TESTING OF W152X23.8 (W6X16) STEEL POSTS -

SOIL EMBEDMENT DEPTH STUDY

FOR THE MIDWEST GUARDRAIL SYSTEM

(Non-Proprietary Guardrail System)

Submitted by

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16. Abstract (Limit: 200 words)

Dynamic impact testing of W152x23.8 (W6x16) steel posts at various embedment depths has been detailed and the results stated. The results are consistent within each group of tests as can be seen by the near equal profile of the force-deflection curves. The soil used conformed to AASHTO M 147-65 Gradation "B" specifications.

Failure of the post was dependent upon embedment depth. In tests where the embedment depth was 101.6 cm (40 in.) or deeper, the soil failed with occasions of slight yielding within the post. When the embedment depth was 93.98 cm (37 in.) or less, the post pulled out of the ground.

Based on the results presented herein, it appears that the 101.6 cm (40 in.) embedment depth is the depth of choice for the Midwest Guardrail System (MGS), sometimes referred to as the non-proprietary guardrail system (NPG). The force levels and energy absorbed at an embedment depth of 101.6 (40 in.) was comparable to the current W-Beam guardrail system standard embedment depth of 109.2 (43 in.). Force levels and energy absorption were significantly reduced when the embedment depth was reduced further to 94 cm (37 inches).

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1. INTRODUCTION

1.1 Background

From 2000 through 2002, the Midwest Roadside Safety Facility (MwRSF) developed a new strong-post, W-beam guardrail system for use in shielding roadside hazards. This new 787 mm (31 in.) high, longitudinal barrier system has become known as the "Midwest Guardrail System (MGS)," and that which may be used as a replacement to existing W-beam guardrail designs on new construction projects in the future. The new, non-proprietary guardrail (NPG) system was successfully developed, full-scale vehicle crash testes, and evaluated according to the Test Level 3 (TL-3) safety performance criteria provided in NCHRP Report No. 350.

Before full implementation can be expected, a better understanding of the dynamic performance of this barrier is required. It is therefore necessary to conduct bogie testing to better quantify this post-soil interaction. The dynamic properties of this interaction are of great theoretical and practical importance.

The failure mode of the post drastically affects the performance. Post rotation in soil, fracture of the post, bending of the post, twisting of the post, or a combination of failure modes radically affect how much energy is absorbed by a post in a guardrail system. If the post is not allowed to rotate sufficiently and fractures or yields soon after impact, the force levels may be lower than what is commonly observed in full-scale crash tests on guardrail systems using posts embedded in soil (1).

The post used in the MGS is a W150x13.5 (W6x9) steel post. Conducting tests of a W152x23.8 (W6x16) steel post will ensure soil failure at various embedment depths with minimal post yielding while maintaining similar flange width and therefore similar post-soil interaction behavior. From the tests the post-soil interaction parameters can be determined and applied to the MGS dynamic computer model knowing the force limits of the weaker W150x13.5 (W6x9) post as compared to the tested W152x23.8 (W6x16) post.

1.2 Objective

The objective of the research project was to determine the dynamic properties of the post-soil interaction of the W152x23.8 (W6x16) steel posts at various embedment depths under impact loading conditions. Results of this research are used for (1) determining the appropriate embedment depth for the Midwest Guardrail System; (2) input for Barrier VII simulation models, and (3) potential test cases for simulating soil material in LS-DYNA.

2. LITERATURE REVIEW

2.1 Prior Post Testing Results

Due to the wide variations of posts and soil conditions in roadside hardware, many post studies have been previously performed. In 1999, Coon et al. (2) reviewed these previous post-soil interaction studies completed from 1961 through 1996. Coon and researchers at the MwRSF furthered the understanding of steel and wooden posts in both frontal impacts and frontal offset impacts using wide-flanged steel posts and wooden posts.

The tests concluded that at higher speeds the peak force and the amount of energy absorbed by steel posts increased. In wooden post impacts, soil failure only occurred in half of the impacts while post failure occurred in the other half. This was attributed to stress concentrations induced by the instrumentation of the posts, inherent variations in wood quality, and the gradation variations within AASHTO M 147-65 (1990) Gradation "B" specifications. The results of the dynamic testing program are presented in Table 1 and Table 2 for steel and wood, respectively.

In 2002, dynamic impact testing of S75x8.5 (S3x5.7) steel cable barrier posts was conducted by Fating et al. (3) at the MwRSF to determine the behavior of the S75x8.5 S-section post under impact loading. A total of 17 tests were conducted. Dynamic tests were conducted in different soil types and with different axis impacts. It was found that impacts on either axis of the post in a concrete sleeve show that either the post undergoes small displacements and large peak forces, or large displacements and lower peak forces. In both cases the energy absorbed was approximately the same. For impacts in either standard 350 soil or native soil the weak axis impacts always produced lower peak forces and lower energies relative to the strong axis impacts. The results of this post testing study are summarized in Table 3.

Table 1a. Dynamic Steel Post Test Results - Metric

Test No.	Post Type ASTM Designation	Impact Velocity m/s	Peak Force kN	Maximum Deflection cm	Energy Absorbed Joules	Resulting Bogie Condition
1	W150x13.5	4.6	64	23.4	10.2	Stopped
2	W150x13.5	6	32.3	59.7**	14.1	Stopped
3	W150x13.5	5.4	66.9	31.4	14.2	Stopped
4	W150x13.5	5.9	67	34.8	15.8	Stopped
5	W150x23.5	8.9	104.7	59.7**	28.9	Ride Over
6	W150x23.5	8.9	86.3	59.7**	23.2	Ride Over
7	Static Test					
8*	W150x23.5	8.9	63.8	59.7**	26.2	Ride Over
9	Not Used					
10	W150x23.5	14.1	122.2	59.7**	29.1	Ride Over
11	W150x23.5	12.7	89.6	59.7**	19.8	Ride Over

*Offset impact **Test terminated at D_{max} = 59.7 cm

Table 1b. Dynamic Steel Post Test Results - English

Test No.	Post Type ASTM Designation	Impact Velocity mph	Peak Force kips	Maximum Deflection in.	Energy Absorbed kip-in.	Resulting Bogie Condition
1	W6x9	10.4	14.4	9.2	89.9	Stopped
2	W6x9	13.4	7.3	23.5**	124.8	Stopped
3	W6x9	21.1	15.0	12.4	125.9	Stopped
4	W6x9	13.1	15.1	13.7	139.6	Stopped
5	W6x16	19.9	23.5	23.5**	256.4	Ride Over
6	W6x16	20.0	19.4	23.5**	205.4	Ride Over
7	Static Test					
8*	W6x16	20.0	14.3	23.5**	231.9	Ride Over
9	Not Used					
10	W6x16	31.5	27.5	23.5**	257.1	Ride Over
11	W6x16	28.4	20.2	23.5**	174.8	Ride Over

*Offset impact **Test terminated at D_{max} = 23.5 in.

Table 2a. Dynamic Wood Post Test Results - Metric

Test Name	Post Type ASTM Designation	Impact Velocity m/s	Peak Force kN	Maximum Deflection cm	Energy Absorbed Joules	Resulting Bogie Condition
Wood-01	Static Test					
Wood-02	Static Test					
Wood-03	150x200 mm	4.9	36.30	44.4	11.2	Stopped
Wood-04	150x200 mm	4.8	38.80	45	10.3	Stopped
Wood-05	150x200 mm	9.6	77.80	59.7*	27.1	Stopped
Wood-06	150x200 mm	9.0	64.20	14.5	5.4	Post Fracture
Wood-07	Not Used					
Wood-08	150x200 mm	6.0	51.70	27.6	10.4	Post Fracture
Wood-09	150x200 mm	6.7	55.00	18.2	5.3	Post Fracture

*Test terminated at D_{max} = 59.7 cm

Table 2b. Dynamic Wood Post Test Results - English

Test Name	Post Type ASTM Designation	Impact Velocity mph	Peak Force kips	Maximum Deflection in.	Energy Absorbed kip-in.	Resulting Bogie Condition
Wood-01	Static Test					
Wood-02	Static Test					
Wood-03	6x8 in	11.0	8.15	17.5	98.8	Stopped
Wood-04	6x8 in	10.9	7.82	17.7	90.8	Stopped
Wood-05	6x8 in	21.5	17.48	23.5*	240.0	Stopped
Wood-06	6x8 in	20.1	14.43	5.7	47.6	Post Fracture
Wood-07	Not Used					
Wood-08	6x8 in	13.4	11.62	10.9	91.6	Post Fracture
Wood-09	6x8 in	15.0	12.36	7.2	47.3	Post Fracture

*Test terminated at D_{max} = 23.5 in.

Table 3a. Dynamic Testing Results of S75x8.5 (S3x5.7) Posts - Metric

Test Name	Impact Axis	Soil Type	Moisture Content % wt	Maximum Force Encountered kN	Maximum Displacement Encountered cm	Maximum Energy Absorbed kJ
CPB-2	Strong	Std 350 Soil	5.41	23.72	99.37	15.85
CPB-3	Strong	Std 350 Soil	4.91	17.93	113.18	12.51
CPB-4	Strong	Std 350 Soil	4.91	25.41	101.18	13.75
CPB-5	Weak	Std 350 Soil	5.49	28.42	109.61	8.52
CPB-6	Weak	Std 350 Soil	5.49	12.67	93.39	5.78
CPB-7	Weak	Std 350 Soil	5.99	14.44	98.68	6.26
CPB-8	Strong	Native Soil	-NA-	27.30	91.21	12.89
CPB-9	Strong	Native Soil	-NA-	28.65	95.76	15.01
CPB-10	Weak	Native Soil	-NA-	25.95	100.43	7.19
CPB-11	Weak	Native Soil	-NA-	28.64	82.88	7.71
CPB-12	Strong	-NA-	-NA-	64.39	65.34	11.12
CPB-13	Strong	-NA-	-NA-	87.02	60.32	11.28
CPB-14	Strong	-NA-	-NA-	89.98	59.10	11.53
CPB-15	Weak	-NA-	-NA-	38.92	102.05	11.05
CPB-16	Weak	-NA-	-NA-	39.55	100.38	9.85
CPB-17	Weak	-NA-	-NA-	40.34	110.71	11.01

Table 3b. Dynamic Testing Results of S75x8.5 (S3x5.7) Posts - English

Test Name	Impact Axis	Soil Type	Moisture Content % wt	Maximum Force Encountered kips	Maximum Displacement Encountered in.	Maximum Energy Absorbed kips-in.
CPB-2	Strong	Std 350 Soil	5.41	5.33	39.12	140.28
CPB-3	Strong	Std 350 Soil	4.91	4.03	44.56	110.72
CPB-4	Strong	Std 350 Soil	4.91	5.71	39.83	121.70
CPB-5	Weak	Std 350 Soil	5.49	6.39	43.15	75.41
CPB-6	Weak	Std 350 Soil	5.49	2.85	36.77	51.16
CPB-7	Weak	Std 350 Soil	5.99	3.25	38.85	55.41
CPB-8	Strong	Native Soil	-NA-	6.14	35.91	114.09
CPB-9	Strong	Native Soil	-NA-	6.44	37.70	132.85
CPB-10	Weak	Native Soil	-NA-	5.83	39.54	63.64
CPB-11	Weak	Native Soil	-NA-	6.44	32.63	68.24
CPB-12	Strong	-NA-	-NA-	14.48	25.72	98.42
CPB-13	Strong	-NA-	-NA-	19.56	23.75	99.84
CPB-14	Strong	-NA-	-NA-	20.23	23.27	102.05
CPB-15	Weak	-NA-	-NA-	8.75	40.18	97.80
CPB-16	Weak	-NA-	-NA-	8.89	39.52	87.18
CPB-17	Weak	-NA-	-NA-	9.07	43.59	97.45

3. PHYSICAL TESTING

3.1 Purpose

Physical testing of components is an important aspect of any design process. The researcher is able to get practical insights using this tool. If used properly the researcher can understand the practicality of the design, as it gives the exact representation of the working of the design.

3.2 Test Facility

Physical testing of W152x23.8 (W6x16) wide flange guardrail posts were performed at the MwRSF outdoor testing facility located at the Lincoln airpark, on the northwest side of the Lincoln Municipal Airport. The testing site provides excellent equipment and an advantageous atmosphere to perform physical tests. The tarmac is appropriately cut out to house the post and provide a sufficient length for the bogie to operate.

3.3 Scope

The research objective was achieved by performing bogie crash tests on the steel post under various embedment depths with known soil conditions. The target impact conditions for all the crash tests were a speed of 32 km/h (20 mph) and an angle of 0.0 degrees (strong axis), an impact type of the classical "head-on" or full frontal impact. The post is impacted 63.0 cm (24.8 in.) above the ground line perpendicular to the face of the post. The scope of the physical testing is listed in Table 4.

Initially six crash tests, NPGB-1 through NPGB-6, were conducted and the test results were analyzed and evaluated. An inconsistency in the force-deflection data was found in the 101.6 cm (40 in.) embedment depth tests, as well as concerns being raised with the quality of the soil used in NPGB-5 due to rains between construction and testing. Four further tests, NPGB-7 through NPGB-10, were conducted to resolve these issues and validate the data previously taken. The test results were analyzed, evaluated, and documented. Conclusions were then drawn that pertain to the behavior of the post under dynamic loading.

Table 4a. Scope of Physical Testing - Metric

Test No.	Speed		Embedment Depth	Moisture Content	Axis	Notes
	km/h	m/s	cm	%		
NPGB-1	32.19	8.94	109.22	4.5	Strong	350 Soil, 91.4 cm holes
NPGB-2	33.80	9.39	101.60	4.8	Strong	350 Soil, 91.4 cm holes
NPGB-3	32.19	8.94	109.22	4.9	Strong	350 Soil, 91.4 cm holes
NPGB-4	32.19	8.94	101.60	5.0	Strong	350 Soil, 91.4 cm holes
NPGB-5	32.19	8.94	93.98	4.8	Strong	350 Soil, 91.4 cm holes
NPGB-6	32.99	9.16	86.36	5.7	Strong	350 Soil, 91.4 cm holes
NPGB-7	31.70	8.81	93.98	-NA-	Strong	350 Soil, 91.4 cm holes
NPGB-8	33.31	9.25	93.98	-NA-	Strong	350 Soil, 91.4 cm holes
NPGB-9	33.39	9.28	101.60	-NA-	Strong	350 Soil, 91.4 cm holes
NPGB-10	34.60	9.61	101.60	-NA-	Strong	350 Soil, 91.4 cm holes

Table 4b. Scope of Physical Testing - English

Test No.	Speed		Embedment Depth	Moisture Content	Axis	Notes
	mph	ft/s	in.	%		
NPGB-1	20.00	29.33	43	4.5	Strong	350 Soil, 3' holes
NPGB-2	21.00	30.80	40	4.8	Strong	350 Soil, 3' holes
NPGB-3	20.00	29.33	43	4.9	Strong	350 Soil, 3' holes
NPGB-4	20.00	29.33	40	5.0	Strong	350 Soil, 3' holes
NPGB-5	20.00	29.33	37	4.8	Strong	350 Soil, 3' holes
NPGB-6	20.50	30.07	34	5.7	Strong	350 Soil, 3' holes
NPGB-7	19.70	28.89	37	-NA-	Strong	350 Soil, 3' holes
NPGB-8	20.70	30.36	37	-NA-	Strong	350 Soil, 3' holes
NPGB-9	20.75	30.43	40	-NA-	Strong	350 Soil, 3' holes
NPGB-10	21.50	31.53	40	-NA-	Strong	350 Soil, 3' holes

4. SYSTEM DETAILS

4.1 The Post

The post under study was the W152x23.8 (W6x16) beams manufactured using ASTM A36 steel with a cross-section in accordance with the A6M standards. The post primarily consists of the 3 major components: two flanges and webbing.

The flanges are called either tensile or compressive depending on the type of loading it undergoes upon impact. The two flanges are connected by a web, which acts like a force transmitter. The thickness of the webbing is 6.604 mm (0.260 in.) while the thicknesses of the flanges are generally 10.287 mm (0.405 in.). The total length of the posts tested was 1828.8 mm (72 in.) with variable embedment depth in the ground in the range of 86.4-109.2 cm (34-43 in.). The various dimensions and thickness are shown in Figure 1. Various material properties (4) for the post are provided in Table 5.

Table 5. Material Properties of W152x23.8 (W6x16) Post

ASTM Designation	**Area, A** mm^2 (in^2)	**Flange Width, b_f** mm (in)	**Moment of Inertia, I_x** mm^4 (in^4)	**Section Modulus, S_x** mm^3 (in^3)	**Plastic Section Modulus, Z_z** mm^3 (in^3)
W152x23.8 (W6x16)	3058 (4.74)	102.4 (4.03)	$1.34x10^7$ (32.1)	$1.67x10^5$ (10.2)	$1.92x10^5$ (11.7)

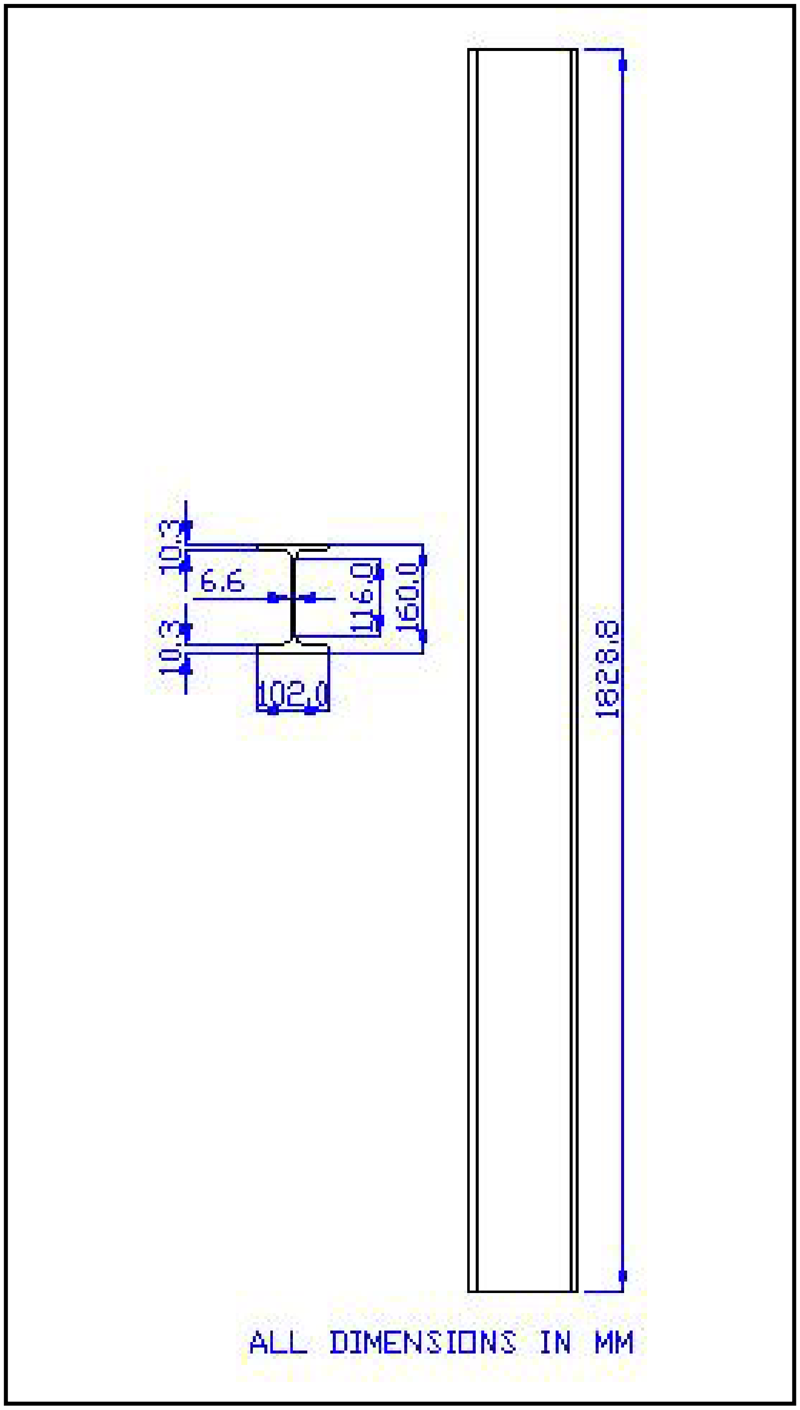

Figure 1. Major Dimensions of the W152x23.8 (W6x16) Steel Post

4.2 The Soil

A crusher run coarse aggregate material consisting of gravel and crushed limestone was used for filling the excavated pit area. The soil conformed to AASHTO standard specifications for "Materials for Aggregate and Soil Aggregate Subbase, Base, and Surface Courses," designation M 147-65 (1990), grading B. The moisture content was relatively dry (4% to 6%), which was considerably below the optimum moisture content of 17%. Due to the gradation of the material, additional moisture content would have greatly increased the *in situ* density.

4.3 Equipment and Instrumentation

A variety of equipment and instrumentation were used to record and collect data. It is important to gather correct data using affordable instrumentation in order to understand and derive meaningful conclusions of the physical tests. The main equipment and instruments used for the tests were:

- Bogie
- Accelerometer
- Pressure Tape Switches
- Photography Cameras

4.3.1 Bogie

A rigid frame bogie, constructed from FHWA specifications (5), was used to impact the posts. An impact head, made of a 203 mm (8 in.) concrete filled standard steel pipe, was mounted to the bogie at the height of 630 mm (24.8 in.) above the ground. Neoprene belting, 19 mm (3/4 in.) thick, was attached to the steel pipe to minimize the local damage to the post from the impact. The bogie is shown in Figure 2.

Figure 2. Bogie and Test Setup

The bogie weight was 1014 kg (2237 lbs). Calculations and computer simulations prior to testing indicate that this weight, in combination with a velocity of approximately 32 kilometers per hour (20 mph or 8.9 m/s), would closely replicate the actual impact conditions that a post as a part of the guardrail system would be subjected to in a 96 kilometers per hour (60 mph), 25 deg impact with a 2040 kg (4500 lbs) car.

4.3.2 Accelerometer

The initial velocity and the accelerometer data were used to determine the forces, velocity, displacement, and the energy absorbed by the post during the impact. Although the accelerometer was located at the center of gravity of the bogie, and measured the acceleration of the bogie's center of gravity, this data was used to approximate the bogie/post forces at the point of impact using Newton's Second Law.

A tri-axial piezo-resistive accelerometer system with a range of ± 200 G's was mounted on the frame of the bogie at approximately the center of gravity. It measured the accelerations in the longitudinal, lateral, and vertical directions. The accelerometer system, known as the Model EDR-3, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan.

The EDR-3 is a self-contained, user programmable acceleration sensor/recorder with a 74dB dynamic range. During active recording, acceleration signals are digitized to 10-bit resolution and stored in digital memory onboard the unit. The EDR-3 was configured with 256 KB of RAM and was set to sample data at 3,200 Hz. The EDR-3 offers recording capability from six input channels simultaneously. Analog low-pass filtering was used internally in the EDR-3 to condition the input signal. A Butterworth low-pass filter with a –3dB cut-off frequency of 1120 Hz was used for anti-aliasing. The EDR-3 had a maximum cross axis sensitivity of ±3%.

A laptop computer downloaded the raw acceleration data immediately following each test. The computer made the use of "DynaMax 1.75" accelerometer software (6) and then loaded into "DADiSP 4.0" data processing program (7). The data is processed as per the SAE J211/1 specifications. The details of these specifications are discussed in the subsequent chapter of data processing.

4.3.3 Pressure Tape Switches

Three pressure tape switches spaced at a distance of 1-meter (3.3 ft) intervals were used to determine the speed of the bogie before the impact. As the front right tire of the bogie passed over each tape switch, a strobe light was fired, sending an electronic timing signal to the data acquisition system. Test speeds were determined by knowing the time between these signals from the data acquisition system and the distance between the switches.

4.3.4 Photography Cameras

One high-speed Red Lake E/cam video camera, with an operating speed of 500 frames/sec, and one Canon digital video camera, with an operating speed of 29.97 frames/sec, was used to film the crash test. The cameras were placed perpendicular to the side of the guardrail post. The film was analyzed using the Vanguard Motion Analyzer. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

4.4 Methodology of Testing

A total of 10 tests were carried out along the strong axis of impact and at different embedment depths in standard NCHRP 350 soil. Impact of the post flanges perpendicular to the direction of motion of the bogie head is a strong axis impact. Graphical representation of the impact is shown in Figure 3 and the test parameters can be seen in Table 6.

Table 6. Test Parameters

NPGB Test Parameters
NPG: Non-Proprietary Guardrail
Test: Strong Axis Impact at 0 degrees
Accelerometer: EDR-3 Data
Bogie Weight: 2,237 lbs (1014 kg)
Bumper Height: 24.8 in. (630 mm)
Posts: W6x16 (W152x23.8) Steel
Post Length: 72 in. (1829 mm)
Soil: 135 lb/ft^3 (2163 kg/m^3) NCHRP 350 (AASHTO 147-65 (1990) Grade B)

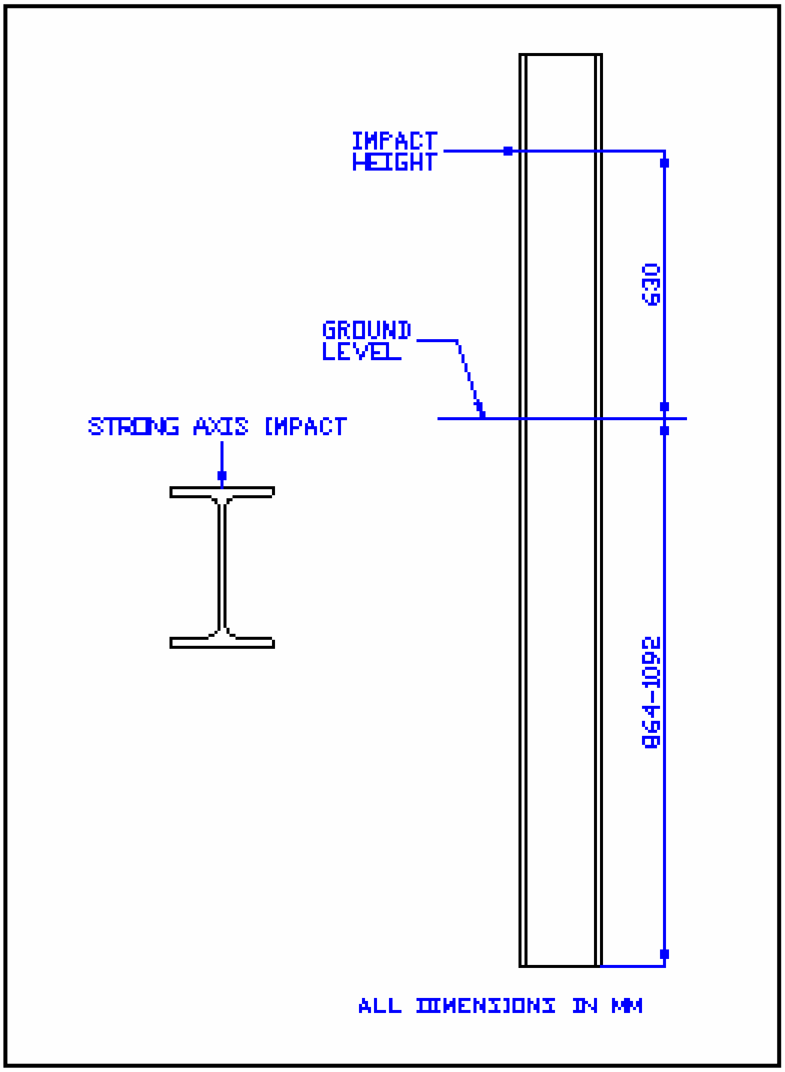

Figure 3. Impact Location and Impact Type

A plan view of the test setup and the post-testing pit is shown in Figure 4. The pits were located at a sufficient distance from the edge of the concrete apron so as not to interfere with the soil response during the impact.

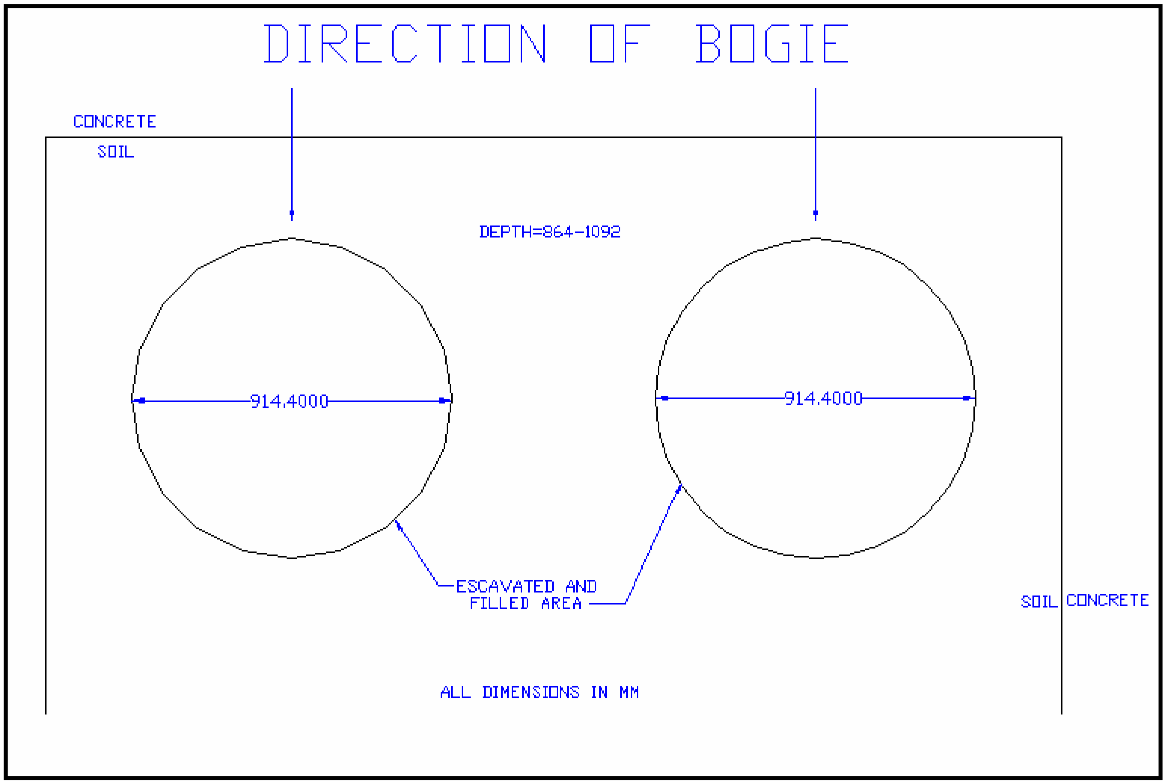

Figure 4. Plan View of the Post Testing Area

For the tests, holes measuring 0.914 m (36 in.) in diameter and 0.864 to 1.092 m (34 to 43 in.) in depth were dug out in the test area. These holes were filled with soil meeting the AASHTO standard specification for "Materials and Aggregates and Soil Aggregates Sub-base, Base and Surface Courses," designation M147-65 (1990), grading A or B and compacted in accordance with AASHTO guide specifications for highway construction, section 304.05 and 304.07. The moisture content was relatively dry (4% - 6%) with the primary considerations being the homogeneity, consistency and the ease of compaction.

The tests were conducted using a steel corrugated beam guardrail to guide the tire of the bogie. A pickup truck was used to propel the test vehicle to the required impact velocity, at which point the pickup truck released, allowing the bogie to become a free projectile as it came off the guide track. The bogie positioned in the guide track can be seen in Figure 5.

Figure 5. Bogie Positioned in the Guide Track Configuration

The bogie wheels rode in the steel corrugated beam, ensuring the proper direction and position of the bogie prior to the impact. In all of the tests conducted the bogie wheels were aligned for caster and toe-in values of zero so that the bogie would track properly along the guidance system. A remote braking system was installed on the bogie to allow the bogie to be brought safely to a stop after the test. Accelerometers, located at the bogie's center of gravity record lateral, horizontal and vertical acceleration data.

4.5 End of Test Determination

When the bogie overrides the post, the end of the test cannot be the entire duration of the contact between the post and the bogie head, because a portion of the force is consumed to lift the bogie in the vertical direction. When the bogie head initially impacts the post, the force exerted by the bogie is directed perpendicular to the face of the post. As the post begins to rotate, however, the bogie head is no longer perpendicular to the face of the post and begins to slide along the face of the post as shown in the Figure 6.

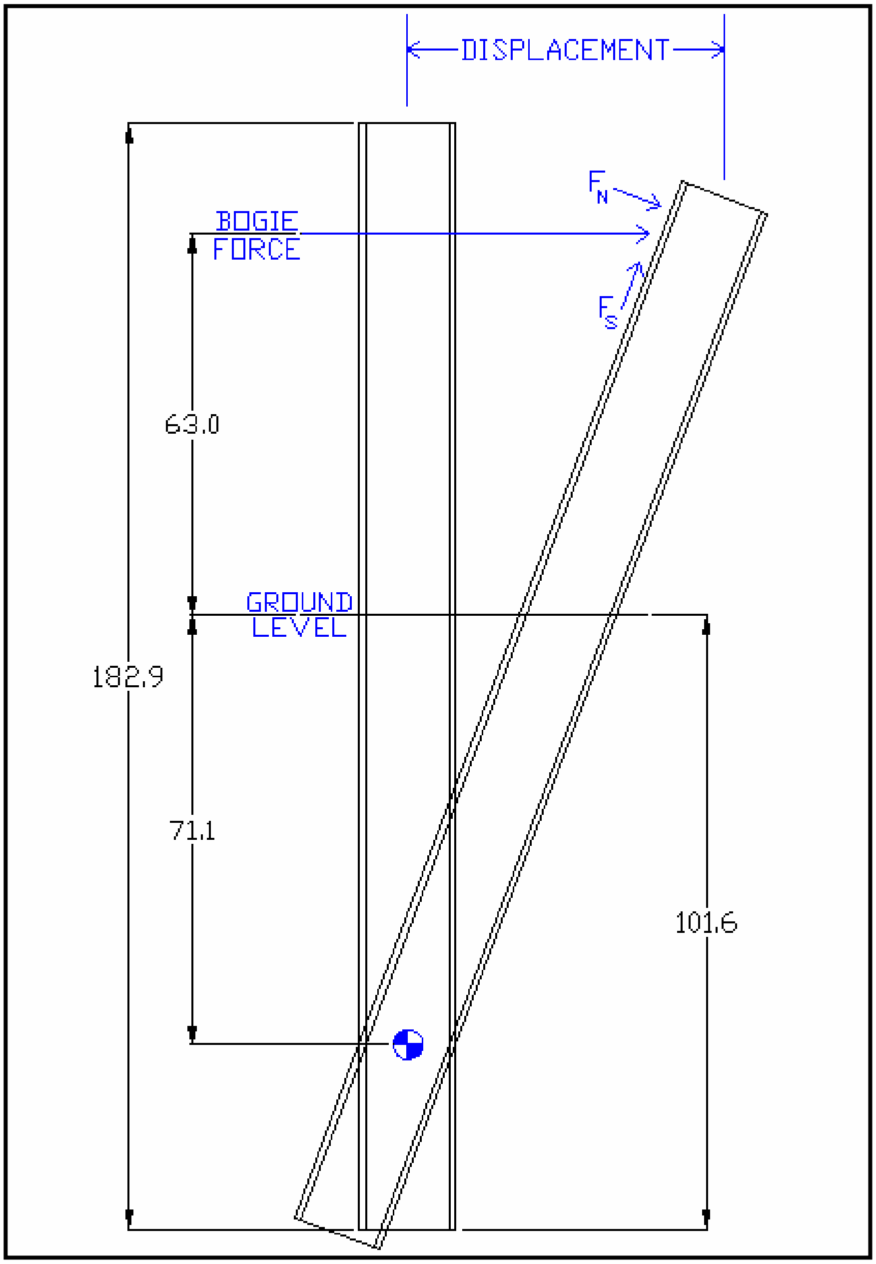

Figure 6. Various Forces Acting on the Post and Their Orientation (dimensions cm)

In addition to the variation due to the changing angle of impact, the neoprene on the bogie head, used to minimize local stress concentration at the point of impact, increased the frictional forces acting on the surface of the post. Additionally, since the accelerometer was used to represent the contact forces rather than the actual center of gravity forces it truly observes, additional error was added to the data. This required that only the initial portion of the accelerometer trace be used. This is because the variations in the data start to become more significant as the post rotates.

4.6 Data Processing

Initially the bulk of the data was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications. Pertinent acceleration signal was extracted from the bulk of the data. The processed acceleration data is 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 rate of change of velocity. Initial velocity of the bogie, calculated using the data from the pressure tape switches, was then used to determine the bogie velocity. The calculated velocity trace was integrated to find the displacement. Subsequently using the previous results, the force deflection curve was plotted for each test. Finally, integration of the force-deflection curve provides the energy-displacement curve for each test.

5. TEST RESULTS AND DISCUSSION

Accelerometer data was processed for each test in order to obtain acceleration, velocity, and displacement curves, as well as force-deflection curves. Individual test results are provided in Appendix A. A summary of all the tests is provided in Table 7 and Figures 7-10. This section discusses those results.

5.1 Results

Soil failure was the primary mode of failure in all tests. The posts rotated in the soil, with slight deformation of the posts in tests nos. 1, 3, 9 and 10. However, in the cases where there was slight deformation of the posts, the accelerometer data closely matched the tests where post deformation had not occurred. The other soil failure encountered was posts being pulled out of the ground. The accelerometer data is similar in most regards to the other tests, but small differences are apparent.

The data is grouped and plotted according to post embedment depth. Using the embedment depth as a basis for comparison, it is possible to see how the embedment depth affects the force at the impact location. Force-Deflection curves for the tests with an embedment depth of 109.22 cm (43 in.), NPGB-1 and NPGB-3, are shown in Figure 7. Force-Deflection curves for the tests with an embedment depth of 101.6 cm (40 in.), NPGB-2, NPGB-4, NPGB-9, and NPGB-10, are shown in Figure 8. Force-Deflection curves for the tests with an embedment depth of 93.98 cm (37 in.), NPGB-5, NPGB-7, and NPGB-8, are shown in Figure 9. Force-Deflection curve for the test with an embedment depth of 86.36 cm (34 in.), NPGB-6, is shown in Figure 10.

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

It should be noted that although the acceleration data was applied to the impact location, the data came from the center of gravity of the bogie. This added some error to the data, since the bogie was not perfectly rigid, causing vibrations in the bogie. Also the bogie may have 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, it was believed that the data was not greatly influenced by them, and as a result, the data was useful for analysis. One useful aspect of using accelerometer data was that it included influences of the post inertia on the reaction force. This is important since the post's mass would affect the results.

The bogie, in each case, continued to travel forward after the soil failure, and after clearing the post, along its path and was stopped when the onboard braking system was enacted.

Table 7a. Summary of Tests NPGB-1 through NPGB-10 - Metric

Test No.	Embedment Depth	Impact Velocity	Initial Peak Force		Total Energy	
			Displacement	Force	Displacement	Energy
	cm	m/s	cm	kN	cm	kJ
NPGB-1	109.2	8.94	6.12	47.91	104.53	29.82
NPGB-3	109.2	8.94	5.29	43.00	124.17	28.45
Average	**109.2**	**8.9**	**5.7**	**45.5**	**114.4**	**29.1**
NPGB-2	101.6	9.39	5.56	36.76	115.29	29.15
NPGB-4	101.6	8.94	5.56	52.83	109.23	29.14
NPGB-9	101.6	9.28	5.48	58.04	122.15	29.16
NPGB-10	101.6	9.61	5.97	62.89	118.56	31.78
Average	**101.6**	**9.3**	**5.6**	**52.6**	**116.3**	**29.8**
NPGB-5	94.0	8.94	7.24	52.39	136.50	27.37
NPGB-7	94.0	8.81	4.93	57.23	132.63	22.50
NPGB-8	94.0	9.25	7.19	72.34	116.41	24.83
Average	**94.0**	**9.0**	**6.5**	**60.7**	**128.5**	**24.9**
NPGB-6	86.4	9.16	4.56	55.44	134.01	24.20

Table 7b. Summary of Tests NPGB-1 through NPGB-10 - English

Test No.	Embedment Depth	Impact Velocity	Initial Peak Force		Total Energy	
			Displacement	Force	Displacement	Energy
	in.	mph	in.	kips	in.	kip-in.
NPGB-1	43	20.0	2.41	10.77	41.15	263.94
NPGB-3	43	20.0	2.08	9.67	48.89	251.78
Average	**43**	**20.0**	**2.2**	**10.2**	**45.0**	**257.9**
NPGB-2	40	21.0	2.19	8.26	45.39	257.99
NPGB-4	40	20.0	2.19	11.88	43.00	257.93
NPGB-9	40	20.75	2.16	13.05	48.09	258.13
NPGB-10	40	21.5	2.35	14.14	46.68	281.24
Average	**40**	**20.8**	**2.2**	**11.8**	**45.8**	**263.8**
NPGB-5	37	20.0	2.85	11.78	53.74	242.28
NPGB-7	37	19.7	1.94	12.87	52.22	199.10
NPGB-8	37	20.7	2.83	16.26	45.83	219.76
Average	**37**	**20.1**	**2.5**	**13.6**	**50.6**	**220.4**
NPGB-6	34	20.5	1.80	12.46	52.76	214.16

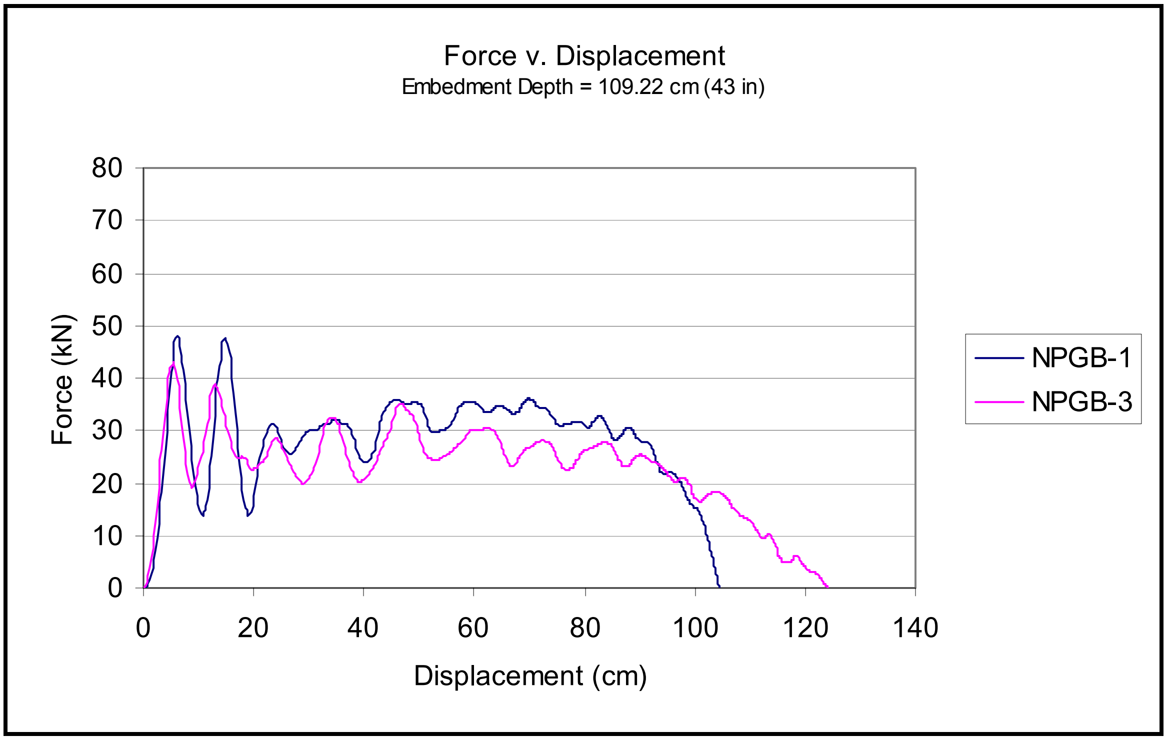

Figure 7. Force-Displacement Curves for Tests NPGB-1 and 3

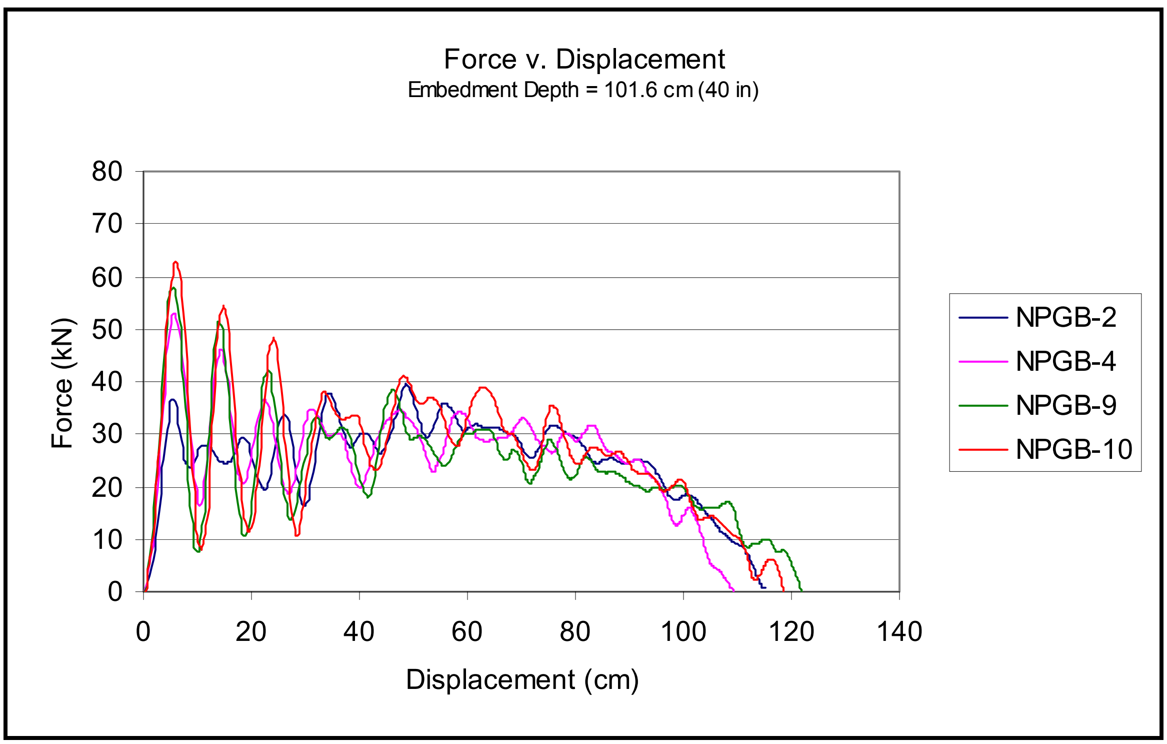

Figure 8. Force-Displacement Curves for Tests NPGB-2, 4, 9, and 10

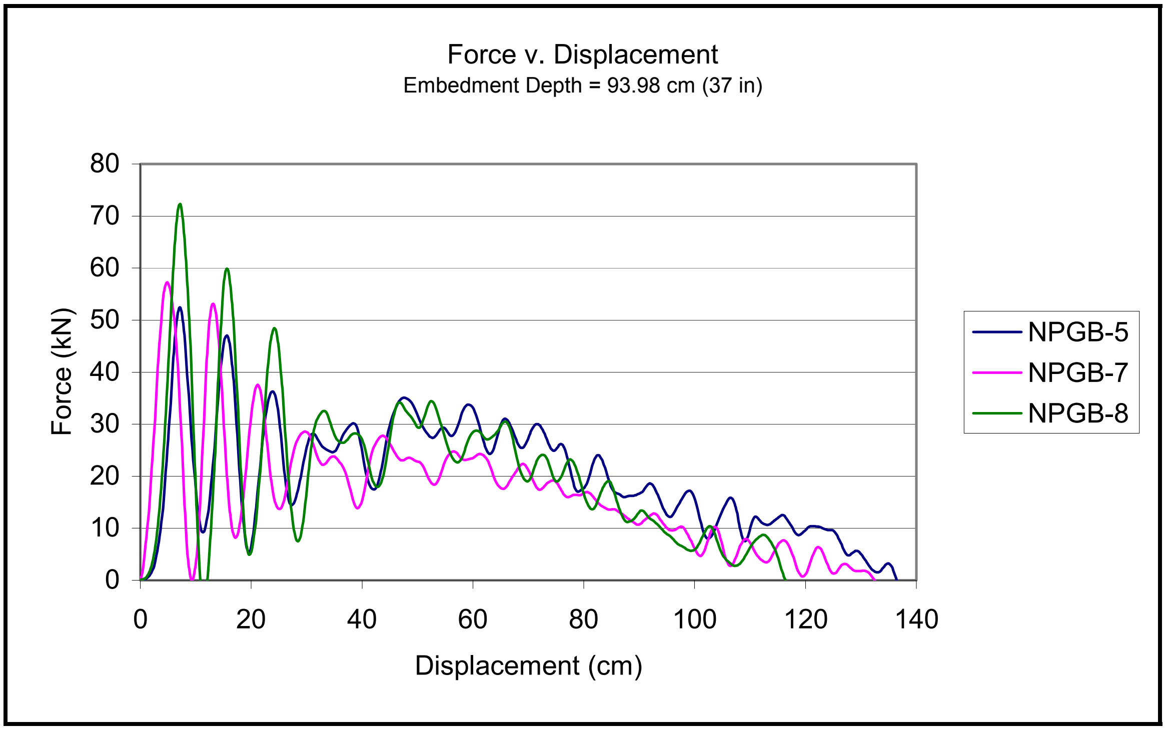

Figure 9. Force-Displacement Curves for Tests NPGB-5, 7, and 8

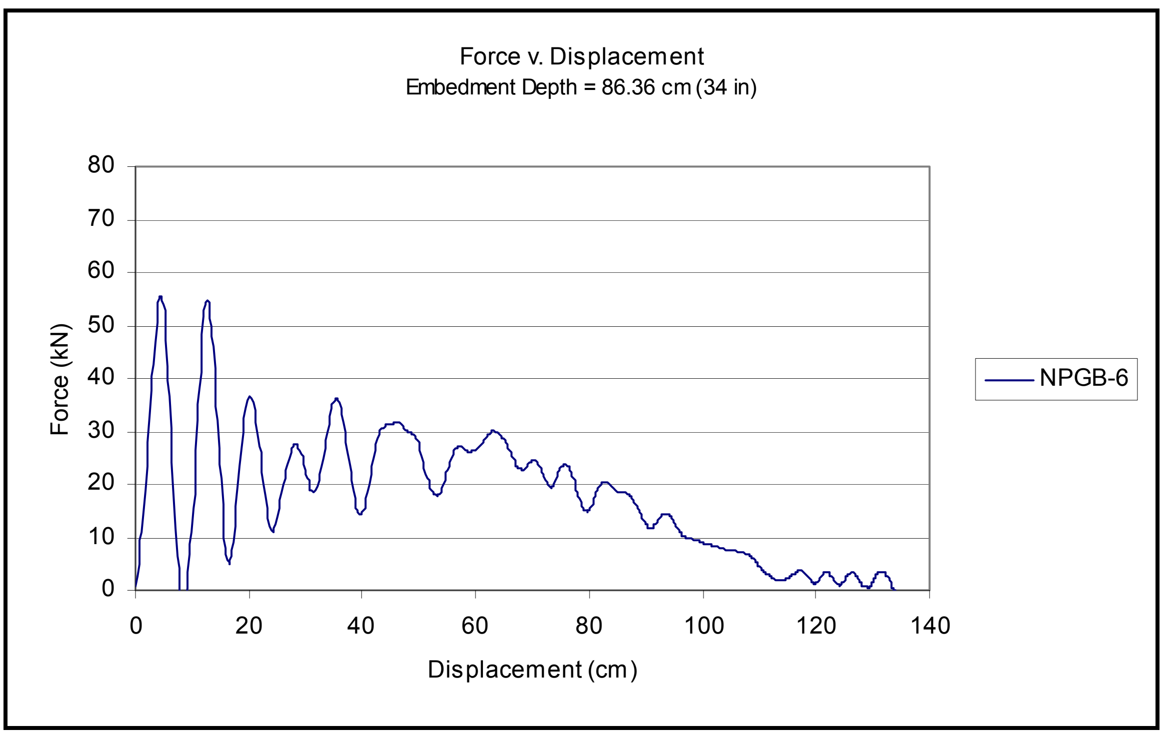

Figure 10. Force-Displacement Curve for Test NPGB-6

5.2 Force Discussion

This section discusses tests NPGB-1 through NPGB-10 in detail.

5.2.1 Tests NPGB-1 and NPGB-3

Tests NPGB-1 and NPGB-3 resulted with the posts rotating in the soil, with only slight yielding (see Figure 11). The profile of the force-deflection curve for these tests indicates that the forces acting on the posts were fairly uniform over the duration of the impact. The post-impact investigation showed that the post had not undergone considerable plastic deformation under the action of the impact forces. As a result, the reaction forces of the post can be attributed to the constant shear failure of the soil. Both test plots show comparable forces during impact and validate the data taken (see Figure 7). Photographs and film analysis of the system clearly indicate that the soil offered resistance to the failure and pivoted the post in the soil.

Figure 11. Post-Impact of NPGB-1, Embedment Depth of 109.2 cm (43 in.)

5.2.2 Tests NPGB-2, NPGB-4, NPGB-9, and NPGB-10

The behavior of tests NPGB-2, NPGB-4, NPGB-9, and NPGB-10 are very similar to tests NPGB-1 and NPGB-3, which during impact the posts rotated in the soil and in two instances, NPGB-9 and NPGB-10, resulted in slight yielding of the post as before (see Figure 12). The profile of the force-deflection curves for the tests NPGB-2, NPGB-4, NPGB-9, and NPGB-10 show the forces were fairly uniform and are of similar magnitude as compared to the previous tests (see Figure 8). All four tests also show comparable forces during impact and validate the data taken. Photographs and film analysis of the system clearly indicate that the soil offered resistance to the failure and pivoted the post in the soil.

Figure 12. Post-Impact of NPGB9 and 10, Embedment Depth of 101.6 cm (40 in.)

5.2.3 Tests NPGB-5, NPGB-7, and NPGB-8

The force-deflection for the tests NPGB-5, NPGB-7, and NPGB-8 is shown in Figure 9. The force during each impact, as seen from the curves, is similar to the previous tests over the initial impact period being fairly level, but a difference is apparent after 60 cm (23.6 in.) of deflection. The force begins to fade in a linear fashion. This phenomenon can be attributed to the post being pulled out of the ground after rotating in the soil for some distance.

Figure 13. Post-Impact of NPGB-8, Embedment Depth of 93.98 cm (37 in.)

5.2.4 Test NPGB-6

This test was not much different in nature as compared to the tests with a post embedment depth of 93.98 cm (37 in.). The forces experienced by the post are of similar nature and magnitude (see Figure 10). Again the force fades in a linear fashion as the post is being pulled out of the ground, as shown in Figure 14. The result was as excepted because the embedment depth was so shallow.

Figure 14. Post-Impact of NPGB-6, Embedment Depth of 86.36 cm (34 in.)

5.3 Energy Discussion

As stated previously, the energy dissipated during the impact is of significant interest. Two failure modes arose during impact testing, either post rotation or having the post being pulled from the ground, after significant rotation. It was also noted previously that there was a difference in the force plots of each failure mode, as shown in Figure 15.

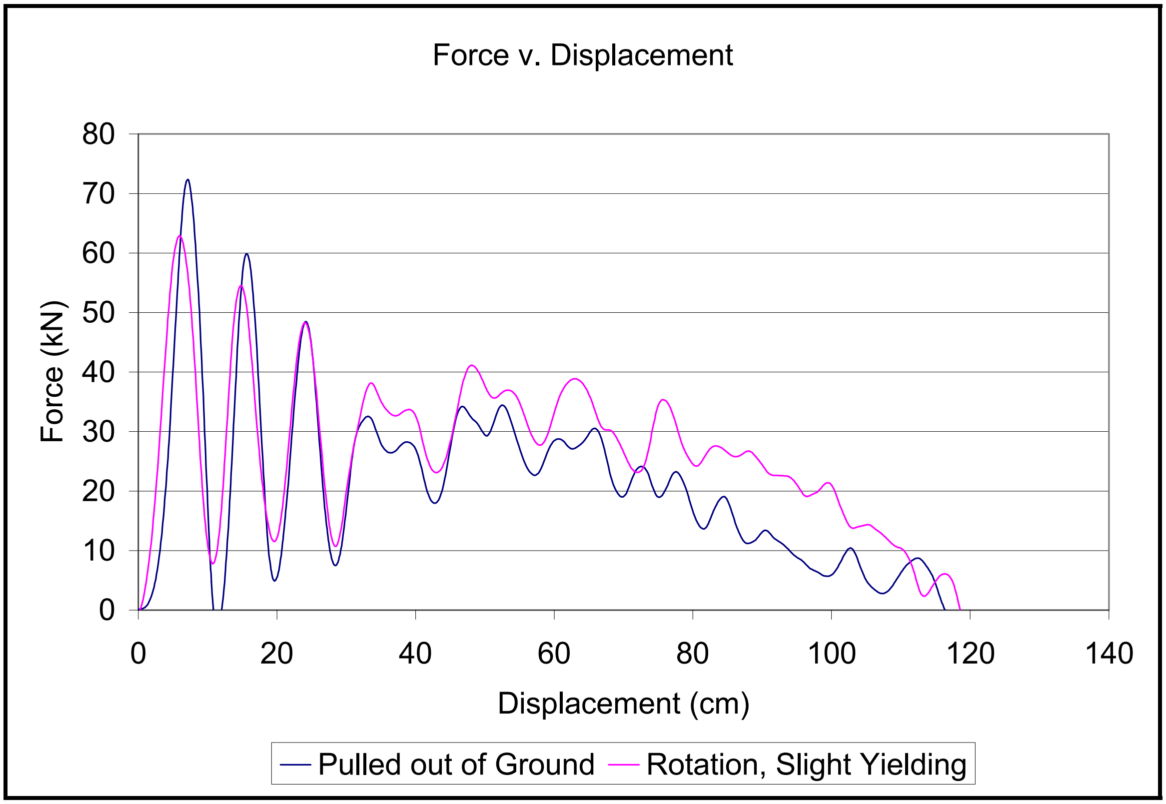

Figure 15. Comparison Force-Displacement Curves for Both Failure Modes

These two curves are typical for each failure mode and are especially important in the following analysis due to their initial force similarities and displacements. The linear decrease in the force is apparent in both curves, but the initiation of the force decrease in the post the pulled out of the ground can be seen to occur first. The area under the curve is then integrated to calculate the energy dissipated as shown in Figure 16.

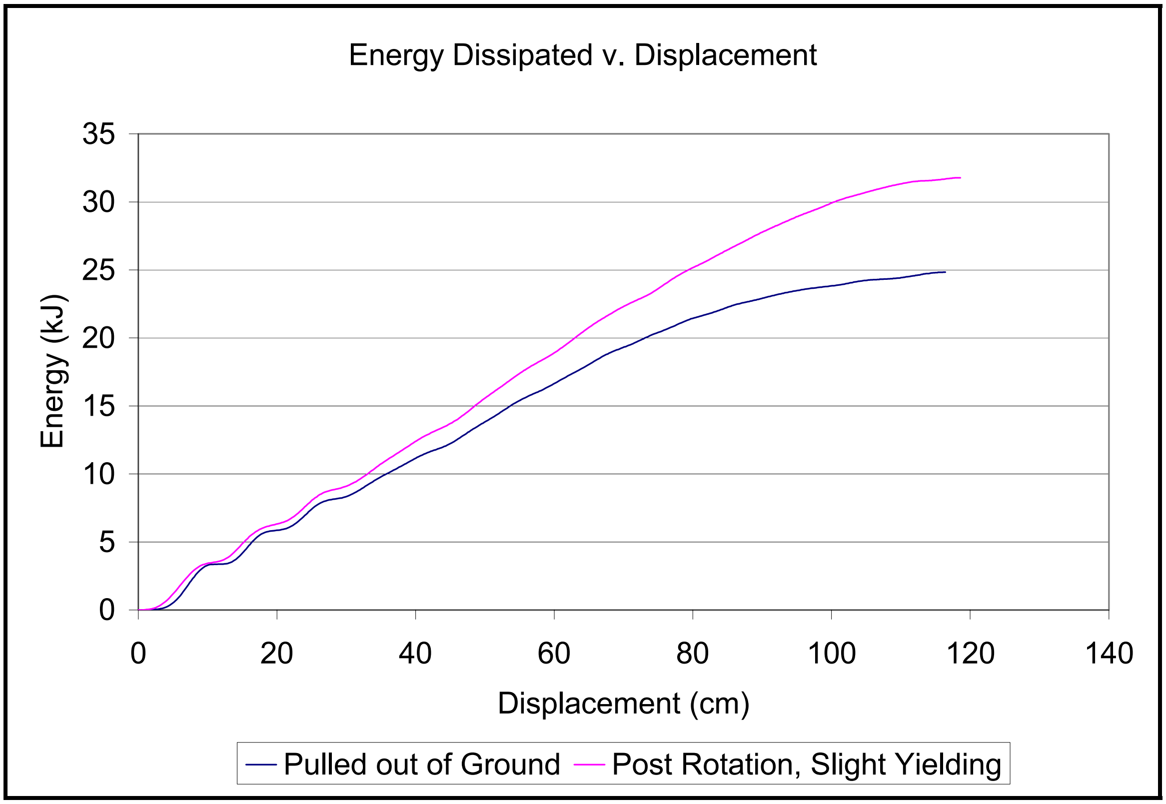

Figure 16. Comparison Plot of Energy Dissipated During Impact

The significance of the post pulling out of the ground is now apparent. More energy is dissipated during an impact as the post pivots in the ground causing it to fail. Pulling the post out of the ground requires less force as evident previously and as an end result more energy will be kept in the bogie system.

6. POST-SOIL INTERACTION PARAMETERS

One purpose of analyzing the forces and energy dissipated during the impact test is to quantify the post-soil interaction parameters for their implementation into computer simulation modeling. As stated previously, the post-soil interaction parameters are of great interest for their use in dynamic computer modeling of the newly developed MGS. This section discusses those parameters.

6.1 Post-Soil Interaction Parameters for W150x13.5 (W6x9) Posts in BARRIER VII

In determining the post-soil characteristics that can be used in dynamic computer modeling a maximum deflection of 59.7 cm (23.5 in.) was allowed. This deflection corresponds to a 10% discrepancy between the normal force exerted against the post and the force measured by the accelerometer and is also the maximum limit of displacement based on observations from full-scale crash tests (8).

BARRIER VII is a computer simulation code used extensively in the roadside safety community to model longitudinal barriers (9,10), and has been shown to be accurate in simulating a longitudinal barrier. BARRIER VII has also been used and accepted by the Federal Highway Administration (FWHA) in lieu of full-scale testing and is suggested for use in NCHRP Report 350 (11,12).

Pertinent results from this study, to be used in BARRIER VII modeling, are the estimated initial stiffness and the estimated average force for the first 38.1-59.7 cm (15.0-23.5 in.) of dynamic displacement after the initial slope of the impact force. As stated previously, at 38.1-59.7 cm (15.0-23.5 in.) of displacement, the post is typically being separated from the guardrail based on observations from full-scale crash tests. The calculated parameters are listed in Table 8.

Table 8a. Dynamic Properties of Post-Soil Interaction - Metric

Bogie Test No.	Impact Speed	Embedment Depth	Estimated Average Force[1] 381 mm dynamic deflection	Estimated Average Force[1] 597 mm dynamic deflection	Estimated Initial Stiffness[2]
	m/s	mm	kN	kN	kN/mm
NPGB-1	8.94	1092	28.98	30.63	0.783
NPGB-3	8.94	1092	25.57	26.35	0.813
Average	**8.9**	**1092**	**27.3**	**28.5**	**0.798**
NPGB-2	9.39	1016	27.27	29.93	0.661
NPGB-4	8.94	1016	28.73	29.30	0.950
NPGB-9	9.28	1016	28.14	28.31	1.059
NPGB-10	9.61	1016	29.99	31.47	1.053
Average	**9.3**	**1016**	**28.5**	**29.8**	**0.931**
NPGB-5	8.94	940	24.85	26.95	0.724
NPGB-7	8.81	940	23.13	24.04	1.161
NPGB-8	9.25	940	26.38	27.01	1.006
Average	**9.0**	**940**	**24.8**	**26.0**	**0.964**
NPGB-6	9.16	864	24.63	24.79	1.216

1 – Determined after initial slope.
2 – Determined using initial peak force and deflection as reported in Table 7.

Table 8b. Dynamic Properties of Post-Soil Interaction - English

Bogie Test No.	Impact Speed	Embedment Depth	Estimated Average Force[1] 15 in. dynamic deflection	Estimated Average Force[1] 23.5 in. dynamic deflection	Estimated Initial Stiffness[2]
	mph	in.	kips	kips	kips/in.
NPGB-1	20.00	43	6.51	6.89	4.47
NPGB-3	20.00	43	5.75	5.92	4.65
Average	**20**	**43**	**6.1**	**6.4**	**4.56**
NPGB-2	21.00	40	6.13	6.73	3.77
NPGB-4	20.00	40	6.46	6.59	5.42
NPGB-9	20.75	40	6.36	6.33	6.04
NPGB-10	21.50	40	6.74	7.07	6.02
Average	**20.8**	**40**	**6.4**	**6.7**	**5.31**
NPGB-5	20.00	37	5.59	6.06	4.13
NPGB-7	19.70	37	5.20	5.40	6.63
NPGB-8	20.70	37	5.93	6.07	5.75
Average	**20.1**	**37**	**5.6**	**5.8**	**5.50**
NPGB-6	20.50	34	5.54	5.57	6.92

1 – Determined after initial slope.
2 – Determined using initial peak force and deflection as reported in Table 7.

6.2 Post-Soil Behavior for W152x23.8 (W6x16) Posts

Although the tests were performed primarily to help determine the embedment depth for the Midwest Guardrail System, which uses W150x13.5 (W6x9) wide flanged posts, it is also important to realize that post-soil interaction for W152x23.8 (W6x16) posts has been obtained. The situation may arise in a future roadside barrier project where a stiffer post is required. This data can then be analyzed to provide useful post-soil parameters of a W152x23.8 (W6x16) post. The failure mode, force and energy results of the W152x23.8 (W6x16) post have been previously discussed in Section 5.

6.3 Other Options for the Post-Soil Interaction Parameters

Additionally, the data gathered in this project would be suitable for validating soil material models in nonlinear finite element analysis, such as in using LS-DYNA.

7. CONCLUSIONS AND RECOMMENDATIONS

Dynamic impact testing of W152x23.8 (W6x16) steel posts at various embedment depths has been detailed and the results stated. The results are consistent within each group of tests as can be seen by the near equal profile of the force-deflection curves. The soil used conformed to AASHTO M 147-65 Gradation "B" specifications.

Failure of the post was dependent upon embedment depth. In tests where the embedment depth was 101.6 cm (40 in.) or deeper, the soil failed with occasions of slight yielding within the post. When the embedment depth was 93.98 cm (37 in.) or less, the post pulled out of the ground.

There were measurable differences in the impact forces between the two modes of failure. For the initial 60 cm (23.6 in.) of displacement, the force-deflection curves for the two failure modes were very similar. At 60 cm (23.6 in.), for the posts that pulled out of the ground, the force levels began to fade in a linear manner. While for the posts which only rotated in the soil, a nearly level force-deflection curve was maintained for 80 cm (31.5 in.) after which it decreased. As a result of measurable differences in the impact forces, the amount of energy dissipated also differed. Posts that failed by rotating in the soil dissipated more energy than posts that initially rotated but eventually pulled out of the ground.

Based on the results presented herein, it appears that the 101.6 cm (40 in.) embedment depth is the depth of choice for the Midwest Guardrail System (MGS). The force levels and energy absorbed at an embedment depth of 101.6 (40 in.) was comparable to the current W-Beam guardrail system standard embedment depth of 109.2

(43 in.). Force levels and energy absorption were significantly reduced when the embedment depth was reduced further to 94 cm (37 inches).

Since the MGS raises the guardrail height, this study indicates that this new height can be accomplished by simply reducing the embedment depth to 101.2 cm (40 in.) while using the same post that is currently in use by most states. It is critical, however, that full-scale crash testing be performed before specifying this new embedment depth recommendation. It is widely known that the behavior of a post during a full-scale impact can be drastically different than the behavior during a simple strong-axis bogie test.

Additionally, the data gathered in this report should prove useful for various barrier simulation studies, including those using Barrier VII and LS-DYNA.

8. REFERENCES

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Appendix A

A.1 Test Summary Information

A summary sheet for each test is provided in this section. Summary sheets include acceleration, velocity, and displacement versus time plots, as well as force and energy versus deflection plots.

Table 9. Post Testing Summary

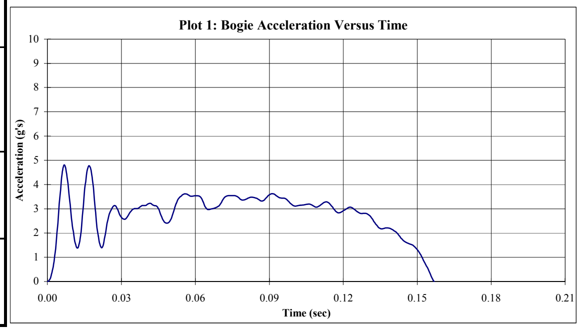
NPGB Test Parameters
NPG: Non-Proprietary Guardrail
Test: Strong Axis Impact at 0 degrees
Accelerometer: EDR-3 Data
Bogie Weight: 2,237 lbs (1014 kg)
Bumper Height: 24.8 in. (630 mm)
Posts: W6x16 (W152x23.8) Steel
Post Length: 72 in. (1829 mm)
Soil: 135 lb/ft^3 (2163 kg/m^3) NCHRP 350 (AASHTO 147-65 (1990) Grade B)

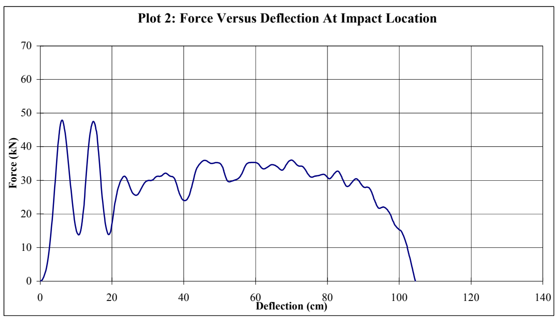
Test No.	**Velocity**		**Embedment Depth**		**Moisture Content**	**Figure Number**
	mph	m/s	inches	cm	%	
NPGB-1	20.00	8.94	43	109.22	4.5	Figure 17
NPGB-2	21.00	9.39	40	101.60	4.8	Figure 18
NPGB-3	20.00	8.94	43	109.22	4.9	Figure 19
NPGB-4	20.00	8.94	40	101.60	50	Figure 20
NPGB-5	20.00	8.94	37	93.98	4.8	Figure 21
NPGB-6	20.50	9.16	34	86.36	5.7	Figure 22
NPGB-7	19.70	8.81	37	93.98	-NA-	Figure 23
NPGB-8	20.70	9.25	37	93.98	-NA-	Figure 24
NPGB-9	20.75	9.28	40	101.60	-NA-	Figure 25
NPGB-10	21.50	9.61	40	101.60	-NA-	Figure 26

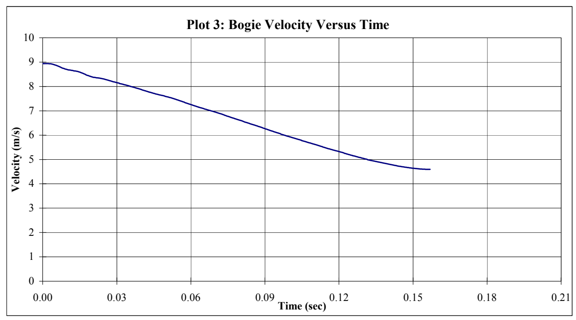
Midwest Roadside Safety Facility

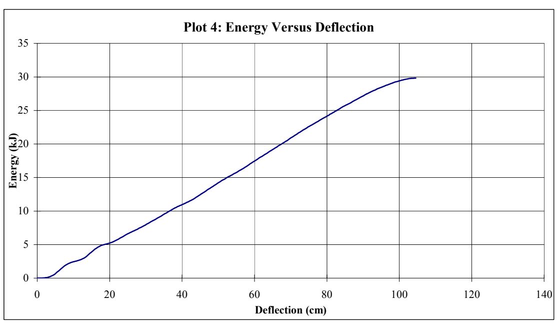
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees		
Test Number:	NPGB-1		
Test Date:	1-Jun-2001		
Failure Type:	Post Rotation, Slight Yielding		
Post Properties			
Post Type:	Steel		
Post Size:	W152x23.8 metric	W6x16	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	109.2 cm	(43.0 in)	
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	4.5%		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	2162 kg/m^3	(135 pcf)	
Bogie Properties			
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)
Impact Location:	63.0 cm	(24.8 in)	above groundline
Bogie Mass:	1015 kg	(2237 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-digital and ecam		









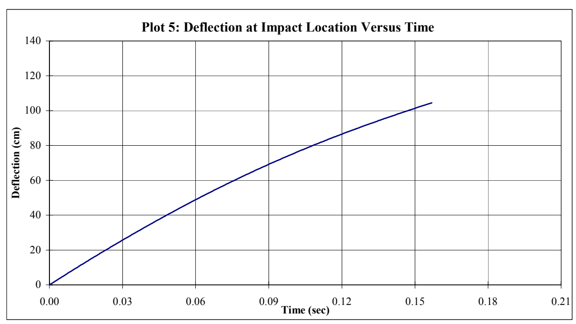


Figure 17. Results of NPGB-1

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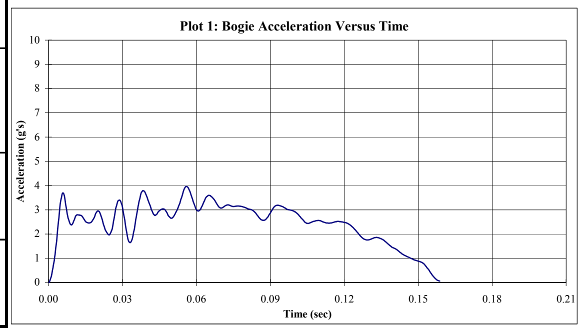
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees		
Test Number:	NPGB-2		
Test Date:	1-Jun-2001		
Failure Type:	Post Rotation		
Post Properties			
Post Type:	Steel		
Post Size:	W152x23.8 metric	W6x16	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	101.6 cm	(40.0 in)	
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	4.8%		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	2162 kg/m^3	(135 pcf)	
Bogie Properties			
Impact Velocity:	9.4 m/s	(21.0 mph)	(30.8 fps)
Impact Location:	63.0 cm	(24.8 in)	above groundline
Bogie Mass:	1015 kg	(2237 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-digital and ecam		



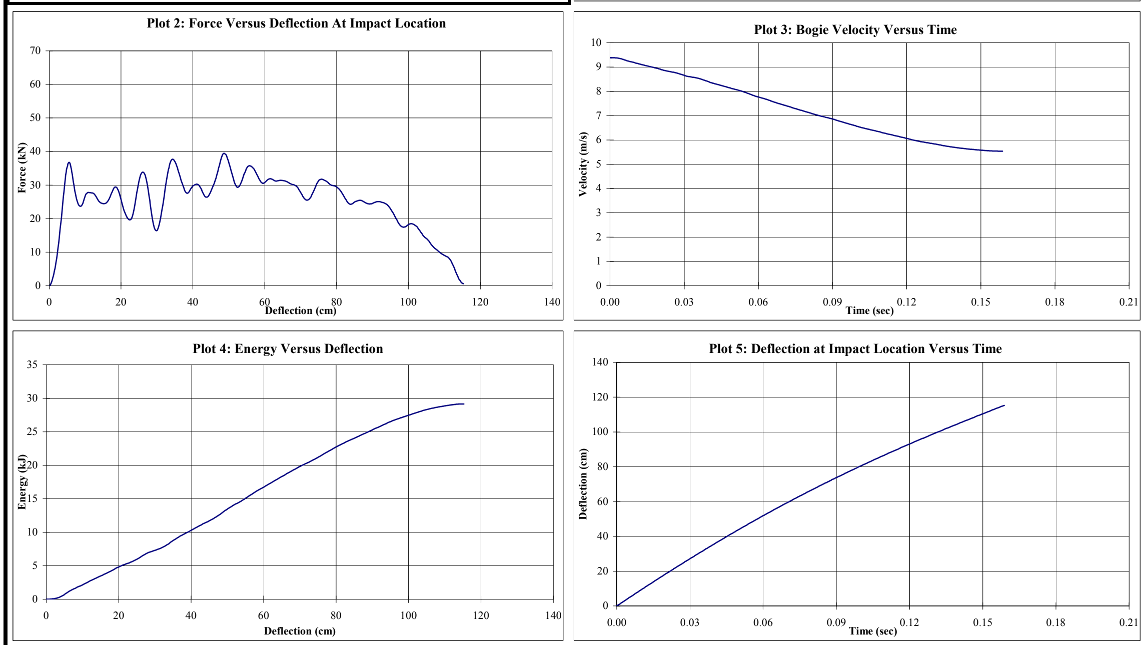
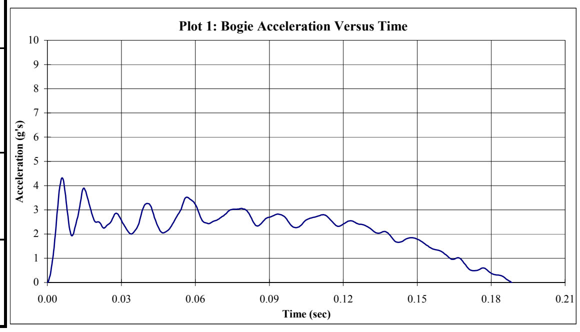


Figure 18. Results of NPGB-2

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees		
Test Number:	NPGB-3		
Test Date:	1-Jun-2001		
Failure Type:	Post Rotation, Slight Yielding		
Post Properties			
Post Type:	Steel		
Post Size:	W152x23.8 metric	W6x16	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	109.2 cm	(43.0 in)	
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	5.0%		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	2162 kg/m^3	(135 pcf)	
Bogie Properties			
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)
Impact Location:	63.0 cm	(24.8 in)	above groundline
Bogie Mass:	1015 kg	(2237 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-digital and ecam		



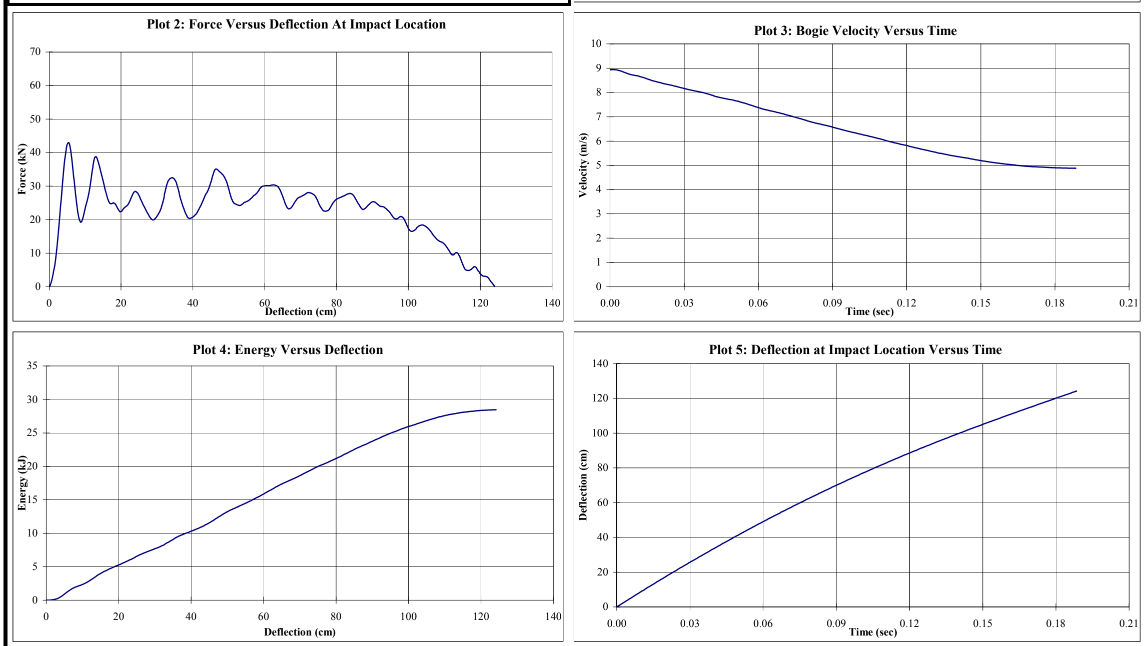
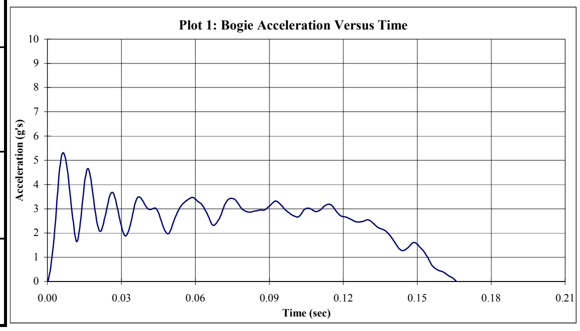


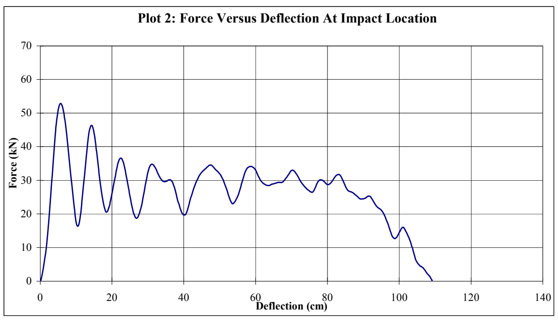
Figure 19. Results of NPGB-3

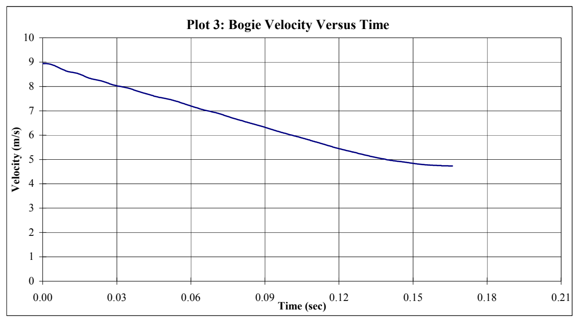
Midwest Roadside Safety Facility

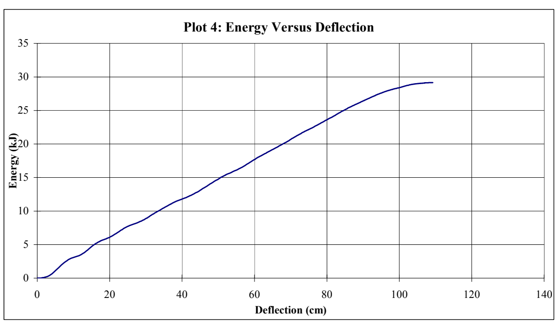
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees		
Test Number:	NPGB-4		
Test Date:	1-Jun-2001		
Failure Type:	Post Rotation		
Post Properties			
Post Type:	Steel		
Post Size:	W152x23.8 metric	W6x16	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	101.6 cm	(40.0 in)	
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	5.0%		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	2162 kg/m^3	(135 pcf)	
Bogie Properties			
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)
Impact Location:	63.0 cm	(24.8 in)	above groundline
Bogie Mass:	1015 kg	(2237 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-digital and ecam		









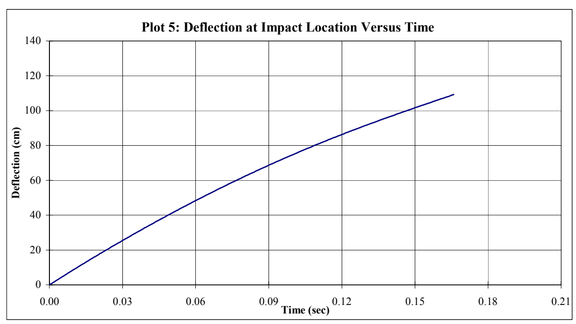


Figure 20. Results of NPGB-4

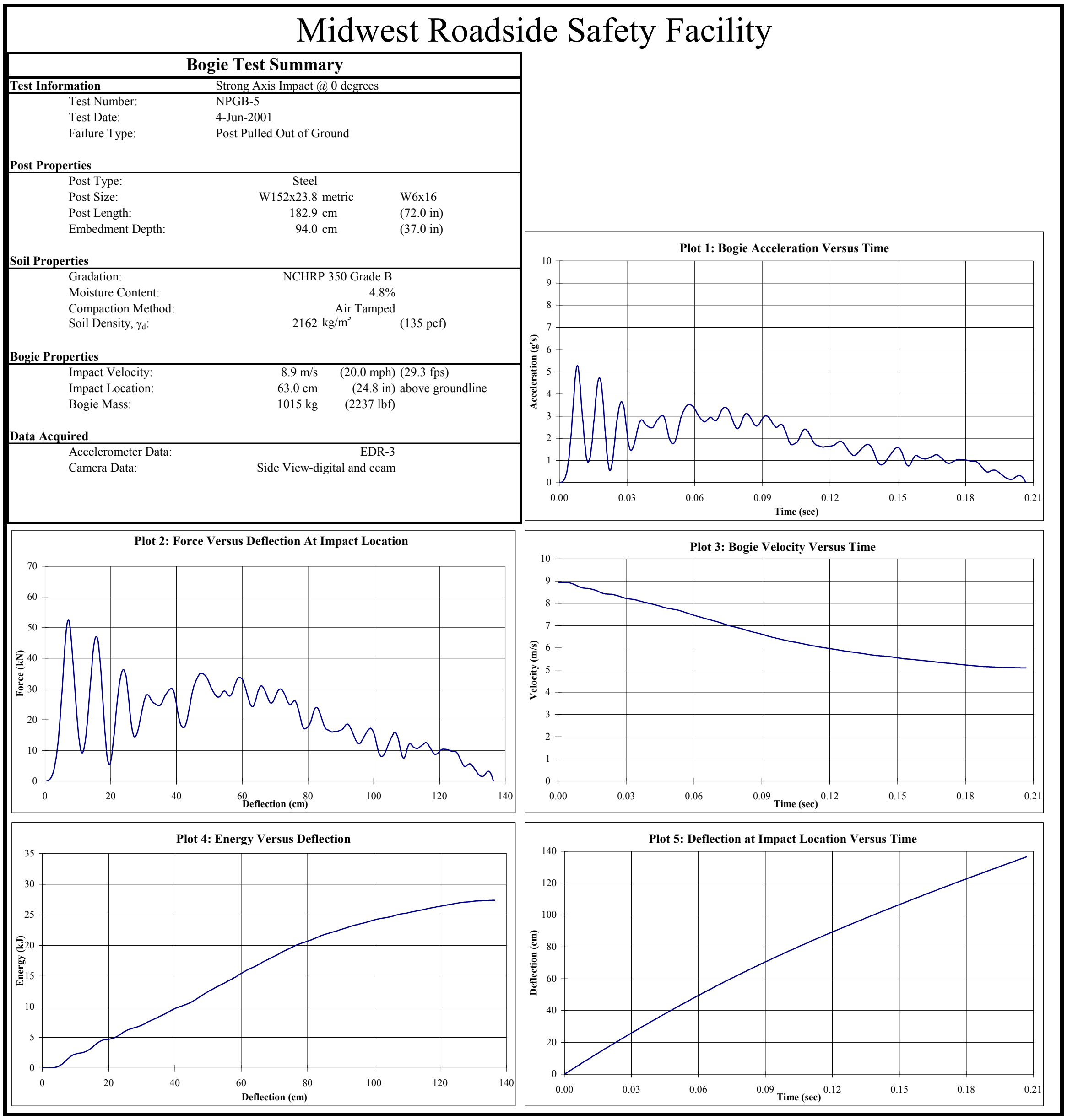
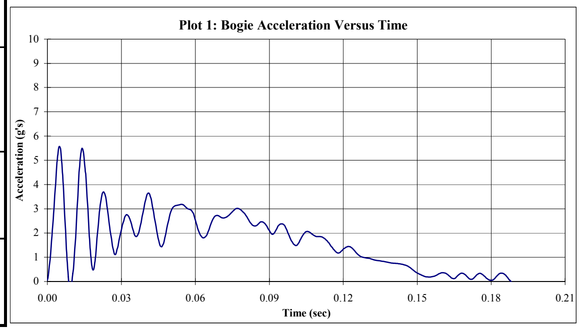


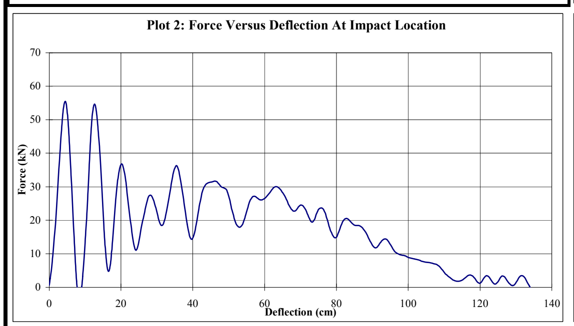
Figure 21. Results of NPGB-5

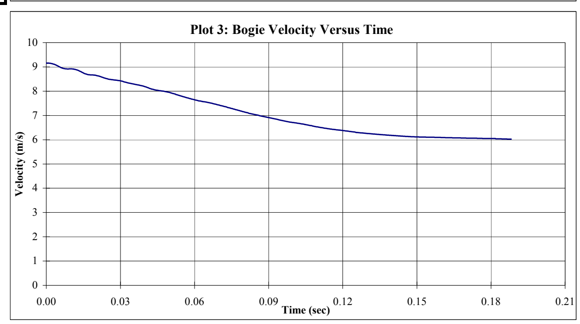
Midwest Roadside Safety Facility

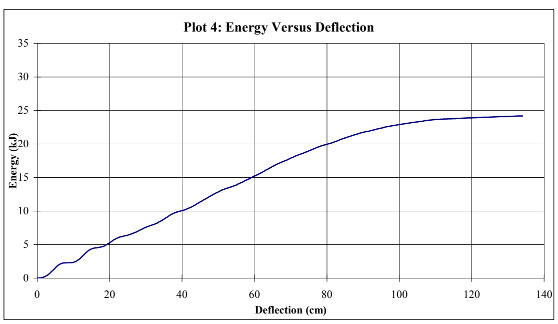
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees		
Test Number:	NPGB-6		
Test Date:	4-Jun-2001		
Failure Type:	Post Pulled Out of Ground		
Post Properties			
Post Type:	Steel		
Post Size:	W152x23.8 metric	W6x16	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	86.4 cm	(34.0 in)	
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	5.7%		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	2162 kg/m^3	(135 pcf)	
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.5 mph)	(30.1 fps)
Impact Location:	63.0 cm	(24.8 in)	above groundline
Bogie Mass:	1015 kg	(2237 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-digital and ecam		









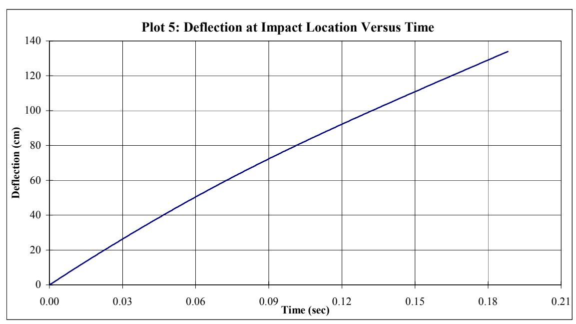
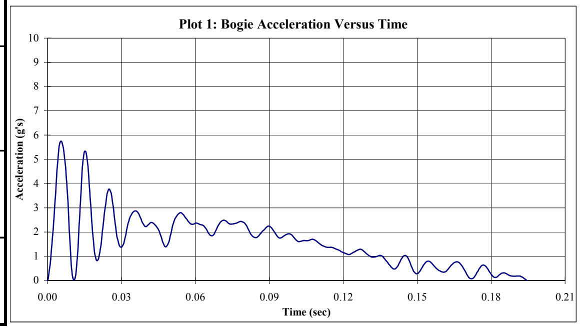


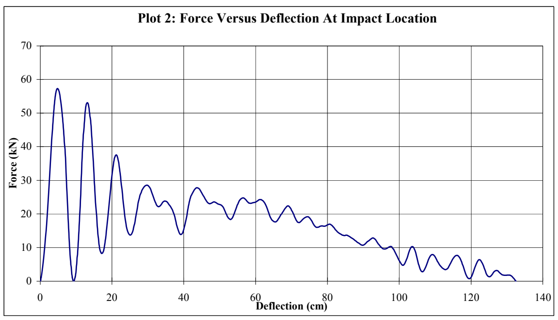
Figure 22. Results of NPGB-6

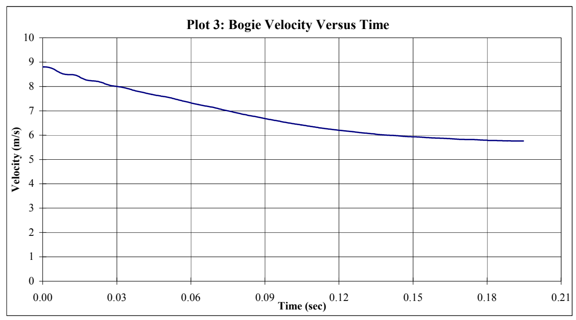
Midwest Roadside Safety Facility

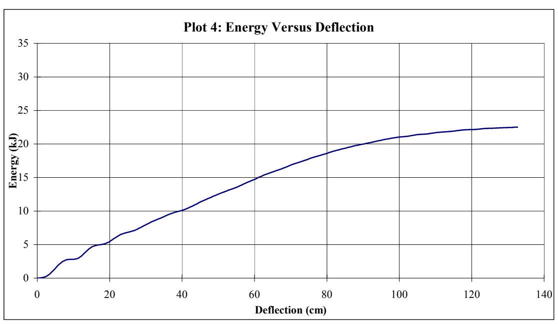
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees		
Test Number:	NPGB-7		
Test Date:	7-Jun-2001		
Failure Type:	Post Pulled Out of Ground		
Post Properties			
Post Type:	Steel		
Post Size:	W152x23.8 metric	W6x16	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	94.0 cm	(37.0 in)	
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	2162 kg/m^3	(135 pcf)	
Bogie Properties			
Impact Velocity:	8.8 m/s	(19.7 mph)	(28.9 fps)
Impact Location:	63.0 cm	(24.8 in)	above groundline
Bogie Mass:	1015 kg	(2237 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-digital and ecam		









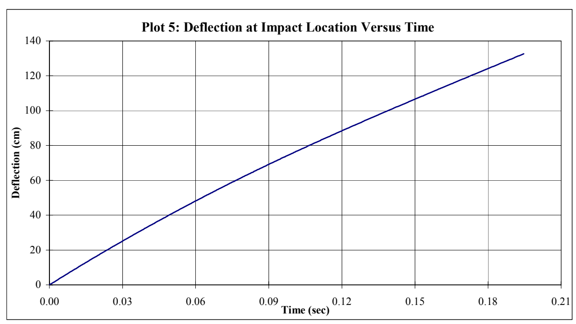
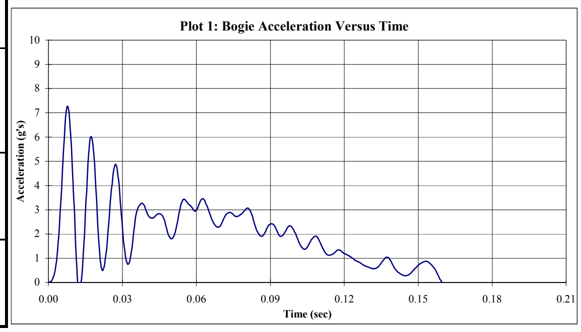


Figure 23. Results of NPGB-7

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees		
Test Number:	NPGB-8		
Test Date:	7-Jun-2001		
Failure Type:	Post Pulled Out of Ground		
Post Properties			
Post Type:	Steel		
Post Size:	W152x23.8 metric	W6x16	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	94.0 cm	(37.0 in)	
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	2162 kg/m^3	(135 pcf)	
Bogie Properties			
Impact Velocity:	9.3 m/s	(20.7 mph)	(30.4 fps)
Impact Location:	63.0 cm	(24.8 in)	above groundline
Bogie Mass:	1015 kg	(2237 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-digital and ecam		



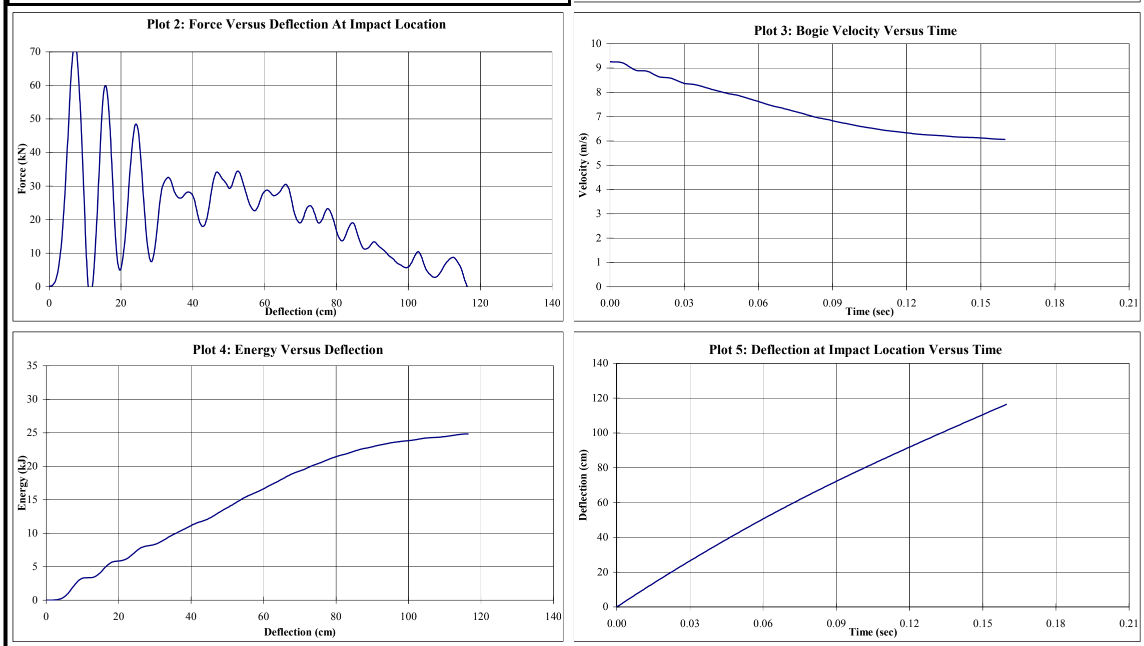


Figure 24. Results of NPGB-8

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information — Strong Axis Impact @ 0 degrees

Test Number:	NPGB-9
Test Date:	7-Jun-2001
Failure Type:	Post Rotation, Slight Yielding

Post Properties

Post Type:	Steel	
Post Size:	W152x23.8 metric	W6x16
Post Length:	182.9 cm	(72.0 in)
Embedment Depth:	101.6 cm	(40.0 in)

Soil Properties

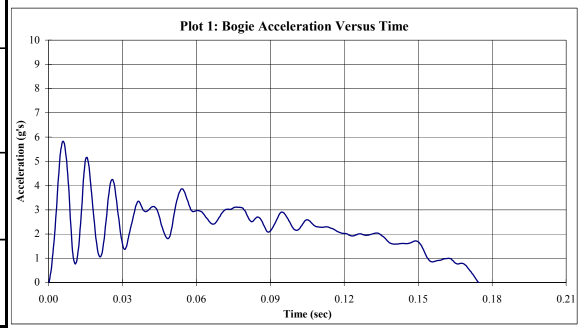
Gradation:	NCHRP 350 Grade B	
Moisture Content:	NA	
Compaction Method:	Air Tamped	
Soil Density, γ_d:	2162 kg/m^3	(135 pcf)

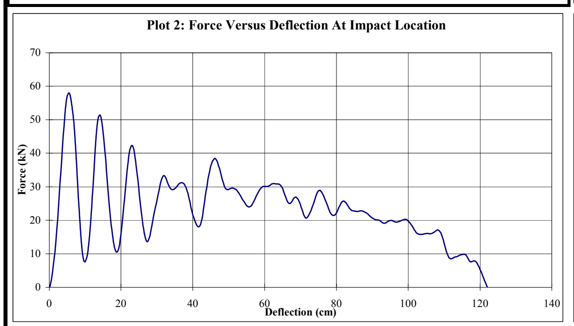
Bogie Properties

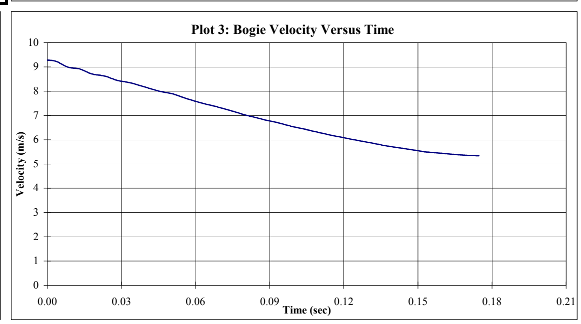
Impact Velocity:	9.3 m/s	(20.8 mph)	(30.4 fps)
Impact Location:	63.0 cm	(24.8 in)	above groundline
Bogie Mass:	1015 kg	(2237 lbf)	

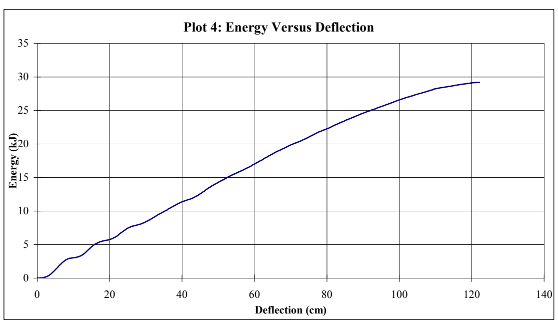
Data Acquired

Accelerometer Data:	EDR-3
Camera Data:	Side View-digital and ecam









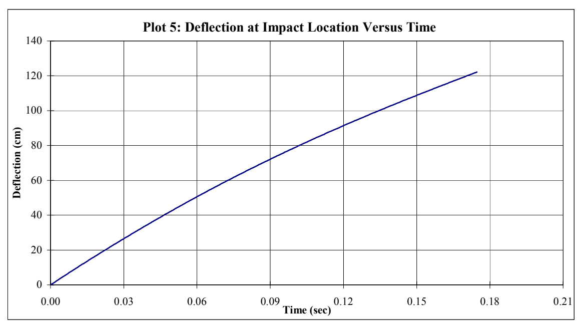
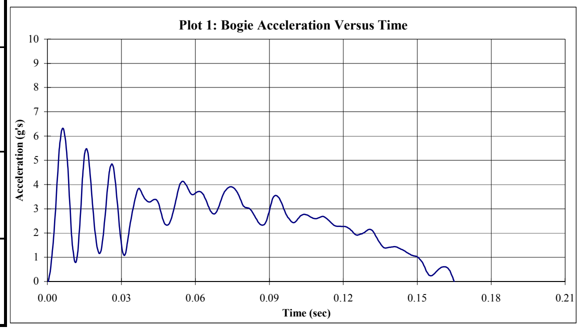


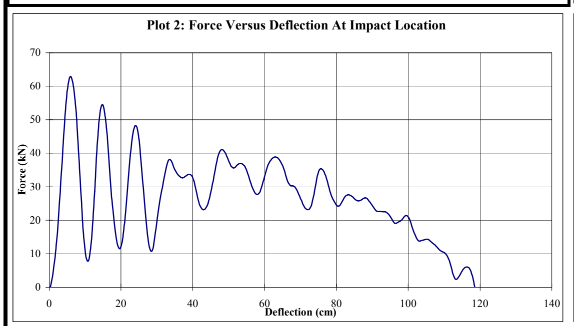
Figure 25. Results of NPGB-9

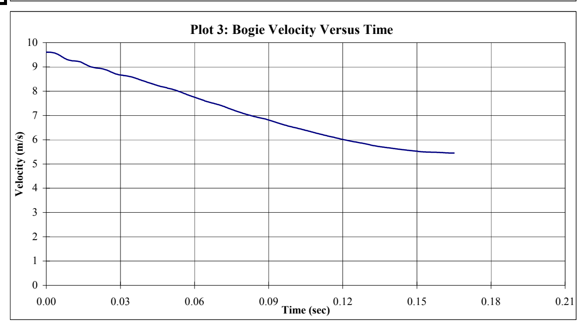
Midwest Roadside Safety Facility

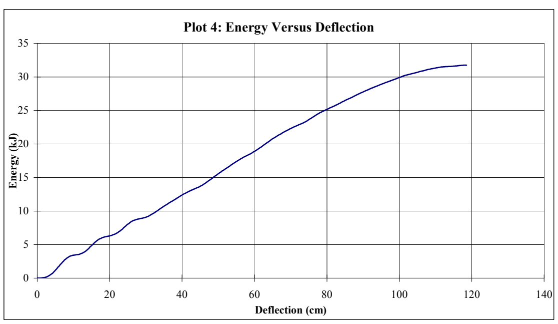
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees		
Test Number:	NPGB-10		
Test Date:	7-Jun-2001		
Failure Type:	Post Rotation, Slight Yielding		
Post Properties			
Post Type:	Steel		
Post Size:	W152x23.8 metric	W6x16	
Post Length:	182.9 cm	(72.0 in)	
Embedment Depth:	101.6 cm	(40.0 in)	
Soil Properties			
Gradation:	NCHRP 350 Grade B		
Moisture Content:	NA		
Compaction Method:	Air Tamped		
Soil Density, γ_d:	2162 kg/m^3	(135 pcf)	
Bogie Properties			
Impact Velocity:	9.6 m/s	(21.5 mph)	(31.5 fps)
Impact Location:	63.0 cm	(24.8 in)	above groundline
Bogie Mass:	1015 kg	(2237 lbf)	
Data Acquired			
Accelerometer Data:	EDR-3		
Camera Data:	Side View-digital and ecam		









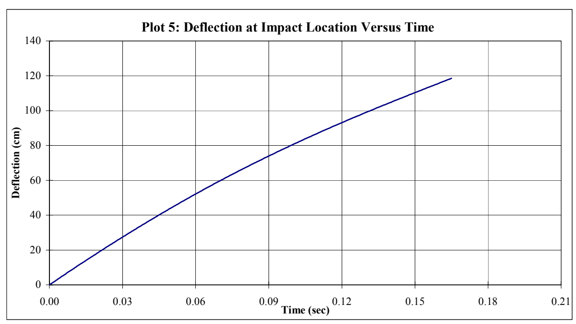


Figure 26. Results of NPGB-10