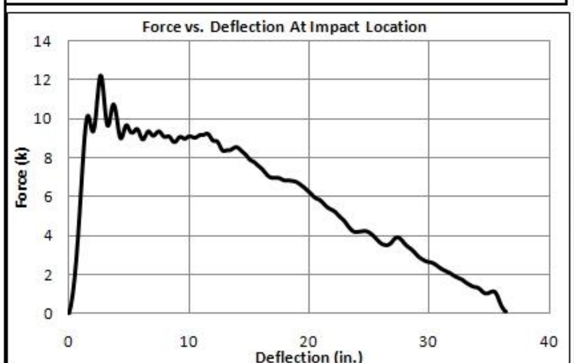
MIDWEST ROADSIDE SAFETY FACILITY

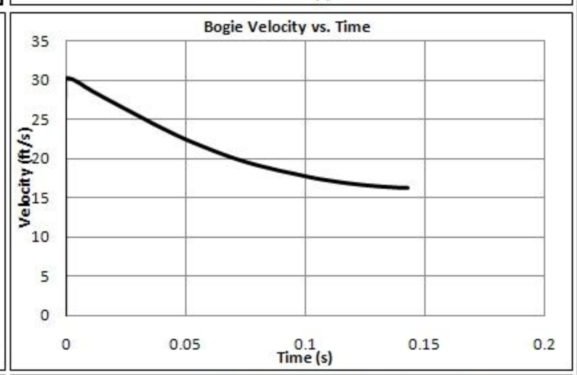
Bogie Test Summary

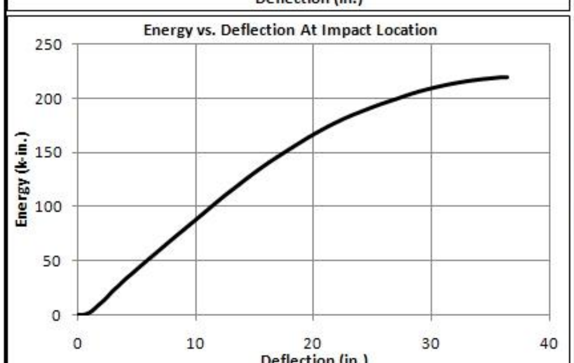
Test Information	Gabion Wall Post Testing	
Test Number:	GWR5-4	
Test Date:	19-May-2009	
Failure Type:	Lateral-Torsional Buckling of Post	
Post Properties		
Post Type:	Steel - Galvanized	
Post Size:	W6x8.5	W152x12.6
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil)	
Moisture Content:	3.8%	
Compaction Method:	Pnuematic Tamper	
Slope	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	20.62 mph (30.2 fps)	9.22 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1812 lb	821.9 kg
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-7 Perpendicular - 32ft-11.5in.	

Test Results Summary		
Max. Deflection:	36.4	in.
Peak Force:	12.2	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	219.6	k-in.









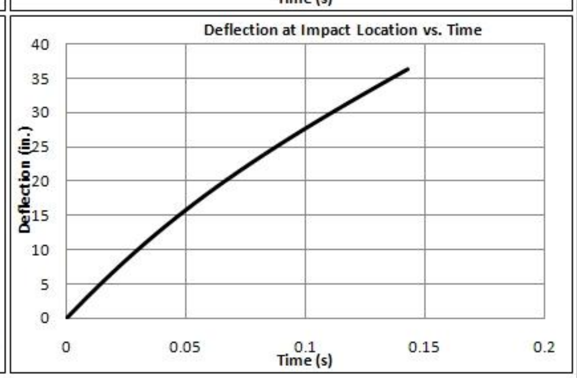


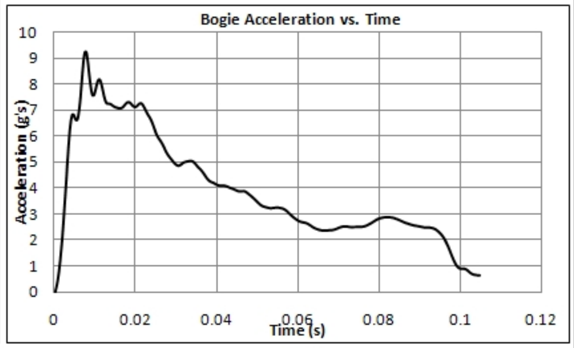
Figure 122. Graph. Test No. GWR5-4 Results (EDR-4).

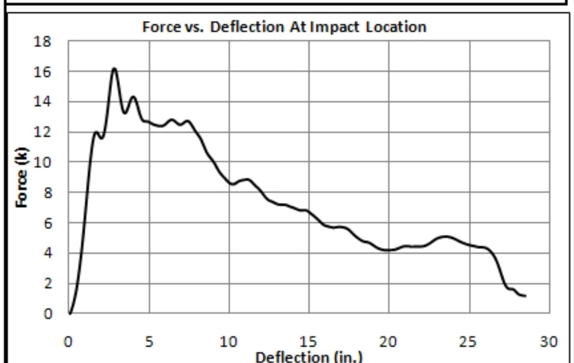
MIDWEST ROADSIDE SAFETY FACILITY

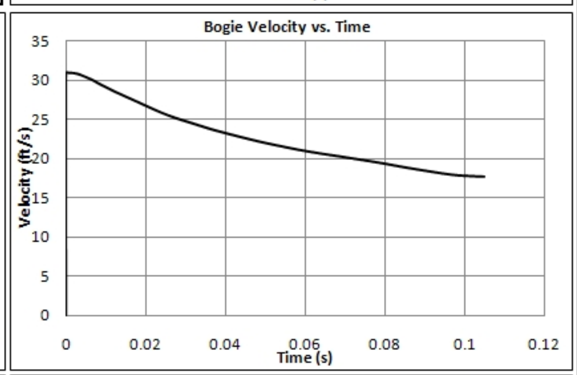
Bogie Test Summary

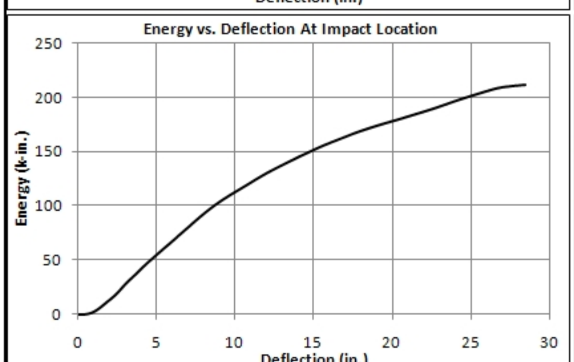
Test Information	Gabion Wall Post Testing	
Test Number:	GWBR5-1	
Test Date:	25-Aug-2009	
Failure Type:	Post yielding and rotation	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.4
Post Length:	84 in.	213.4 cm
Embedment Depth:	52 in.	132.1 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil) on Gabion Wall	
Moisture Content:	NA	
Compaction Method:	Driven Post - Roller Compacted	
Terrain:	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	21.09 mph (30.9 fps)	9.43 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1751.5 lb	794.5 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS 6 Perpendicular - 17ft-6in.	

Test Results Summary		
Max. Deflection:	28.5	in.
Peak Force:	16.2	k
Initial Linear Stiffness:	5.9	k/in.
Total Energy:	211.0	k-in.









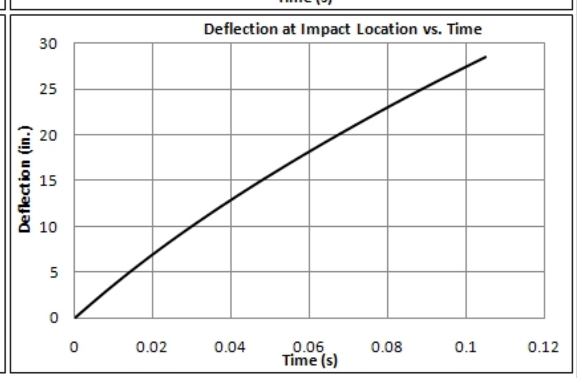


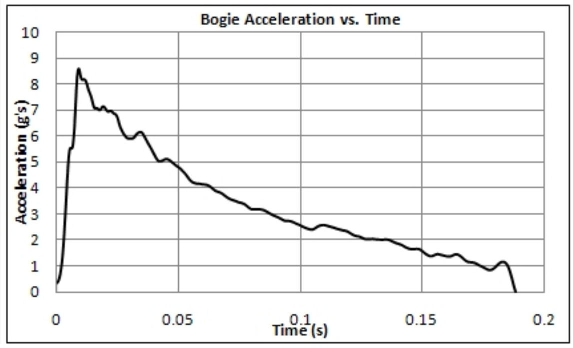
Figure 123. Graph. Test No. GWBR5-1 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Gabion Wall Post Testing	
Test Number:	GWBR5-2	
Test Date:	11-Sep-2009	
Failure Type:	Post rotation and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.4
Post Length:	78 in.	198.1 cm
Embedment Depth:	46 in.	116.8 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil) on Gabion Wall	
Moisture Content:	NA	
Compaction Method:	Driven Post - Roller Compacted	
Terrain:	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	19.39 mph (28.4 fps)	8.67 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1755.5 lb	796.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 - Perpendicular - 23ft-8in.	

Test Results Summary		
Max. Deflection:	35.0	in.
Peak Force:	15.1	k
Initial Linear Stiffness:	4.8	k/in.
Total Energy:	240.8	k-in.



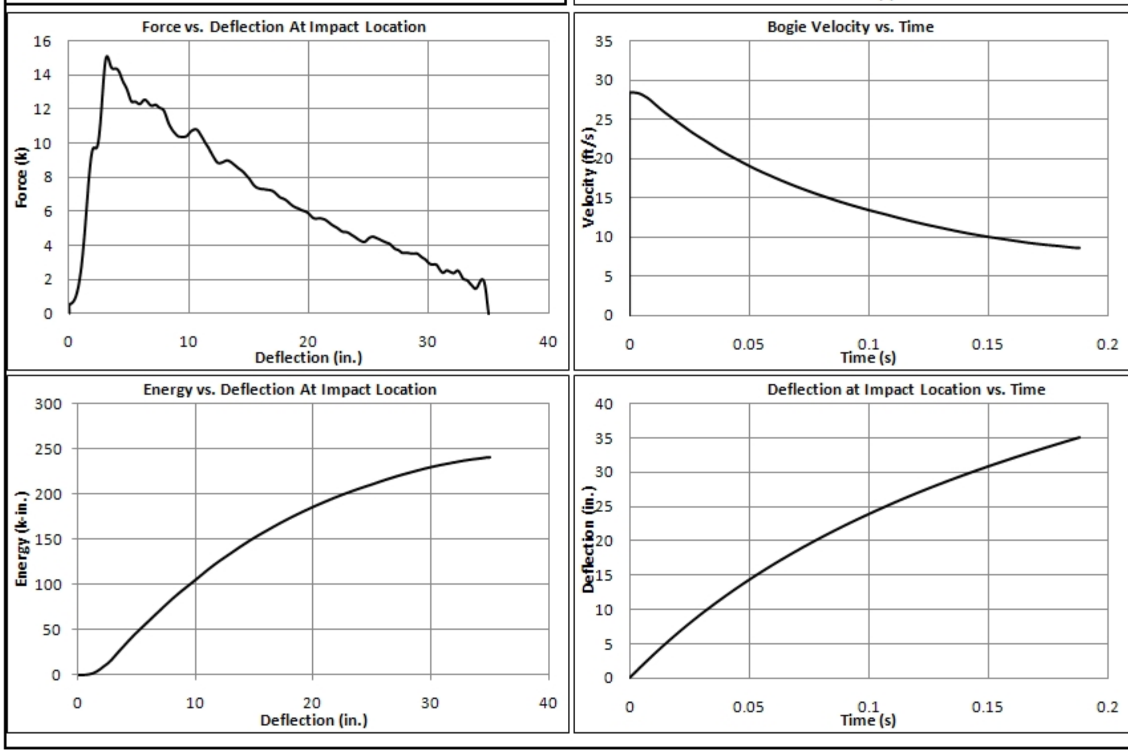


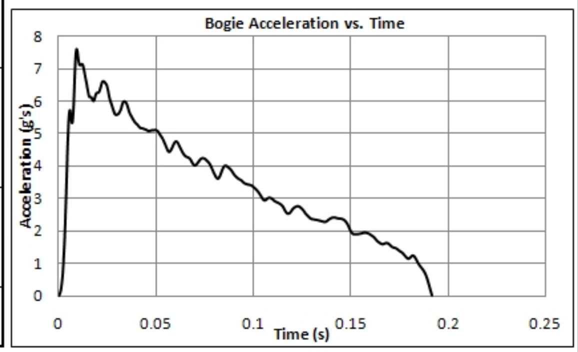
Figure 124. Graph. Test No. GWBR5-2 Results (EDR-3).

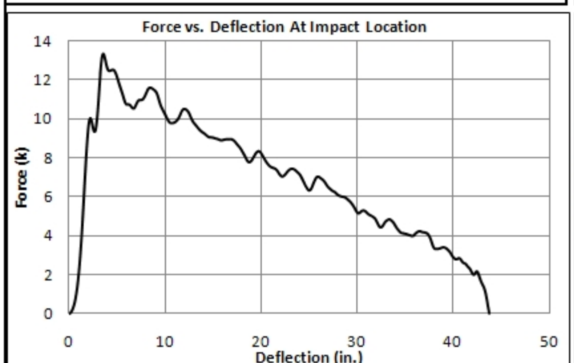
MIDWEST ROADSIDE SAFETY FACILITY

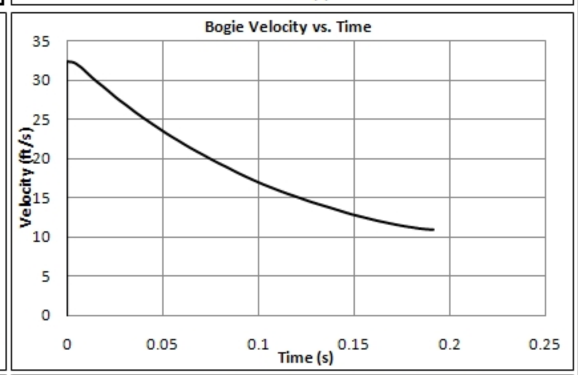
Bogie Test Summary

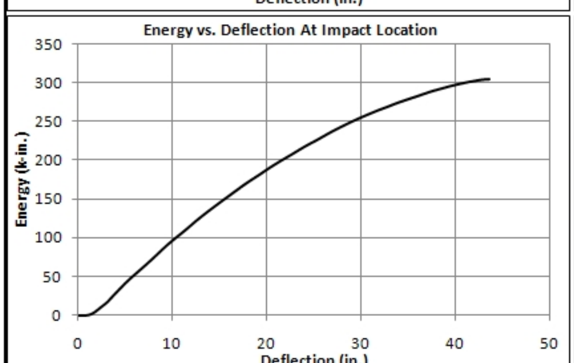
Test Information	Gabion Wall Post Testing	
Test Number:	GWBR5-3	
Test Date:	11-Sep-2009	
Failure Type:	Post rotation and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x8.5	W152x12.6
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil) on Gabion Wall	
Moisture Content:	NA	
Compaction Method:	Driven Post - Roller Compacted	
Terrain:	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	22.12 mph (32.4 fps)	9.89 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1755.5 lb	796.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 - Perpendicular - 27ft-6in.	

Test Results Summary		
Max. Deflection:	43.7	in.
Peak Force:	13.3	k
Initial Linear Stiffness:	3.8	k/in.
Total Energy:	305.4	k-in.









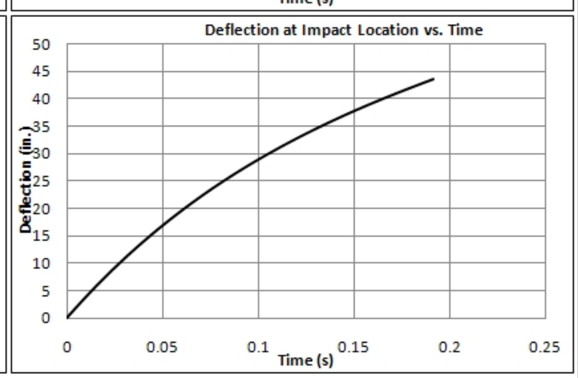
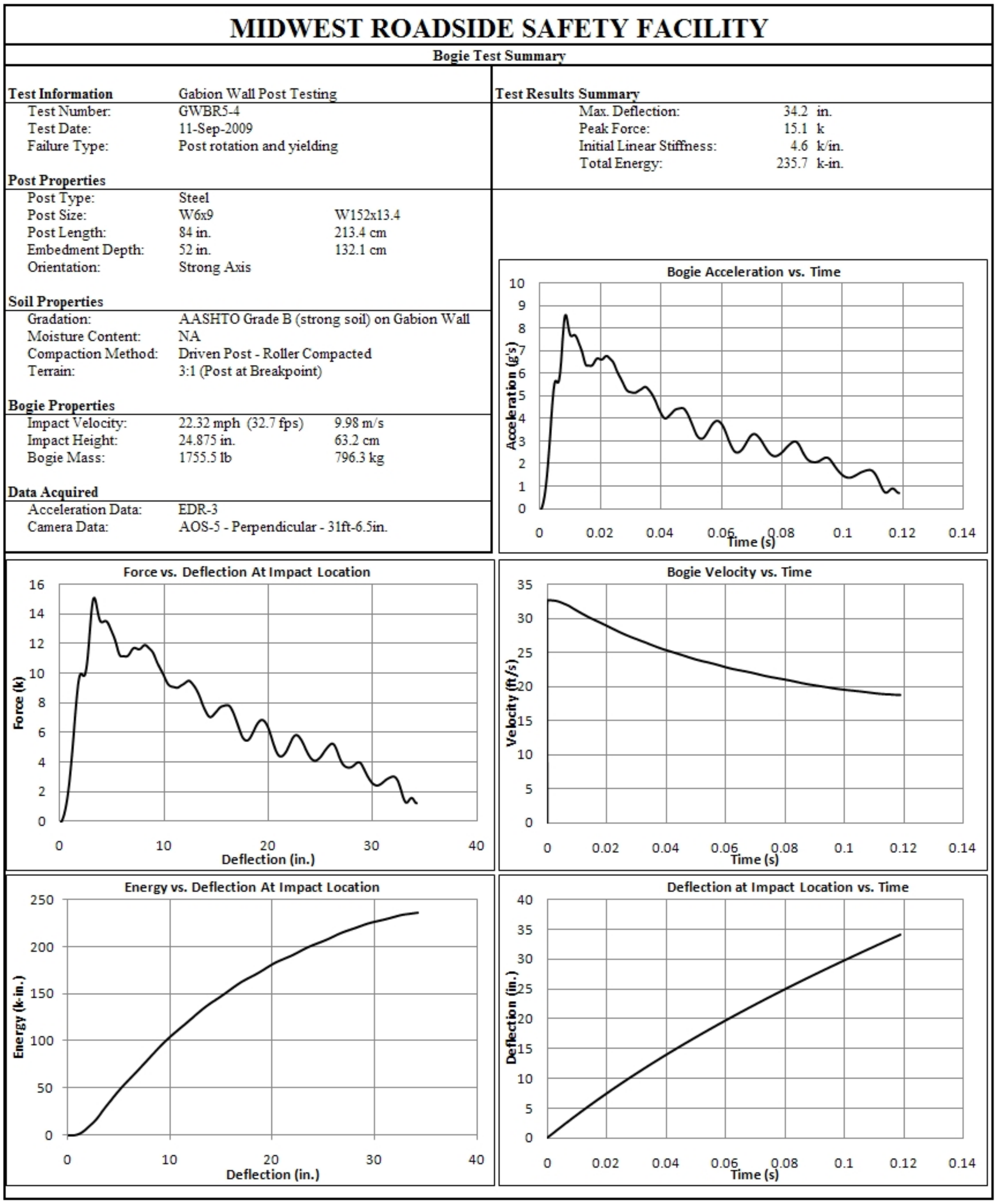


Figure 125. Graph. Test No. GWBR5-3 Results (EDR-3).


MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Gabion Wall Post Testing	
Test Number:	GWBR5-4	
Test Date:	11-Sep-2009	
Failure Type:	Post rotation and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.4
Post Length:	84 in.	213.4 cm
Embedment Depth:	52 in.	132.1 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil) on Gabion Wall	
Moisture Content:	NA	
Compaction Method:	Driven Post - Roller Compacted	
Terrain:	3:1 (Post at Breakpoint)	
Bogie Properties		
Impact Velocity:	22.32 mph (32.7 fps)	9.98 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1755.5 lb	796.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 - Perpendicular - 31ft-6.5in.	

Test Results Summary		
Max. Deflection:	34.2	in.
Peak Force:	15.1	k
Initial Linear Stiffness:	4.6	k/in.
Total Energy:	235.7	k-in.

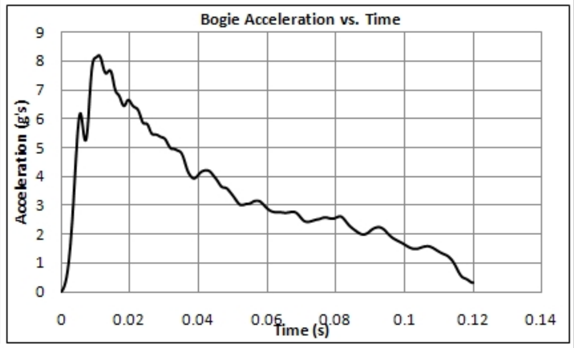
Figure 126. Graph. Test No. GWBR5-4 Results (EDR-3).

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	Gabion Wall Post Testing	
Test Number:	GWBR5-5	
Test Date:	11-Sep-2009	
Failure Type:	Post rotation and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x9	W152x13.4
Post Length:	78 in.	198.1 cm
Embedment Depth:	46 in.	116.8 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil) on Gabion Wall	
Moisture Content:	NA	
Compaction Method:	Driven Post - Roller Compacted	
Terrain:	3:1 (Post on Breakpoint)	
Bogie Properties		
Impact Velocity:	23.89 mph (35 fps)	10.68 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1755.5 lb	796.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 - Perpendicular 35ft-7.25in.	

Test Results Summary		
Max. Deflection:	38.5	in.
Peak Force:	14.4	k
Initial Linear Stiffness:	3.2	k/in.
Total Energy:	244.5	k-in.



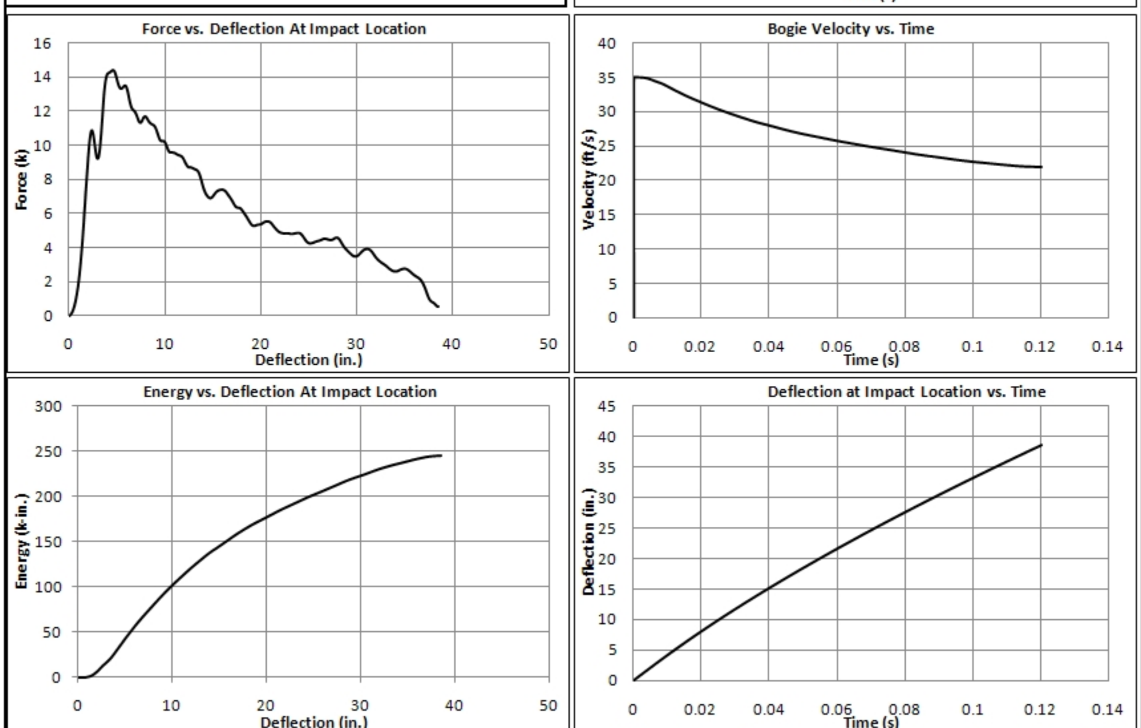


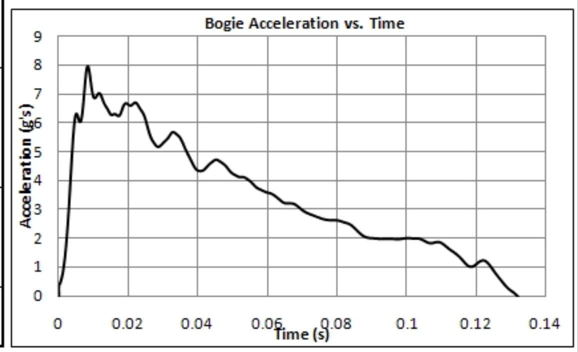
Figure 127. Graph. Test No. GWBR5-5 Results (EDR-3).

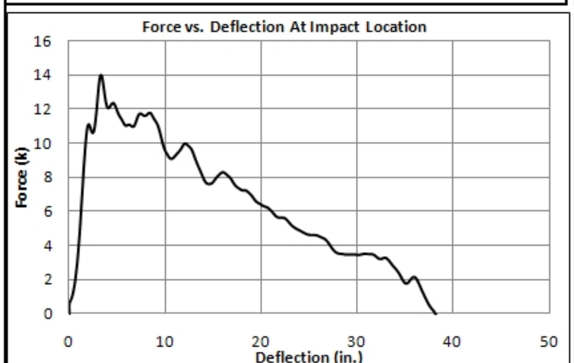
MIDWEST ROADSIDE SAFETY FACILITY

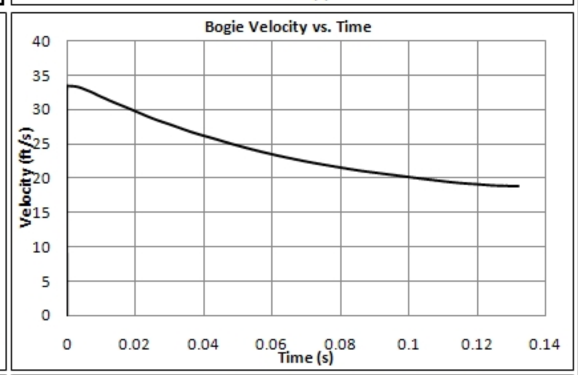
Bogie Test Summary

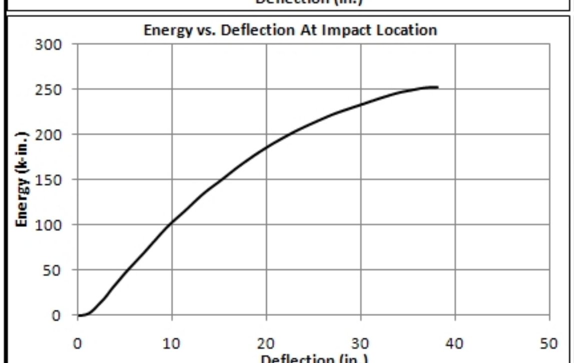
Test Information	Gabion Wall Post Testing	
Test Number:	GWBR5-6	
Test Date:	11-Sep-2009	
Failure Type:	Post rotation and yielding	
Post Properties		
Post Type:	Steel	
Post Size:	W6x8.5	W152x12.6
Post Length:	72 in.	182.9 cm
Embedment Depth:	40 in.	101.6 cm
Orientation:	Strong Axis	
Soil Properties		
Gradation:	AASHTO Grade B (strong soil) on Gabion Wall	
Moisture Content:	NA	
Compaction Method:	Driven Post - Roller Compacted	
Terrain:	3:1 (Post on Breakpoint)	
Bogie Properties		
Impact Velocity:	22.86 mph (33.5 fps)	10.22 m/s
Impact Height:	24.875 in.	63.2 cm
Bogie Mass:	1755.5 lb	796.3 kg
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 - Perpendicular - 39ft-6in.	

Test Results Summary		
Max. Deflection:	38.2	in.
Peak Force:	14.0	k
Initial Linear Stiffness:	4.3	k/in.
Total Energy:	251.7	k-in.









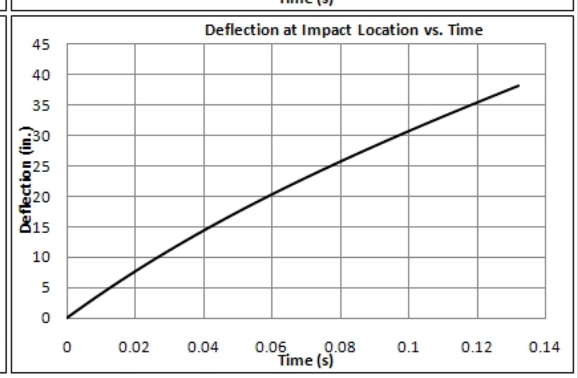


Figure 128. Graph. Test No. GWBR5-6 Results (EDR-3).

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