TESTING OF M203x9.7 (M8x6.5) AND

S76x8.5 (S3x5.7) STEEL POSTS -

POST COMPARISION STUDY FOR

THE CABLE MEDIAN BARRIER

Submitted by

Beau D. Kuipers, B.S.M.E., E.I.T.
Graduate Research Assistant

John D. Reid, Ph.D.
Associate Professor

MIDWEST ROADSIDE SAFETY FACILITY
University of Nebraska-Lincoln
527 Nebraska Hall
Lincoln, Nebraska 68588-0529
(402) 472-0965

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16. Abstract (Limit: 200 words)

Dynamic impact testing of M203x9.7 (M8x6.5) and S76x8.5 (S3x5.7) steel posts with various embedment conditions and impact angles has been detailed and the results stated. The results provided the basis for a comparison of the two posts. The soil used conformed to AASHTO M 147-65 Gradation "B" specifications.

Post type and embedment depth played an important role in the amount of energy dissipated during the impacts. For both angled and head-on impacts of similar nature, in soil and in a concrete sleeve, the M203x9.7 (M8x6.5) steel post was able to dissipate more energy than the S76x8.5 (S3x5.7) steel post with soil plate attached.

Based on the results presented herein, the M203x9.7 (M8x6.5) with a 106.68 cm (42 in.) embedment depth should be considered for new cable guardrail systems. The force levels and energy absorbed at an embedment depth of 106.68 (42 in.) were greater than the current S76.8.5 (S3x5.7) post with standard embedment depth of 76.20 cm (30 in.). The M-post is stronger in the strong axis and weaker in the weak axis compared to the S-post, both believed desirable attributes for this application.

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1. INTRODUCTION

1.1 Background

From December 2002 through May 2003, the Midwest Roadside Safety Facility (MwRSF) conducted bogie testing of M203x9.7 (M8x6.5) and S76x8.5 (S3x5.7) steel posts. The tests were conducted to gain an understanding of the posts dynamic impact behavior at varying angles and embedment conditions. The results provide the performance properties necessary to evaluate the M203x9.7 (M8x6.5) post for possible replacement of the S76x8.5 (S3x5.7) posts in cable median barrier designs on new construction projects in the future.

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 significantly affect how much energy is absorbed by a post in a guardrail system. If a post is not allowed to rotate in the soil sufficiently before yielding 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).

1.2 Objective

The objective of the research project was to determine the dynamic impact properties of the M203x9.7 (M8x6.5) steel post at various embedment depths and impact angles for comparison to the S76x8.5 (S3x5.7) steel post at standard embedment conditions. Results of this research are used for (1) determining the appropriate post and installation specifications for the cable median barrier; and (2) input for BARRIER VII and LS-DYNA simulation models.

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 June 2003, Kuipers et al. (2) referenced and updated these previous post-soil interaction studies completed from 1961 through 2002. Researchers at the MwRSF then furthered the understanding of the post-soil interaction in frontal impacts using W152.4x23.8 (W6x16) wide-flanged steel posts. From their study they were able to quantify the dynamic interaction for use in BARRIER VII simulation models and provide data for potential test cases for simulating soil material in LS-DYNA. The results of the dynamic testing study are summarized in Table 1.

Table 1a. Dynamic Properties of Post-Soil Interaction – Metric (W152.4x23.8)

Bogie Test No.	Impact Speed	Embedment Depth	Estimated Average Force[1]		Estimated Initial Stiffness[2]
			381 mm dynamic deflection	597 mm dynamic deflection	
	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

Table 1b. Dynamic Properties of Post-Soil Interaction – English (W6x16)

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

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 the M203x9.7 (M8x6.5) and S76x8.5 (S3x5.7) steel 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 posts 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 installation conditions. The target impact conditions for the crash tests were a speed of 32 km/h (20 mph) and angles of 0.0°, 7.5°, 15.0°, and 30.0°, relative to the strong axis, at a height of 55.0 cm (21.65 in.) above the ground line. The scope of the physical testing is listed in Table 2.

Initially six crash tests, CMPB-1 through CMPB-6, were conducted with the posts embedded in a rigid concrete sleeve. This set of tests was conducted in the concrete sleeve to ensure post failure, from which data regarding the post properties during a dynamic impact could be determined. The next nine bogie crash tests, CMPB-7 through CMPB-15, were conducted with the posts embedded in standard National Cooperative Highway Research Program (NCHRP) Report 350 (3) strong soil. These tests were conducted to quantify the post-soil interaction during a dynamic impact. The methodology of the different tests will be described in a subsequent chapter.

The test results were analyzed, evaluated, and documented. Conclusions were then drawn that pertain to the behavior of the post under dynamic loading.

Table 2a. Scope of Physical Testing - Metric

Test No.	Post Size	Speed		Embedment Depth	Embedment Material	Impact
		km/h	m/s	cm		Angle*
CMPB-1	M203x9.7	35.6	9.88	93.98	Concrete Sleeve	0°
CMPB-2	M203x9.7	33.6	9.34	93.98	Concrete Sleeve	15°
CMPB-3	M203x9.7	33.0	9.16	93.98	Concrete Sleeve	30°
CMPB-4	S76x8.5	34.8	9.66	76.2	Concrete Sleeve	15°
CMPB-5	S76x8.5	33.3	9.25	76.2	Concrete Sleeve	30°
CMPB-6	S76x8.5	31.9	8.85	76.2	Concrete Sleeve	0°
CMPB-7	M203x9.7	31.9	8.85	91.44	NCHRP 350 Soil	0°
CMPB-8	M203x9.7	34.4	9.57	106.68	NCHRP 350 Soil	0°
CMPB-9	M203x9.7	34.4	9.57	121.92	NCHRP 350 Soil	0°
CMPB-10	M203x9.7	33.2	9.21	106.68	NCHRP 350 Soil	0°
CMPB-11	M203x9.7	34.8	9.66	106.68	NCHRP 350 Soil	15°
CMPB-12	M203x9.7	34.8	9.66	106.68	NCHRP 350 Soil	7.5°
CMPB-13	M203x9.7	33.5	9.30	91.44	NCHRP 350 Soil	7.5°
CMPB-14	S76x8.5	34.8	9.66	76.2	NCHRP 350 Soil	0°
CMPB-15	S76x8.5	32.3	8.99	76.2	NCHRP 350 Soil	7.5°

*****Angle Relative to Strong Axis Impact

Table 2b. Scope of Physical Testing - English

Test No.	Post Size	Speed		Embedment Depth	Embedment Material	Impact
		mph	f/s	inches		Angle*
CMPB-1	M8x6.5	22.1	32.41	37	Concrete Sleeve	0°
CMPB-2	M8x6.5	20.9	30.65	37	Concrete Sleeve	15°
CMPB-3	M8x6.5	20.5	30.07	37	Concrete Sleeve	30°
CMPB-4	S3x5.7	21.6	31.68	30	Concrete Sleeve	15°
CMPB-5	S3x5.7	20.7	30.36	30	Concrete Sleeve	30°
CMPB-6	S3x5.7	19.8	29.04	30	Concrete Sleeve	0°
CMPB-7	M8x6.5	19.8	29.04	36	NCHRP 350 Soil	0°
CMPB-8	M8x6.5	21.4	31.39	42	NCHRP 350 Soil	0°
CMPB-9	M8x6.5	21.4	31.39	48	NCHRP 350 Soil	0°
CMPB-10	M8x6.5	20.6	30.21	42	NCHRP 350 Soil	0°
CMPB-11	M8x6.5	21.6	31.68	42	NCHRP 350 Soil	15°
CMPB-12	M8x6.5	21.6	31.68	42	NCHRP 350 Soil	7.5°
CMPB-13	M8x6.5	20.8	30.51	36	NCHRP 350 Soil	7.5°
CMPB-14	S3x5.7	21.6	31.68	30	NCHRP 350 Soil	0°
CMPB-15	S3x5.7	20.1	29.48	30	NCHRP 350 Soil	7.5°

*****Angle Relative to Strong Axis Impact

4. SYSTEM DETAILS

4.1 The Posts

This section describes the two posts under study in detail.

4.1.1 M203x9.7 (M8x6.5) Steel Post

The first post under study was the M203x9.7 (M8x6.5) beam 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 3.429 mm (0.135 in.) while the thickness of the flanges are 4.801 mm (0.189 in.). The total length of the posts tested was 1803.4 mm (71 in.) with variable embedment depths in the range of 914.4-1219.2 mm (36-48 in.). Major cross-section dimensions are shown in Figure 1. Various material properties (4) for the post are provided in Table 3.

Table 3. Material Properties of M203x9.7 (M8x6.5) Post

ASTM Designation	Area, A	Flange Width, bf	Post Depth, d	Moment of Inertia, I_x	Section Modulus, S_x	Plastic Section Modulus, Z_x
	mm^2 (in^2)	mm (in)	mm (in)	mm^4 (in^4)	mm^3 (in^3)	mm^3 (in^3)
M203x9.7 (M8x6.5)	1238.7 (1.92)	57.91 (2.28)	203.2 8.0	$7.70x10^6$ (18.5)	$7.59x10^4$ (4.63)	$8.90x10^4$ (5.43)

4.1.2 S76x8.5 (S3x5.7) Steel Post

The second post under study was the S76x8.5 (S3x5.7) beam manufactured using galvanized ASTM A36 steel with a cross-section in accordance with the A6M standards. This post is used in the construction of a variety of roadside barriers such as the flexible system W-beam, semi-rigid system box beam guardrail systems and is currently the standard post used in three-strand cable median barrier systems. 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 4.318 mm (0.170 in.) while the thickness of the flanges are 6.604 mm (0.260 in.). The total length of the posts tested was 1600.2 mm (63 in.) with standard cable median barrier embedment depth of 762.0 mm (30 in.). Major cross-section dimensions are shown in Figure 1. Various material properties (4) for the post are provided in Table 4.

Table 4. Material Properties of S76x8.5 (S3x5.7) Post

ASTM Designation	Area, A	Flange Width, bf	Post Depth, d	Moment of Inertia, I_x	Section Modulus, S_x	Plastic Section Modulus, Z_x
	mm^2 (in^2)	mm (in)	mm (in)	mm^4 (in^4)	mm^3 (in^3)	mm^3 (in^3)
S76x8.5 (S3x5.7)	1071 (1.66)	59.18 (2.33)	76.2 3.00	$1.04x10^6$ (2.5)	$2.74x10^4$ (1.67)	$3.18x10^4$ (1.94)

A soil plate was welded to the bottom of the S76x8.5 (S3x5.7) post for all the tests. The thickness of the 203 mm x 610 mm (8 in. x 24 in.) steel plate was 6.4 mm (0.25 in) and was made of galvanized steel.

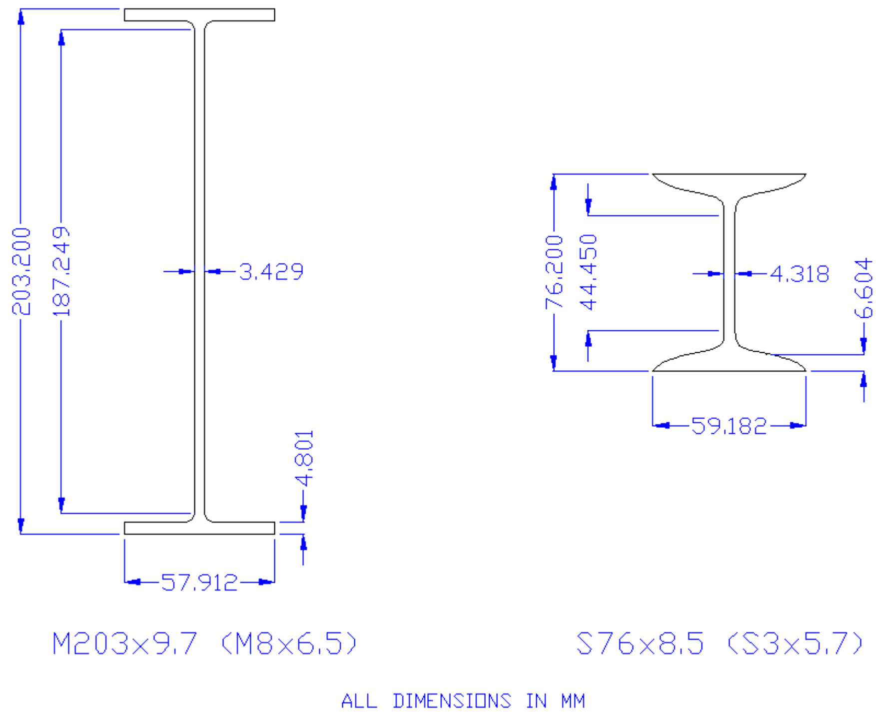


Figure 1. Major Cross-Section Dimensions of the Steel Posts

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, also referred to as standard NCHRP Report 350 strong soil.

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 by MwRSF under the direction of Dr. John Rohde, was used to impact the posts. An impact head, made of a 203 mm (8 in.) standard steel pipe, was mounted to the bogie at the height of 550 mm (21.65 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 613.7 kg (1353 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

One tri-axial piezo-resistive accelerometer system with a range of ± 200 G's was used to measure the acceleration in the longitudinal, lateral, and vertical and was mounted on the frame of the bogie near its center of gravity. The environmental shock and vibration sensor/recorder system, known as the Model EDR-4, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels.

The EDR-4 is a self-contained, user programmable acceleration sensor/recorder. During testing the EDR-4 was configured with 6 MB of RAM memory and was set to sample data at 10,000 Hz. A Butterworth low-pass filter with a –3dB cut-off frequency of 1500 Hz was used for anti-aliasing.

Although the accelerometer was located at the center of gravity and measured the acceleration of the bogie's center of gravity, the sampled data was used to approximate the bogie/post forces at the point of impact using Newton's Second Law.

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 left 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 direction of the bogie. 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

Two types of tests were conducted to obtain a complete understanding of the dynamic behavior of the post. This section discusses those two methodologies. The test parameters can be seen in Table 5.

Table 5. Test Parameters

CMPB Test Parameters
CMP: Cable Median Post
Test: Strong Axis Impact at Various Angles & Embedment Conditions
Accelerometer: EDR-4 Data
Bogie Weight: 613.7 kg (1,353 lbs)
Bumper Height: 55 cm (21.65 in.)
Posts: M230x9.7 (M8x6.5) Steel and S76x8.5 (S3x5.7) Steel
Post Length: 180.34 cm (71 in.) and 160 cm (63 in.), respectively

In all tests, a reverse cable tow and guide rail system was used to propel the test vehicle. The bogie was accelerated towards the post along the 30-meter (98.4 ft) long tracking system, which consisted of a steel pipe anchored 100 mm (3.94 in) above the tarmac. Rollers attached to the bogie straddled the pipe, and ensured the proper direction and position of the bogie. The tow cable was released just prior to impact, which allowed the bogie to be free of all external constraints. The bogie positioned on the guide rail can be seen in Figure 3.

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, recorded lateral, horizontal, and vertical acceleration data.

Figure 3. Bogie Positioned on the Guide Track

4.4.1 Posts in a Concrete Sleeve

For tests CMPB-1 through CMPB-6, a rectangular section was cut out in the tarmac to house the post. The section was lined with a tube, approximately 254 mm x 222.25 mm (10.0 in. x 8.75 in) and 10 mm (0.394 in.) thick, of mild steel to prevent the erosion of the concrete around the hole. The post was fitted into the steel lined section with a block of wood to keep it upright and rigidly hold the post against the casing. A steel plate was then placed between the post and the wood block to prevent the deformation of the wood by the post and ensure only post failure. An effort was also made to minimize the slop in the posts by inserting an additional steel plate or a piece of plywood to fill the gaps when the post is set at an angle. The post, with the wood block, fitted into the steel lining at the three different angles of attack is shown in Figure 4.

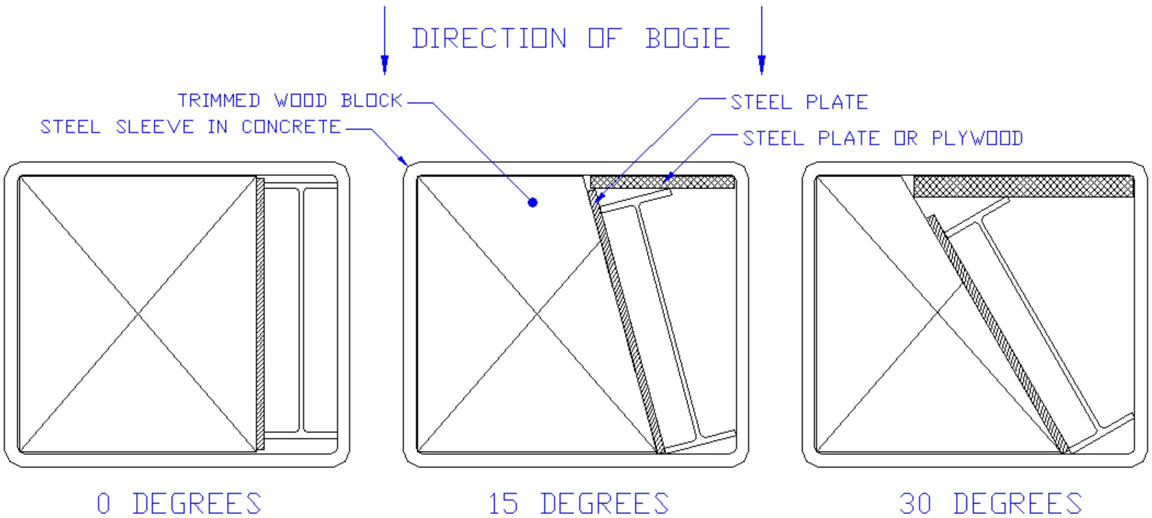


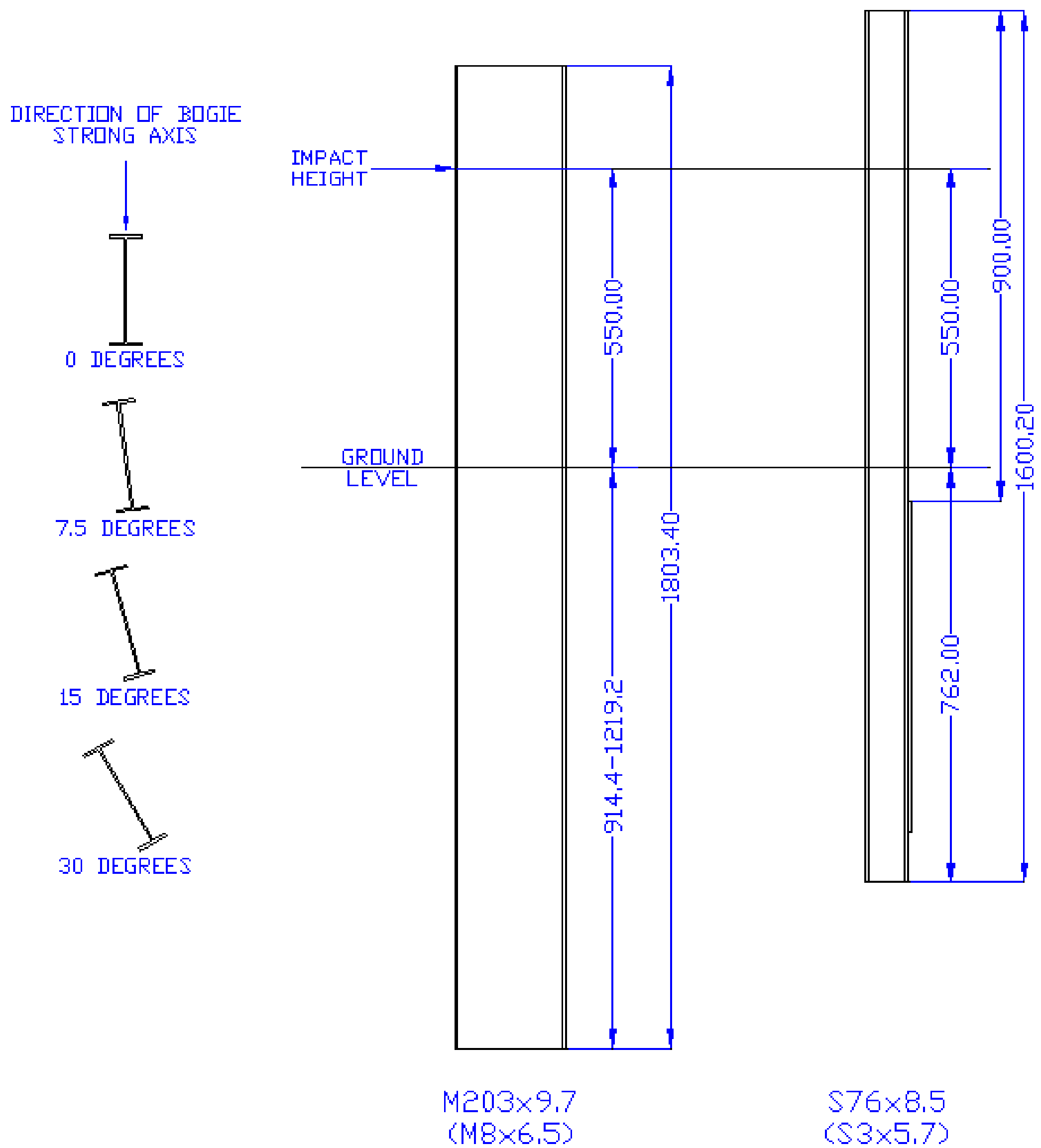
Figure 4. M203x9.7 (M8x6.5) Posts in a Concrete Sleeve Setup

The setup for the testing of the S76x8.5 (S3x5.7) posts in the concrete is very similar, but accommodations were made for the attached soil plate. The installation setup prior to test CMPB-4 can be seen in Figure 5. The addition of the neoprene was to prevent damage from the impact that may have affected the post properties subsequently determined.

Figure 5. Typical Post and Wood Block Setup for Tests CMPB-1 through CMPB-6

4.4.2 Posts in Soil

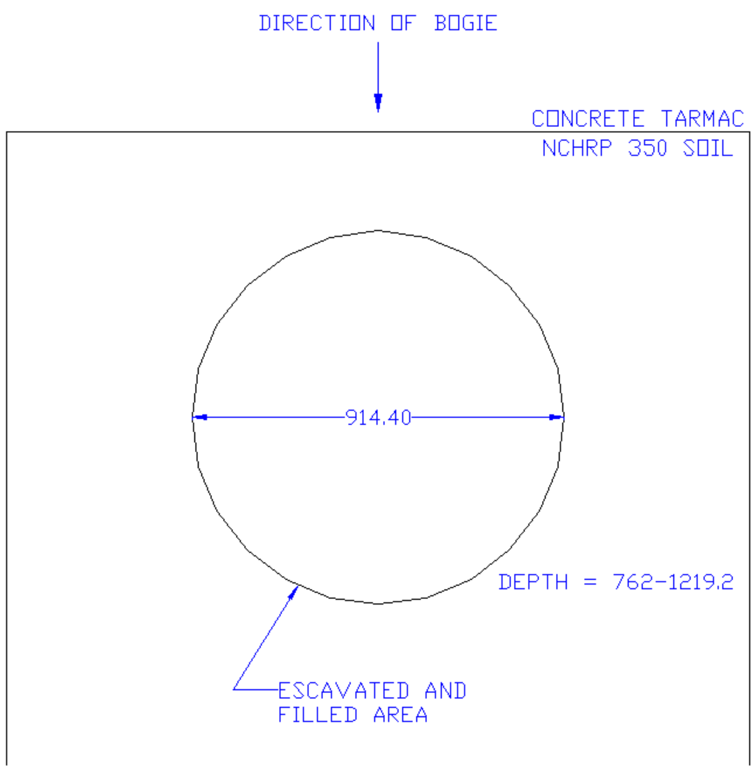
A total of 9 tests were carried out along and at angles to the strong axis of impact and at different embedment depths in standard NCHRP 350 soil. Impact of the post flanges perpendicular to the direction of motion of the bogie head is a strong axis impact; this also serves as the reference position from which the angled impact may be measured. Graphical representation of the impacts is shown in Figure 6.



(dimensions in mm)

Figure 6. Impact Location and Types

A plan view of the test setup and the post-testing pit is shown in Figure 7. The pit was located at a sufficient distance from the edge of the concrete apron so as not to interfere with the soil response during the impact.



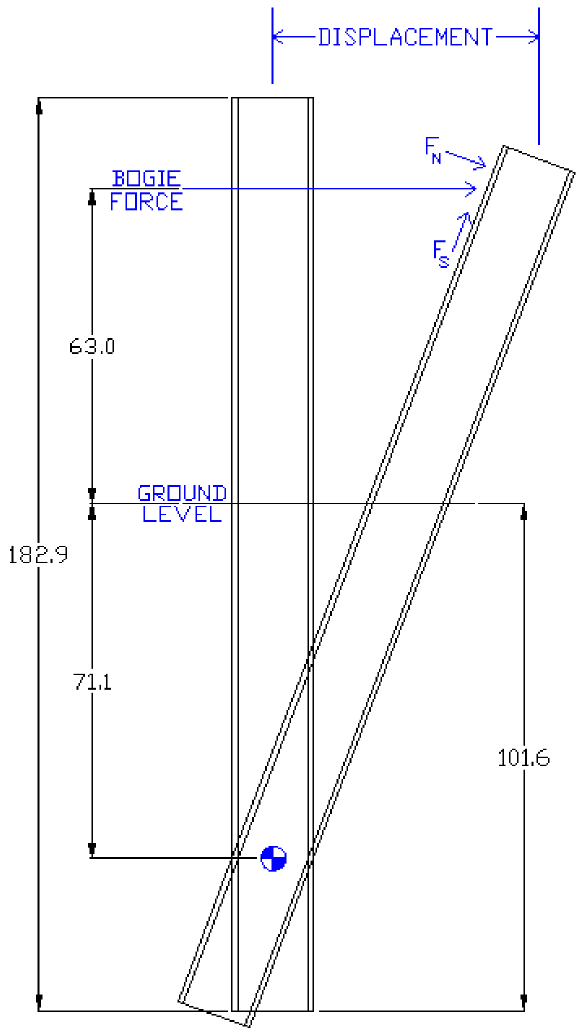
(dimensions in mm)

Figure 7. Plan View of the Post Testing Area

For the tests, a hole measuring 0.914 m (36 in.) in diameter and 0.762 to 1.219 m (30 to 48 in.) in depth was dug out in the test area. The hole was 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.

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 8.



(dimensions in cm)

Figure 8. Various Forces Acting on the Post in Soil and Their Orientations

It should also be noted that the location of post rotation is different for the two tests. The post in soil is known to rotate around a depth of 71.1 cm (28 in) (8), while the post in the mild steel sleeve in concrete was seen to rotate at the ground level.

In addition to the variation due to the changing angle of impact, the neoprene on the bogie head, used to minimize the local stress concentration at the point of impact, increases 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.

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

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

5.1 Results

The information 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 accelerometer data was processed for each test in order to obtain acceleration, velocity, and displacement curves, as well as force-deflection curves. This section discusses those results. Individual test results are provided in Appendix A.

5.1.1 Posts in Concrete

The first six bogie tests were conducted with the posts in concrete, as previously discussed. The objective of these tests was to determine the dynamic post behavior when the post undergoes major plastic deformation, which is the primary mode of failure in these tests. Tests CMPB-1 through CMPB-3 were conducted on the M203x9.7 (M8x6.5) steel post. Tests CMPB-4 through CMPB-6 were conducted on the S76x8.5 (S3x5.7) steel post. The data was grouped and plotted according to post type, while taking into account the impact angle. A summary of tests CMPB-1 through CMPB-6 is provided in Table 6 and Figures 9 and 10 are plots for CMPB-1 through CMPB-3 and tests CMPB-4 through CMPB-6, respectively.

Table 6a. Posts in Concrete, CMPB-1 through CMPB-6 – Metric

Test No.	Impact		Embedment Depth	Initial Peak Force		Total Energy	
	Velocity	Angle		Displacement	Force	Displacement	Energy
	m/s	degrees	cm	cm	kN	cm	kJ
M203x9.7 (M8x6.5) Post Tests							
CMPB-1	9.88	0	94.0	6.73	55.60	88.90	17.5
CMPB-2	9.34	15	94.0	4.93	23.89	89.66	10.1
CMPB-3	9.16	30	94.0	5.13	16.81	92.96	7.8
S76x8.5 (S3x5.7) Post Tests							
CMPB-4	9.66	15	76.2	5.00	21.00	86.87	8.7
CMPB-5	9.25	30	76.2	4.70	19.35	84.58	7.7
CMPB-6	8.85	0	76.2	4.75	26.96	88.39	12.1

Table 6b. Posts in Concrete, CMPB-1 through CMPB-6 – English

Test No.	Impact		Embedment Depth	Initial Peak Force		Total Energy	
	Velocity	Angle		Displacement	Force	Displacement	Energy
	mph	degrees	in	in	kips	in	kip-in
M203x9.7 (M8x6.5) Post Tests							
CMPB-1	22.1	0	37.0	2.65	12.50	35.0	154.5
CMPB-2	20.9	15	37.0	1.94	5.37	35.3	89.0
CMPB-3	20.5	30	37.0	2.02	3.78	36.6	69.0
S76x8.5 (S3x5.7) Post Tests							
CMPB-4	21.6	15	30.0	1.97	4.72	34.2	77.2
CMPB-5	20.7	30	30.0	1.85	4.35	33.3	68.0
CMPB-6	19.8	0	30.0	1.87	6.06	34.8	106.9

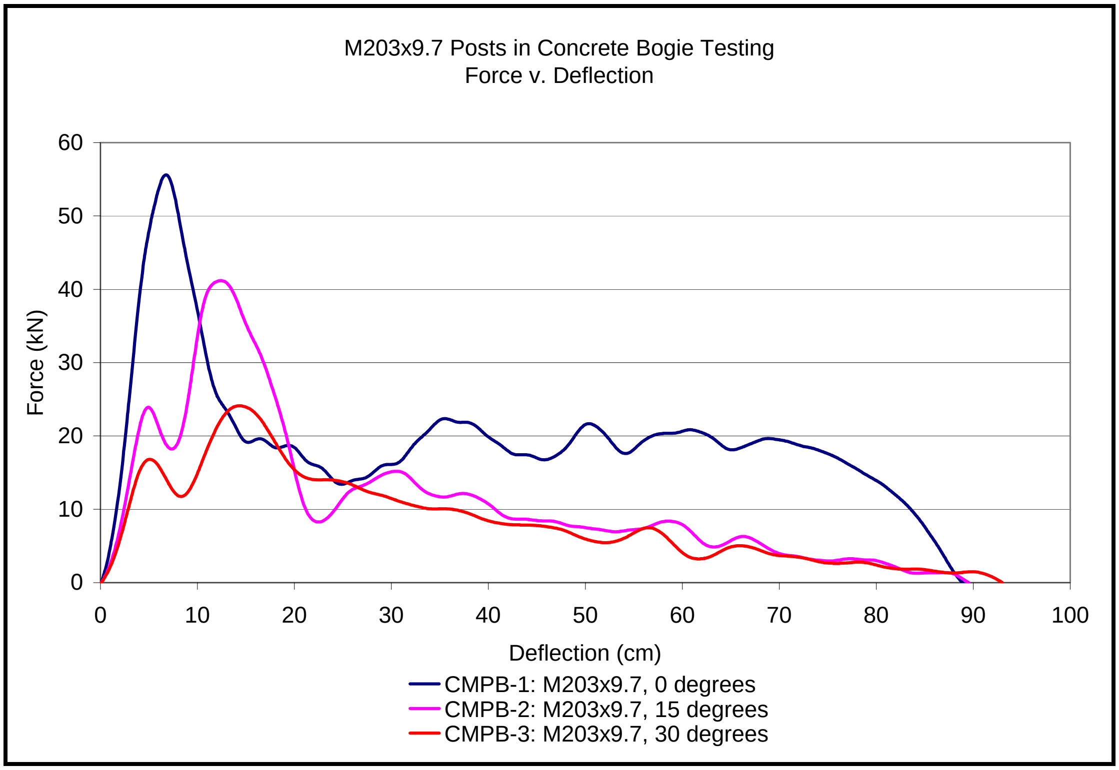


Figure 9a. Force-Deflection Curves for CMPB-1, 2, and 3 – Metric

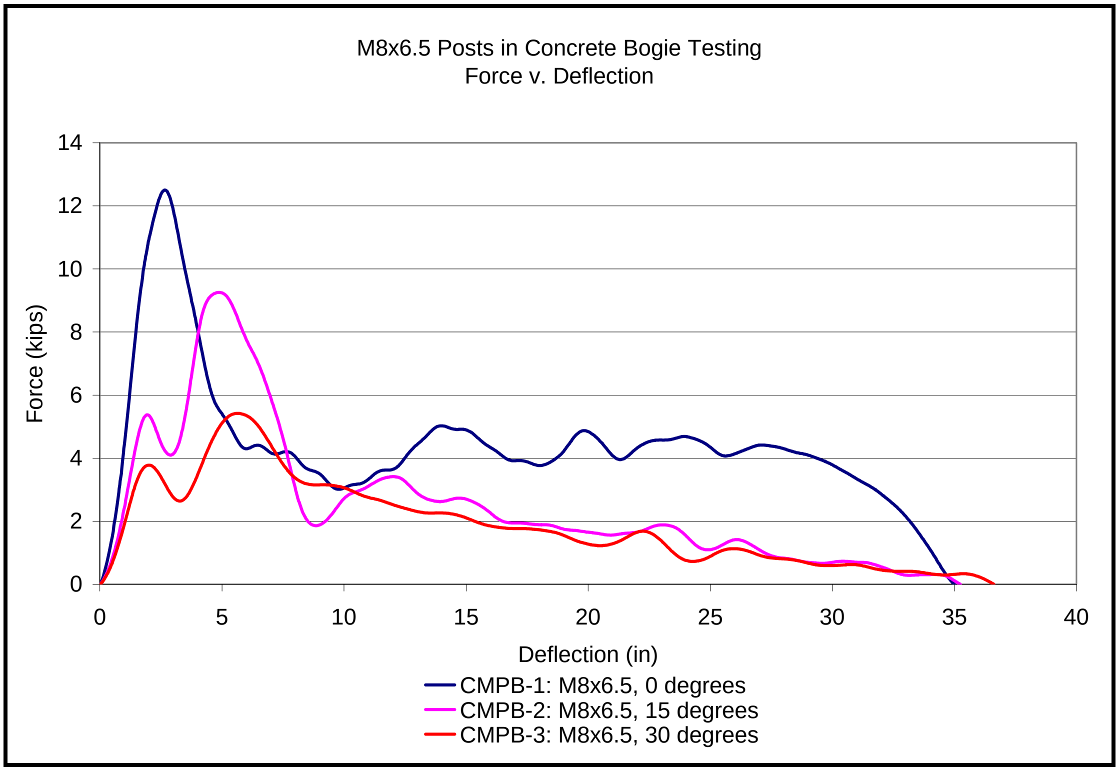


Figure 9b. Force-Deflection Curves for CMPB-1, 2, and 3 - English

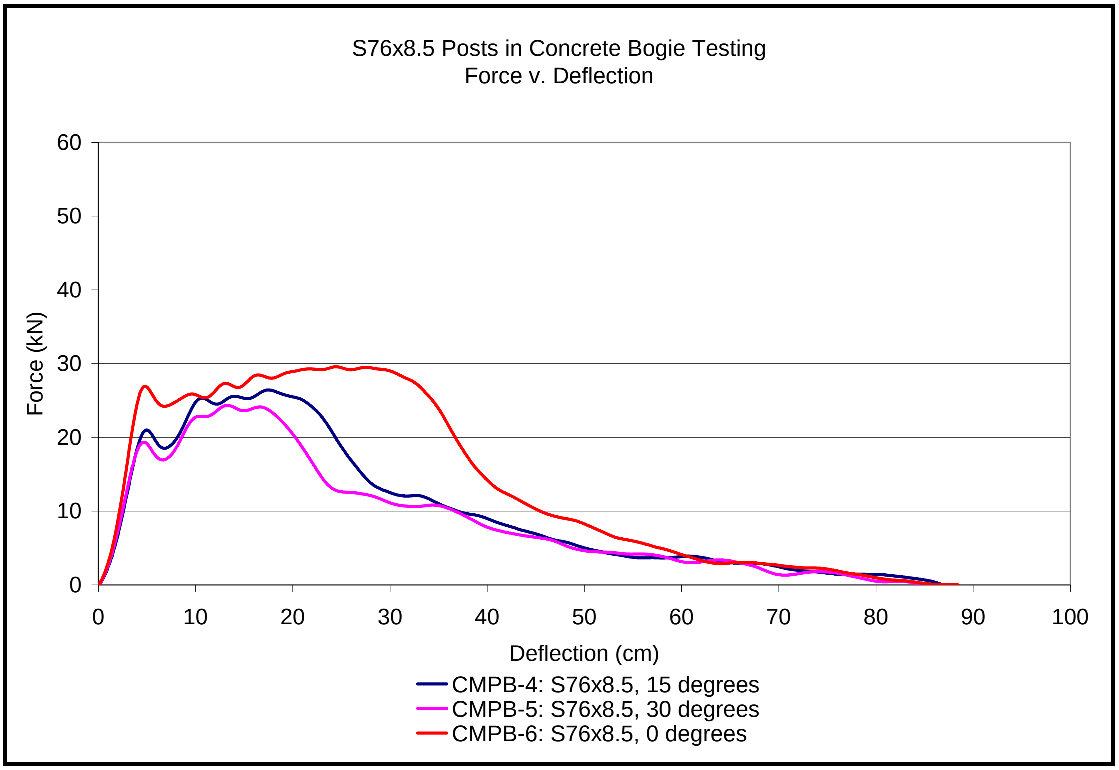


Figure 10a. Force-Deflection Curves for CMPB-4, 5, and 6 – Metric

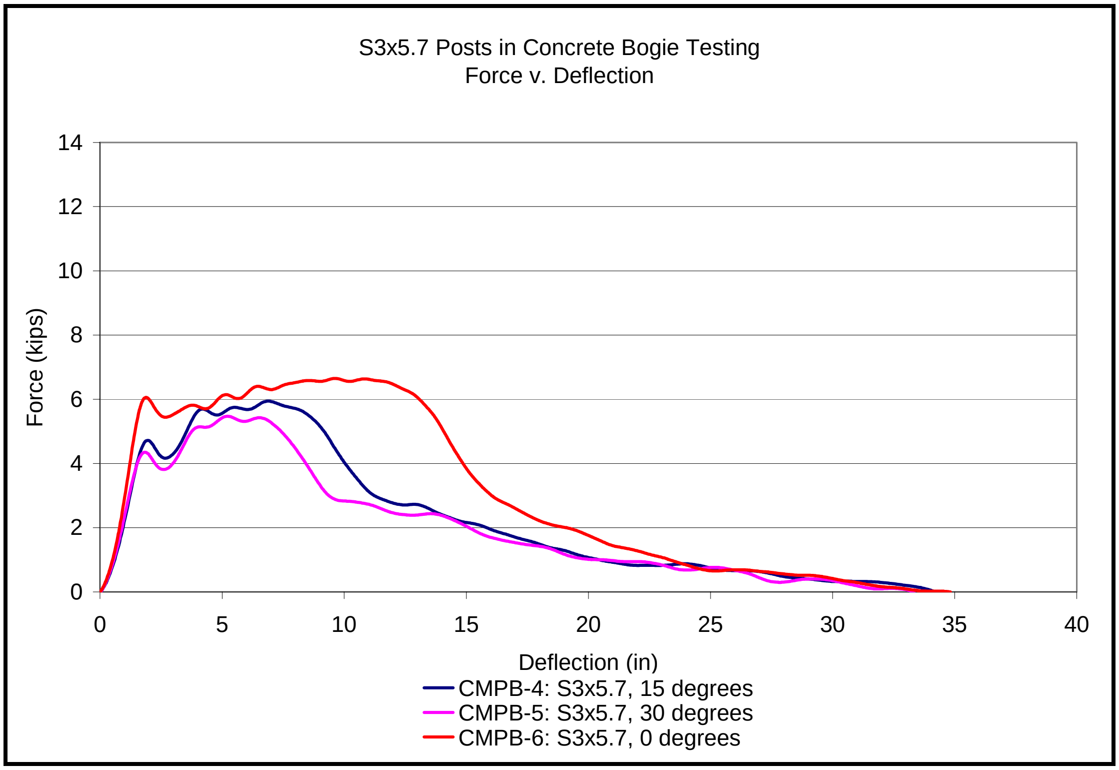


Figure 10b. Force-Deflection Curves for CMPB-4, 5, and 6 – English

5.1.2 Posts in Soil

Soil failure in some combination with post bending and/or twisting was the primary mode of failure in all the post in soil tests. The objective of this portion of testing was to determine the dynamic impact behavior of the posts in soil. Post in soil tests CMPB-7 through CMPB-13 were conducted on the M203x9.7 (M8x6.5) steel post. Tests CMPB-14 and CMPB-15 were conducted on the S76x8.5 (S3x5.7) steel post with attached soil plate.

The data was grouped and plotted according to embedment depth and post type. 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, while taking into account the impact angle. A summary of CMPB-7 through CMPB-15 is provided in Table 7. The force-deflection curves for the tests with an embedment depth of 91.44 cm (36 in.) and angles of 0° and 7.5°, CMPB-7 and CMPB-13, are shown in Figure 11. The force-deflection curves for the tests with an embedment depth of 106.68 cm (42 in.) and angles of 0°, 7.5°, and 15°, CMPB-8 and CMPB-10 through CMPB-12, are shown in Figure 12. The force-deflection curve for the test with an embedment depth of 121.92 cm (48 in.) and angle of 0°, CMPB-9, is shown in Figure 13. The force-deflection curves for the tests with an embedment depth of 76.2 cm (30 in.) and angles of 0° and 7.5°, CMPB-14 and CMPB-15, are shown in Figure 14.

The data was also grouped and plotted according to impact angle. Using the impact angle as a basis for comparison, it is possible to see how the impact angle affects the force at the impact location, while taking into account the embedment depth. The force-deflection curves for the tests with an impact angle of 0°, CMPB-7, CMPB-8, CMPB-9, CMPB-10, are shown in Figure 15. The force-deflection curves for the tests with an impact angle of 7.5°, CMPB-12 and CMPB-13, are shown in Figure 16.

Table 7a. Posts in Soil, CMPB-7 through CMPB-15 – Metric

Test No.	Impact		Embedment Depth	Initial Peak Force		Total Energy	
	Velocity	Angle		Displacement	Force	Displacement	Energy
	m/s	degrees	cm	cm	kN	cm	kJ
M203x9.7 (M8x6.5) Post Tests							
CMPB-7	8.85	0.0	91.4	4.83	47.73	118.87	20.7
CMPB-13	9.30	7.5	91.4	5.56	35.81	76.20	14.9
CMPB-8	9.57	0.0	106.7	5.44	37.68	103.89	24.6
CMPB-10	9.21	0.0	106.7	5.49	33.09	95.50	24.6
CMPB-12	9.66	7.5	106.7	8.89	41.55	97.54	16.1
CMPB-11	9.66	15.0	106.7	5.49	29.54	105.92	11.4
CMPB-9	9.57	0.0	121.9	6.20	36.88	111.51	26.1
S76x8.5 (S3x5.7) Post Tests							
CMPB-14	9.66	0.0	76.2	5.77	23.40	96.77	11.5
CMPB-15	8.99	7.5	76.2	5.21	21.13	97.79	9.6

Table 7b. Posts in Soil, CMPB-7 through CMPB-15 – English

Test No.	Impact		Embedment Depth	Initial Peak Force		Total Energy	
	Velocity	Angle		Displacement	Force	Displacement	Energy
	mph	degrees	in	in	kips	in	kips-in
M203x9.7 (M8x6.5) Post Tests							
CMPB-7	19.8	0.0	36.0	1.90	10.73	46.80	183.3
CMPB-13	20.8	7.5	36.0	2.19	8.05	30.00	132.0
CMPB-8	21.4	0.0	42.0	2.14	8.47	40.90	217.7
CMPB-10	20.6	0.0	42.0	2.16	7.44	37.60	217.5
CMPB-12	21.6	7.5	42.0	3.50	9.34	38.40	142.7
CMPB-11	21.6	15.0	42.0	2.16	6.64	41.70	100.8
CMPB-9	21.4	0.0	48.0	2.44	8.29	43.90	231.4
S76x8.5 (S3x5.7) Post Tests							
CMPB-14	21.6	0.0	30.0	2.27	5.26	38.10	102.2
CMPB-15	20.1	7.5	30.0	2.05	4.75	38.50	85.1

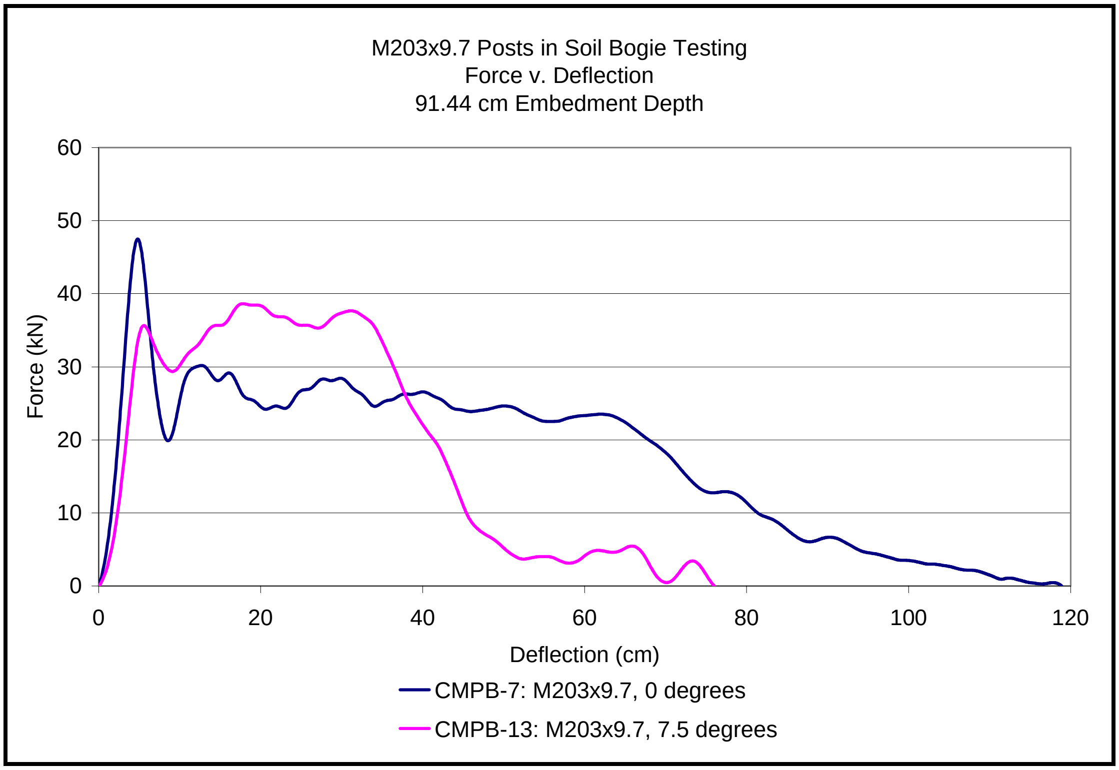


Figure 11a. Force-Deflection Curves for CMPB-7 and 13 - Metric

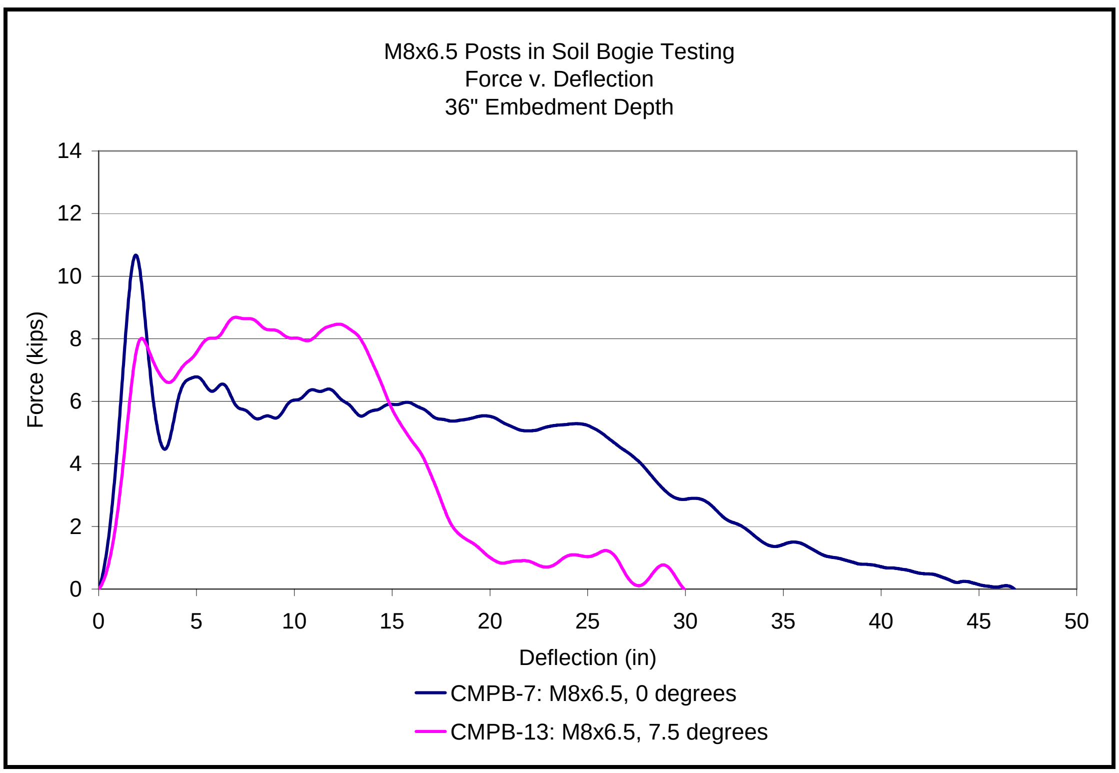


Figure 11b. Force-Deflection Curves for CMPB-7 and 13 - English

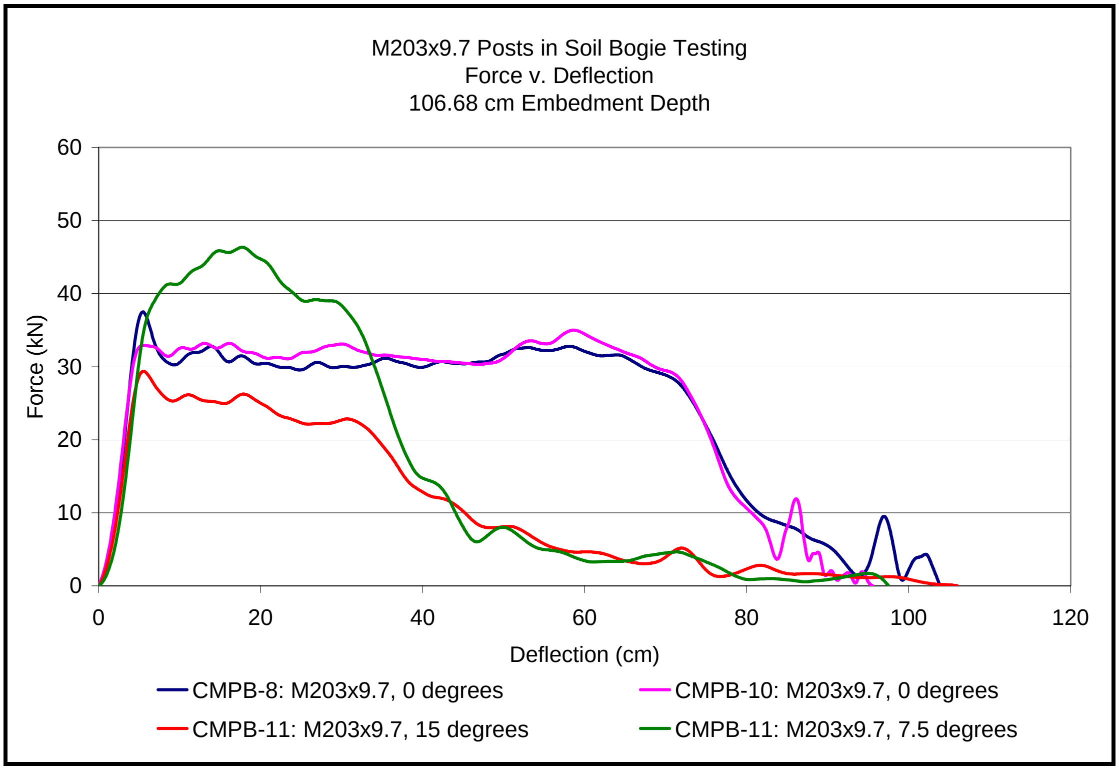


Figure 12a. Force-Deflection Curves for CMPB-8, 10, 11, and 12 - Metric

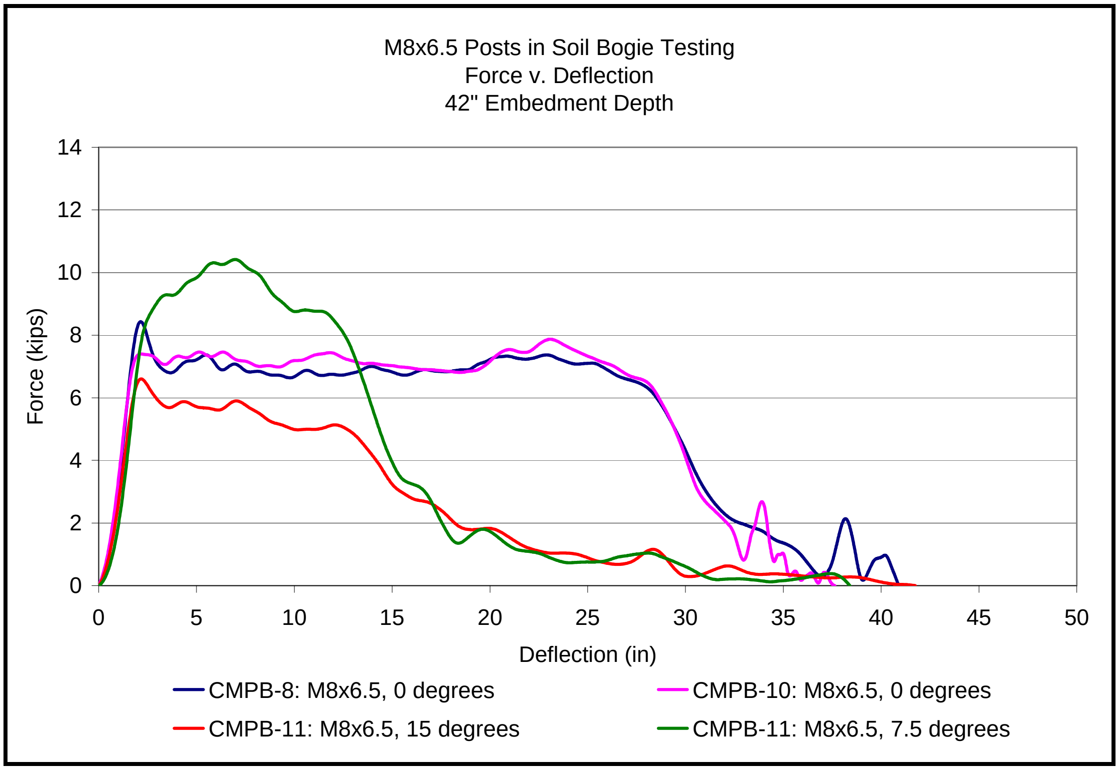


Figure 12b. Force-Deflection Curves for CMPB-8, 10, 11, and 12 - English

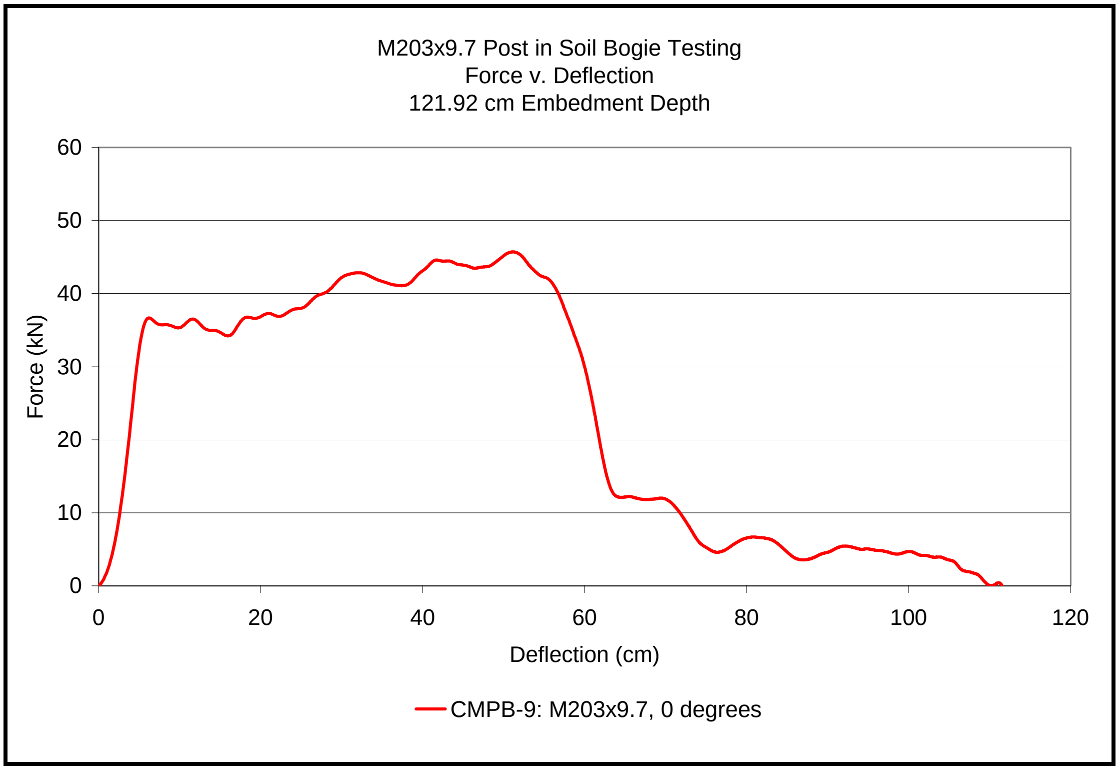


Figure 13a. Force-Deflection Curve for CMPB-9 - Metric

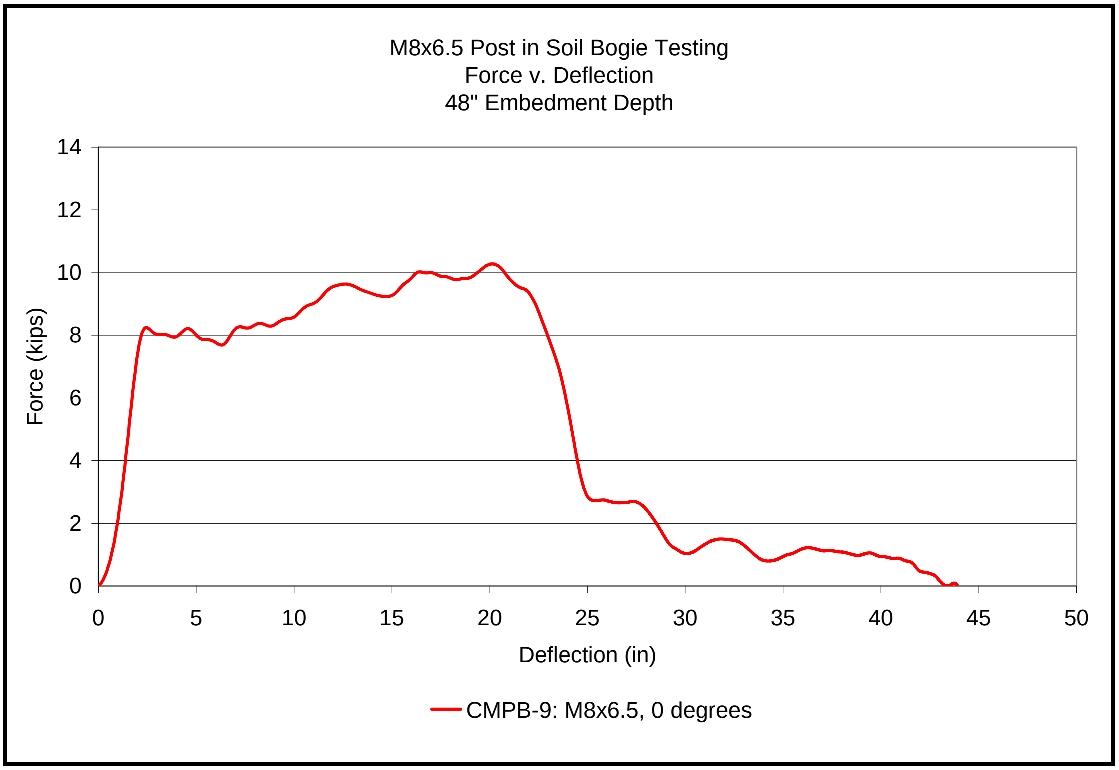


Figure 13b. Force-Deflection Curve for CMPB-9 - English

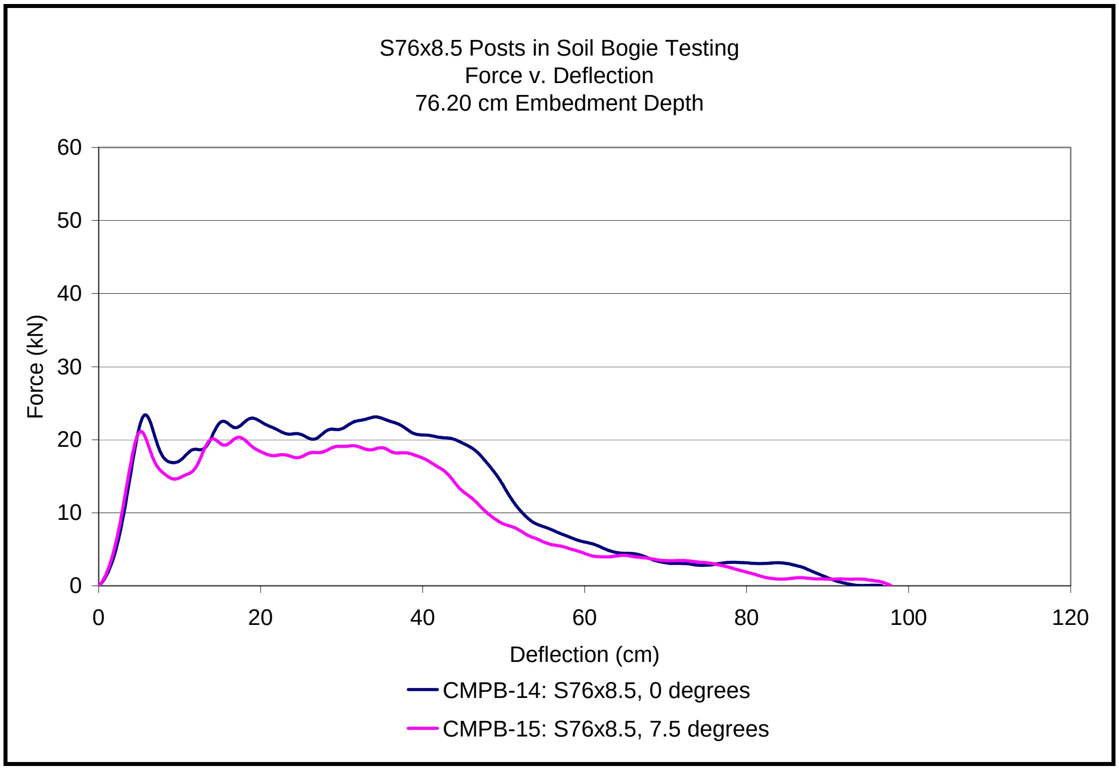


Figure 14a. Force-Deflection Curve for CMPB-14 and 15 - Metric

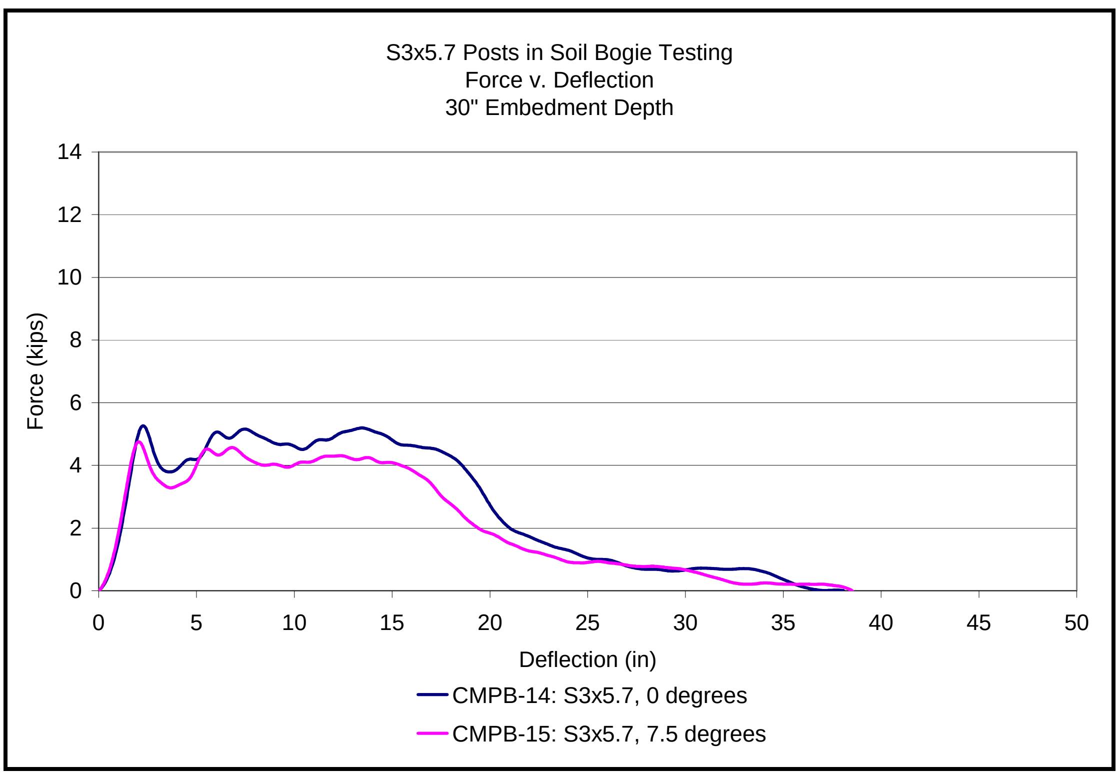


Figure 14b. Force-Deflection Curve for CMPB-14 and 15 - English

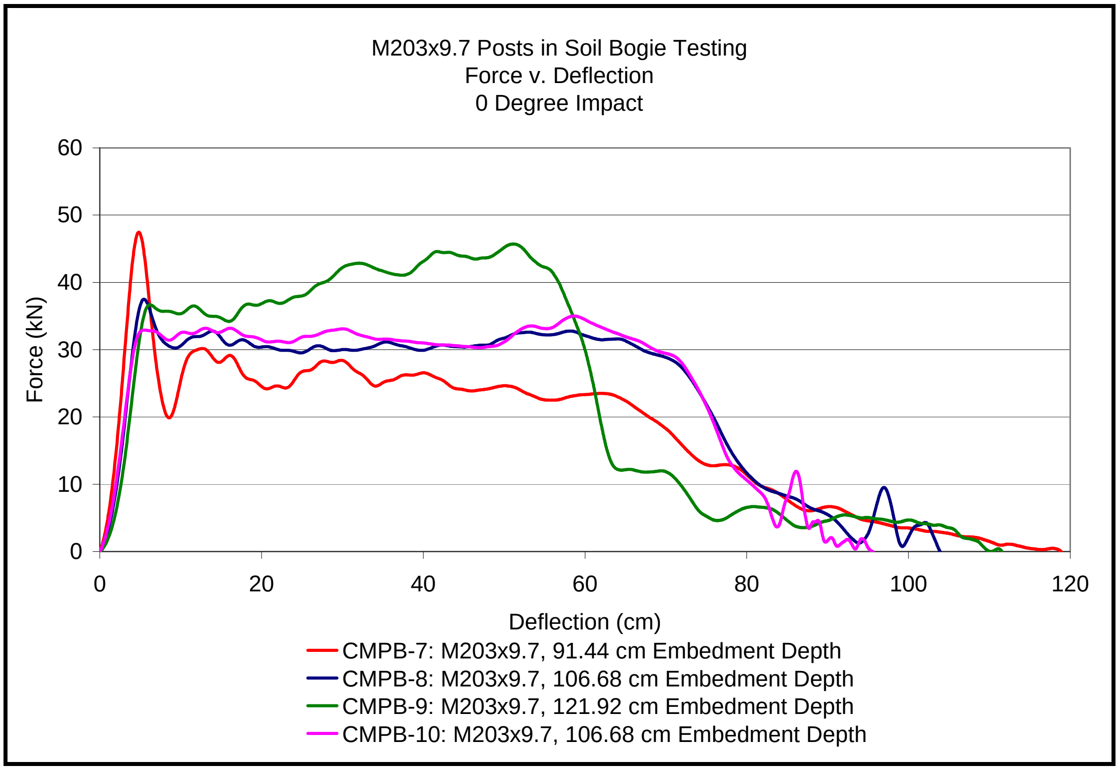


Figure 15a. Force-Deflection Curves for 0 Degree Impacts – Metric

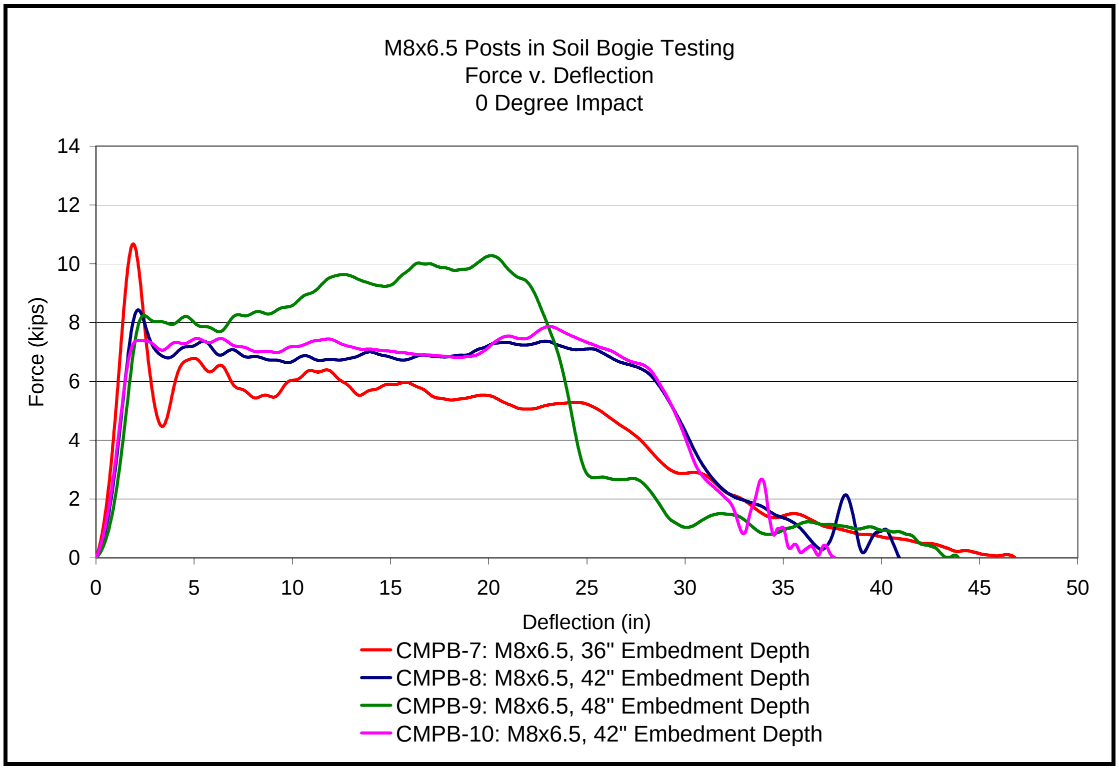


Figure 15b. Force-Deflection Curves for 0 Degree Impacts – English

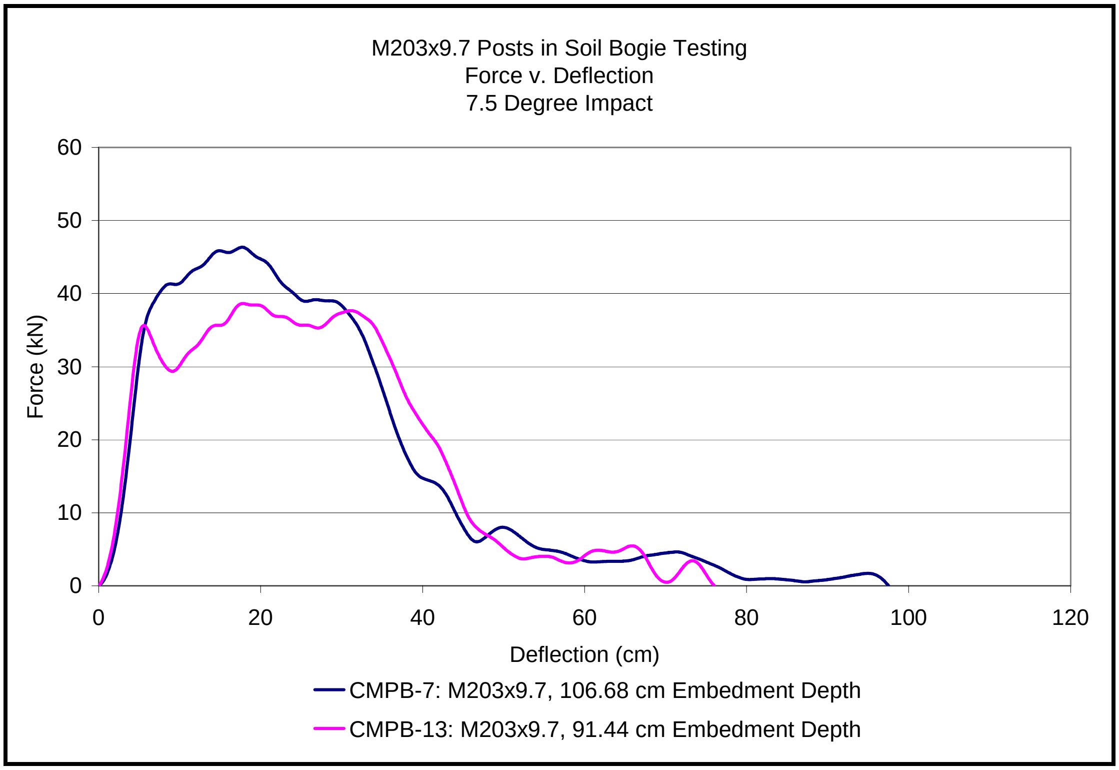


Figure 16a. Force-Deflection Curves for 7.5 Degree Impacts – Metric

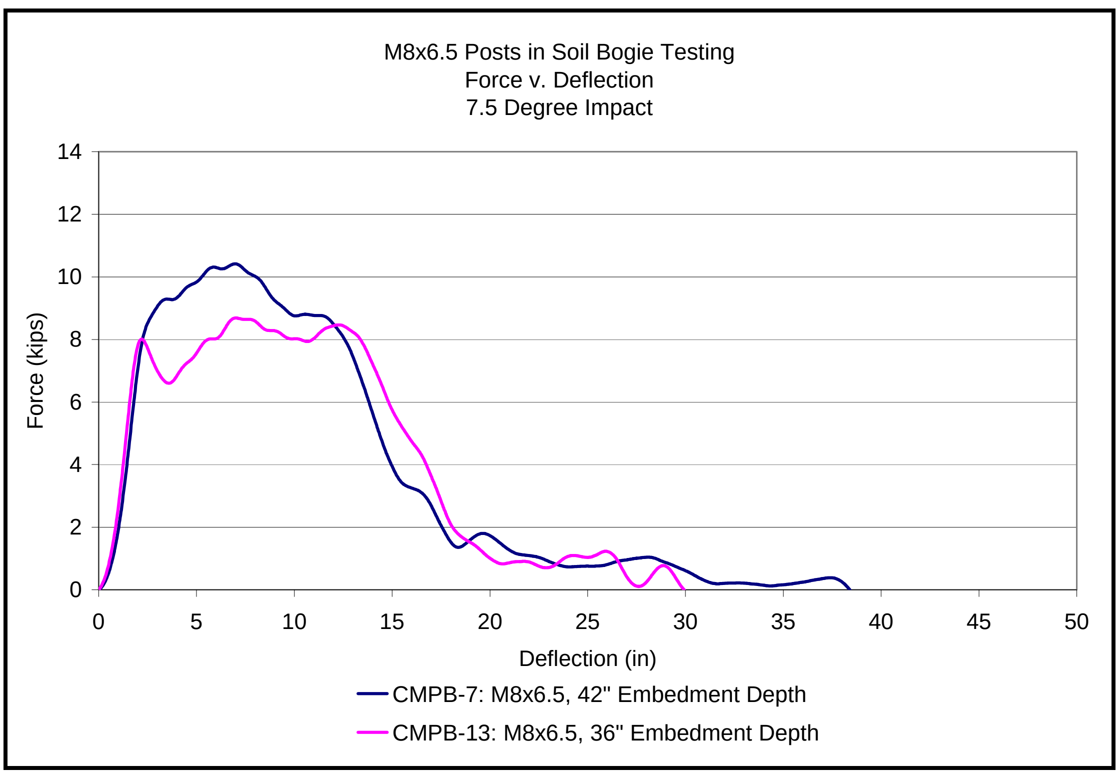
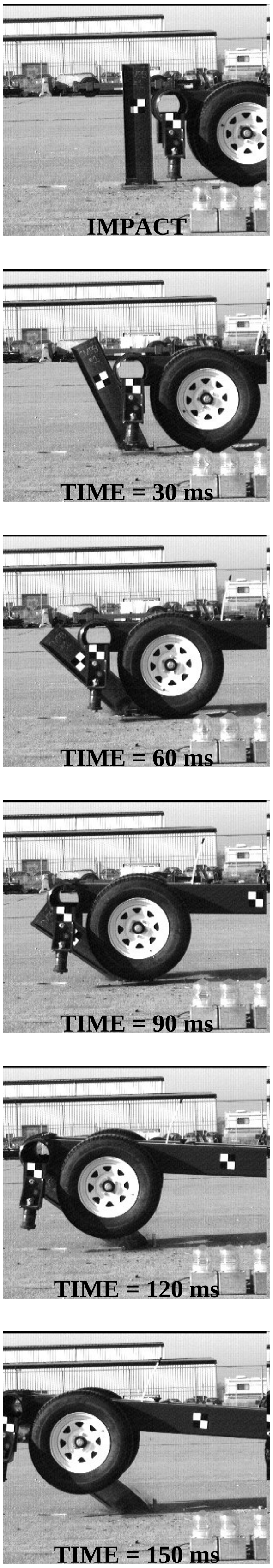


Figure 16b. Force-Deflection Curves for 7.5 Degree Impacts – English

5.2 Observed Dynamic Behaviors and Force Discussion

This section discusses the dynamic behaviors and reaction forces in tests CMPB-1 through CMPB-15 in detail. However, it is not the objective of this section to draw comparisons between the two posts tested, but to identify the behaviors observed during the dynamic impact tests. Conclusions regarding the performance comparison of the two posts are discussed in a subsequent chapter of this report.

5.2.1 Test CMPB-1 – M203x9.7 (M8x6.5) Post in Concrete

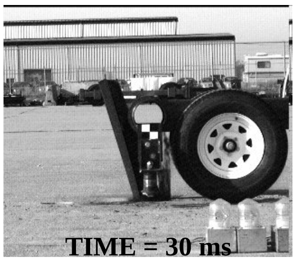


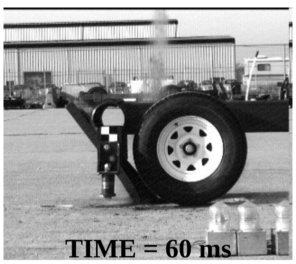
Test CMPB-1 was a strong axis impact at 0 degrees on the M203x9.7 (M8x6.5) steel post embedded in a concrete sleeve. The post was observed to bend at ground level. At 76 ms the bogie began to be lifted, a result of the impact cylinder head sliding up the slope of the bent post. The impact cylinder head lost contact with the post at 113 ms, resulting in the termination of the test and corresponds to a deflection of 88.92 cm (35.0 in).

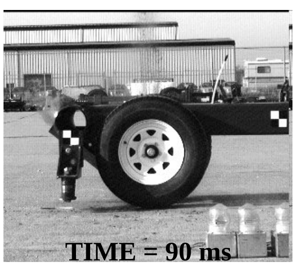
Examination of the Force v. Deflection profile, Figure 9, indicates a significant initial peak in the force level, which can be attributed to inertial effects and initiating the failure of the post. The initial peak is followed by a large region of a fairly uniform force level, 15 cm to 80 cm (5.9 in to 31.5 in) of deflection, corresponding to the uniform failure of the post due to bending at ground level.

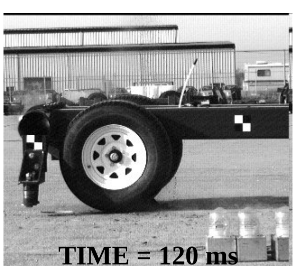
Figure 17. Post-Impact Image of CMPB-1, M203x9.7 (M8x6.5) Post in Concrete

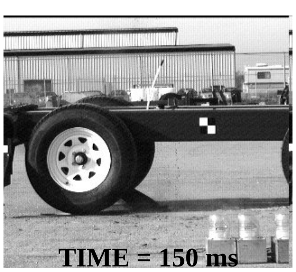
5.2.2 Test CMPB-2 – M203x9.7 (M8x6.5) Post in Concrete









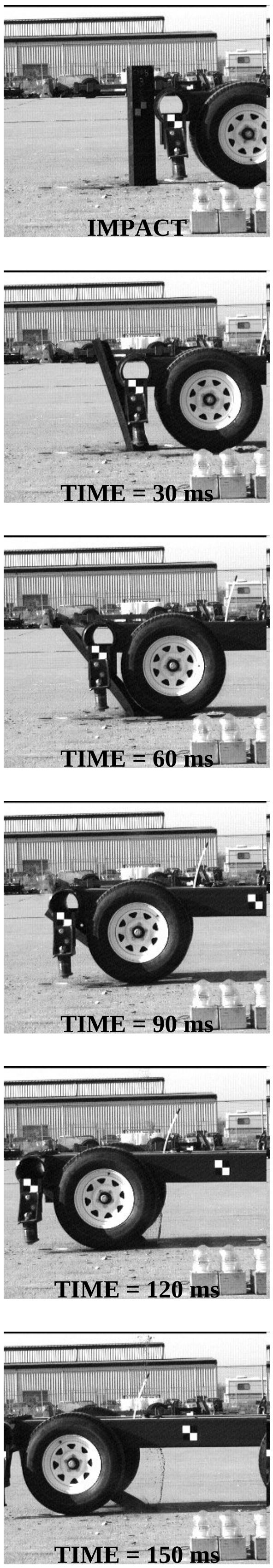


Test CMPB-2 was a strong axis impact at 15 degrees on the M203x9.7 (M8x6.5) steel post embedded in a concrete sleeve. The post was observed to bend at ground level for the first 8 ms, corresponding to a deflection of 7.42 cm (2.9 in). From 8 ms to 32 ms, the post twisted approximately 75 degrees, resulting in the weak axis of the post being parallel to the impact cylinder and 20.64 cm (8.1 in) of further deflection. The post then continued to fail by bending at ground level, with the impact cylinder losing contact with the post at 112 ms, resulting in the termination of the test and a deflection of 89.56 cm (35.3 in).

Examination of the Force v. Deflection profile, Figure 9, indicates an initial small peak at 7 cm (2.8 in) followed by a large peak at 15 cm (5.9 in), which are attributed to the initial deflection and post twisting behaviors, respectively. The force level then tapers off in a linear fashion for the duration of the test.

Figure 18. Post-Impact Image of CMPB-2, M203x9.7 (M8x6.5) Post in Concrete

5.2.3 Test CMPB-3 – M203x9.7 (M8x6.5) Post in Concrete

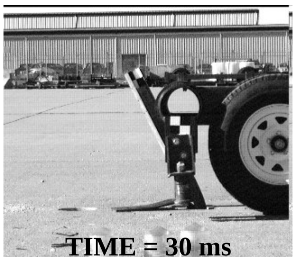


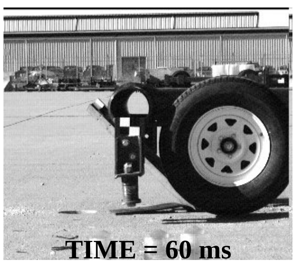
Test CMPB-3 was a strong axis impact at 30 degrees on the M203x9.7 (M8x6.5) steel post embedded in a concrete sleeve. The post was observed to bend at ground level and twist simultaneously for the first 28 ms, corresponding to a deflection of 24.75 cm (9.7 in). The post twisted approximately 60 degrees, resulting in the weak axis of the post being parallel to the impact cylinder. The post then continued to fail by bending at ground level, with the impact cylinder losing contact with the post at 114 ms, resulting in the termination of the test and a deflection of 93.00 cm (36.6 in).

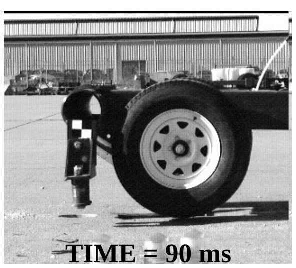
Examination of the Force v. Deflection profile, Figure 9, indicates a similar behavior to CMPB-2. However the magnitude of the peaks is not as high, attributed to the larger impact angle. Following the initial portion of the impact the force level tapers off in a comparable magnitude and duration to CMPB-2, due to their similar failure mode.

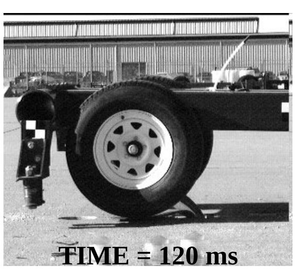
Figure 19. Post-Impact Image of CMPB-3, M203x9.7 (M8x6.5) Post in Concrete

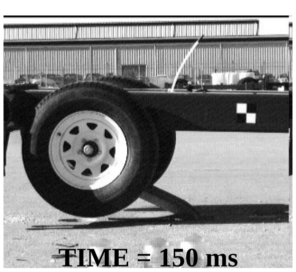
5.2.4 Test CMPB-4 – S76x8.5 (S3x5.7) Post in Concrete









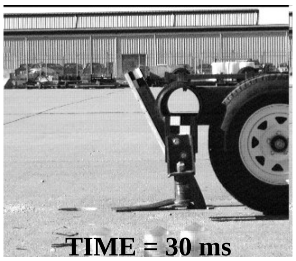


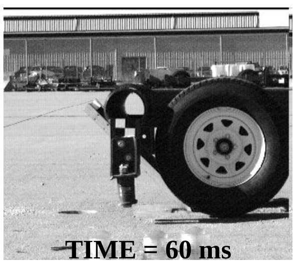
Test CMPB-4 was a strong axis impact at 15 degrees on the S76x8.5 (S3x5.7) steel post embedded in a concrete sleeve. The post was observed to undergo a combination of twisting and bending for the duration of the test. For the first 20 ms of the impact, corresponding to a deflection of 18.77 cm (7.4 in), the twisting aligned the strong axis of the post to impact cylinder. The post then twisted in the opposite direction, past its original orientation, causing the weak axis to become nearly parallel to the impact cylinder at 60 ms, corresponding to a deflection of 52.72 cm (20.8 in). The impact cylinder lost contact with the post at 102 ms and a deflection of 86.83 cm (34.2 in).

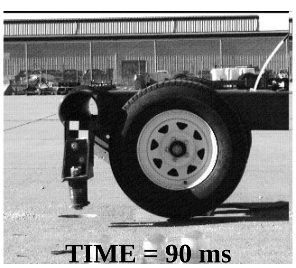
Examination of the Force v. Deflection curve, Figure 10, indicates that the orientation of the post, the result of post twisting previously discussed, has a major role in the strength of the post. The highest force levels are observed when the impact cylinder is impacting the post on the strong axis and lowest when impacting on the weak axis.

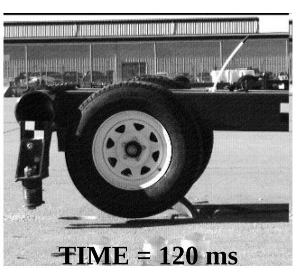
Figure 20. Post-Impact Image of CMPB-4, S76x8.5 (S3x5.7) Post in Concrete

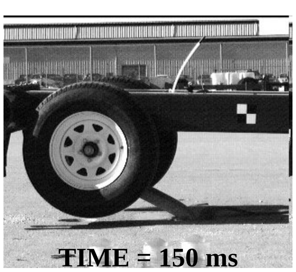
5.2.5 Test CMPB-5 – S76x8.5 (S3x5.7) Post in Concrete









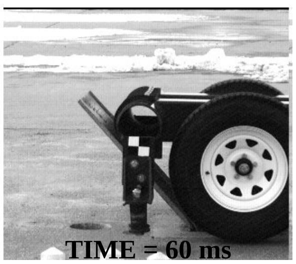


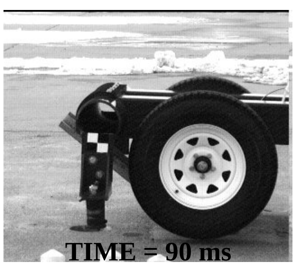
Test CMPB-5 was a strong axis impact at 30 degrees on the S76x8.5 (S3x5.7) steel post embedded in a concrete sleeve. The observed dynamic behavior of the post was very similar to test CMPB-4 and a similar explanation is offered. However only 14 ms, corresponding to a deflection of 12.75 cm (5.0 in), was required to have the strong axis of the post parallel to the cylinder head.

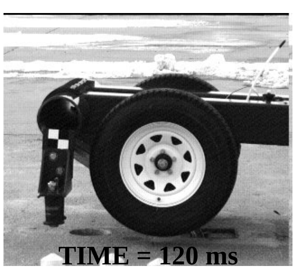
Examination of the Force v. Deflection curve, Figure 10, also indicates the dynamic behavior observed in test CMPB-5 was similar to that observed in CMPB-4. However, the magnitude of the force levels observed during the strong axis portion of the impact, from 4 cm to 37 cm (1.6 in to 13.8 in), is lower. The lower force levels can be attributed to the higher impact angle. Examination of the Force v. Deflection curve after 35 cm (13.8 in) reveals that the failure modes in CMPB-4 and CMPB-5 are most likely the same.

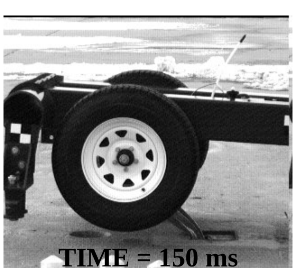
Figure 21. Post-Impact Image of CMPB-5, S76x8.5 (S3x5.7) Post in Concrete

5.2.6 Test CMPB-6 – S76x8.5 (S3x5.7) Post in Concrete









Test CMPB-6 was a strong axis impact at 0 degrees on the S76x8.5 (S3x5.7) steel post embedded in a concrete sleeve. The post was observed to bend at ground level for the first 40 ms, corresponding to 32.34 cm (12.7 in) of deflection. After 40 ms, the post continues to fail in a combination of twisting and bending. The impact cylinder lost contact with the post at 127 ms and a deflection of 88.45 cm (34.8 in).

Examination of the Force v. Deflection curve, Figure 10, indicates similar behavior to the previous two tests. While the post is being impacted along its strong axis, it produces a uniform force level. However, in CMPB-6, the post takes significantly longer to twist than observed in CMPB-4 and CMPB-5, and is therefore the reason for the larger region of uniform force output. After significant twisting has occurred to the post in CMPB-6, 60 cm (23.9 in) of deflection, the force level drops to that of CMPB-4 and CMPB-5.

Figure 22. Post-Impact Image of CMPB-6, S76x8.5 (S3x5.7) Post in Concrete

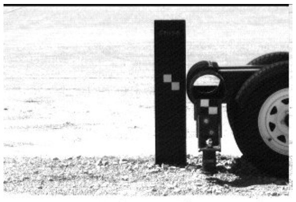
5.2.7 Test CMPB-7 – M203x9.7 (M8x6.5) Post in Soil

Test CMPB-7 was a strong axis impact at 0 degrees on the M203x9.7 (M8x6.5) steel post embedded 91.44 cm (36 in.) in NCHRP 350 soil. The post was observed to rotate in the soil, with only slight yielding. It has been previously shown that analyzed accelerometer data with slight post yielding is similar to data when no yielding occurs (2). Specific timing details and sequential photographs are unavailable due to video recording problems.

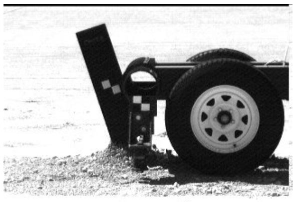
Examination of the Force v. Deflection curve, Figure 11, is a further indication that the post rotated in the soil, due to the uniform force level observed over the duration of the impact. A drop in the force level was observed in the range of 35-37.5 cm (13.78 – 14.76 in.) for test CMPB-7.

Figure 23. Post-Impact Image from CMPB-7, M203x9.7 (M8x6.5) Post in Soil

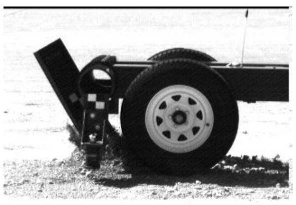
5.2.8 Test CMPB-8 – M203x9.7 (M8x6.5) Post in Soil



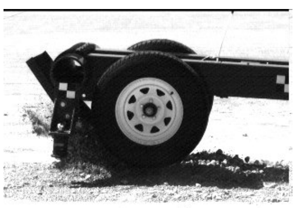
IMPACT



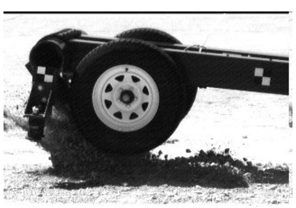
TIME = 50 ms



TIME = 100 ms



TIME = 150 ms



TIME = 200 ms

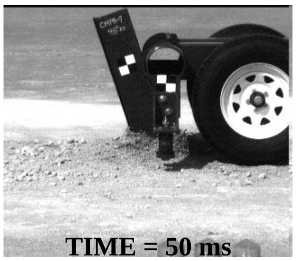
TIME = 250 ms

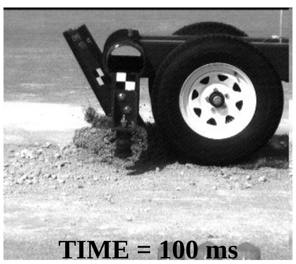
Test CMPB-8 was a strong axis impact at 0 degrees on the M203x9.7 (M8x6.5) steel post embedded 106.7 cm (42 in) in NCHRP 350 soil. The post was observed to rotate in the soil for the first 92 ms, corresponding to a deflection of 67.7 cm (26.7 in), after which the post twisted and bent simultaneously for 84 ms, causing a further 32.3 cm (12.7 in) of deflection. At this point the bogie was undergoing significant lifting, resulting in the termination of the test, before the impact cylinder lost contact with the post at 242 ms.

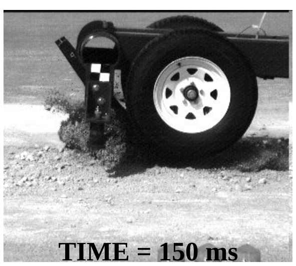
Examination of the Force v. Deflection curve, Figure 12, indicates a significant change in the force level at 67.7 cm (26.7 in) of deflection, corresponding to the change in the failure mode, previously discussed. The duration of the reaction forces in this test is longer and the magnitude is higher than seen in CMPB-7.

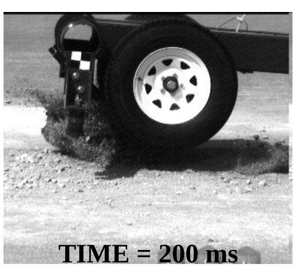
Figure 24. Post-Impact Image of CMPB-8, M203x9.7 (M8x6.5) Post in Soil

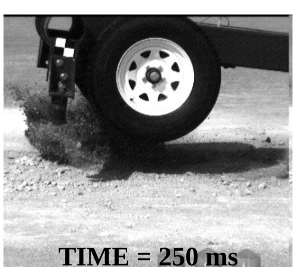
5.2.9 Test CMPB-9 – M203x9.7 (M8x6.5) Post in Soil









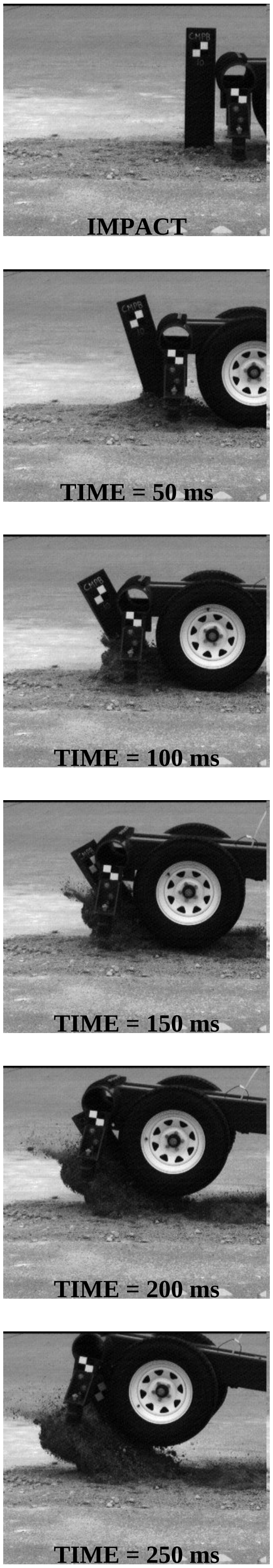


Test CMPB-9 was a strong axis impact at 0 degrees on the M203x9.7 (M8x6.5) steel post embedded 121.92 cm (48 in) in NCHRP 350 soil. The post was observed to rotate in the soil for the first 74 ms, corresponding to a deflection of 55.05 cm (21.7 in). The post was then observed to twist for 20 ms, corresponding to a further 8.65 cm (3.4 in) of deflection. The post then began to twist and bend simultaneously until the impact cylinder lost contact with the post after 253 ms and 111.55 cm (43.9 in) of deflection.

Examination of the Force v. Deflection curve, Figure 13, indicates a uniform force level until 55 cm (21.7 in) of deflection. At this point the post began to twist and thus the force level decreased significantly due to the change in failure mode. The duration of the force levels is less than observed in test CMPB-8, although the uniform force level is larger.

Figure 25. Post-Impact Image of CMPB-9, M203x9.7 (M8x6.5) Post in Soil

5.2.10 Test CMPB-10 – M203x9.7 (M8x6.5) Post in Soil

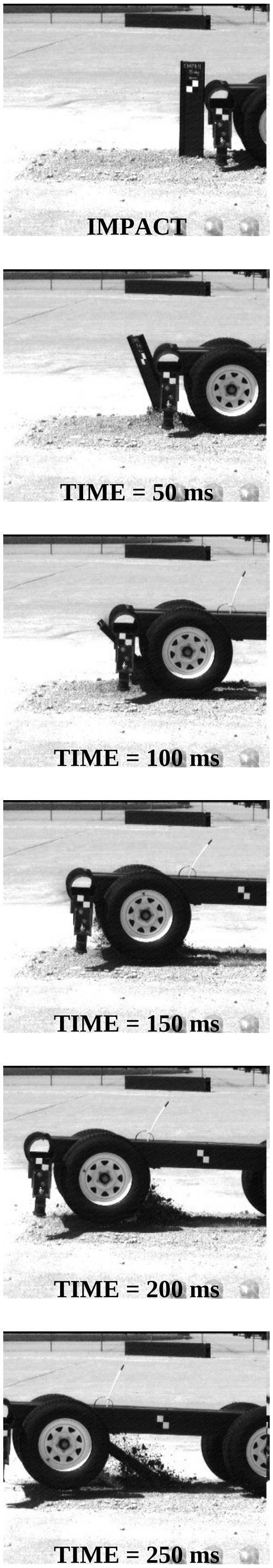


Test CMPB-10 was a strong axis impact at 0 degrees on the M203x9.7 (M8x6.5) steel post embedded 106.7 cm (42 in) in NCHRP 350 soil. The observed dynamic behavior in CMPB-10 was very similar to that seen in CMPB-8 and a similar explanation is offered. However test CMPB-10 was shorter with a duration time of 206 ms, but the total deflection was still similar at 95.57 cm (37.6 in).

Examination of the Force v. Deflection curve, Figure 12, also verifies the observed behaviors in test CMPB-10 were similar to test CMPB-8. The force levels are observed to drop off at the same dynamic deflection of 67.7 cm (26.7 in). However, the force levels during test CMPB-10 were up to 2 kN (0.450 kips) greater than the force levels in CMPB-8, while the post was observed to be rotating in soil. Further observations about CMPB-8 and CMPB-10 will be introduced in the energy discussion section.

Figure 26. Post-Impact Image of CMPB-10, M203x9.7 (M8x6.5) Post in Soil

5.2.11 Test CMPB-11 – M203x9.7 (M8x6.5) Post in Soil

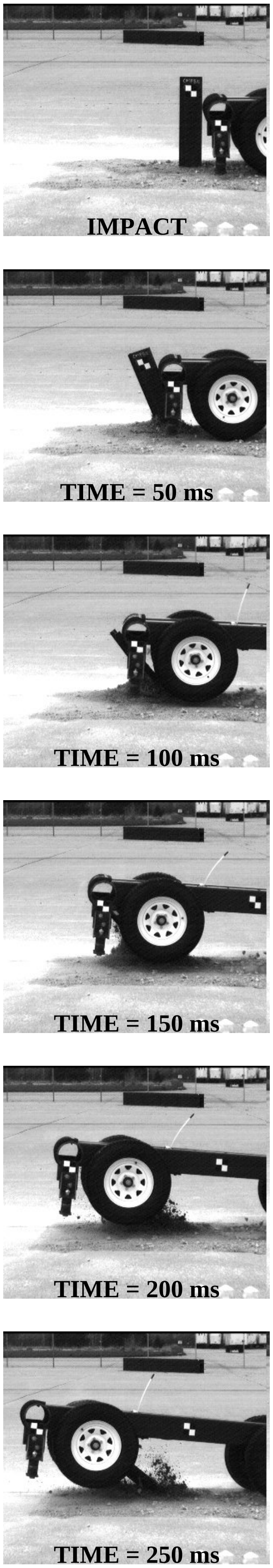


Test CMPB-11 was a strong axis impact at 15 degrees on the M203x9.7 (M8x6.5) steel post embedded 106.7 cm (42 in) in NCHRP 350 soil. The post was observed to rotate in the soil for the first 36 ms, corresponding to a deflection of 32.43 cm (12.8 in), after which the post twisted and bent simultaneously for 46 ms, causing a further 36.19 cm (14.2 in) of deflection, and orienting the weak axis of the post parallel to the impact cylinder. The post then bent at the ground level until the impact cylinder lost contact with the post at 132 ms and a final deflection of 106.02 cm (41.7 in).

Examination of the Force v. Deflection curve, Figure 12, indicates a significant force level drop at a displacement of 32.43 cm (12.8 in), corresponding to the change in failure mode. The duration of the soil failure is most likely due to the amount of soil behind the post while it is rotating, eventually causing post failure.

Figure 27. Post-Impact Image of CMPB-11, M203x9.7 (M8x6.5) Post in Soil

5.2.12 Test CMPB-12 - M203x9.7 (M8x6.5) Post in Soil

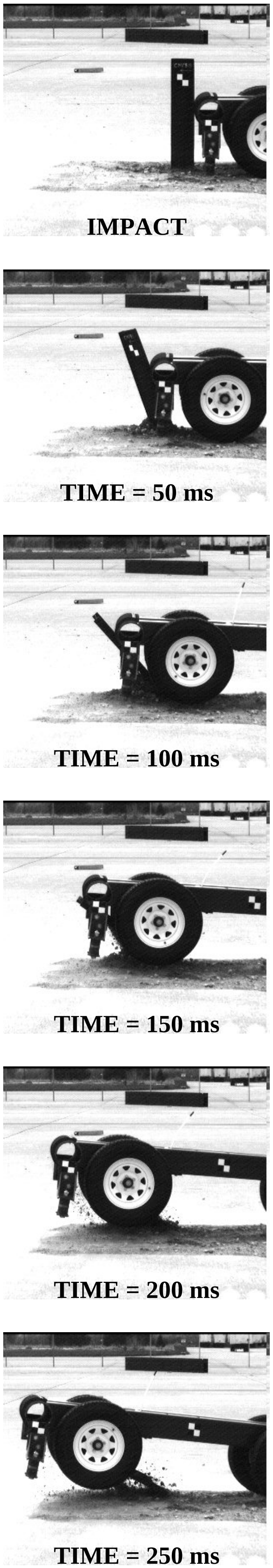


Test CMPB-12 was a strong axis impact at 7.5 degrees on the M203x9.7 (M8x6.5) steel post embedded 106.7 cm (42 in) in NCHRP 350 soil. The post was observed to rotate in the soil for the first 46 ms, corresponding to a deflection of 38.40 cm (15.1 in), after which the post twisted and bent simultaneously for 62 ms, causing a further 41.11 cm (16.2 in) of deflection, and orienting the weak axis of the post nearly parallel to the impact cylinder. The post then bent at the ground level until the impact cylinder lost contact with the post at 136 ms and a final deflection of 97.56 cm (38.4 in).

Examination of the Force v. Deflection curve, Figure 12, indicates a significant drop in the force level at 31.68 cm (12.5 in) of deflection, slightly before the post was observed to begin twisting. The initial force level was higher and the duration was slightly longer than observed during test CMPB-11, attributed to the amount of soil behind the post, previously discussed.

Figure 28. Post-Impact Image of CMPB-11, M203x9.7 (M8x6.5) Post in Soil

5.2.13 Test CMPB-13 - M203x9.7 (M8x6.5) Post in Soil

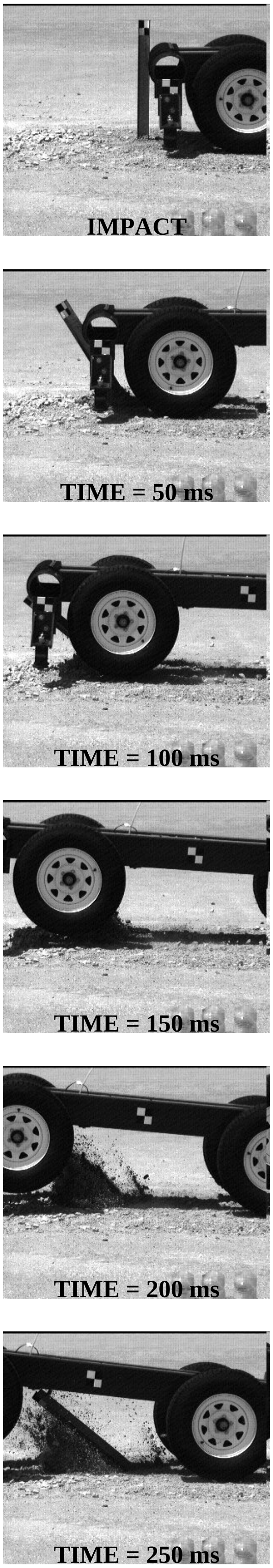


Test CMPB-7 was a strong axis impact at 7.5 degrees on the M203x9.7 (M8x6.5) steel post embedded 91.44 cm (36 in.) in NCHRP 350 soil. The post was observed to rotate in the soil for 42 ms, corresponding to a deflection of 34.77 cm (13.7 in), after which the post twisted and bent simultaneously for 44 ms, causing a further 28.49 cm (11.2 in) of deflection, and orienting the weak axis of the post parallel to the impact cylinder. The post then bent at the ground level until the impact cylinder lost contact with the post at 106 ms and a final deflection of 76.07 cm (29.9 in).

Examination of the Force v. Deflection curve, Figure 11, also indicates a change in the force level at 34.77 cm (13.7) in of deflection. The force level observed while the post was rotating in the soil, during CMPB-13 is larger than in CMPB-7, due to the amount of soil behind the post, previously discussed, while the duration is comparable.

Figure 29. Post-Impact Image of CMPB-13, M203x9.7 (M8x6.5) Post in Soil

5.2.14 Test CMPB-14 – S76x8.5 (S3x5.7) Post in Soil

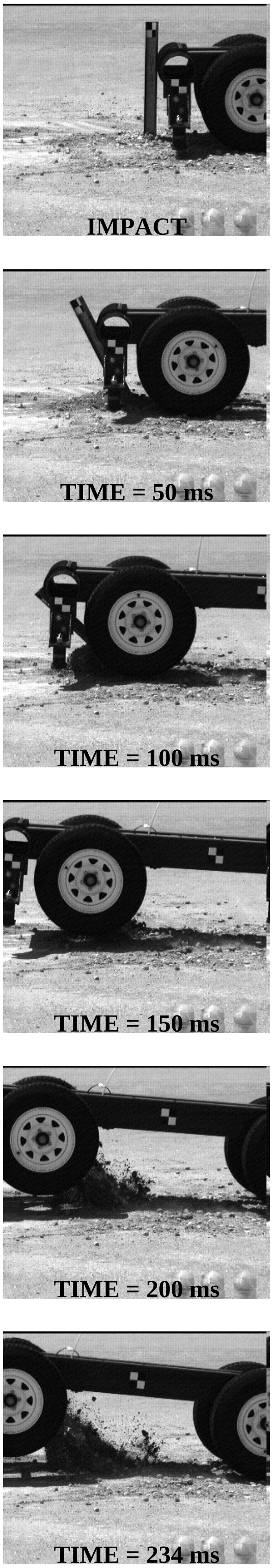


Test CMPB-14 was an impact on the S76x8.5 (S3x5.7) steel post with attached soil plate embedded 76.2 cm (30 in.) in soil at 0 degrees. The post was observed to rotate in the soil for 52 ms, corresponding to a deflection of 46.16 cm (18.2 in). The post then twisted and bent simultaneously until the impact cylinder lost contact with the post at 118 ms and a deflection of 96.74 cm (38.1 in).

Examination of the Force v. Deflection curve, Figure 14, indicates a drop in the force level at 46.16 cm (18.2 in) of deflection, corresponding to the change in failure mode. The force level observed during post rotation in soil is fairly uniform, which can be attributed to the presence of the soil plate. However the soil plate compacts the soil behind it, which leads to the increased resistance of the soil and eventual yielding failure of the post, instead of continued soil failure.

Figure 30. Post-Impact Image of CMPB-14, S76x8.5 (S3x5.7) Post in Soil

5.2.15 Test CMPB-15 – S76x8.5 (S3x5.7) Post in Soil



Test CMPB-15 was an impact on the S76x8.5 (S3x5.7) steel post with attached soil plate embedded 76.2 cm (30 in.) in soil at 7.5 degrees. The post was observed to rotate in the soil for 50 ms, corresponding to a deflection of 41.65 cm (16.4 in). The post then twisted and bent simultaneously until the impact cylinder lost contact with the post at 128 ms and a deflection of 97.87 cm (38.5 in).

Examination of the Force v. Deflection curve, Figure 14, indicates a similar behavior between CMPB-15 and CMPB-14. However, the magnitude of the force level observed in test CMPB-14 is on average 3 kN (0.674 kips) larger than the force level observed in test CMPB-15, while the post was observed to be rotation in the soil. This behavior was expected from the results of the concrete sleeve testing of the S76x8.5 (S3x5.7) steel post.

Figure 31. Post-Impact Image of CMPB-15, S76x8.5 (S3x5.7) Post in Soil

5.3 Energy Discussion

The energy dissipated during an impact is of significant interest in the selection of the post. It is therefore desirable to examine the energy dissipated during the dynamic impacts of the two different posts embedded in soil. The data presented in this section is grouped according to impact angle and will provide insights into the importance of the post embedment depth.

The energy dissipated during each test was calculated by integrating the area under its force-deflection curve, shown previously in Figures 11 through 14. The results of which are shown in Figures 32 and 33 for impact angles of 0 and 7.5 degrees, respectively.

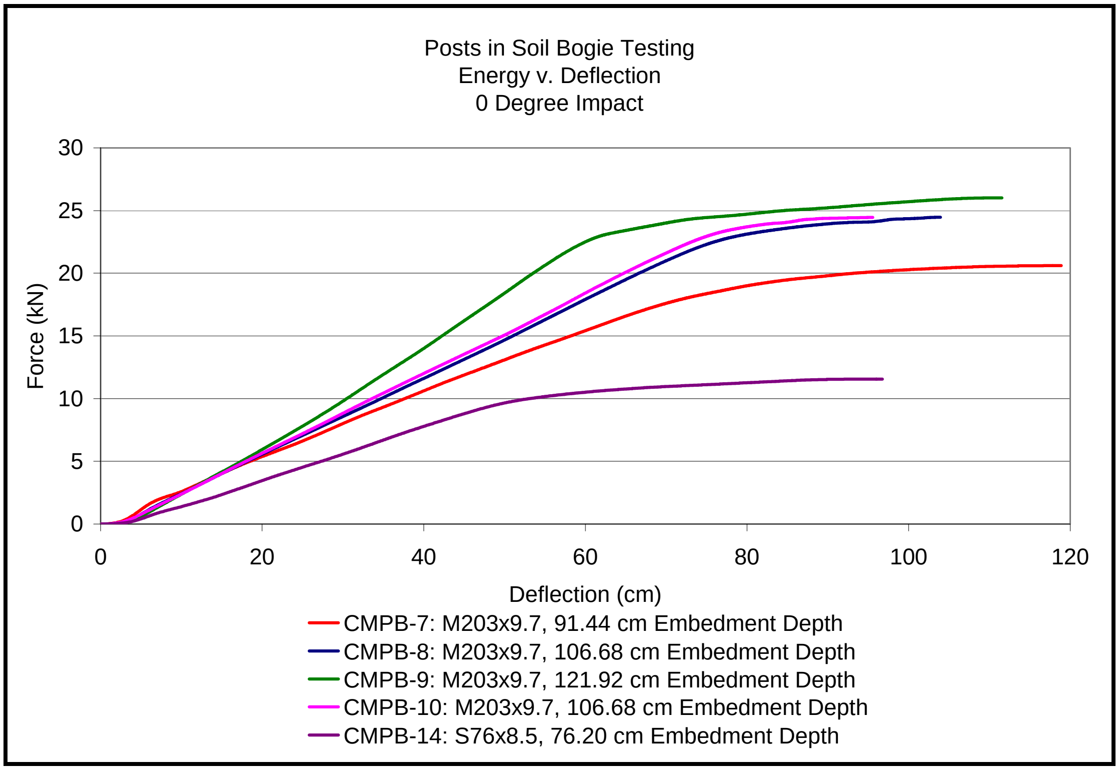


Figure 32a. Energy-Deflection Curves for 0 Degree Impacts - Metric

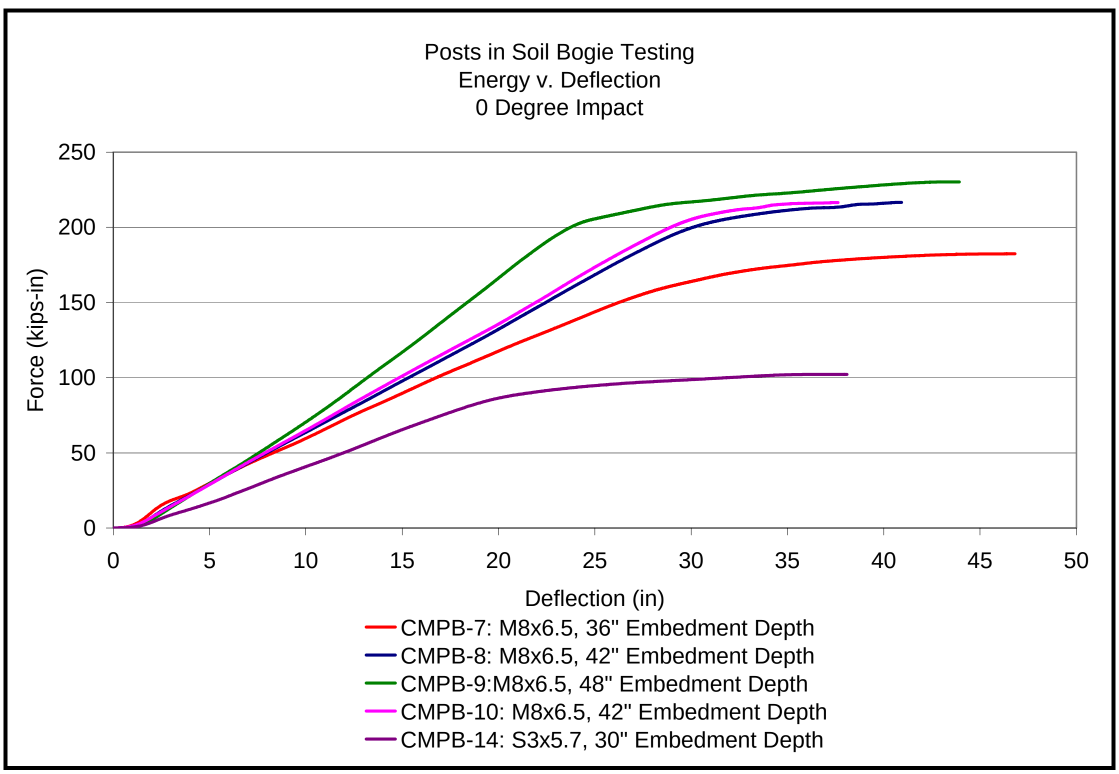


Figure 32b. Energy-Deflection Curves for 0 Degree Impacts - English

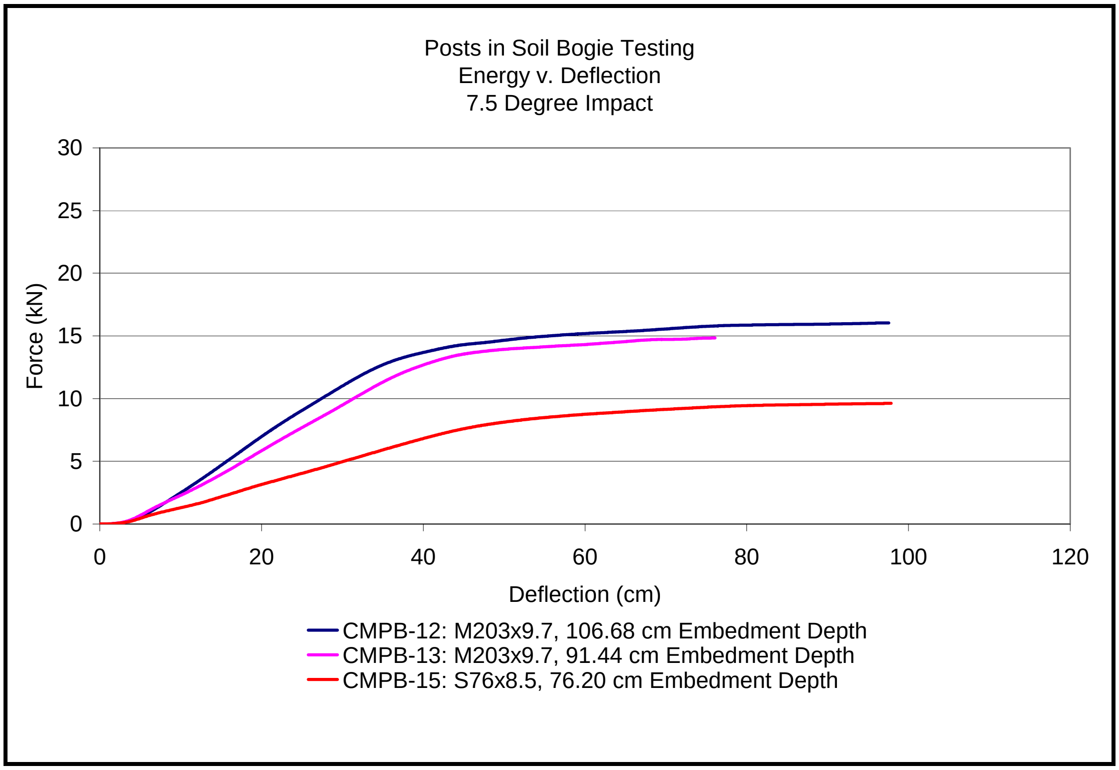


Figure 33a. Energy-Deflection Curves for 7.5 Degree Impacts - Metric

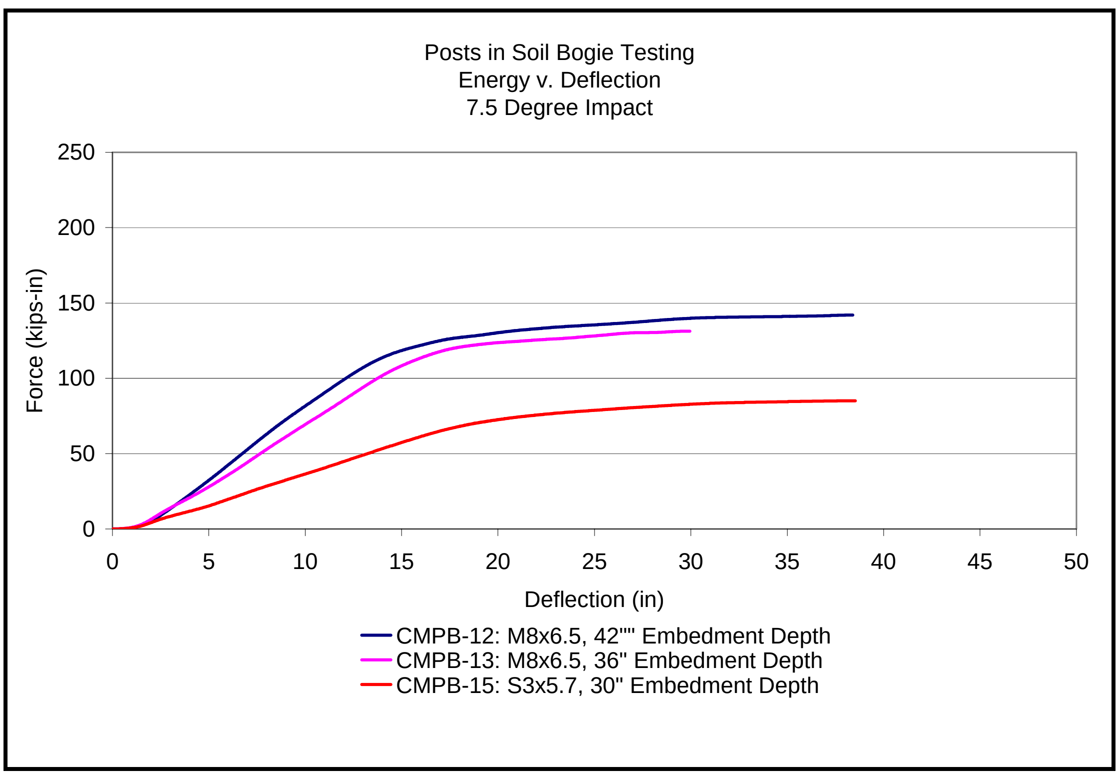


Figure 33b. Energy-Deflection Curves for 7.5 Degree Impacts - English

There is a clear difference in the amount of energy absorbed between the two posts under study, as shown in Figures 32 and 33. The M203x9.7 (M8x6.5) post dissipated more energy than the S76x8.5 (S3x5.7) post, while having similar displacements. Also, the significance of the embedment depth is now appreciable. It is evident from the M203x9.7 (M8x6.5) post tests that the deeper the post is embedded into the soil the more energy it will dissipate. However, when comparing the curve from CMPB-9, with an embedment depth of 121.92 cm (48 in.), to the curves from CMPB-8 and CMPB-10, with an embedment depth of 106.68 cm (42 in.), there are three important features to notice (1) the slope of CMPB-9 is steeper than that of CMPB-8 and CMPB-10 while, (2) the energy level at which the curves begin to level off is very similar (both curves near 23.0-23.5 kJ (203.6-208.0 kip-in), and (3) the total displacement is similar.

Further examination of energy-deflection curves at 0 degrees reveals the CMPB-7 curve, M203x9.7 (M8x6.5) post with an embedment depth of 91.44 cm (36 in.), has the longest displacement while dissipating nearly twice the energy as the S76x8.5 (S3x5.7) post, CMPB-14, and only approximately 15% less energy than the M203x9.7 (M8x6.5) posts with an embedment depth of 106.68 cm (42 in.), CMPB-8 and CMPB-10, while having a similar displacement at which the curves tended to level off.

Analysis of the energy-deflection curves at 7.5 degrees indicates there is still a dependence on embedment depth. The M203x9.7 (M8x6.5) posts dissipated approximately 60% more energy than the S76x8.5 (S3x5.7) post, but the difference in energy dissipated between CMPB-12 and CMPB-13, M203x9.7 (M8x6.5) posts with embedment depths of 106.68 cm (42 in.) and 91.44 cm (36 in.), respectively, is only 7.5%. However, test CMPB-12 has a longer deflection during this phase of testing and is more comparable to the standard cable barrier S76x8.5 (S3x5.7) post.

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 a new cable barrier. This section discusses those parameters.

6.1 Post-Soil Interaction Parameters for CM 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 (9).

BARRIER VII is a computer simulation code used extensively in the roadside safety community to model longitudinal barriers (10,11), 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) (12) in lieu of full-scale testing and is suggested for use in NCHRP Report 350.

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 during a 0° strong axis impact. 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 from the relevant tests are listed in Table 8.

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

Bogie Test No.	Impact		Embedment Depth	Estimated Average Force[1]		Estimated Initial Stiffness[2]
				381 mm of dynamic deflection	597 mm of dynamic deflection	
	Velocity	Angle				
	m/s	degrees	cm	kN	kN	kN/mm
M203x9.7 (M8x6.5) Post Tests						
CMPB-7	8.85	0.0	91.44	27.22	25.89	0.99
CMPB-8	9.57	0.0	106.68	31.05	31.32	0.70
CMPB-10	9.21	0.0	106.68	32.29	32.25	0.60
Average	**9.39**	**0.0**	**106.68**	**31.67**	**31.78**	**0.65**
CMPB-9	9.57	0.0	121.92	38.66	40.57	0.60
S76x8.5 (S3.5.7) Post Tests						
CMPB-14	9.66	0.0	76.20	21.08	18.15	0.40
CMPB-15						

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		Embedment Depth	Estimated Average Force[1] 15 in of dynamic deflection	Estimated Average Force[1] 23 in of dynamic deflection	Estimated Initial Stiffness[2]
	Velocity	**Angle**				
	f/s	**degrees**	**in**	**kips**	**kips**	**kips/in**
M203x9.7 (M8x6.5) Post Tests						
CMPB-7	29.04	0.0	36	6.12	5.82	5.63
CMPB-8	31.39	0.0	42	6.98	7.04	3.97
CMPB-10	30.21	0.0	42	7.26	7.25	3.44
Average	**30.80**	**0.0**	**42.00**	**7.12**	**7.15**	**3.71**
CMPB-9	31.39	0.0	48	8.69	9.12	3.40
S76x8.5 (S3.5.7) Post Tests						
CMPB-14	31.68	0.0	30	4.74	4.08	2.31
CMPB-15						

1 – Determined after initial slope.

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

7. CONCLUSIONS AND RECOMMENDATIONS

Dynamic impact testing of M203x9.7 (M8x6.5) and S76x8.5 (S3x5.7) steel posts at various embedment conditions (depth and material) have been detailed and the results stated. The results provided the basis for a comparison of the two posts. The soil used conformed to AASHTO M 147-65 Gradation “B” specifications.

Impacts in the concrete sleeve indicated the M203x9.7 (M8x6.5) post can withstand a higher impact force before it begins to fail at 0 and 15 degrees and having a very similar force magnitude at 30 degrees when compared with the S76x8.5 (S3x5.7) steel post. The duration of the reaction forces during this portion of testing for both posts was very comparable.

Impacts in soil showed there were measurable differences in the reaction force magnitude and duration between the two types of posts. As a result of measurable differences of the impact forces, the amount of energy dissipated also differed. The M203x9.7 (M8x6.5) posts were shown to have dissipated more energy in each type of impact than the S76x8.5 (S3x5.7) posts.

Based on the results presented herein, it appears that the M203x9.7 (M8x6.5) steel post with an embedment depth of 106.68 cm (42 in.) may have more desirable dynamic characteristics and should be considered as a possible replacement post for the S76x8.5 (S3x5.7) post in the cable median barrier.

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

CMPB Test Parameters
CMP: Cable Median Post
Test: Strong Axis Impact at Various Angles & Embedment Conditions
Accelerometer: EDR-4 Data
Bogie Weight: 613.7 kg (1,353 lbs)
Bumper Height: 55 cm (21.65 in.)
Posts: M230x9.7 (M8x6.5) Steel and S76x8.5 (S3x5.7) Steel
Post Length: 180.34 cm (71 in.) and 160 cm (63 in.), respectively

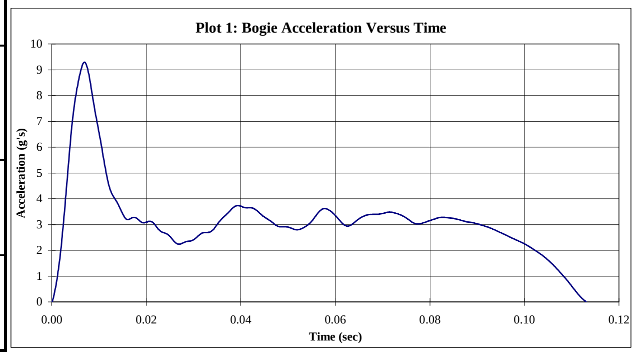
Table 10. Post Testing Results Reference

Test No.	**Impact Angle**	**Velocity**		**Embedment Depth**		**Post Type**	**Figure Number**
		mph	m/s	inches	cm		
CMPB-1	0	22.1	9.88	37	93.98	M203x9.7 (M8x6.5)	Figure 34
CMPB-2	15	20.9	9.34	37	93.98	M203x9.7 (M8x6.5)	Figure 35
CMPB-3	30	20.5	9.16	37	93.98	M203x9.7 (M8x6.5)	Figure 36
CMPB-4	15	21.6	9.66	30	76.2	S76x8.5 (S3x5.7)	Figure 37
CMPB-5	30	20.7	9.25	30	76.2	S76x8.5 (S3x5.7)	Figure 38
CMPB-6	0	19.8	8.85	30	76.2	S76x8.5 (S3x5.7)	Figure 39
CMPB-7	0	19.8	8.85	36	91.44	M203x9.7 (M8x6.5)	Figure 40
CMPB-8	0	21.4	9.57	42	106.68	M203x9.7 (M8x6.5)	Figure 41
CMPB-9	0	21.4	9.57	48	121.92	M203x9.7 (M8x6.5)	Figure 42
CMPB-10	0	20.6	9.21	42	106.68	M203x9.7 (M8x6.5)	Figure 43
CMPB-11	15	21.6	9.66	42	106.68	M203x9.7 (M8x6.5)	Figure 44
CMPB-12	7.5	21.6	9.66	42	106.68	M203x9.7 (M8x6.5)	Figure 45
CMPB-13	7.5	20.8	9.30	36	91.44	M203x9.7 (M8x6.5)	Figure 46
CMPB-14	0	21.6	9.66	30	76.2	S76x8.5 (S3x5.7)	Figure 47
CMPB-15	7.5	20.1	8.99	30	76.2	S76x8.5 (S3x5.7)	Figure 48

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees, in Concrete		
Test Number:	CMPB-1		
Test Date:	12-Dec-2002		
Failure Type:	Major Web Buckling, Tearing, Bogie Launched		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67 metric		M8x6.5
Post Length:	180.3 cm		(71.0 in)
Embedment Depth:	94.0 cm		(37.0 in)
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³		#VALUE!
Bogie Properties			
Impact Velocity:	9.9 m/s	(22.1 mph)	(32.4 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		



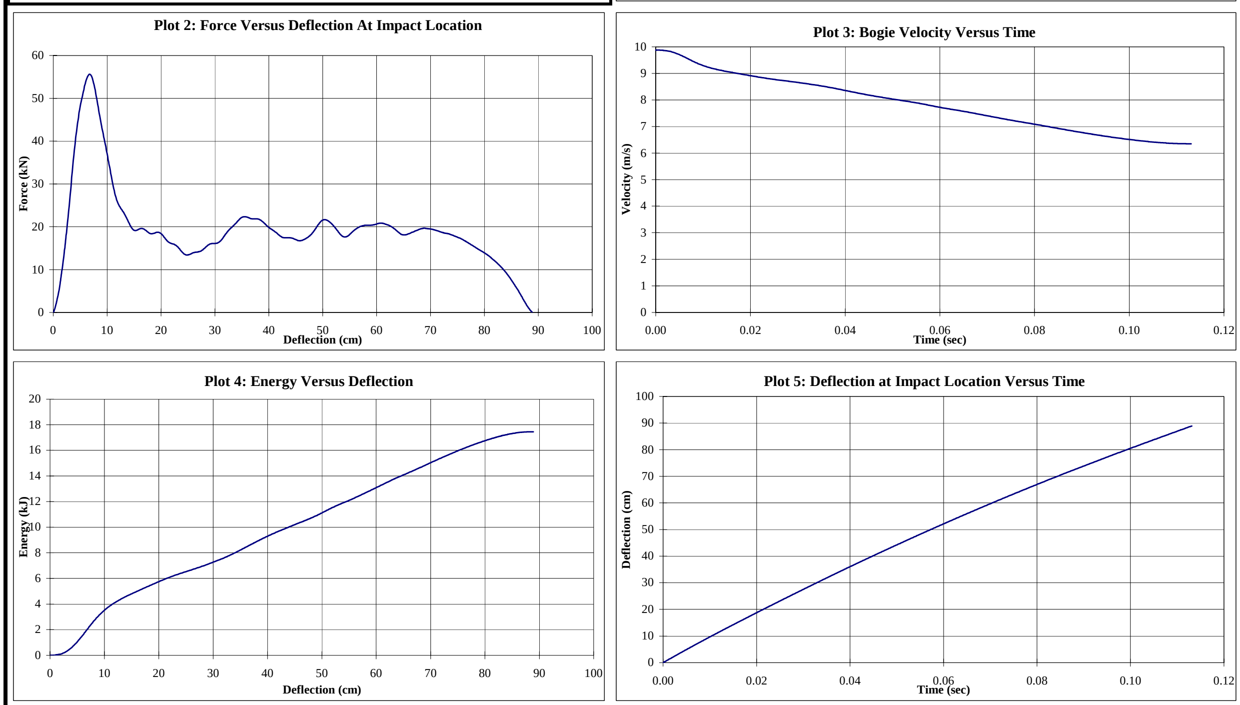
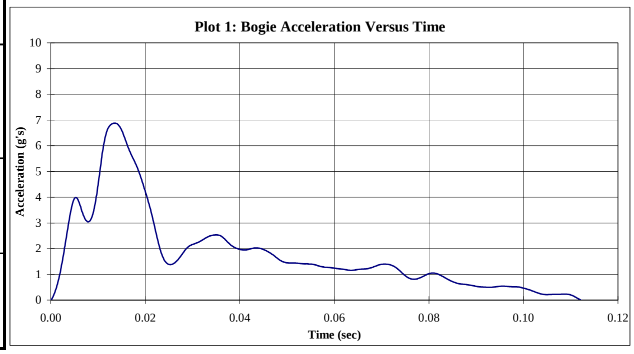


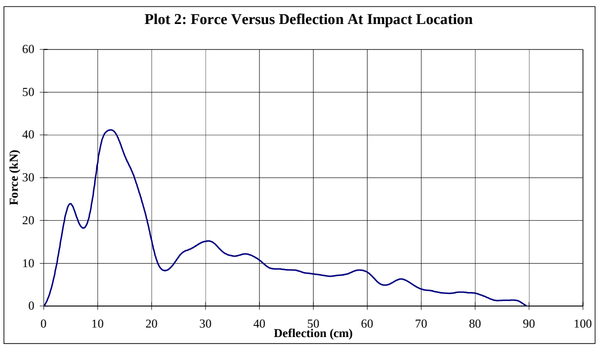
Figure 34. Results of CMPB-1

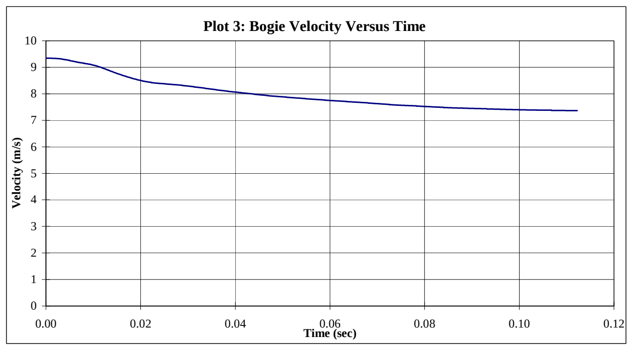
Midwest Roadside Safety Facility

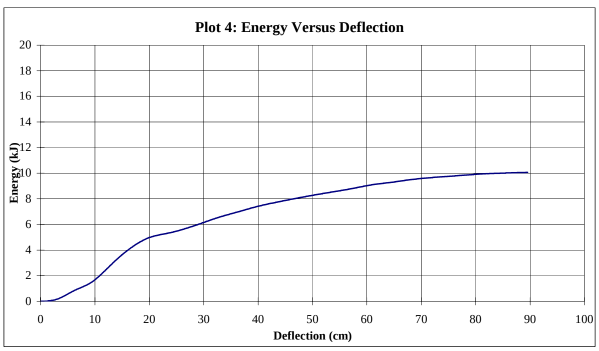
Bogie Test Summary

Test Information	Strong Axis Impact @ 15 degrees, in Concrete		
Test Number:	CMPB-2		
Test Date:	12-Dec-2002		
Failure Type:	Twists/Bends, Minor Lifting of Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67 metric	M8x6.5	
Post Length:	180.3 cm	(71.0 in)	
Embedment Depth:	94.0 cm	(37.0 in)	
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	9.3 m/s	(20.9 mph)	(30.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









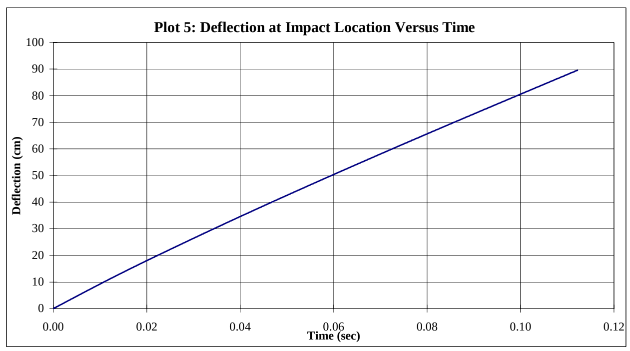
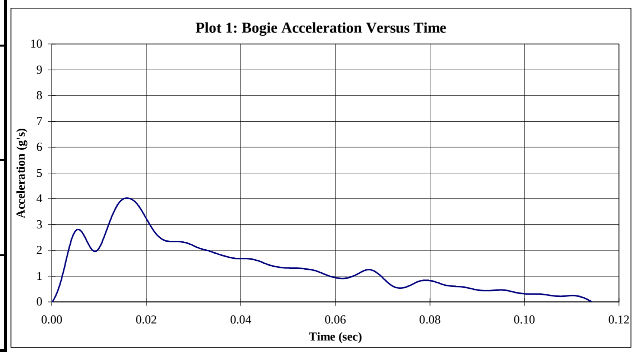


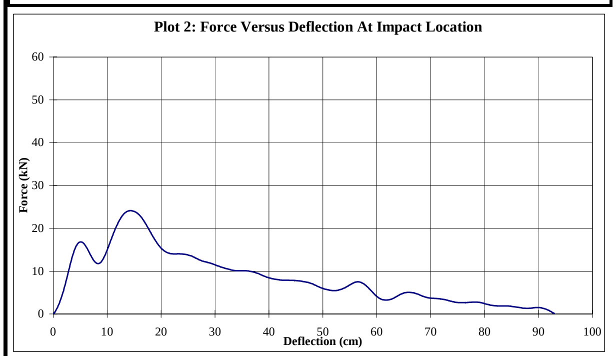
Figure 35. Results of CMPB-2

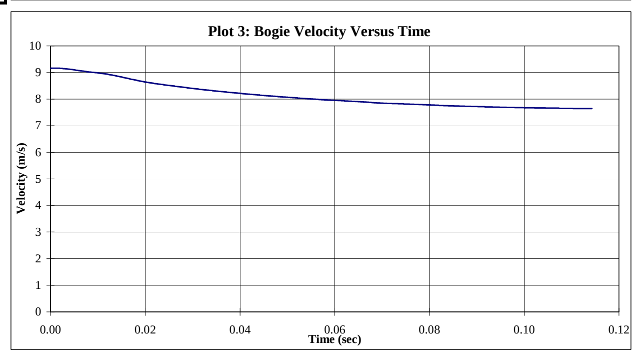
Midwest Roadside Safety Facility

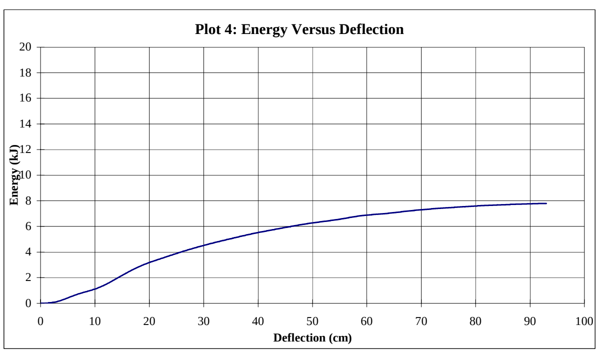
Bogie Test Summary

Test Information	Strong Axis Impact @ 30 degrees, in Concrete		
Test Number:	CMPB-3		
Test Date:	12-Dec-2002		
Failure Type:	Twists/Bends, Minor Lifting of Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67 metric		M8x6.5
Post Length:	180.3 cm		(71.0 in)
Embedment Depth:	94.0 cm		(37.0 in)
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³		#VALUE!
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.5 mph)	(30.1 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









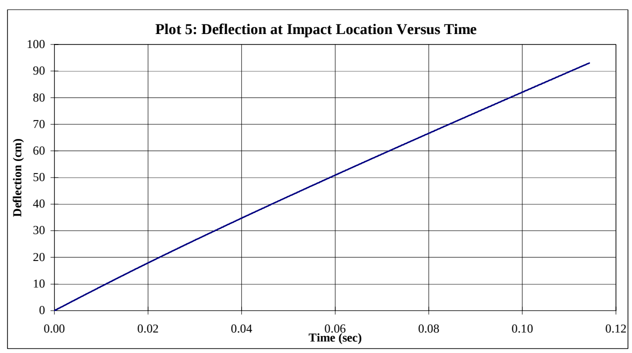
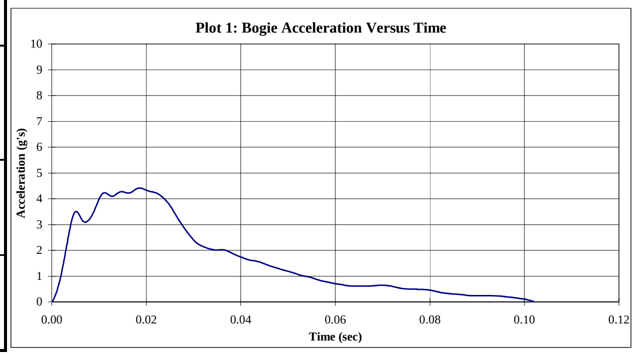


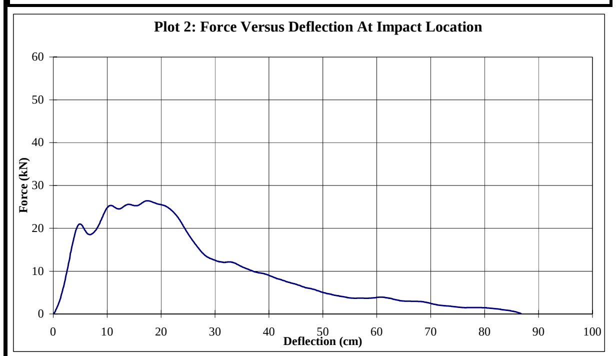
Figure 36. Results of CMPB-3

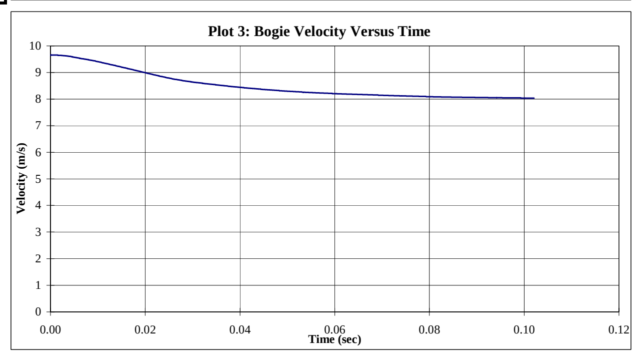
Midwest Roadside Safety Facility

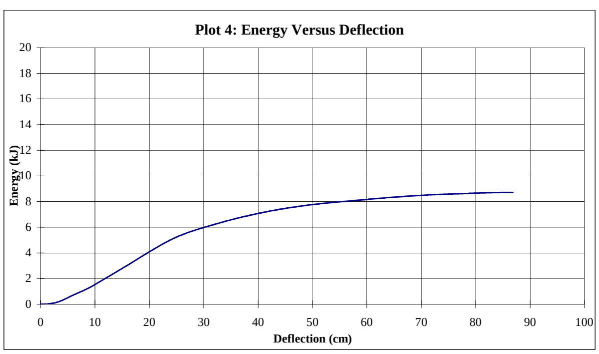
Bogie Test Summary

Test Information	Strong Axis Impact @ 15 degrees, in Concrete		
Test Number:	CMPB-4		
Test Date:	12-Dec-2002		
Failure Type:	Twists/Bends, Minor Lifting of Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	S3x5.7 metric	S3x5.7	
Post Length:	180.3 cm	(71.0 in)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	9.7 m/s	(21.6 mph)	(31.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









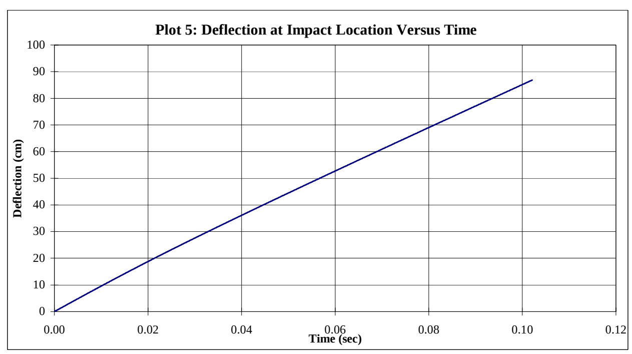
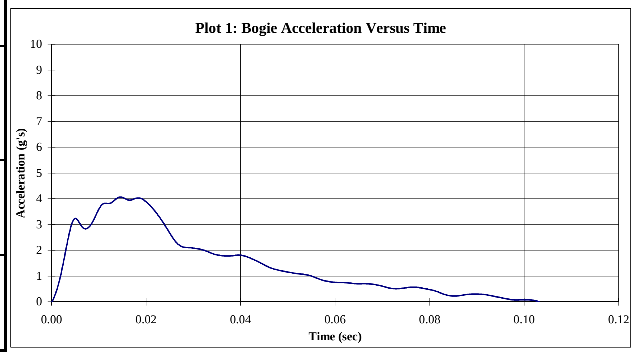


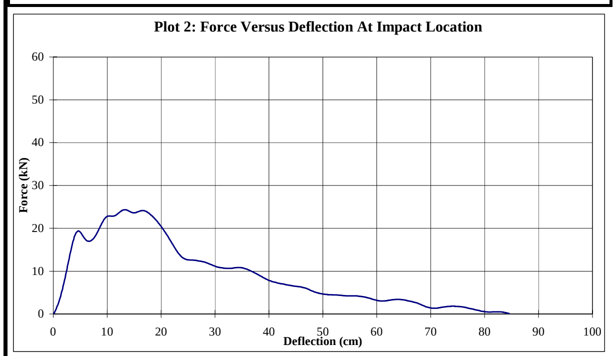
Figure 37. Results of CMPB-4

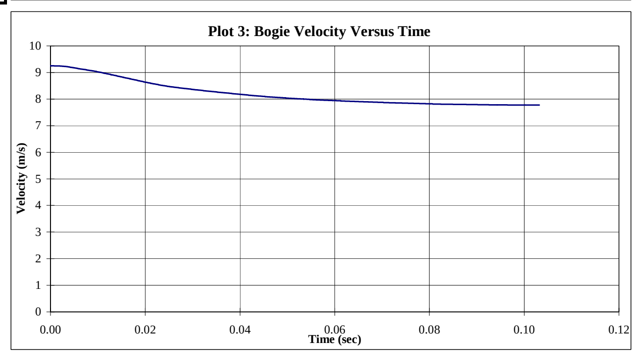
Midwest Roadside Safety Facility

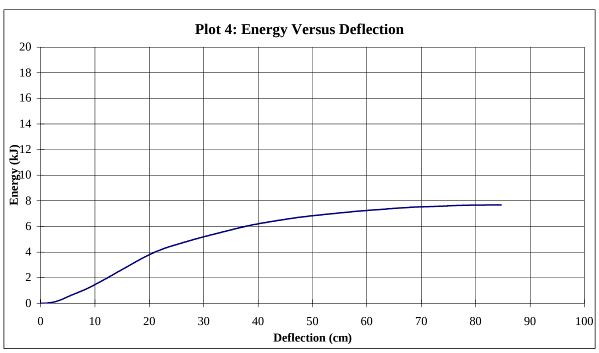
Bogie Test Summary

Test Information	Strong Axis Impact @ 30 degrees, in Concrete		
Test Number:	CMPB-5		
Test Date:	12-Dec-2002		
Failure Type:	Twists/Bends, Minor Lifting of Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	S76x8.5 metric		S3x5.7
Post Length:	180.3 cm		(71.0 in)
Embedment Depth:	76.2 cm		(30.0 in)
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m^3		#VALUE!
Bogie Properties			
Impact Velocity:	9.3 m/s	(20.7 mph)	(30.4 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









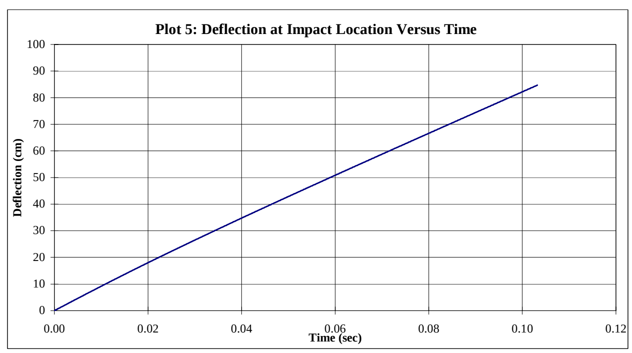
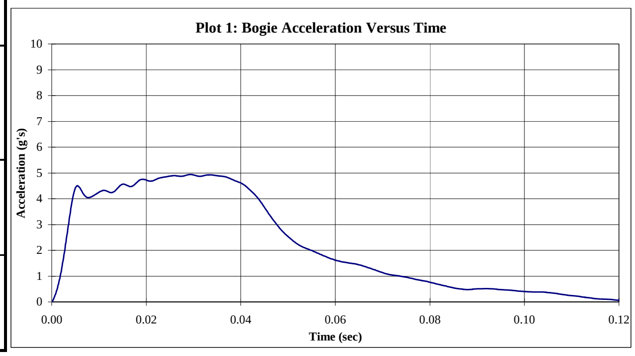


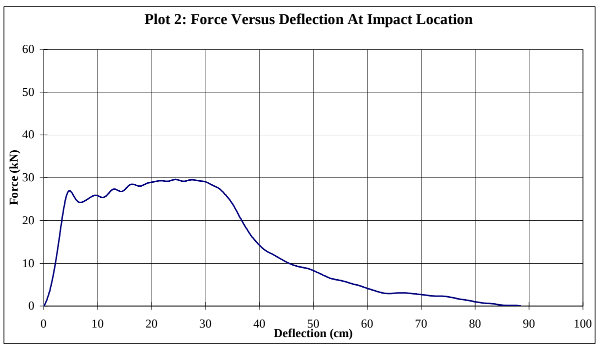
Figure 38. Results of CMPB-5

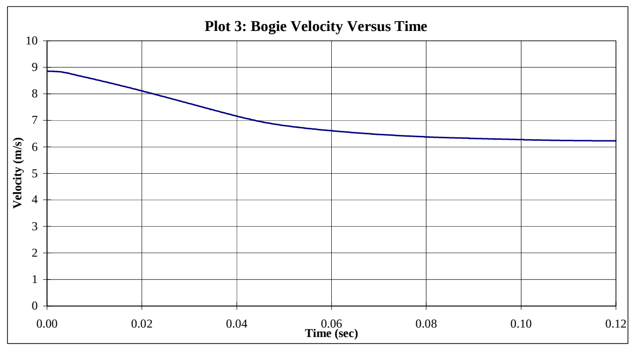
Midwest Roadside Safety Facility

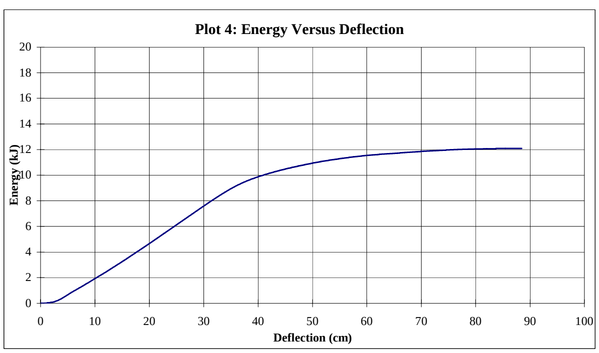
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees, in Concrete		
Test Number:	CMPB-6		
Test Date:	12-Dec-2002		
Failure Type:	Bends, then Twists, Lifts Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	S76x8.5 metric	S3x5.7	
Post Length:	180.3 cm	(71.0 in)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	8.9 m/s	(19.8 mph)	(29.0 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	611 kg	(1346 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









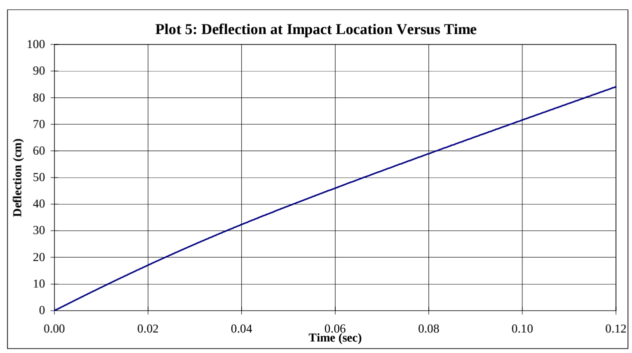
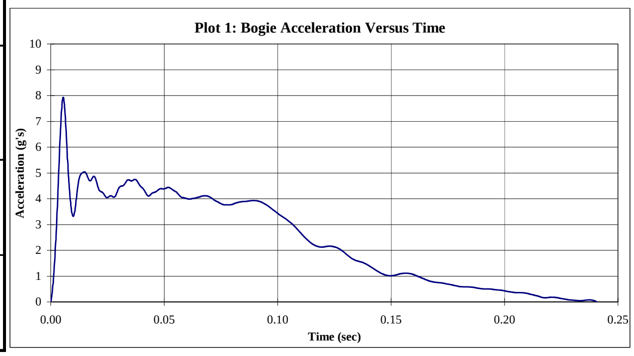


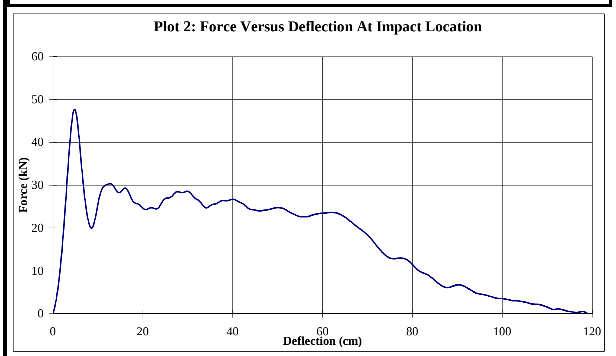
Figure 39. Results of CMPB-6

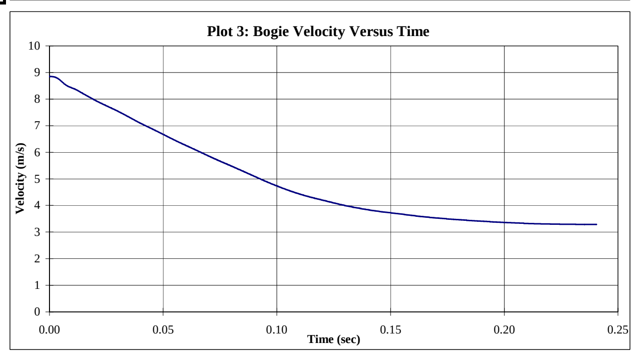
Midwest Roadside Safety Facility

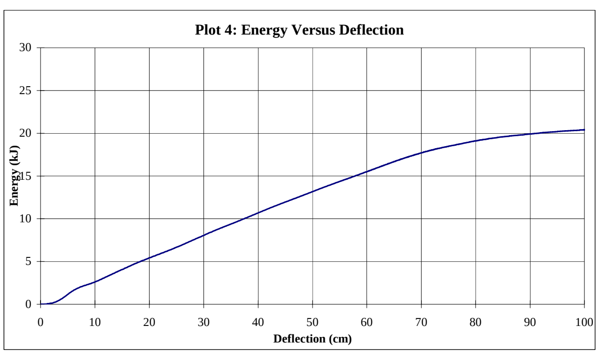
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees, in Soil		
Test Number:	CMPB-7		
Test Date:	4/2003 and 5/2003		
Failure Type:	Rotate in Soil, Minor Bend		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67 metric		M8x6.5
Post Length:	180.3 cm		(71.0 in)
Embedment Depth:	91.4 cm		(36.0 in)
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³		#VALUE!
Bogie Properties			
Impact Velocity:	8.9 m/s	(19.8 mph)	(29.0 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	614 kg	(1353 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









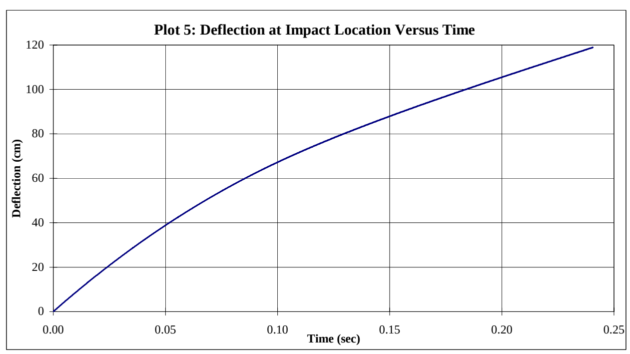
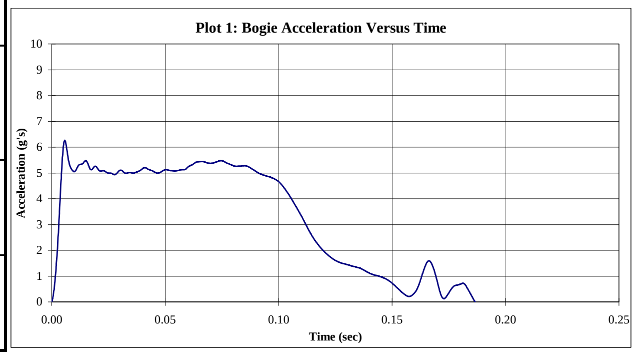


Figure 40. Results of CMPB-7

Midwest Roadside Safety Facility

Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees, in Soil		
Test Number:	CMPB-8		
Test Date:	4/2003 and 5/2003		
Failure Type:	Rotates in Soil, then Twists/Bends some, Lifts Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67	metric	M8x6.5
Post Length:	180.3	cm	(71.0 in)
Embedment Depth:	106.7	cm	(42.0 in)
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.6 m/s	(21.4 mph)	(31.4 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	614 kg	(1353 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		



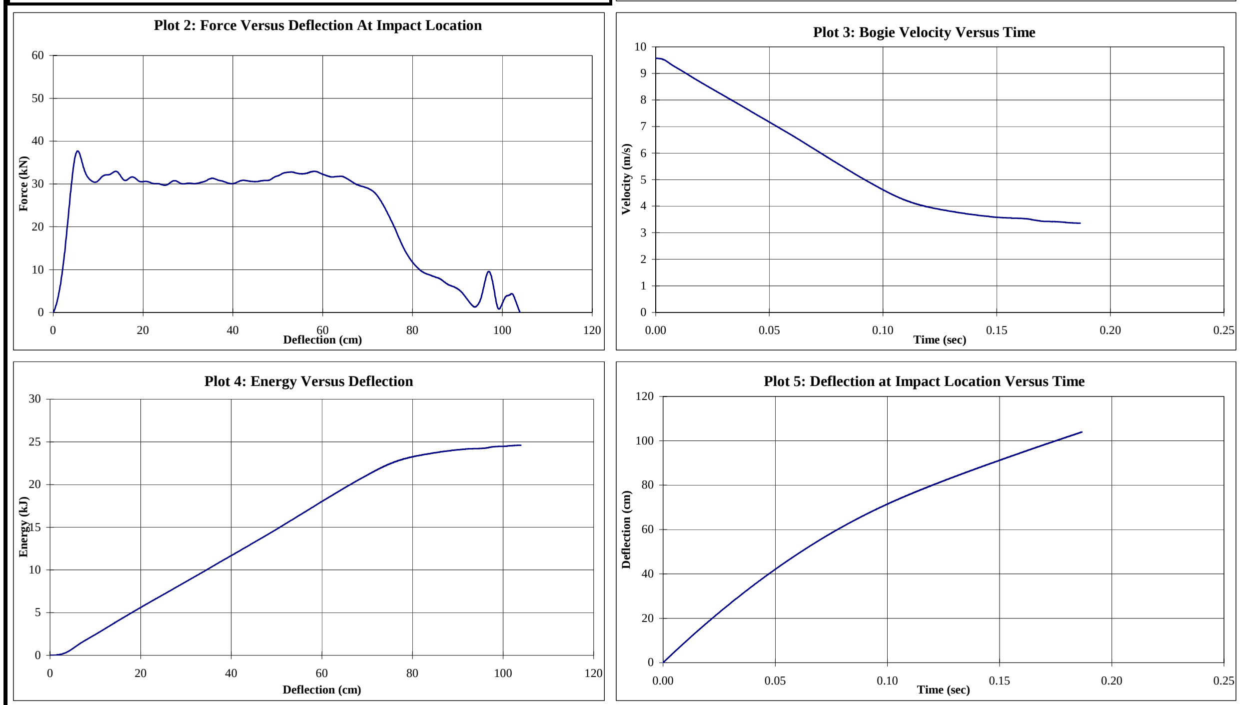
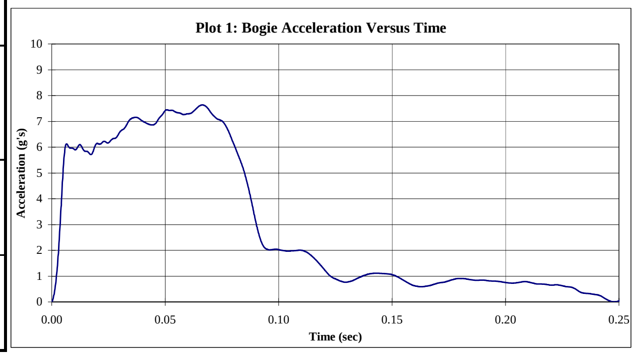


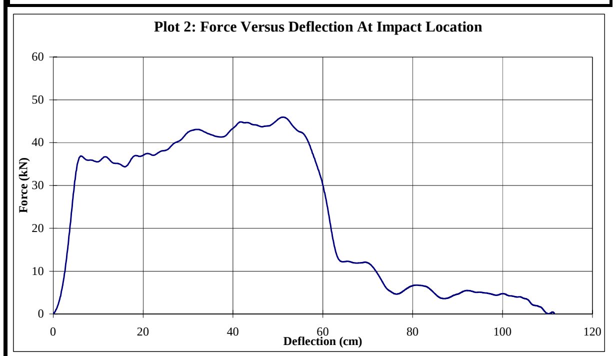
Figure 41. Results of CMPB-8

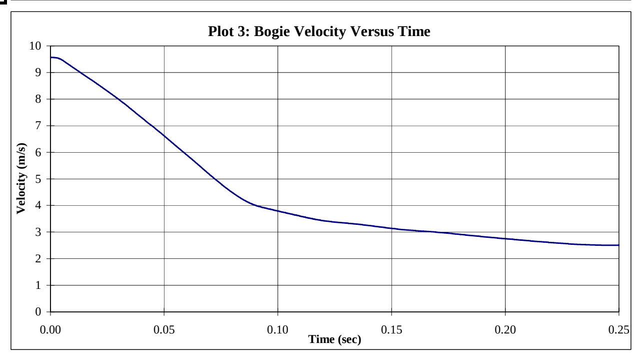
Midwest Roadside Safety Facility

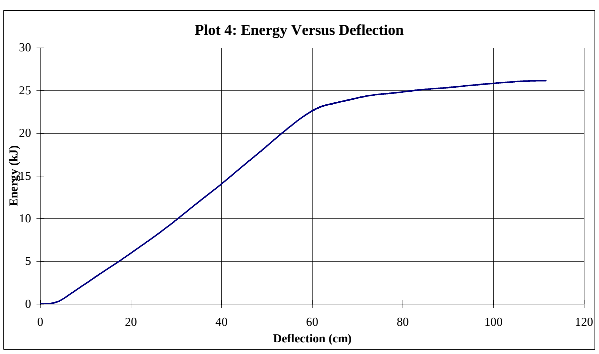
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees, in Soil		
Test Number:	CMPB-9		
Test Date:	4/2003 and 5/2003		
Failure Type:	Rotates in Soil, then Twists/Bends some, Lifts Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67	metric	M8x6.5
Post Length:	180.3	cm	(71.0 in)
Embedment Depth:	121.9	cm	(48.0 in)
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	9.6 m/s	(21.4 mph)	(31.4 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	614 kg	(1353 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









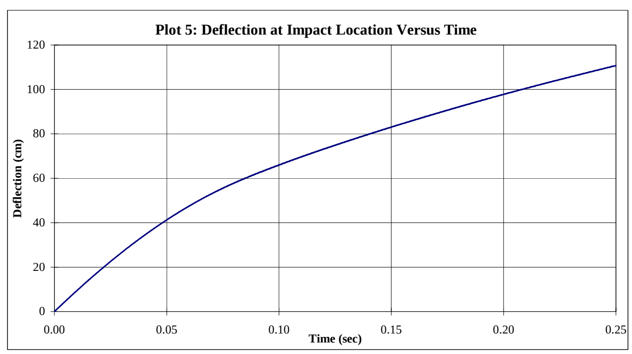
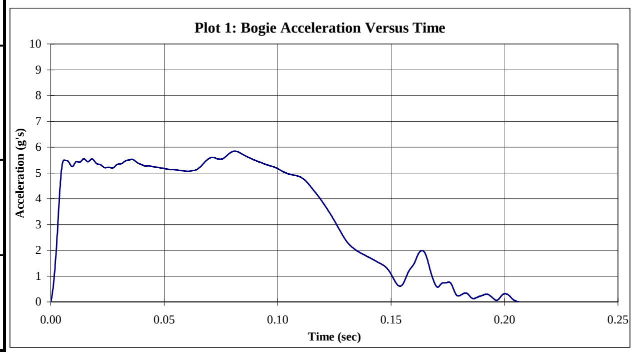


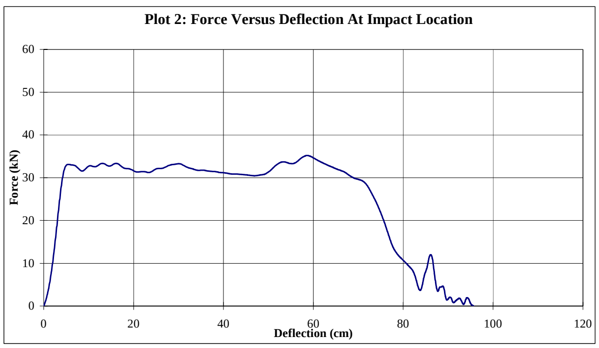
Figure 42. Results of CMPB-9

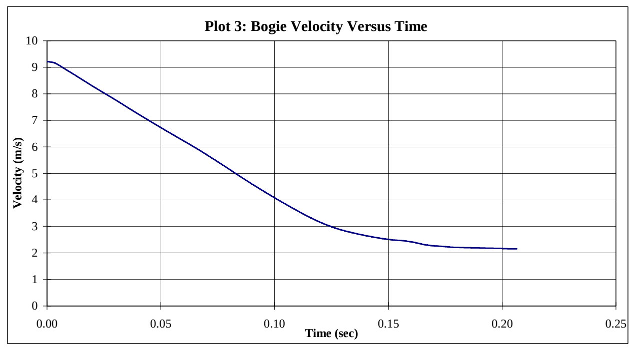
Midwest Roadside Safety Facility

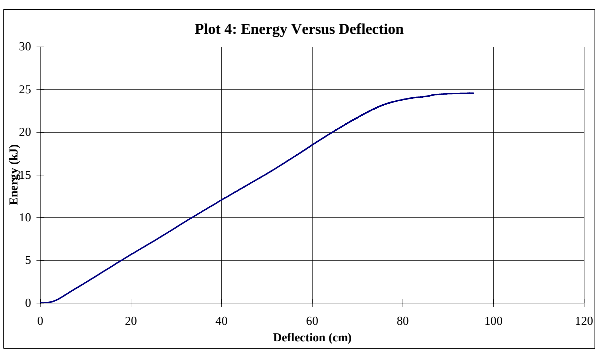
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees, in Soil		
Test Number:	CMPB-10		
Test Date:	4/2003 and 5/2003		
Failure Type:	Rotates in Soil, Lifts Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67	metric	M8x6.5
Post Length:	180.3	cm	(71.0 in)
Embedment Depth:	106.7	cm	(42.0 in)
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.2 m/s	(20.6 mph)	(30.2 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	614 kg	(1353 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









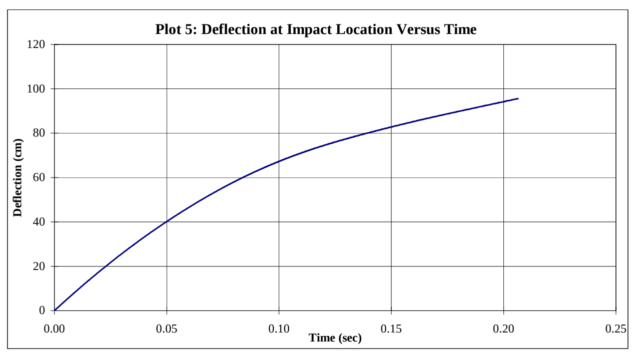
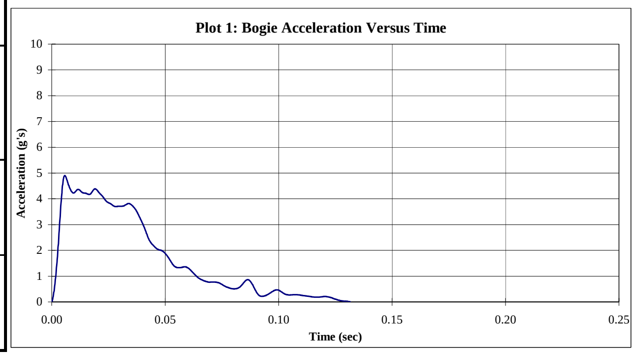


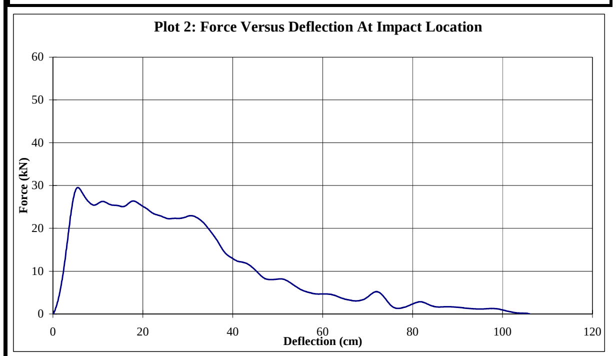
Figure 43. Results of CMPB-10

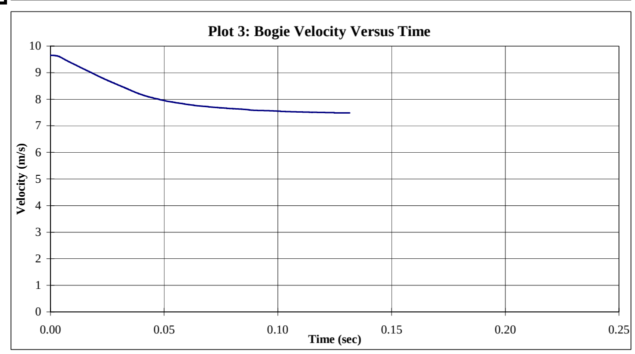
Midwest Roadside Safety Facility

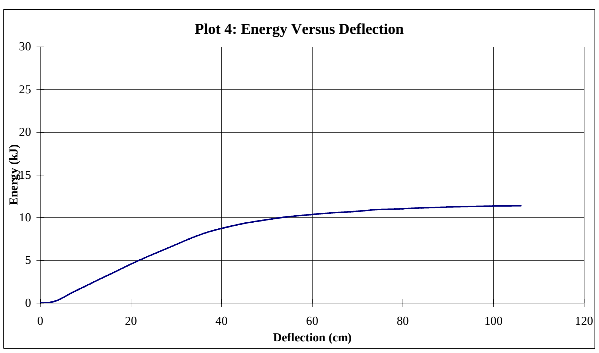
Bogie Test Summary

Test Information	Strong Axis Impact @ 15 degrees, in Soil		
Test Number:	CMPB-11		
Test Date:	4/2003 and 5/2003		
Failure Type:	Some Rotation in Soil, Increased Bending, Minimal Bogie Lifting		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67	metric	M8x6.5
Post Length:	180.3	cm	(71.0 in)
Embedment Depth:	106.7	cm	(42.0 in)
Soil Properties			
Gradation:			NA
Moisture Content:			NA
Compaction Method:			NA
Soil Density, γ_d:	NA	kg/m³	#VALUE!
Bogie Properties			
Impact Velocity:	9.7 m/s	(21.6 mph)	(31.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	614 kg	(1353 lbf)	
Data Acquired			
Accelerometer Data:			EDR-4
Camera Data:			Side Views-Digital and ecam









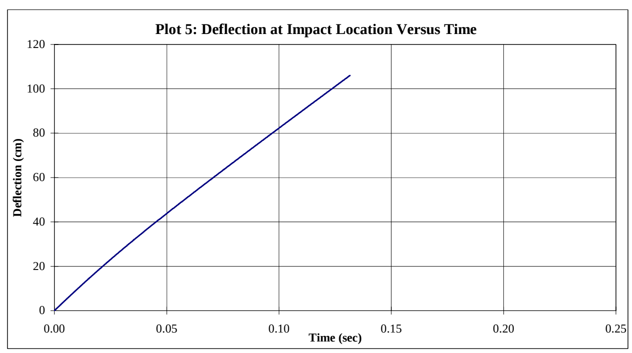
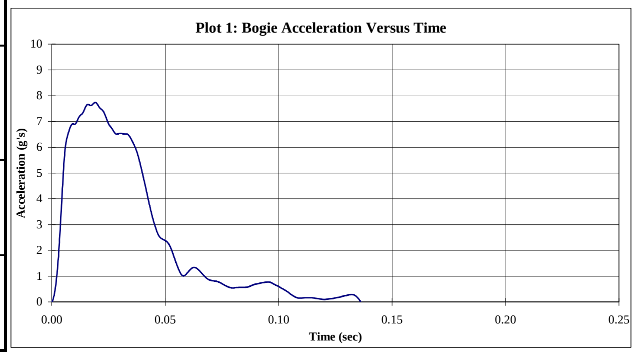


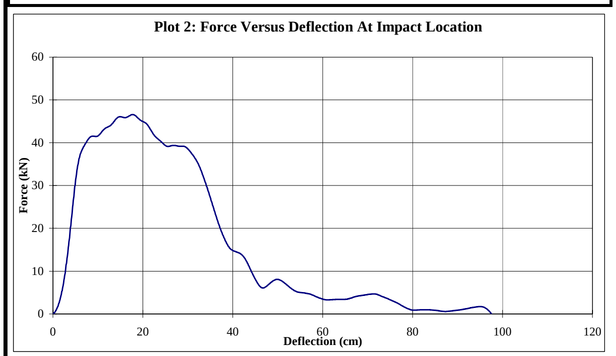
Figure 44. Results of CMPB-11

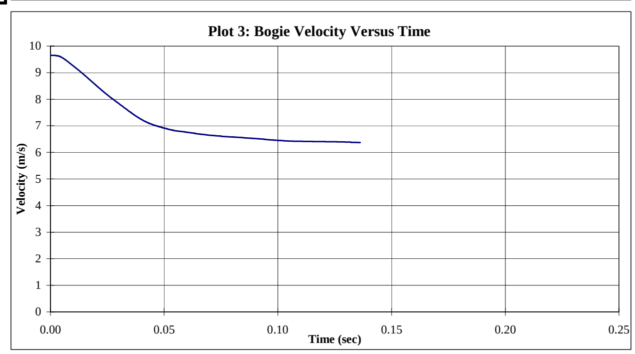
Midwest Roadside Safety Facility

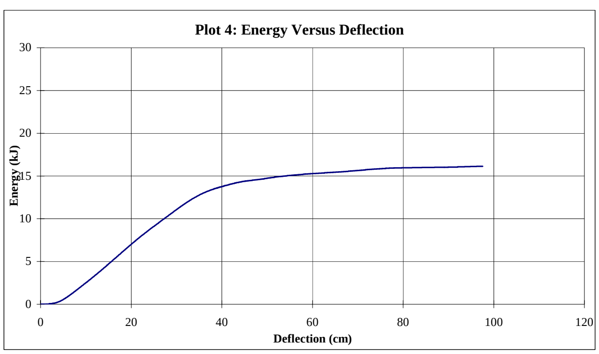
Bogie Test Summary

Test Information	Strong Axis Impact @ 7.5 degrees, in Soil		
Test Number:	CMPB-12		
Test Date:	4/2003 and 5/2003		
Failure Type:	Rotates in Soil, Twists/Bends, Minor Lifting of Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67 metric		M8x6.5
Post Length:	180.3 cm		(71.0 in)
Embedment Depth:	106.7 cm		(42.0 in)
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m³		#VALUE!
Bogie Properties			
Impact Velocity:	9.7 m/s	(21.6 mph)	(31.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	614 kg	(1353 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









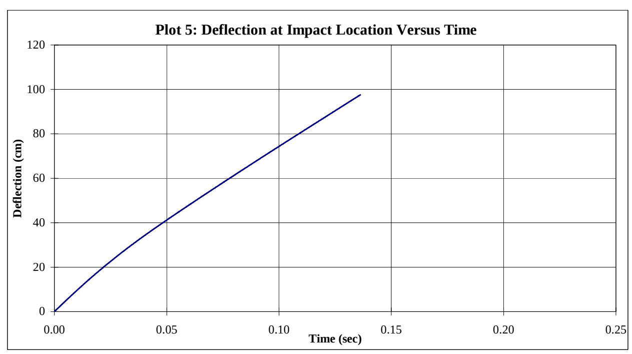
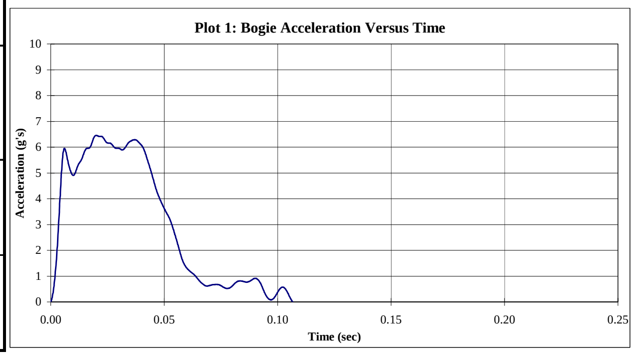


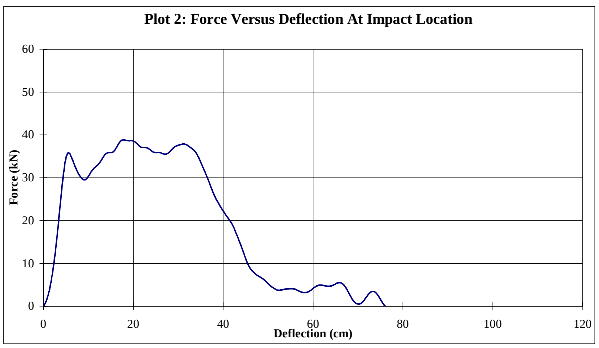
Figure 45. Results of CMPB-12

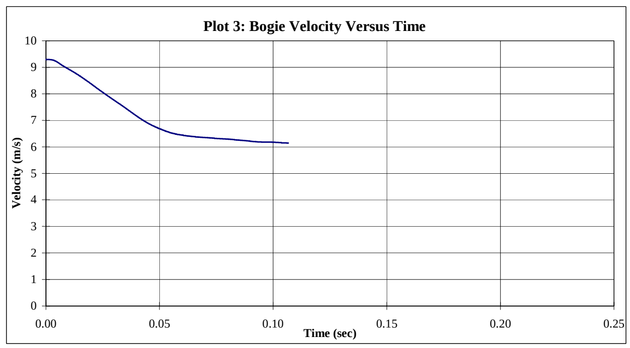
Midwest Roadside Safety Facility

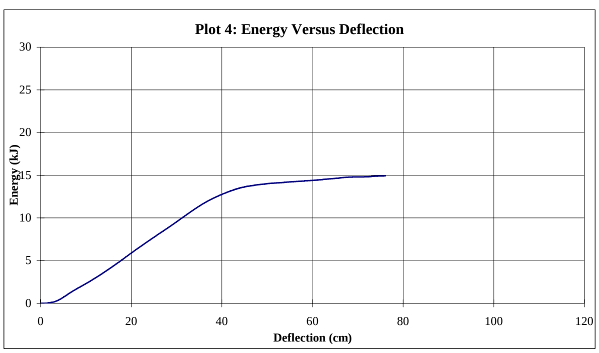
Bogie Test Summary

Test Information	Strong Axis Impact @ 7.5 degrees, in Soil		
Test Number:	CMPB-13		
Test Date:	4/2003 and 5/2003		
Failure Type:	Rotates in Soil, Twists/Bends, Minor Lifting of Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	M203x9.67	metric	M8x6.5
Post Length:	180.3	cm	(71.0 in)
Embedment Depth:	91.4	cm	(36.0 in)
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA	kg/m^3	#VALUE!
Bogie Properties			
Impact Velocity:	9.3 m/s	(20.8 mph)	(30.5 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	614 kg	(1353 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









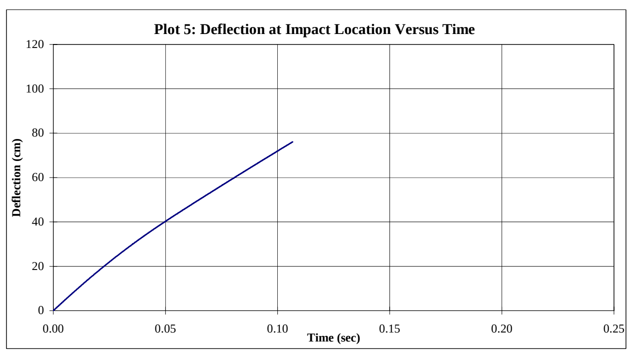
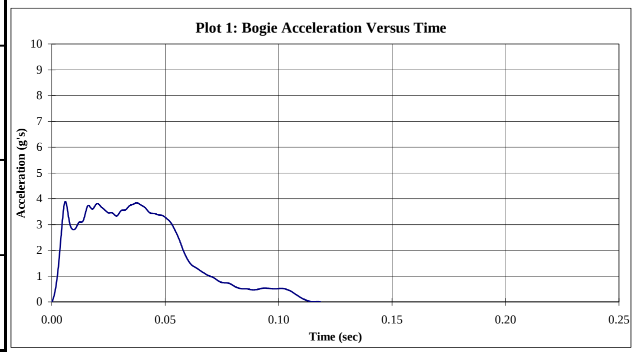


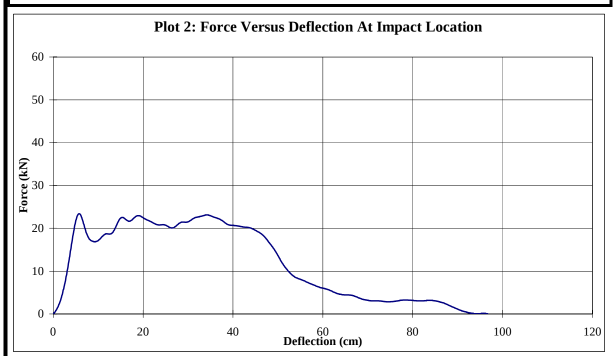
Figure 46. Results of CMPB-13

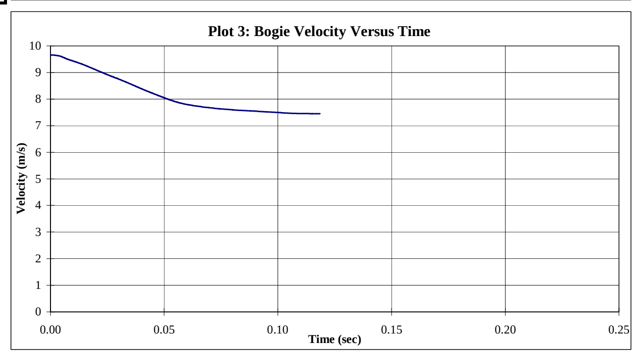
Midwest Roadside Safety Facility

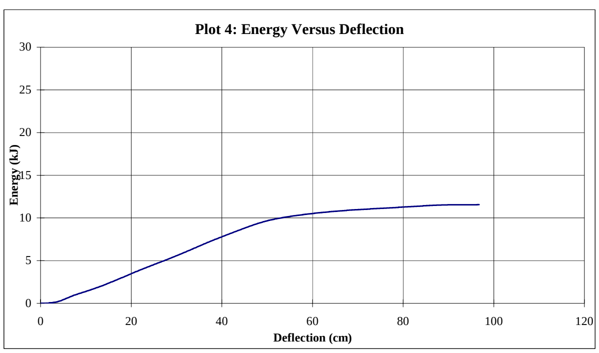
Bogie Test Summary

Test Information	Strong Axis Impact @ 0 degrees, in Soil		
Test Number:	CMPB-14		
Test Date:	28-May-2003		
Failure Type:	Rotates in Soil, Twists/Bends, Minor Lifting of Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	S76x8.5 metric	S3x5.7	
Post Length:	160.0 cm	(63.0 in)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Gradation:	NA		
Moisture Content:	NA		
Compaction Method:	NA		
Soil Density, γ_d:	NA kg/m³	#VALUE!	
Bogie Properties			
Impact Velocity:	9.7 m/s	(21.6 mph)	(31.7 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	614 kg	(1353 lbf)	
Data Acquired			
Accelerometer Data:	EDR-4		
Camera Data:	Side Views-Digital and ecam		









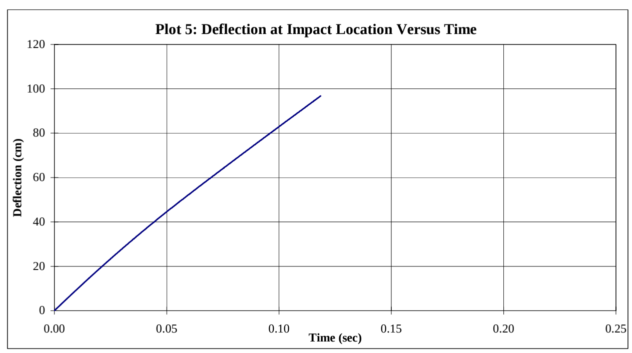
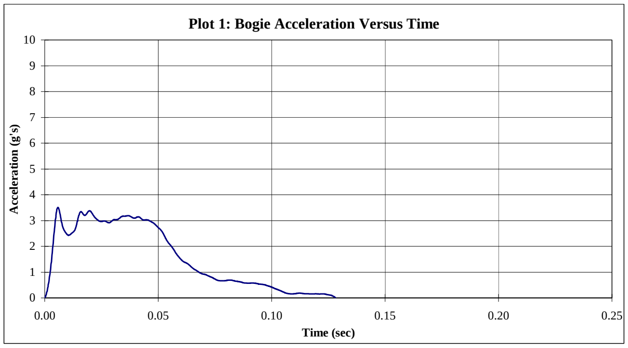


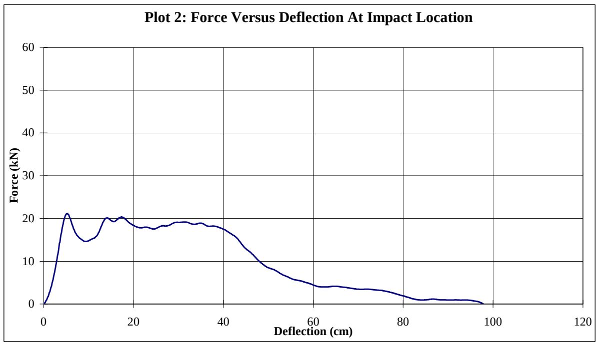
Figure 47. Results of CMPB-14

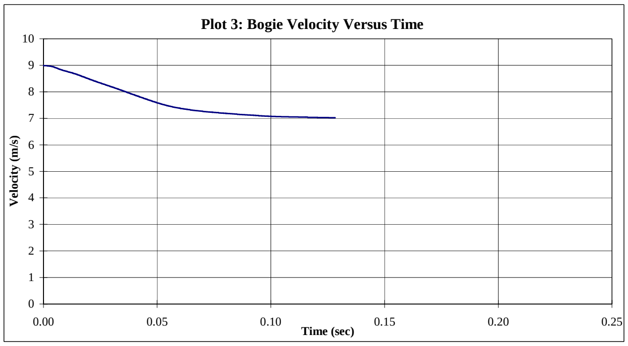
Midwest Roadside Safety Facility

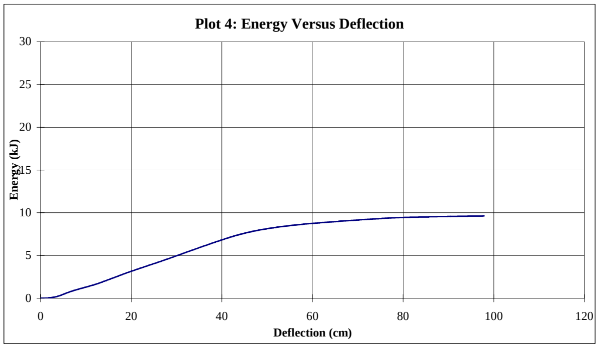
Bogie Test Summary

Test Information	Strong Axis Impact @ 7.5 degrees, in Soil		
Test Number:	CMPB-15		
Test Date:	28-May-2003		
Failure Type:	Rotates in Soil, Twists/Bends, Minor Lifting of Bogie		
Post Properties			
Post Type:	Steel		
Post Size:	S76x8.5 metric	S3x5.7	
Post Length:	160.0 cm	(63.0 in)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Gradation:		NA	
Moisture Content:		NA	
Compaction Method:		NA	
Soil Density, γ_d:	NA kg/m^3	#VALUE!	
Bogie Properties			
Impact Velocity:	9.0 m/s	(20.1 mph)	(29.5 fps)
Impact Location:	55.0 cm	(21.7 in)	above groundline
Bogie Mass:	614 kg	(1353 lbf)	
Data Acquired			
Accelerometer Data:		EDR-4	
Camera Data:	Side Views-Digital and ecam		









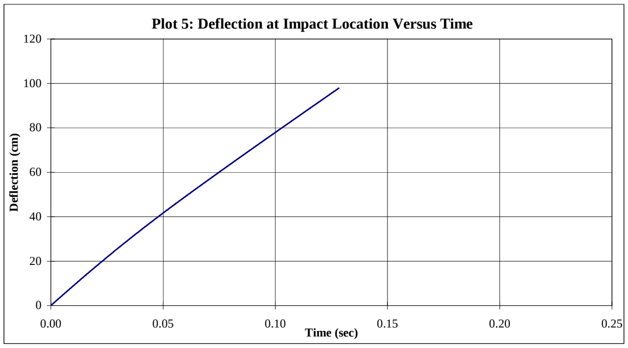


Figure 48. Results of CMPB-15