DYNAMIC IMPACT TESTING

OF

S 75 x 8.5 STEEL POSTS

(Cable Barrier Posts)

Submitted by

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Weak steel posts are used in a variety of applications, the significant one being the Three Strand Cable Barrier. Bogie impact testing of weak steel post under various soil conditions was studied.

Seventeen crash tests were performed using a bogie weighing 1014 kgs and post impact depth set at 762 mm. The first set of tests, test CPB-2 through CPB-4, were strong axis hits on a standard S75x8.5 steel sections in standard 350 soil. The second set of tests, test CPB-5 through CPB-7 were weak axis impact tests in standard 350 soil. Tests CPB-8 and CPB-9 were strong axis impacts of the posts in native soil, while tests CPB-10 and CPB-11 were weak axis hits in native soil. The next set of tests consisted of the S-section embedded in a sleeve on concrete. The strong axis impacts were tests CPB-12 through CPB-14, while CPB-15 to CPB-17 were weak axis impact tests.

The accelerometer meter data was processed and force-deflection curves for the various tests were plotted and discussed. Conclusions were drawn from the discussions.

Note: Due to a data processing error this report replaces the report of June 28, 2002 (same Title and number). Changes consist of new Tables 2 and 3, and an entirely new Appendix A.

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The contents of this report reflect the views of the author(s) who is/are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration nor State Highway Departments participating in the Midwest States Regional Pooled Fund. This report does not constitute a standard, specification, or regulation.

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TABLE OF CONTENTS

List of Figures

1. PHYSICAL TESTING

1.1 Introduction

Physical testing of cable guardrail posts (S75 x8.5 S-section) was performed at the Midwest Roadside Safety Facility's (MwRSF) outdoor testing facility located at the Lincoln airpark. This site, located in the northwest direction of Lincoln Municipal Airport, provides excellent equipment and conducive atmosphere to conduct physical tests. The tarmac is appropriately cut out at the east end to house the post and provide a sufficient length for the bogie to operate.

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.

1.2 Objective

The objective of the research project was to determine the behavior of the S75 x 8.5 S-section steel posts under impact loading conditions.

1.3 Scope

The research objective was achieved by performing several tasks. First, bogie crash tests were performed on the steel post at two impact angles and under various soil conditions. A total of seventeen crash tests were performed. The target impact conditions for all the crash tests were a speed of 32 km/h and an angle of either 0.0 degrees or 90.0 degrees. The test results were analyzed, evaluated, and documented. Conclusions were then drawn that pertain to the behavior of the post under dynamic loading.

2. SYSTEM DETAILS

2.1 The Post

The post under study was the S75 x 8.5 S-section beams manufactured using galvanized ASTM A36 steel with a cross-section in accordance with the A6M standards. The 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 three strand cable barrier systems.

The post primarily consists of the 3 major components: two flanges and webbing. The flange are called either tensile or compressive depending on the type of loading it undergoes upon impact. The two flanges are connected by a webbing, which acts like a force transmitter. The thickness of the webbing is 4.32 mm while the thickness of the flanges are generally 6.35 mm. The total length of the posts tested was 1600 mm with 760 mm embedded in the ground. The various dimensions and thickness are shown in Figure 1. Various material properties for the post are provided in Table 1.

ASTM Designation	**Area A, mm^2 (in^2)**	**Flange Width b_f mm (in)**	**Moment of Inertia I_x mm^4(in^4)**	**Section Modulus S_x mm^3(in^3)**	**Plastic Section Modulus Z_z mm^3(in^3)**
S75x8.5 (S3x7.5)	4175 (1.67)	58.25 (2.33)	1.04×10^6 (2.52)	27.52×10^3 (1.68)	31.95×10^3 (1.95)

Table 1. Material properties of the 75x8.5 S-Section

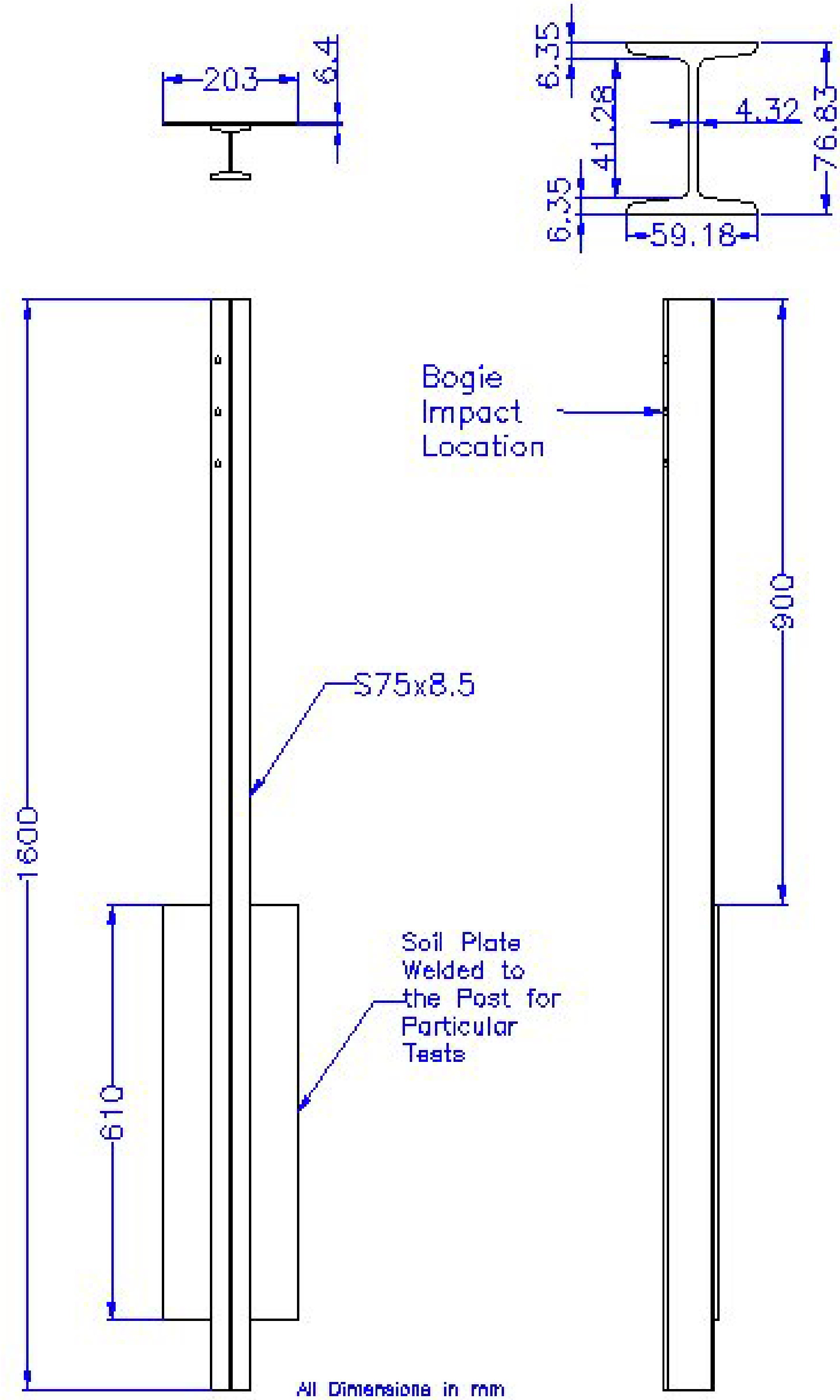


Figure 1. Major dimensions of the S 75x8.5 steel beam

A soil plate was welded to the bottom of the post for all the tests except for tests CPB-15 through CPB-17. The thickness of the 203 mm x 610 mm steel plate was 6.4 mm and it was made up of galvanized mild steel.

2.2 Equipments and Instrumentation

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

- Bogie
- Accelerometer
- Pressure Tape Switches
- High-Speed Photography Camera

2.2.1 Bogie

The bogie is an intricate structure made up of steel tubes welded together. An impact head, made of a 203 mm (8-inches) concrete filled standard steel pipe, was mounted to the bogie at the height of 685 mm (27 inches) above the ground. A 19 mm (3/4 inch) neoprene belting was attached to the steel pipe to minimize the local damage to the post from the impact. The bogie is shown in Figure 2.

The bogie weight was 1014 Kg (2237 lbs). Calculations prior to the testing showed that this weight, in combination with a velocity of approximately 32 kilometers per hour (20 mph or 8.8 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 (60mph), 25 deg impact with a 2040 kg (4500 lbs) car.

Figure 2. Bogie and the test setup

2.2.2 Accelerometer

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

A tri-axial Piezo-resistive accelerometer system with a range of ± 200 g's was mounted on the frame of the bogie at approximately the center of gravity. It measured the accelerations in the longitudinal direction at a sample rate of 3200 Hz. The accelerometer system known as the Model EDR-3 developed by the instrumented sensor technology (IST) of Okemos, Michigan.

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

A laptop computer downloaded the acceleration values immediately following each test. The computer made the use of "DynaMax 1.75" accelerometer software and then loaded into "DaDisp 4.0 " data processing program. 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.

2.2.3 Pressure Tape Switches

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

2.2.4 High Speed Photography Camera

For all the tests high-speed 16-mm Red Lake E/cam video camera, with operating speeds of 500 frames/sec was used to film the impacts.

2.3 Methodology of Testing

A total of 17 tests were carried out along both axes of impact and in different soil conditions. Impact of the post flanges perpendicular to the direction of motion of the bogie head is a strong axis impact, while weak axis impact was when the flanges are parallel to the direction of motion of the bogie head. Graphical representation of the different types of impact is shown in Figure 3.

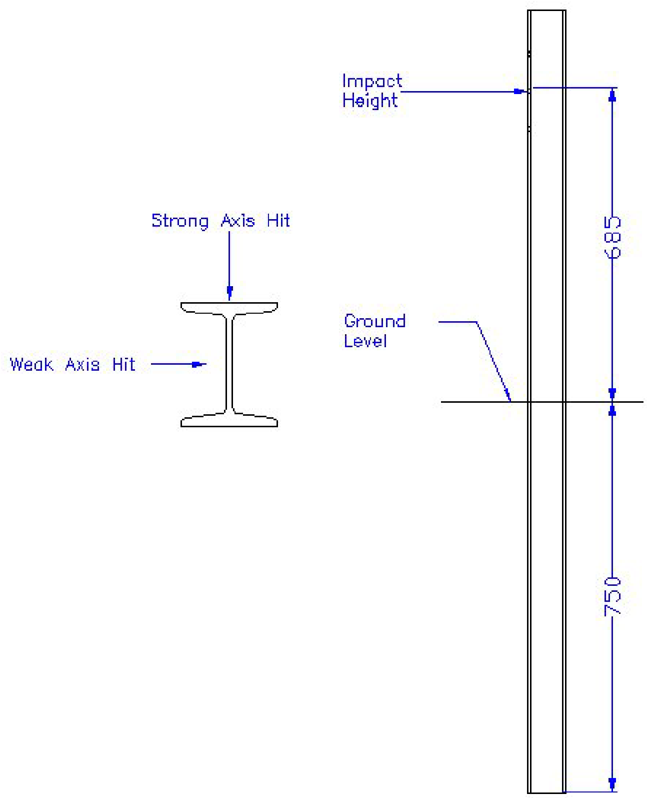


Figure 3. Impact location and types of impacts

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

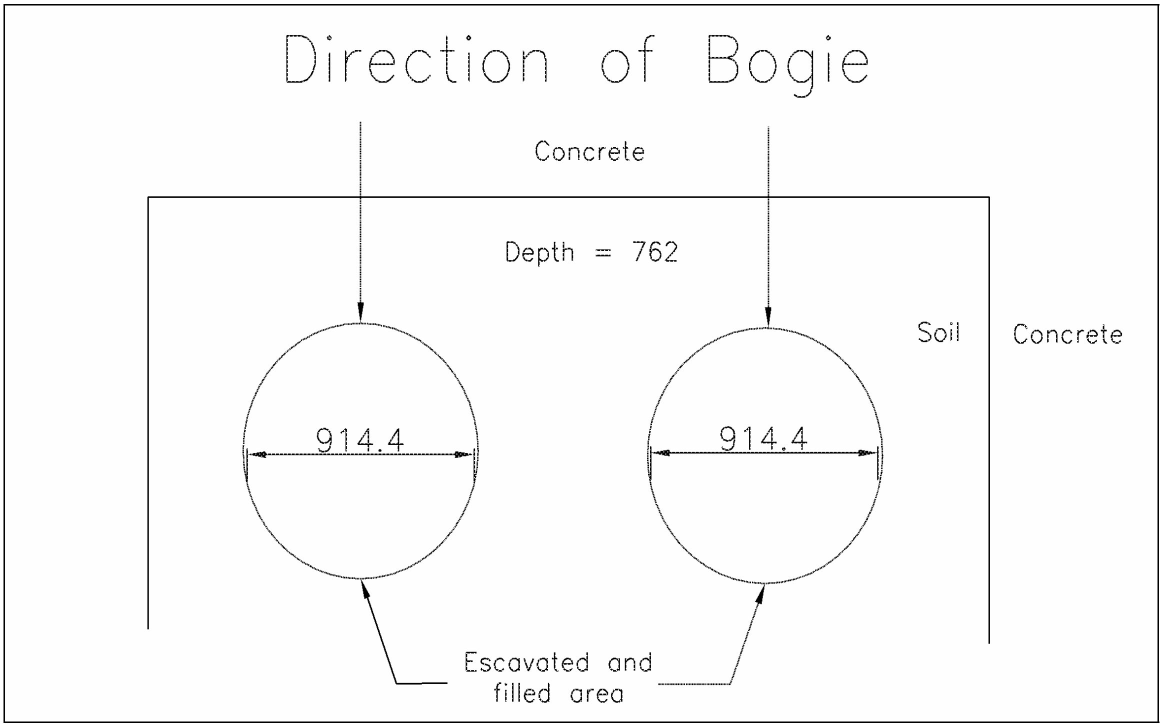


Figure 4. Plan view of the post testing area

For the tests CPB-2 through CPB-7, holes measuring 0.915 meters in diameter and 0.76 meters in depth were dug out in the test area. These holes were filled with soil meeting the AASHTO standard specification for "Materials and Aggregates and Soil Aggregates Sub-base, Base and Surface Courses," designation M147-65 (1990), grading A or B and compacted in accordance with AASHTO guide specifications for highway construction, section 304.05 and 304.07.

The moisture content was relatively dry (4% - 6%) with the primary considerations being the homogeneity, consistency and the ease of compaction. The posts were then driven into the soil as shown in Figure 5. CPB-2, CPB-3 and CPB-4 were strong axis impacts; CPB-5, CPB-6 and CPB-7 were weak impact axis impacts.

Figure 5. Post setup for the CPB-2 through CPB-4 tests

The set up was changed for tests CPB-8 through CPB-11. In these cases the posts were driven in native soil surrounding the test area. CPB-8 and CPB-9 had strong axis orientation while CPB-10 and CPB-11 had weak axis orientation. No moisture samples were taken for the native soil tests.

For tests CPB-12 through CPB-17, a square section was cut out in the tarmac to house the post. The section was lined with 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 act as a footing material. The post, with the woodblock fitted in the steel lining is shown in Figure 6.

Figure 6. Post and woodblock setup for tests CPB-12 through CPB-14

A reverse cable tow system was used to propel the test vehicle. The bogie was accelerated towards the post along a 30 meter long tracking system, which consisted of a steel pipe that was anchored 100 millimeters above the tarmac.

Rollers attached to the underside of the bogie straddled the pipe, ensuring the proper direction and position of the bogie prior to the impact. In all of the tests conducted the bogie wheels were aligned for caster and toe-in values of zero so that the bogie would track properly along the guidance system. A remote braking system was installed on the bogie to allow the bogie to be brought to a complete stop after the test. Accelerometers, located at the bogies center of gravity record lateral, horizontal and vertical acceleration data.

2.4 End of Test Determination

When the bogie overrides the post, the end of the test cannot be 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 7.

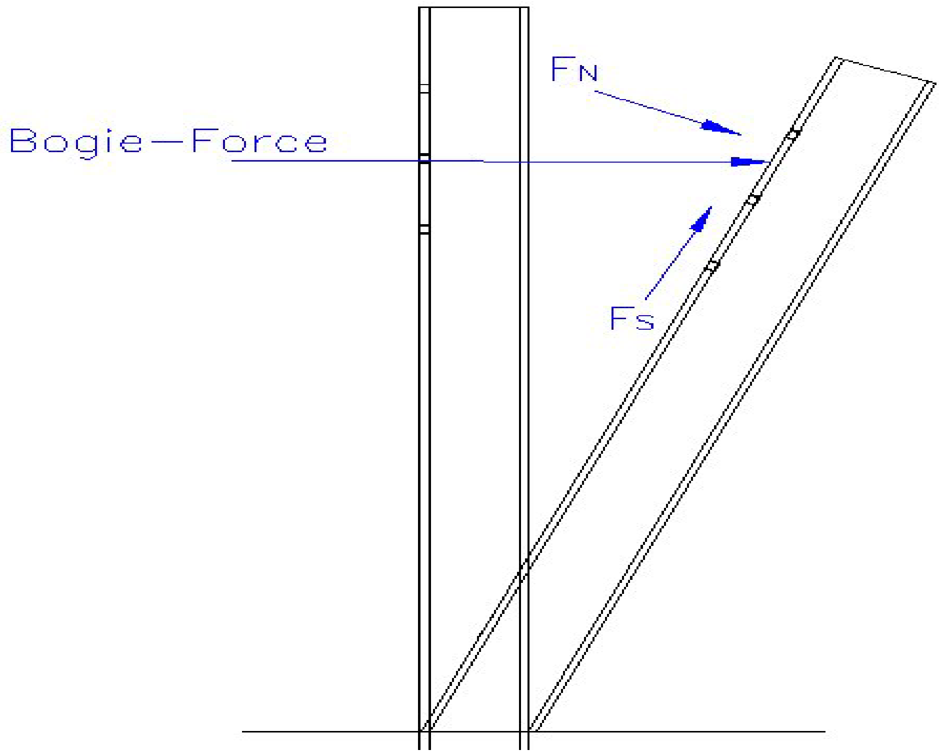


Figure 7. Various forces acting on the post and their orientation

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

2.5 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 force deflection curve was plotted for each test. Integration of the force-deflection curve provides the energy-displacement curve for each test.

3. RESULTS AND DISCUSSION

3.1 Results

Using commercially available spreadsheet software, the accelerometer data was graphed and tabulated. The tests CPB-2 through CPB-11 are documented in Table 2 while Table 3 documents the tests CPB-12 through CPB-17.

Force-Deflection curves for the tests CPB-2, CPB-3 and CPB-4 and tests CPB-5 through CPB-7 are shown in Figure 8 and Figure 9 respectively. The force-deflection for the tests CPB-8 and CPB-9, tests CPB-10 and CPB-11, tests CPB12 through CPB-14 and tests CPB-15 through CPB-17 are shown in Figures 10,11,12 and 13 respectively.

The information that was desired from the physical tests was the relation between force on the post and deflection of the post at the impact location. This data then was 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.

Test Name	Impact Axis	Soil Type	Moisture Content (% wt)	Max Force Encountered (kN)	Max Displacement Encountered (cm)	Max Energy Absorbed (kJ)	Comments
CPB-2	Strong	Std 350 Soil	5.41	23.72	99.37	15.85	Negligible Plastic deformation of the post, Soil underwent considerable amount of shear failure
CPB-3	Strong	Std 350 Soil	4.91	17.93	113.18	12.15	Negligible Plastic deformation of the post, Soil underwent considerable amount of shear failure
CPB-4	Strong	Std 350 Soil	4.91	25.41	101.31	13.75	Negligible Plastic deformation of the post, Soil underwent considerable amount of shear failure
CPB-5	Weak	Std 350 Soil	5.49	28.42	109.61	8.52	High plastic deformation of the post†
CPB-6	Weak	Std 350 Soil	5.49	12.67	93.39	5.78	High plastic deformation of the post†
CPB-7	Weak	Std 350 Soil	5.99	14.44	98.68	6.26	High plastic deformation of the post†
CPB-8	Strong	Native Soil	-NA-	27.30	91.21	12.89	Soil offers greater resistance as compared to CPB-2-CPB4 tests, high plastic deformation of the post†
CPB-9	Strong	Native Soil	-NA-	28.65	95.76	15.01	Soil offers greater resistance, high plastic deformation of the post †
CPB-10	Weak	Native Soil	-NA-	25.95	100.43	7.19	Soil offers greater resistance, high plastic deformation of the post †
CPB-11	Weak	Native Soil	-NA-	28.64	82.88	7.71	Soil offers greater resistance, high plastic deformation of the post †

Table 2. Summary of tests CPB-2 through CPB-11

† High Plastic Deformation of the post is defined as the bending and twisting of the post at the ground level. The displacement of the tip of the post is in excess of 150 mm as compared to the base of the post.

Test Name	Impact Axis	Soil Type	Moisture Content (% wt)	Max Force Encountered (kN)	Max Displacement Encountered (cm)	Max Energy Absorbed (kJ)	Comments
CPB-12	Strong	-NA-	-NA-	64.39	65.34	11.12	High plastic deformation of the post†
CPB-13	Strong	-NA-	-NA-	87.02	60.32	11.28	High plastic deformation of the post†
CPB-14	Strong	-NA-	-NA-	89.98	59.10	11.53	High plastic deformation of the post†
CPB-15	Weak	-NA-	-NA-	38.92	102.05	11.05	High plastic deformation of the post†
CPB-16	Weak	-NA-	-NA-	39.55	100.38	9.85	High plastic deformation of the post†
CPB-17	Weak	-NA-	-NA-	40.34	110.71	11.01	High plastic deformation of the post†

Table 3. Summary of tests CPB-12 through CPB-17

† High Plastic Deformation of the post is defined as the bending and twisting of the post at the ground level. The displacement of the tip of the post is in excess of 150 mm as compared to the base of the post.

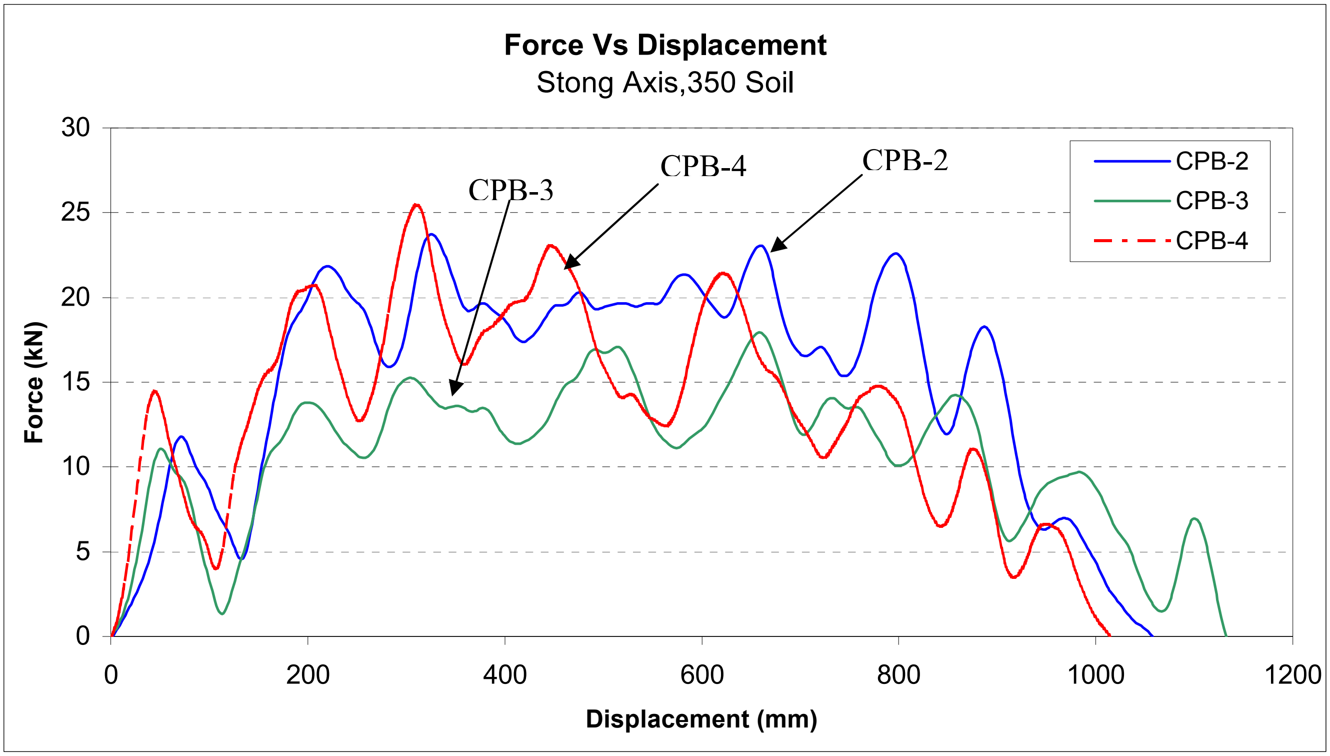


Figure 8. Force-deflection curves for tests CPB-2 through CPB-4

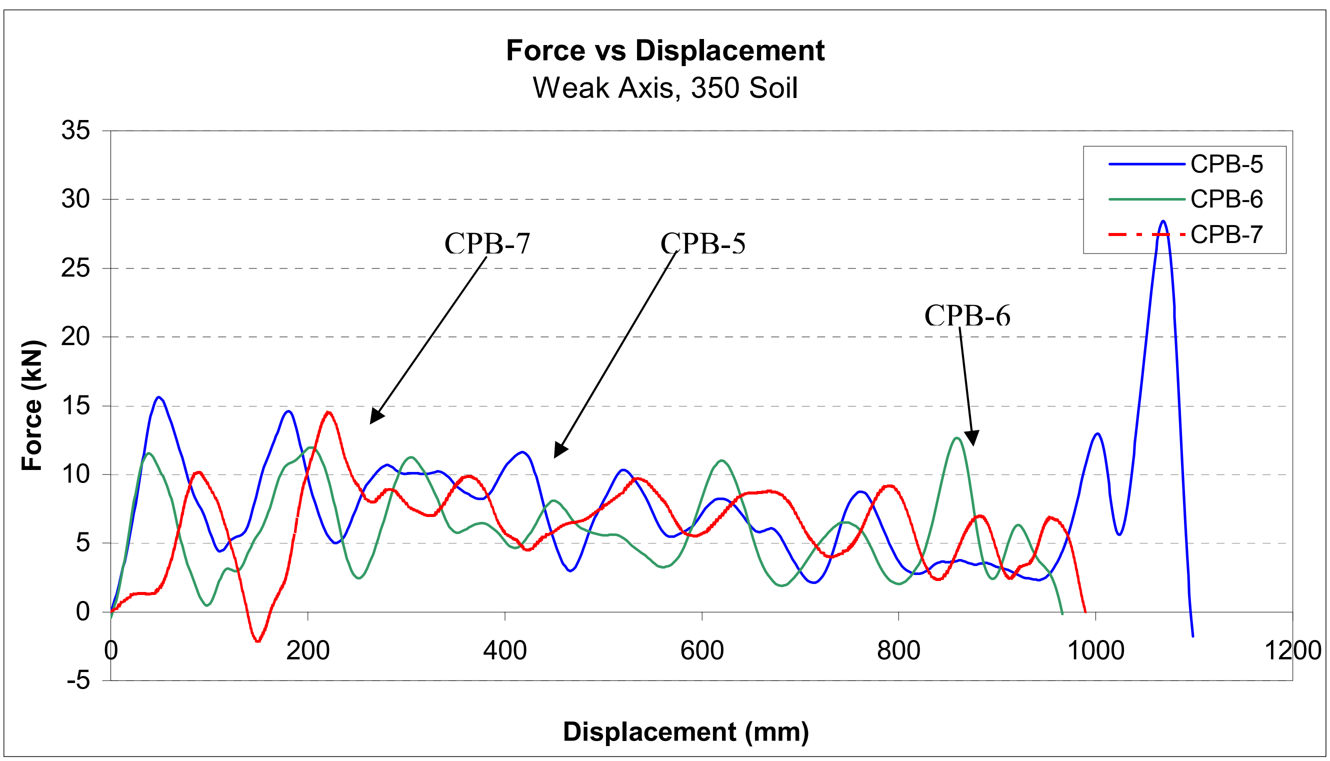


Figure 9. Force-deflection curves for tests CPB-5 through CPB-7

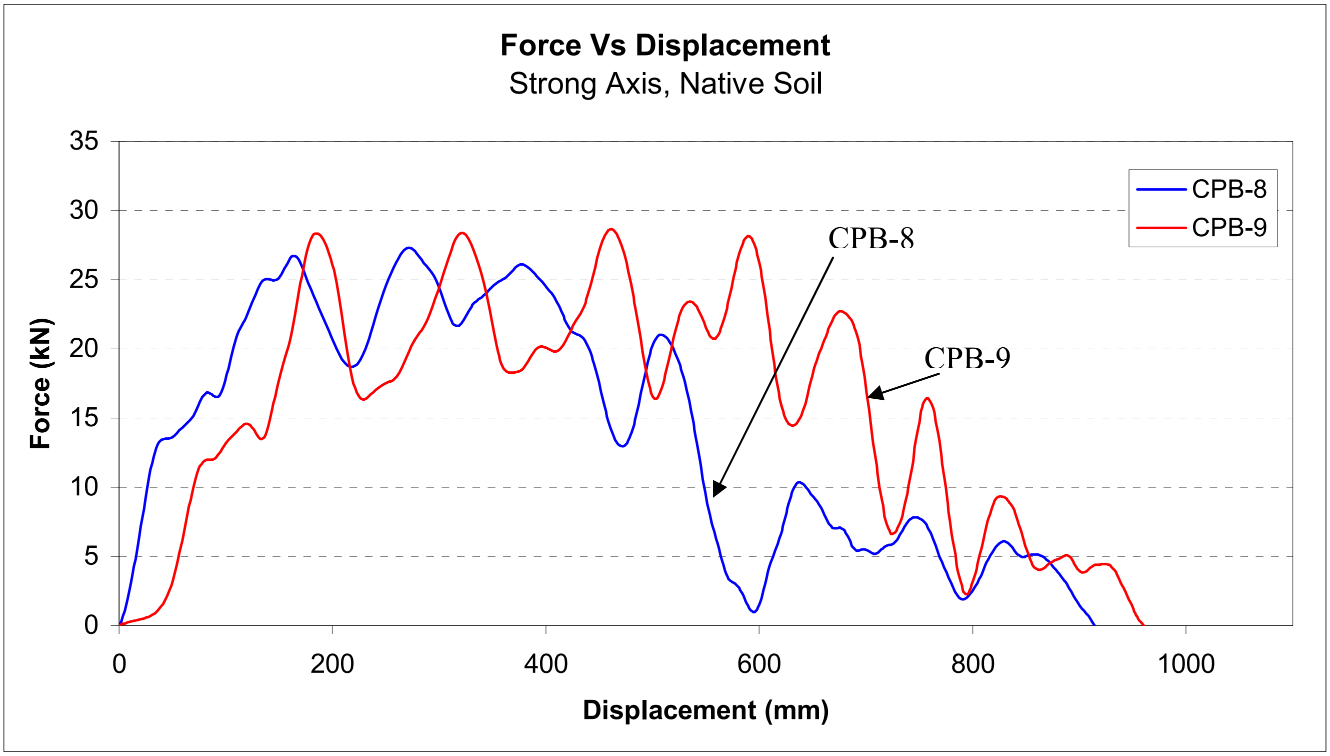


Figure 10. Force-deflection curves for tests CPB-8 and CPB-9

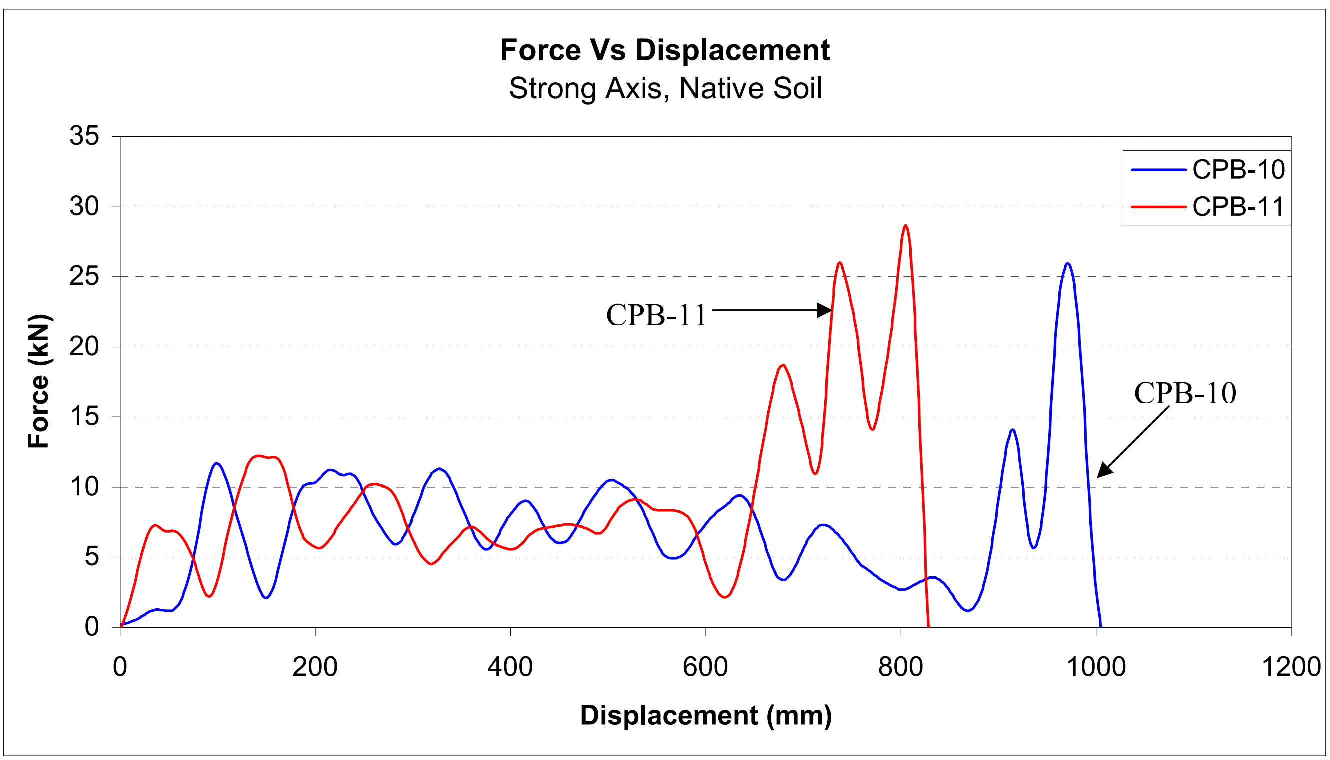


Figure 11. Force-deflection curves for the tests CPB-10 and CPB-11

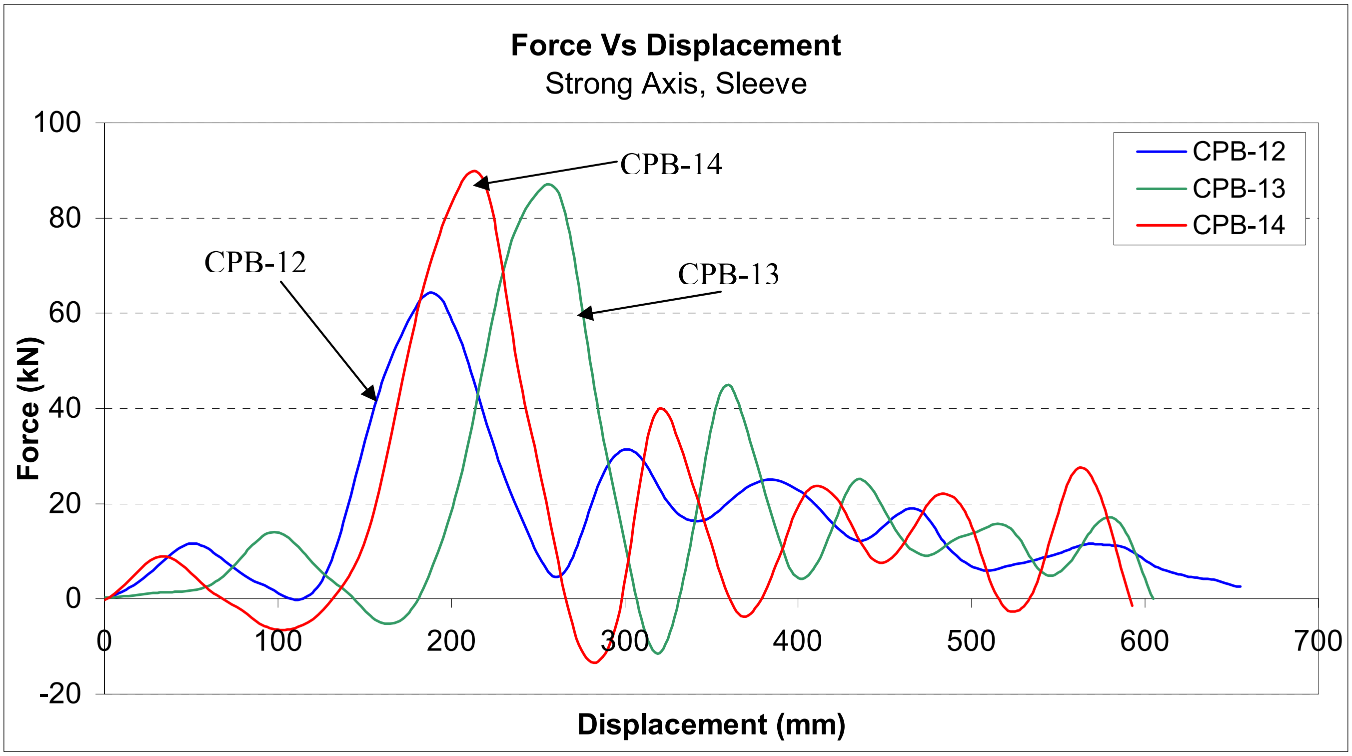


Figure 12. Force-deflection curves for the tests CPB-12 through CPB-14

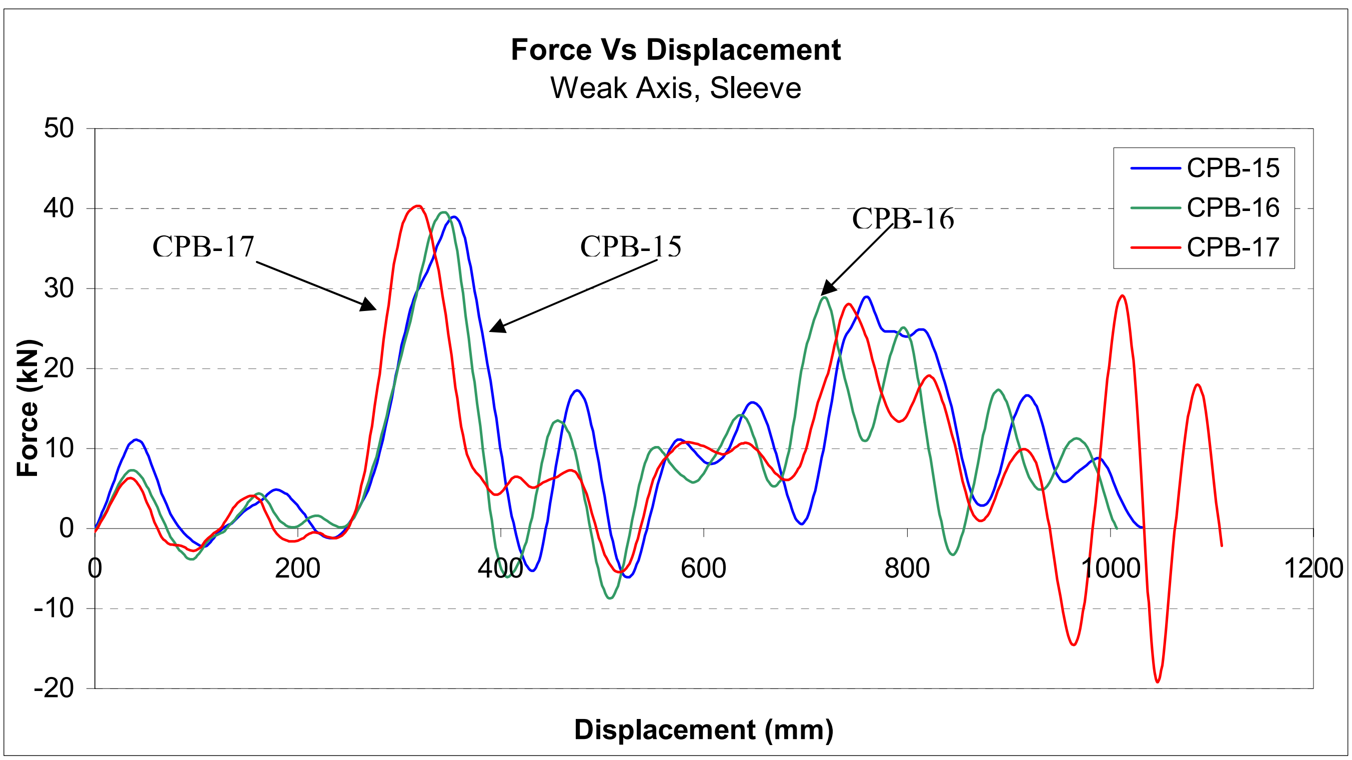


Figure 13. Force-deflection curves for the tests CPB-15 through CPB17

3.2 Discussion

This section discusses tests CPB-2 through CPB-17 in detail.

3.2.1 Tests CPB-2 – CPB-4

The profile of the force-deflection curve for these tests indicates the forces acting on the posts were fairly uniform over the duration of the impact. However, the post-impact investigation showed that the post had not undergone considerable plastic deformation under the action of the impact forces. The reaction forces of the post can be attributed to the constant shear failure of the soil behind the soil plate. This failure of the soil behind the soil plate attribute to the forces. There was negligible plastic deformation of the post. Photographs and film analysis of the system clearly indicate that the soil offered resistance to the failure and pivoted the post at ground level. The post impact system (post and the soil) is shown in Figure 14.

Figure 14. Post impact scenario for test CBP-2

3.2.2 Tests CPB-5 – CPB-7

The profile of the force-deflection curves for the tests CPB-5 through CPB-7 show the forces were fairly uniform, however the values are considerably lower as compared to the previous tests. The post in this case, however, undergoes considerable amount of bending, as this was a weak axis impact. The deformed post is shown in Figure 15. The forces were attributed to the plastic deformation of the post. There was negligible shear failure of the soil.

Figure 15. Plastically deformed post for test CPB-5

3.2.3 Tests CPB-8 – CPB-9

The force-deflection for the tests CPB-8 thorough CPB-9 is shown in Figure 10. This was a strong axis impact in the native soil. The peculiarity of the test was the soil offering more resistance as compared to the standard 350 soils under the same impact conditions, resulting in prominent plastic deformation of the post. The force, as seen from the curves is uniformly distributed over the impact period with no prominent peaks of loads. The deformed posts are shown in Figure 16.

Figure 16. CPB-8 and CPB-9 deformed post geometries

3.2.4 Tests CPB-10 - CPB-11

These tests are not much different in nature as compared to the weak axis impacts in standard 350 soil (Tests CPB-5 though CPB-7). The forces experienced by the post are of similar nature and magnitude as the standard 350 soil tests. The results were as excepted because the impact was at the weak axis and the soil acted stronger, resulting in large plastic deformation of the post.

3.2.5 Tests CPB-12 – CPB-14

As described in the section 2.3, the set up for the tests CPB-12 through CPB-17 was changed. In these cases, the 350 soil or the native soil was replaced with a rigid concrete sleeve. The sleeve was cut out in the tarmac at an appropriate location and was lined with a hollow steel tube approximately 225 mm square and 10 mm in thickness. A wood block was used to rigidly hold the post against the casing. The setup is shown in Figure 6. CPB-12 through CPB-14 were impacts on the strong axis of the post while CPB-15, CPB-16 and CPB-17 were the weak axis impacts.

The force deflection curve for the test CPB-12 through CPB-14 can be divided into three prominent regions based on the deflection of the post as shown in Figure 17.

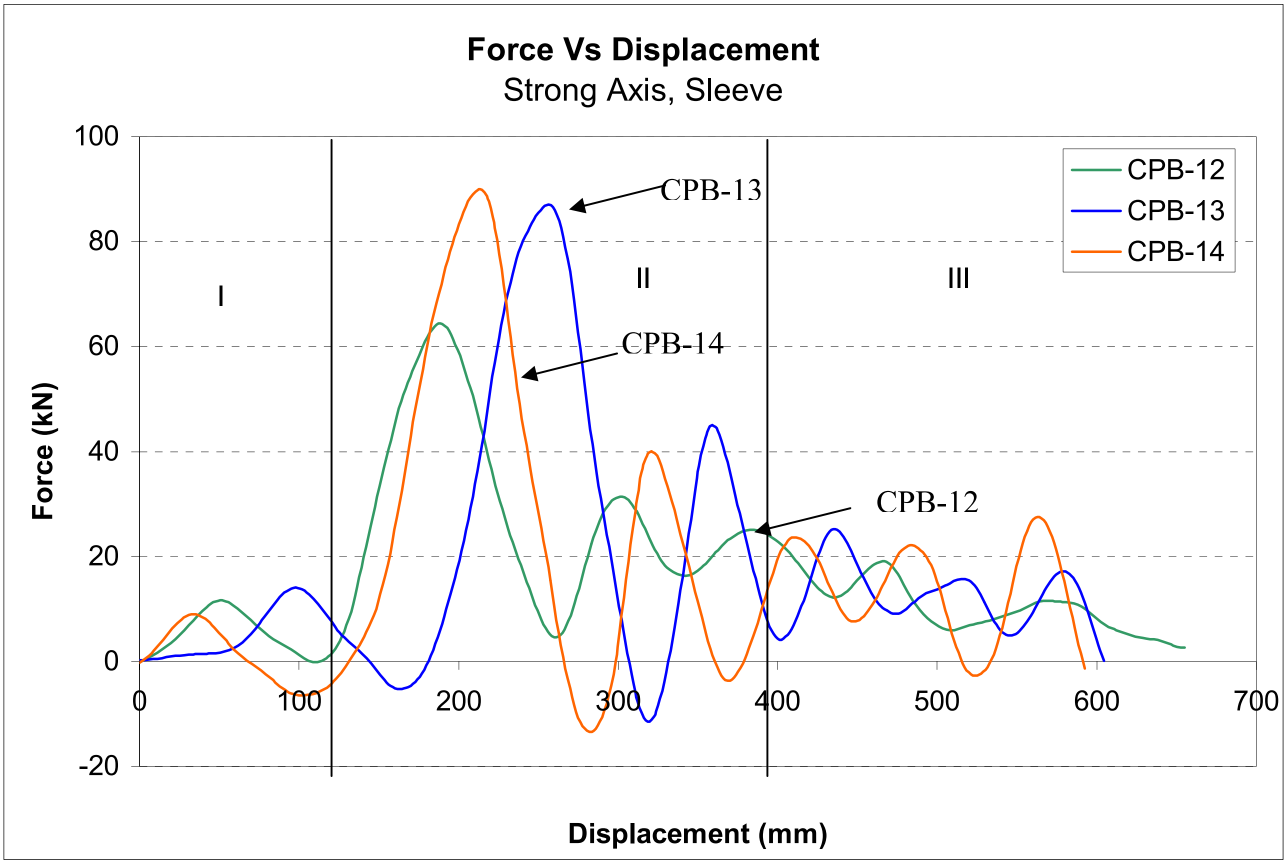


Figure 17. Force-deflection curves for the tests CPB-12 through CPB-14

3.2.5.1 Region I

This region of the curves covers the displacement of the post from the time of impact up to ten millisecond into impact. In this region of the curve there are small force peaks with a maximum force value reaching a value of 18 kN. The occurrence of such lower forces in this region can be attributed to three phenomenons happening in the same region of the curve. This section, primarily, accounts for the slack in the system.

A closer look at the ECAM footage of the physical test showed that the post underwent an elastic deformation in the first few milliseconds of the test. On the other hand the neoprene covering the bogie head underwent compression thus preventing the occurrence of a force peak. The wood block placed in the concrete sleeve also underwent compression loading. Compression tests carried out on Southern Yellow Pine (SYP) by

MwRSF show that SYP was not fully compressible and the resistive force offered by the wood increases drastically after 5 mm of lateral compression. The ECAM pictures detailing the impact process are shown in Figure 19.

3.2.5.2 Region II

This region of the curve extends from 10 milliseconds to about 40 milliseconds into impact during which the displacement of the post is from 125 mm to about 400 mm from the initial position. The region is marked with the occurrence of very high force peaks over short displacements of the post. The maximum force reaches a value of up to 100 KN.

The post, in this region shows an elastic-plastic behavior as shown in Figure 18. The raise in the force can be attributed to the elastic deformation of the post. Yield was reached when the elastic deformation of the steel post was complete. At yield the force reached a maximum value, thus leading to the peak in the curve. After yield was reached the post undergoes plastic deformation. The plastic deformation of the post results in the buckling of the post at the ground level. The buckling however did not lead to the formation of peak force, as was the case with elastic deformation.

The compression flange deformed plastically with the webbing collapsing on to the flange. The force required to deform the post plastically however does not exceed the force required to induce elastic deformation. Also in this region the wood block placed behind the soil plate offers greater resistance, thus increasing the reactive force. The neoprene on the bogie head that had undergone compression no longer absorbs energy and exposes the rigid head of the bogie to the post.

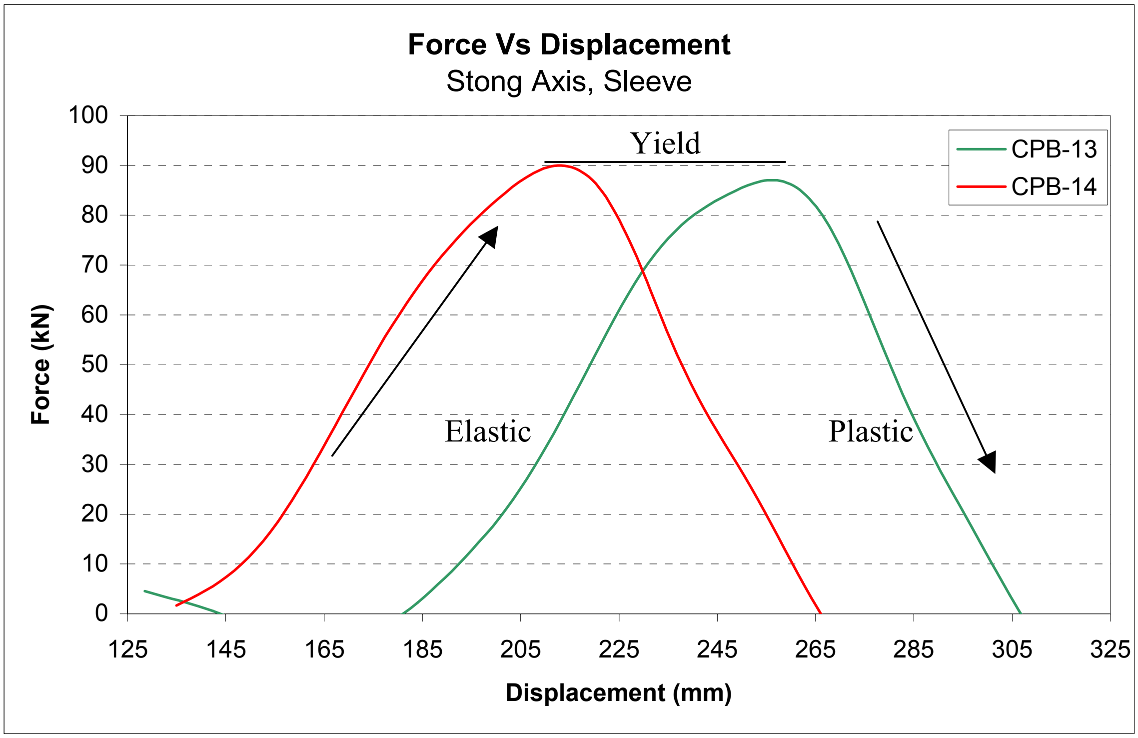


Figure 18. Enlarged force-deflection curve for CPB-13 and CPB-14

3.2.5.3 Region III

This region covers the impact from 40 milliseconds to end of the test. In this region of the curve the forces arise mainly due to the friction of the neoprene and bogie head over the post and further compression of the webbing on to the flange. The forces were fairly constant in this region.

The documentary photographs for the test CPB-14 are shown in Figure 19.

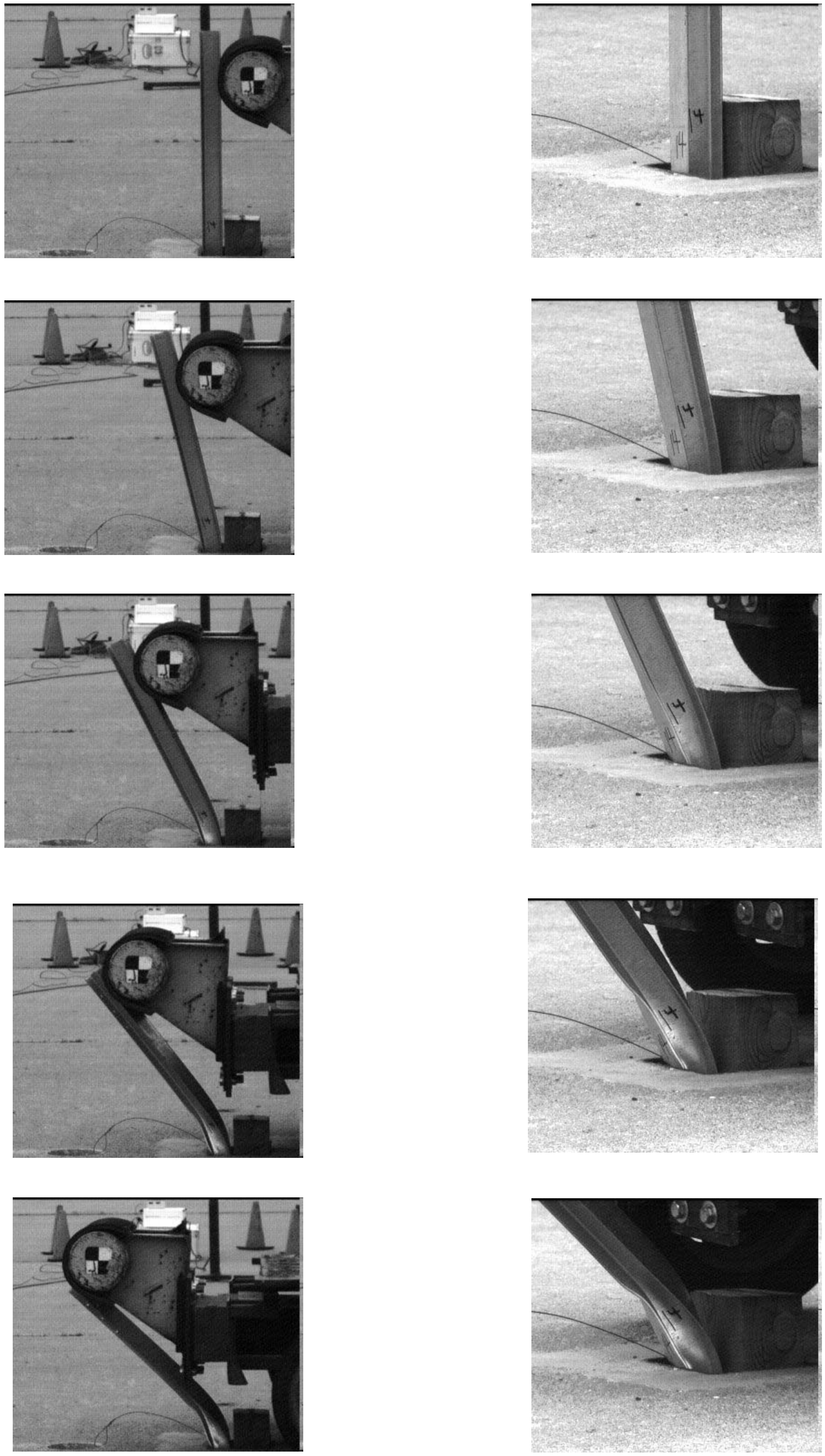


Figure 19. Documentary pictures for test CPB-14

3.2.6 Tests CPB-15- CPB-17

As in the earlier case of strong axis impact, the force deflection curve for the weak axis impact can also be broken down into 3 distinct regions and analyzed. The division of the curve into regions is shown in Figure 20.

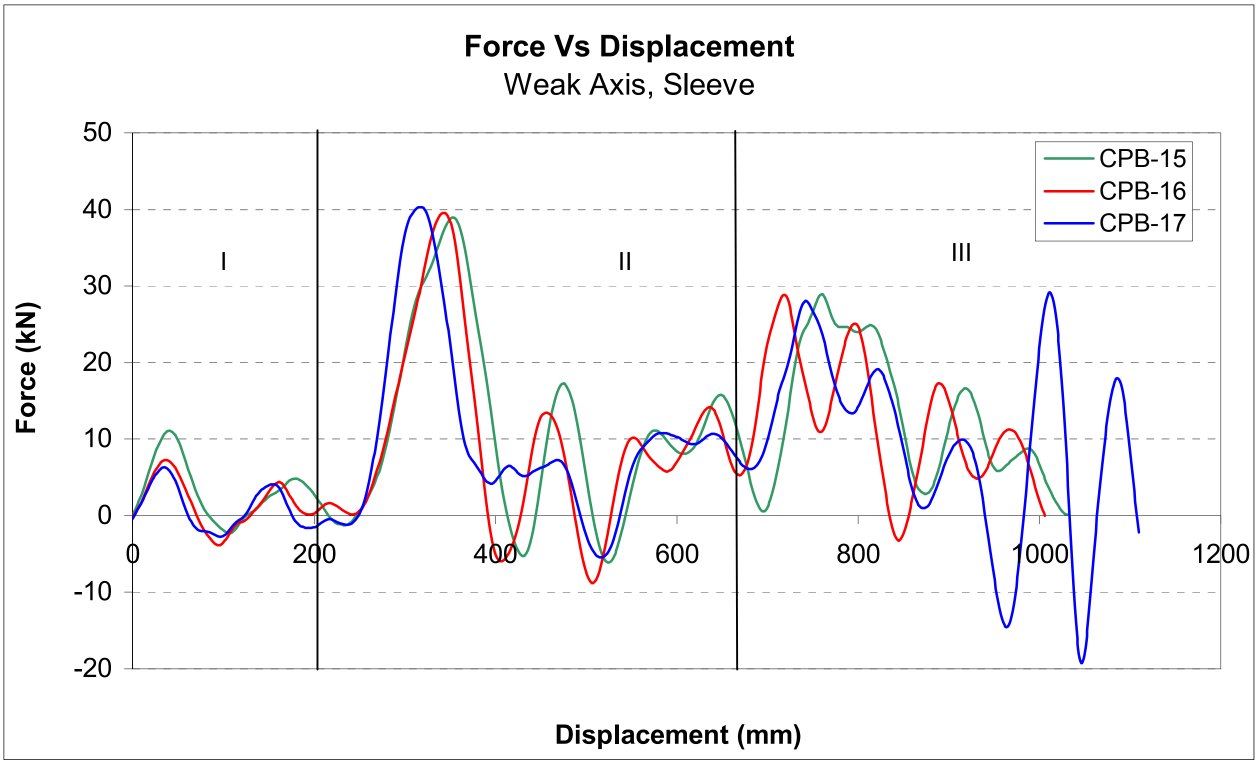


Figure 20. Force-deflection curves for tests CPB-15-CPB-17

3.2.6.1 Region I

This region of the curve covers the deflection of the post from the point of impact up to 200 mm. As seen from the curves, the forces in this region are not high with the maximum reaching a value of 5 kN. The forces in this region are due to the elastic bending of both the flanges and the web and due to taking up the slack in the system.

3.2.6.2 Region II

This portion of the curve shows the elastic-plastic behavior of the post from 200 mm to 650 mm. The exploded curve for this region is shown in figure 21. The raise in the force were attributed to the elastic deformation of the post. Yield was reached once the elastic deformation of the steel post was complete. At yield the force reached a maximum value, thus leading to the peak in the curve. Once yield was reached the post undergoes plastic deformation. The plastic deformation of the post results in the buckling of the post at the ground level. The buckling however does not lead to the formation of peak force, as is the case with elastic deformation.

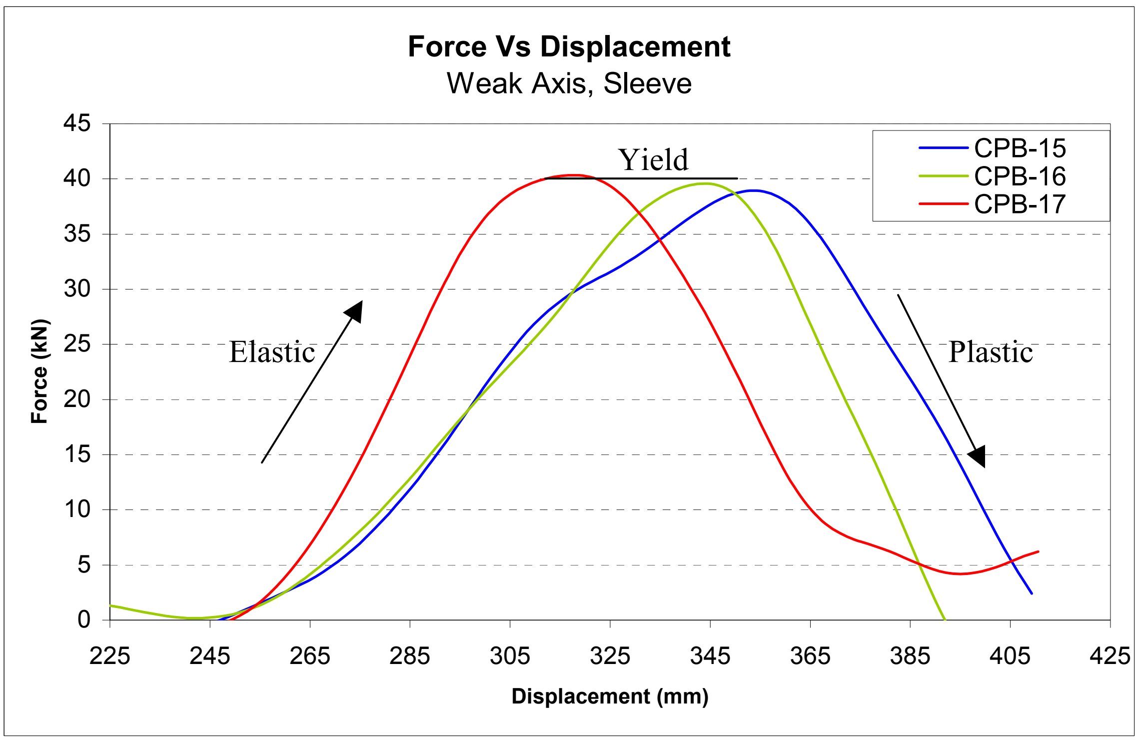


Figure 21. Enlarged force-deflection curve for test CPB-15 through CPB-17

3.2.6.3 Region III

Local buckling and crushing of the flanges in this region of the curve led to the formation of force peaks. Though the numerical value is not as high as in region II the maximum value for the force is 30 kN. The documentary photographs for the test CPB-15 are shown in Figure 22.

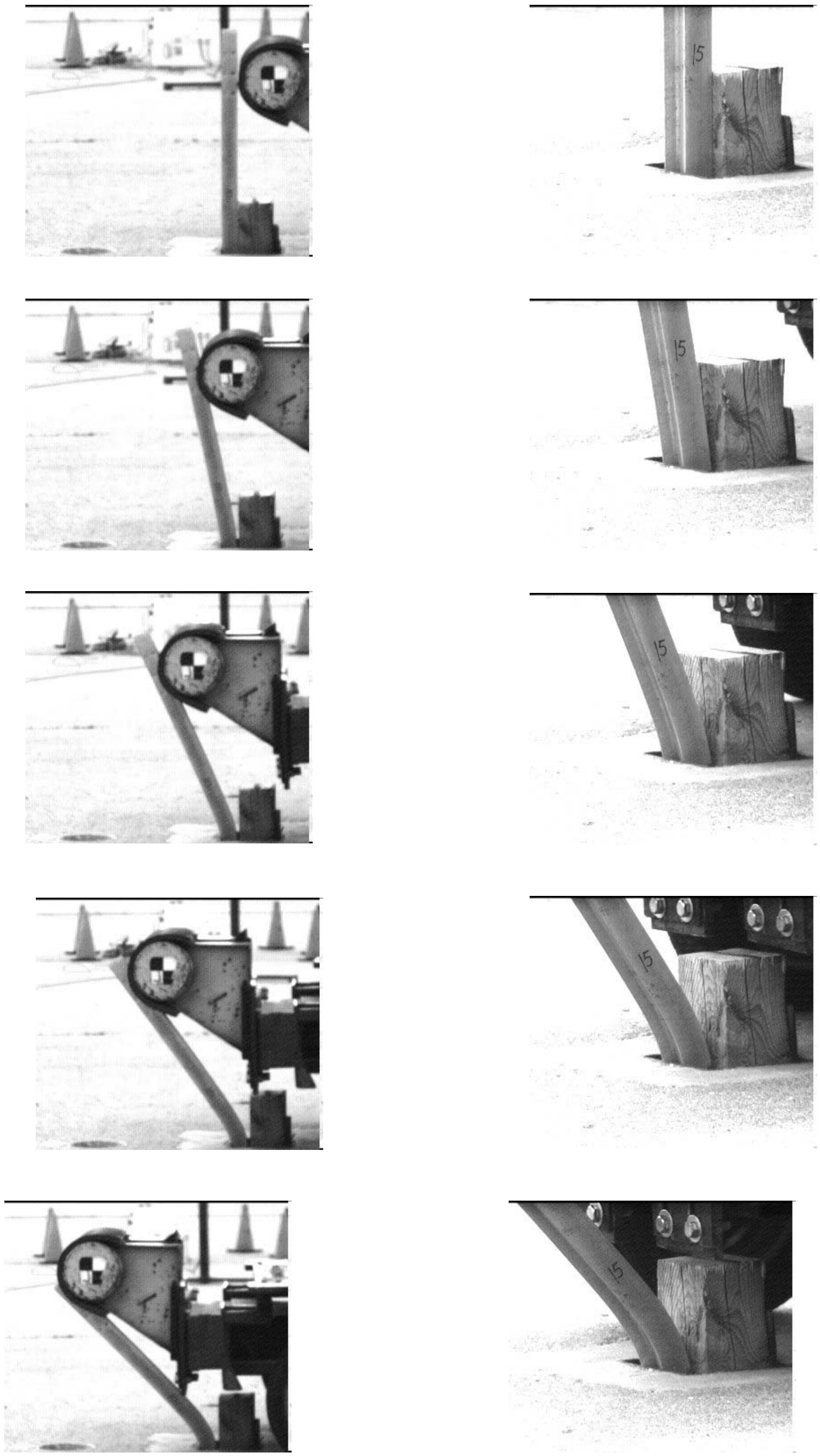


Figure 22. Documentary photographs for test CPB-15

4. CONCLUSIONS

The physical testing of weak steel posts has been detailed and the results stated. The results are consistent within each group of tests as can be seen by the near equal profile of the force-deflection curves within each group.

Strong axis impacts tests in standard 350 soil show that the soil under goes shear failure resulting in lower peak forces to be developed on the post as compared to the native soil and concrete sleeve tests. However the soil failure, and negligible plastic deformation of the post, tend to absorb more energy as compared to the post in native soil and post in concrete tests.

Native soil, on the other hand, is more resistant to shear as compared to the 350 soil leading to the development of higher forces and noticeable plastic deformation of the post, but the deflection of the post does not lead to the greater absorption of energy. Moisture content plays an important role in the behavior of the soil. However, due to the lack of moisture content reading of native soil, a thorough comparison cannot be made between native and standard 350 soil.

Impacts on either axis of the post in concrete sleeve show that either the post undergoes small displacements (up to 650 mm) and large peak forces, or large displacements (in excess of 1000 mm) and lower peak forces. In both cases the energy absorbed is approximately the same. This is not the case with the other group of tests, and it is seen that the weak axis impacts on the posts either in standard 350 or native soil always produces lower peak forces and energies relative the strong axis impacts.

APPENDIX A

DATA SHEETS FOR TESTS CPB-2 THROUGH CPB-17

CPB: Cable Post Testing
EDR-3 Data
Bogie Weight -- 2,237 lbs (1014 kgs) Bumper height - 27" (685mm)
s3x5.7 Posts (s75x8.5)

Test No.	Speed mph	Speed fps	Embedment Depth inches	Post Weight lbs.	Axis	Notes
CPB-1	20.5	30.1	30	NA	Strong	No EDR/No e-cam
CPB-2	21	30.8	30	NA	Strong	350 Soil, 3' holes
CPB-3	20.5	30.1	30	NA	Strong	350 Soil, 3' holes
CPB-4	20.5	30.1	30	NA	Strong	350 Soil, 3' holes
CPB-5	20	29.3	30	NA	Weak	350 Soil, 3' holes
CPB-6	20	29.3	30	NA	Weak	350 Soil, 3' holes
CPB-7	20	29.3	30	NA	Weak	350 Soil, 3' holes
CPB-8	18.4	27.0	30	NA	Strong	Native Soil
CPB-9	18.4	27.0	30	NA	Strong	Native Soil
CPB-10	18.1	26.5	30	NA	Weak	Native Soil
CPB-11	18.43	27.0	30	NA	Weak	Native Soil
CPB-12	20	29.3	30	45	Strong	In Sleeve on Concrete
CPB-13	20	29.3	30	44	Strong	In Sleeve on Concrete
CPB-14	21	30.8	30	44	Strong	In Sleeve on Concrete
CPB-15	21	30.8	30	31	Weak	In Sleeve on Concrete
CPB-16	21	30.8	30	31	Weak	In Sleeve on Concrete
CPB-17	21	30.8	30	31	Weak	In Sleeve on Concrete

Test No.	Speed Kmph	Speed mps	Embedment Depth mm	Post Weight kgs.	Axis	Notes
CPB-1	32.8	9.1	762	NA	Strong	No EDR/No e-cam
CPB-2	33.6	9.3	762	NA	Strong	350 Soil, 0.9m holes
CPB-3	32.8	9.1	762	NA	Strong	350 Soil, 0.9m holes
CPB-4	32.8	9.1	762	NA	Strong	350 Soil, 0.9m holes
CPB-5	32	8.9	762	NA	Weak	350 Soil, 0.9m holes
CPB-6	32	8.9	762	NA	Weak	350 Soil, 0.9m holes
CPB-7	32	8.9	762	NA	Weak	350 Soil, 0.9m holes
CPB-8	29.4	8.2	762	NA	Strong	Native Soil
CPB-9	29.4	8.2	762	NA	Strong	Native Soil
CPB-10	29	8.0	762	NA	Weak	Native Soil
CPB-11	29.5	8.2	762	NA	Weak	Native Soil
CPB-12	32	8.9	762	20	Strong	In Sleeve on Concrete
CPB-13	32	8.9	762	20	Strong	In Sleeve on Concrete
CPB-14	33.6	9.3	762	20	Strong	In Sleeve on Concrete
CPB-15	33.6	9.3	762	14	Weak	In Sleeve on Concrete
CPB-16	33.6	9.3	762	14	Weak	In Sleeve on Concrete
CPB-17	33.6	9.3	762	14	Weak	In Sleeve on Concrete

Table of Comparisons for various tests

English

Test Name	Impact Axis	Soil Type	Moisture Content(% wt)	Max Force Encountered (kips)	Max Displacement Encountered (in)	Max Energy Absorbed (kip*in)
CPB-2	Strong	Std 350 Soil	5.41	5.33	39.12	140.33
CPB-3	Strong	Std 350 Soil	4.91	4.03	44.56	107.58
CPB-4	Strong	Std 350 Soil	4.91	5.71	39.88	121.77
CPB-5	Weak	Std 350 Soil	5.49	6.39	43.15	75.49
CPB-6	Weak	Std 350 Soil	5.49	2.85	37.95	51.15
CPB-7	Weak	Std 350 Soil	5.99	3.25	38.85	55.48
CPB-8	Strong	Native Soil	-NA-	6.14	35.91	114.12
CPB-9	Strong	Native Soil	-NA-	6.44	37.70	132.82
CPB-10	Weak	Native Soil	-NA-	5.83	39.54	63.65
CPB-11	Weak	Native Soil	-NA-	6.44	32.63	68.30
CPB-12	Strong	-NA-	-NA-	14.47	25.72	98.42
CPB-13	Strong	-NA-	-NA-	19.56	23.74	99.83
CPB-14	Strong	-NA-	-NA-	20.23	23.27	102.12
CPB-15	Weak	-NA-	-NA-	8.75	40.18	97.80
CPB-16	Weak	-NA-	-NA-	8.89	39.52	87.25
CPB-17	Weak	-NA-	-NA-	9.07	43.58	97.53

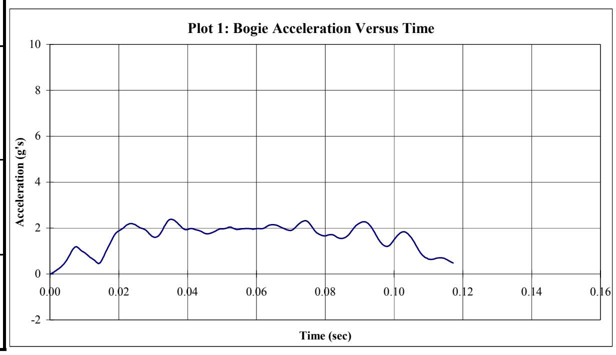
Metric

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

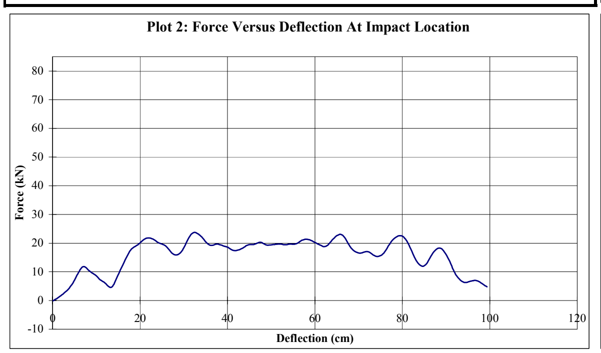
Midwest Roadside Safety Facility

Bogie Test Summary

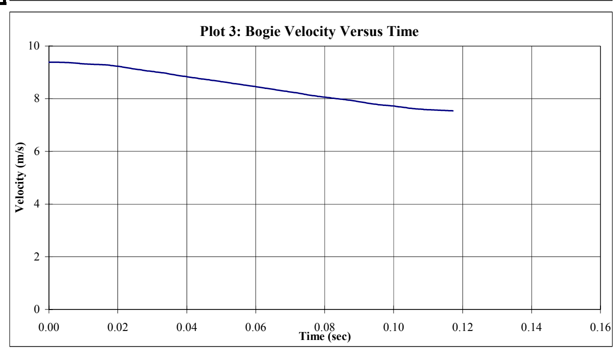
Test Information			
	Test Number:	CPB-2	
	Test Date:	8-Jun-01	
	Failure Type:	Soil Shear Failure	
Post Properties			
	Post Type:	Steel	
	Post Size:	S75x8.5	S3x5.7
	Post Length:	160.0 cm	(5.3 ft)
	Embedment Depth:	76.2 cm	(30.0 in)
Soil Properties			
	Moisture Content:	Dry (5.41 % wt)	
	Gradation:	-	
	Soil Density, γ_d:	NA kg/m^3	
	Compaction Method:	Standard	
Bogie Properties			
	Impact Velocity:	9.3 m/s	(21.0 mph) (30.8 fps)
	Impact Location:	68.6 cm	(27.0 in.) above groundline
	Bogie Mass:	1015 kg	(2237 lbf.)
Data Acquired			
	Accelerometer Data		
	Side View, S-VHS		



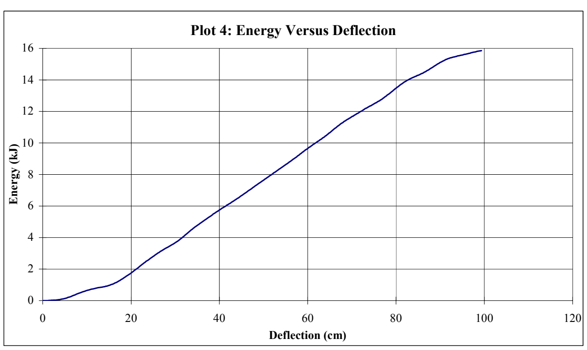
Plot 1: Bogie Acceleration Versus Time



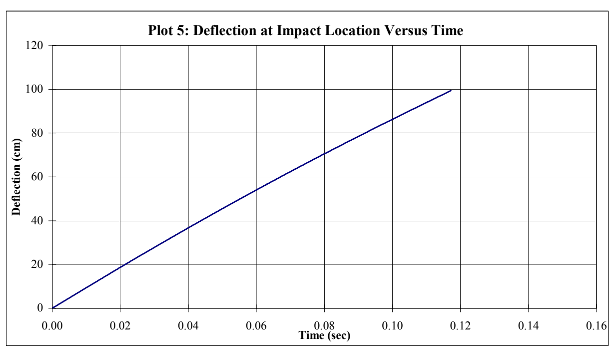
Plot 2: Force Versus Deflection At Impact Location



Plot 3: Bogie Velocity Versus Time



Plot 4: Energy Versus Deflection

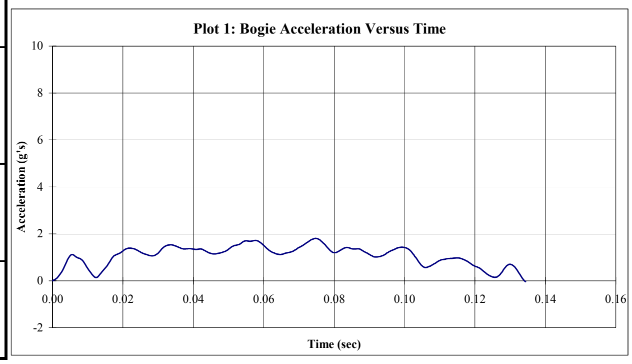


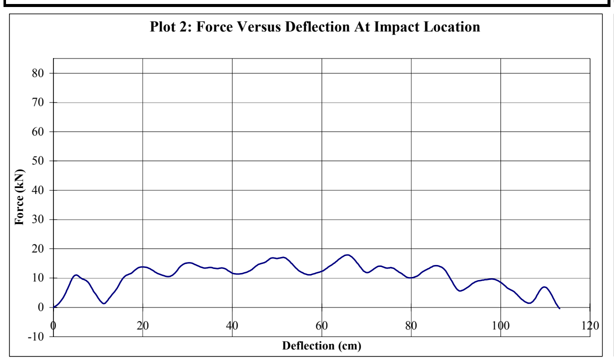
Plot 5: Deflection at Impact Location Versus Time

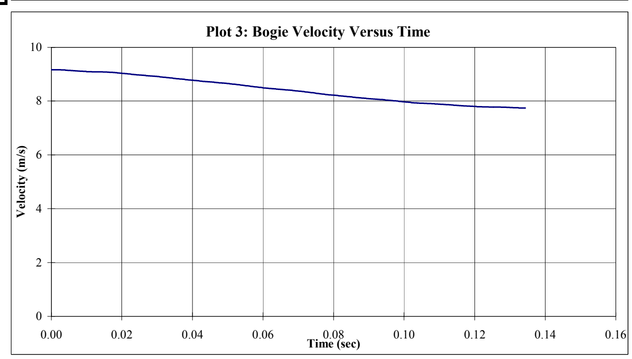
Midwest Roadside Safety Facility

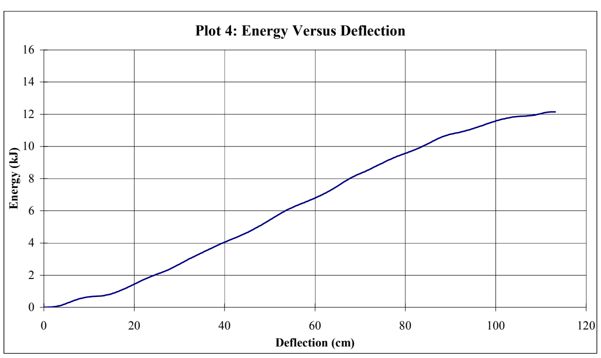
Bogie Test Summary

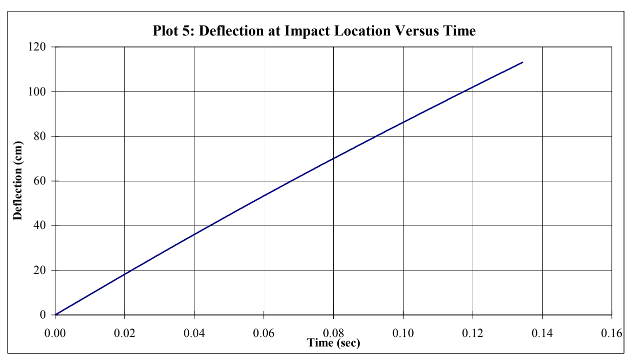
Test Information			
Test Number:	CPB-3		
Test Date:	8-Jun-01		
Failure Type:	Soil Shear Failure		
Post Properties			
Post Type:	Steel		
Post Size:	S75x8.5	S3x5.7	
Post Length:	160.0 cm	(5.3 ft)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Moisture Content:	Dry (4.91 %wt)		
Gradation:	--		
Soil Density, γ_d:	NA	kg/m³	
Compaction Method:	Standard		
Bogie Properties			
Impact Velocity:	9.1 m/s	(20.5 mph)	(30.1 fps)
Impact Location:	68.6 cm	(27.0 in.)	above groundline
Bogie Mass:	1015 kg	(2237 lbf.)	
Data Acquired			
Accelerometer Data			
Side View, S-VHS			







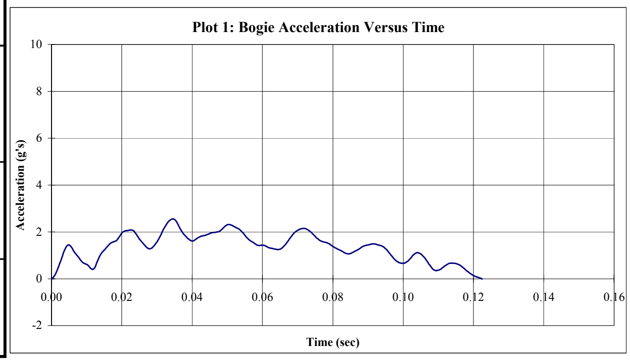


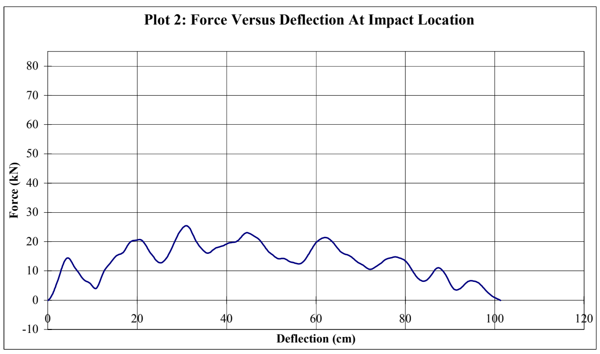


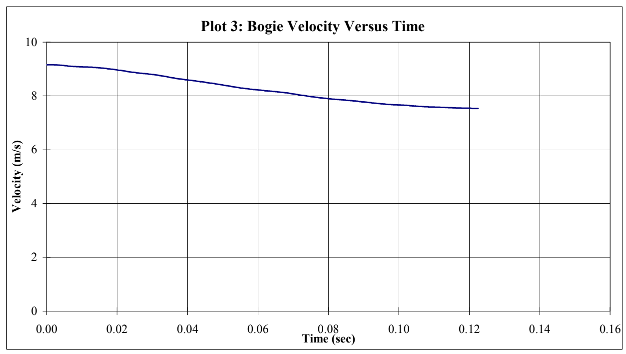
Midwest Roadside Safety Facility

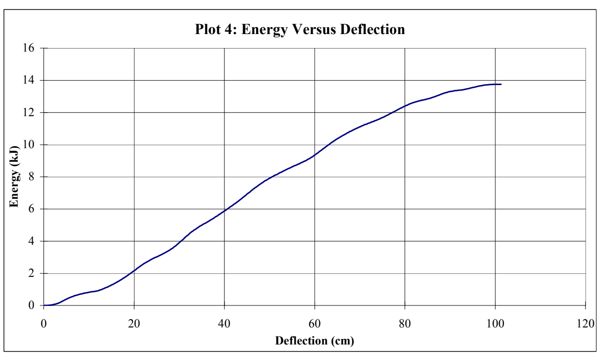
Bogie Test Summary

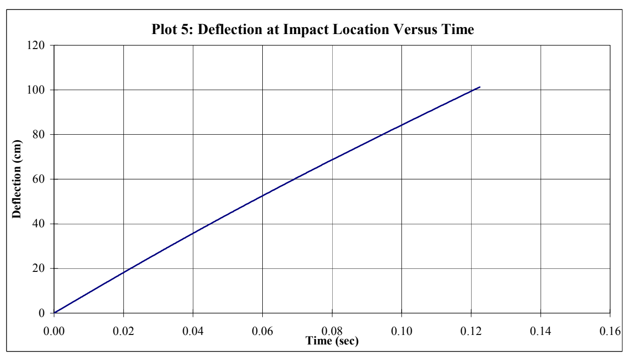
Test Information			
Test Number:	CPB-4		
Test Date:	8-Jun-01		
Failure Type:	Soil Shear Failure		
Post Properties			
Post Type:	Steel		
Post Size:	S75x8.5	S3x5.7	
Post Length:	160.0 cm	(5.3 ft)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Moisture Content:	Dry (4.91% wt)		
Gradation:	--		
Soil Density, γ_d:	NA	kg/m³	
Compaction Method:	Standard		
Bogie Properties			
Impact Velocity:	9.1 m/s	(20.5 mph)	(30.1 fps)
Impact Location:	68.6 cm	(27.0 in.) above groundline	
Bogie Mass:	1015 kg	(2237 lbf.)	
Data Acquired			
Accelerometer Data			
Side View, S-VHS			





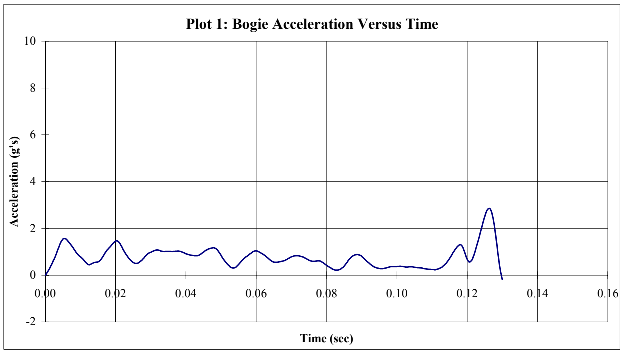


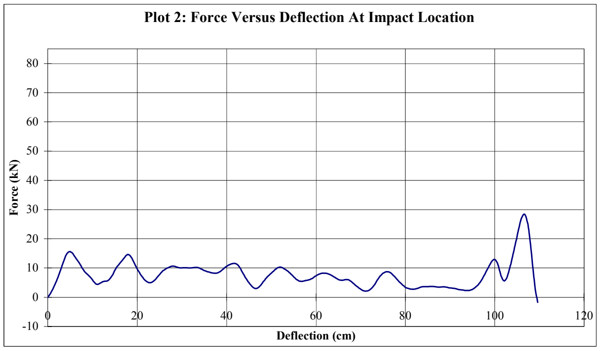


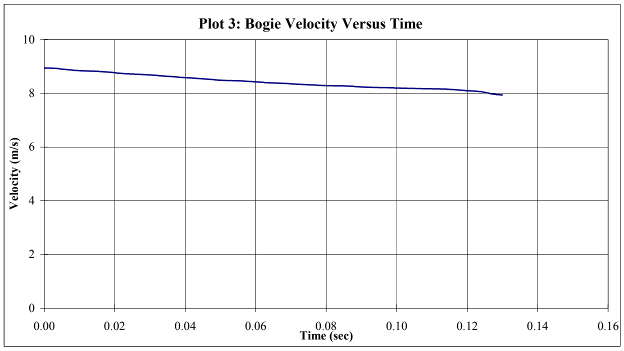


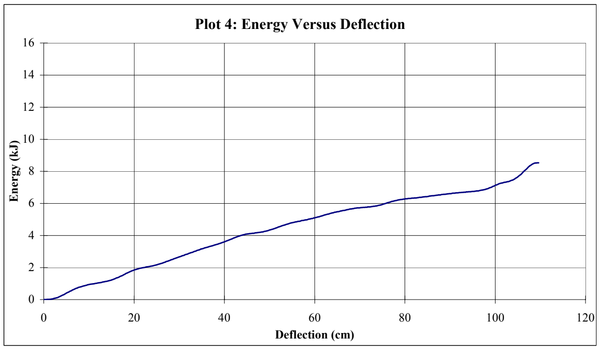
Midwest Roadside Safety Facility

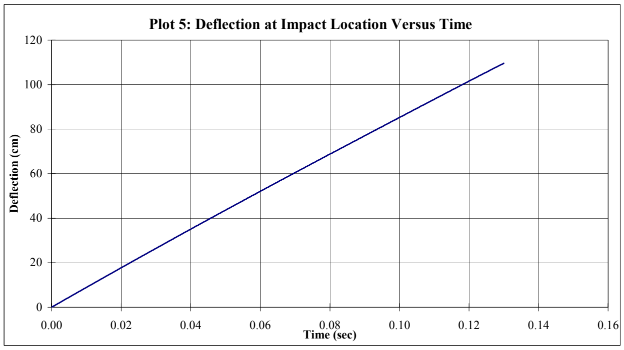
Bogie Test Summary		
Test Information		
Test Number:	CPB-5	
Test Date:	8-Jun-01	
Failure Type:	Plastic Deformation of Post	
Post Properties		
Post Type:	Steel	
Post Size:	S75x8.5	S3x5.7
Post Length:	160.0 cm	(5.3 ft)
Embedment Depth:	76.2 cm	(30.0 in)
Soil Properties		
Moisture Content:	Dry (5.49 %wt)	
Gradation:	--	
Soil Density, γ_d:	NA kg/m³	
Compaction Method:	Standard	
Bogie Properties		
Impact Velocity:	8.9 m/s	(20.0 mph) (29.3 fps)
Impact Location:	68.6 cm	(27.0 in.) above groundline
Bogie Mass:	1015 kg	(2237 lbf.)
Data Acquired		
Accelerometer Data		
Side View, S-VHS		











Midwest Roadside Safety Facility

Bogie Test Summary

Test Information

Test Number:	CPB-6	
Test Date:	8-Jun-01	
Failure Type:	Plastic Deformation of Post	

Post Properties

Post Type:	Steel	
Post Size:	S75x8.5	S3x5.7
Post Length:	160.0 cm	(5.3 ft)
Embedment Depth:	76.2 cm	(30.0 in)

Soil Properties

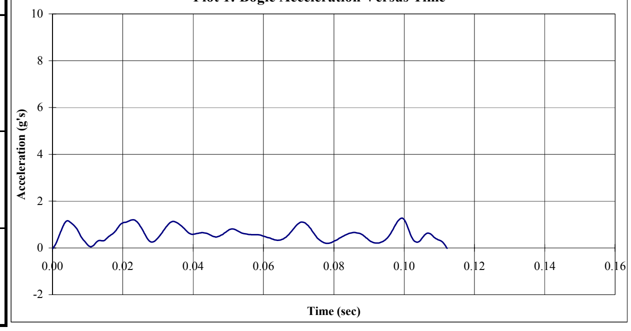
Moisture Content:	Dry (5.49 %wt)	
Gradation:	--	
Soil Density, γ_d:	NA	kg/m^3
Compaction Method:	Standard	

Bogie Properties

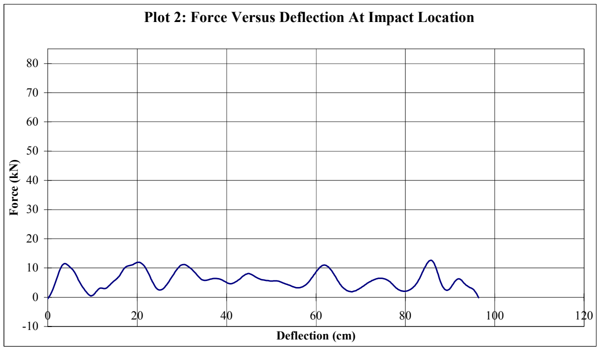
Impact Velocity:	8.9 m/s	(20.0 mph) (29.3 fps)
Impact Location:	68.6 cm	(27.0 in.) above groundline
Bogie Mass:	1015 kg	(2237 lbf.)

Data Acquired

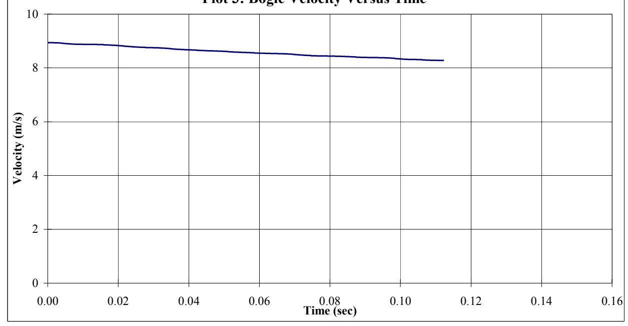
Accelerometer Data
Side View, S-VHS



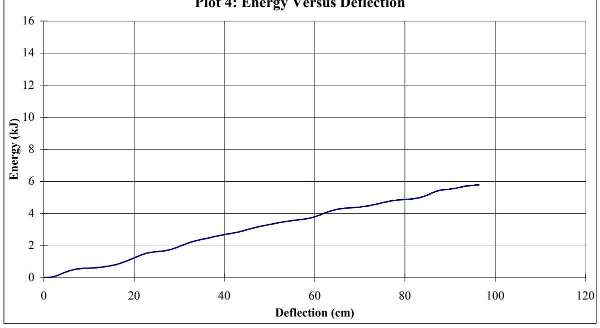
Plot 1: Bogie Acceleration Versus Time



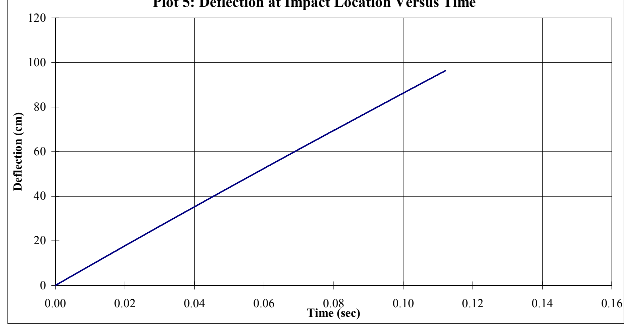
Plot 2: Force Versus Deflection At Impact Location



Plot 3: Bogie Velocity Versus Time



Plot 4: Energy Versus Deflection

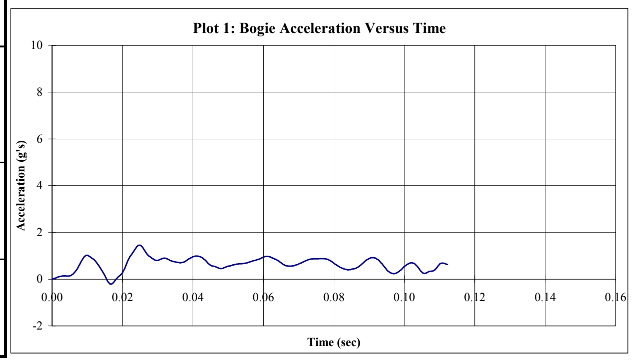


Plot 5: Deflection at Impact Location Versus Time

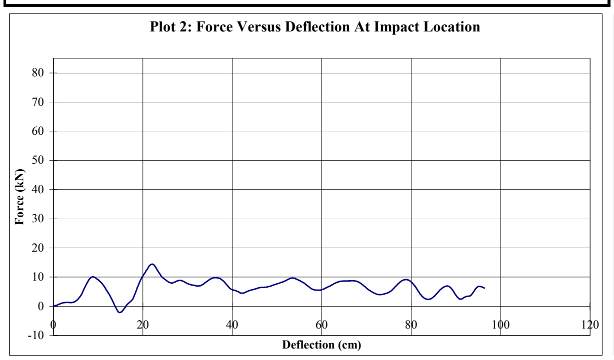
Midwest Roadside Safety Facility

Bogie Test Summary

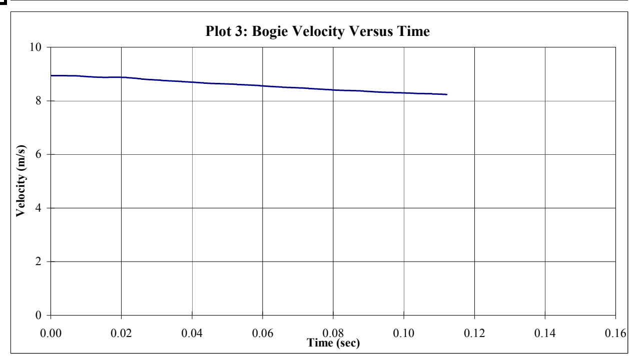
Test Information			
Test Number:	CPB-7		
Test Date:	8-Jun-01		
Failure Type:	Plastic Deformation of Post		
Post Properties			
Post Type:	Steel		
Post Size:	S75x8.5	S3x5.7	
Post Length:	160.0 cm	(5.3 ft)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Moisture Content:	Dry (5.99 %wt)		
Gradation:	--		
Soil Density, γ_d:	N/A	kg/m^3	
Compaction Method:	Standard		
Bogie Properties			
Impact Velocity:	8.9 m/s	(20.0 mph)	(29.3 fps)
Impact Location:	68.6 cm	(27.0 in.) above groundline	
Bogie Mass:	1015 kg	(2237 lbf.)	
Data Acquired			
Accelerometer Data			
Side View, S-VHS			



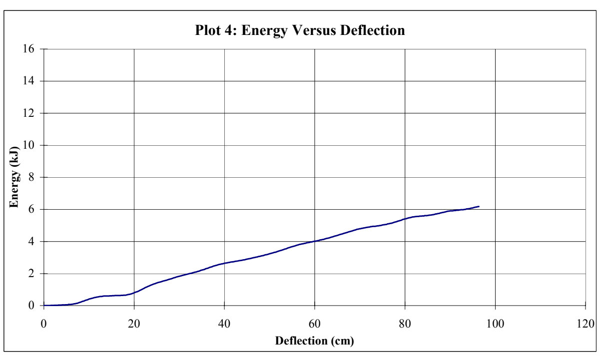
Plot 1: Bogie Acceleration Versus Time



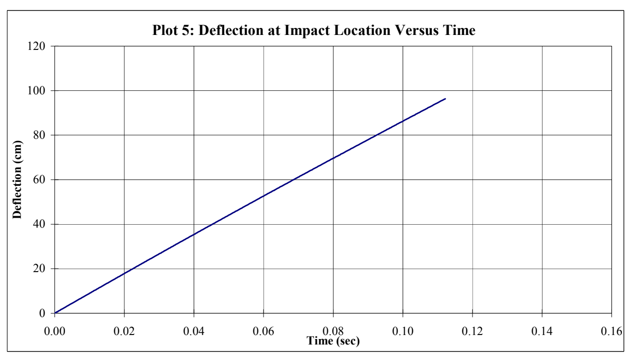
Plot 2: Force Versus Deflection At Impact Location



Plot 3: Bogie Velocity Versus Time



Plot 4: Energy Versus Deflection

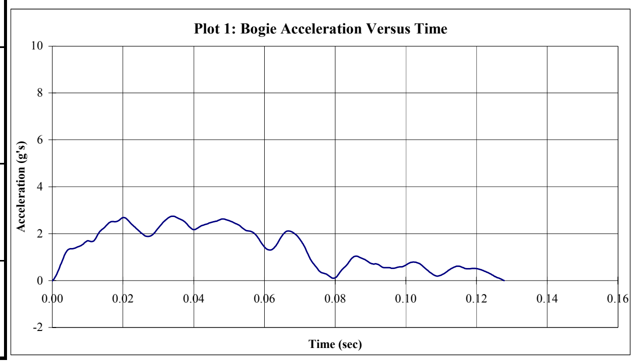


Plot 5: Deflection at Impact Location Versus Time

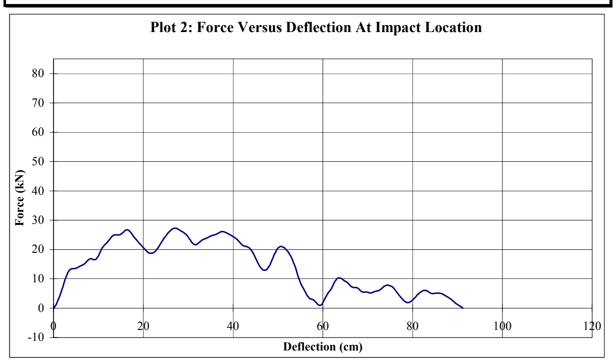
Midwest Roadside Safety Facility

Bogie Test Summary

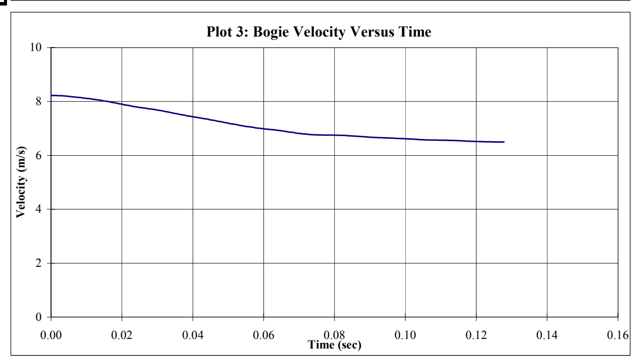
Test Information			
Test Number:	CPB-8		
Test Date:	8-Jun-01		
Failure Type:	--		
Post Properties			
Post Type:	Steel		
Post Size:	S75x8.5	S3x5.7	
Post Length:	160.0 cm	(5.3 ft)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Moisture Content:	--		
Gradation:	--		
Soil Density, γ_d:	NA	kg/m³	
Compaction Method:	Standard		
Bogie Properties			
Impact Velocity:	8.2 m/s	(18.4 mph)	(27.0 fps)
Impact Location:	68.6 cm	(27.0 in.)	above groundline
Bogie Mass:	1015 kg	(2237 lbf.)	
Data Acquired			
Accelerometer Data			
Side View, S-VHS			



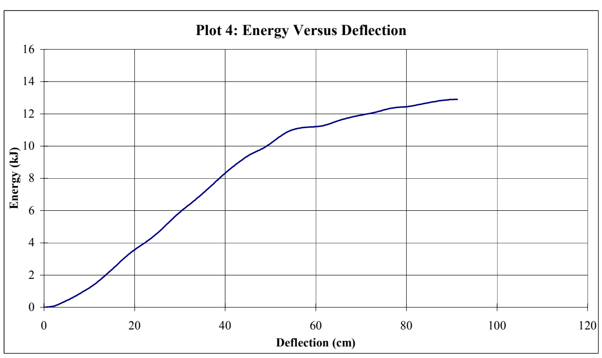
Plot 1: Bogie Acceleration Versus Time



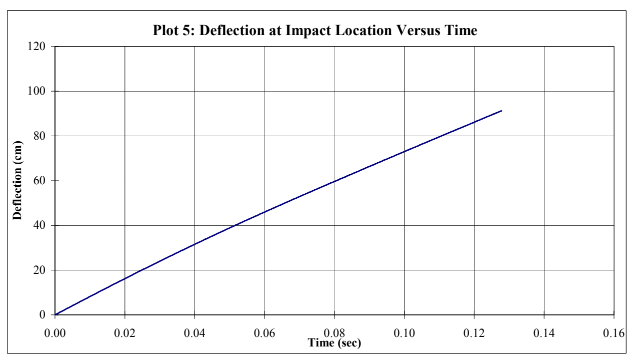
Plot 2: Force Versus Deflection At Impact Location



Plot 3: Bogie Velocity Versus Time



Plot 4: Energy Versus Deflection

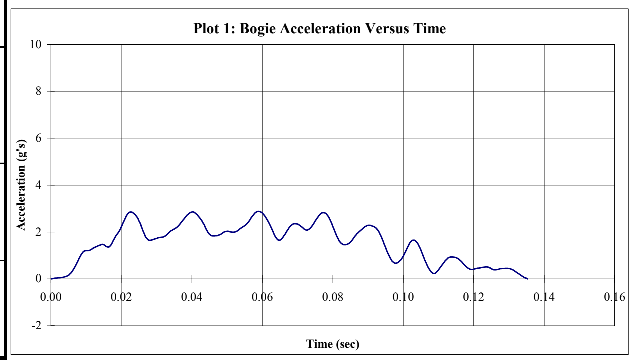


Plot 5: Deflection at Impact Location Versus Time

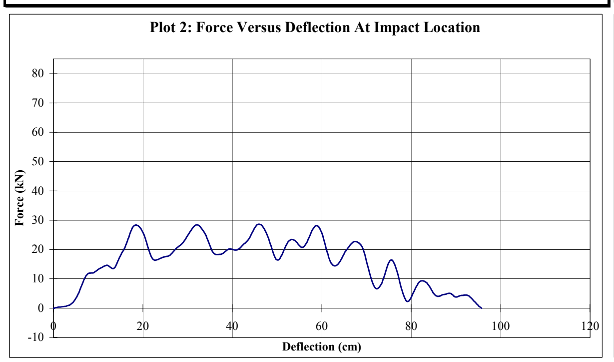
Midwest Roadside Safety Facility

Bogie Test Summary

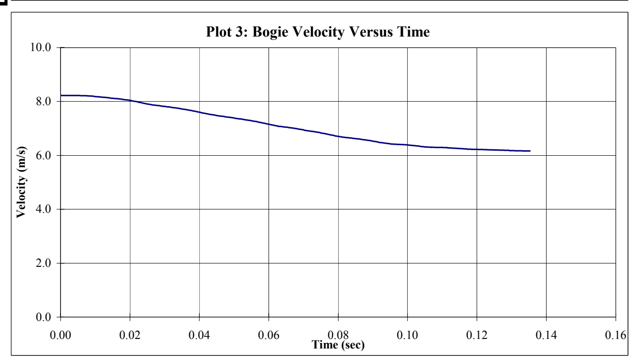
Test Information			
Test Number:	CPB-9		
Test Date:	8-Jun-01		
Failure Type:	--		
Post Properties			
Post Type:	Steel		
Post Size:	S75x8.5	S3x5.7	
Post Length:	160.0 cm	(5.3 ft)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Moisture Content:	--		
Gradation:	--		
Soil Density, γ_d:	NA	kg/m³	
Compaction Method:	Standard		
Bogie Properties			
Impact Velocity:	8.2 m/s	(18.4 mph)	(27.0 fps)
Impact Location:	68.6 cm	(27.0 in.)	above groundline
Bogie Mass:	1015 kg	(2237 lbf.)	
Data Acquired			
Accelerometer Data			
Side View, S-VHS			



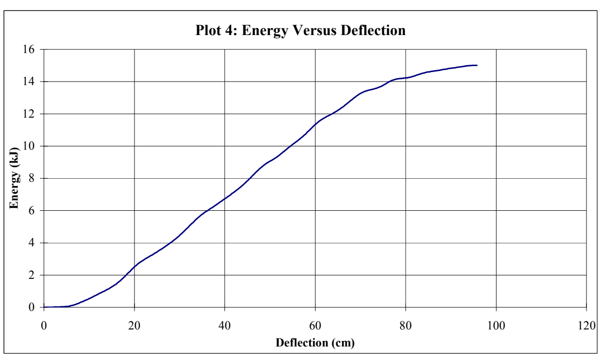
Plot 1: Bogie Acceleration Versus Time



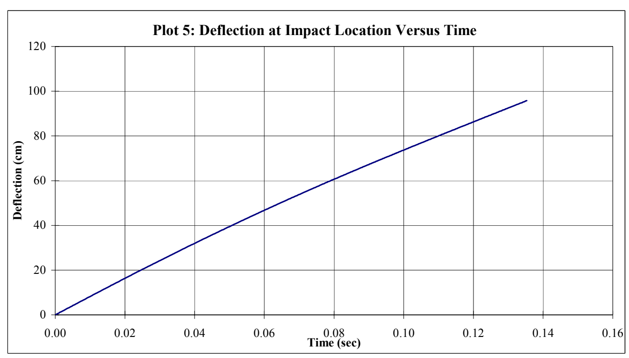
Plot 2: Force Versus Deflection At Impact Location



Plot 3: Bogie Velocity Versus Time



Plot 4: Energy Versus Deflection

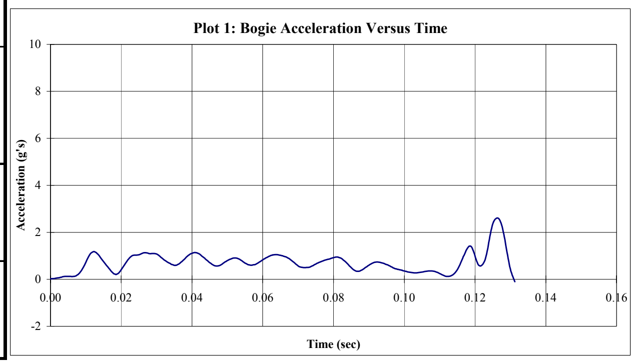


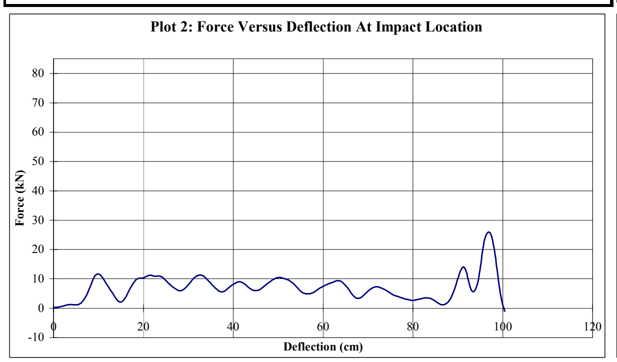
Plot 5: Deflection at Impact Location Versus Time

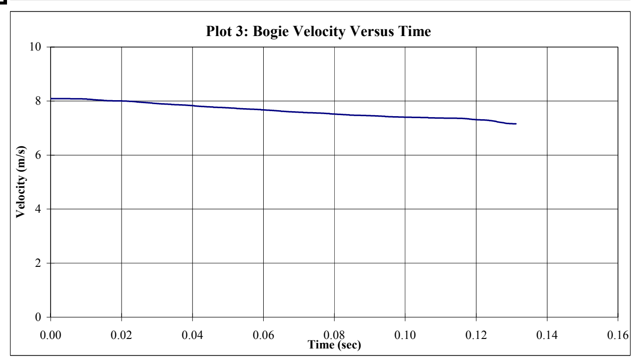
Midwest Roadside Safety Facility

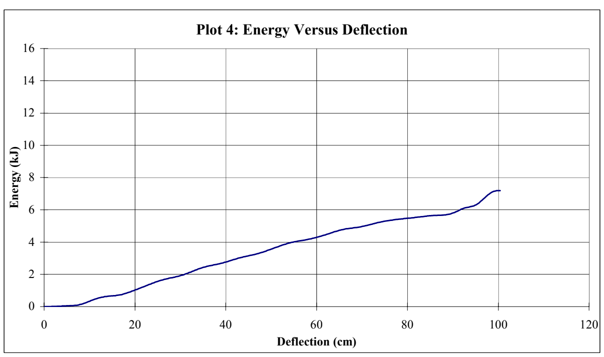
Bogie Test Summary

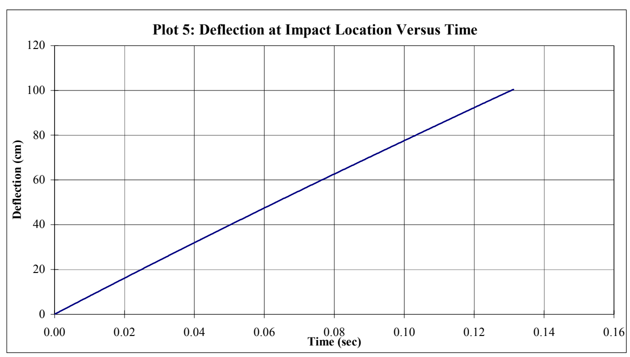
Test Information			
Test Number:	CPB-10		
Test Date:	8-Jun-01		
Failure Type:	--		
Post Properties			
Post Type:	Steel		
Post Size:	S75x8.5	S3x5.7	
Post Length:	160.0 cm	(5.3 ft)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Moisture Content:	--		
Gradation:	--		
Soil Density, γ_d:	NA	kg/m³	
Compaction Method:	Standard		
Bogie Properties			
Impact Velocity:	8.0 m/s	(18.1 mph)	(26.5 fps)
Impact Location:	68.6 cm	(27.0 in.)	above groundline
Bogie Mass:	1015 kg	(2237 lbf.)	
Data Acquired			
Accelerometer Data			
Side View, S-VHS			











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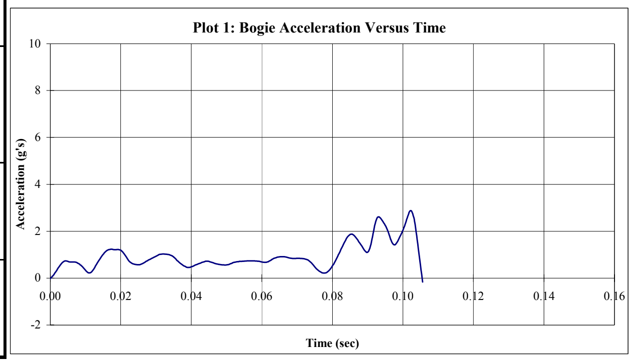
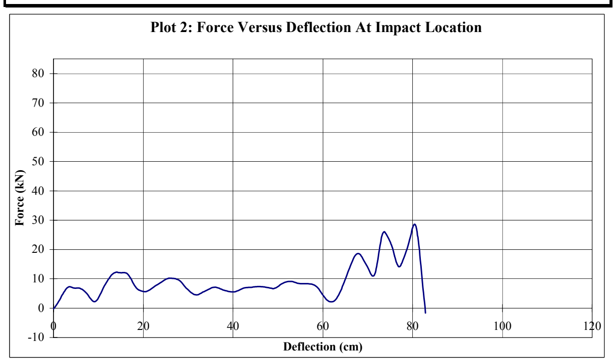
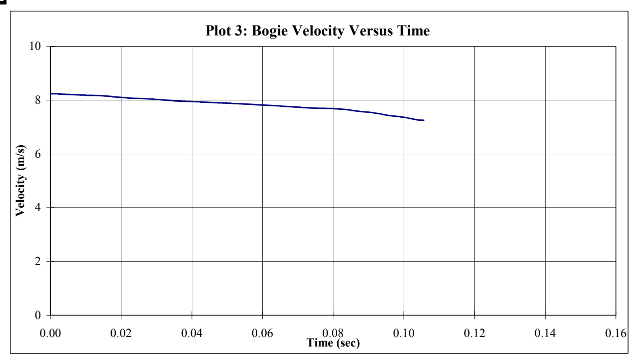
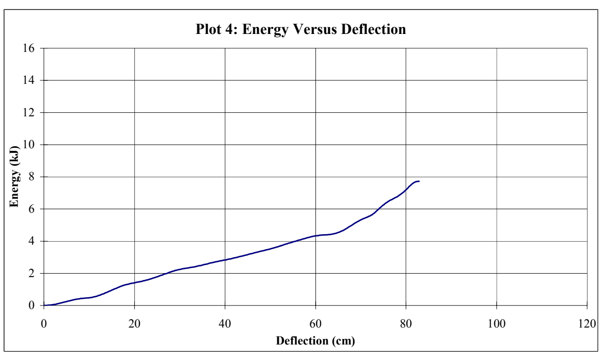
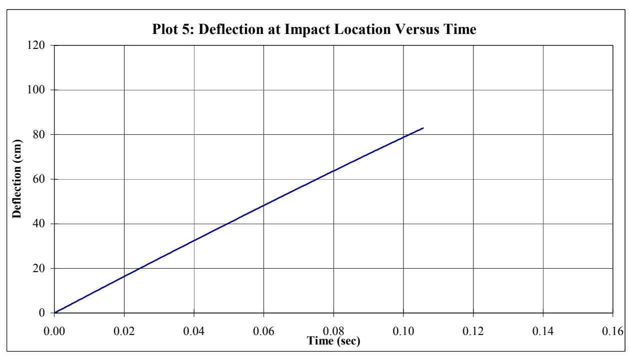
Bogie Test Summary		
Test Information		
Test Number:	CPB-11	
Test Date:	8-Jun-01	
Failure Type:	--	
Post Properties		
Post Type:	Steel	
Post Size:	S75x8.5	S3x5.7
Post Length:	160.0 cm	(5.3 ft)
Embedment Depth:	76.2 cm	(30.0 in)
Soil Properties		
Moisture Content:	--	
Gradation:	--	
Soil Density, γ_d:	NA kg/m³	
Compaction Method:	Standard	
Bogie Properties		
Impact Velocity:	8.2 m/s	(18.4 mph) (27.0 fps)
Impact Location:	68.6 cm	(27.0 in.) above groundline
Bogie Mass:	1015 kg	(2237 lbf.)
Data Acquired		
Accelerometer Data		
Side View, S-VHS		







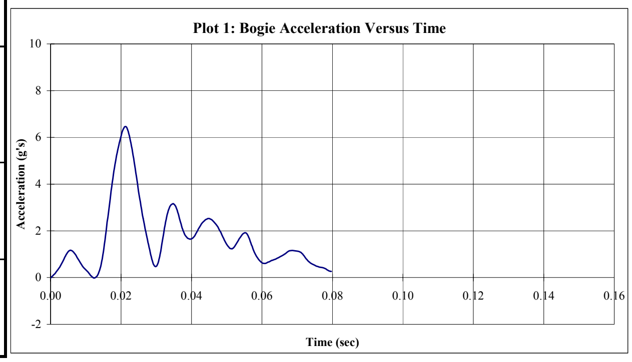


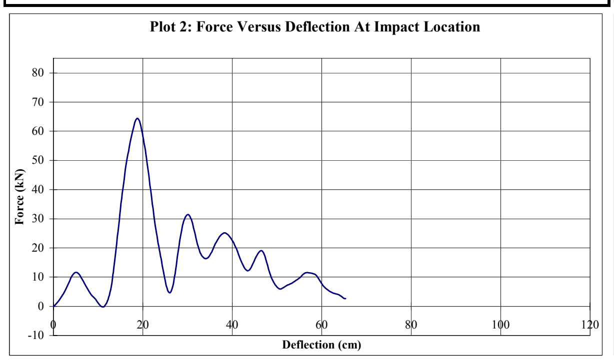


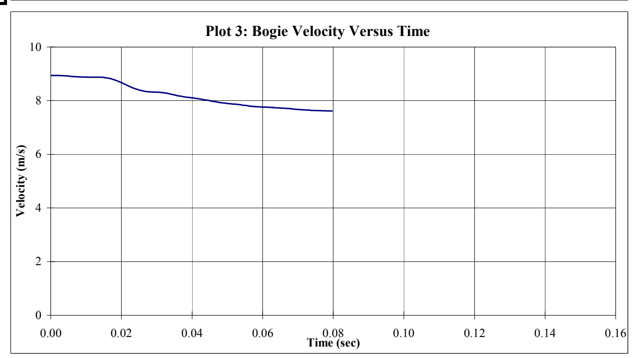
Midwest Roadside Safety Facility

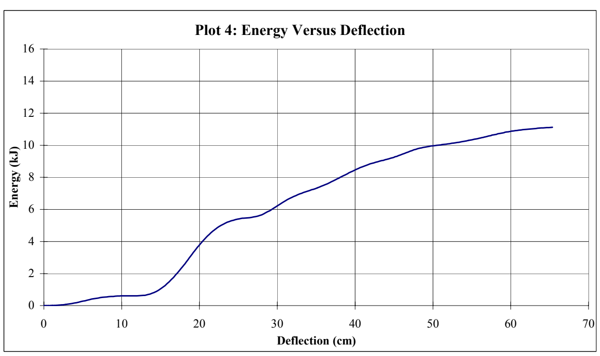
Bogie Test Summary

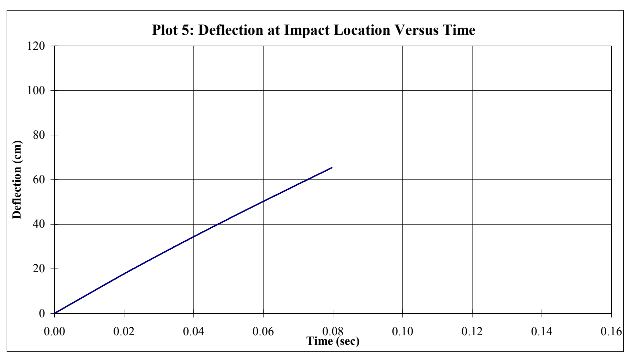
Test Information		
Test Number:	CPB-12	
Test Date:	8-Jun-01	
Failure Type:	--	
Post Properties		
Post Type:	Steel	
Post Size:	S75x8.5	S3x5.7
Post Length:	160.0 cm	(5.3 ft)
Embedment Depth:	76.2 cm	(30.0 in)
Soil Properties		
Moisture Content:	--	
Gradation:	NA	
Soil Density, γ_d:	NA	kg/m³
Compaction Method:	NA	
Bogie Properties		
Impact Velocity:	8.9 m/s	(20.0 mph) (29.3 fps)
Impact Location:	68.6 cm	(27.0 in.) above groundline
Bogie Mass:	1015 kg	(2237 lbf.)
Data Acquired		
Accelerometer Data		
Side View, S-VHS		











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Bogie Test Summary

Test Information

Test Number:	CPB-13	
Test Date:	8-Jun-01	
Failure Type:	--	

Post Properties

Post Type:	Steel	
Post Size:	S75x8.5	S3x5.7
Post Length:	160.0 cm	(5.3 ft)
Embedment Depth:	76.2 cm	(30.0 in)

Soil Properties

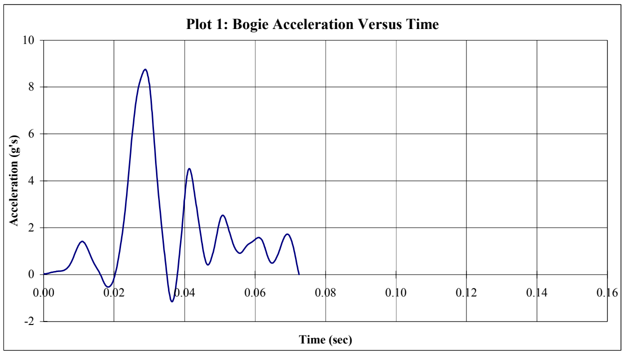
Moisture Content:	--	
Gradation:	NA	
Soil Density, γ_d:	NA	kg/m^3
Compaction Method:	NA	

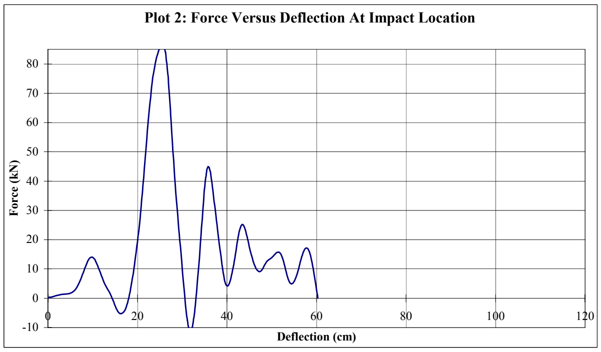
Bogie Properties

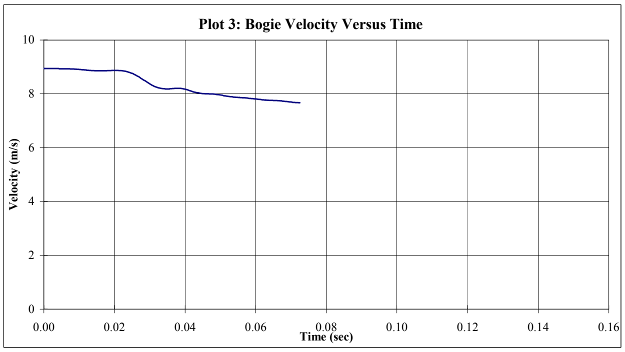
Impact Velocity:	8.9 m/s	(20.0 mph) (29.3 fps)
Impact Location:	68.6 cm	(27.0 in.) above groundline
Bogie Mass:	1015 kg	(2237 lbf.)

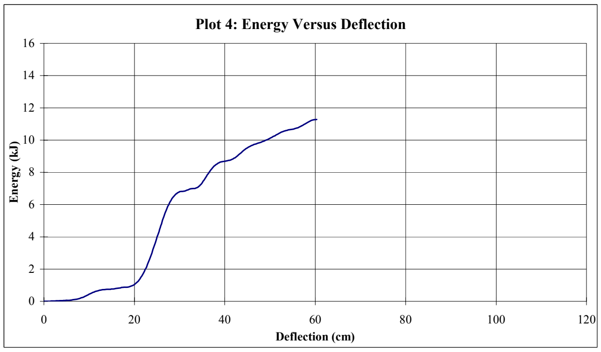
Data Acquired

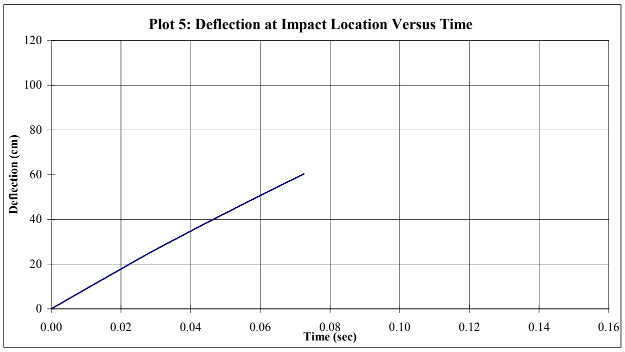
Accelerometer Data
Side View, S-VHS







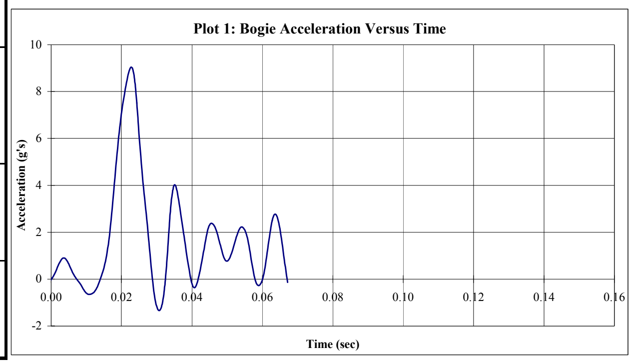




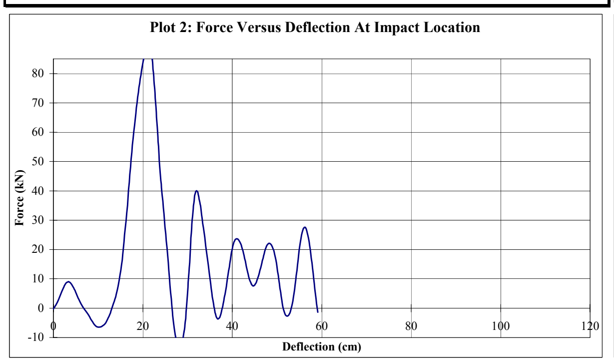
Midwest Roadside Safety Facility

Bogie Test Summary

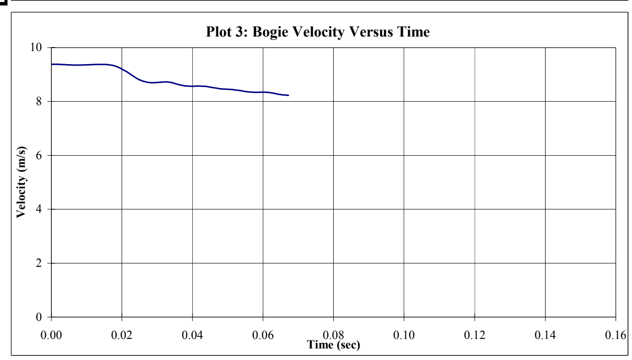
Test Information			
Test Number:	CPB-14		
Test Date:	8-Jun-01		
Failure Type:	--		
Post Properties			
Post Type:	Steel		
Post Size:	S75x8.5	S3x5.7	
Post Length:	160.0 cm	(5.3 ft)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Moisture Content:	--		
Gradation:	NA		
Soil Density, γ_d:	NA	kg/m³	
Compaction Method:	NA		
Bogie Properties			
Impact Velocity:	9.3 m/s	(21.0 mph)	(30.8 fps)
Impact Location:	68.6 cm	(27.0 in.) above groundline	
Bogie Mass:	1015 kg	(2237 lbf.)	
Data Acquired			
Accelerometer Data			
Side View, S-VHS			



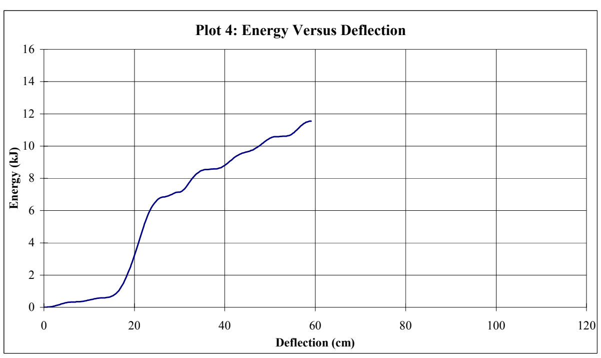
Plot 1: Bogie Acceleration Versus Time



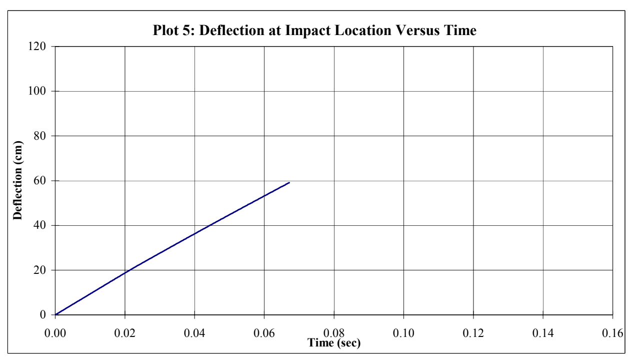
Plot 2: Force Versus Deflection At Impact Location



Plot 3: Bogie Velocity Versus Time



Plot 4: Energy Versus Deflection

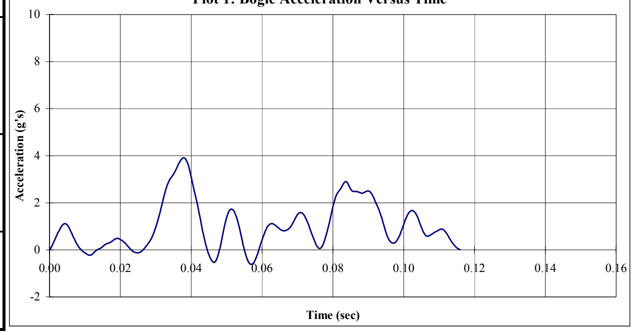


Plot 5: Deflection at Impact Location Versus Time

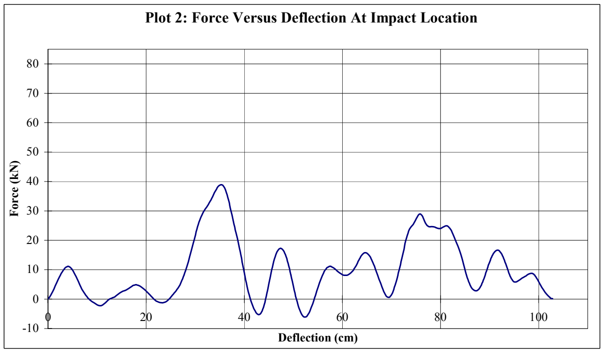
Midwest Roadside Safety Facility

Bogie Test Summary

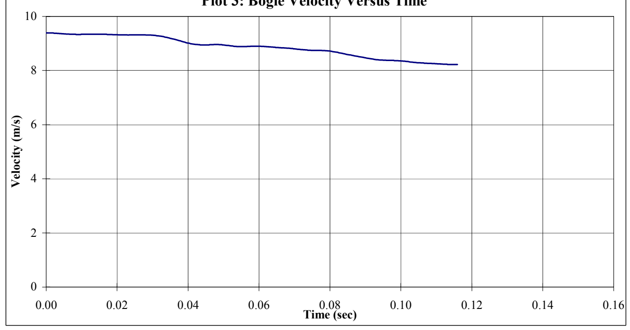
Test Information			
	Test Number:	CPB-15	
	Test Date:	8-Jun-01	
	Failure Type:	--	
Post Properties			
	Post Type:	Steel	
	Post Size:	S75x8.5	S3x5.7
	Post Length:	160.0 cm	(5.3 ft)
	Embedment Depth:	76.2 cm	(30.0 in)
Soil Properties			
	Moisture Content:	--	
	Gradation:	NA	
	Soil Density, γ_d:	NA	kg/m³
	Compaction Method:	NA	
Bogie Properties			
	Impact Velocity:	9.3 m/s	(21.0 mph) (30.8 fps)
	Impact Location:	68.6 cm	(27.0 in.) above groundline
	Bogie Mass:	1015 kg	(2237 lbf.)
Data Acquired			
	Accelerometer Data		
	Side View, S-VHS		



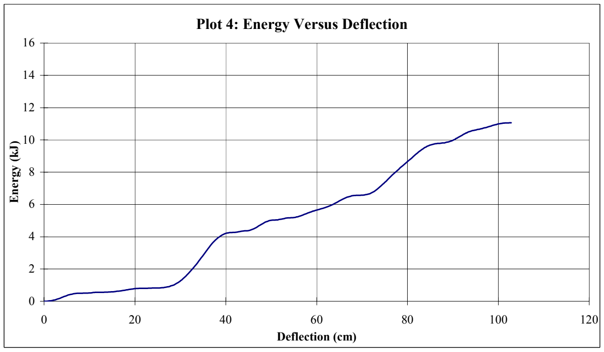
Plot 1: Bogie Acceleration Versus Time



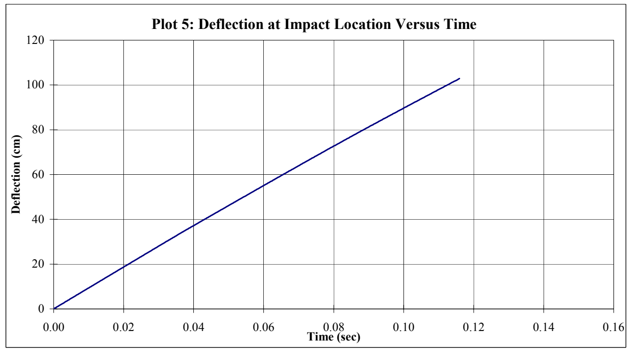
Plot 2: Force Versus Deflection At Impact Location



Plot 3: Bogie Velocity Versus Time



Plot 4: Energy Versus Deflection

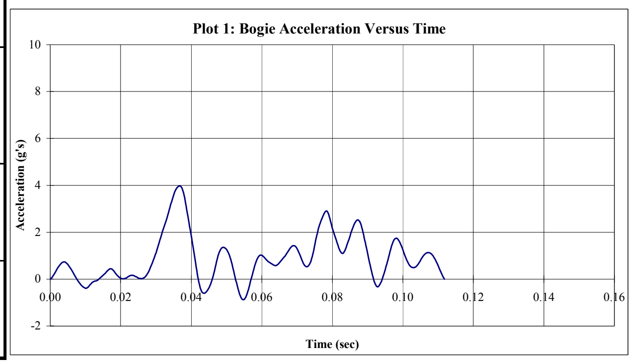


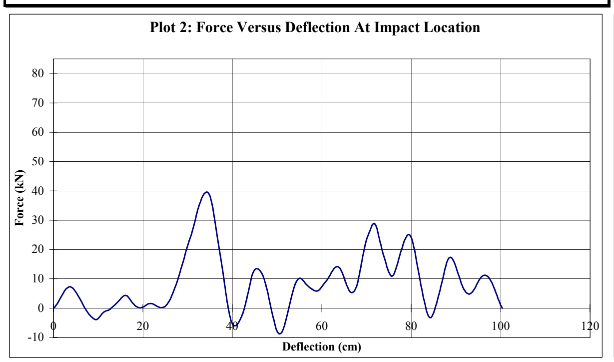
Plot 5: Deflection at Impact Location Versus Time

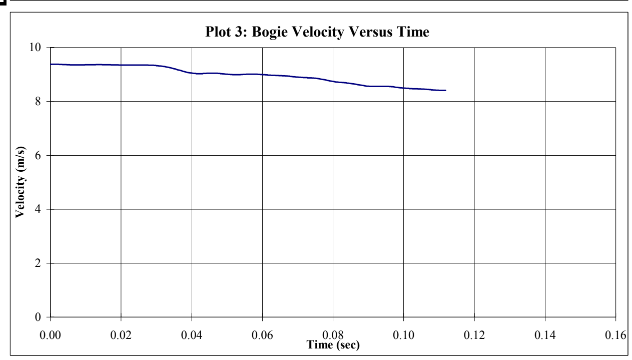
Midwest Roadside Safety Facility

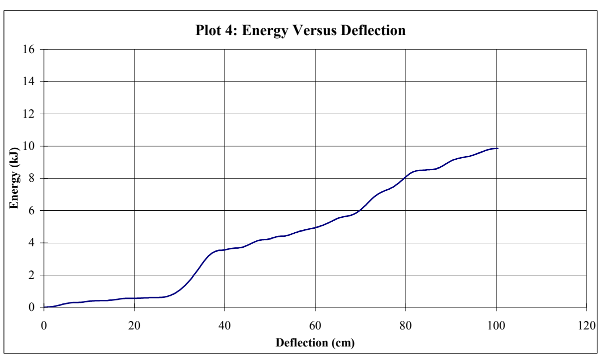
Bogie Test Summary

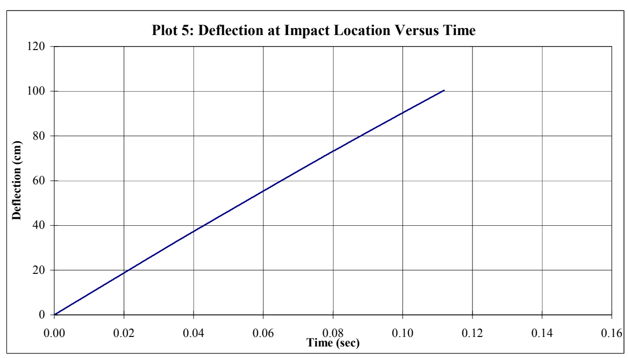
Test Information			
Test Number:	CPB-16		
Test Date:	8-Jun-01		
Failure Type:	--		
Post Properties			
Post Type:	Steel		
Post Size:	S75x8.5	S3x5.7	
Post Length:	160.0 cm	(5.3 ft)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Moisture Content:	--		
Gradation:	NA		
Soil Density, γ_d:	NA	kg/m³	
Compaction Method:	NA		
Bogie Properties			
Impact Velocity:	9.3 m/s	(21.0 mph)	(30.8 fps)
Impact Location:	68.6 cm	(27.0 in.)	above groundline
Bogie Mass:	1015 kg	(2237 lbf.)	
Data Acquired			
Accelerometer Data			
Side View, S-VHS			











Midwest Roadside Safety Facility

Bogie Test Summary

Test Information			
Test Number:	CPB-17		
Test Date:	8-Jun-01		
Failure Type:	--		
Post Properties			
Post Type:	Steel		
Post Size:	S75x8.5	S3x5.7	
Post Length:	160.0 cm	(5.3 ft)	
Embedment Depth:	76.2 cm	(30.0 in)	
Soil Properties			
Moisture Content:	--		
Gradation:	NA		
Soil Density, γ_d:	NA	kg/m³	
Compaction Method:	NA		
Bogie Properties			
Impact Velocity:	9.3 m/s	(21.0 mph)	(30.8 fps)
Impact Location:	68.6 cm	(27.0 in.)	above groundline
Bogie Mass:	1015 kg	(2237 lbf.)	
Data Acquired			
Accelerometer Data			
Side View, S-VHS