Load and Resistance Factor Design of Drilled Shafts in Shale for Lateral Loading

Prepared By
Andrew Boeckmann
Sarah Myers
Minh Uong
J. Erik Loehr
University of Missouri Department of Civil and Environmental Engineering

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16. Abstract: A research project involving 32 drilled shaft load tests was undertaken to establish LRFD procedures for design of drilled shafts subjected to lateral loads. Tests were performed at two Missouri Department of Transportation (MoDOT) geotechnical research sites. All shafts were founded in shale. Shafts were instrumented to measure the displacement of the shaft head, and the structural response of each shaft was interpreted from strain gage data as well as from ShapeAccelArray (SAA) data. The load tests achieved significant displacement of the top of the shaft, and successfully transferred load into the rock layers. A p-y model was created from the data by using a FEM code to match the measured deflection data. The fitted p-y models were generally stiffer and with greater values of p_{ult} than those predicted using the popular "stiff clay" model of Ensoft's L-PILE. The FEM code was then used to perform reliability calculations and produce resistance factors as a function of the coefficient of variation of the foundation material strength.		
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Missouri Department of Transportation

by

Andrew Boeckmann, Sarah Myers, Minh Uong, and J. Erik Loehr

University of Missouri
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Dan Ding
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Joseph Gillam
Rex Gish
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1. Introduction

The Missouri Department of Transportation (MoDOT) has adopted new guidelines for design of drilled shaft foundations subjected to axial loading that implement Load and Resistance Factor Design (LRFD) techniques. Currently, there are no MoDOT guidelines implementing LRFD techniques for design of drilled shaft foundations subjected to lateral loads. On a national level, the AASHTO LRFD Bridge Design Specifications (AASHTO, 2012) stipulate that a resistance factor of 1.0 be used for design of drilled shafts subjected to lateral load. The FHWA/NHI Drilled Shaft Manual (Brown et al., 2010) recommends use of a resistance factor of 0.67, but this factor is based on the authors' judgment rather than a reliability study. A research project involving a significant drilled shaft load testing program was therefore undertaken to establish LRFD procedures for design of drilled shafts subjected to lateral loads. Another primary objective of the project was to improve knowledge and reduce the uncertainty associated with models for lateral resistance in shale.

This report documents the load testing program and the accompanying analyses that were used to develop p-y curves for drilled shafts in shale and to establish resistance factors for design of laterally loaded drilled shafts. Background information on the test sites and previous research is presented before summarizing the load test methods that were used. A summary of the results is presented in the body of this report, but the majority of the results are included in appendices because of the volume of data. A computer program developed by the authors was used to interpret p-y response from the load tests and to perform the reliability analyses necessary to establish appropriate resistance factors. Finally, conclusions drawn from development and evaluation of the proposed procedures and recommendations for implementation and for future work are provided.

2. Background

This chapter presents information regarding the larger MoDOT research program of which this project was a part. Information about the two test sites and the test shafts, including subsurface conditions and details of drilled shaft construction, concrete testing, and instrumentation is also provided. Appendix A contains as-built information for each of the tested drilled shafts.

2.1 MoDOT Research Program

The MoDOT laterally loaded drilled shafts research program follows MoDOT's "Geotechnical Thrust" research program. Detailed information regarding the previous research program is documented in the MoDOT technical report "Load and Resistance Factor Design of Drilled Shafts in Shale using SPT and TCP Measurements" (Pierce et al., 2014). Drilled shafts, which were constructed as part of the previous research program, were load tested for this research to measure the response to lateral loading. Twenty-five drilled shafts were constructed at the Frankford and Warrensburg Load Test sites in Missouri during the summer of 2010.

The purpose for the previous research program was to develop specific design relations for MoDOT for predicting side and tip resistance for drilled shafts in Missouri shale and to establish appropriate resistance factors to achieve target levels of reliability. Each shaft was load tested using the Osterberg Cell (O-Cell™) load testing technique. O-Cells™ and RIM-Cells were used for full-scale axial load testing of the drilled shafts and were pressurized during the load test to apply "bi-directional" load to the respective portions of the shaft above and below the cell. Standard Penetration Tests and Modified Texas Cone Penetration tests were also conducted at each site. To utilize the results of the in-situ tests for design of drilled shafts using Load and Resistance Factor Design, it was necessary to correlate in-situ measurements with side and tip resistances and to establish calibrated resistance factors that account for the reliability of the correlations and the in-situ test measurements. This lateral load testing program, completed during the summer of 2012, was similar to the axial load testing program completed during the summer of 2010.

2.2 Frankford Load Test Site

The Frankford Load Test site is located near Frankford, Missouri along U.S. Highway 61 northwest of St. Louis as shown in Figure 2.1. The test shafts were constructed along the ditch line of the outer gravel road on the west side of U.S. 61, south of the intersection with Pike County Road 58 as shown in Figure 2.2.

Figure 2.1 – Location of Frankford Load Test Site. (Google Earth, 2011a)

Figure 2.2 – Location of Frankford Load Test Site south of Frankford, MO along U.S. Highway 61, near the intersection with Pike County Road 58. (Google Earth, 2011b)

2.2.1 Subsurface Conditions

The Ordovician Maquoketa shale formation in the area is typically laminated, silty, calcareous or dolomitic shale. The site is composed of weathered shale overlying unweathered shale underlain by competent limestone. The uniaxial compressive strength (UCS) for the weathered shale ranged from 3 to 30 ksf while UCS for the unweathered shale ranged from 40 to 100 ksf. The strength of the shale varies with the degree of weathering, but is fairly consistent and uniform throughout the site. The weathered shale had equivalent SPT N-values ranging from 29 to 101 blows/ft while N-values for the unweathered shale ranged from 203 to 304 blows/ft. Figure 2.3 presents measured values of UCS from the site along with the mean and standard deviation for the UCS of each layer. The mean values for each stratum are shown as solid vertical lines. The dashed vertical lines reflect the mean value plus or minus one standard deviation.

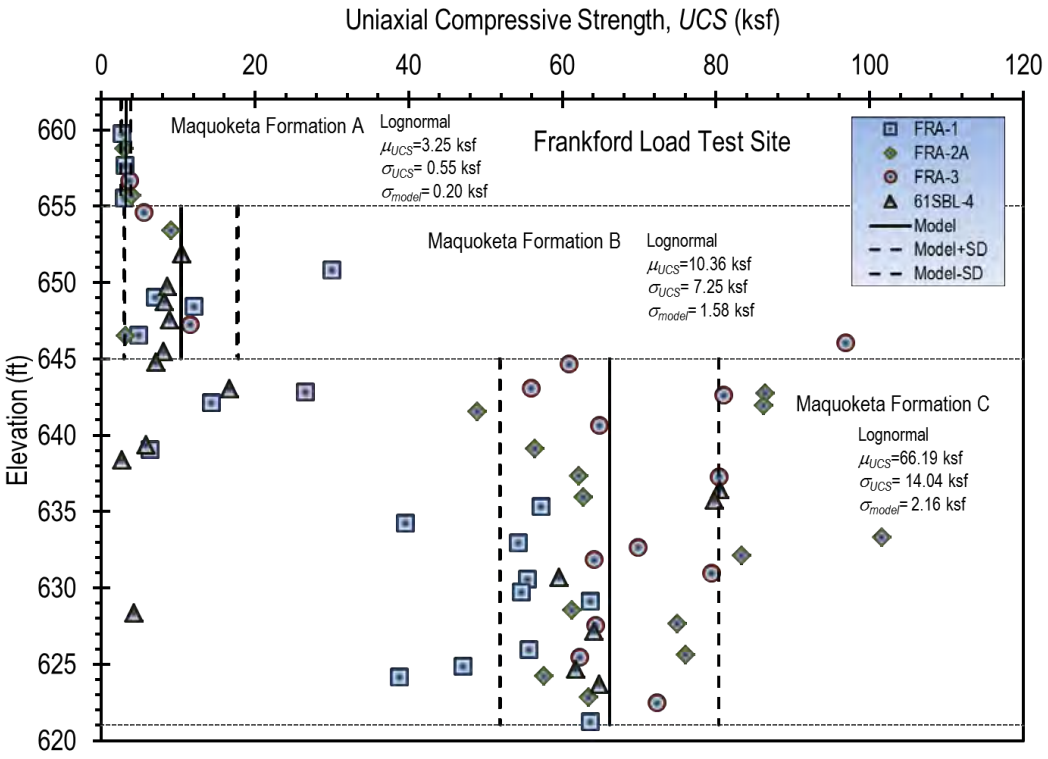

Figure 2.3 – Measured values of UCS shown with mean and standard deviation values for the Frankford Load Test Site.

2.2.2 Drilled Shafts

Ten shafts, designated F1, F2, …, F10, were constructed with diameters ranging from 3 to 5 ft and lengths ranging from 20 to 35 ft. The test shafts were arranged in a straight line parallel with U.S. 61 as shown in Figure 2.4. Details of shaft construction, concrete testing, and instrumentation are described below and summarized in Table 2.1, and as-built information for each shaft is provided in Appendix A.

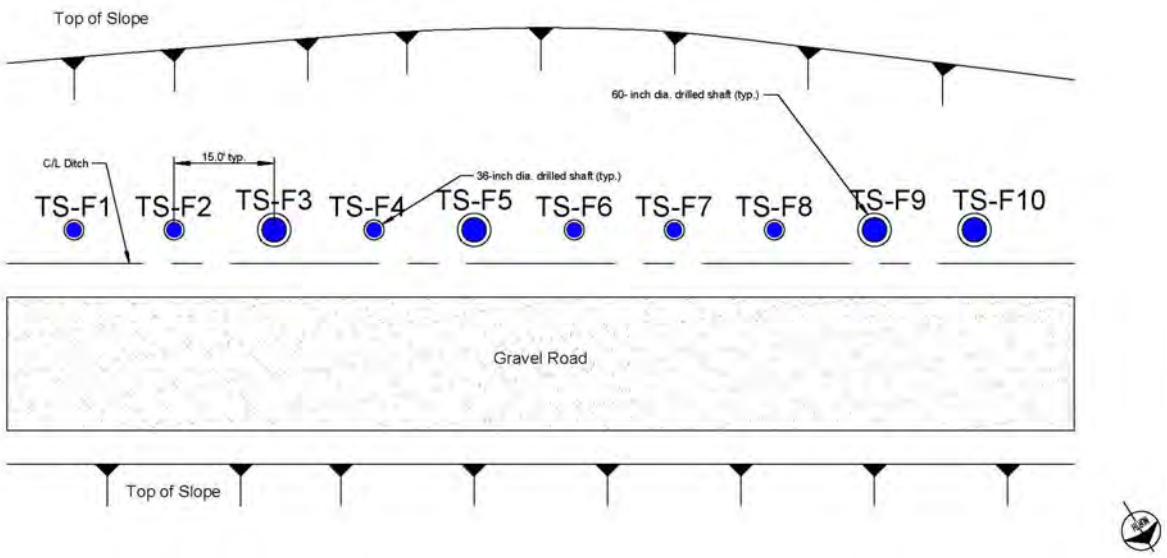

Figure 2.4 – Layout of test shafts at Frankford Load Test Site.

Shafts were constructed using the "dry" method without slurry and with a short section of permanent casing through the overburden material (embedment of 5 ft or less). A Watson-3100 CM rig with a 60-in. or 36-in. auger (according to the shaft size) was used to excavate to a depth of approximately 5 ft. A short, oversized section of the temporary casing was placed in the hole to prevent sloughing of the surficial soil and gravel. The rock sockets were then excavated to the desired depth and cleaned using either the augers or a cleanout bucket. Permanent steel casing was placed in the middle of the temporary casing. Measured shaft diameters are listed in Table 2.1, and additional details are provided in Appendix A. Shaft diameters were measured after construction using a sonar caliper.

Following excavation and cleanout of each shaft, the reinforcing cage was lifted into a vertical alignment by the drill rig and lowered into the hole. For all 3-ft diameter shafts, several feet of concrete were placed in the hole prior to positioning the reinforcing cage. No concrete was placed prior to installation of the reinforcing cage for the 5-ft diameter shafts. Wheel spacers were placed on the reinforcing cages to maintain alignment of the reinforcing cages within the shafts.

The concrete placed was MoDOT Class B-2 concrete with a minimum compressive strength of 4,000 psi and a maximum aggregate size of 0.75-in. The concrete was adjusted using super plasticizers to achieve a slump of 9 to 10 in and then placed using a "ported" tremie pipe. Concrete slump and entrained air tests were performed for each shaft according to AASHTO standard methods T119 and T152. Concrete cylinders were taken for each shaft to establish the concrete strength and modulus. Table 2.1 presents the measured compressive strengths of the concrete for each shaft.

Table 2.1 – Summary of shaft construction details for Frankford Load Test Site.

Shaft	Total Length Below Ground Surface (ft)	Diameter (in.)				Thickness of Permanent Casing (in.)	f_c' (psi) (days after pour)
		Of Casing		Below Casing			
		Temporary	Permanent	Minimum	Maximum		
F1	17.8	43.0	36.8	38.1	42.4	0.375	4083 (5?)
F2	20.6	43.0	36.0	38.6	40.4	0.25	3810 (7)
F3	22.9	65.8	61	62.2	65	0.5	4882 (6)
F4	24.1	43.0	36.5	39.3	39.6	0.375	4895 (6)
F5	31.7	65.8	61.5	61.1	62.5	0.75	3823 (5)
F6	25.1	43.0	36.8	37.9	38.9	0.375	4623 (7)
F7	32.6	43.0	36	37.4	38.7	0.5	4271 (4)
F8	21.6	43.0	36.3	39.9	40.8	0.375	3841 (6)
F9	15.2	65.8	61.5	63	63.5	0.75	4600 (6)
F10	17.1	65.8	61.5	58.5	60.9	0.75	5149 (6)

Each shaft was instrumented with six levels of vibrating wire strain gages, four or five telltale rods and one inclinometer casing. The strain gages were vibrating wire, concrete embedment gages (Geokon Model 4200) attached to u-brackets welded inside the reinforcing cage as shown in Figure 2.5. All shafts were instrumented with four gages at each level (24 gages per shaft). Due to vandalism at the site, additional cable lengths were spliced together for all the strain gages. A single inclinometer casing was installed in each test shaft as shown in Figure 2.6. Two geophones were also installed in most of the shafts to evaluate small-strain concrete modulus. Cross-hole sonic logging (CSL) pipes were installed in two of the test shafts. Six CSL tubes were installed in test shaft F5, and four CSL tubes were installed in test shaft F7. Osterberg Cell (O-Cell™) loading devices were installed in eight test shafts, and RIM Cells™ were installed in the other two shafts. Those devices were used for an axial load test program performed earlier (Pierce et al., 2014).

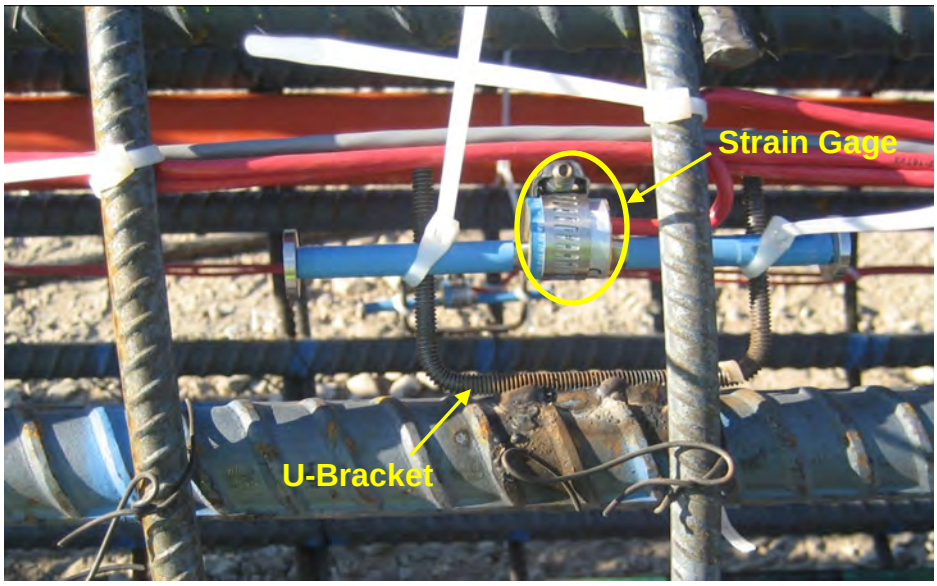

Figure 2.5 – Vibrating wire strain gage mounted on reinforcing cage.

Figure 2.6 – Inclinometer casing attached to reinforcing cage.

2.3 Warrensburg Load Test Site

The Warrensburg Load Test site is located near the city of Warrensburg, in west-central Missouri approximately 60 miles east of Kansas City as shown in Figure 2.7. The test shafts were constructed in the right-of-way for U.S. Highway 50, near the intersection of Missouri Highway 13 and State Highway HH, as shown in Figure 2.8.

Figure 2.7 – Location of Warrensburg Load Test Site. (Google Earth, 2011c)

Figure 2.8 – Location of Warrensburg Load Test Site east of Warrensburg, MO on U.S. Highway 50, near the intersection with State Highway HH. (Google Earth, 2011d)

2.3.1 Subsurface Conditions

The site is composed of approximately 15 ft of silty clay overburden soil overlying shale formations with highly variable strength along with sporadic sandstone. The bedrock consists of the Pennsylvanian Croweburg and Fleming formations containing sandstone, siltstone, limestone, and coal beds. The Croweburg formation had a UCS ranging from 3 to 80 ksf while UCS for the Fleming formation ranged from 5 to 240 ksf. The Croweburg formation had equivalent Standard Penetration Test (SPT) N-values ranging from 93 to 122 blows/ft while equivalent N-values for the Fleming formation ranged from 122 to 304 blows/ft. Figure 2.9 presents UCS measurements from the site along with the mean and standard deviation of UCS for each layer.

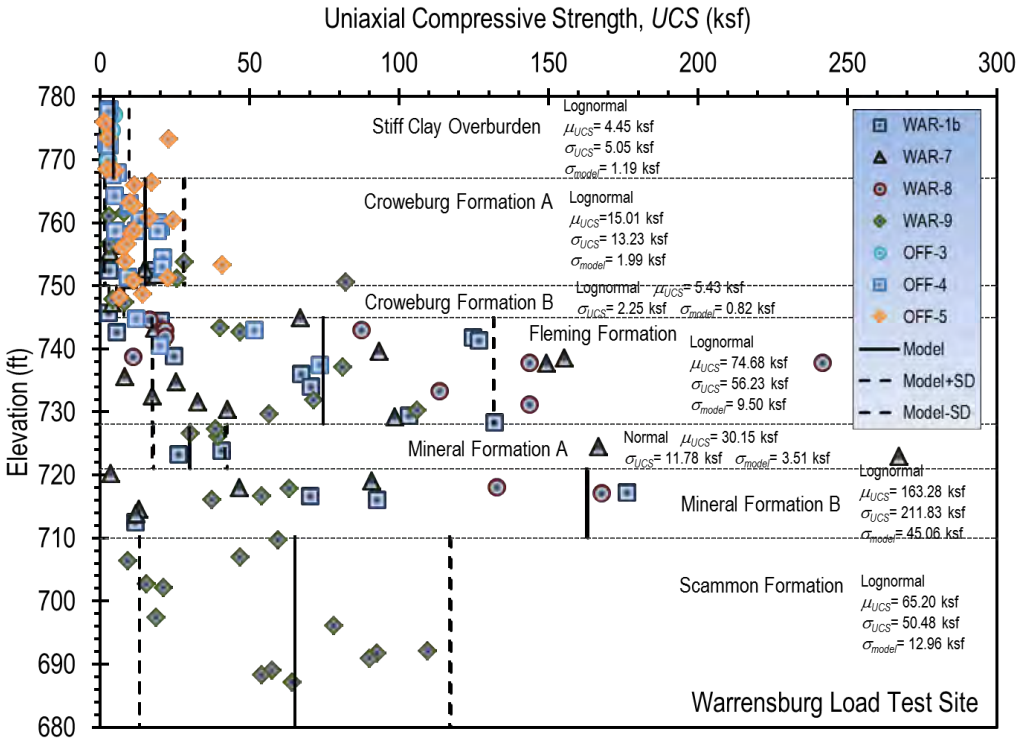

Figure 2.9 – Measured values of UCS shown with mean and standard deviation values for Warrensburg Load Test Site.

2.3.2 Drilled Shafts

The test shafts were constructed in three rows of five shafts between U.S. 50 and the westbound entrance ramp to U.S. 50 as shown in Figure 2.10. Fifteen shafts, designated W1, W2, …, W15, were constructed with a diameter of 3 ft and lengths ranging from 30 to 50 ft. Details of shaft construction, concrete testing, and instrumentation are described below and summarized in Table 2.2, and as-built information for each shaft is provided in Appendix A.

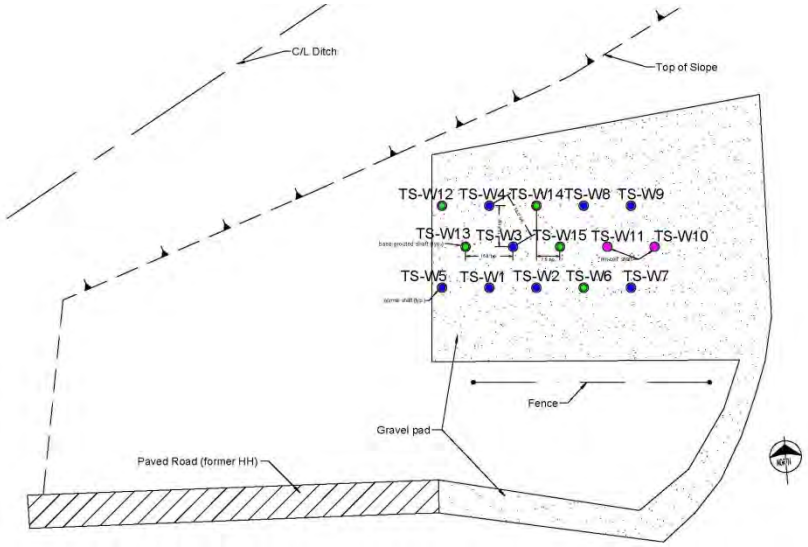

Figure 2.10 – Layout of test shafts at the Warrensburg Load Test Site.

Shafts were constructed using the “dry” method without slurry and with permanent casing through the overburden material (approximately 15 ft embedment). A LoDrill rig was used for shaft construction using a 36-in. diameter auger bit to drill approximately 10 to 15 feet then using a 42-in. core barrel to expand the hole for placement of the permanent casing. Drilling continued with a 36-in. auger to excavate the rock socket. Measured shaft diameters are listed in Table 2.2, with diameters measured after construction using a sonar caliper. Following excavation and cleanout of each shaft, the reinforcing cage was lifted into a vertical alignment using a boom truck and lowered into the hole. Wheel spacers were placed on the reinforcing cage as it was lowered into the drilled hole to keep the cage centered.

Concrete was placed using a concrete pump with a tremie pipe following placement of the reinforcing cage. MoDOT Class B-2 concrete with aggregate gradation D, which has a maximum aggregate size of 1 in., was utilized. The specified minimum compressive strength of the concrete was 4,000 psi. The concrete was adjusted using super plasticizer to achieve a slump of 10 in prior to placement. Slump and entrained air tests were performed for each concrete batch according to AASHTO standard methods T119 and T152. Cylinders were prepared to determine the compressive strength of the concrete, which is summarized in Table 2.2. Self-consolidating concrete (SCC) was used in shafts W7 and W9. Slump flow tests and J-ring tests following ASTM Standard C1621M-09b were performed on the SCC. SCC was used for two shafts as part of a separate experiment. It is unlikely that the use of SCC had any impact on the results of this project.

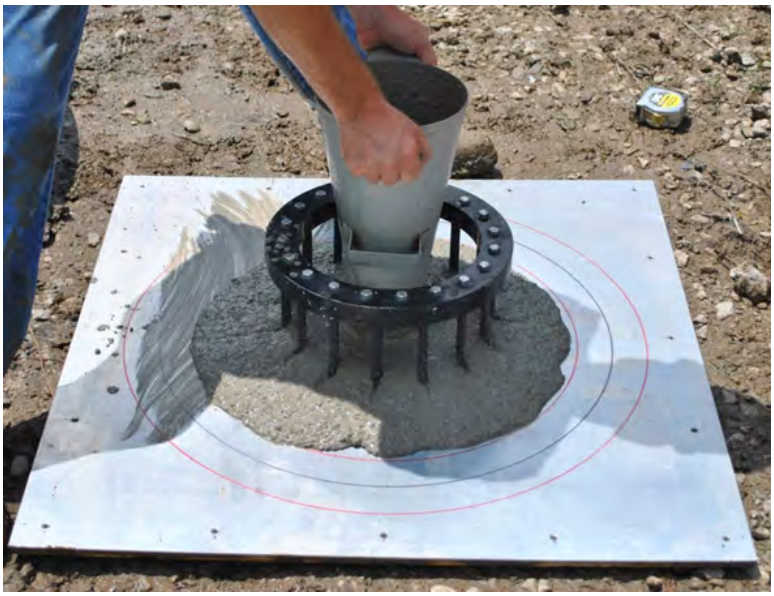

Figure 2.11 – Slump flow test and J-ring tests performed on self-consolidating concrete.

Test shafts W6, W12, W13, W14, and W15 were post-grouted shafts. Post-grouting was achieved using a “flat-jack” base plate, which was attached to the reinforcing cage along with grouting tubes prior to the cage being lowered into the hole. Due to limited space, neat cement grout with a water-cement ratio of 0.45 was placed into these shafts through a grout tube until the grout reached a level above the O-cell™ top plate. Class B-2 concrete was then used for the remainder of the shafts above the O-cells.

Table 2.2 – Summary of shaft construction details for Warrensburg Load Test Site.

Shaft	Total Length Below Ground Surface (ft)	Diameter (in.)			Thickness of Permanent Casing (in.)	f_c' (psi) (days after pour)
		Of Permanent Casing	Below Permanent Casing			
			Minimum	Maximum		
W1	29.4	42.0	36.5	38.2	0.25	5942 (5)
W2	30.3	42.0	37.3	38.9	0.25	7677 (9)
W3	44.9	42.0	36.2	38.7	0.25	8219 (10)
W4	47.1	42.0	37.5	37.5	0.25	5652 (9); 5896 (20)
W5	23.0	42.0	36.3	37.8	0.25	5157 (11)
W6	30.6	42.0	36.1	38.0	0.25	6590 (48)
W7	31.5	42.0	36.0	38.1	0.25	7646 (7)
W8	46.1	42.0	38.1	39.0	0.25	5938 (11)
W9	45.9	42.0	36.7	38.1	0.25	8189 (7)
W10	34.6	42.0	37.2	39.0	0.25	5122 (8)
W11	34.8	42.0	37.5	39.0	0.25	4952 (8)
W12	30.9	42.0	37.7	38.1	0.25	9160 (55)
W13	30.1	42.0	36.1	37.9	0.25	8920 (53)
W14	30.7	42.0	35.6	39.6	0.25	9120 (54)
W15	30.9	42.0	35.0	38.9	0.25	7390 (53)

Each shaft was instrumented with six levels of vibrating wire strain gages, four to five tell-tale rods and one inclinometer casing. The strain gages were vibrating wire, concrete embedment gages (Geokon Model 4200) attached to u-brackets welded inside the reinforcing cage. Most shafts were instrumented with four gages at each level (24 gages total per shaft), but the post-grouted shafts were instrumented with two gages at each level (12 gages total per shaft). Six of the shafts also contained sister bar resistance-type strain gages and two contained tip gages for high strain dynamic testing. Two geophones were also installed in most of the shafts to evaluate small-strain concrete modulus. Four cross-hole sonic logging (CSL) pipes were installed in test shafts W1 and W2. Osterberg Cell (O-Cell™) loading devices were installed on 13 of the test shafts while the alternative RIM Cells™ were installed on the other two shafts.

3. Field Testing Program and Apparatus

In total, three lateral load tests were performed at the Frankford Load Test Site and 13 lateral load tests were performed at the Warrensburg Load Test Site. This chapter presents details of the load testing program, load test frame, instrumentation, and testing procedure.

3.1 Testing Program

The primary focus of the load testing program was to measure the response of the foundations to static lateral loading. All tests were performed by pulling two shafts together, so that two foundations were loaded and monitored simultaneously, producing two sets of test results for each individual lateral load test. The lateral load testing was performed by members of the University of Missouri Geotechnical Engineering Department. Shaft pairs were determined primarily by location, but consideration was also given to pairing shafts of similar length.

3.1.1 Frankford Load Test Site

Three tests were performed at the Frankford Load Test Site as shown in Figure 3.1. Test shaft F1 was paired with shaft F2, shaft F7 was paired with shaft F8, and shaft F4 was paired with shaft F6 in a test that spanned around shaft F5. Test shafts F3, F5, F9 and F10 are 5-ft diameter shafts. The ultimate load for these shafts was predicted to be substantially greater than the 3-ft diameter shafts, resulting in higher loads on the load frame and greater capabilities from the hydraulic system, so the 5-ft shafts were not tested. The distance between shafts was 15 ft (30 ft for shafts F4-F6), which is comparable to the recommendation of a clear distance of 5 shaft diameters in ASTM D3966 (2007). Work described by Reese (2006) suggests that beyond a spacing of 3.75 pile diameters, there is no reduction in pile group lateral capacity compared to the sum of the individual pile capacities. Based on these references, and considering the similarity of results for all tests at Frankford, whether spaced at five shaft diameters or ten, the spacing for all tests was likely sufficient to avoid interaction between the tested shafts.

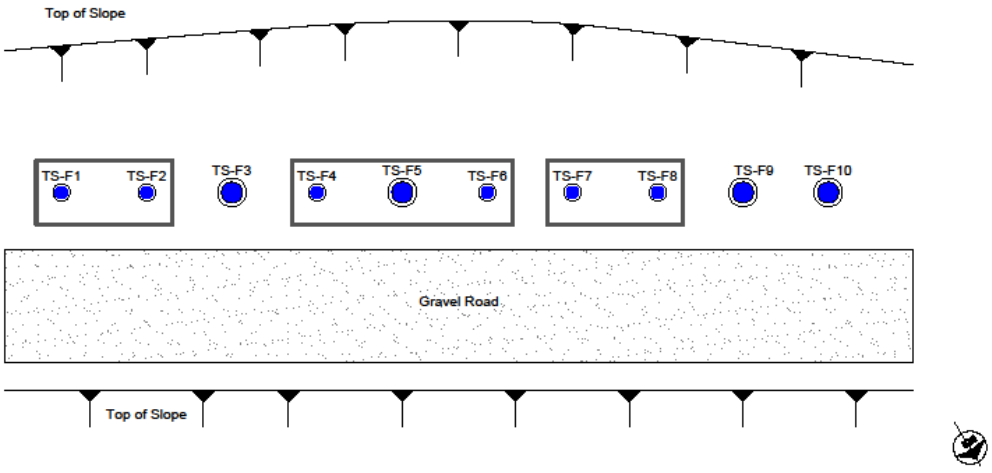

Figure 3.1 – Layout of test shafts at the Frankford Load Test Site with rectangles indicating test shaft pairs.

3.1.2 Warrensburg Load Test Site

Thirteen tests were performed at the Warrensburg Load Test Site as shown in Figure 3.2. Test shafts W1 and W2 were paired together; test shaft W1 was also paired with shaft W5 in a subsequent test. The other pairings were shafts W3 with W4, W6 with W7, W8 with W9, W10 with W11, W12 with W13, and W14 with W15. Cased sections for all shafts are 3.5-ft diameter, and all shafts were tested at least once.

Spacing of the shafts at the Warrensburg Load Test Site is 15 ft, which is likely sufficient, as explained for the Frankford Load Test Site (Section 3.1.1).

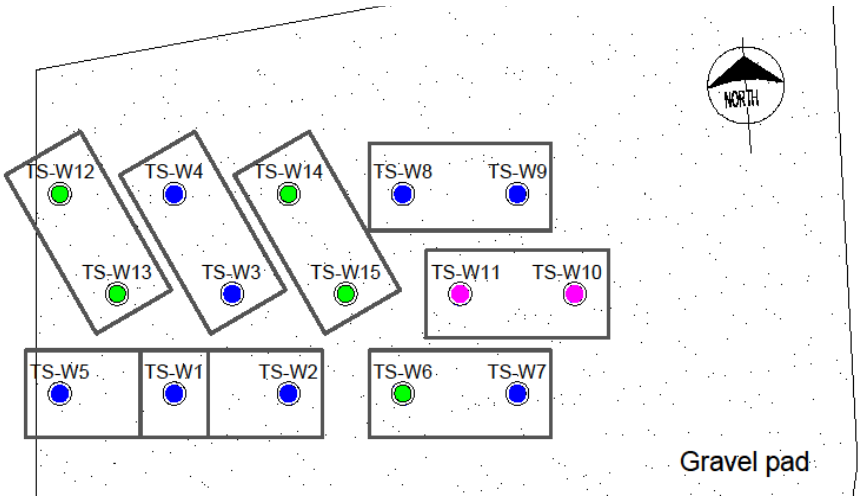

Figure 3.2 – Layout of test shaft pairs at the Warrensburg Load Test Site. Green shafts (W6, W12, W13, W14, and W15) were post-grouted; pink shafts (W10 and W11) had RIM Cells™, while the other shafts had O-Cells™.

It is difficult to transfer lateral load to the shale layers, which are overlain by 10 to 15 ft of stiff clay overburden. Therefore, after an initial set of tests, soil adjacent to the test shafts was removed in order to soften the lateral load response of the overburden. MoDOT personnel removed soil by drilling 5 or 6 holes approximately 15-ft deep between test shaft pairs as shown in Figure 3.3 and Figure 3.4. The holes were drilled as close as possible to the shafts and in alignment with the opposing shaft of the pair. Due to schedule issues, test pairs W12-W13, W14-W15, and W1-W5 were not tested prior to soil removal. Soil removal will be indicated hereafter for those tests performed following soil removal.

Figure 3.3 – MoDOT personnel drilling holes next to drilled shafts.

Figure 3.4 – Drilled holes adjacent to test shaft prior to testing.

3.2 Loading Frame

Each test was performed by pulling paired shafts together using four hydraulic jacks as shown in Figure 3.5. The center-hole jacks (110 MP series 03) were provided by Dywidag-Systems International (DSI) and were used to tension Grade 150 steel THREADBAR®, also supplied by DSI. The bars were installed through the flanges of two beams, one behind each shaft as shown in Figure 3.5 and in the loading frame plan of Figure 3.6. Application of pressure to the jacks tensioned the bars, which loaded the beams, which in turn applied load to seatings that were placed around each shaft, thereby loading the test shafts.

Together, the two beams, two seatings, and four bars compose the steel loading frame, which is shown in plan set drawings in Figure 3.6 and Figure 3.7. Each seating consisted of three plates designed to transfer load from the beam to the shaft via a pipe section collared around the shaft. The same seatings were used for tests of 3.5-ft diameter shafts at Warrensburg and 3-ft diameter shafts at Frankford. For the Frankford shafts, Masonite shims were used to fill the annular space between the collar and the shaft to improve the load distribution. For initial tests, a spherical bearing shown in Figure 3.8 and Figure 3.9 was used between the beam and the seating to ensure proper alignment during the tests as the shafts deflected and rotated. The bearing was removed for subsequent tests as shown in Figure 3.10 since it allowed too much independence of movement, particularly considering the length of the bars, which tended to buckle during initial tests. Tests performed without the bearings were successful and proved to be self-aligning.

The loading frame was designed for an ultimate load of 600 kips. Design checks for the loading frame included shear and bending moment capacity of the beam and axial capacity and deflection of the bars. The beams were W24x131 sections with multiple stiffeners included to increase the shear resistance. In addition, bearing plates were placed between the jacks and beams to reduce stress concentrations at the points of load application.

Figure 3.5 – One side of lateral load test frame in place at Frankford Load Test Site.

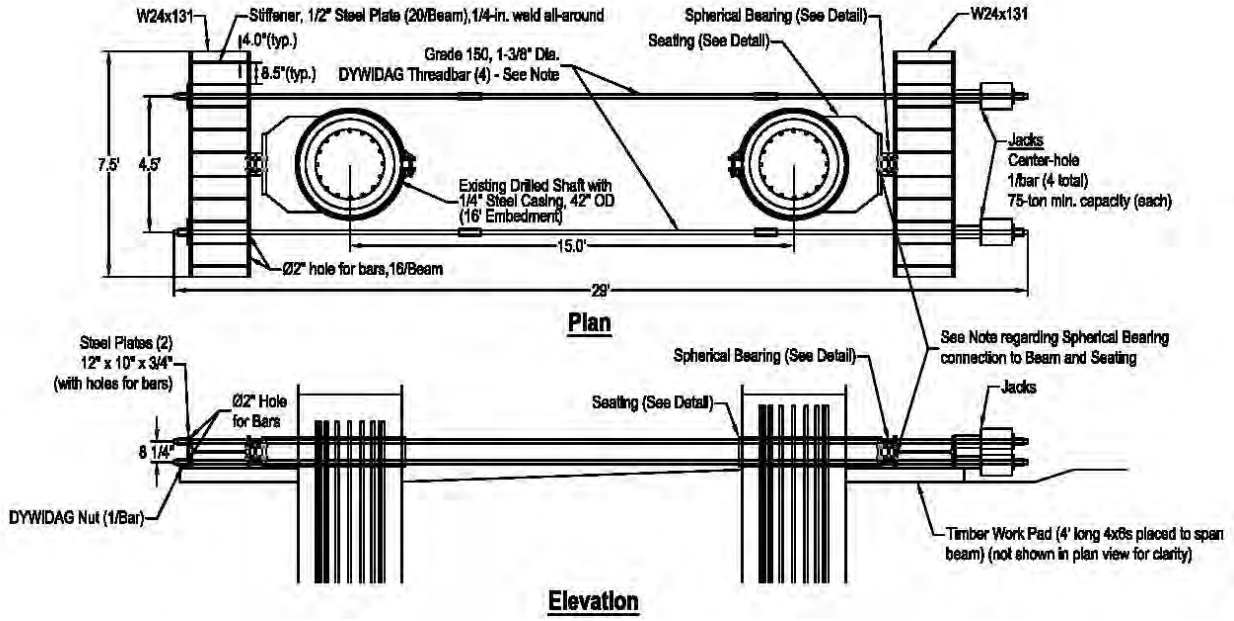

Figure 3.6 – Plan and elevation views of lateral load test frame.

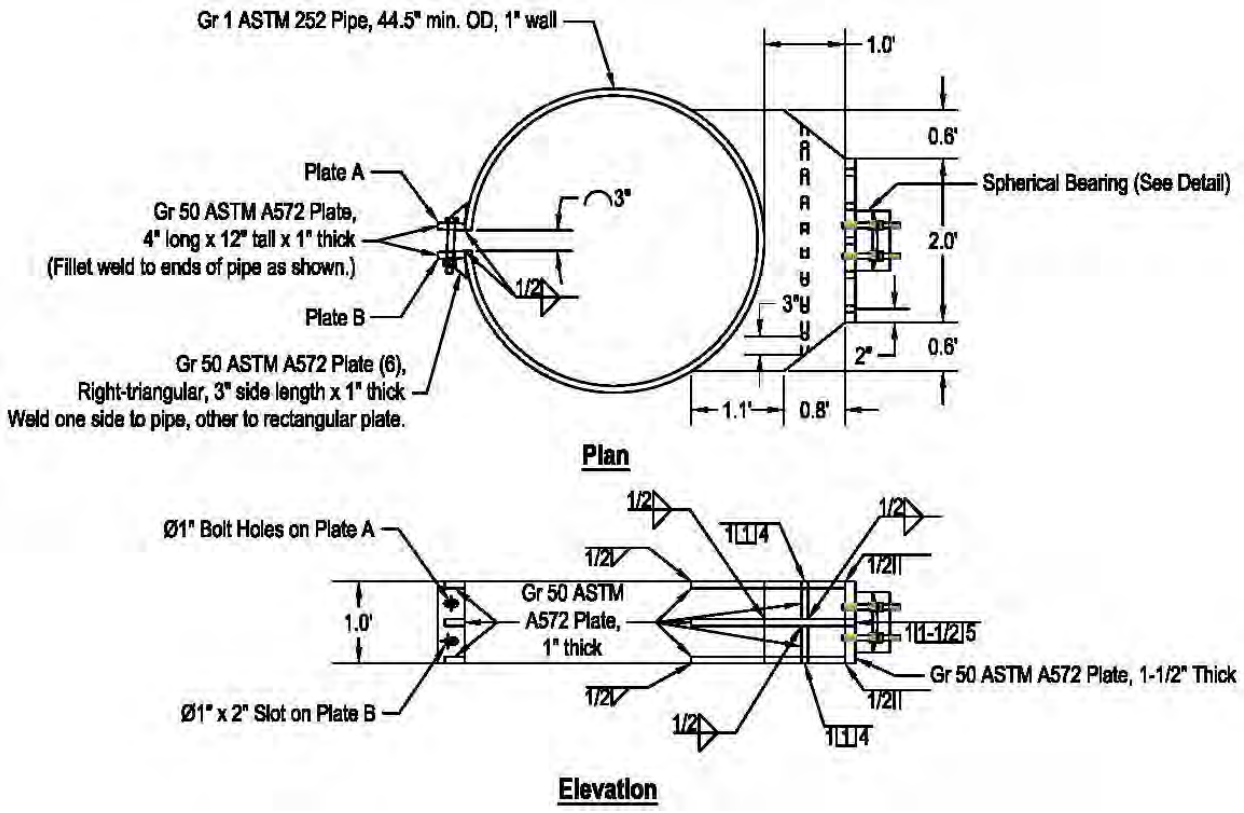

Figure 3.7 – Plan and elevation view of lateral load test frame seating detail.

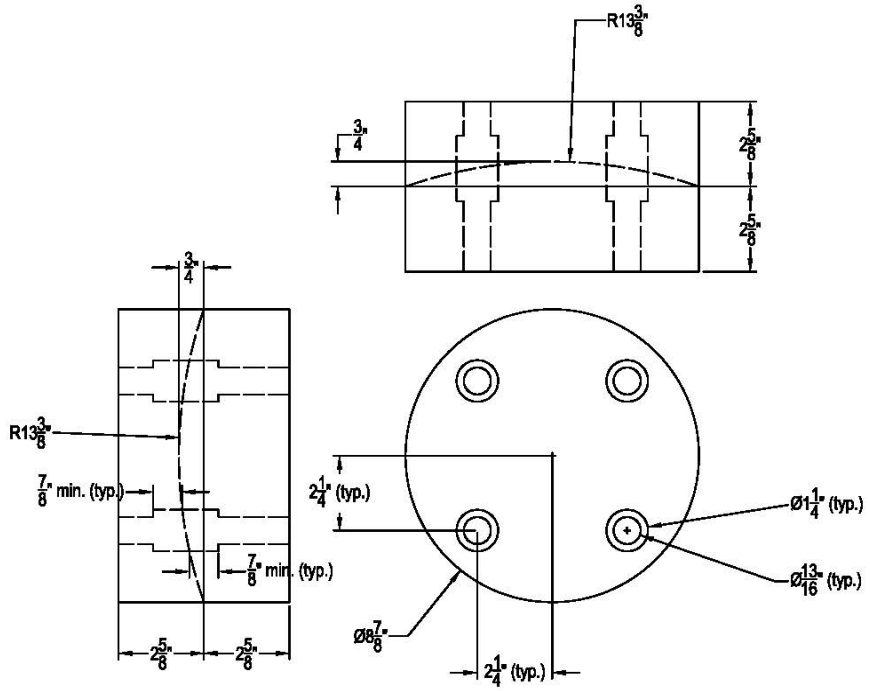

Figure 3.8 – Schematic of spherical bearing used for initial tests.

Figure 3.9 – Test beam, seating, and bearing in place around shaft W2.

Figure 3.10 – Beam and seating in place without bearing.

3.3 Instrumentation and Data Acquisition

Each test shaft was instrumented with a ShapeAccelArray (SAA) to measure deflection along the shaft length, vibrating wire strain gages to measure strain at discrete elevations, and vibrating wire displacement transducers and dial gages to measure displacement of the shaft head. In addition, the load applied to the shafts was measured by monitoring the hydraulic pressure supplied to the jacks and via DYNA force sensors. Each instrument is described in more detail in the sections that follow.

The DataTaker™ DT85G data logger shown in Figure 3.11 was used to record the vibrating wire displacement transducers and strain gages throughout each test. The SAA was connected directly to a laptop computer that recorded its readings, and the dial gage readings were recorded by hand along with the hydraulic pressure and DYNA force readings. The dial gages and displacement transducers were mounted to a reference beam (one for each shaft) to provide a stationary reference as shown in Figure

3.12 and Figure 3.13. The instrument installation and reference beam are described in more detail in Section 3.4.1.

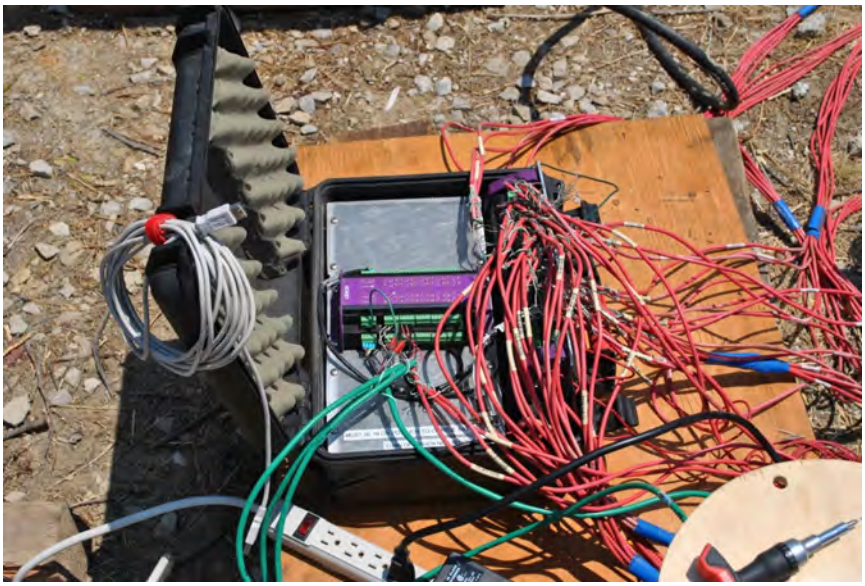

Figure 3.11 – DataTaker data acquisition system with vibrating wire strain gages and LVDTs connected to the multiplexer.

Figure 3.12 – LVDT and dial gage reference beams in place.

Figure 3.13 – Reference beams.

3.3.1 Vibrating Wire Strain Gages

As described in Section 2.2.2 and 2.3.2, six levels of four vibrating wire strain gages were included in all test shafts, except the five post-grouted shafts at the Warrensburg site, which had six levels of two gages. All vibrating wire strain gages were Geokon Model 4200 series (Geokon, 2012).

3.3.2 Shape Array Accelerometer

ShapeAccelArray (SAA) devices were used to measure shaft deflection profiles in lieu of conventional inclinometers. The SAA is a chain of rigid segments with sensors that use MEMS (microelectromechanical systems) technology to measure the tilt of each segment/joint (Measurand, 2012). The measuring principle of the SAA is therefore similar to that of traditional inclinometers, and both provide excellent precision and accuracy, but the SAA provides a continuous record of shaft deflection throughout testing. This presents safety, reliability, and time advantages compared with taking manual readings with the conventional inclinometers at the end of each load step.

SAA Data were recorded continuously using the SAA software program. In order to use the SAA, a PVC casing was grouted inside the inclinometer casing that had been installed in the drilled shafts during construction (during the planning phase of the research, it was anticipated that conventional inclinometers would be used). Before grouting the PVC casing, water was bailed out of the inclinometer casings as shown in Figure 3.14. A lean neat grout of cement and water was used to fill the annular space between the inclinometer casing and PVC as shown in Figure 3.15. Sand was poured in the remaining annular space after the grout cured, as shown in Figure 3.16. Figure 3.17 shows the placement of the SAA on top of the drilled shaft during testing. The sensorized segment and joint are shown in Figure 3.18.

Figure 3.14 – MoDOT personnel bailing water out of inclinometer casing.

Figure 3.15 – MoDOT personnel grouting the PVC pipe for SAA installation into the inclinometer casing.

Figure 3.16 – Placement of SAA inside the PVC. PVC pipe is installed in the inclinometer casing with grout and sand filling the annulus.

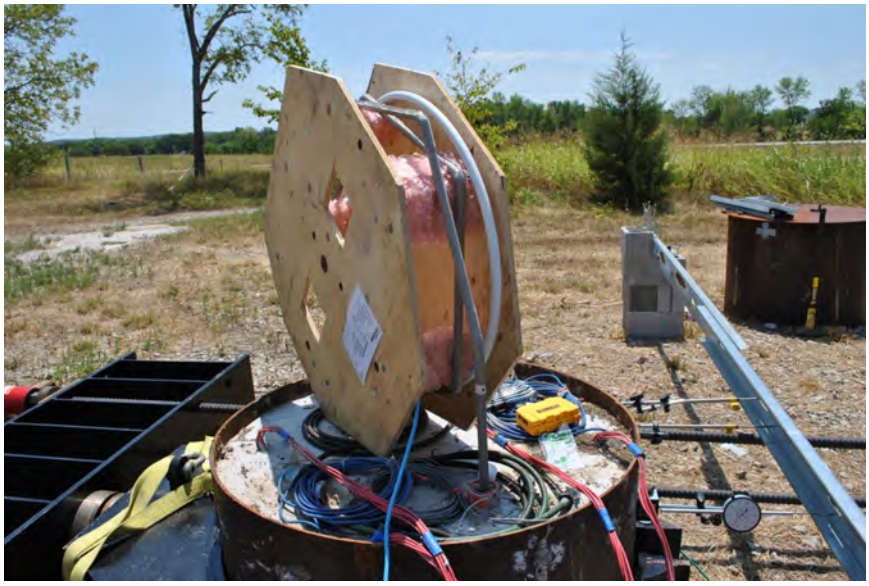

Figure 3.17 – SAA resting atop the drilled shaft during testing.

Figure 3.18 – SAA segment and joint.

3.3.3 Vibrating Wire Displacement Transducers

The vibrating wire displacement transducers used were Geokon model 4450 transducers. As shown in Figure 3.19, the displacement transducers were connected between the steel casing of the shaft and the reference beam. Each shaft had two displacement transducers mounted at the top of the shaft, one above the other as shown in Figure 3.20. Mounting the transducers above one another allowed for interpretation of shaft head rotation and displacement at the ground surface. Data from the vibrating wire displacement transducers were recorded continuously by the DT85G data logger.

Figure 3.19 – Vibrating wire LVDTs attached to the reference beam.

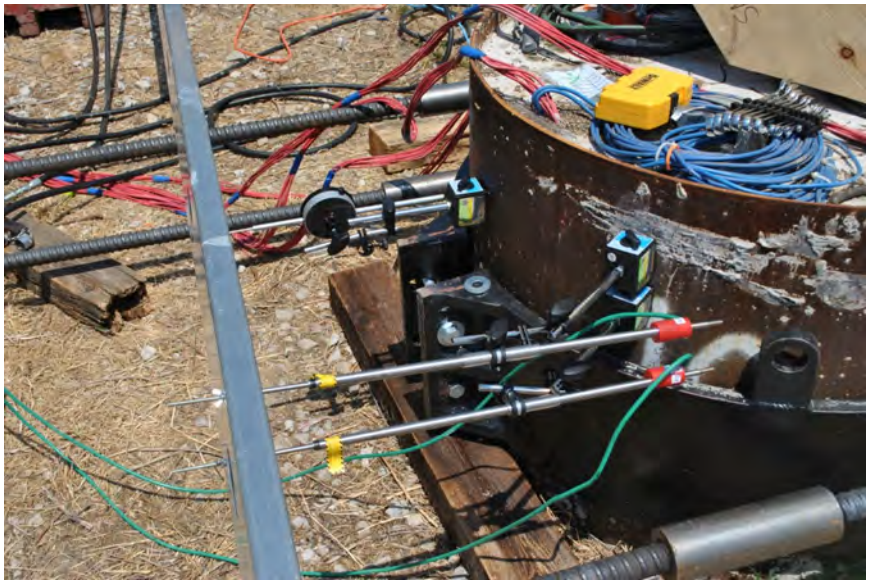

Figure 3.20 – Two vibrating wire LVDTs mounted to head of drilled shaft, one directly above the other.

3.3.4 Dial Gages

One dial gage was mounted on each shaft during each test. Like the displacement transducers, the dial gages were mounted between the drilled shaft casing and the reference beam as shown in Figure 3.21. Dial gage measurements were recorded manually in one-minute intervals during testing.

Figure 3.21 – Dial gage mounted to the head of the drilled shaft and connected to the reference beam.

3.3.5 Load Measurements

Two measurements of load applied to the shafts were recorded. The first was from the hydraulic pressure applied to each jack (Figure 3.22) by the pump (Figure 3.23). This pressure can be converted to a force via a simple calibration provided for each jack. Pressure readings were recorded manually for each load step. The pressure gage for the pump had a maximum recordable pressure of 10,000 psi, corresponding to a maximum load of approximately 1500 kips for the four jacks. Typically, the pressure was increased in 200 psi increments, corresponding to 29 kips for the four jacks, up to a maximum load typically around 300 kips at a pressure of 2000 psi. The pressure gage was marked in 100 psi increments.

Figure 3.22 – Hydraulic jack on threadbar applying load to beam through a bearing plate.

Figure 3.23 – Hydraulic pump with pressure gage.

A second measure of the load was recorded using DYNA Force sensors. According to DSI (2013), DYNA Force sensors "are based on the magneto-elastic properties of ferrous material. The permeability of steel in a magnetic field changes with the stress level in the steel. By measuring the change in permeability the stress in the steel element can be determined." Each testing pair contained four DYNA force sensors as shown in Figure 3.24. Figure 3.25 shows the readout unit which "is designed to magnetically energize the steel through the sensor and converts the response into a direct force reading" (DSI, 2013). In addition to the direct force reading, a thermistor allowed for temperature readings. Readings from the sensors were recorded at the beginning and end of each loading stage. Readings from the DYNA Force sensors were inconsistent and questionable, likely because of temperature effects due to extreme heat during the testing, with daily high temperatures often above 100 °F. Therefore, the results presented in this report are based on the hydraulic pressure measurements.

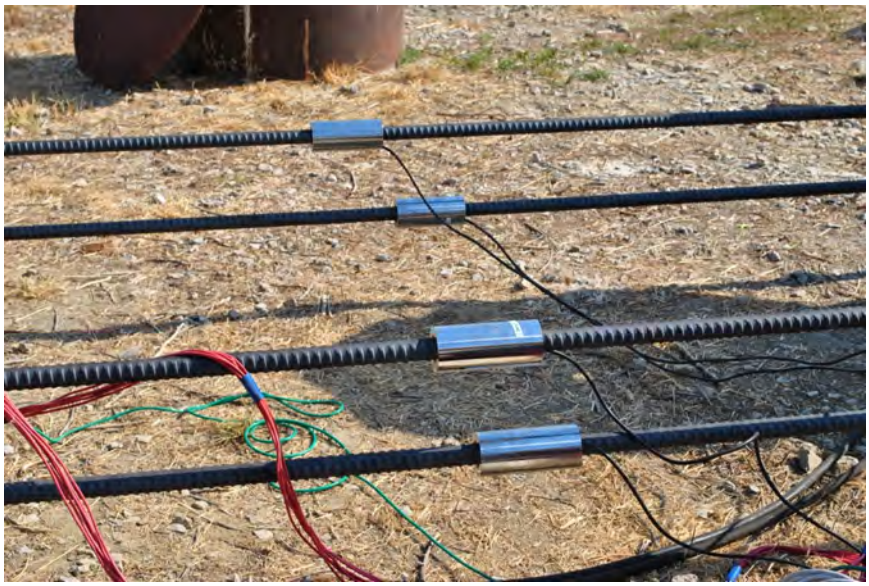

Figure 3.24 – DYNA Force sensors connected to each of four load frame rods.

Figure 3.25 – DYNA Force sensor readout unit.

3.4 Testing Procedure

The testing procedure typically required one day for set up of the frame and instruments and one day for conducting the test. Both procedures are described in detail in this section.

3.4.1 Setup and Installation

Typically, one day was spent setting up the loading frame and instrumentation for each testing pair. The loading frame was installed carefully for each shaft with the objective of establishing an initial alignment that would allow the shafts to displace toward one another safely and without damage to the loading frame or instrumentation. For the horizontal alignment, the beams and seatings for each shaft were installed in line with the beams and seatings for the opposing shaft. For the vertical alignment, the beams and seatings were installed at approximately the same elevation, i.e. level. Beams and seatings were placed atop timber work pads consisting of different size pieces of lumber. The loading frame was moved using a telehandler at the Warrensburg site as shown in Figure 3.26 and a forklift at the Frankford site. Seatings were placed first, followed by the beams. Minor adjustments to the beam location were made by adding and/or removing pieces of lumber from the work pad and by shifting the beam using a pry bar (Figure 3.27) to ensure alignment. The alignment was checked in several ways: visually, using a hand level, and by measuring distances between corners of the loading frame beams.

Once the beams and seatings were in place with proper alignment, the threadbars were installed through the holes in the flanges of the beams, which served as a final check of the alignment. The threadbars were in approximately 10-ft segments, which were connected using couplers that were also supplied by DSI. At the Frankford site, testing of shafts F4 and F6 required additional threadbars in order to bypass shaft F5, as shown in Figure 3.28. Steel bearing plates were placed along the threadbars against the outside of the beams before sliding the hydraulic jacks onto the threadbars. Hydraulic supply and return lines were then connected between the hydraulic pump and jacks. After the frame was assembled and the hydraulic system was in place, both reference beams (for displacement instrumentation) were placed perpendicular to the threadbars. The ends of the reference beams were connected via vice grips to stacks of cinder blocks. The height of the cinder block stacks was established to position the beams at a height that allowed level installation of the dial gages and LVDTs between the reference beam and the shaft casing.

Figure 3.26 – Telehandler used to install load beam on timber work pad at the Warrensburg Load Test Site.

Figure 3.27 – Placement of test beam using forklift at the Frankford Load Test Site showing use of pry bar to align the beam with the seating.

Figure 3.28 – Set up for test of shaft pair F4-F6.

Figure 3.29 shows the typical test setup for the lateral loading program. Instrumentation for each test pair was installed on the day of testing (typically the day after loading frame installation), with the exception of the DYNA Force sensors, which had to be installed on the threadbars as the frame was assembled. One SAA was placed atop each shaft and unspooled to lower the tip of the SAA to the bottom of the inclinometer casing. Three people were involved during unspooling to ensure the SAA joints were not bent beyond 45 degrees. The strain gage and displacement transducers cables were connected to the DataTaker™ multiplexer. The displacement transducers and dial gages were attached to the shaft casing with magnetic bases that had adjustable arms and connectors (Figure 3.19) and to the reference beam with small threaded rods and wing nuts. The rods screwed into the tips of the dial gages and displacement transducers, and the wing nuts were used to secure the rod installation through a hole in the reference beam.

Figure 3.29 – Set up for test of shaft pair W10-W11.

3.4.2 Lateral Load Testing

A summary of the lateral load tests, including final loads and displacements, is presented in Table 3.1. In general, the lateral load testing program followed ASTM D3966 (2007). The loads were applied for each test following the loading sequence of Procedure B for Static Excess Loading. Loads were applied using the hydraulic system provided by DSI following the provided operating instructions including preparation, bleeding the jack, and stressing. For the first test, the load was increased by 10% of the design load until 100% was reached. For the remaining tests, the load was increased in 200-psi increments, corresponding to approximately 30 kips using four jacks. During each load step, a near constant pressure was maintained until several consecutive dial gage readings taken in one-minute increments were unchanged. For small loads, each load step lasted approximately 10 minutes. The load was never increased if either shaft was still moving considerably. This resulted in longer load increments at higher loads, during which the pump was operated frequently to maintain a constant pressure as the shafts displaced. It was not uncommon for the final load increments of some of the tests to last at least 30 minutes. The tests were terminated when a constant hydraulic pressure could not be maintained because one or both of the shafts had reached an ultimate limit state.

Initial base readings for all of the instrumentation were recorded prior to loading. Readings from the dial gages were recorded every minute. The SAA, displacement transducers, and strain gages were recorded continuously with the data acquisition devices described in Section 3.3. The DYNA force sensors were measured at the beginning and end of every load increment. Readings for all instruments were also recorded during the unloading process. The displacement transducers, dial gages, and jacks were monitored to ensure they did not run out of stroke during loading. Due to the amount of shaft displacement, this usually required resetting the reference beams once or twice during loading and again during unloading. The hydraulic jacks had to be reset even more frequently since their stroke was consumed by displacement of both shafts (as opposed to just one for the displacement instruments) as well as by elastic elongation of the threadbars. During resetting of the jacks, the load was locked into the loading frame by tightening locking nuts housed within the neck of the centerhole jacks against the bearing plates. Any adjustments to the instrumentation or equipment were recorded in the test notes.

Table 3.1 – Summary of field observations from lateral load tests.

Test Pair	Test Date in 2012	Number of Load Increments	Maximum Load (kips)	Maximum Displacement (in.)	Notes
F1-F2	8/23	11	306	8	Popping noise from F2 during 88-kip load increment.
F4-F6	8/29	11	321	9	Popping noise heard from load frame beam due to stress relief during 263-kip load increment. Popping noise from F4 heard 6 minutes into 321-kip load increment.
F7-F8	8/27	13	365	7	
W1-W2	8/1	16	321	4	Popping noise from W2 during 263-kip load increment.
W1-W2 Soil Removed	8/9	10	277	4	Popping noise from W1 16 minutes into 263-kip load increment.
W1-W5 Soil Removed	8/20	12	350	9	
W3-W4	8/6	11	321	5	Strong wind blew canopy into reference beam 33 minutes into 263-kip load increment.
W3-W4 Soil Removal	8/7	10	292	5	
W6-W7	7/30	8	204	2	Jacks readjusted several times during test.
W6-W7 Soil Removed	8/11	11	306	7	
W8-W9	7/24	20	115	1	Load and displacement were limited for first two tests as research team became familiar with testing equipment and procedure.
W8-W9 Soil Removed	8/15	12	350	8	
W10-W11	7/27	20	146	1	Load and displacement were limited for first two tests as research team became familiar with testing equipment and procedure.
W10-W11 Soil Removed	8/13	9	262	6	Soil removal in front of W11 only due to rig access issues in front of W10.
W12-W13 Soil Removed	8/18	8	233	11	
W14-W15 Soil Removed	8/17	9	262	7	

4. Experimental Results

After the test program described in Chapter 3 was completed, shaft responses were calculated from the load test data. The shaft response is characterized by the load-displacement behavior at the top of the shaft and the bending moment profile along the length of the shaft. This chapter presents example load-displacement curves as measured by LVDTs, dial gages, and the SAA segment at the top of the shaft, example SAA displacement profiles, a summary of the methodology for interpreting bending moments from strain gage and SAA data, and examples of bending moment profiles from both test sites using strain gage and SAA data. Only representative data are presented and discussed in this chapter; additional load-displacement curves, displacement profiles, and bending moment profiles are included in Appendix B, Appendix C, and Appendix D, respectively.

4.1 Load-Displacement Curves

As explained in Chapter 3, the displacement of the top of each shaft was measured with two LVDTs, one above the other, and with one dial gage. In addition, the SAA data provided a fourth measure of the displacement of the top of the shaft. The total load applied to the shaft, which was interpreted from the pressure gage on the hydraulic pump, was plotted versus each of the measures of displacement of the top of the shaft. The resulting load-displacement curves are included in Appendix B (one plot for each paired test). An example set for one test is shown in Figure 4.1, and plots with all curves for each site are shown in Figure 4.2 (Frankford) and Figure 4.3 through Figure 4.5 (Warrensburg).

Figure 4.1 shows four load-displacement curves for shafts W10 and W11 from the test performed after soil removal. For each shaft, the curves with displacement based on dial gages and LVDTs are almost indistinguishable, a result of the three devices (one dial gage, two LVDTs) providing consistent measurements of displacement. Close inspection of the curves for each shaft reveals the top LVDT curve showing slightly more displacement, which is consistent with rotation of the shaft. At the ultimate load, the displacement interpreted from the SAA is about 10 to 20 percent greater than that from the other devices. This can likely also be explained by shaft rotation, since the dial gages and LVDTs were placed below top of the shaft. Also, it is difficult to interpret the precise location of the SAA segment that aligns with the top of the shaft.

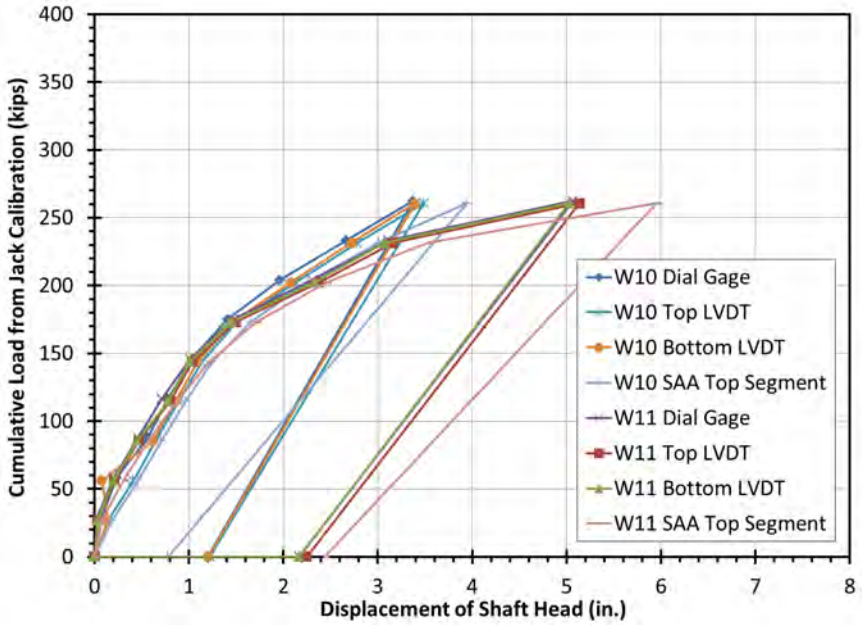

Figure 4.1 – Load-displacement curves for test of shafts W10 and W11 after soil removal at Warrensburg test site.

The Frankford load-displacement curves presented in Figure 4.2 are all relatively similar, especially for displacements less than 2 in. Beyond 2 in., some of the shafts showed greater capacities than others, but all were between 300 and 350 kips. At Warrensburg, the number of tests before soil removal was limited by schedule constraints, and several of the tests before soil removal reached only limited displacements as the research team became familiar with testing equipment and procedures. Nevertheless, several observations can be made from the Warrensburg load-displacement curves presented in Figure 4.3 through Figure 4.5. Like for Frankford, the curves are all similar to one another, particularly if the curves for tests before and after soil removal are considered separately. Tests performed after soil removal resulted in notably less stiff responses and perhaps slightly lower ultimate capacity values (about 300 kips or greater before soil removal vs. between 200 and 350 kips after soil removal). The difference in the shaft responses is discussed in more detail in Chapter 6, where interpreted p-y parameters are presented.

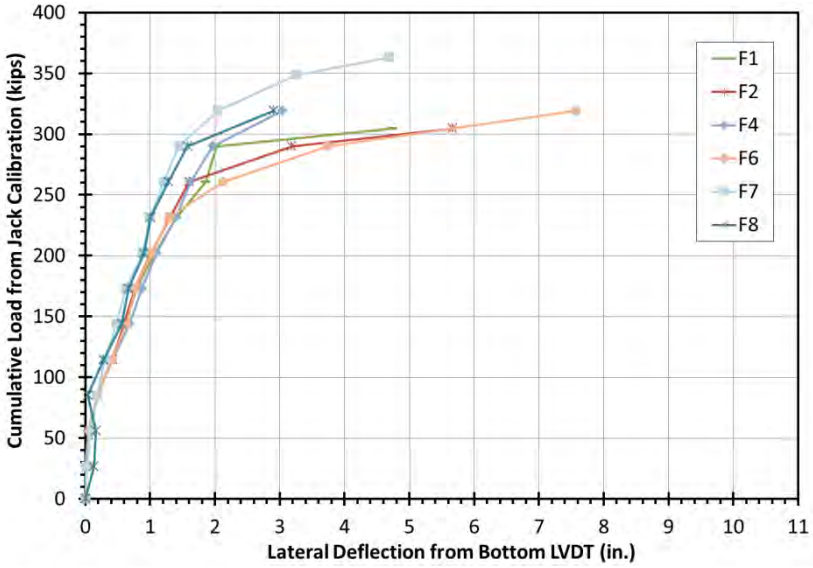

Figure 4.2 – Load-deflection curves from load tests conducted at Frankford Load Test Site.

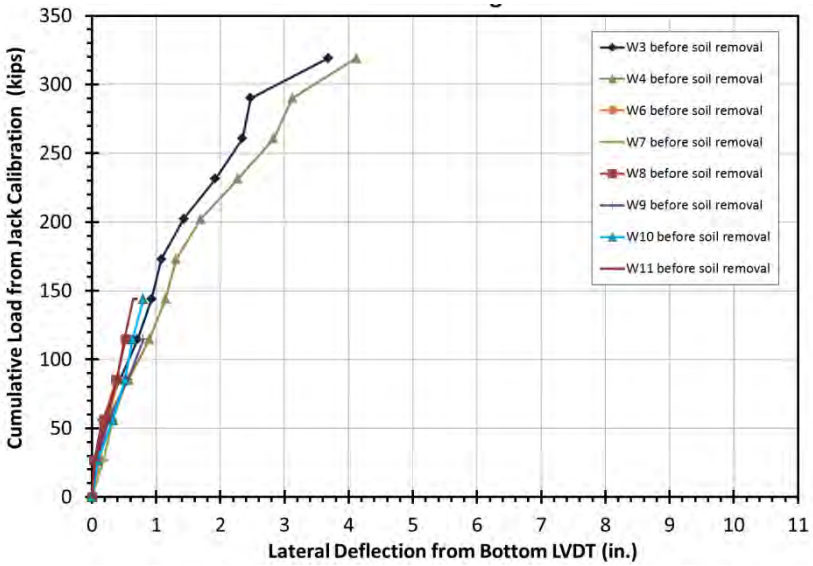

Figure 4.3 – Load-deflection curves from load tests before soil removal at Warrensburg Load Test Site.

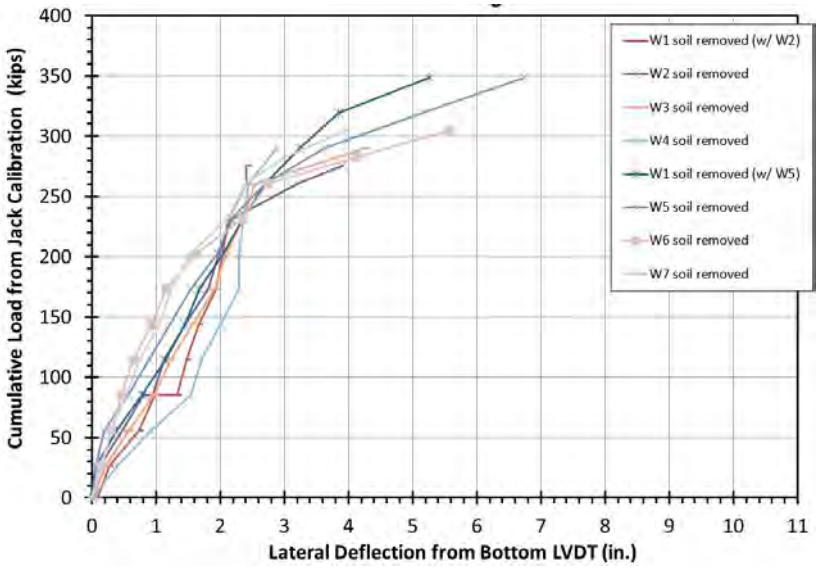

Figure 4.4 – Load-deflection curves from load tests after soil removal at Warrensburg Load Test Site (shafts W1 through W7).

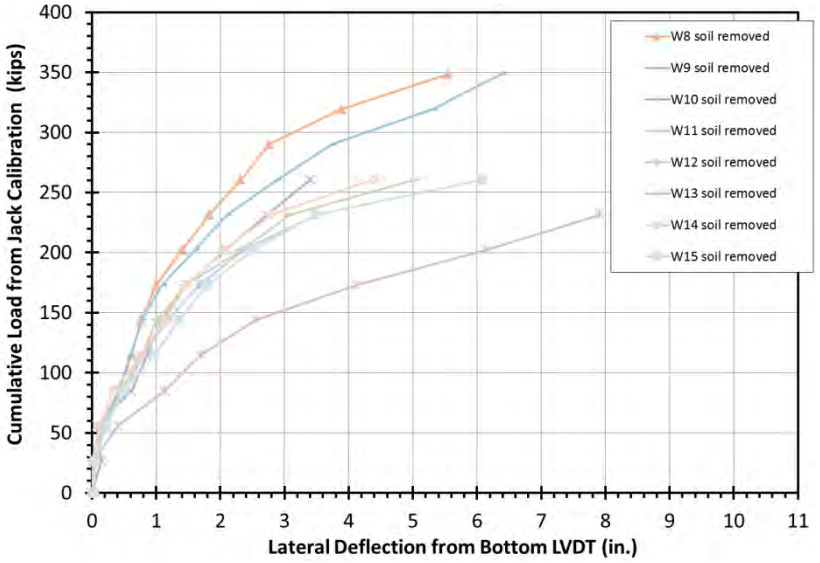

Figure 4.5 – Load-deflection curves from load tests after soil removal at Warrensburg Load Test Site (shafts W8 through W15).

4.2 Displacement Profiles from SAA

The SAAs used consist of a chain of 30 segments, each 500 mm (19.7 in.) in length. Position data for each segment were recorded by SAA software in three dimensions, with the cross section of the shaft defined on the horizontal x and y axes and the vertical z axis. Transverse displacement values at the end of each load increment were calculated from the differential movement in the x and y directions:

$$\delta_i = \sqrt{(x_i - x_{i0})^2 + (y_i - y_{i0})^2} \qquad \text{(consistent units of length)} \qquad \textbf{Eq. 4.1}$$

where δ_i = total transverse displacement of the i^{th} segment of the SAA
x_i = position of the i^{th} segment along the x-axis
x_{i0} = initial (zero load) position of the i^{th} segment along the x-axis

y_i = position of the i^{th} segment along the y-axis
y_{i0} = initial (zero load) position of the i^{th} segment along the y-axis

This calculation is necessary since the direction in which the shafts were pulled was aligned somewhere between the x and y axes. Presumably, the total displacement occurred along the line between the center of the two test shafts.

Profiles of displacement with depth for each load step were calculated according to Eq. 4.1 for each shaft. The results are included in Appendix C, with all profiles for one shaft test contained in the same plot and with plots from the test shaft pairings (e.g. W1 and W2, F4 and F6) presented side-by-side. An example of such a pairing is presented in Figure 4.6.

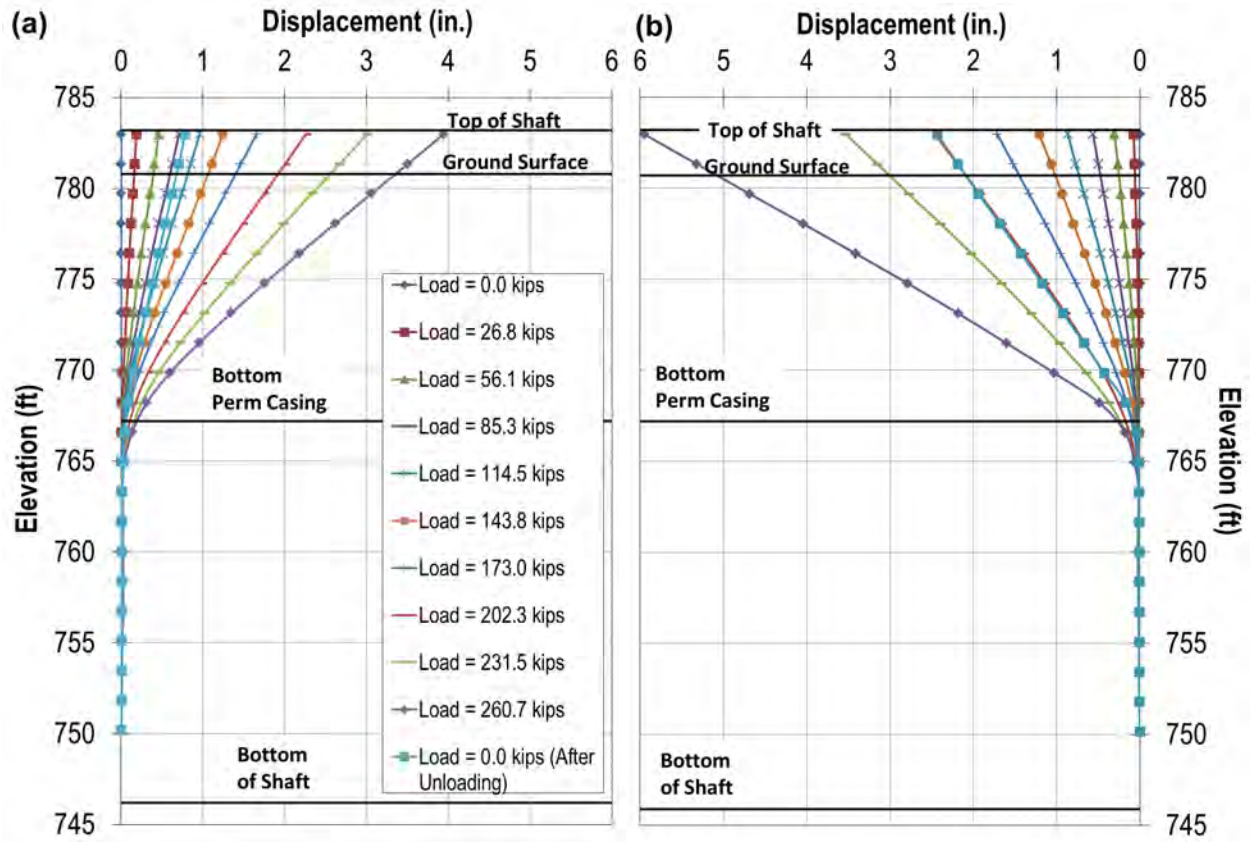

Figure 4.6 – Displacement profiles from SAA data for test of shafts (a) W10 and (b) W11 after soil removal at Warrensburg test site.

The shapes of the displacement profiles in Figure 4.6 are consistent for both shafts as well as for all load steps. Each profile indicates the respective shaft is essentially fixed around elevation 765, which is 2 to 3 ft below the permanent casing. The bottom of the permanent casing is approximately at the depth of the overburden, so a point of fixity could be interpreted 2 to 3 ft into the shale layer. Above the shale, the shaft deflects without much curvature; the rotation in the overburden is relatively uniform. The displacement at the top of the shaft for each load step is consistent with the load-displacement curve presented in Figure 4.1.

4.3 Methodology for Interpretation of Bending Moment Data

Interpretation of bending moments from measurements of strain (via strain gages) and displacement (via SAA) is a nontrivial exercise, primarily because the bending stiffness, EI, is nonlinear and greatly influenced by concrete cracking, which is difficult to predict. The procedure used here was to predict

values of bending stiffness along the length of the shaft as a function of the bending curvature, which was interpreted from the SAA displacement data. Values for bending stiffness as a function of curvature were computed using Ensoft L-Pile v2012. The predicted values of bending stiffness were used to calculate bending moment profiles from SAA data and from strain gage data, and the bending moment profiles were differentiated in an attempt to determine shear force and lateral pressure profiles. Each of these steps is described in more detail in the sections below.

The displacement profiles interpreted from the SAA data were differentiated to calculate profiles of cross-sectional rotation of the shaft:

$$\theta_i = \frac{d\delta}{dz} \approx \tan^{-1}\left(\frac{\delta_i - \delta_{i-1}}{L}\right) \qquad \textbf{Eq. 4.2}$$

where θ_i = cross-sectional rotation of the i^{th} segment of the SAA, radians
L = SAA segment length (500 mm = 19.7 in.)

Profiles of cross-sectional displacement are also included in Appendix C, with all profiles for one shaft test contained in the same plot and with plots from the test shaft pairings (e.g. W1 and W2, F4 and F6) presented side-by-side.

The rotation profiles were then differentiated to calculate profiles of bending curvature of the shaft:

$$\phi_i = \frac{1}{\rho_i} = \frac{d^2\delta}{dz^2} = \frac{d\theta}{dz} \approx \frac{\theta_i - \theta_{i-1}}{L} \qquad \textbf{Eq. 4.3}$$

where ϕ_i = bending curvature of the i^{th} segment of the SAA, radians per unit length
ρ_i = radius of curvature of the i^{th} segment of the SAA, consistent units of length
L = SAA segment length (500 mm = 19.7 in.)

L-Pile was used to estimate EI along the length of the shaft from the values of bending curvature. The routine employed by L-Pile is documented in the program's technical manual (Isenhower & Wang, 2011). In summary, L-Pile iterates the location of the neutral axis until force equilibrium is satisfied, accounting for concrete cracking. Cracking of the concrete is predicted as a function of the compressive strength of the concrete, which was estimated from compression tests performed on cylinders from each shaft pour.

An example of the shaft bending stiffness predicted by L-Pile as a function of the bending curvature is shown in Figure 4.7. The bending stiffness decreases abruptly at small values of curvature, which corresponds to initial cracking of the concrete. After the concrete cracks, the decrease in stiffness is more gradual as the steel yields.

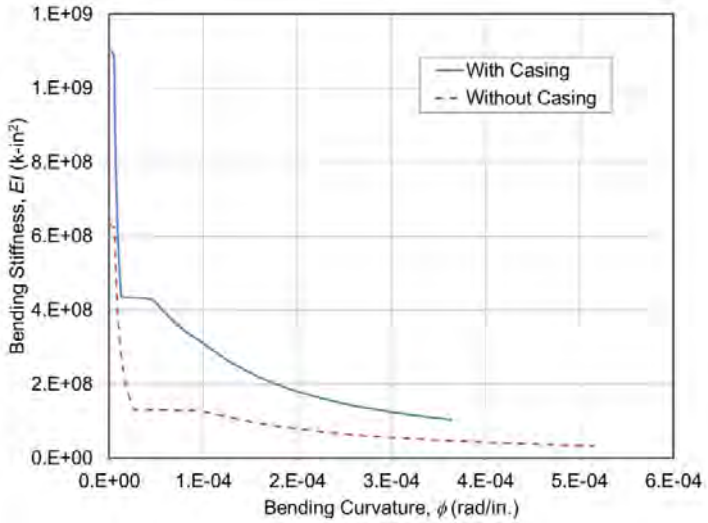

Figure 4.7 – Example bending stiffness curve for shaft at Warrensburg test site (W7).

The estimated bending stiffness from L-Pile was used to calculate two profiles of bending moment along the length of the shaft: one from the SAA data (Eq. 4.4) and the other from strain gage data (Eq. 4.5).

$$M_i = \phi_i \cdot EI_i \qquad \text{(consistent units)} \qquad \textbf{Eq. 4.4}$$

where M_i = bending moment of the i^{th} segment of the SAA
EI_i = shaft bending stiffness at the i^{th} segment of the SAA

$$M_j = \frac{\varepsilon_j \cdot EI_j}{c_j} \qquad \text{(consistent units)} \qquad \textbf{Eq. 4.5}$$

where M_j = bending moment at the level of the j^{th} strain gage
ε_j = bending strain measured by the j^{th} strain gage
EI_j = shaft bending stiffness at the j^{th} strain gage
c_j = distance from compressive edge of shaft to neutral axis at j^{th} strain gage

For all calculations, the bending stiffness at a particular depth was limited to its minimum historic value if the L-Pile analysis indicated concrete cracking had ever occurred at that depth. For example, if the curvature at a depth of 10 ft was great enough to initiate concrete cracking for an applied lateral load of 100 kips, the bending stiffness used to calculate the bending moment for subsequent loads would be limited to a maximum value of the stiffness calculated for the 100-kip load, even if the bending curvature at a subsequent load was less than it had been at a load of 100 kips. This reasoning was extended to the shafts at Warrensburg that were tested twice, once before drilling out soil between shafts and once after.

4.4 Drilled Shaft Response

The methodology and equations presented in Section 4.3 were used to create profiles with depth of displacement, cross-sectional rotation, and bending moments from SAA data. Additional bending moment profiles were calculated from strain gage data. Each of the four profiles (displacement, rotation, and bending moment from SAA data and bending moment from strain gage data) was calculated for each load step of each shaft test. The results are included in Appendix D, with all four profiles for each shaft test presented side-by-side. Example profiles are presented and discussed in this section.

4.4.1 Comparison of Bending Moments from SAA and strain gage data

Section 4.3 describes two methods for interpreting bending moment from the data that was collected. The first involves differentiating the displacement profiles measured by the SAA twice and then

multiplying the resulting bending curvature by the interpreted bending stiffness. The second method calculates the bending moment directly from the strain measured by the strain gages and the interpreted bending stiffness. Bending moment profiles from both data sources are presented below side-by-side for Frankford (Figure 4.8), Warrensburg before soil removal (Figure 4.9), and Warrensburg after soil removal (Figure 4.10).

Both sets of bending moment profiles for Frankford test shaft F4 (Figure 4.8) show similar shapes and magnitudes below the permanent casing and in the first shale layer, where the strain gage data suggest the maximum moment occurs. The bending moment profile from the SAA data shows considerably more "noise" than the strain gage profile. This could perhaps be partially explained because there are more SAA segments than there are strain gages, but the noise is better explained by having to differentiate the SAA data twice to calculate bending moment, whereas the strain gages provide a more direct measurement of the bending moment. The large negative bending moments shown near the ground surface for SAA data are also most likely a result of taking the second derivatives. The strain gages provide a more realistic bending moment profile.

The same observations apply to the Warrensburg data before (Figure 4.9) and after (Figure 4.10) soil removal. For both tests shown, the shape and magnitudes from SAA and strain gage data are similar, but interpretation of the SAA data produces considerably more noise and unreasonable values toward the top of the shaft. Two main observations arise from comparing the results before and after soil removal: (1) the ultimate load was decreased after soil removal by about 30 kips, and (2) after soil removal, the bending moment in the soil was decreased considerably while the bending moment in the rock increased, producing a flatter bending moment profile that extends deeper than before soil removal. This indicates the drilling operation was successful for increasing the depth of load transfer.

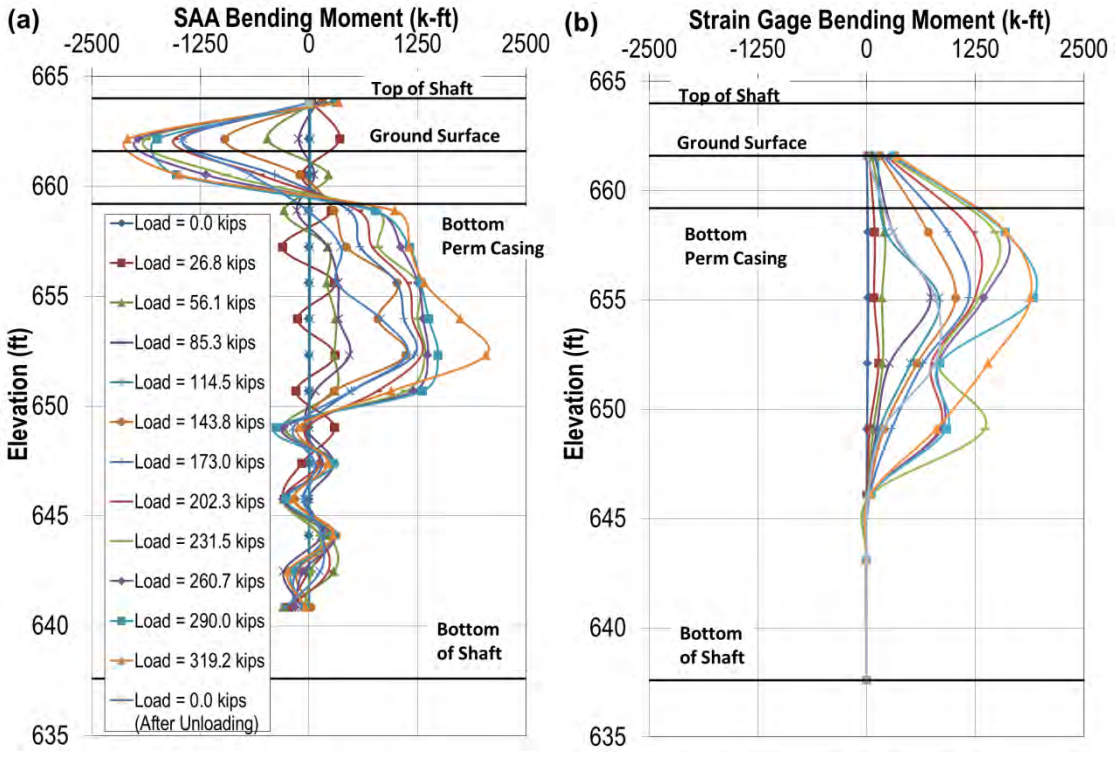

Figure 4.8 – Comparison of bending moments in test shaft F4 at Frankford test site from (a) SAA data and (b) strain gage data.

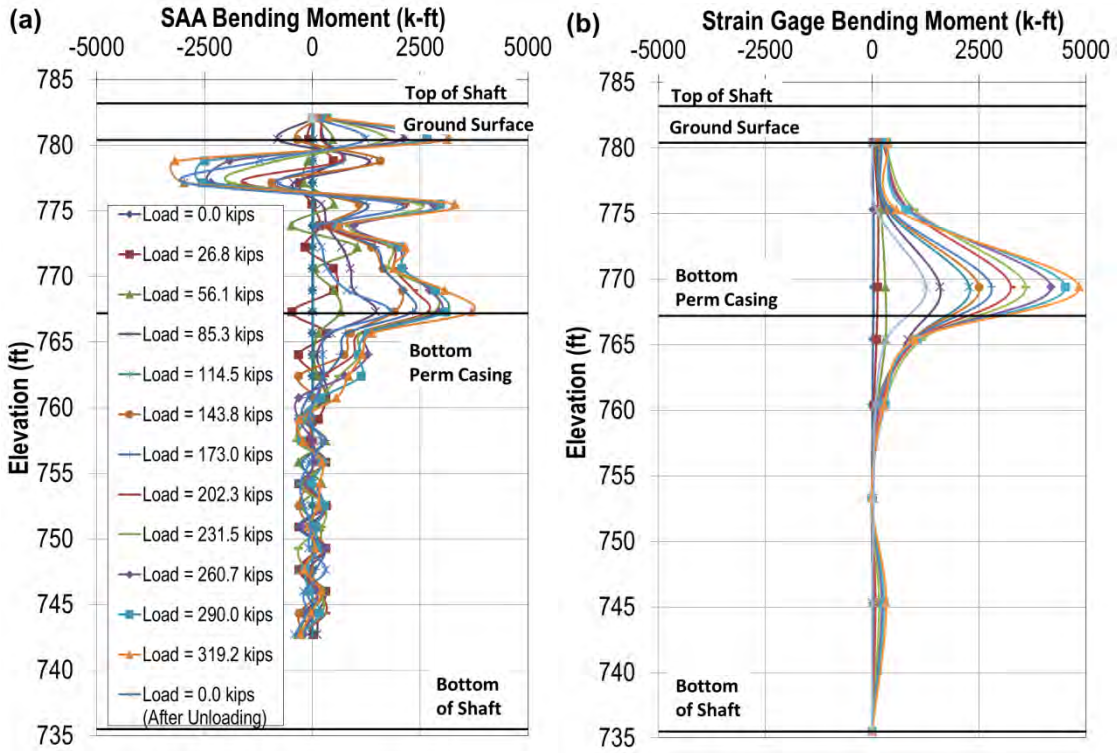

Figure 4.9 – Comparison of bending moments in test shaft W3 at Warrensburg test site before soil removal from (a) SAA data and (b) strain gage data.

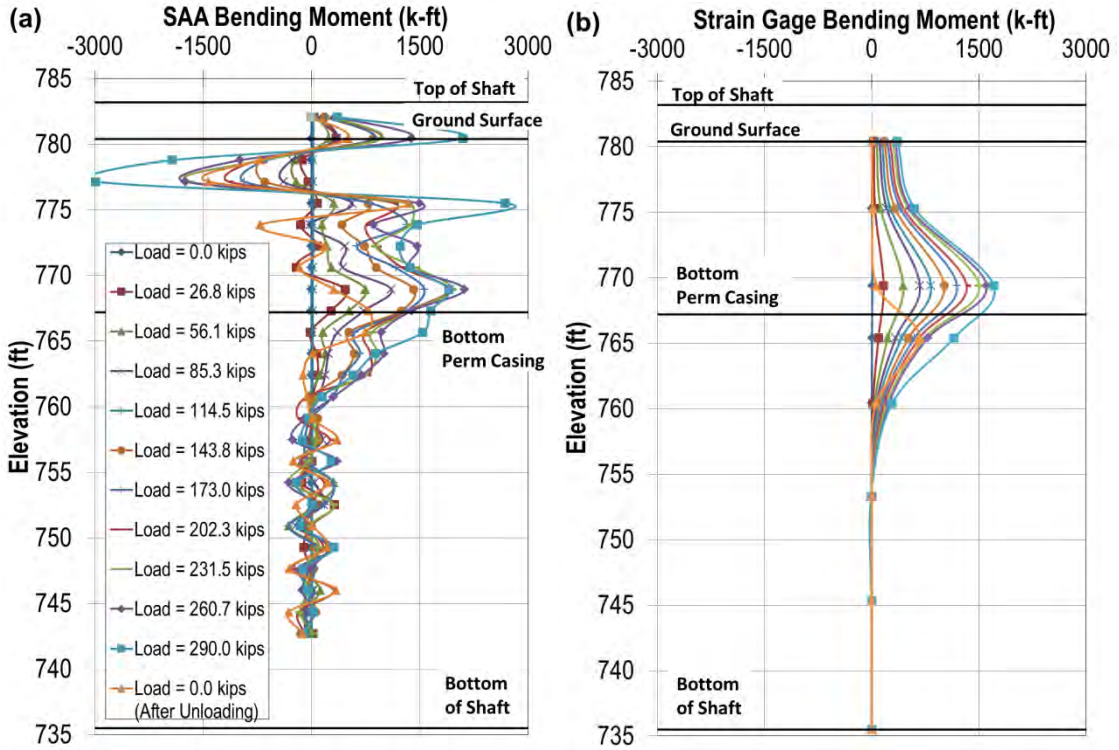

Figure 4.10 – Comparison of bending moments in test shaft W3 at Warrensburg test site after soil removal from (a) SAA data and (b) strain gage data.

4.4.2 Shear Force and Lateral Pressure

The interpretation technique described in Section 4.3 can be extended to calculate profiles of shear force and unit lateral pressure as the first and second derivatives, respectively, of bending moment. The results of such a calculation are presented for test shaft F4 from the Frankford site in Figure 4.11. The shear force and unit lateral pressure profiles are noisy to the point of not being useful. This is consistent with the findings of Section 4.4.1; measurement limitations make it very difficult to produce meaningful results for second and higher-order derivative quantities. Differentiating the strain gage bending moment profiles is similarly fruitless; each differentiation effectively removes a data point, and with only six levels of strain gages to begin with, the resulting shear and unit lateral pressure profiles almost certainly will not capture the shapes of the true profiles. The limitations of numerical differentiation provided a large motivation for using the computer model documented in Chapter 5 to further interpret the test results.

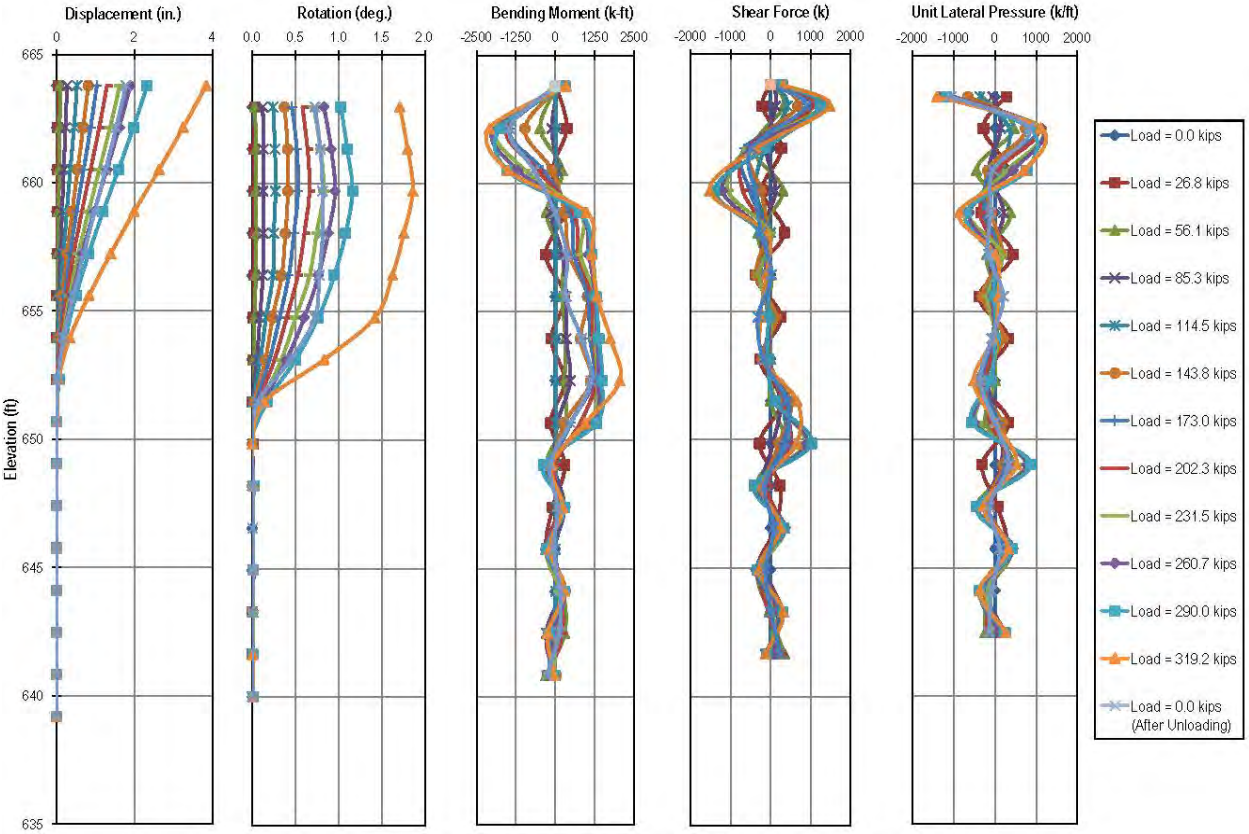

Figure 4.11 – Example of interpreting shear force and unit lateral pressure from SAA data (Frankford shaft F4).

5. Analysis of Experimental Results

A finite element computer program was developed using MATLAB to analyze drilled shafts subjected to lateral loading. The program was used to establish p-y curves that produce the best match between predicted and measured shaft displacement profiles for a given shaft geometry and loading. This chapter describes the methodology adopted for use of the program and presents example results. A complete set of fitted results is included as Appendix E, and the fitted p-y curves are included at the end of this chapter.

5.1 p-y Method

The program employs the "p-y method" (e.g. Reese et al., 2006; Isenhower and Wang, 2011) to predict the response of a drilled shaft to lateral loading. The p-y method was implemented using the finite element method (FEM), with the shaft modeled using beam elements and the soil modeled as a series of nonlinear springs as shown in Figure 5.1. Each spring is governed by a p-y curve, where p is the soil resistance on a unit length of the shaft (force/length) and y is the relative lateral deflection between the soil and the shaft (length). An example p-y curve is shown in Figure 5.2. An initial straight-line portion is connected by a curve to a final straight-line portion defined by ultimate lateral resistance, p_{ult}.

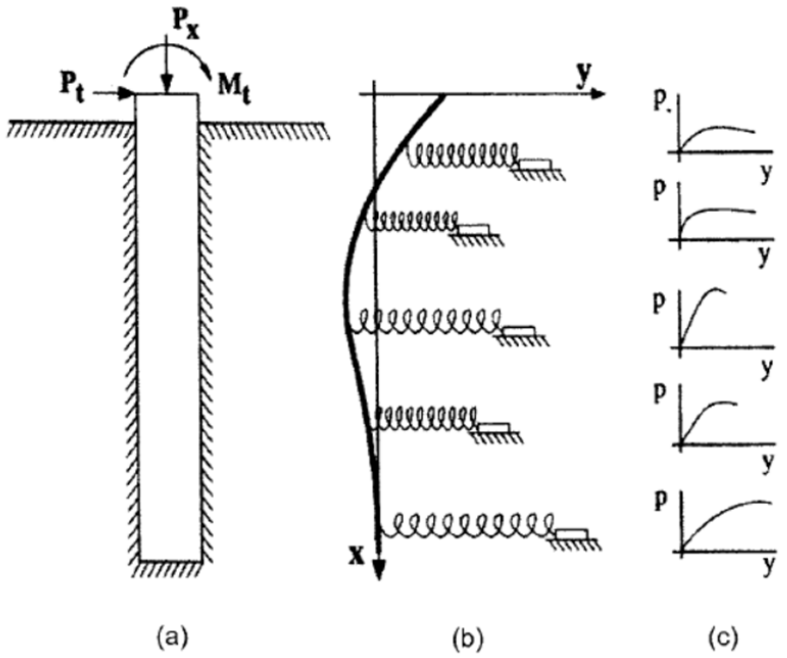

Figure 5.1 – Schematic representation of the p-y method: (a) drilled shaft subjected to lateral loading, (b) soil modeled as a series of springs, and (c) p-y curves governing spring stiffness (Reese et al., 2006).

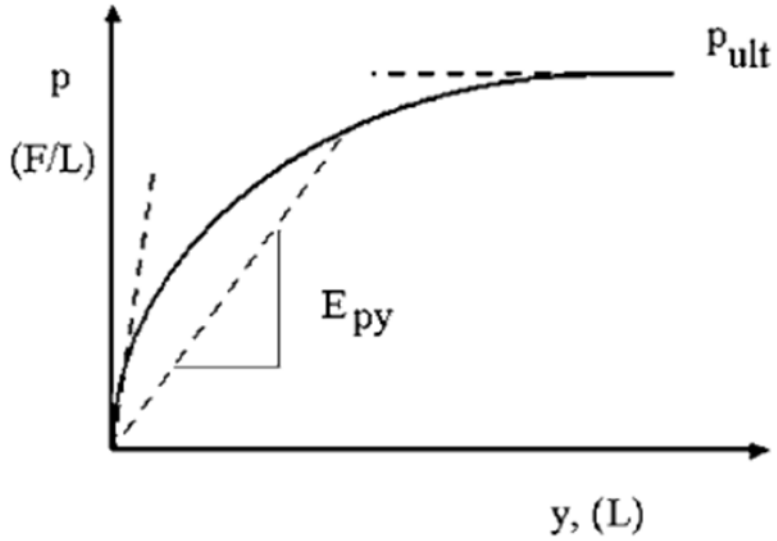

Figure 5.2 – Conceptual p-y curve (Reese et al., 2006).

The shaft response is governed by Eq. 5.1, which the code solves using the finite element method to produce the vector of shaft deflections. The bending moments and shear forces are then calculated consistent with the methodology presented in 4.3.

$$\left([K_p] + [K_s]\right)\{y_p\} = \{F\} \qquad \text{(consistent units)} \qquad \textbf{Eq. 5.1}$$

where $[K_p]$ = soil stiffness matrix represented by p-y model
$[K_s]$ = stiffness matrix for all the beam elements forming the drilled shaft
$\{y_p\}$ = vector of shaft deflections and rotations at the shaft nodes
$\{F\}$ = vector of induced lateral forces acting on the shaft

5.2 Computer Program Overview

The computer program implements the p-y method in a manner similar to that described by Reese et al. (2006). The program adjusts assumed p-y curves using a p-multiplier to produce the best fit of measured displacement data. Three iterative processes are required to produce the best fit as shown in the flow chart of Figure 5.3. The first process iterates values of the secant modulus to implement a nonlinear p-y curve. The second process iterates values of bending stiffness to implement the nonlinear bending stiffness-bending curvature relationship described in Section 4.3. The third process iterates values of the p-multiplier to minimize the difference between measured and predicted displacements. The processes are embedded such that each iteration of the third process requires a full pass through the second, and each iteration of the second process requires a full pass through the first process. A single operation of the computer program considers just one load of one shaft, so many operations were required to fit all of the data collected for the test program.

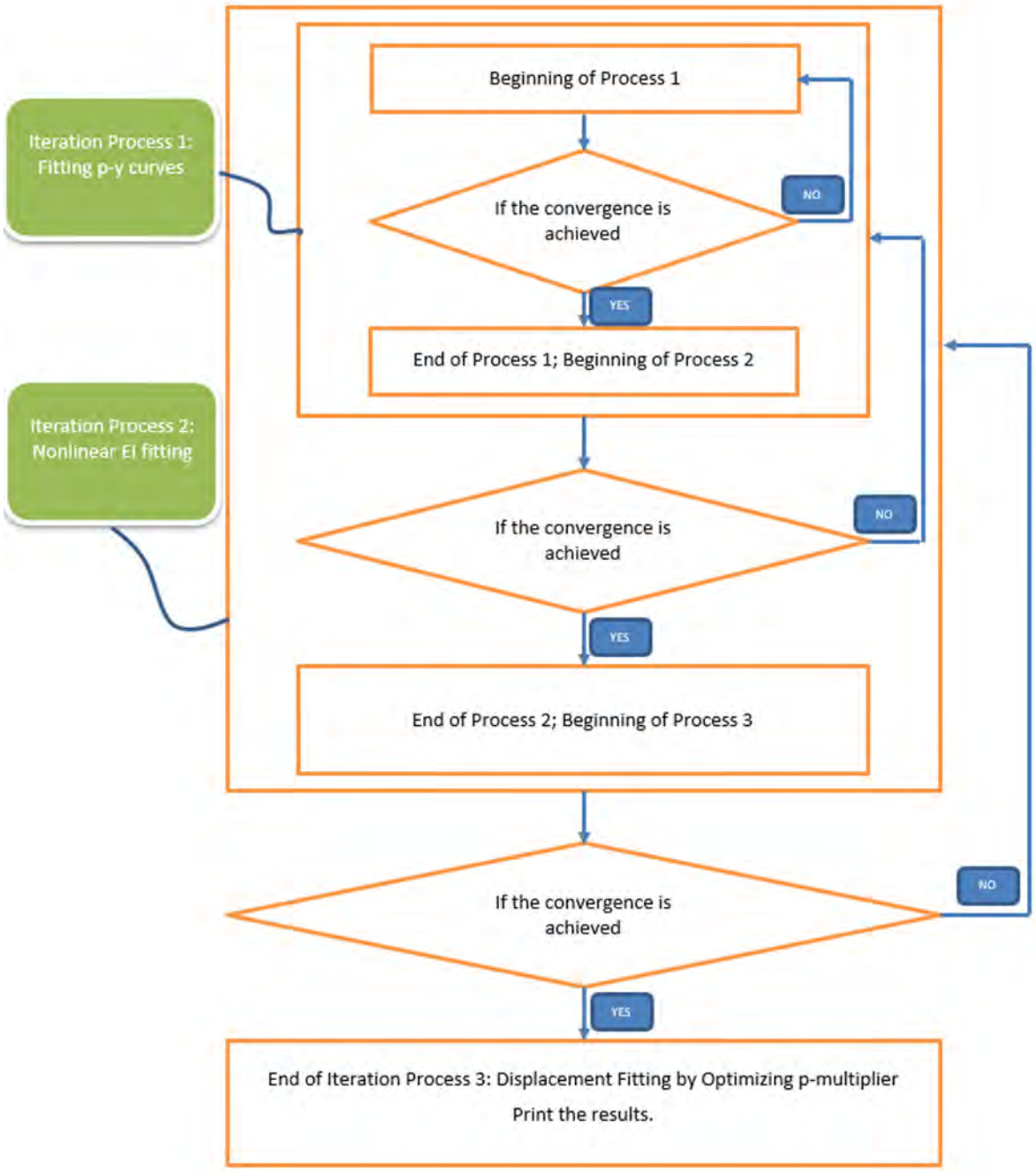

Figure 5.3 – Flow chart outlining operation of FEM computer code.

5.2.1 Iteration Process 1: Fitting p-y Curves

The conceptual p-y curve of Figure 5.2 also shows a dashed line labeled E_{py}, which is the secant modulus of the p-y curve. The secant modulus is used to account for the nonlinear response of the soil to deflection, as implemented in the following procedure:

1. Select trial values of E_{py}.
2. Assemble stiffness matrices for the shaft and soil.
3. Solve Eq. 5.1 for a given loading to find the nodal displacements and rotations of the shaft.

4. Back-calculate the soil resistance using theoretical p-y curves. For the work presented in this report, the stiff clay with no free water model popularly used in L-PILE (Isenhower, 2006) was used.
5. For each node, the difference between the p value from the trial value of E_{py} and that from the assumed p-y curve is calculated and stored in a difference vector.
6. Steps 2 through 5 are repeated until the approximate relative error in the norm of the difference vector between successive iterations is less than 0.001.

5.2.2 Iteration Process 2: Nonlinear EI Fitting

As described in Section 4.3 and shown in Figure 4.7, the bending stiffness of the shaft is a nonlinear function of the bending curvature. L-Pile was used to define the relationship for each shaft. The second iterative process used by the program establishes the bending stiffness according to the relationship established using L-Pile. The steps are outlined below.

1. An initial bending stiffness value of 1.0×10^{12} kips-in^2 is assigned to each element of the shaft.
2. Calculate the bending curvature from the deflections resulting from running Process 1.
3. Obtain improved values of bending stiffness EI using the calculated bending curvatures from Step 2 and the predicted EI curve from L-PILE.
4. Repeat steps 2 and 3 until the approximate relative error in EI values is less than 0.001.

5.2.3 Iteration Process 3: Displacement Fitting by Optimizing p-multiplier

The program applies a p-multiplier to the assumed p-y curve in order to match the measured shaft response. The p-multiplier simply factors the values of p on the p-y curves (essentially stretching or shrinking the vertical axis of Figure 5.2). The program is capable of matching results of the displacement profile from SAA or bending moments from the strain gages, but all the results in this report are based on matching the displacement profiles. The matching process involves minimizing the difference between the response predicted using Processes 1 and 2 and the response measured by the SAA, as outlined in the steps below.

1. A range of p-multiplier values is an input for the program.
2. Run through Processes 1 and 2 for each value of the p-multiplier. For each value, calculate the difference between the measured and predicted displacement values for each node and store the values in a vector. Calculate the norm of each difference vector.
3. Plot the norm of the difference vector versus the p-multiplier as shown in the example in Figure 5.4. The example would output a p-multiplier value between 1.4 and 1.5.
4. If the curve does not have a minimum, adjust the range of p-multiplier values and repeat steps 2 and 3.
5. Fit a high-order polynomial through the norm-p-multiplier curve. The value of the p-multiplier that minimizes the norm corresponds to the best fit of the measured data.

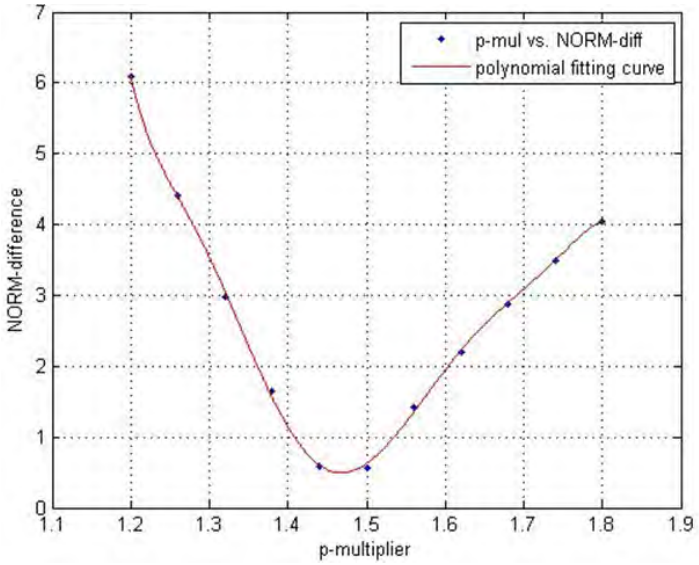

Figure 5.4 – p-multiplier optimization. The p-multiplier resulting from this operation of the FEM code is between 1.4 and 1.5.

5.3 Program Output

Successful completion of the procedure described in Section 5.2 produces profile plots of displacement and bending moment as well as a set of individual points on the p-y curve for each depth (i.e. one point per depth). These results correspond to a single loading of the shaft; additional runs through the computer program are required for each load step. An example set of profile plots is discussed below, and a complete set of all profile plots is included as Appendix E. Running the procedure for all load steps of a single test shaft results in one p-y curve for each analysis depth. The complete set of p-y curves at representative depths for both test sites is also presented below.

5.3.1 Profiles of Shaft Response

An example output from the computer code for one load of one shaft is shown in Figure 5.5. The first plot shows values of displacement measured with the SAA as well as values predicted using the FEM code. The second plot shows values of bending moment interpreted from the strain gage data as well as values predicted by the FEM code. The example result shown in Figure 5.5 includes a good fit to the displacement data from the shape array as well as a reasonably good fit to the bending moments interpreted from the strain gage data. The quality of the fits is consistent with the matching routine of Process 3, which only considered the SAA data for the results presented in this report.

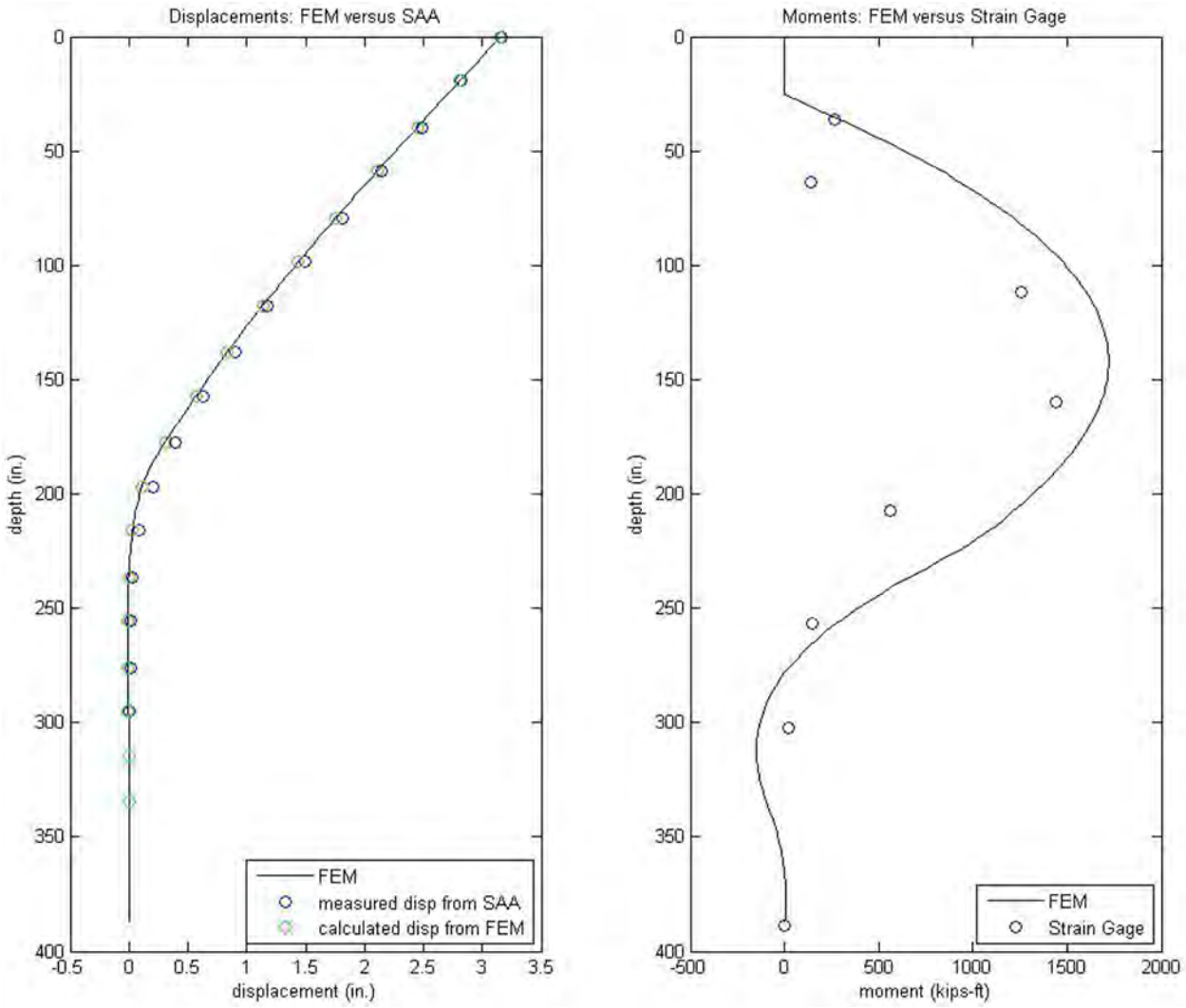

Figure 5.5 – Fitted results from analyses for test shaft W1 before soil removal at a load of 319 kips.

5.3.2 p-y Curve Results

One successful run of the FEM computer code for a single load of a single shaft produces a single point on the p-y curve for each analysis depth along the shaft. One set of p-y curves for each analysis depth for one test shaft can therefore be obtained by running the FEM code for a series of loads corresponding to the testing sequences described in Chapter 3. An example "measured" p-y curve derived from fitting to the experimental measurements is shown in Figure 5.6. The p-y curve is a reasonable result, with an initial linear portion transitioning to a value of p_{ult} of about 2700 lbs/in. Similar curves were prepared for other test shafts, and the results are presented and discussed in Chapter 6.

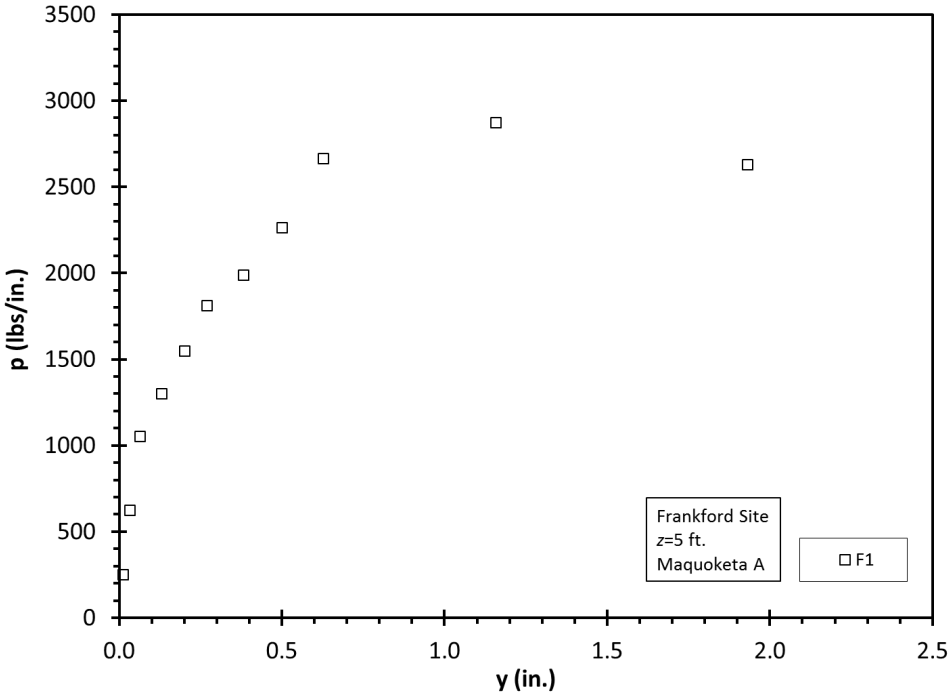

Figure 5.6 – Example p-y curve derived from fitting results for shaft F1 at a depth of 5 ft.

6. Characterization of p-y Models

The analyses described in Chapter 5 produced p-y curves for multiple depths along each of the 25 test shafts as presented below. This chapter describes how models were fit to the p-y curves. It is intended that the models presented can be used for future MoDOT practice in similar soils.

6.1 Proposed Model Format

The sets of p-y curves for each depth were fitted to an exponential function shown in Eq. 6.1. Several different equation forms were investigated, but the exponential function was versatile enough to fit all of the data sets and is relatively simple from a computational standpoint.

$$p = a\left(1 - \exp(-b * y)\right) \qquad \text{(consistent units)} \qquad \textbf{Eq. 6.1}$$

Values of the parameters a and b were obtained using MATLAB's curve fitting tool to establish a best-fit to the experimental p-y "measurements" established as described in Chapter 5. Another advantage of the exponential function is that its parameters are easily related to the more familiar terms p_{ult} and k_{py}, the initial slope of the p-y curve, as described by Eq. 6.2 and Eq. 6.3.

$$\begin{cases} p_{ult} = a \\ k_{py} = a * b \end{cases} \qquad \text{(consistent units)} \qquad \textbf{Eq. 6.2}$$

$$p = p_{ult}\left(1 - \exp\left(-\frac{k_{py}}{p_{ult}} * y\right)\right) \qquad \text{(consistent units)} \qquad \textbf{Eq. 6.3}$$

6.2 Fitted p-y Curves

The analyses described in Chapter 5 were used to create "measured" p-y curves for each shaft at representative depths, as described in Section 5.3.2 and presented in Figure 5.5. The collection of p-y curves were grouped together by site and depth, and the results are plotted in Figure 6.1 (Frankford Maquoketa A), Figure 6.2 (Frankford Maquoketa B), Figure 6.3 (Frankford Maquoketa C), Figure 6.4 (Warrensburg Silty Clay), and Figure 6.5 (Warrensburg Shale). Curve fitting procedures were implemented in MATLAB to fit the exponential function of Eq. 6.1 to each set of measured p-y curves. These best fit lines are plotted with the p-y data along with bounds corresponding to plus or minus one standard deviation from the model values. In addition, p-y curves for L-PILE's stiff clay model for the values of UCS at each depth (Figure 2.3, Figure 2.9) are included for comparison (see Section 6.4) in Figure 6.1 through Figure 6.5.

In general, the exponential model produces a good fit to the observed data, and the variability is relatively small. One limitation of the exponential function of Eq. 6.1 is that the function is non-decreasing for all positive values of a and b, which makes it unsuitable for capturing any strain-softening response. Data for the Maquoketa A shale layer at Frankford (Figure 6.1) seem to indicate some minor strain-softening, but not so much as to disqualify use of the exponential model. Data for the deeper layers at both test sites are limited by the magnitude of the displacement that was achieved at these depths during testing (Figure 6.3, Figure 6.5(c)). However, the shape of p-y data for these deeper layers does include a notable change in slope that is consistent with achieving p_{ult}. Nevertheless, the best-fit p-y model established for the deeper layers would benefit from additional data derived from greater displacements, and the p-y model should be applied to similarly stiff layers at greater displacements with some caution.

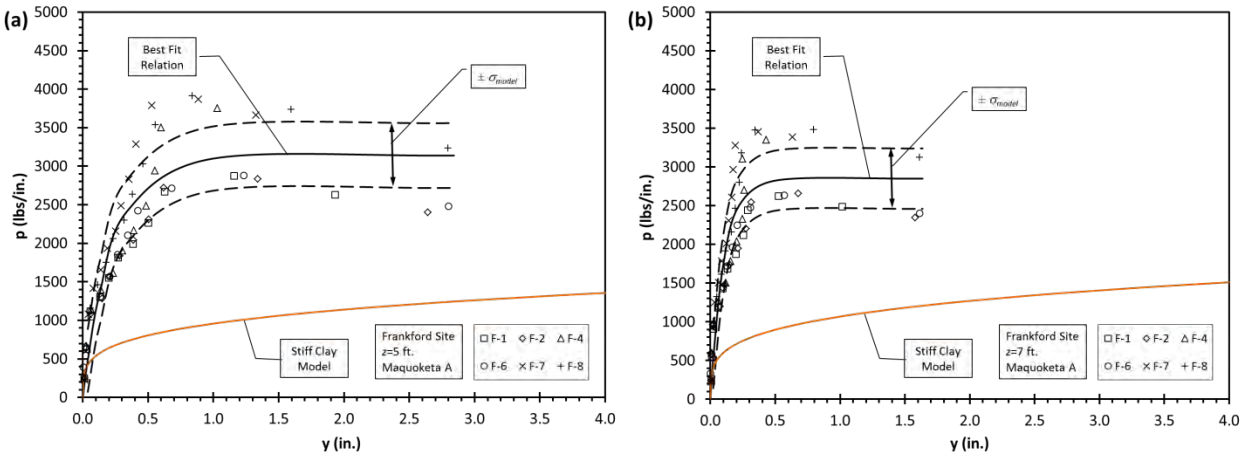

Figure 6.1 – *p-y* curves for Maquoketa A shale layer at Frankford Load Test Site for depths of (a) 5 ft and (b) 7 ft.

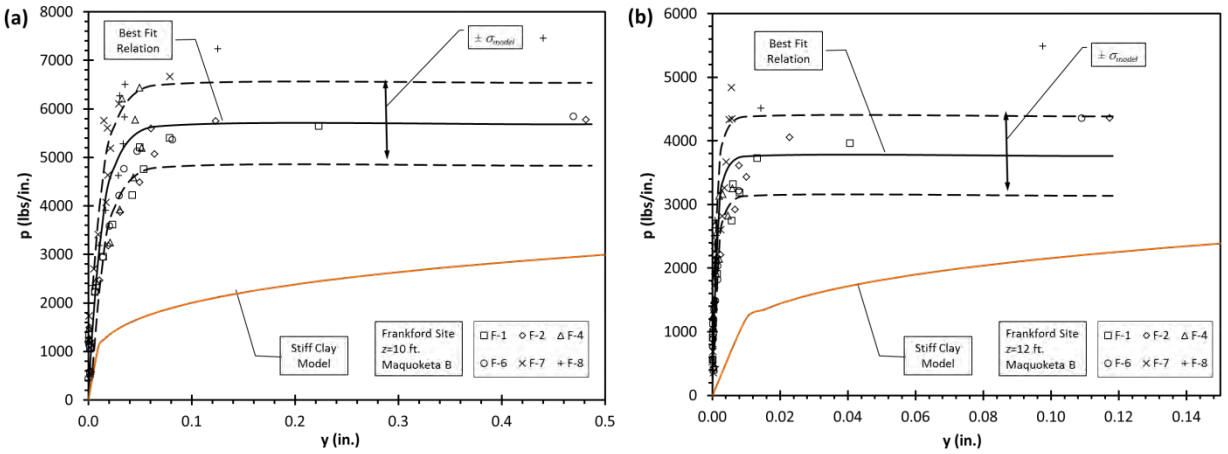

Figure 6.2 – *p-y* curves for Maquoketa B shale layer at Frankford Load Test Site for depths of (a) 10 ft and (b) 12 ft.

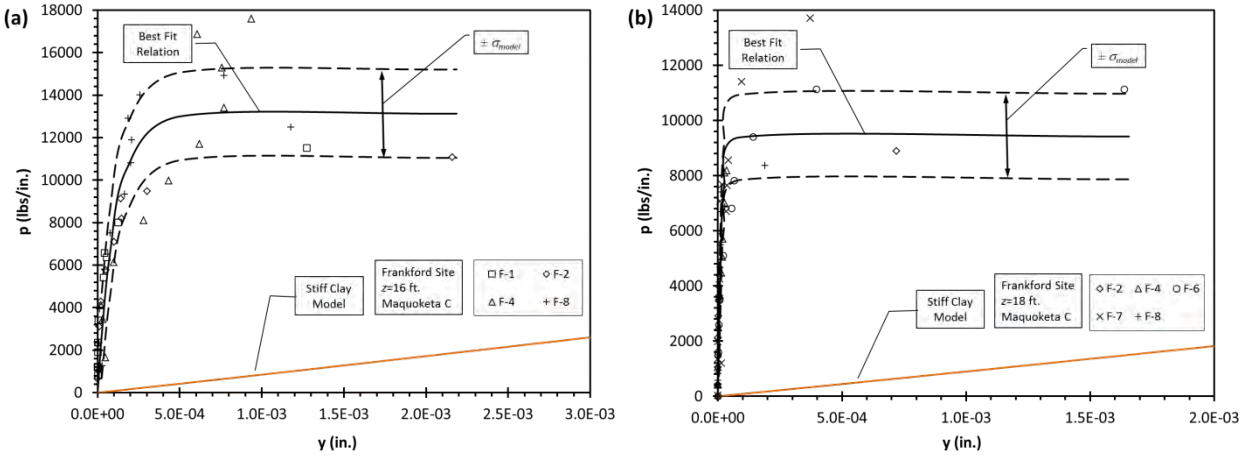

Figure 6.3 – *p-y* curves for Maquoketa C shale layer at Frankford Load Test Site for depths of (a) 16 ft and (b) 18 ft.

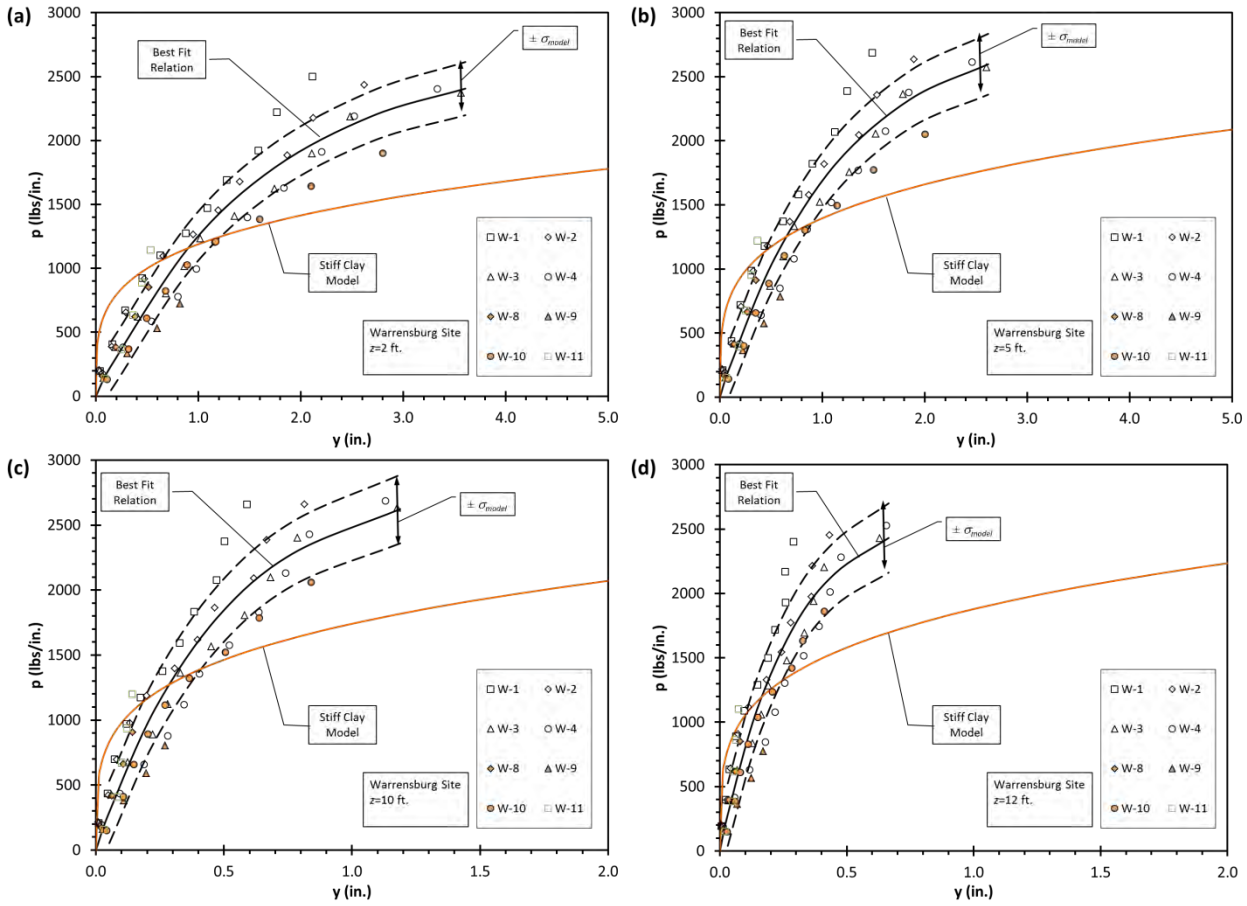

Figure 6.4 – *p-y* curves for silty clay layer at Warrensburg Load Test Site for depths of (a) 2 ft, (b) 5 ft, (c) 10 ft, and (d) 12 ft. All data are from tests without soil removal.

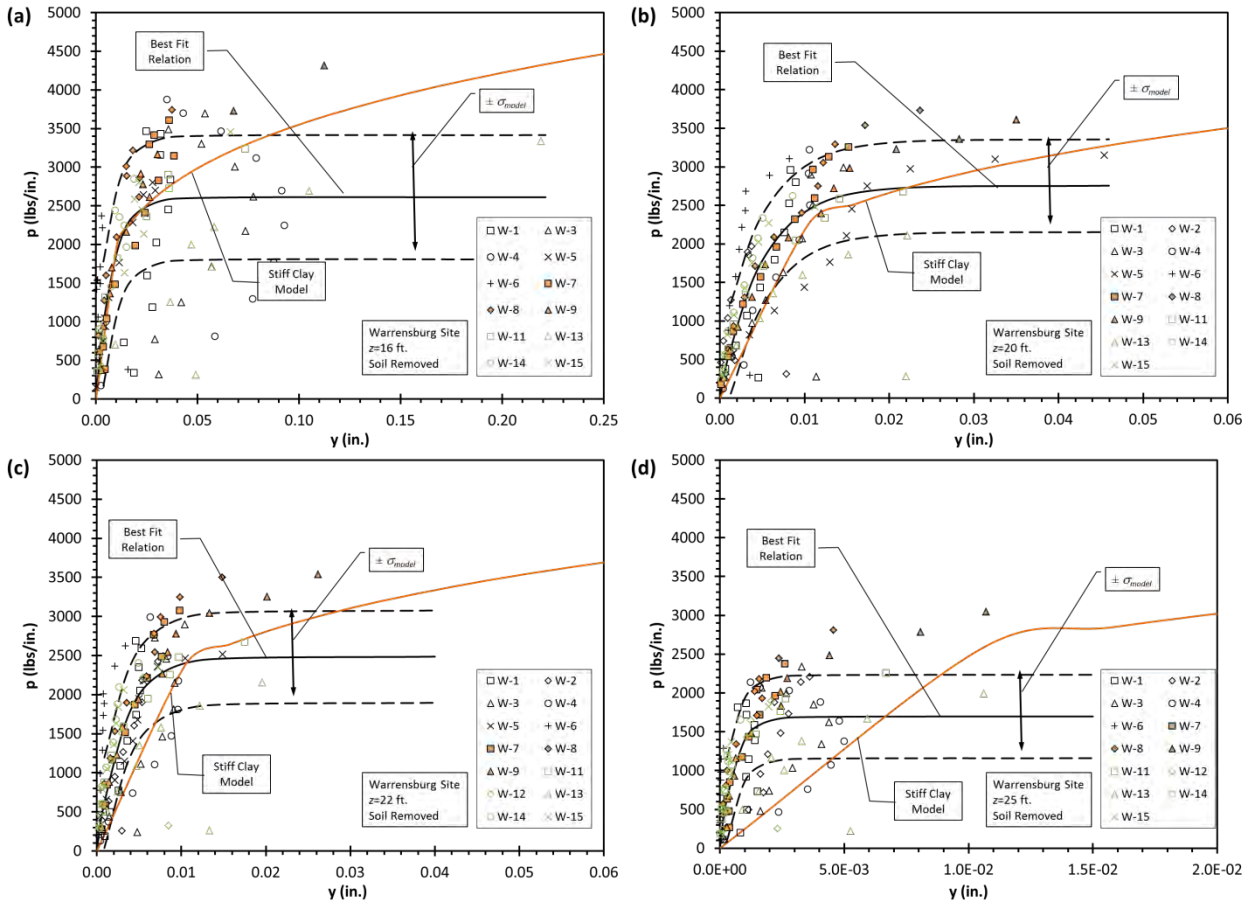

Figure 6.5 – p-y curves for shale layers at Warrensburg Load Test Site for depths of (a) 16 ft, (b) 20 ft, (c) 22 ft, and (d) 25 ft. All data are from tests with soil removal.

6.3 Proposed p-y Models from Fitted p-y Curves

The results of model fitting for all depths and layers at both sites are presented in Table 6.1. For the Warrensburg site, model parameters for the silty clay layer are from tests without soil removal, and model parameters for the shale layers are from tests with soil removal. The model parameters p_{ult} and k_{py} were plotted versus the uniaxial compressive strength (UCS) for each depth in Figure 6.6 and Figure 6.7, respectively. The plots include the proposed models, a linear function for p_{ult} and a power function for k_{py}, as summarized in Eq. 6.4 and Eq. 6.5.

$$p_{ult} = 0.136 \cdot UCS + 1.89$$

p_{ult} in kip/in.; UCS in ksf

3 ksf < UCS < 100 ksf **Eq. 6.4**

$$k_{py} = 0.052 \cdot UCS^{3.68}$$

k_{py} in kip/in.^{2}; UCS in ksf

3 ksf < UCS < 100 ksf **Eq. 6.5**

In general, the data from Warrensburg fall below the regression model predictions, while the data from Frankford lie above the regression model predictions, as can be seen in Figure 6.6 and Figure 6.7. More data, especially from material with UCS between 15 and 65 ksf, would strengthen the models. The recommended range for the models, UCS between 3 and 100 ksf, is representative of the stiff clay and shale materials that were tested at Frankford and Warrensburg. Tests of other materials (e.g. clay with UCS less than 3 ksf, or tests in stronger rock) should be conducted rather than extending the models

outside the recommended range. The data of Table 6.1 suggest k_{py} increases with depth as well as UCS, but the model only reflects the effect of UCS. The model likely would benefit from a multiple regression model to include the effect of depth, but this would require additional data.

Table 6.1 – Summary of model fitting for each layer.

Site	Layer	UCS ksf	z ft	a	b	p_{ult} kips/in.	k_{py} kips/in.^{2}
Frankford	Maquoketa A	3.25	5	3139	4.35	3.14	13.7
			7	2849	9.54	2.85	27
	Maquoketa B	10.4	10	5683	74.4	5.68	423
			12	3761	719	3.76	2702
	Maquoketa C	66.2	16	13,131	9191	13.13	120,682
			18	9418	66,386	9.42	625,203
Warrensburg	Silty Clay	4.45	2	2684	0.63	2.68	1.69
			5	2884	0.88	2.88	2.54
			10	2873	2.06	2.87	5.91
			12	2670	3.63	2.67	9.69
	Sandy Shale	15	16	2612	127	2.61	331
			20	2756	209	2.76	576
			22	2487	322	2.49	800
			25	1698	1716	1.70	2913

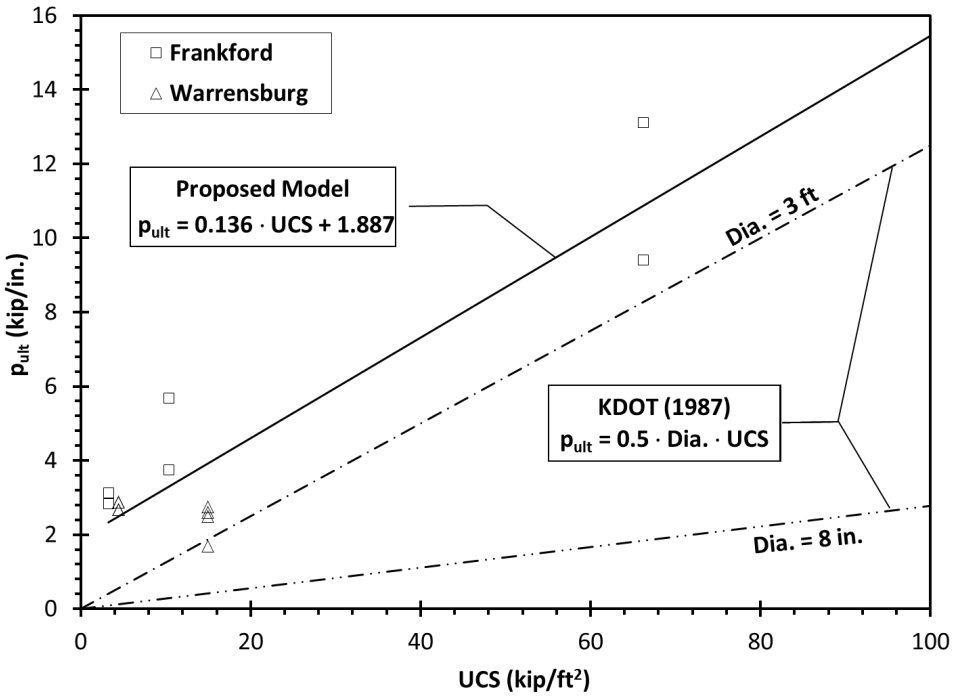

Figure 6.6 – Proposed relationship between p_{ult} and UCS.

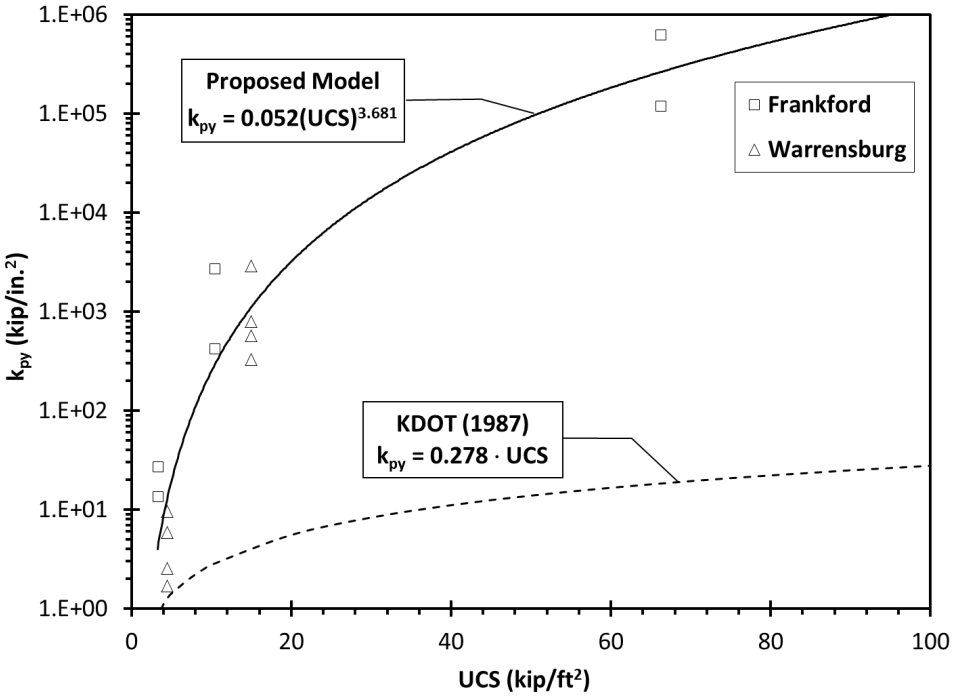

Figure 6.7 – Proposed relationship between k_{py} and UCS.

6.4 Comparison of Proposed Model with Existing Models

The p-y curves fitted from the test measurements and presented in Section 6.2 are compared to curves from L-PILE's stiff clay model and to p-y curves proposed by Frantzen and Stratton (1987) for the Kansas Department of Transportation for use in shale and sandstone. The comparisons are useful for perspective on how the test data align with models commonly assumed in practice.

6.4.1 Comparison with L-PILE's Stiff Clay Model

The plots of Figure 6.1 through Figure 6.5 show p-y data established from matching predicted and measured response using the FEM computer code, the exponential function fitted to these data, and the p-y curve predicted using L-PILE's stiff clay model based on appropriate values of UCS. For data from the Frankford site, the p-y curves fitted to test data indicate significantly greater resistance (i.e. higher values of p) than predicted using the L-PILE stiff clay model. This is especially true at high displacements; the values of p_{ult} fitted to test data are much greater than those predicted by the L-PILE stiff clay model. The initial stiffness (k_{py}) values are similar for the measured test data and L-PILE stiff clay model predictions, except for the Maquoketa C layer, for which test data suggest greater stiffness.

Results from the Warrensburg tests indicate closer agreement between the interpretation of test data and predictions using L-PILE's stiff clay model. For the silty clay overburden, test data generally indicate greater values of p_{ult} but lower values of k_{py}. For the shale layers, the p-y curves fitted to test data are similar to the ones predicted by L-PILE's stiff clay model, with the test data showing the same or slightly greater values of k_{py}. The L-PILE stiff clay models predict a strain hardening response that was not observed for shale from the Warrensburg test data.

6.4.2 Comparison with KDOT's p-y Curve for Sandstone and Sandy Shale

The Kansas Department of Transportation published a report (Frantzen and Stratton, 1987) that proposed p-y curves derived from a series of lateral load tests on 8-in. pipe piles installed in weak rock at four sites in the Kansas City area. Based on results for shallow depths (up to 2 ft), the authors recommended a p-y

model with an initial linear region, a less steeply inclined linear transition region, and a constant ultimate region. The initial stiffness was defined as 80 times the undrained strength of the material (consistent units), and the ultimate resistance was defined as the diameter of the pile times the undrained strength (also consistent units). These recommendations are plotted with the proposed models from this report (Section 6.3) in Figure 6.6 and Figure 6.7. The KDOT values of p_{ult} for a diameter of 3 ft (like the shafts documented in this report) are less than those proposed in Eq. 6.4, with a similar slope with respect to material strength but no y-intercept. For a diameter of 8 in. (like the KDOT piles), the KDOT values of p_{ult} are significantly less than those proposed in Eq. 6.4. The initial stiffness, k_{py}, of the KDOT model is also significantly less than that proposed in Eq. 6.5, as can be seen in Figure 6.7. In general, the results of the research documented in this report found significantly greater resistance to lateral loads than that predicted using the KDOT models. Scale effects (8-in. piles for KDOT vs. 3- or 3.5-ft shafts for this work) may account for much of the difference, but the test shafts at Frankford and Warrensburg are more representative of shafts that would be used for bridge foundations.

7. Calibration of Resistance Factors

This chapter presents results of resistance factor calibration based on Monte Carlo simulations using the computer code described in Chapter 5. The resistance factors presented in this chapter are intended to be applied to the p-y curves directly, i.e. by factoring the p values, which can be implemented using p-multipliers. This approach is different and, in the authors' opinion, more rational than the approach of applying the resistance factor as an additional load factor, which is the approach presented in the FHWA Drilled Shafts manual (Brown et al., 2010).

7.1 Monte Carlo Method

Resistance factors were calibrated using Monte Carlo simulations. The Monte Carlo method is shown conceptually in Figure 7.1. The Monte Carlo method is a numerical approach to reliability analyses that is useful when the distribution of outcomes (e.g. displacement, bending moment, etc.) is unknown and is a function of other random variables (e.g. material strength, material stiffness, model uncertainty, etc.). The numerical approach involves running many model simulations with input parameters assigned randomly according to their probability distributions. The probability of failure can be calculated from the number of simulations that result in failure.

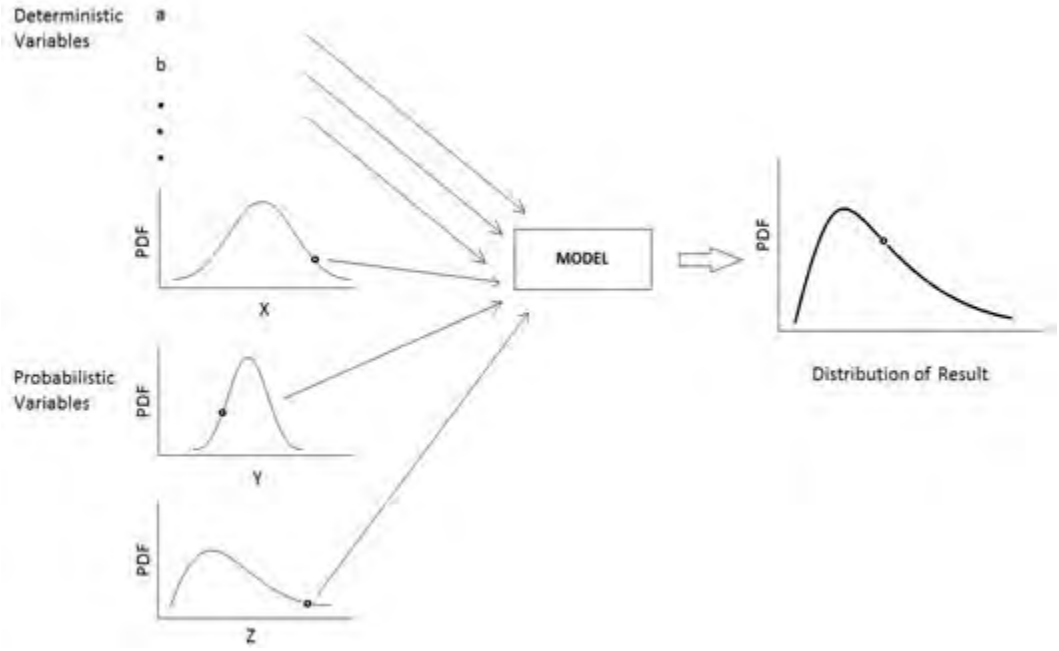

Figure 7.1 – Conceptual diagram of Monte Carlo method.

7.2 Calibration Simulations

The Monte Carlo simulations for this work were performed for conditions similar to the load test scenario: a shallow soil layer overlying a weak rock with a lateral load applied at the top of the shaft. The loading and shaft length were assumed to be deterministic, while the geomaterial strength (UCS), bending stiffness (EI), and p-y model parameters (p_{ult} and k_{py}) were assigned probabilistic distributions as defined in Table 7.1. The load applied to the top of the shaft for the simulations, 200 kips, is approximately 70 percent of the ultimate load encountered during the test program. The bending stiffness values used in the simulations were calculated consistent with the approach of Section 4.3, and a probabilistic model uncertainty factor (m-EI) was applied. A similar approach was used for p_{ult} and k_{py}, which were calculated according to Eq. 6.4 and Eq. 6.5, respectively, while a model uncertainty factor was applied to the resulting p-y curve to account for most of the uncertainty.

Table 7.1 – Monte Carlo input parameters.

Parameter	Assumed Distribution	Mean	COV
Load	(Deterministic)	200 kips	0
UCS-soil	Lognormal	5 ksf	0.1, 0.3,
UCS-rock	Lognormal	50 ksf	0.5, 0.7, 0.9
m-EI	Lognormal	1	0.2
m-p_{ult}	Lognormal	1	0.01
m-k_{py}	Lognormal	1	0.01
m$-$ p-y curve	Lognormal	1	0.2

7.3 Results

Two sets of resistance factors were calibrated using the results of the Monte Carlo simulations. The first corresponds to the service limit state and was based on the deflection of the top of the shaft. Results for the service limit state are shown in Figure 7.2. The second corresponds to the strength limit state and corresponds to the maximum bending moment in the pile. Results for the strength limit state are shown in Figure 7.3. The target probabilities of failure used for the analyses correspond to those for axially loaded foundations (Pierce et al., 2014). Alternative values should potentially be considered. The resistance factors are intended to be applied directly to the resistance predicted by the p-y models. This can be implemented using p-multipliers as explained in Chapter 5 and as implemented in L-Pile.

Both sets of resistance factors may seem low, especially considering that current AASHTO guidance (6th Ed., 2012 with 2013 Interim Revisions) includes a resistance factor of 1.0. However, it is important to note that the proposed p-y models presented in Chapter 6 predict substantially greater resistance than do existing p-y models. These findings will likely offset one another for many cases. Moreover, any differences between previous design approaches (i.e. either L-PILE's stiff clay model or KDOT curves with a resistance factor of 1.0) and the models and resistance factors presented in this report are rational and should improve the state of practice for MoDOT since the recommended models are based on full-scale load tests and the resistance factors achieve target levels of reliability.

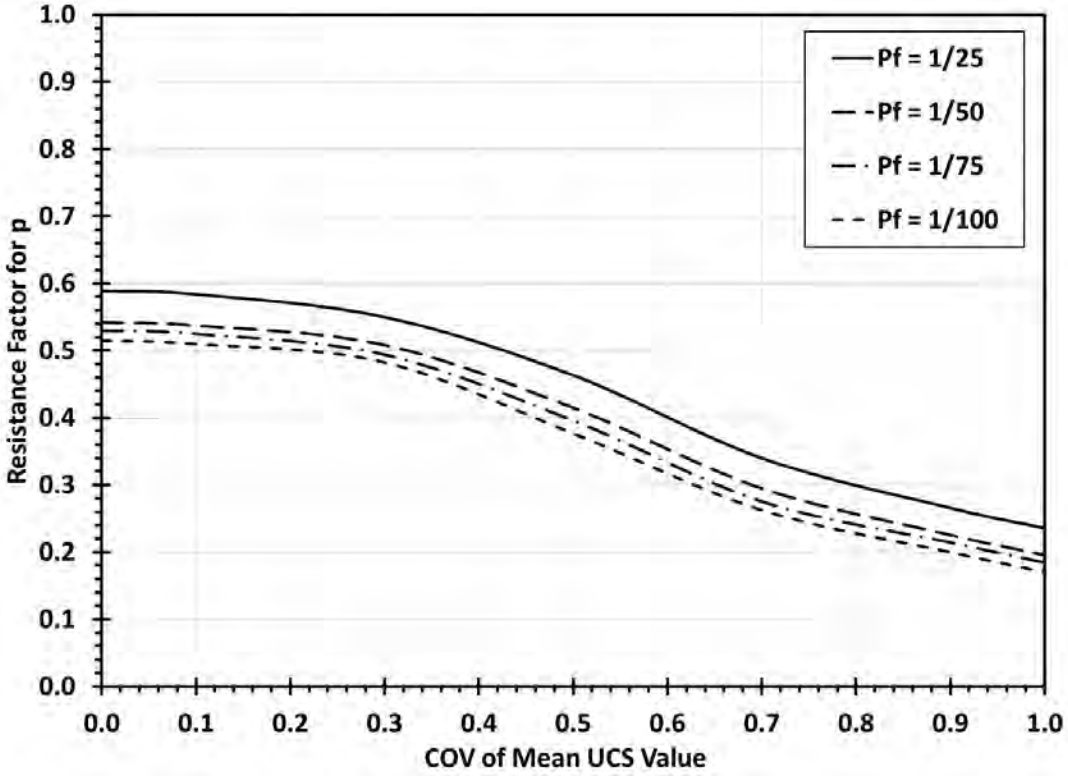

Figure 7.2 – Calibrated resistance factors for service limit state design.

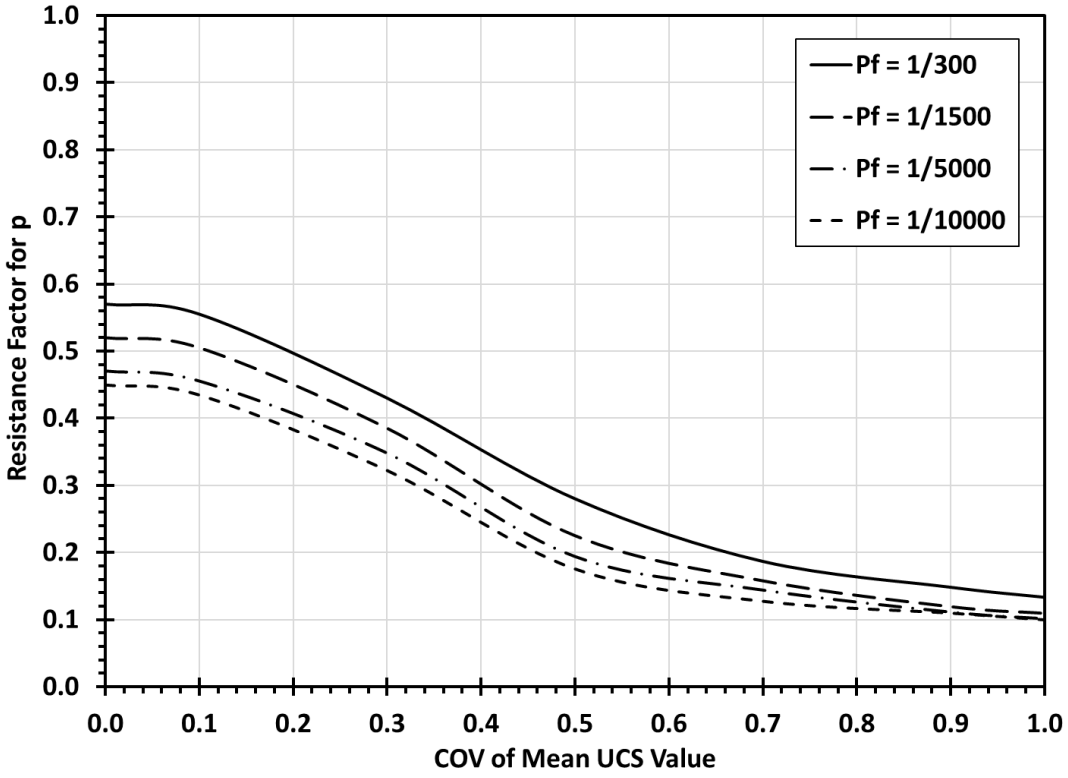

Figure 7.3 – Calibrated resistance factors for strength limit state design.

8. Conclusions & Recommendations

The results of the load test program, data interpretation, modeling, and resistance factor calibration produced several important conclusions:

- The load test program was successful. The load tests achieved significant displacement of the top of the shaft, and successfully transferred load into the weak rock layers. The resulting data set is vast and useful. The instrumentation effectively measured loads and displacements, and the SAA data were particularly useful from a data analysis perspective.
- The FEM code written to fit p-y model parameters to the observed data was similarly effective.
- The p-y curves fitted to the observed data had significantly greater values of p_{ult} than predicted using L-Pile's stiff clay model, as reflected by Eq. 6.4. In addition, the proposed model predicts significantly greater resistance to lateral loading than the resistance predicted by the model proposed by Frantzen and Stratton (1987).
- The models would benefit from additional testing from materials with uniaxial compressive strength (UCS) between 15 and 65 ksf. Additional test data with greater displacement (y) within shale layers would also be beneficial.
- The variability of the measured load-deflection response and of the fitted p-y curves was relatively small. The authors suspect this is a result of the "averaging" nature of lateral loading wherein the strength of an adjacent layer can often compensate for a weak layer.
- The resistance factors presented in Chapter 7 range from 0.2 to 0.6 for serviceability (shaft head deflection) and from 0.1 to 0.6 for strength (maximum moment). These factors may seem low, but they are likely offset by the increased stiffness and significantly increased ultimate resistance predicted by the recommended p-y models.
- The resistance factors are to be implemented by directly factoring the resistance predicted by the p-y curves. This can be accomplished using p-multipliers as described in Chapter 5 and implemented in L-Pile. This approach is different and, in the authors' opinion, more rational than the approach of applying the resistance factor as an additional load factor, which is the approach presented in the FHWA Drilled Shafts manual (Brown et al., 2010).

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Google Earth (2011a), 38º 08' 58.34" N and -90º 56' 47.11" E. Google Earth. May 3, 2010, October 29, 2011.

Google Earth (2011b), 39º 28' 45.38" N and -91º 18' 17.85" E. Google Earth. May 3, 2010, August 13, 2011.

Google Earth (2011c), 38º 56' 08.74" N and -92º 22' 17.03" E. Google Earth. May 3, 2010, August 13, 2011.

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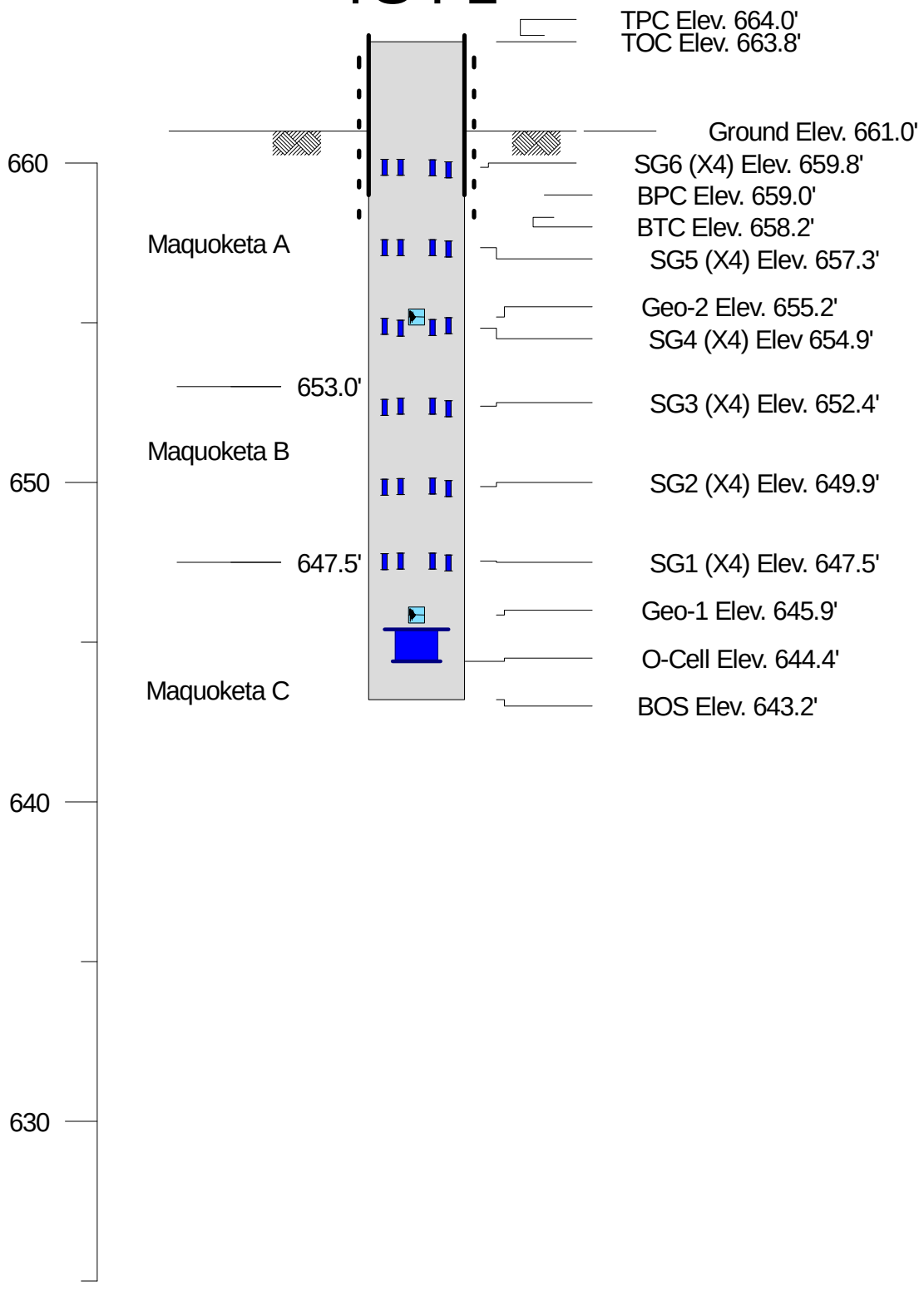
Appendix A – As-Built Shaft Information

Abbreviations used in this Appendix

BOS	Bottom of Shaft
BPC	Bottom of Permanent Casing
BTC	Bottom of Temporary Casing
Geo	Geophone
Mat	Concrete Maturity Meter
SG	Strain Gage
TOC	Top of Concrete
TPC	Top of Permanent Casing
TTC	Top of Temporary Casing

TS-F1



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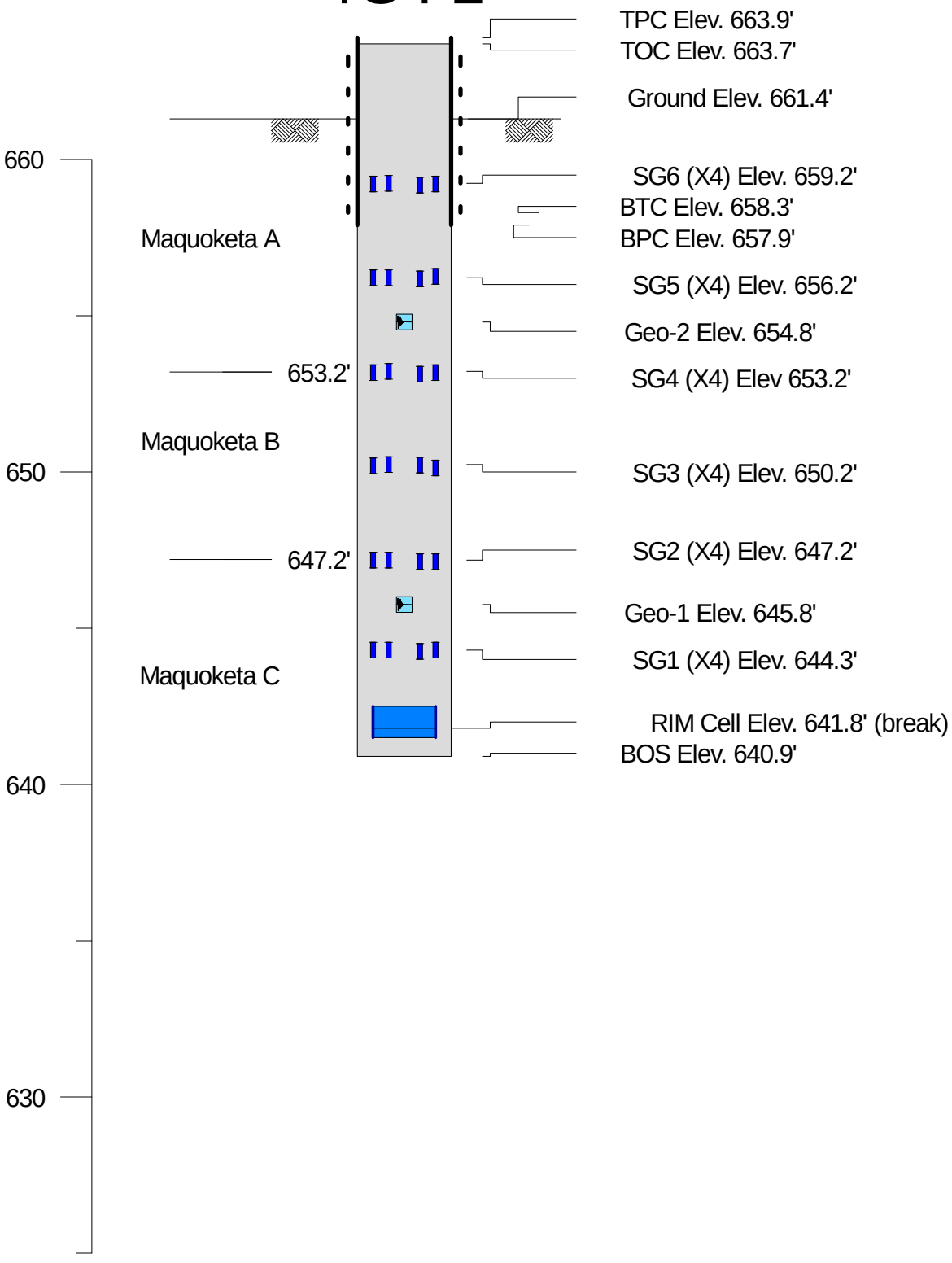
TS-F2



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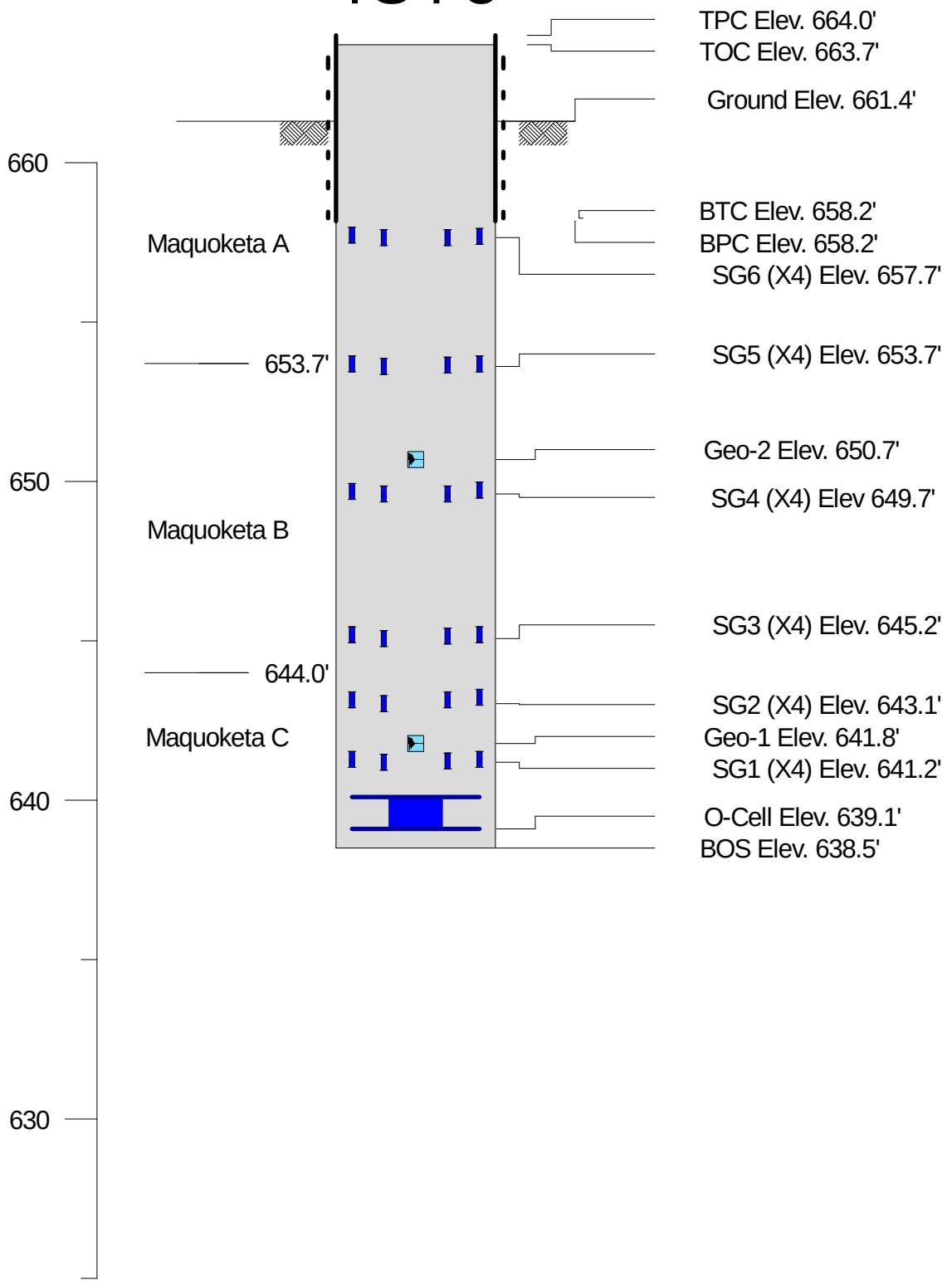

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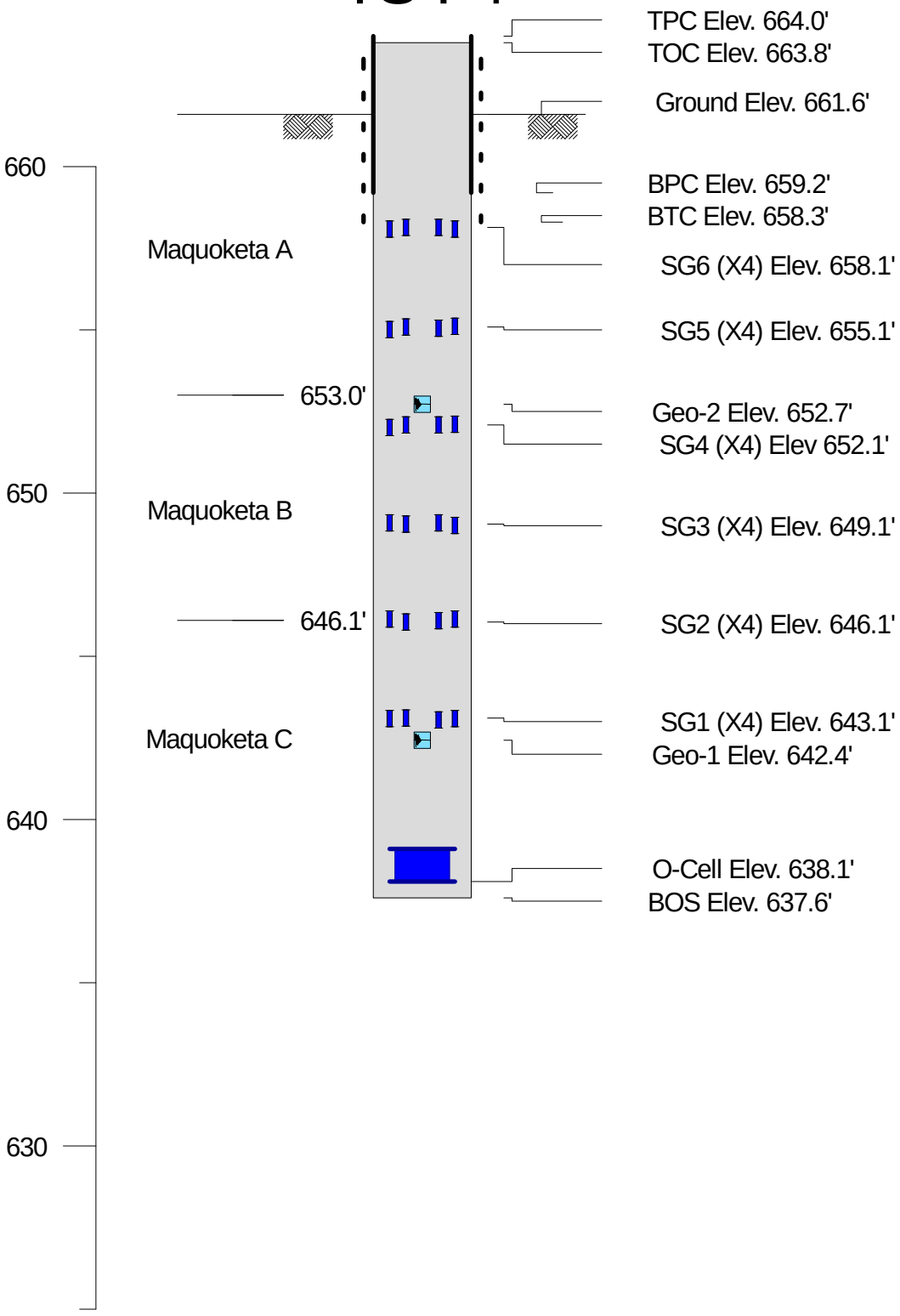
TS-F4



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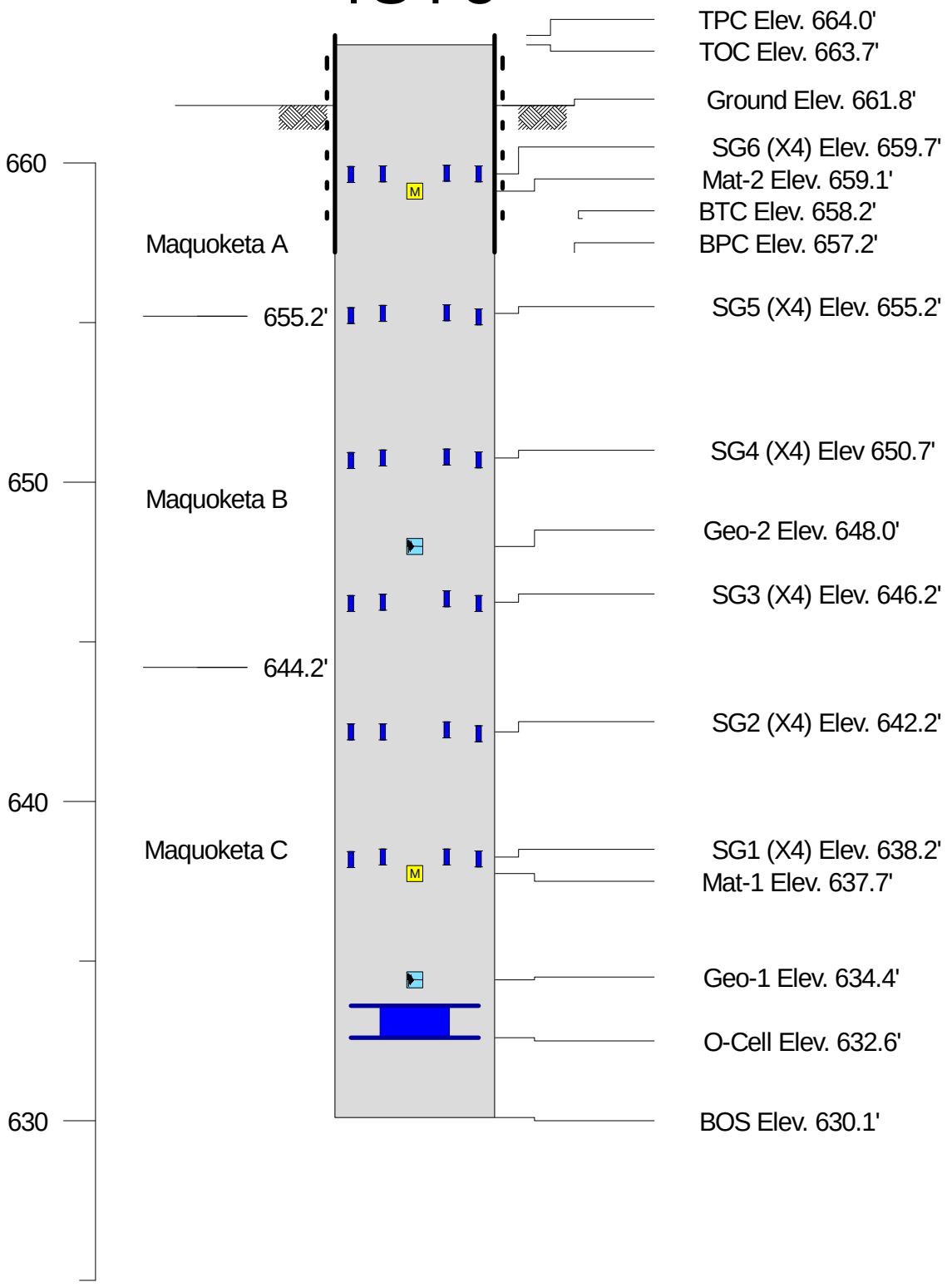
TS-F5



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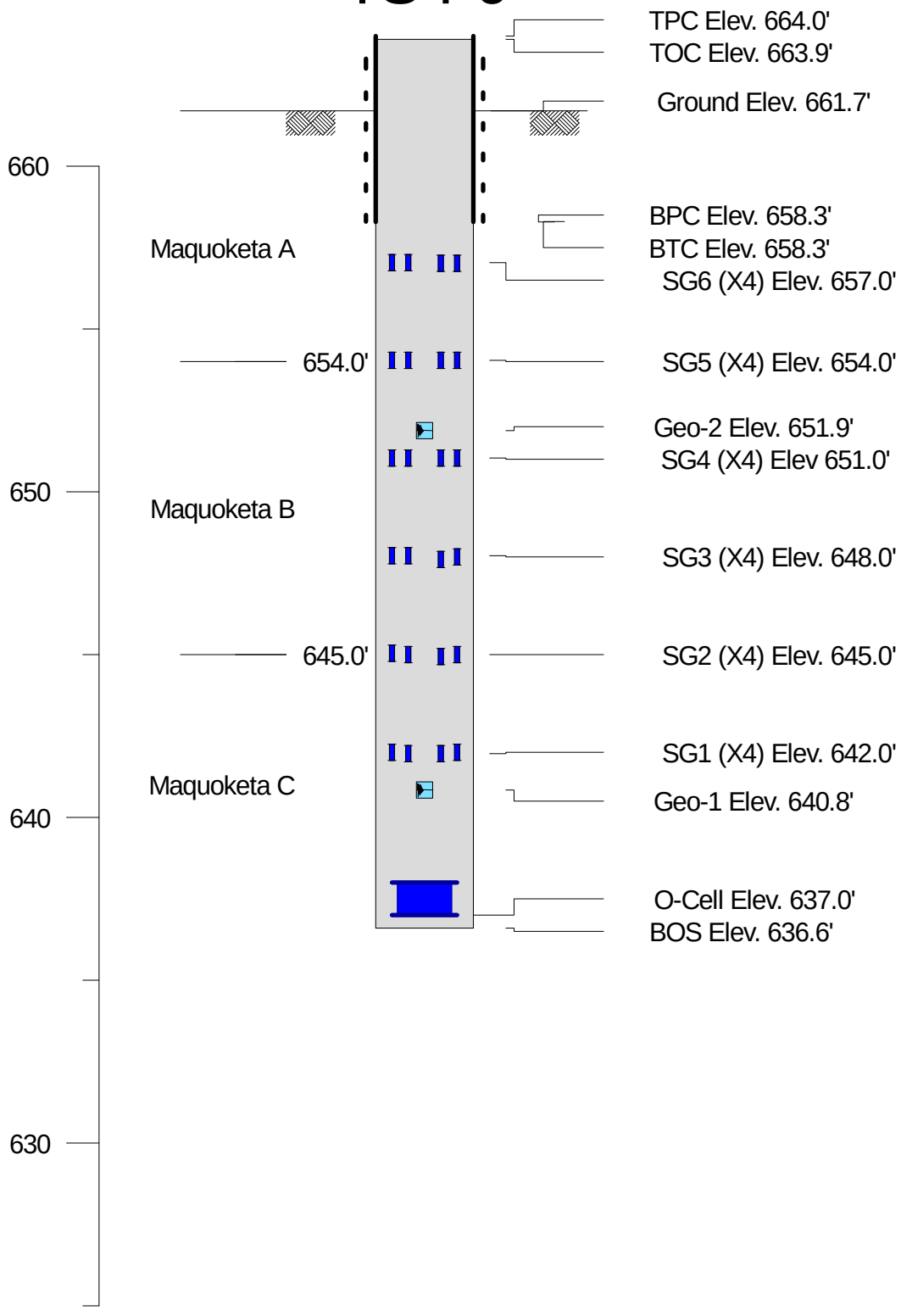
TS-F6



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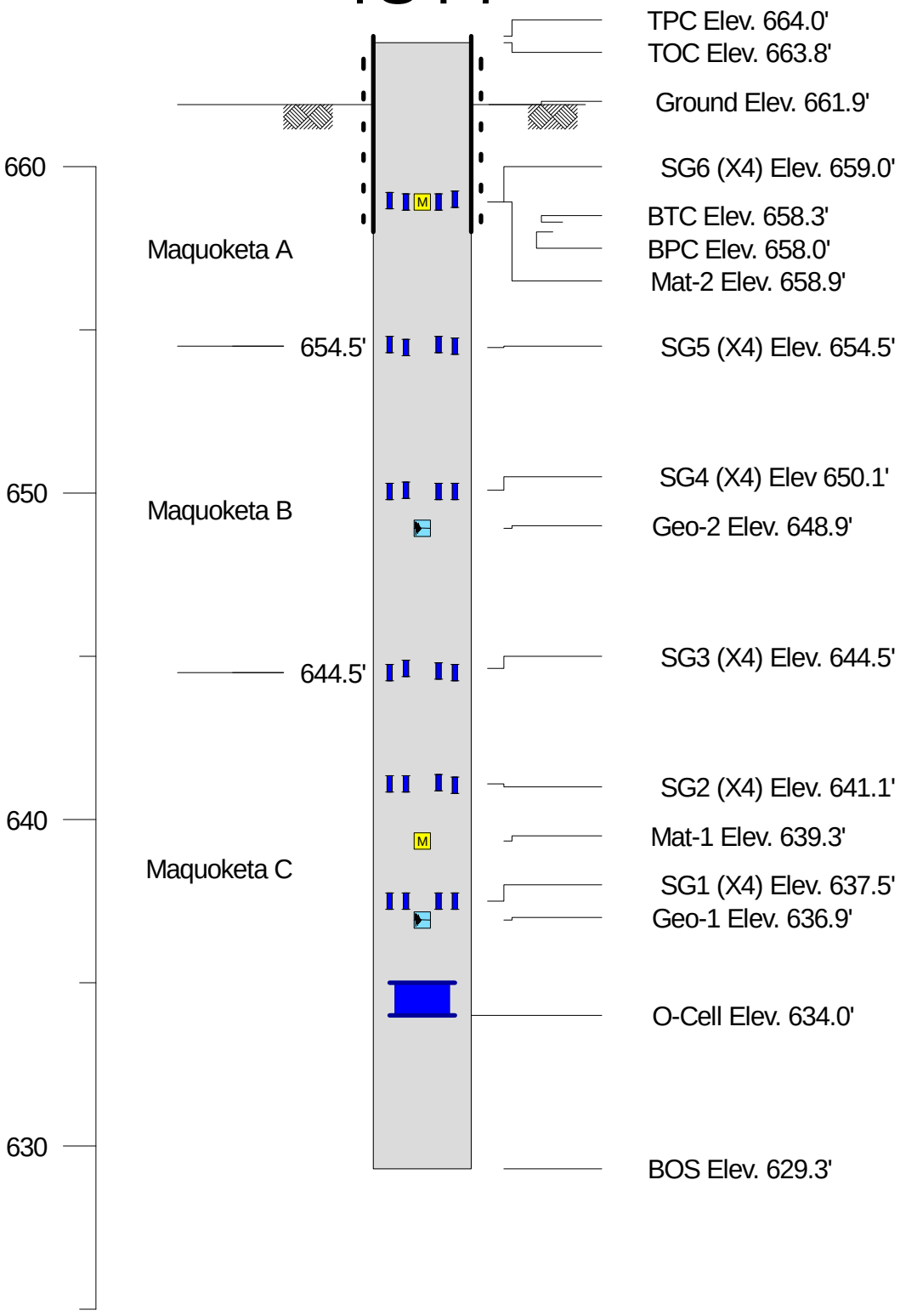
TS-F7



University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-F7 Frankford Load Test Site	2 1 0 5 10 1" = 5'
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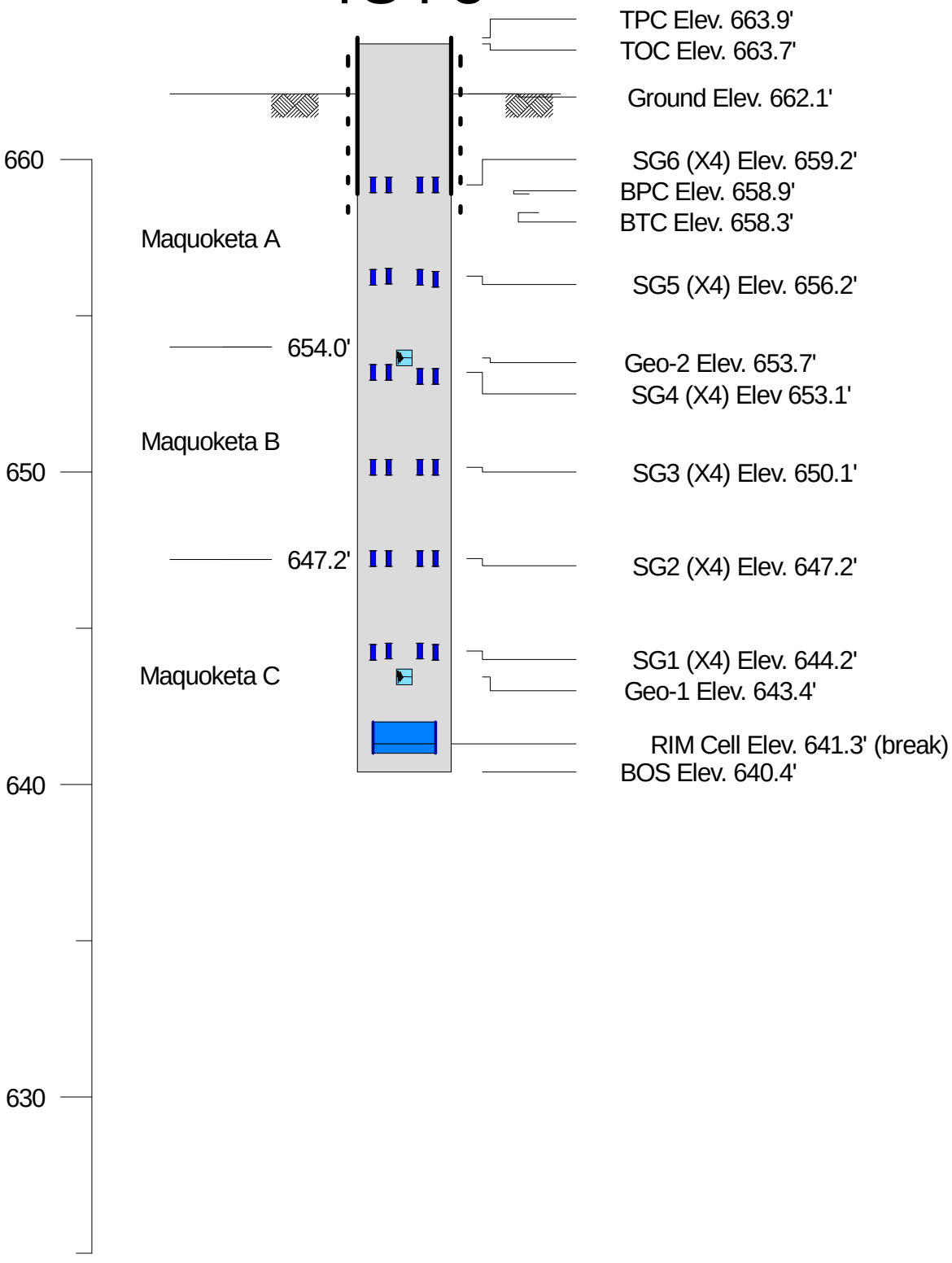
TS-F8



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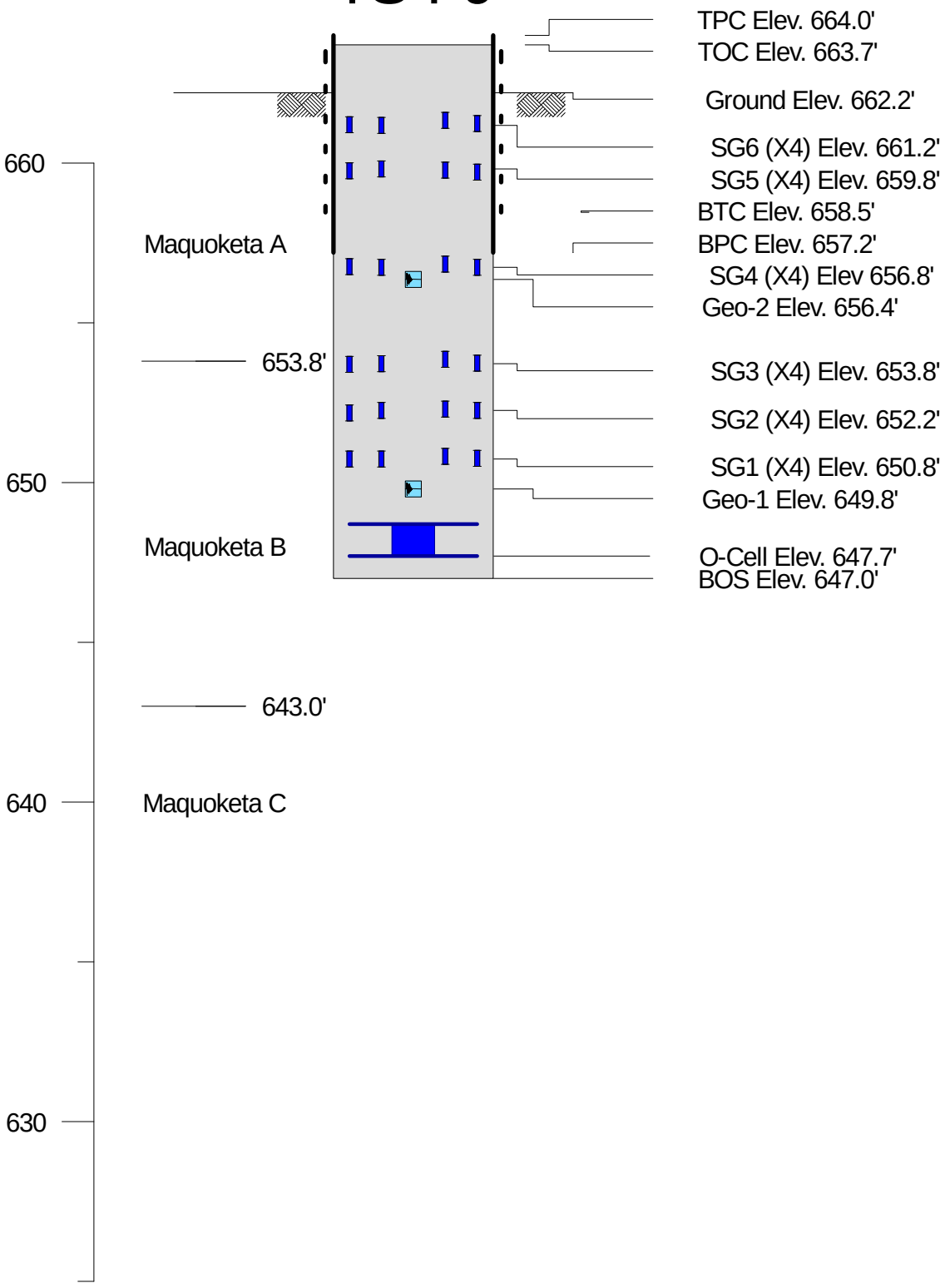
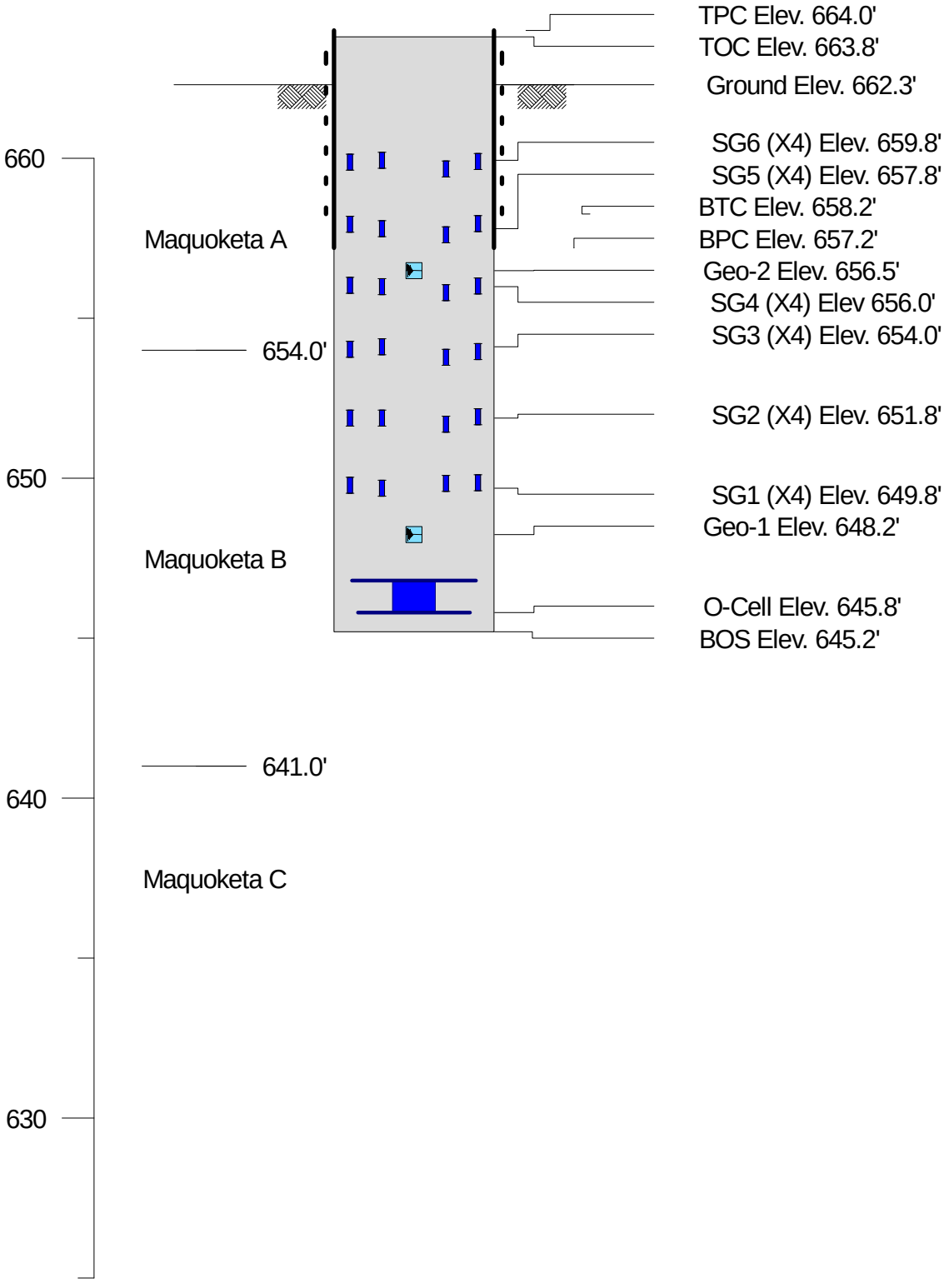
TS-F9



University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-F9 Frankford Load Test Site Date: Dec. 30, 2011 / Drawing 1 of 1	2 1 0 5 10 1" = 5'

TS-F10



University of Missouri
Civil Engineering
MoDOT Transportation Geotechnics
Research Program

As-built Drawing - Test Shaft TS-F10

Frankford Load Test Site

Date: Dec. 30, 2011 | Drawing 1 of 1

2 1 0 5 10

1" = 5'

TS-F1

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	36.8
Diam. Uncased (in)	36.0
TPC Elev. (ft)	663.98
TTC Elev. (ft)	663.19
TOC Elev. (ft)	663.77
Ground Elev. (ft)	661.01
BPC Elev. (ft)	658.96
BTC Elev. (ft)	658.19
BOS Elev. (ft)	643.23
Grout elev. (ft)	

O-Cell Information

Serial #	16-6-00269
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	23.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	18.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	644.43

Reinforcing Steel Information

Bar size	#14
# bars	9
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	19.08
Top Elev. (ft)	663.43
Bottom Elev. (ft)	644.35

Temporary Casing

OD (in)	43.0
Thickness (in)	0.250
Length (ft)	5.00

Permanent Casing

OD (in)	36.8
Thickness (in)	0.375
Length (ft)	5.02

Instrument Elevations Reference Elev. (ft): 644.4

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	3	2	3.17	3.17	3.2	24.50	22.75
SG1-B	3	2.25	3.19	3.19			
SG1-C	3	2.25	3.19	3.19			
SG1-D	3	1.5	3.13	3.13			
SG2-A	5	6	5.50	5.50	5.5	25.00	24.50
SG2-B	5	6.25	5.52	5.52			
SG2-C	5	6.5	5.54	5.54			
SG2-D	5	5.5	5.46	5.46			
SG3-A	8	0	8.00	8.00	8.0	24.00	23.75
SG3-B	8	0.5	8.04	8.04			
SG3-C	8	0.5	8.04	8.04			
SG3-D	7	11.5	7.96	7.96			
SG4-A	10	6.5	10.54	10.54	10.5	23.75	24.00
SG4-B	10	5.75	10.48	10.48			
SG4-C	10	6	10.50	10.50			
SG4-D	10	6.75	10.56	10.56			
SG5-A	13	0	13.00	13.00	13.0	24.25	24.00
SG5-B	13	0	13.00	13.00			
SG5-C	13	0	13.00	13.00			
SG5-D	12	11.5	12.96	12.96			
SG6-A	15	6.25	15.52	15.52	15.5	24.25	23.75
SG6-B	15	6.25	15.52	15.52			
SG6-C	15	6	15.50	15.50			
SG6-D	15	5.25	15.44	15.44			
Geo-1	1.5	0	1.50	1.50			
Geo-2	10	10	10.83	10.83			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	643.2	38.1
Bottom Cell	644.4	38.8
Top Cell	645.5	38.9
SG1	647.5	39.5
SG2	649.9	39.6
SG3	652.4	42.4
SG4	654.9	38.3
SG5	657.3	39.4
SG6	659.8	36.0
Top	664.0	36.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	643.2	38.1

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F1

TS-F2 (Rim Cell)

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	36.5
Diam. Uncased (in)	36.0
TPC Elev. (ft)	663.92
TTC Elev. (ft)	663.24
TOC Elev. (ft)	663.69
Ground Elev. (ft)	661.35
BPC Elev. (ft)	663.92
BTC Elev. (ft)	663.24
BOS Elev. (ft)	640.80
Grout elev. (ft)	

O-Cell Information

Serial #	RIM Cell
Diameter (in)	24
Capacity-rated (kips)	
Capacity-max (kips)	
Top plate diameter (in)	24.0
Top plate thickness (in)	
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	0.00
O-cell elevation (ft)	641.80

Reinforcing Steel Information

Bar size	#14
# bars	9
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	22.50
Top Elev. (ft)	663.48
Bottom Elev. (ft)	640.98

Temporary Casing

OD (in)	43.0
Thickness (in)	0.250
Length (ft)	5.00

Permanent Casing

OD (in)	36.0
Thickness (in)	0.250
Length (ft)	6.00

Instrument Elevations Reference Elev. (ft): 641.8

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	2	6	2.50	644.30	644.3	24.25	24.50
SG1-B	2	6	2.50	644.30			
SG1-C	2	5.5	2.46	644.26			
SG1-D	2	6	2.50	644.30			
SG2-A	5	4.5	5.38	647.18	647.2	24.50	24.50
SG2-B	5	4.5	5.38	647.18			
SG2-C	5	4	5.33	647.13			
SG2-D	5	4	5.33	647.13			
SG3-A	8	4.75	8.40	650.20	650.2	24.50	25.00
SG3-B	8	5.25	8.44	650.24			
SG3-C	8	5	8.42	650.22			
SG3-D	8	4	8.33	650.13			
SG4-A	11	4.5	11.38	653.18	653.2	24.50	25.25
SG4-B	11	5	11.42	653.22			
SG4-C	11	4	11.33	653.13			
SG4-D	11	4.5	11.38	653.18			
SG5-A	14	5	14.42	656.22	656.2	24.75	25.00
SG5-B	14	5	14.42	656.22			
SG5-C	14	4.5	14.38	656.18			
SG5-D	14	5.5	14.46	656.26			
SG6-A	17	5	17.42	659.22	659.2	24.25	25.00
SG6-B	17	5.25	17.44	659.24			
SG6-C	17	4.5	17.38	659.18			
SG6-D	17	5	17.42	659.22			
Geo-1	3	11.5	3.96	645.76			
Geo-2	13	0	13.00	654.80			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	640.9	38.6
Bottom Cell	641.8	38.6
Top Cell	641.8	38.6
SG1	644.3	40.4
SG2	647.2	39.5
SG3	650.2	39.9
SG4	653.2	40.4
SG5	656.2	39.7
SG6	659.2	36.0
Top	663.9	36.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	640.9	38.6

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F2

TS-F3

Shaft Information

Nominal diameter (in)	60
Diam. Cased (in)	61.0
Diam. Uncased (in)	60.0
TPC Elev. (ft)	664.00
TTC Elev. (ft)	663.25
TOC Elev. (ft)	663.70
Ground Elev. (ft)	661.35
BPC Elev. (ft)	664.00
BTC Elev. (ft)	663.25
BOS Elev. (ft)	638.50
Grout elev. (ft)	

O-Cell Information

Serial #	20-6-00202
Diameter (in)	20
Capacity-rated (kips)	2251
Capacity-max (kips)	4503
Top plate diameter (in)	47.0
Top plate thickness (in)	2.00
Bot. plate diameter (in)	47.0
Bot. plate thickness (in)	2.00
O-cell elevation (ft)	639.07

Reinforcing Steel Information

Bar size	#11
# bars	13
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	52
Cage length (ft)	24.50
Top Elev. (ft)	663.40
Bottom Elev. (ft)	638.90

Temporary Casing

OD (in)	65.8
Thickness (in)	0.500
Length (ft)	5.04

Permanent Casing

OD (in)	61.0
Thickness (in)	0.500
Length (ft)	5.83

Instrument Elevations Reference Elev. (ft): 638.9

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	2	4.5	2.38	641.28	641.2		
SG1-B	2	3.5	2.29	641.19			
SG1-C	2	4	2.33	641.23			
SG1-D	2	4.5	2.38	641.28			
SG2-A	4	3	4.25	643.15	643.1		
SG2-B	4	1.5	4.13	643.03			
SG2-C	4	3	4.25	643.15			
SG2-D	4	4	4.33	643.23			
SG3-A	6	3.5	6.29	645.19	645.2		
SG3-B	6	2	6.17	645.07			
SG3-C	6	3	6.25	645.15			
SG3-D	6	3.5	6.29	645.19			
SG4-A	10	9.5	10.79	649.69	649.7		
SG4-B	10	8.5	10.71	649.61			
SG4-C	10	8.5	10.71	649.61			
SG4-D	10	10	10.83	649.73			
SG5-A	14	9.5	14.79	653.69	653.7		
SG5-B	14	8.5	14.71	653.61			
SG5-C	14	9	14.75	653.65			
SG5-D	14	9.5	14.79	653.69			
SG6-A	18	10	18.83	657.73	657.7		
SG6-B	18	9	18.75	657.65			
SG6-C	18	9	18.75	657.65			
SG6-D	18	9.5	18.79	657.69			
Geo-1	2	10.5	2.88	641.78			
Geo-2	11	9.5	11.79	650.69			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	638.5	62.2
Bottom Cell	639.1	62.2
Top Cell	640.2	62.2
SG1	641.2	62.3
SG2	643.1	62.5
SG3	645.2	63.0
SG4	649.7	65.0
SG5	653.7	64.7
SG6	657.7	63.3
Top	664.0	61.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	638.5	62.2

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F3

TS-F4

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	36.8
Diam. Uncased (in)	36.0
TPC Elev. (ft)	664.04
TTC Elev. (ft)	663.25
TOC Elev. (ft)	663.80
Ground Elev. (ft)	661.63
BPC Elev. (ft)	659.21
BTC Elev. (ft)	658.25
BOS Elev. (ft)	637.55
Grout elev. (ft)	

O-Cell Information

Serial #	20-6-00206
Diameter (in)	20
Capacity-rated (kips)	2251
Capacity-max (kips)	4503
Top plate diameter (in)	23.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	23.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	638.09

Reinforcing Steel Information

Bar size	#14
# bars	9
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	25.42
Top Elev. (ft)	663.43
Bottom Elev. (ft)	638.01

Temporary Casing

OD (in)	43.0
Thickness (in)	0.250
Length (ft)	5.00

Permanent Casing

OD (in)	36.5
Thickness (in)	0.375
Length (ft)	4.83

Instrument Elevations Reference Elev. (ft): 638.0

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	5	1	5.08	643.09	643.1	24.00	24.50
SG1-B	5	1.25	5.10	643.11			
SG1-C	5	0.5	5.04	643.05			
SG1-D	5	1	5.08	643.09			
SG2-A	8	1.5	8.13	646.14	646.1	24.00	24.00
SG2-B	8	0.5	8.04	646.05			
SG2-C	8	1	8.08	646.09			
SG2-D	8	1.5	8.13	646.14			
SG3-A	11	1	11.08	649.09	649.1	24.75	24.75
SG3-B	11	0.5	11.04	649.05			
SG3-C	11	1	11.08	649.09			
SG3-D	11	0	11.00	649.01			
SG4-A	14	0	14.00	652.01	652.1	24.50	24.00
SG4-B	14	1	14.08	652.09			
SG4-C	14	1	14.08	652.09			
SG4-D	14	1.25	14.10	652.11			
SG5-A	17	0	17.00	655.01	655.1	24.00	24.75
SG5-B	17	1	17.08	655.09			
SG5-C	17	0.5	17.04	655.05			
SG5-D	17	1.25	17.10	655.11			
SG6-A	20	1	20.08	658.09	658.1	24.25	24.25
SG6-B	20	1.5	20.13	658.14			
SG6-C	20	1.5	20.13	658.14			
SG6-D	20	1	20.08	658.09			
Geo-1	4	5	4.42	642.43			
Geo-2	14	8.5	14.71	652.72			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	637.6	39.5
Bottom Cell	638.1	39.4
Top Cell	639.2	39.4
SG1	643.1	39.6
SG2	646.1	39.4
SG3	649.1	39.3
SG4	652.1	39.6
SG5	655.1	39.3
SG6	658.1	42.0
Top	664.0	36.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	637.6	39.5

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F4

TS-F5

Shaft Information

Nominal diameter (in)	60
Diam. Cased (in)	61.5
Diam. Uncased (in)	60.0
TPC Elev. (ft)	664.00
TTC Elev. (ft)	663.25
TOC Elev. (ft)	663.70
Ground Elev. (ft)	661.80
BPC Elev. (ft)	657.17
BTC Elev. (ft)	658.21
BOS Elev. (ft)	630.08
Grout elev. (ft)	

O-Cell Information

Serial #	26-6-00161
Diameter (in)	26
Capacity-rated (kips)	3845
Capacity-max (kips)	7691
Top plate diameter (in)	47.0
Top plate thickness (in)	2.00
Bot. plate diameter (in)	47.0
Bot. plate thickness (in)	2.00
O-cell elevation (ft)	632.58

Reinforcing Steel Information

Bar size	#11
# bars	13
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	52
Cage length (ft)	31.17
Top Elev. (ft)	663.58
Bottom Elev. (ft)	632.41

Temporary Casing

OD (in)	65.8
Thickness (in)	0.500
Length (ft)	5.04

Permanent Casing

OD (in)	61.5
Thickness (in)	0.750
Length (ft)	6.83

Instrument Elevations Reference Elev. (ft): 632.4

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A		69.25	5.77	638.18	638.2	48.00	47.75
SG1-B		70.25	5.85	638.26			
SG1-C		70.25	5.85	638.26			
SG1-D		69.5	5.79	638.20			
SG2-A		117.25	9.77	642.18	642.2	48.00	48.00
SG2-B		117.25	9.77	642.18			
SG2-C		118	9.83	642.24			
SG2-D		116.5	9.71	642.12			
SG3-A		165.5	13.79	646.20	646.2	48.50	48.00
SG3-B		166	13.83	646.24			
SG3-C		167.25	13.94	646.35			
SG3-D		165.5	13.79	646.20			
SG4-A		219.25	18.27	650.68	650.7	48.25	48.00
SG4-B		220.25	18.35	650.76			
SG4-C		220.5	18.38	650.79			
SG4-D		219.5	18.29	650.70			
SG5-A		273.75	22.81	655.22	655.2	48.00	48.00
SG5-B		274.5	22.88	655.29			
SG5-C		274.75	22.90	655.31			
SG5-D		273.25	22.77	655.18			
SG6-A		326.75	27.23	659.64	659.7	48.50	48.75
SG6-B		327	27.25	659.66			
SG6-C		327.25	27.27	659.68			
SG6-D		327	27.25	659.66			
Geo-1		24	2.00	634.41			
Geo-2		187	15.58	647.99			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	630.1	61.1
Bottom Cell	632.6	61.1
Top Cell	633.7	61.1
SG1	638.2	61.7
SG2	642.2	61.3
SG3	646.2	61.4
SG4	650.7	61.9
SG5	655.2	62.5
SG6	659.7	61.5
Top	664.0	61.5

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	630.1	61.1

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F5

TS-F6

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	36.8
Diam. Uncased (in)	36.0
TPC Elev. (ft)	664.02
TTC Elev. (ft)	663.26
TOC Elev. (ft)	663.88
Ground Elev. (ft)	661.69
BPC Elev. (ft)	658.31
BTC Elev. (ft)	658.26
BOS Elev. (ft)	636.55
Grout elev. (ft)	

O-Cell Information

Serial #	20-6-00207
Diameter (in)	20
Capacity-rated (kips)	2251
Capacity-max (kips)	4503
Top plate diameter (in)	23.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	23.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	637.04

Reinforcing Steel Information

Bar size	#14
# bars	9
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	26.42
Top Elev. (ft)	663.38
Bottom Elev. (ft)	636.96

Temporary Casing

OD (in)	43.0
Thickness (in)	0.250
Length (ft)	5.00

Permanent Casing

OD (in)	36.8
Thickness (in)	0.375
Length (ft)	5.71

Instrument Elevations Reference Elev. (ft): 637.0

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	5	0.5	5.04	642.00	642.0	24.75	23.50
SG1-B	5	0	5.00	641.96			
SG1-C	5	0	5.00	641.96			
SG1-D	5	0.5	5.04	642.00			
SG2-A	8	1	8.08	645.04	645.0	24.75	23.25
SG2-B	8	0.5	8.04	645.00			
SG2-C	7	11.75	7.98	644.94			
SG2-D	8	0.5	8.04	645.00			
SG3-A	11	1	11.08	648.04	648.0	24.75	23.00
SG3-B	11	1	11.08	648.04			
SG3-C	10	11.5	10.96	647.92			
SG3-D	11	0.5	11.04	648.00			
SG4-A	14	1	14.08	651.04	651.0	24.75	23.25
SG4-B	14	1	14.08	651.04			
SG4-C	14	1	14.08	651.04			
SG4-D	14	1	14.08	651.04			
SG5-A	17	1	17.08	654.04	654.0	24.50	23.25
SG5-B	17	1	17.08	654.04			
SG5-C	17	1	17.08	654.04			
SG5-D	17	1	17.08	654.04			
SG6-A	20	1	20.08	657.04	657.0	24.00	23.75
SG6-B	20	1	20.08	657.04			
SG6-C	20	0.75	20.06	657.02			
SG6-D	20	0.75	20.06	657.02			
Geo-1		46.5	3.88	640.84			
Geo-2	14	11	14.92	651.88			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	636.6	38.7
Bottom Cell	637.0	38.7
Top Cell	638.1	38.7
SG1	642.0	38.1
SG2	645.0	38.5
SG3	648.0	37.9
SG4	651.0	38.6
SG5	654.0	38.5
SG6	657.0	38.9
Top	664.0	36.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	636.6	38.7

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F6

TS-F7

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	36.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	664.00
TTC Elev. (ft)	663.25
TOC Elev. (ft)	663.79
Ground Elev. (ft)	661.87
BPC Elev. (ft)	664.00
BTC Elev. (ft)	663.25
BOS Elev. (ft)	629.25
Grout elev. (ft)	

O-Cell Information

Serial #	20-6-00203
Diameter (in)	20
Capacity-rated (kips)	2251
Capacity-max (kips)	4503
Top plate diameter (in)	23.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	23.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	634.00

Reinforcing Steel Information

Bar size	#11
# bars	13
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	29.58
Top Elev. (ft)	663.50
Bottom Elev. (ft)	633.92

Temporary Casing

OD (in)	43.0
Thickness (in)	0.250
Length (ft)	5.00

Permanent Casing

OD (in)	36.0
Thickness (in)	0.500
Length (ft)	6.00

Instrument Elevations Reference Elev. (ft): 633.9

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	3	7	3.58	637.50	637.5	24.25	25.50
SG1-B	3	7	3.58	637.50			
SG1-C	3	7	3.58	637.50			
SG1-D	3	7	3.58	637.50			
SG2-A	7	2	7.17	641.09	641.1	25.50	25.00
SG2-B	7	2	7.17	641.09			
SG2-C	7	2.5	7.21	641.13			
SG2-D	7	1.5	7.13	641.05			
SG3-A	10	7	10.58	644.50	644.5	24.75	25.25
SG3-B	10	8.5	10.71	644.63			
SG3-C	10	7.5	10.63	644.55			
SG3-D	10	7	10.58	644.50			
SG4-A	16	1.5	16.13	650.05	650.1	24.50	25.00
SG4-B	16	2	16.17	650.09			
SG4-C	16	1.5	16.13	650.05			
SG4-D	16	1.5	16.13	650.05			
SG5-A	20	7.5	20.63	654.55	654.5	24.50	25.00
SG5-B	20	6.5	20.54	654.46			
SG5-C	20	7.5	20.63	654.55			
SG5-D	20	7	20.58	654.50			
SG6-A	25	0.5	25.04	658.96	659.0	25.00	25.25
SG6-B	25	0	25.00	658.92			
SG6-C	25	0	25.00	658.92			
SG6-D	25	1	25.08	659.00			
Geo-1	3	0	3.00	636.92			
Geo-2	15	0	15.00	648.92			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	629.3	38.4
Bottom Cell	634.0	38.1
Top Cell	635.1	38.1
SG1	637.5	38.0
SG2	641.1	37.4
SG3	644.5	38.5
SG4	650.1	38.3
SG5	654.5	38.7
SG6	659.0	36.0
Top	664.0	36.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	629.3	38.4

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F7

TS-F8

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	36.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	663.91
TTC Elev. (ft)	663.25
TOC Elev. (ft)	663.66
Ground Elev. (ft)	662.05
BPC Elev. (ft)	658.91
BTC Elev. (ft)	658.25
BOS Elev. (ft)	640.41
Grout elev. (ft)	

O-Cell Information

Serial #	Rim Cell
Diameter (in)	24
Capacity-rated (kips)	
Capacity-max (kips)	
Top plate diameter (in)	24.0
Top plate thickness (in)	
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	
O-cell elevation (ft)	641.27

Reinforcing Steel Information

Bar size	#14
# bars	9
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	23.00
Top Elev. (ft)	663.45
Bottom Elev. (ft)	640.45

Temporary Casing

OD (in)	43.0
Thickness (in)	0.250
Length (ft)	5.00

Permanent Casing

OD (in)	36.3
Thickness (in)	0.375
Length (ft)	5.00

Instrument Elevations Reference Elev. (ft): 641.3

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	2	11.5	2.96	644.23	644.2	25.50	24.00
SG1-B	3	0	3.00	644.27			
SG1-C	3	0	3.00	644.27			
SG1-D	2	11.5	2.96	644.23			
SG2-A	5	11.5	5.96	647.23	647.2	25.00	24.00
SG2-B	5	11.5	5.96	647.23			
SG2-C	5	11.5	5.96	647.23			
SG2-D	5	11.5	5.96	647.23			
SG3-A	8	10.5	8.88	650.15	650.1	25.25	24.00
SG3-B	8	10.5	8.88	650.15			
SG3-C	8	10.5	8.88	650.15			
SG3-D	8	10.5	8.88	650.15			
SG4-A	11	11	11.92	653.19	653.1	25.00	24.50
SG4-B	11	11	11.92	653.19			
SG4-C	11	9.5	11.79	653.06			
SG4-D	11	9.5	11.79	653.06			
SG5-A	14	11.5	14.96	656.23	656.2	24.75	24.00
SG5-B	15	0	15.00	656.27			
SG5-C	14	11.5	14.96	656.23			
SG5-D	14	10.75	14.90	656.17			
SG6-A	17	11	17.92	659.19	659.2	24.50	24.00
SG6-B	17	11	17.92	659.19			
SG6-C	17	11	17.92	659.19			
SG6-D	17	11	17.92	659.19			
Geo-1	2	2	2.17	643.44			
Geo-2	12	4.5	12.38	653.65			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	640.4	40.6
Bottom Cell	641.3	40.8
Top Cell	641.3	40.8
SG1	644.2	40.2
SG2	647.2	40.5
SG3	650.1	40.7
SG4	653.1	40.0
SG5	656.2	39.9
SG6	659.2	36.0
Top	663.9	36.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	640.4	40.6

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F8

TS-F9

Shaft Information

Nominal diameter (in)	60
Diam. Cased (in)	61.0
Diam. Uncased (in)	60.0
TPC Elev. (ft)	664.00
TTC Elev. (ft)	663.50
TOC Elev. (ft)	663.70
Ground Elev. (ft)	662.20
BPC Elev. (ft)	657.17
BTC Elev. (ft)	658.46
BOS Elev. (ft)	647.00
Grout elev. (ft)	

O-Cell Information

Serial #	16-6-00261
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	48.0
Top plate thickness (in)	2.00
Bot. plate diameter (in)	48.0
Bot. plate thickness (in)	2.00
O-cell elevation (ft)	647.72

Reinforcing Steel Information

Bar size	#11
# bars	13
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	52
Cage length (ft)	15.95
Top Elev. (ft)	663.50
Bottom Elev. (ft)	647.55

Temporary Casing

OD (in)	65.8
Thickness (in)	0.500
Length (ft)	5.04

Permanent Casing

OD (in)	61.5
Thickness (in)	0.750
Length (ft)	6.83

Instrument Elevations Reference Elev. (ft): 647.6

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A		38.25	3.19	650.74	650.8		
SG1-B		38.25	3.19	650.74			
SG1-C		39.25	3.27	650.82			
SG1-D		38.5	3.21	650.76			
SG2-A		55.5	4.63	652.18	652.2		
SG2-B		56.5	4.71	652.26			
SG2-C		57	4.75	652.30			
SG2-D		56.5	4.71	652.26			
SG3-A		73.75	6.15	653.70	653.8		
SG3-B		74	6.17	653.72			
SG3-C		75.75	6.31	653.86			
SG3-D		74.25	6.19	653.74			
SG4-A		110.5	9.21	656.76	656.8		
SG4-B		110.25	9.19	656.74			
SG4-C		111.5	9.29	656.84			
SG4-D		110.5	9.21	656.76			
SG5-A		146.5	12.21	659.76	659.8		
SG5-B		147.25	12.27	659.82			
SG5-C		146.75	12.23	659.78			
SG5-D		146	12.17	659.72			
SG6-A		163.75	13.65	661.20	661.2		
SG6-B		163.5	13.63	661.18			
SG6-C		165.5	13.79	661.34			
SG6-D		164.25	13.69	661.24			
Geo-1		27	2.25	649.80			
Geo-2		105.75	8.81	656.36			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	647.0	63.0
Bottom Cell	647.7	63.0
Top Cell	648.8	63.3
SG1	650.8	63.5
SG2	652.2	63.2
SG3	653.8	63.1
SG4	656.8	63.0
SG5	659.8	60.0
SG6	661.2	60.0
Top	664.0	60.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	647.0	63.0

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F9

TS-F10

Shaft Information

Nominal diameter (in)	60
Diam. Cased (in)	61.5
Diam. Uncased (in)	60.0
TPC Elev. (ft)	664.00
TTC Elev. (ft)	663.25
TOC Elev. (ft)	663.80
Ground Elev. (ft)	662.27
BPC Elev. (ft)	657.17
BTC Elev. (ft)	658.21
BOS Elev. (ft)	645.18
Grout elev. (ft)	

O-Cell Information

Serial #	16-6-00268
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	46.5
Top plate thickness (in)	2.00
Bot. plate diameter (in)	42.0
Bot. plate thickness (in)	2.00
O-cell elevation (ft)	645.78

Reinforcing Steel Information

Bar size	#14
# bars	9
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	52
Cage length (ft)	17.83
Top Elev. (ft)	663.44
Bottom Elev. (ft)	645.61

Temporary Casing

OD (in)	65.8
Thickness (in)	0.500
Length (ft)	5.04

Permanent Casing

OD (in)	61.5
Thickness (in)	0.750
Length (ft)	6.83

Instrument Elevations Reference Elev. (ft): 645.6

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	4	2	4.17	649.78	649.8	48.50	47.00
SG1-B	4	1	4.08	649.69			
SG1-C	4	2.75	4.23	649.84			
SG1-D	4	3	4.25	649.86			
SG2-A	6	3.25	6.27	651.88	651.8	48.00	47.25
SG2-B	6	3.25	6.27	651.88			
SG2-C	6	1	6.08	651.69			
SG2-D	6	3.75	6.31	651.92			
SG3-A	8	5	8.42	654.03	654.0	48.50	46.75
SG3-B	8	6	8.50	654.11			
SG3-C	8	2	8.17	653.78			
SG3-D	8	4.25	8.35	653.96			
SG4-A	10	5	10.42	656.03	656.0	48.25	47.50
SG4-B	10	4.5	10.38	655.99			
SG4-C	10	2.25	10.19	655.80			
SG4-D	10	4.75	10.40	656.01			
SG5-A	12	4	12.33	657.94	657.8	48.00	47.00
SG5-B	12	2.25	12.19	657.80			
SG5-C	12	0	12.00	657.61			
SG5-D	12	4.25	12.35	657.96			
SG6-A	14	3.25	14.27	659.88	659.8	48.25	47.25
SG6-B	14	4	14.33	659.94			
SG6-C	14	0.75	14.06	659.67			
SG6-D	14	3.5	14.29	659.90			
Geo-1	2	7.5	2.63	648.24			
Geo-2	10	10.5	10.88	656.49			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	645.2	58.5
Bottom Cell	645.8	59.5
Top Cell	647.0	60.6
SG1	649.8	60.9
SG2	651.8	60.2
SG3	654.0	60.8
SG4	656.0	60.0
SG5	657.8	60.0
SG6	659.8	60.0
Top	664.0	60.0

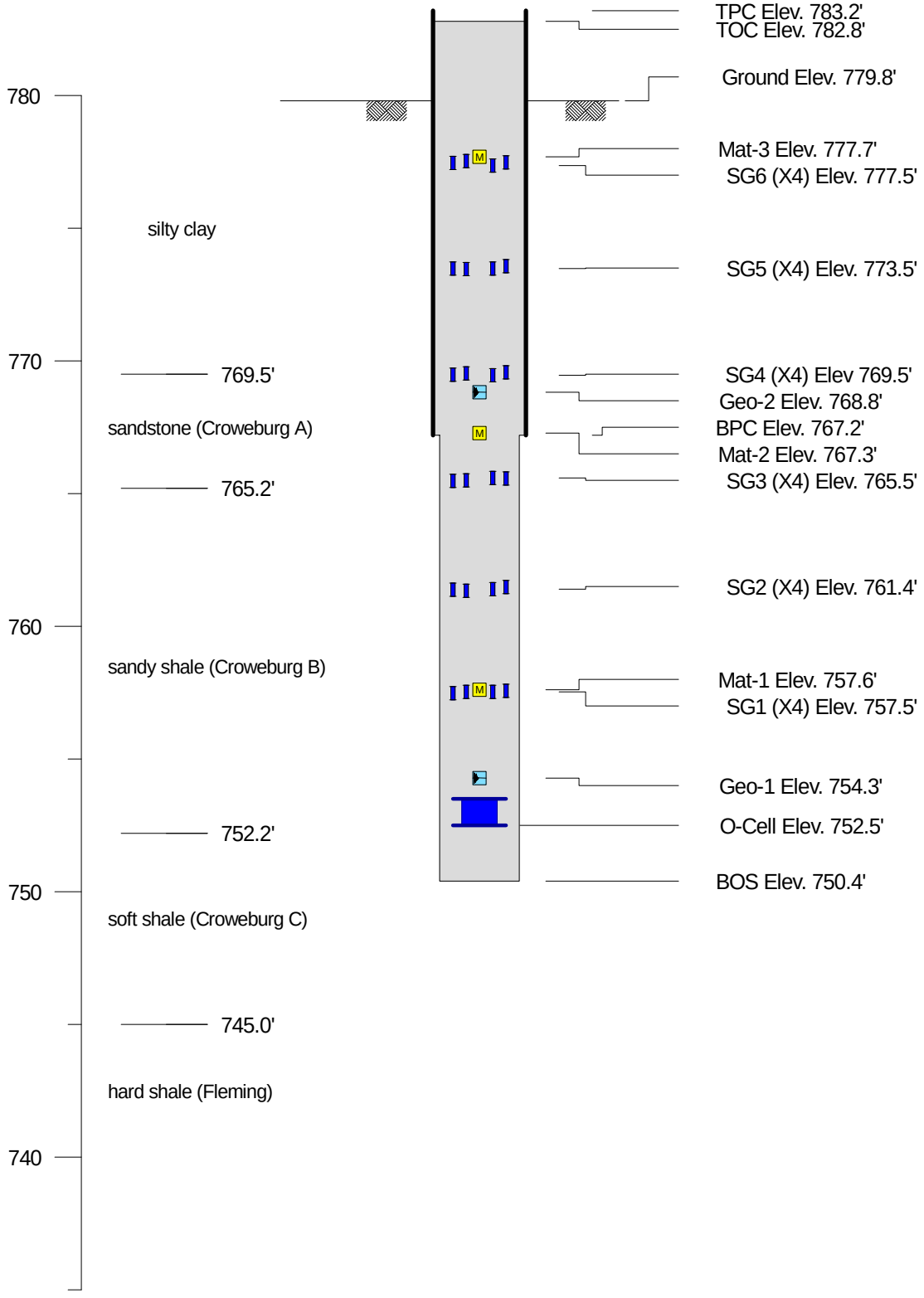
Presumed EB Diameter

	Elevation	Diameter (in)
Tip	645.2	58.5

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

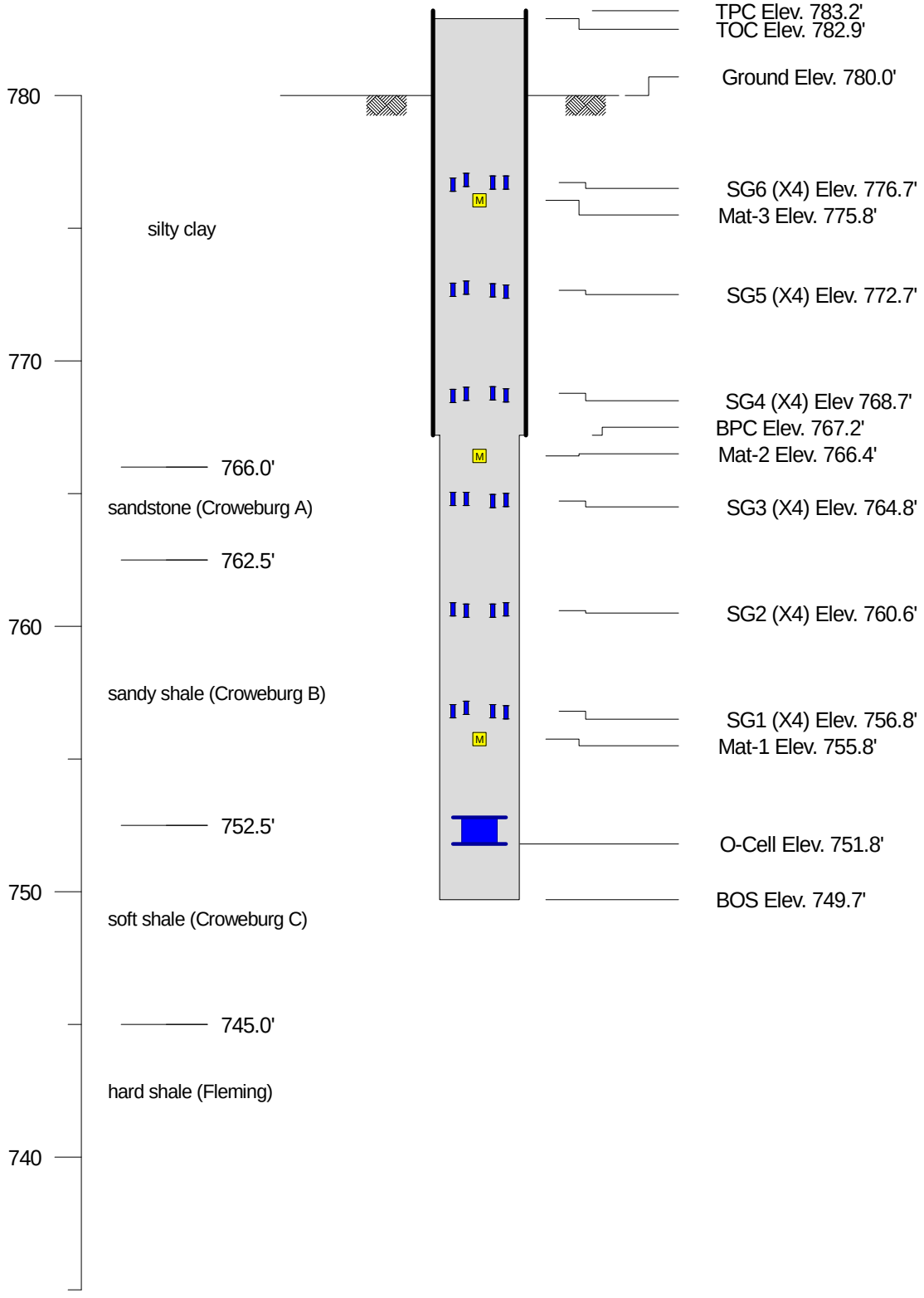
As-Built Shaft Information
Site: Frankford Load Test Site
Shaft: F10

TS-W1



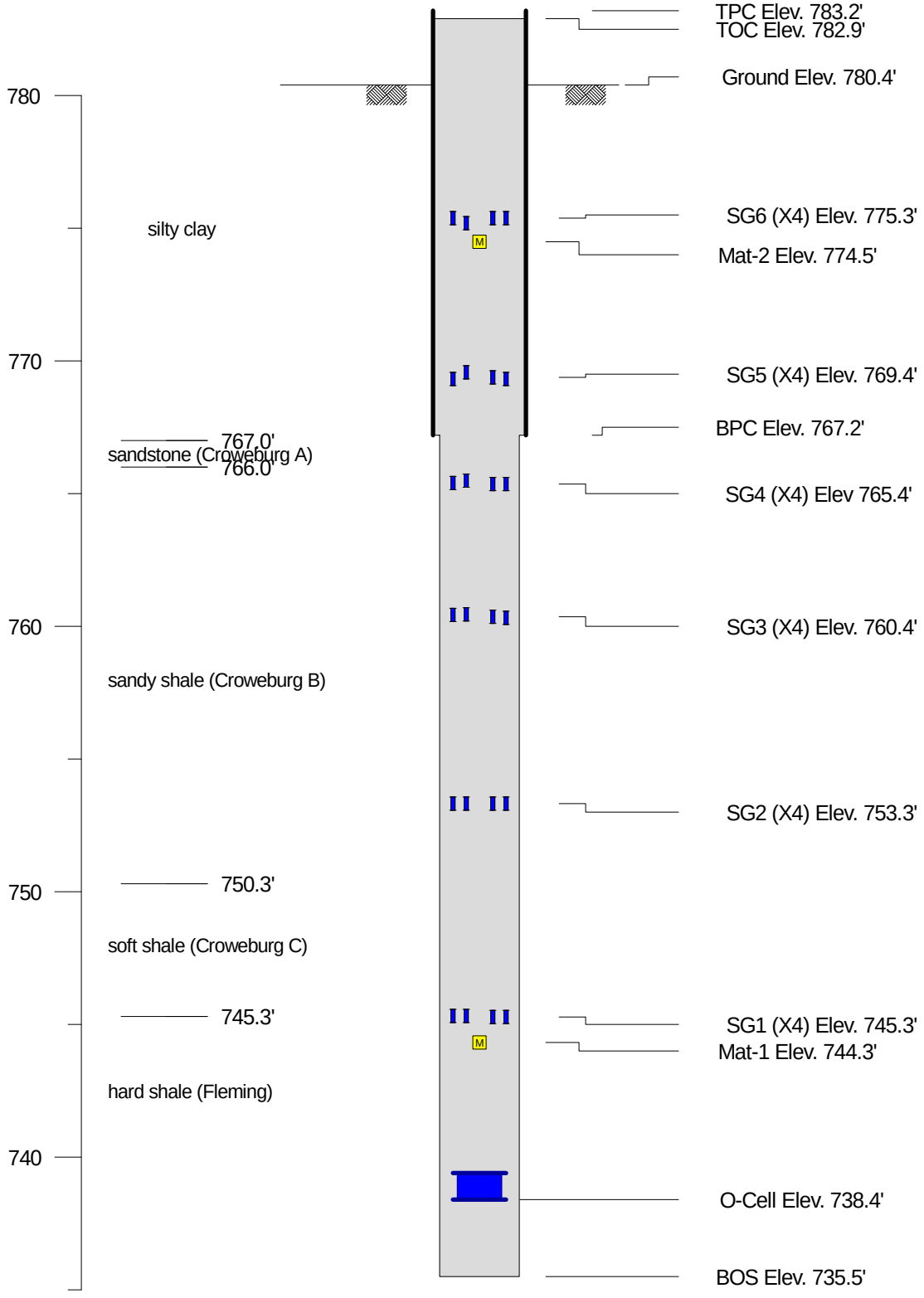
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W1 Warrensburg Load Test Site	3 2 1 0 3 6 9 12 1" = 6'
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W2



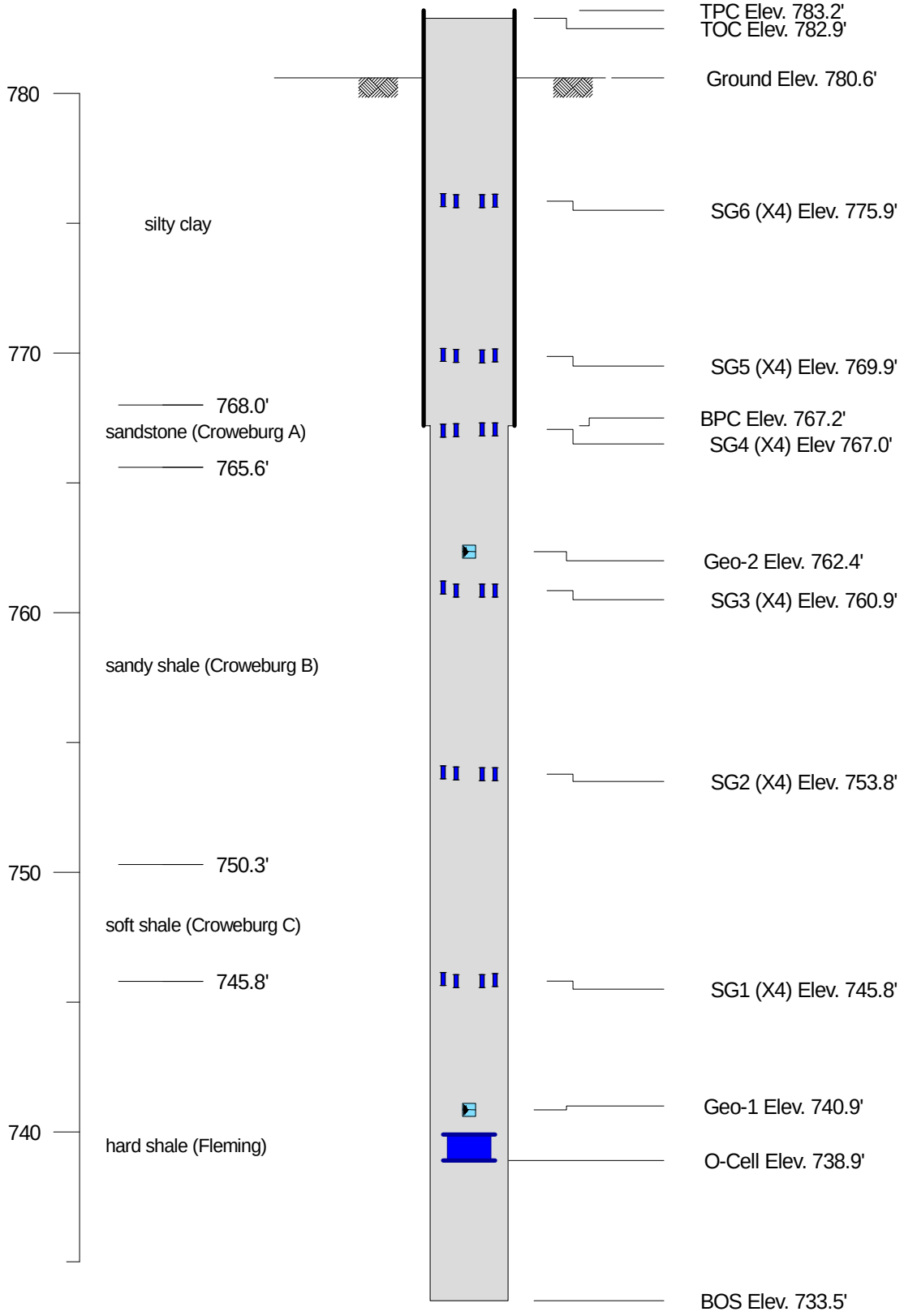
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W2 Warrensburg Load Test Site	3 2 1 0 3 6 9 12 1" = 6'
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W3



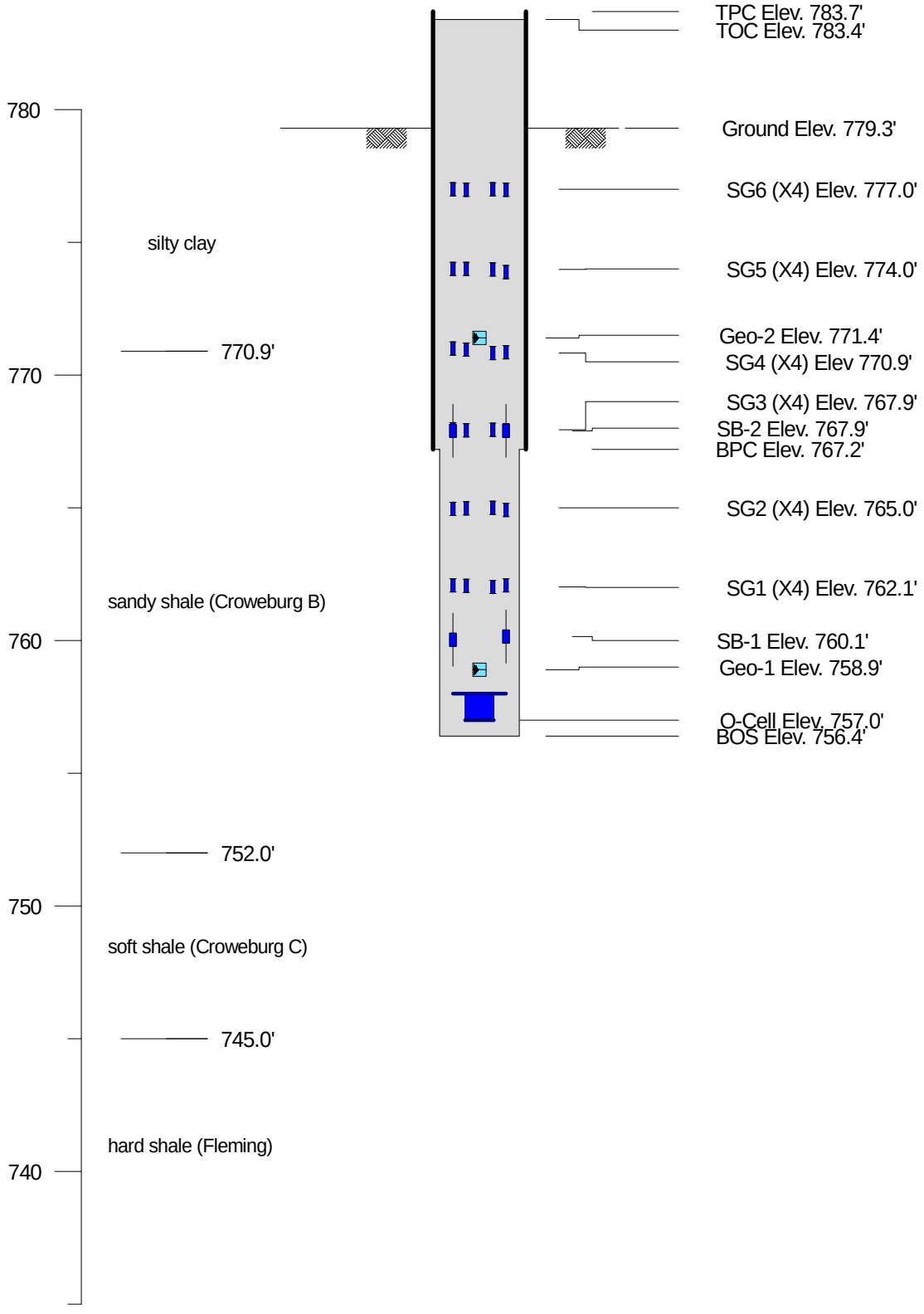
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W3 Warrensburg Load Test Site Date: Dec. 30, 2011 / Drawing 1 of 1	3 2 1 0 3 6 9 12 1" = 6'

TS-W4



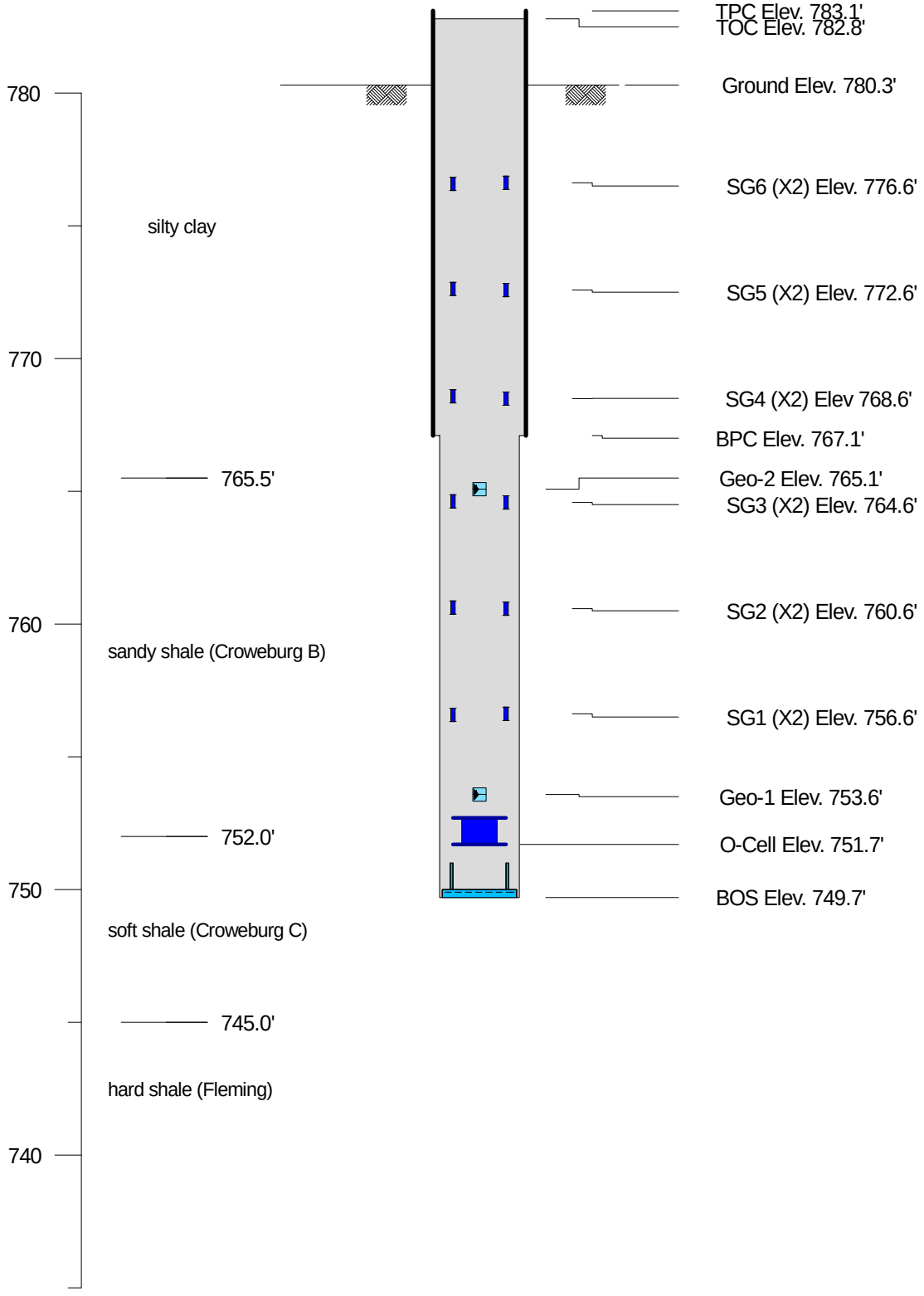
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W4 Warrensburg Load Test Site Date: Dec. 30, 2011 | Drawing 1 of 1	3 2 1 0 3 6 9 12 1" = 6'

TS-W5



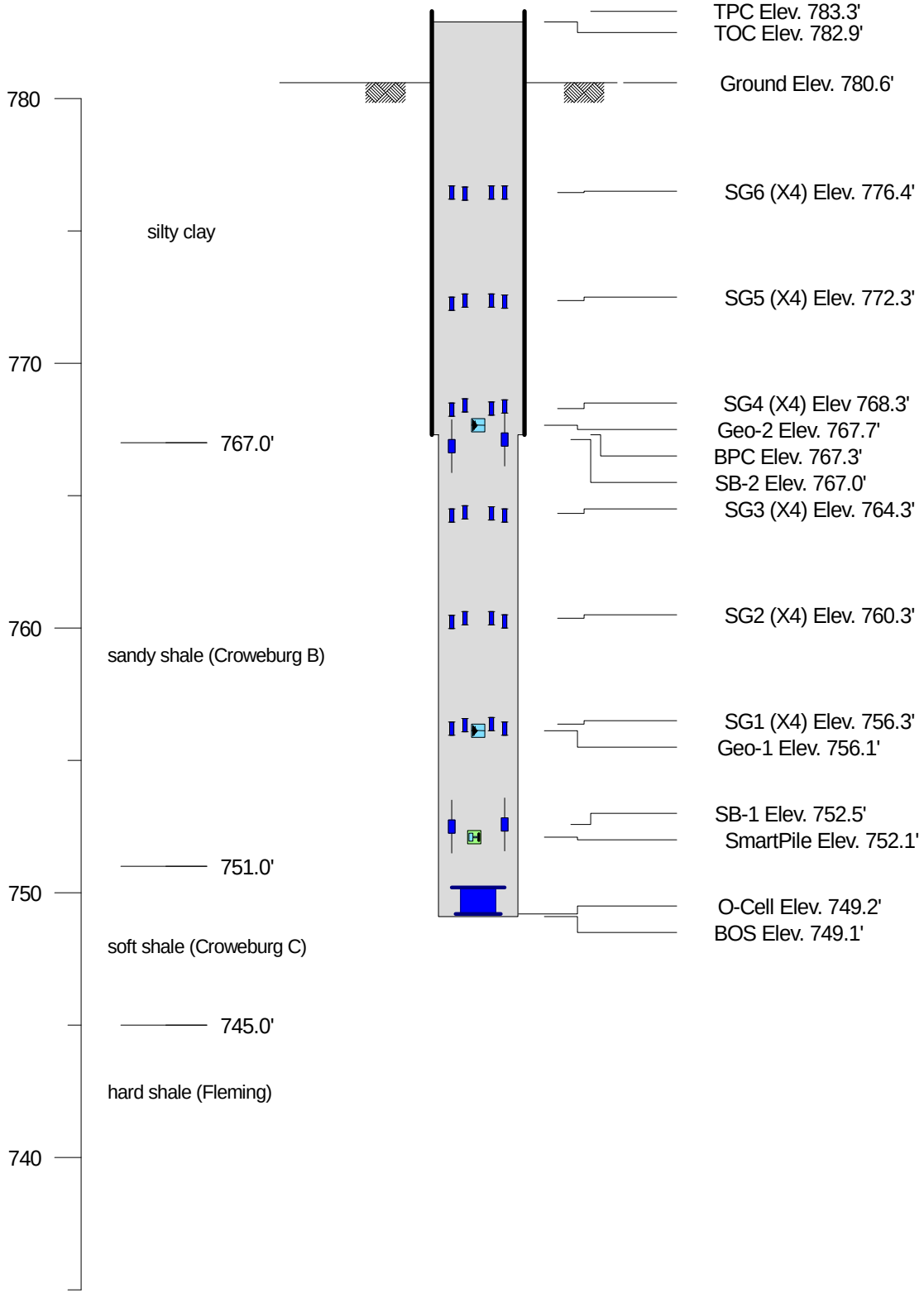
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W5 Warrensburg Load Test Site	3 2 1 0 3 6 9 12 1" = 6'
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W6



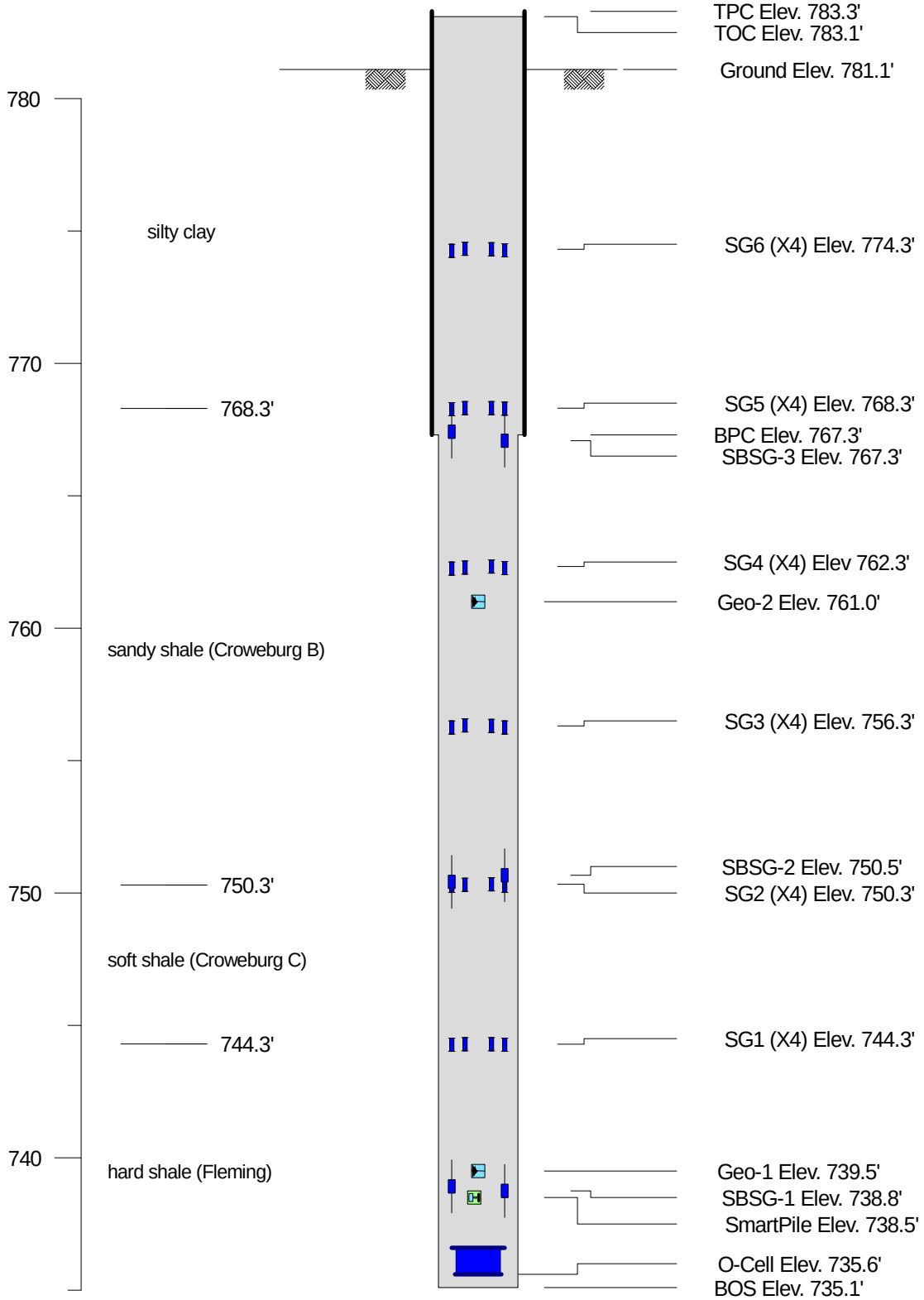
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W6 Warrensburg Load Test Site	3 2 1 0 3 6 9 12 1" = 6'
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W7



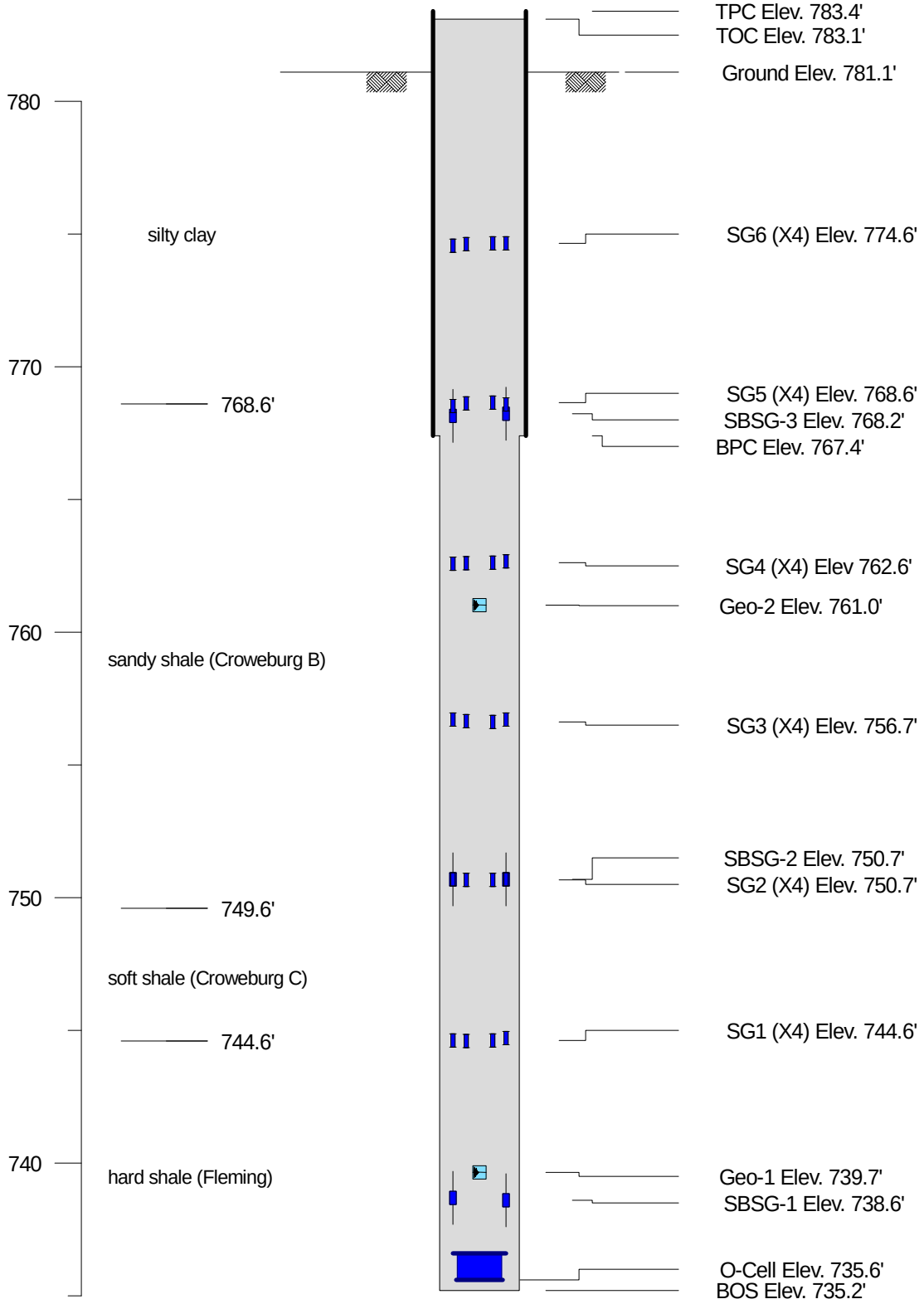
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W7 Warrensburg Load Test Site	3 2 1 0 3 6 9 12 1" = 6'
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W8



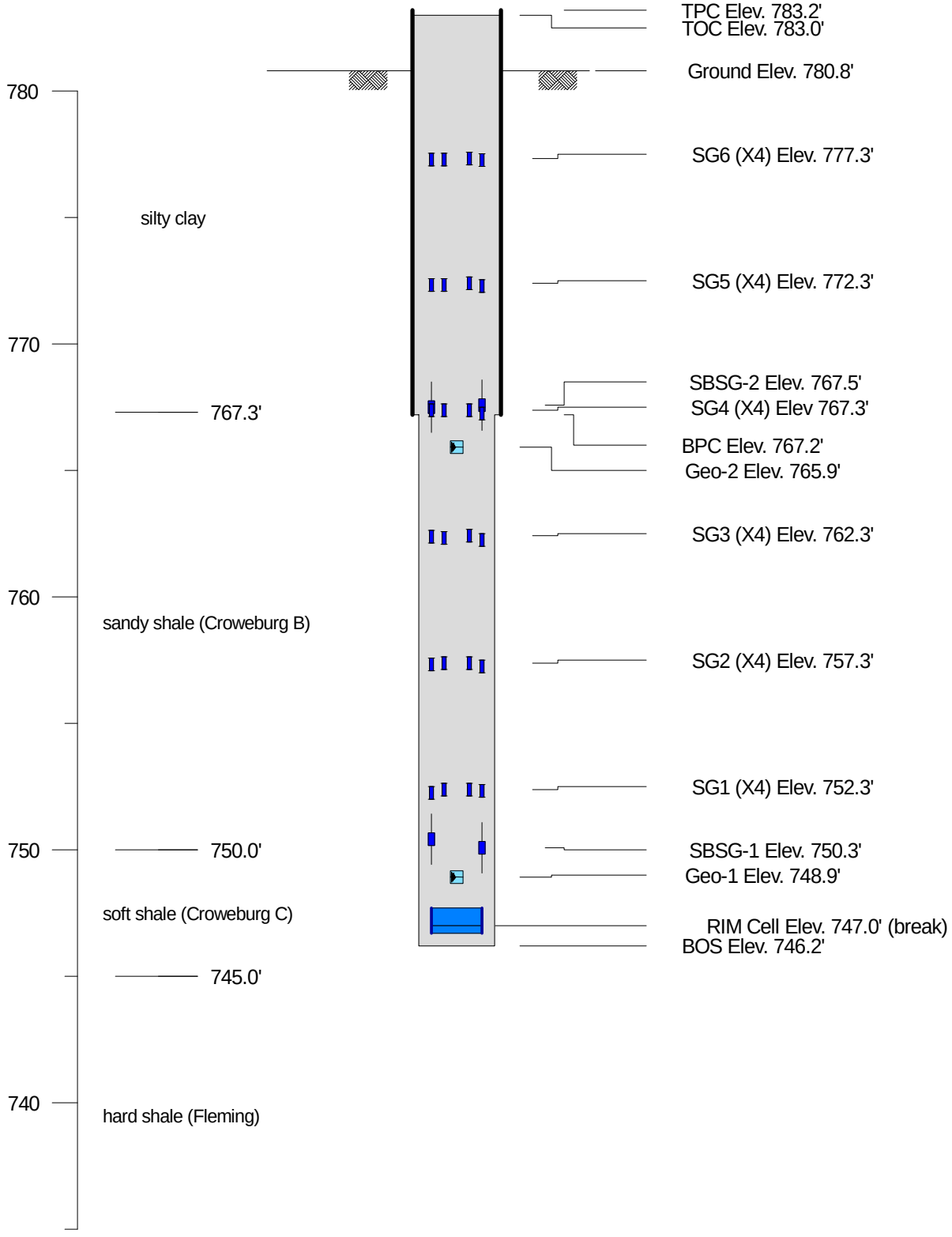
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W8 Warrensburg Load Test Site	3 2 1 0 3 6 9 12 1" = 6'
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W9



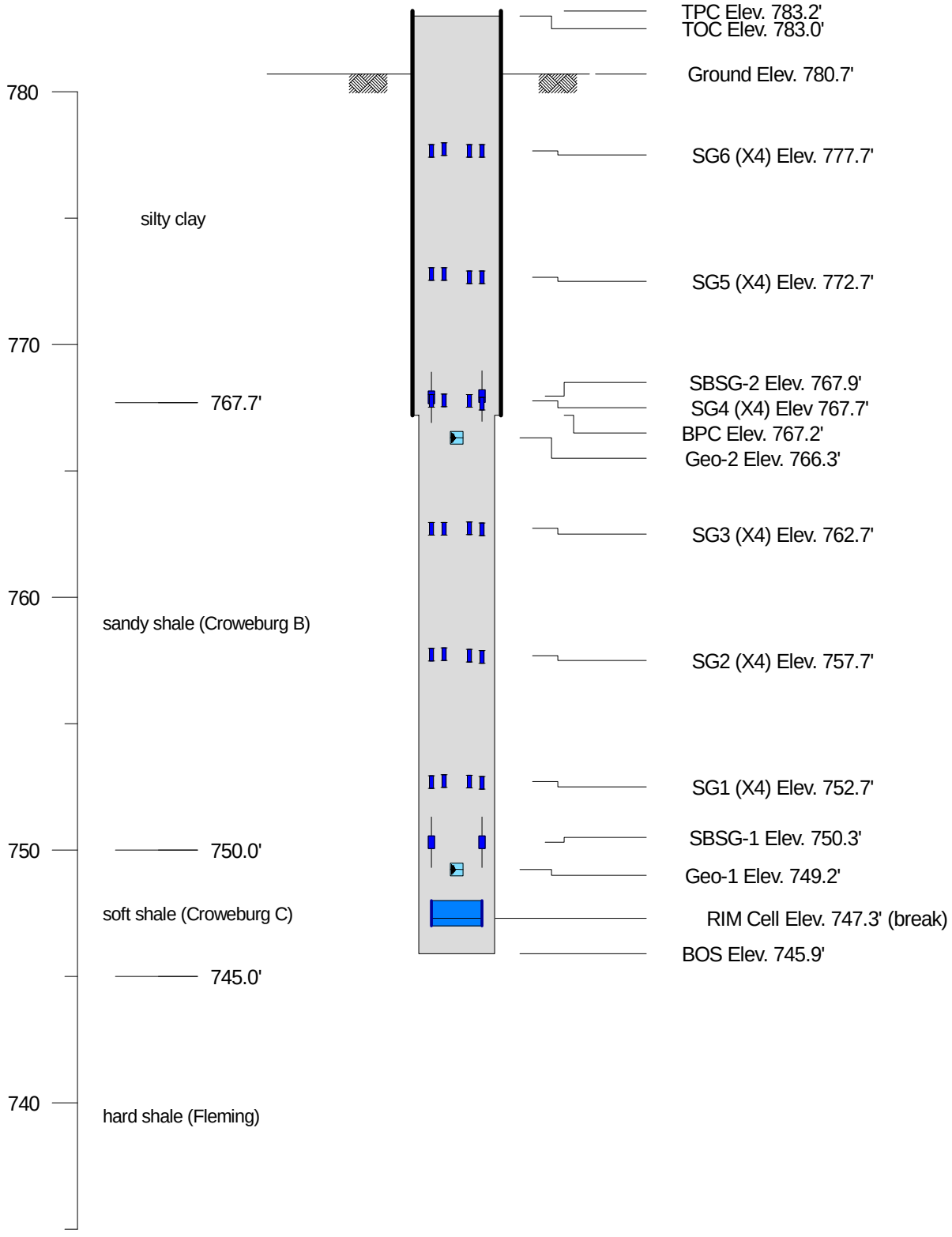
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W9 Warrensburg Load Test Site Date: Dec. 30, 2011 | Drawing 1 of 1	3 2 1 0 3 6 9 12 1" = 6'

TS-W10



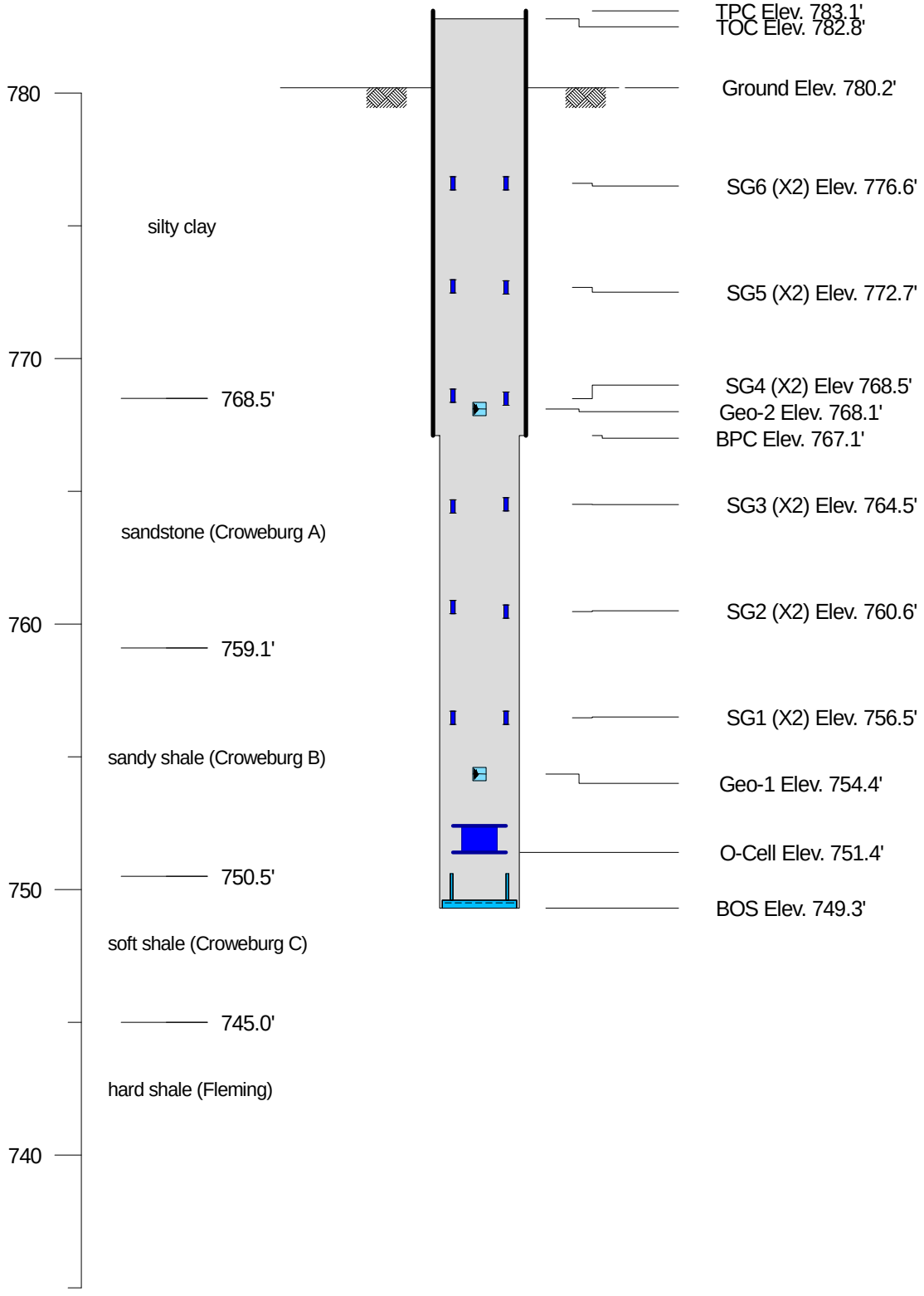
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W10 Warrensburg Load Test Site	3 2 1 0 3 6 9 12 1" = 6'
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W11



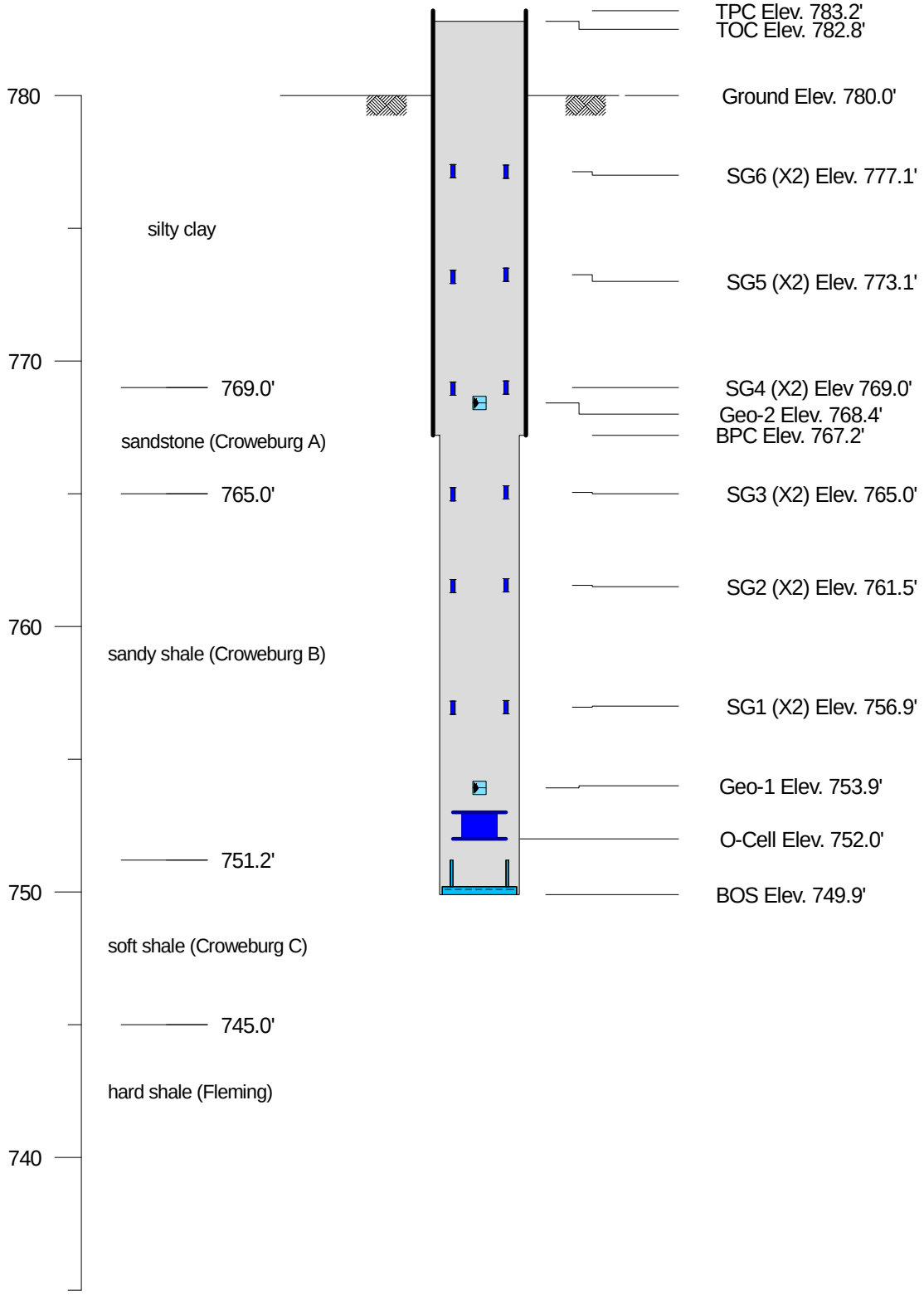
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W11 Warrensburg Load Test Site Date: Dec. 30, 2011 / Drawing 1 of 1	3 2 1 0 3 6 9 12 1" = 6'

TS-W12



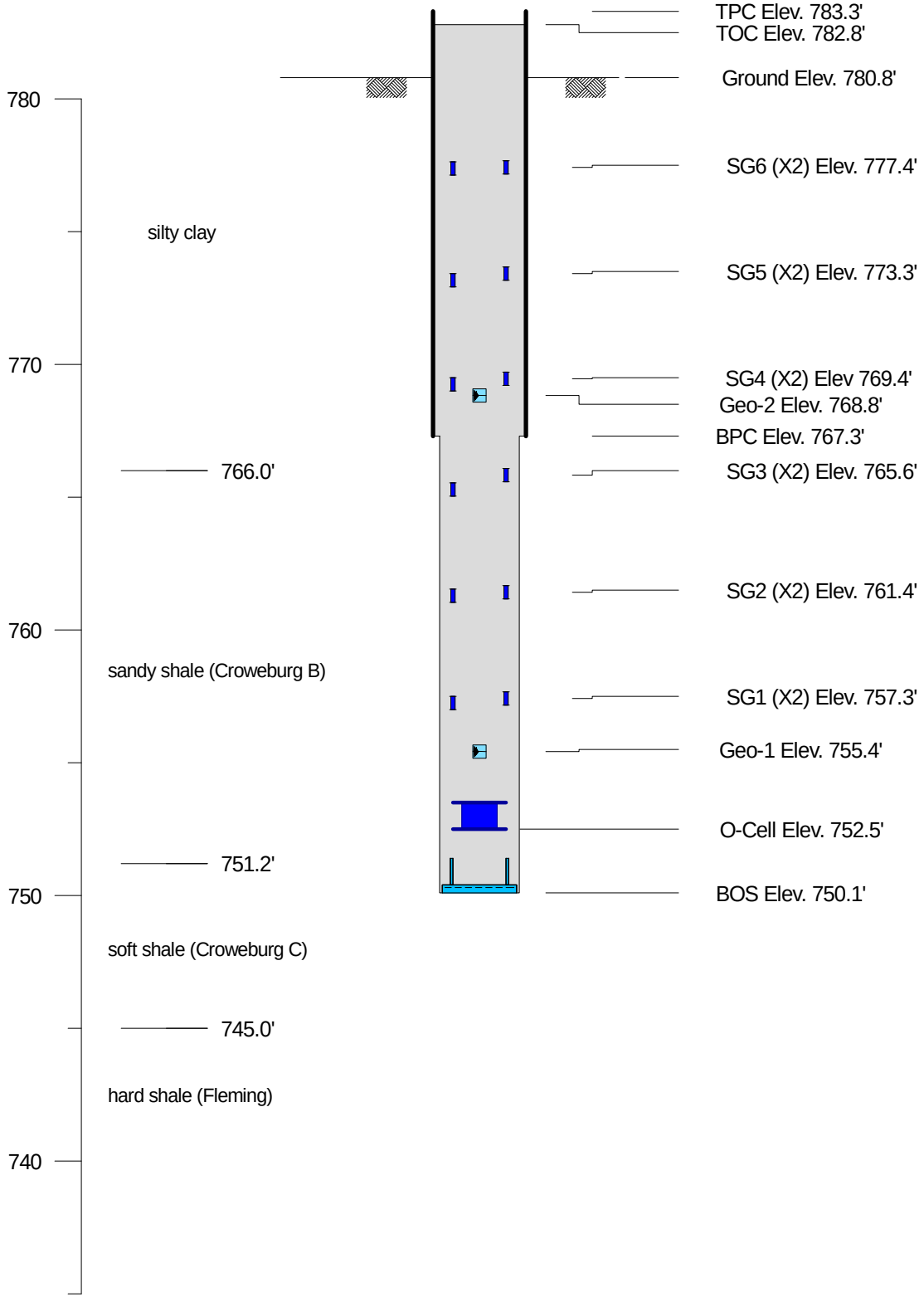
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W12	3 2 1 0 3 6 9 12 1" = 6'
	Warrensburg Load Test Site	
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W13



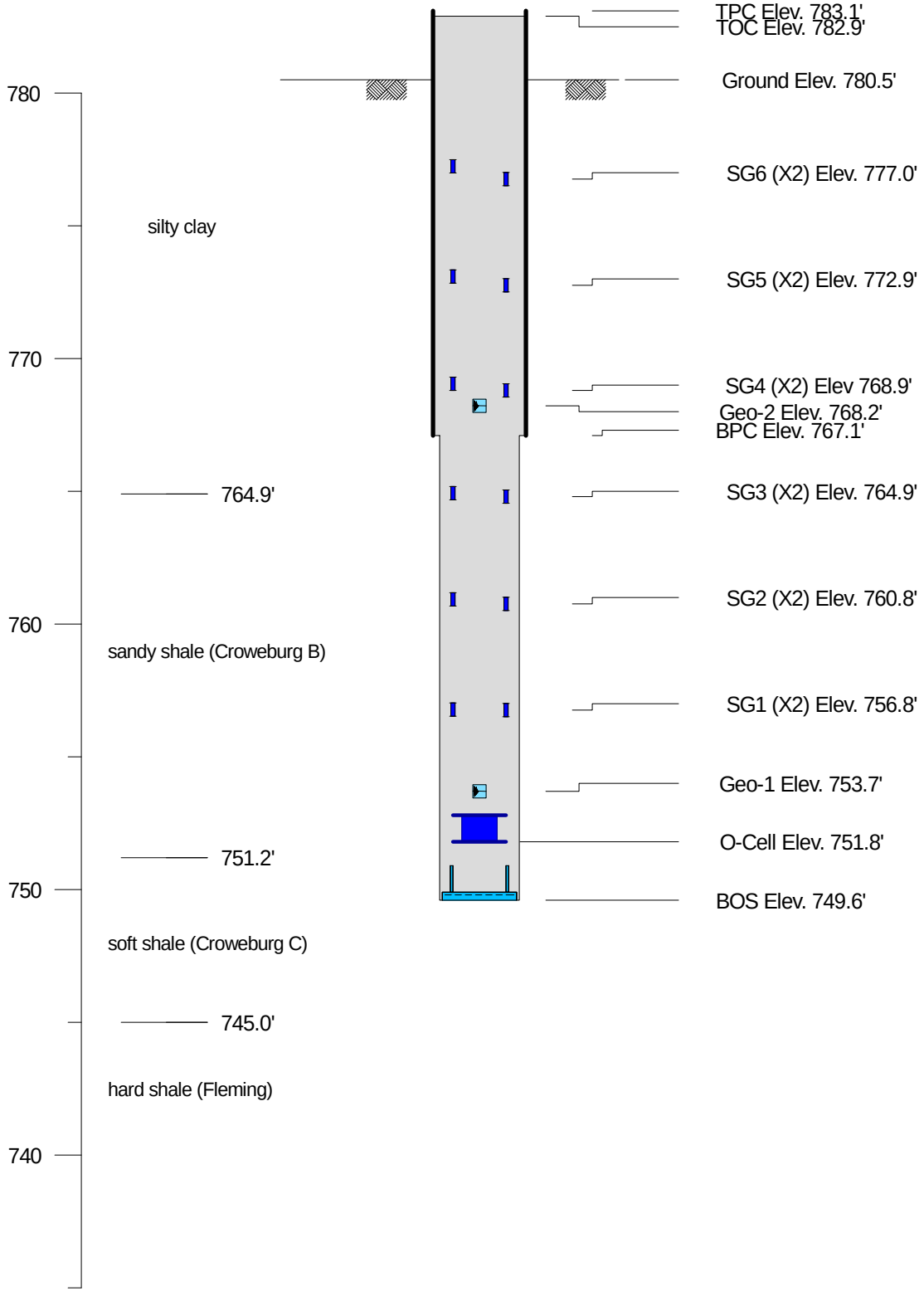
University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W13	3 2 1 0 3 6 9 12 1" = 6'
	Warrensburg Load Test Site	
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W14



University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W14 Warrensburg Load Test Site	3 2 1 0 3 6 9 12 1" = 6'
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W15



University of Missouri Civil Engineering MoDOT Transportation Geotechnics Research Program	As-built Drawing - Test Shaft TS-W15 Warrensburg Load Test Site	3 2 1 0 3 6 9 12 1" = 6'
	Date: Dec. 30, 2011 / Drawing 1 of 1	

TS-W1

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.18
TTC Elev. (ft)	
TOC Elev. (ft)	782.84
Ground Elev. (ft)	779.77
BPC Elev. (ft)	767.18
BTC Elev. (ft)	
BOS Elev. (ft)	750.38
Grout elev. (ft)	752.68

O-Cell Information

Serial #	16-6-00260
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	752.48

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	30.20
Top Elev. (ft)	782.60
Bottom Elev. (ft)	752.40

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 752.4

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	5	1	5.08	757.48	757.5	24.00	24.00
SG1-B	5	1.5	5.13	757.53			
SG1-C	5	1.5	5.13	757.53			
SG1-D	5	2	5.17	757.57			
SG2-A	8	11.75	8.98	761.38	761.4	24.25	24.00
SG2-B	8	11.25	8.94	761.34			
SG2-C	9	0	9.00	761.40			
SG2-D	9	1	9.08	761.48			
SG3-A	13	1	13.08	765.48	765.5	24.25	24.00
SG3-B	13	1.25	13.10	765.50			
SG3-C	13	2.25	13.19	765.59			
SG3-D	13	2	13.17	765.57			
SG4-A	17	1	17.08	769.48	769.5	24.50	25.00
SG4-B	17	1.5	17.13	769.53			
SG4-C	17	0.75	17.06	769.46			
SG4-D	17	2	17.17	769.57			
SG5-A	21	1	21.08	773.48	773.5	24.25	25.25
SG5-B	21	0.75	21.06	773.46			
SG5-C	21	1	21.08	773.48			
SG5-D	21	2	21.17	773.57			
SG6-A	25	0.75	25.06	777.46	777.5	24.25	25.25
SG6-B	25	1.5	25.13	777.53			
SG6-C	24	11.5	24.96	777.36			
SG6-D	25	1	25.08	777.48			
Geo-1	0	22.5	1.88	754.28			
Geo-2	16	5	16.42	768.82			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	750.4	36.9
Bottom Cell	752.5	36.5
Top Cell	753.6	36.5
SG1	757.5	37.7
SG2	761.4	37.0
SG3	765.5	38.2
SG4	769.5	42.0
SG5	773.5	42.0
SG6	777.5	42.0
Top	783.2	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	750.4	36.9

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W1

TS-W2

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.18
TTC Elev. (ft)	
TOC Elev. (ft)	782.87
Ground Elev. (ft)	779.96
BPC Elev. (ft)	767.18
BTC Elev. (ft)	
BOS Elev. (ft)	749.68
Grout elev. (ft)	

O-Cell Information

Serial #	16-6-00259
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	751.75

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	30.33
Top Elev. (ft)	782.00
Bottom Elev. (ft)	751.67

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 751.7

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	5	1.5	5.13	756.80	756.8	25.50	24.75
SG1-B	5	3	5.25	756.92			
SG1-C	5	1.5	5.13	756.80			
SG1-D	5	1	5.08	756.75			
SG2-A	8	11.5	8.96	760.63	760.6	25.25	24.25
SG2-B	8	11	8.92	760.59			
SG2-C	8	11	8.92	760.59			
SG2-D	8	11.5	8.96	760.63			
SG3-A	13	1.5	13.13	764.80	764.8	25.25	23.50
SG3-B	13	1.5	13.13	764.80			
SG3-C	13	0.5	13.04	764.71			
SG3-D	13	1	13.08	764.75			
SG4-A	17	0	17.00	768.67	768.7	25.25	23.75
SG4-B	17	1	17.08	768.75			
SG4-C	17	1.25	17.10	768.77			
SG4-D	17	0.25	17.02	768.69			
SG5-A	21	0	21.00	772.67	772.7	25.75	24.25
SG5-B	21	1	21.08	772.75			
SG5-C	20	11.75	20.98	772.65			
SG5-D	20	11.25	20.94	772.61			
SG6-A	24	11.5	24.96	776.63	776.7	25.50	24.00
SG6-B	25	1.75	25.15	776.82			
SG6-C	25	0.5	25.04	776.71			
SG6-D	25	0.5	25.04	776.71			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	749.7	37.3
Bottom Cell	751.8	37.3
Top Cell	752.9	37.6
SG1	756.8	38.9
SG2	760.6	37.9
SG3	764.8	37.8
SG4	768.7	42.0
SG5	772.7	42.0
SG6	776.7	42.0
Top	783.2	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	749.7	37.3

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W2

TS-W3

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.20
TTC Elev. (ft)	
TOC Elev. (ft)	782.88
Ground Elev. (ft)	780.38
BPC Elev. (ft)	767.20
BTC Elev. (ft)	
BOS Elev. (ft)	735.53
Grout elev. (ft)	

O-Cell Information

Serial #	20-6-00200
Diameter (in)	20
Capacity-rated (kips)	2251
Capacity-max (kips)	4503
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	738.36

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	44.25
Top Elev. (ft)	782.53
Bottom Elev. (ft)	738.28

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 738.3

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	7	0.5	7.04	745.32	745.3	24.00	24.25
SG1-B	7	0.5	7.04	745.32			
SG1-C	7	0	7.00	745.28			
SG1-D	7	0	7.00	745.28			
SG2-A	15	0.5	15.04	753.32	753.3	24.25	24.00
SG2-B	15	0.5	15.04	753.32			
SG2-C	15	0.5	15.04	753.32			
SG2-D	15	0.5	15.04	753.32			
SG3-A	22	1.75	22.15	760.43	760.4	24.75	24.75
SG3-B	22	2	22.17	760.45			
SG3-C	22	1	22.08	760.36			
SG3-D	22	0.5	22.04	760.32			
SG4-A	27	1.5	27.13	765.41	765.4	24.75	24.75
SG4-B	27	2.5	27.21	765.49			
SG4-C	27	1	27.08	765.36			
SG4-D	27	1	27.08	765.36			
SG5-A	31	0.5	31.04	769.32	769.4	24.25	24.50
SG5-B	31	3.5	31.29	769.57			
SG5-C	31	1.25	31.10	769.38			
SG5-D	31	0.5	31.04	769.32			
SG6-A	37	1.25	37.10	775.38	775.3	23.75	24.25
SG6-B	36	11	36.92	775.20			
SG6-C	37	1.25	37.10	775.38			
SG6-D	37	1.25	37.10	775.38			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	735.5	36.2
Bottom Cell	738.4	36.2
Top Cell	739.5	37.5
SG1	745.3	37.5
SG2	753.3	37.6
SG3	760.4	38.7
SG4	765.4	38.1
SG5	769.4	42.0
SG6	775.3	42.0
Top	783.2	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	735.5	36.2

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W3

TS-W4

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.17
TTC Elev. (ft)	
TOC Elev. (ft)	782.85
Ground Elev. (ft)	780.61
BPC Elev. (ft)	767.17
BTC Elev. (ft)	
BOS Elev. (ft)	733.50
Grout elev. (ft)	

O-Cell Information

Serial #	20-6-00201
Diameter (in)	20
Capacity-rated (kips)	2251
Capacity-max (kips)	4503
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	738.93

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	43.75
Top Elev. (ft)	782.60
Bottom Elev. (ft)	738.85

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 738.9

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	7	0.5	7.04	745.89	745.8	25.25	23.75
SG1-B	6	11.5	6.96	745.81			
SG1-C	6	11.5	6.96	745.81			
SG1-D	7	0	7.00	745.85			
SG2-A	15	0	15.00	753.85	753.8	24.25	25.00
SG2-B	14	11.5	14.96	753.81			
SG2-C	14	11.25	14.94	753.79			
SG2-D	14	11.25	14.94	753.79			
SG3-A	22	1.5	22.13	760.98	760.9	24.50	24.75
SG3-B	22	0	22.00	760.85			
SG3-C	22	0	22.00	760.85			
SG3-D	22	0	22.00	760.85			
SG4-A	28	2	28.17	767.02	767.0	23.75	24.00
SG4-B	28	2.25	28.19	767.04			
SG4-C	28	2.5	28.21	767.06			
SG4-D	28	2.5	28.21	767.06			
SG5-A	31	1	31.08	769.93	769.9	23.75	25.50
SG5-B	31	0.5	31.04	769.89			
SG5-C	31	0.25	31.02	769.87			
SG5-D	31	0.75	31.06	769.91			
SG6-A	37	0.5	37.04	775.89	775.9	24.75	
SG6-B	37	0	37.00	775.85			
SG6-C	37	0	37.00	775.85			
SG6-D	37	0.25	37.02	775.87			
Geo-1	2		2.00	740.85			
Geo-2	23.5		23.50	762.35			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	733.5	37.5
Bottom Cell	738.9	37.5
Top Cell	740.0	37.5
SG1	745.8	37.5
SG2	753.8	37.5
SG3	760.9	37.5
SG4	767.0	37.5
SG5	769.9	42.0
SG6	775.9	42.0
Top	783.2	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	733.5	37.5

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W4

TS-W5

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.65
TTC Elev. (ft)	
TOC Elev. (ft)	783.41
Ground Elev. (ft)	779.32
BPC Elev. (ft)	767.15
BTC Elev. (ft)	
BOS Elev. (ft)	756.35
Grout elev. (ft)	

O-Cell Information

Serial #	13-6-00111
Diameter (in)	13
Capacity-rated (kips)	928
Capacity-max (kips)	1856
Top plate diameter (in)	23.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	16.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	756.98

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	26.33
Top Elev. (ft)	783.23
Bottom Elev. (ft)	756.90

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.50

Instrument Elevations Reference Elev. (ft): 756.9

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	5	2.25	5.19	762.09	762.1	25.50	25.50
SG1-B	5	2	5.17	762.07			
SG1-C	5	1.5	5.13	762.03			
SG1-D	5	2.25	5.19	762.09			
SG2-A	8	0.75	8.06	764.96	765.0	24.50	24.50
SG2-B	8	1	8.08	764.98			
SG2-C	8	1.25	8.10	765.00			
SG2-D	8	0.25	8.02	764.92			
SG3-A	11	0.75	11.06	767.96	767.9	25.25	24.50
SG3-B	11	0.25	11.02	767.92			
SG3-C	11	0.5	11.04	767.94			
SG3-D	11	0.25	11.02	767.92			
SG4-A	14	1.25	14.10	771.00	770.9	25.50	24.50
SG4-B	14	0.75	14.06	770.96			
SG4-C	13	11.25	13.94	770.84			
SG4-D	13	11.5	13.96	770.86			
SG5-A	17	1.25	17.10	774.00	774.0	24.75	25.00
SG5-B	17	1.25	17.10	774.00			
SG5-C	17	1	17.08	773.98			
SG5-D	16	11.75	16.98	773.88			
SG6-A	20	1.25	20.10	777.00	777.0	25.25	25.25
SG6-B	20	1	20.08	776.98			
SG6-C	20	1.25	20.10	777.00			
SG6-D	20	1	20.08	776.98			
Geo-1	2	0	2.00	758.90			
Geo-2	14	6	14.50	771.40			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	756.4	36.3
Bottom Cell	757.0	36.7
Top Cell	758.1	37.3
SG1	762.1	37.8
SG2	765.0	37.6
SG3	767.9	42.0
SG4	770.9	42.0
SG5	774.0	42.0
SG6	777.0	42.0
Top	783.7	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	756.4	16.0

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W5

TS-W6

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.08
TTC Elev. (ft)	
TOC Elev. (ft)	782.83
Ground Elev. (ft)	780.28
BPC Elev. (ft)	767.08
BTC Elev. (ft)	
BOS Elev. (ft)	749.66
Grout elev. (ft)	753.25

O-Cell Information

Serial #	16-6-00255
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	751.66

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Reinforcing Steel Information

Bar size	#10
# bars	9
Stirrup size	#4
Stirrup spacing (in)	12
Stirrup diameter (in)	28
Cage length (ft)	32.00
Top Elev. (ft)	782.60
Bottom Elev. (ft)	750.60

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 751.6

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)
SG1-A	5	0	5.00	756.58	756.6	25.50
SG1-C	5	0.5	5.04	756.62		
SG2-A	9	0.5	9.04	760.62	760.6	26.00
SG2-C	9	0	9.00	760.58		
SG3-A	13	0.5	13.04	764.62	764.6	25.00
SG3-C	13	0	13.00	764.58		
SG4-A	17	0	17.00	768.58	768.5	24.75
SG4-C	16	11	16.92	768.49		
SG5-A	21	0.5	21.04	772.62	772.6	25.00
SG5-C	21	0	21.00	772.58		
SG6-A	25	0	25.00	776.58	776.6	24.75
SG6-C	25	0.5	25.04	776.62		
Geo-1	2	0	2.00	753.58		
Geo-2	13	6	13.50	765.08		

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	749.7	37.9
Bottom Cell	751.7	36.0
Top Cell	752.8	36.1
SG1	756.6	37.8
SG2	760.6	37.8
SG3	764.6	38.0
SG4	768.6	42.0
SG5	772.6	42.0
SG6	776.6	42.0
Top	783.1	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	749.7	37.9

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W6

TS-W7

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.25
TTC Elev. (ft)	
TOC Elev. (ft)	782.94
Ground Elev. (ft)	780.57
BPC Elev. (ft)	767.25
BTC Elev. (ft)	
BOS Elev. (ft)	749.05
Grout elev. (ft)	

O-Cell Information

Serial #	16-6-00271
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	20.5
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	749.20

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	33.40
Top Elev. (ft)	782.52
Bottom Elev. (ft)	749.12

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 749.1

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	7	1	7.08	756.20	756.3	24.50	24.50
SG1-B	7	2.5	7.21	756.33			
SG1-C	7	3	7.25	756.37			
SG1-D	7	1	7.08	756.20			
SG2-A	11	1.5	11.13	760.25	760.3	23.75	23.75
SG2-B	11	3	11.25	760.37			
SG2-C	11	3	11.25	760.37			
SG2-D	11	1.5	11.13	760.25			
SG3-A	15	1.5	15.13	764.25	764.3	24.25	24.50
SG3-B	15	3	15.25	764.37			
SG3-C	15	2.5	15.21	764.33			
SG3-D	15	1.5	15.13	764.25			
SG4-A	19	1.5	19.13	768.25	768.3	24.75	24.75
SG4-B	19	3.5	19.29	768.41			
SG4-C	19	2	19.17	768.29			
SG4-D	19	3	19.25	768.37			
SG5-A	23	1.5	23.13	772.25	772.3	25.00	25.25
SG5-B	23	3	23.25	772.37			
SG5-C	23	3	23.25	772.37			
SG5-D	23	2.5	23.21	772.33			
SG6-A	27	4	27.33	776.45	776.4	24.00	25.00
SG6-B	27	3.5	27.29	776.41			
SG6-C	27	4	27.33	776.45			
SG6-D	27	4	27.33	776.45			
Geo-1	7	0	7.00	756.12			
Geo-2	18	6.5	18.54	767.66			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	749.1	36.0
Bottom Cell	749.2	36.0
Top Cell	750.3	37.4
SG1	756.3	37.8
SG2	760.3	38.1
SG3	764.3	37.6
SG4	768.3	42.0
SG5	772.3	42.0
SG6	776.4	42.0
Top	783.3	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	749.1	20.5

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W7

TS-W8

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.25
TTC Elev. (ft)	
TOC Elev. (ft)	783.12
Ground Elev. (ft)	781.11
BPC Elev. (ft)	767.25
BTC Elev. (ft)	
BOS Elev. (ft)	735.05
Grout elev. (ft)	

O-Cell Information

Serial #	20-6-00218
Diameter (in)	20
Capacity-rated (kips)	2251
Capacity-max (kips)	4503
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	21.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	735.58

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	47.33
Top Elev. (ft)	782.83
Bottom Elev. (ft)	735.50

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 735.5

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	8	9.25	8.77	744.27	744.3	25.75	25.75
SG1-B	8	9.5	8.79	744.29			
SG1-C	8	9.5	8.79	744.29			
SG1-D	8	9.25	8.77	744.27			
SG2-A	14	9.25	14.77	750.27	750.3	25.50	25.25
SG2-B	14	9.75	14.81	750.31			
SG2-C	14	10	14.83	750.33			
SG2-D	14	9.25	14.77	750.27			
SG3-A	20	9	20.75	756.25	756.3	24.00	24.75
SG3-B	20	10	20.83	756.33			
SG3-C	20	9.75	20.81	756.31			
SG3-D	20	9	20.75	756.25			
SG4-A	26	9	26.75	762.25	762.3	24.25	25.25
SG4-B	26	9.5	26.79	762.29			
SG4-C	26	10	26.83	762.33			
SG4-D	26	9.25	26.77	762.27			
SG5-A	32	9.25	32.77	768.27	768.3	24.25	24.75
SG5-B	32	9.75	32.81	768.31			
SG5-C	32	9.75	32.81	768.31			
SG5-D	32	9.5	32.79	768.29			
SG6-A	38	9	38.75	774.25	774.3	24.50	26.00
SG6-B	38	10	38.83	774.33			
SG6-C	38	9.75	38.81	774.31			
SG6-D	38	9.25	38.77	774.27			
Geo-1	4	0	4.00	739.50			
Geo-2	25.5	0	25.50	761.00			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	735.1	39.0
Bottom Cell	735.6	39.0
Top Cell	736.7	38.5
SG1	744.3	38.7
SG2	750.3	38.4
SG3	756.3	38.1
SG4	762.3	38.6
SG5	768.3	42.0
SG6	774.3	42.0
Top	783.3	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	735.1	39.0

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W8

TS-W9

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.39
TTC Elev. (ft)	
TOC Elev. (ft)	783.08
Ground Elev. (ft)	781.10
BPC Elev. (ft)	767.39
BTC Elev. (ft)	
BOS Elev. (ft)	735.22
Grout elev. (ft)	

O-Cell Information

Serial #	20-6-00219
Diameter (in)	20
Capacity-rated (kips)	2251
Capacity-max (kips)	4503
Top plate diameter (in)	23.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	21.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	735.60

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	47.33
Top Elev. (ft)	782.85
Bottom Elev. (ft)	735.52

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 735.5

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	9	1.25	9.10	744.62	744.6	25.25	25.50
SG1-B	9	1	9.08	744.60			
SG1-C	9	1.25	9.10	744.62			
SG1-D	9	2.25	9.19	744.71			
SG2-A	15	2	15.17	750.69	750.7	25.00	25.00
SG2-B	15	1.75	15.15	750.67			
SG2-C	15	1.75	15.15	750.67			
SG2-D	15	2	15.17	750.69			
SG3-A	21	2.25	21.19	756.71	756.7	24.75	25.00
SG3-B	21	1.5	21.13	756.65			
SG3-C	21	1.25	21.10	756.62			
SG3-D	21	2.25	21.19	756.71			
SG4-A	27	0.75	27.06	762.58	762.6	24.75	24.75
SG4-B	27	1	27.08	762.60			
SG4-C	27	1.25	27.10	762.62			
SG4-D	27	1.75	27.15	762.67			
SG5-A	33	0	33.00	768.52	768.6	24.25	24.25
SG5-B	33	1.25	33.10	768.62			
SG5-C	33	1.5	33.13	768.65			
SG5-D	33	0.75	33.06	768.58			
SG6-A	39	0.5	39.04	774.56	774.6	24.50	25.00
SG6-B	39	1.25	39.10	774.62			
SG6-C	39	1.5	39.13	774.65			
SG6-D	39	1.5	39.13	774.65			
Geo-1	4	1.5	4.13	739.65			
Geo-2	25	6	25.50	761.02			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	735.2	36.7
Bottom Cell	735.6	37.0
Top Cell	736.7	37.9
SG1	744.6	38.1
SG2	750.7	37.5
SG3	756.7	37.5
SG4	762.6	37.5
SG5	768.6	42.0
SG6	774.6	42.0
Top	783.4	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	735.2	36.7

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W9

TS-W10

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.20
TTC Elev. (ft)	
TOC Elev. (ft)	783.03
Ground Elev. (ft)	780.82
BPC Elev. (ft)	767.20
BTC Elev. (ft)	
BOS Elev. (ft)	746.20
Grout elev. (ft)	

O-Cell Information

Serial #	Rim Cell
Diameter (in)	23
Capacity-rated (kips)	
Capacity-max (kips)	
Top plate diameter (in)	23.0
Top plate thickness (in)	
Bot. plate diameter (in)	23.0
Bot. plate thickness (in)	
O-cell elevation (ft)	747.00

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	36.42
Top Elev. (ft)	782.70
Bottom Elev. (ft)	746.28

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 747.0

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	5	3	5.25	752.25	752.3	25.75	25.25
SG1-B	5	4.5	5.38	752.38			
SG1-C	5	4.5	5.38	752.38			
SG1-D	5	4	5.33	752.33			
SG2-A	10	4	10.33	757.33	757.3	25.50	25.75
SG2-B	10	4.5	10.38	757.38			
SG2-C	10	4.5	10.38	757.38			
SG2-D	10	3	10.25	757.25			
SG3-A	15	4.5	15.38	762.38	762.3	25.25	25.75
SG3-B	15	4	15.33	762.33			
SG3-C	15	5	15.42	762.42			
SG3-D	15	3	15.25	762.25			
SG4-A	20	4.5	20.38	767.38	767.3	25.25	25.75
SG4-B	20	4.5	20.38	767.38			
SG4-C	20	4.5	20.38	767.38			
SG4-D	20	3	20.25	767.25			
SG5-A	25	4	25.33	772.33	772.3	24.75	26.00
SG5-B	25	4	25.33	772.33			
SG5-C	25	4.75	25.40	772.40			
SG5-D	25	3.5	25.29	772.29			
SG6-A	30	3.5	30.29	777.29	777.3	25.00	25.00
SG6-B	30	3.5	30.29	777.29			
SG6-C	30	4	30.33	777.33			
SG6-D	30	3.25	30.27	777.27			
Geo-1	1	11	1.92	748.92			
Geo-2	18	11	18.92	765.92			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	746.2	39.0
Bottom Cell	747.0	39.0
Top Cell	747.8	39.0
SG1	752.3	37.9
SG2	757.3	37.2
SG3	762.3	37.4
SG4	767.3	42.0
SG5	772.3	42.0
SG6	777.3	42.0
Top	783.2	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	746.2	39.0

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W10

TS-W11

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.21
TTC Elev. (ft)	
TOC Elev. (ft)	783.04
Ground Elev. (ft)	780.73
BPC Elev. (ft)	767.21
BTC Elev. (ft)	
BOS Elev. (ft)	745.91
Grout elev. (ft)	

O-Cell Information

Serial #	RIM Cell
Diameter (in)	24
Capacity-rated (kips)	
Capacity-max (kips)	
Top plate diameter (in)	24.0
Top plate thickness (in)	
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	
O-cell elevation (ft)	747.31

Reinforcing Steel Information

Bar size	#10
# bars	16
Stirrup size	#4
Stirrup spacing (in)	6
Stirrup diameter (in)	28
Cage length (ft)	36.25
Top Elev. (ft)	782.81
Bottom Elev. (ft)	746.56

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 747.3

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)	B-D (in)
SG1-A	5	4.5	5.38	752.69	752.7	24.25	23.50
SG1-B	5	5	5.42	752.73			
SG1-C	5	4.75	5.40	752.71			
SG1-D	5	4.25	5.35	752.66			
SG2-A	10	5	10.42	757.73	757.7	23.75	24.75
SG2-B	10	5.25	10.44	757.75			
SG2-C	10	4.5	10.38	757.69			
SG2-D	10	4	10.33	757.64			
SG3-A	15	4.75	15.40	762.71	762.7	23.75	25.00
SG3-B	15	4.75	15.40	762.71			
SG3-C	15	5	15.42	762.73			
SG3-D	15	4.5	15.38	762.69			
SG4-A	20	5.5	20.46	767.77	767.7	24.00	25.25
SG4-B	20	5.75	20.48	767.79			
SG4-C	20	5.5	20.46	767.77			
SG4-D	20	4.25	20.35	767.66			
SG5-A	25	5.75	25.48	772.79	772.7	23.75	25.00
SG5-B	25	5.75	25.48	772.79			
SG5-C	25	4.25	25.35	772.66			
SG5-D	25	4.25	25.35	772.66			
SG6-A	30	4.25	30.35	777.66	777.7	23.75	25.25
SG6-B	30	5	30.42	777.73			
SG6-C	30	4.25	30.35	777.66			
SG6-D	30	4.25	30.35	777.66			
Geo-1	1	11	1.92	749.23			
Geo-2	19	0	19.00	766.31			

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	745.9	37.9
Bottom Cell	747.3	37.9
Top Cell	748.0	37.9
SG1	752.7	38.3
SG2	757.7	39.0
SG3	762.7	37.5
SG4	767.7	42.0
SG5	772.7	42.0
SG6	777.7	42.0
Top	783.2	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	745.9	37.9

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W11

TS-W12

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.08
TTC Elev. (ft)	
TOC Elev. (ft)	782.84
Ground Elev. (ft)	780.15
BPC Elev. (ft)	767.08
BTC Elev. (ft)	
BOS Elev. (ft)	749.28
Grout elev. (ft)	

O-Cell Information

Serial #	16-6-00254
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	751.43

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Reinforcing Steel Information

Bar size	#10
# bars	9
Stirrup size	#4
Stirrup spacing (in)	12
Stirrup diameter (in)	28
Cage length (ft)	32.00
Top Elev. (ft)	781.48
Bottom Elev. (ft)	749.48

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 751.3

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)
SG1-A	5	1.5	5.13	756.47	756.5	23.25
SG1-C	5	1.5	5.13	756.47		
SG2-A	9	3.5	9.29	760.64	760.6	23.50
SG2-C	9	1.5	9.13	760.47		
SG3-A	13	1	13.08	764.43	764.5	22.75
SG3-C	13	2	13.17	764.51		
SG4-A	17	3	17.25	768.60	768.5	23.50
SG4-C	17	1.75	17.15	768.49		
SG5-A	21	4.5	21.38	772.72	772.7	23.00
SG5-C	21	4	21.33	772.68		
SG6-A	25	3	25.25	776.60	776.6	23.75
SG6-C	25	3	25.25	776.60		
Geo-1	3	0	3.00	754.35		
Geo-2	16.75	0	16.75	768.10		

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	749.3	37.7
Bottom Cell	751.4	37.7
Top Cell	752.4	37.7
SG1	756.5	37.8
SG2	760.6	38.1
SG3	764.5	37.8
SG4	768.5	42.0
SG5	772.7	42.0
SG6	776.6	42.0
Top	783.1	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	749.3	37.7

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W12

TS-W13

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.23
TTC Elev. (ft)	
TOC Elev. (ft)	782.84
Ground Elev. (ft)	779.96
BPC Elev. (ft)	767.23
BTC Elev. (ft)	
BOS Elev. (ft)	749.90
Grout elev. (ft)	753.15

O-Cell Information

Serial #	16-6-00256
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	752.00

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Reinforcing Steel Information

Bar size	#10
# bars	9
Stirrup size	#4
Stirrup spacing (in)	12
Stirrup diameter (in)	28
Cage length (ft)	32.00
Top Elev. (ft)	782.19
Bottom Elev. (ft)	750.19

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 751.9

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)
SG1-A	5	0.25	5.02	756.94	756.9	22.50
SG1-C	5	0.5	5.04	756.96		
SG2-A	9	7.25	9.60	761.52	761.5	23.25
SG2-C	9	7.5	9.63	761.54		
SG3-A	13	0.75	13.06	764.98	765.0	23.00
SG3-C	13	1.5	13.13	765.04		
SG4-A	17	0.5	17.04	768.96	769.0	23.00
SG4-C	17	1	17.08	769.00		
SG5-A	21	2	21.17	773.08	773.1	24.25
SG5-C	21	3	21.25	773.17		
SG6-A	25	1.75	25.15	777.06	777.1	23.50
SG6-C	25	1.5	25.13	777.04		
Geo-1	2	0	2.00	753.92		
Geo-2	16.5	0	16.50	768.42		

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	749.9	36.9
Bottom Cell	752.0	36.1
Top Cell	753.1	36.8
SG1	756.9	37.4
SG2	761.5	37.9
SG3	765.0	37.5
SG4	769.0	42.0
SG5	773.1	42.0
SG6	777.1	42.0
Top	783.2	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	749.9	36.9

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W13

TS-W14

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.26
TTC Elev. (ft)	
TOC Elev. (ft)	782.84
Ground Elev. (ft)	780.76
BPC Elev. (ft)	767.26
BTC Elev. (ft)	
BOS Elev. (ft)	750.06
Grout elev. (ft)	754.01

O-Cell Information

Serial #	16-6-00258
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	752.50

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Reinforcing Steel Information

Bar size	#10
# bars	9
Stirrup size	#4
Stirrup spacing (in)	12
Stirrup diameter (in)	28
Cage length (ft)	32.00
Top Elev. (ft)	782.68
Bottom Elev. (ft)	750.68

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 752.4

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)
SG1-A	4	10	4.83	757.25	757.3	23.50
SG1-C	5	0	5.00	757.42		
SG2-A	8	10.5	8.88	761.29	761.4	24.00
SG2-C	9	0	9.00	761.42		
SG3-A	12	10.5	12.88	765.29	765.6	23.75
SG3-C	13	5	13.42	765.83		
SG4-A	16	10	16.83	769.25	769.4	23.75
SG4-C	17	0.5	17.04	769.46		
SG5-A	20	9	20.75	773.17	773.3	23.75
SG5-C	21	0	21.00	773.42		
SG6-A	24	11.5	24.96	777.38	777.4	23.75
SG6-C	25	0	25.00	777.42		
Geo-1	3	0	3.00	755.42		
Geo-2	16	5	16.42	768.83		

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	750.1	35.6
Bottom Cell	752.5	37.1
Top Cell	753.5	37.2
SG1	757.3	39.6
SG2	761.4	36.6
SG3	765.6	38.8
SG4	769.4	42.0
SG5	773.3	42.0
SG6	777.4	42.0
Top	783.3	42.0

Presumed EB Diameter

	Elevation	Diameter (in)
Tip	750.1	35.6

MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W14

TS-W15

Shaft Information

Nominal diameter (in)	36
Diam. Cased (in)	42.0
Diam. Uncased (in)	36.0
TPC Elev. (ft)	783.13
TTC Elev. (ft)	
TOC Elev. (ft)	782.90
Ground Elev. (ft)	780.51
BPC Elev. (ft)	767.13
BTC Elev. (ft)	
BOS Elev. (ft)	749.63
Grout elev. (ft)	752.63

O-Cell Information

Serial #	16-6-00257
Diameter (in)	16
Capacity-rated (kips)	1424
Capacity-max (kips)	2849
Top plate diameter (in)	24.0
Top plate thickness (in)	1.00
Bot. plate diameter (in)	24.0
Bot. plate thickness (in)	1.00
O-cell elevation (ft)	751.80

Temporary Casing

OD (in)	
Thickness (in)	
Length (ft)	

Reinforcing Steel Information

Bar size	#10
# bars	9
Stirrup size	#4
Stirrup spacing (in)	12
Stirrup diameter (in)	28
Cage length (ft)	32.00
Top Elev. (ft)	781.92
Bottom Elev. (ft)	749.92

Permanent Casing

OD (in)	42.0
Thickness (in)	0.250
Length (ft)	16.00

Instrument Elevations Reference Elev. (ft): 751.7

Gage	ft	in	ft (dec)	elev	elev-avg	A-C (in)
SG1-A	5	0.75	5.06	756.78	756.8	24.50
SG1-C	5	0.5	5.04	756.76		
SG2-A	9	2.5	9.21	760.93	760.8	23.50
SG2-C	9	0.5	9.04	760.76		
SG3-A	13	2.5	13.21	764.93	764.9	23.50
SG3-C	13	1	13.08	764.80		
SG4-A	17	4	17.33	769.05	768.9	23.50
SG4-C	17	1	17.08	768.80		
SG5-A	21	4.5	21.38	773.09	772.9	23.00
SG5-C	21	0.5	21.04	772.76		
SG6-A	25	6.25	25.52	777.24	777.0	23.25
SG6-C	25	0.5	25.04	776.76		
Geo-1	0	23.75	1.98	753.70		
Geo-2	16	6	16.50	768.22		

Calipered Shaft Diameter

	Elevation	Diameter (in)
Tip	749.6	35.0
Bottom Cell	751.8	37.0
Top Cell	752.8	37.1
SG1	756.8	38.9
SG2	760.8	38.3
SG3	764.9	37.8
SG4	768.9	42.0
SG5	772.9	42.0
SG6	777.0	42.0
Top	783.1	42.0

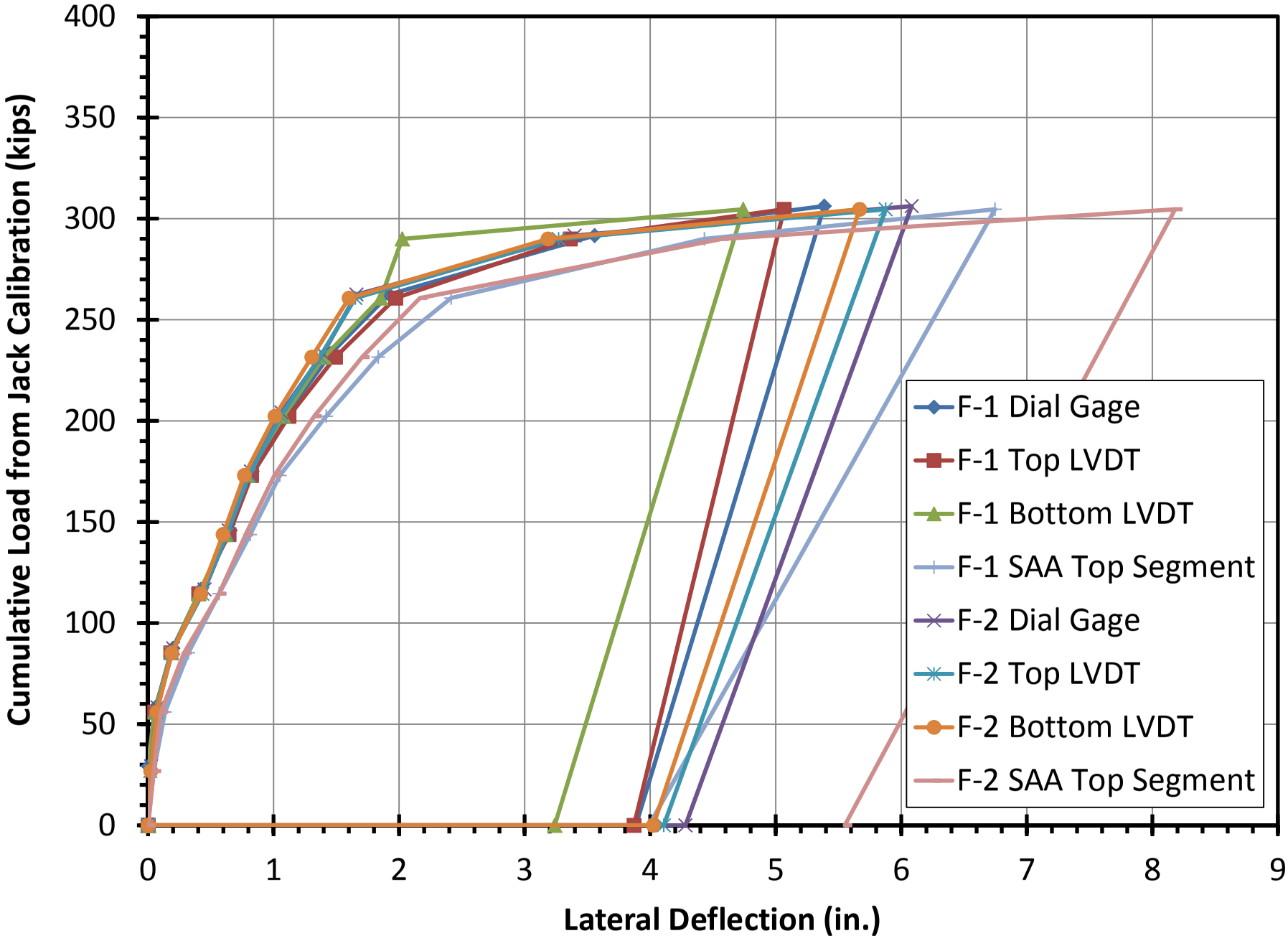
Presumed EB Diameter

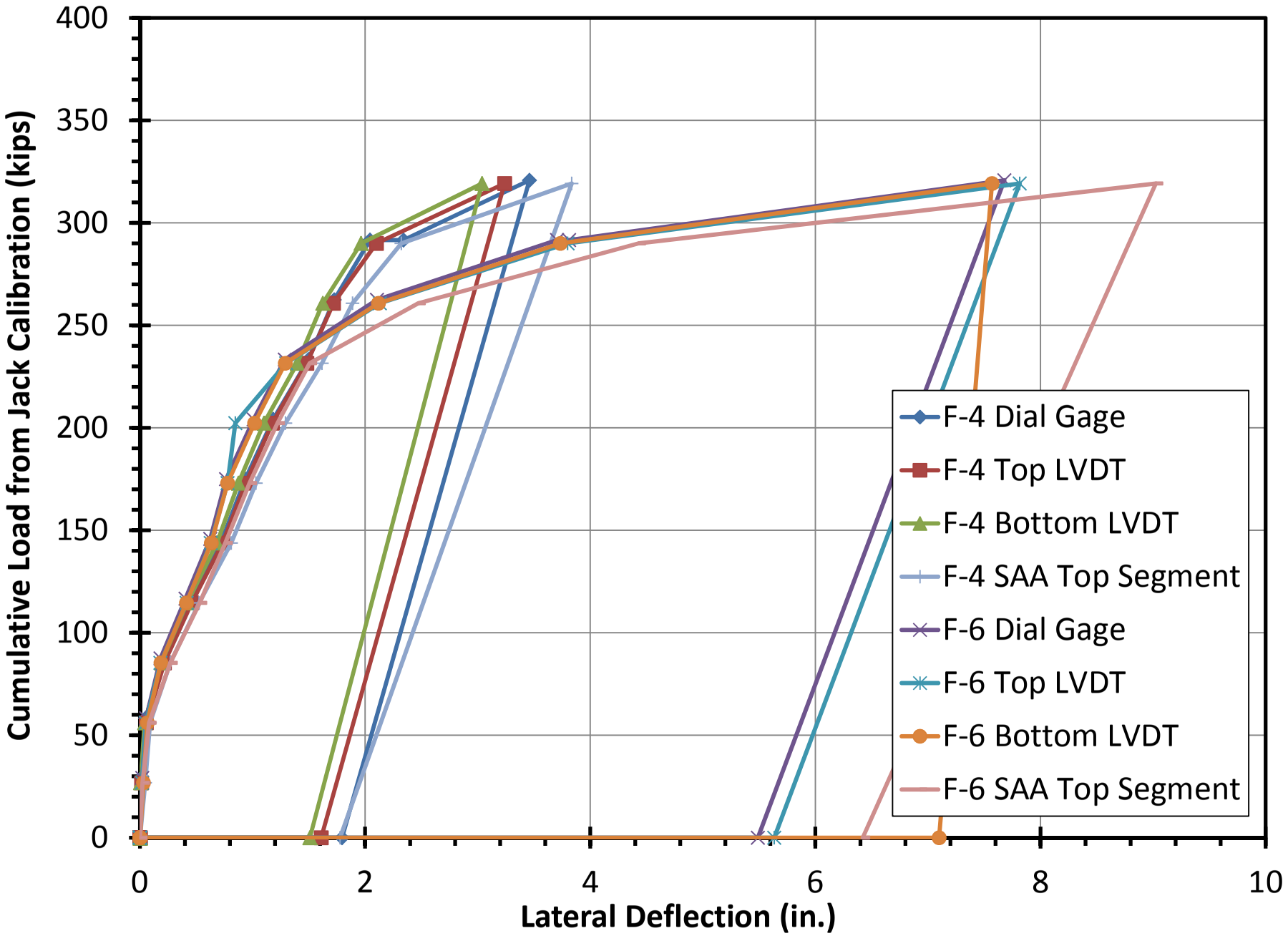
	Elevation	Diameter (in)
Tip	749.6	35.0

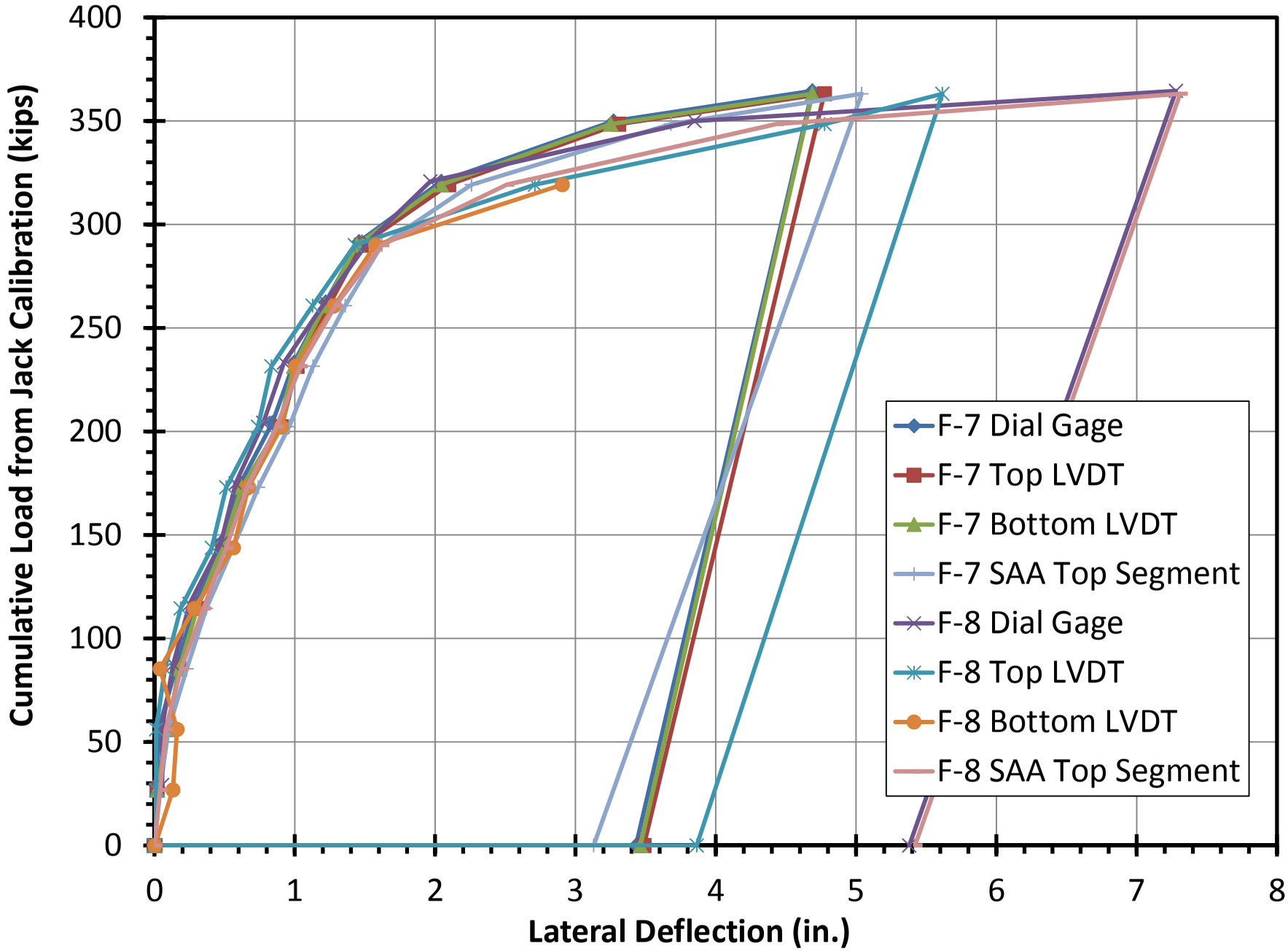
MoDOT Transportation Geotechnics Research Program
Lateral Load Tests

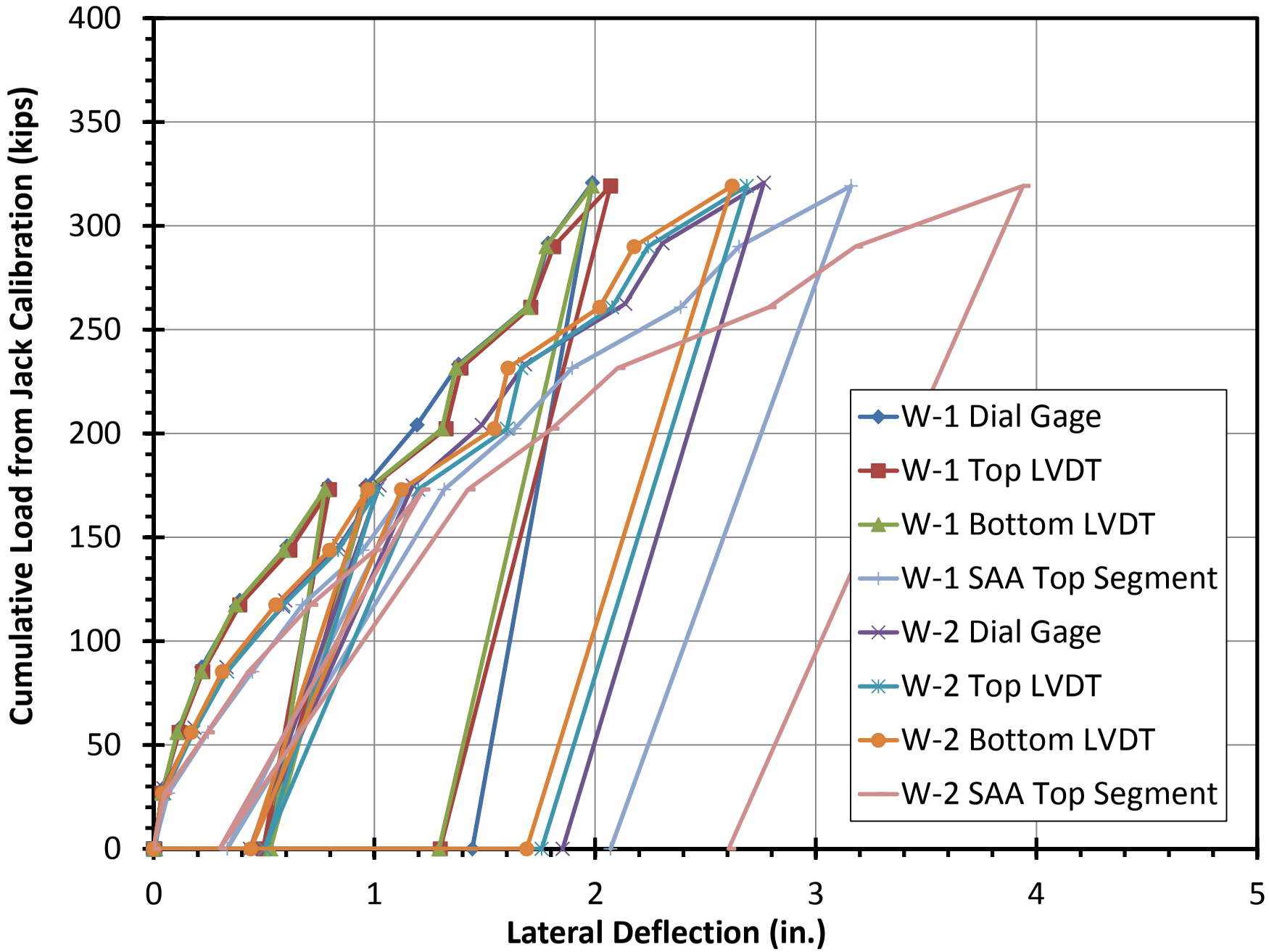
As-Built Shaft Information
Site: Warrensburg Load Test Site
Shaft: W15

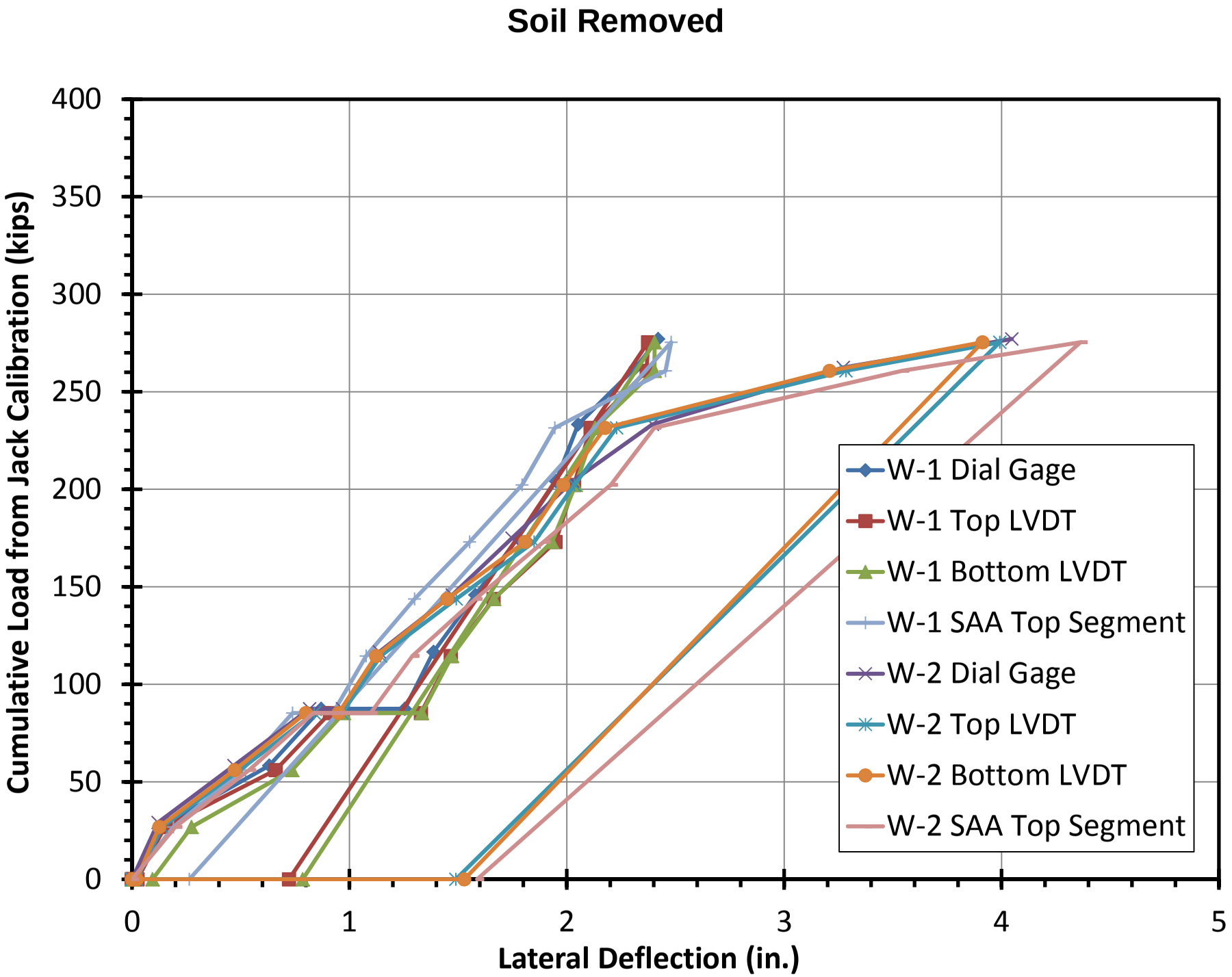
Appendix B – Load-Displacement Curves

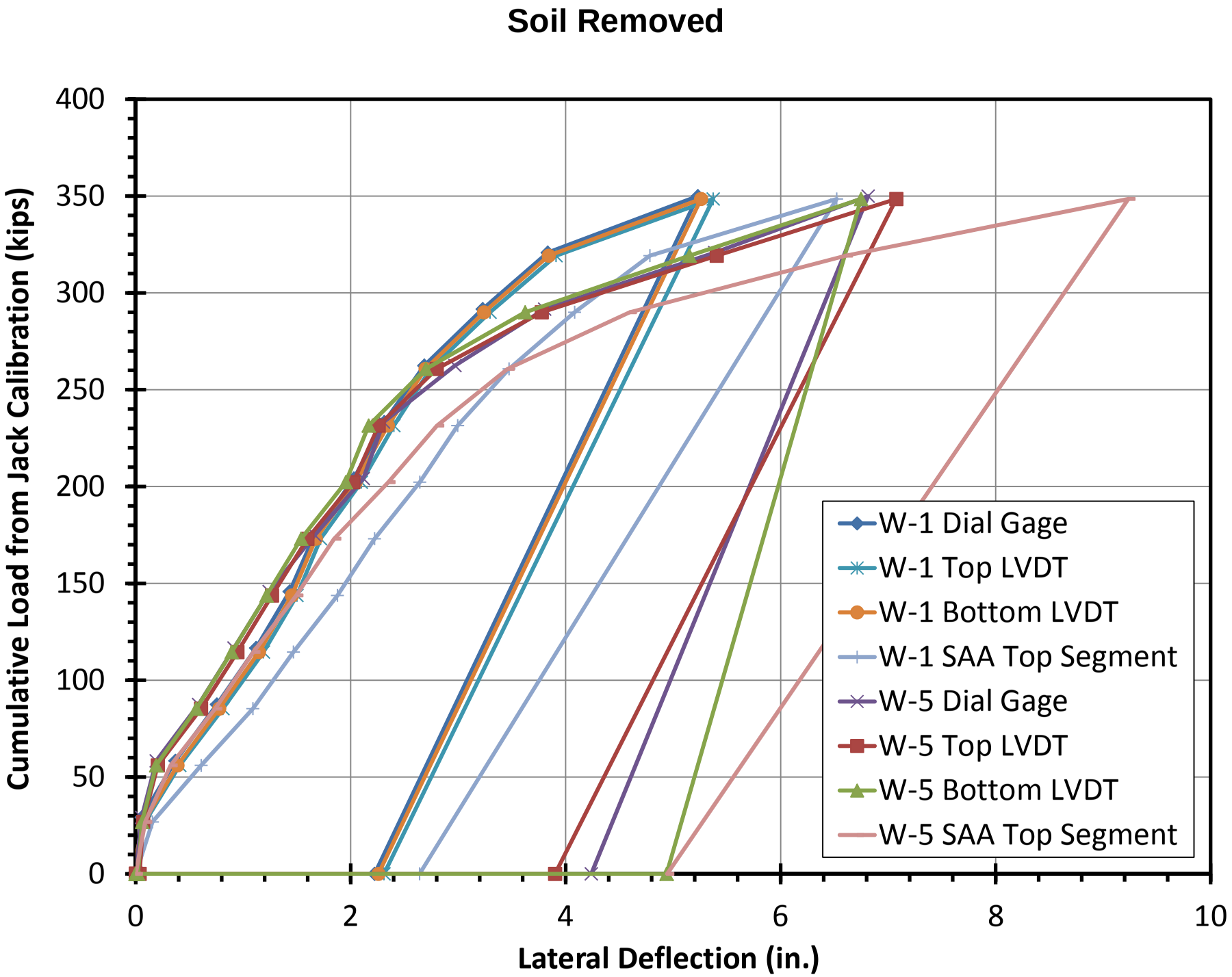

Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
Lateral Deflection (in.)
F-1 Dial Gage
F-1 Top LVDT
F-1 Bottom LVDT
F-1 SAA Top Segment
F-2 Dial Gage
F-2 Top LVDT
F-2 Bottom LVDT
F-2 SAA Top Segment

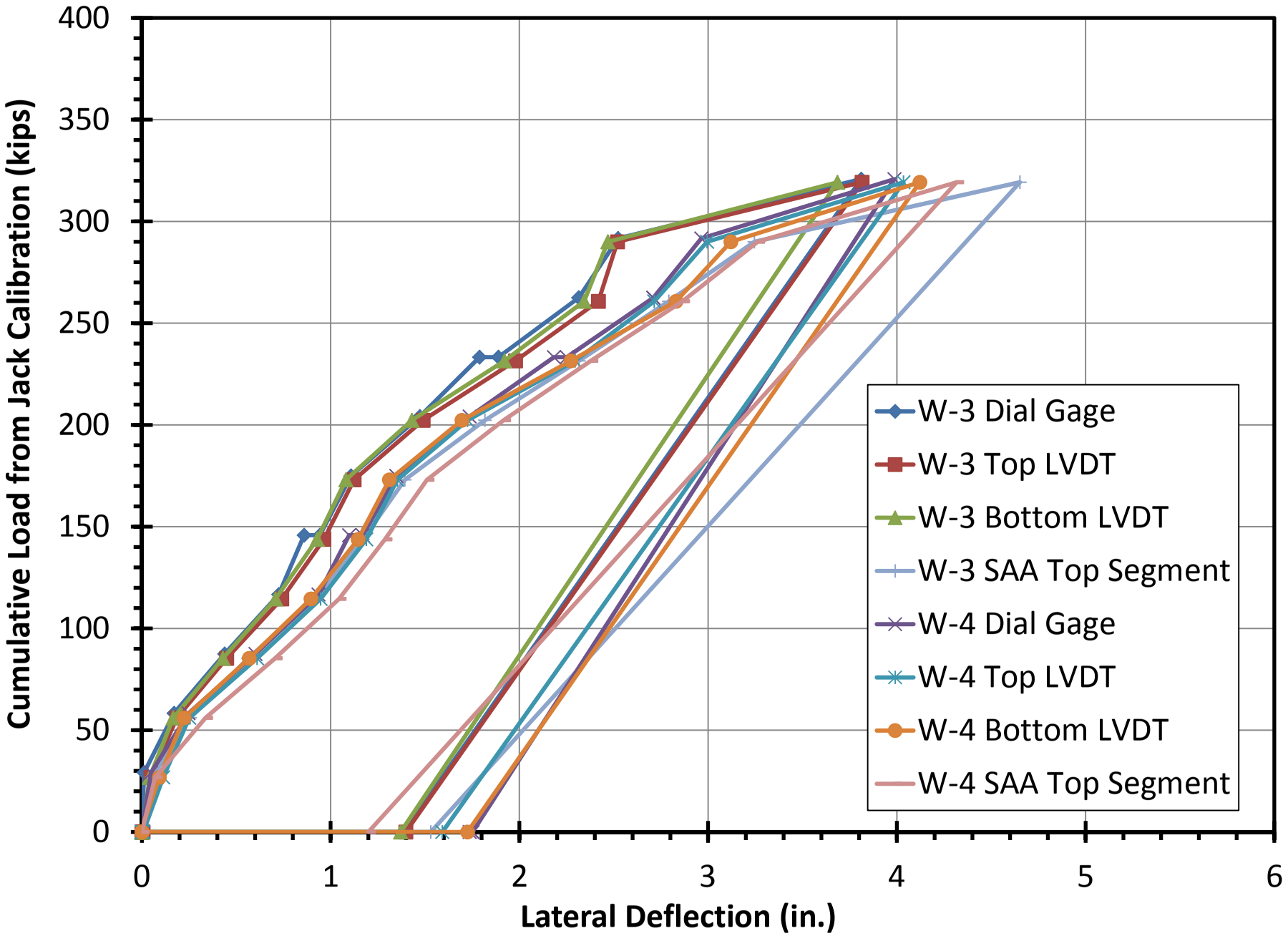

Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
Lateral Deflection (in.)
F-4 Dial Gage
F-4 Top LVDT
F-4 Bottom LVDT
F-4 SAA Top Segment
F-6 Dial Gage
F-6 Top LVDT
F-6 Bottom LVDT
F-6 SAA Top Segment

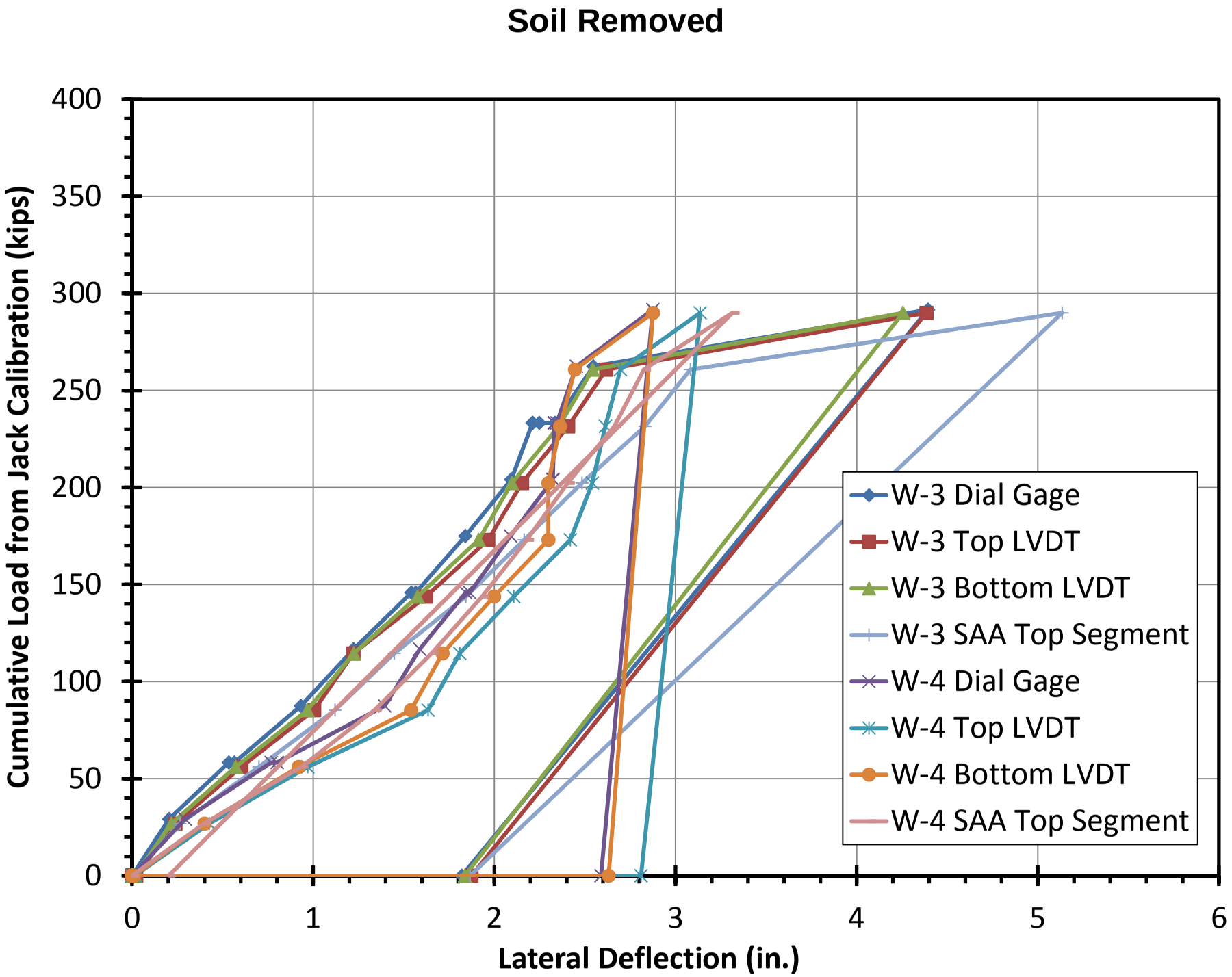

Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
Lateral Deflection (in.)
F-7 Dial Gage
F-7 Top LVDT
F-7 Bottom LVDT
F-7 SAA Top Segment
F-8 Dial Gage
F-8 Top LVDT
F-8 Bottom LVDT
F-8 SAA Top Segment

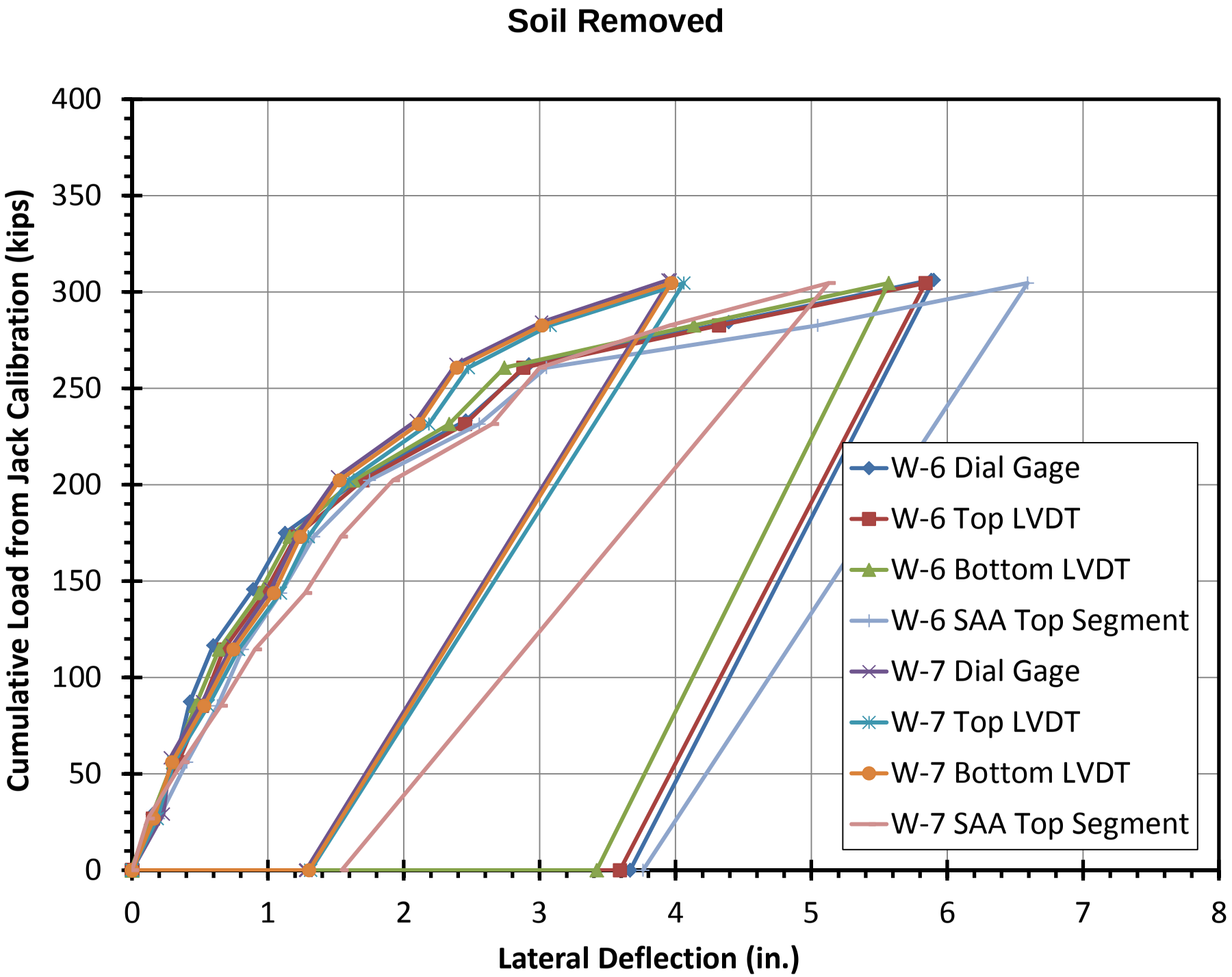

Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
Lateral Deflection (in.)
W-1 Dial Gage
W-1 Top LVDT
W-1 Bottom LVDT
W-1 SAA Top Segment
W-2 Dial Gage
W-2 Top LVDT
W-2 Bottom LVDT
W-2 SAA Top Segment

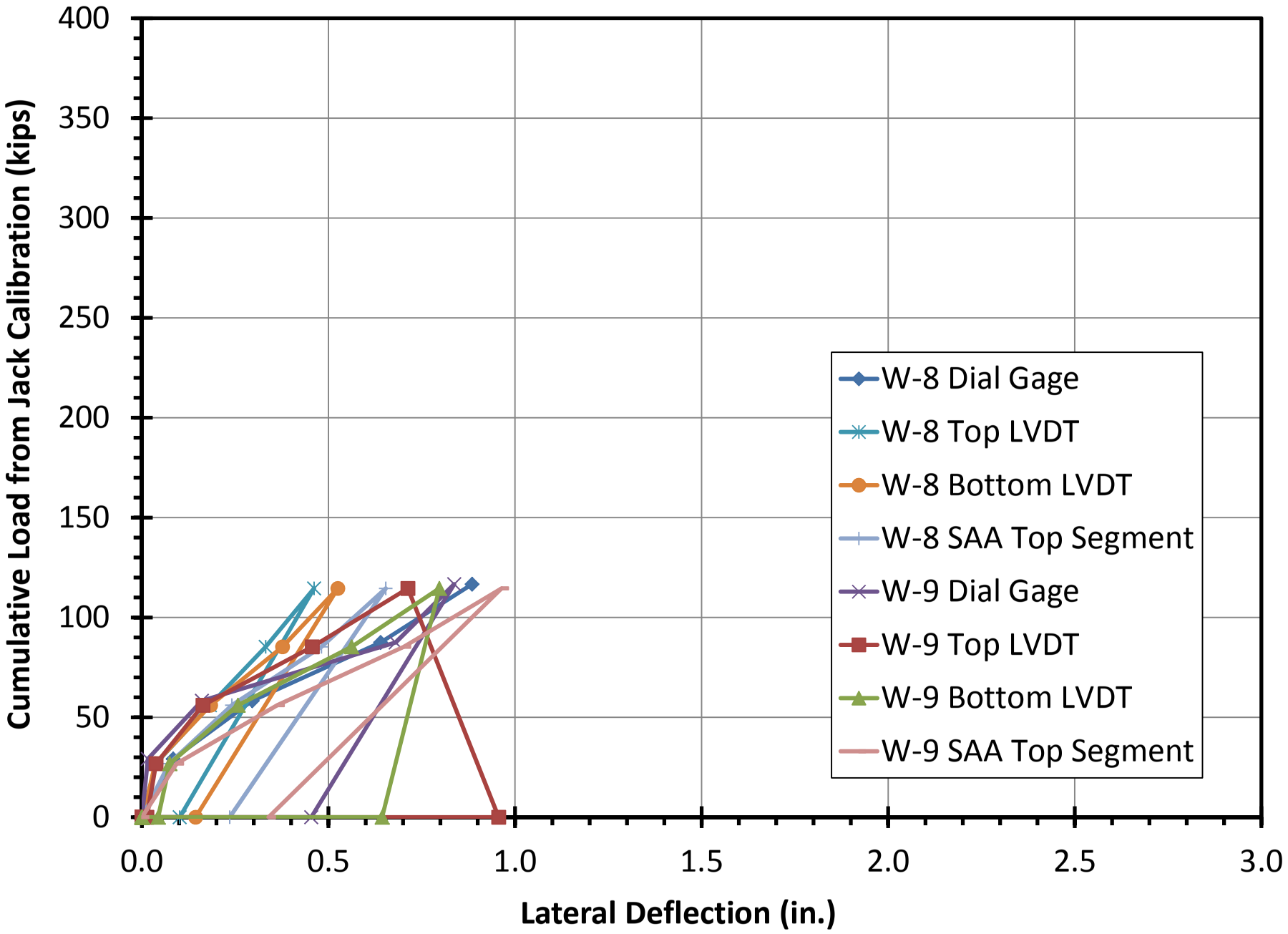

Soil Removed
Cumulative Load from Jack Calibration (kips)
Lateral Deflection (in.)
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
W-1 Dial Gage
W-1 Top LVDT
W-1 Bottom LVDT
W-1 SAA Top Segment
W-2 Dial Gage
W-2 Top LVDT
W-2 Bottom LVDT
W-2 SAA Top Segment

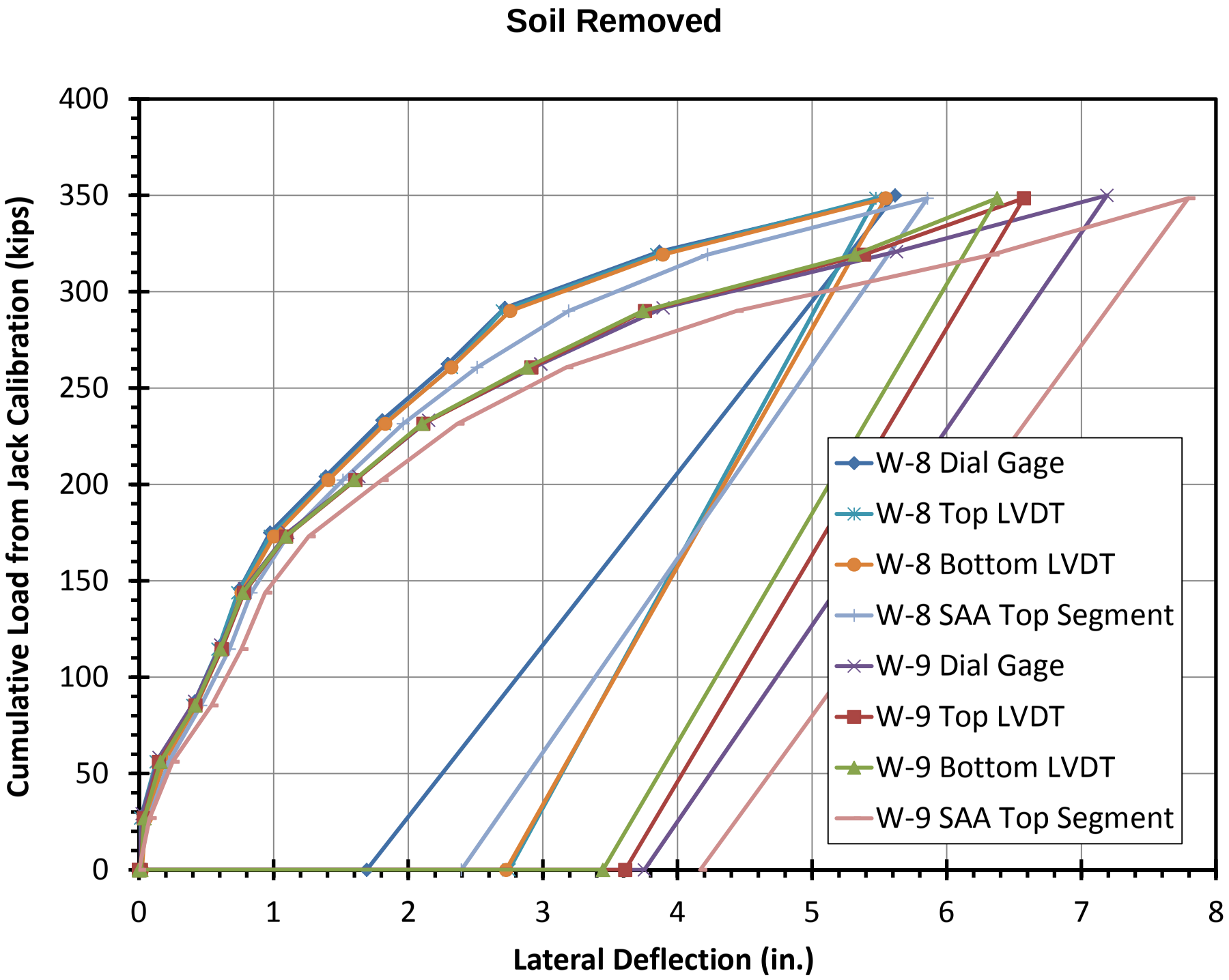

Soil Removed
Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
Lateral Deflection (in.)
W-1 Dial Gage
W-1 Top LVDT
W-1 Bottom LVDT
W-1 SAA Top Segment
W-5 Dial Gage
W-5 Top LVDT
W-5 Bottom LVDT
W-5 SAA Top Segment

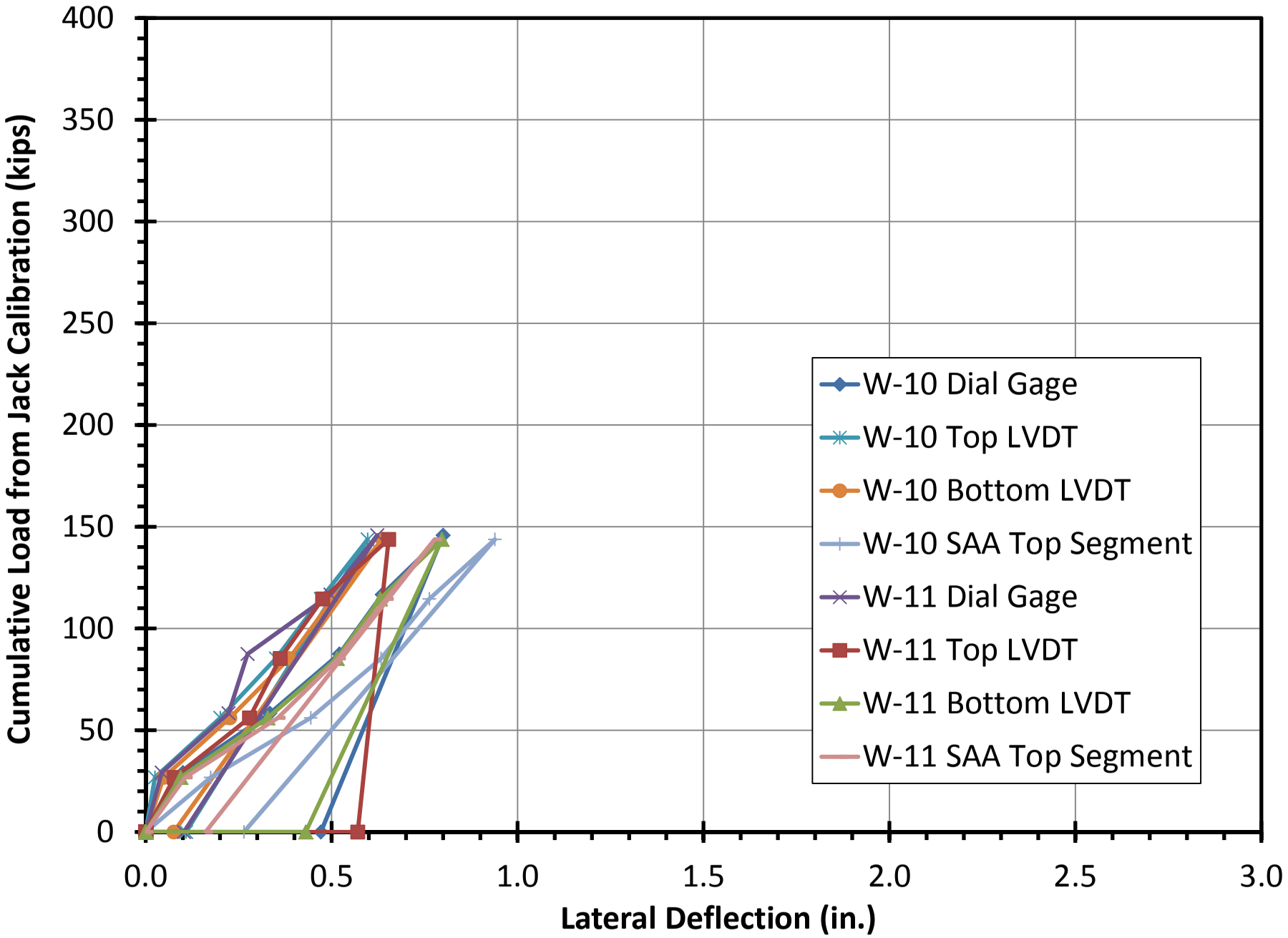

Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
Lateral Deflection (in.)
W-3 Dial Gage
W-3 Top LVDT
W-3 Bottom LVDT
W-3 SAA Top Segment
W-4 Dial Gage
W-4 Top LVDT
W-4 Bottom LVDT
W-4 SAA Top Segment

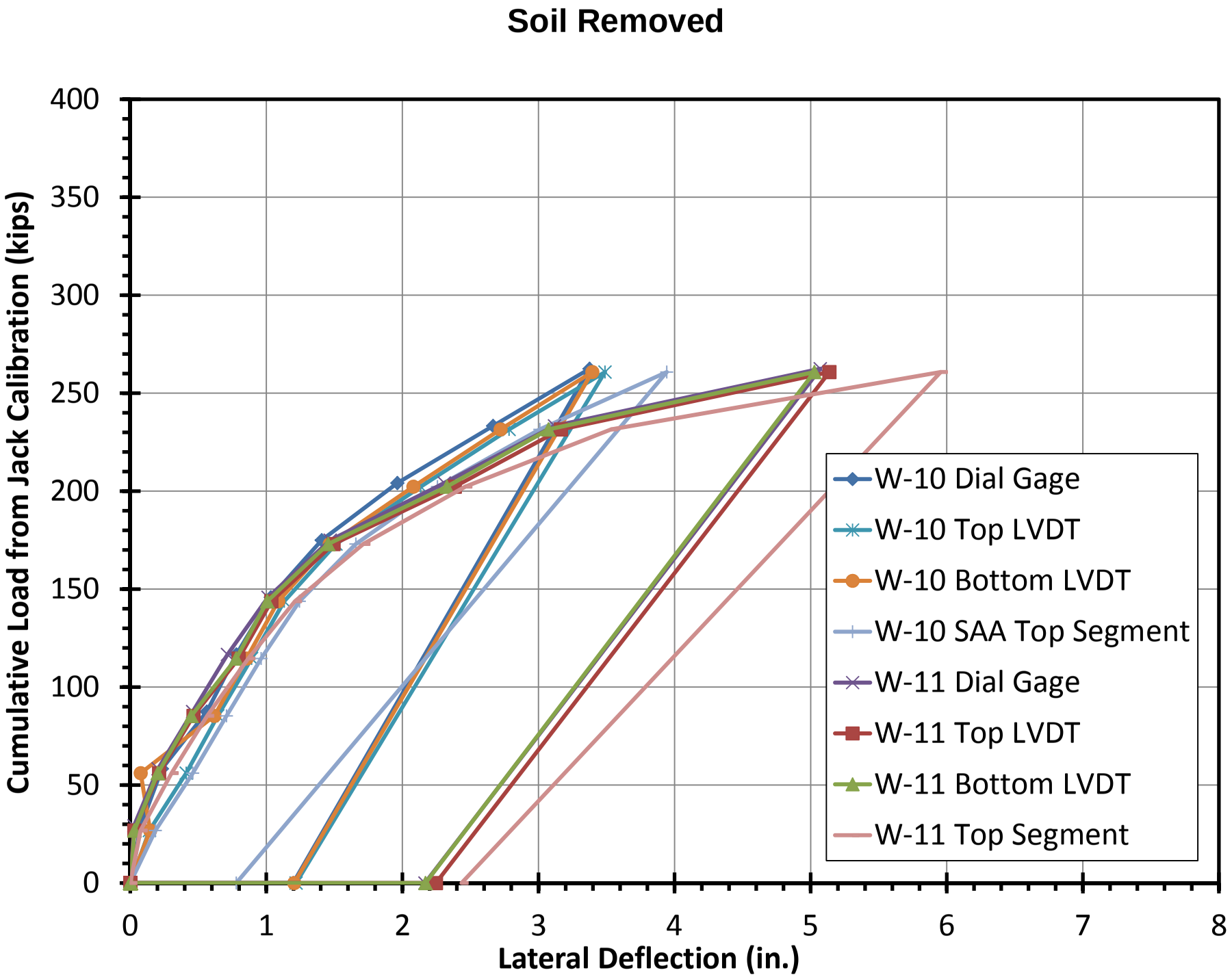

Soil Removed
Cumulative Load from Jack Calibration (kips)
Lateral Deflection (in.)
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
6
W-3 Dial Gage
W-3 Top LVDT
W-3 Bottom LVDT
W-3 SAA Top Segment
W-4 Dial Gage
W-4 Top LVDT
W-4 Bottom LVDT
W-4 SAA Top Segment

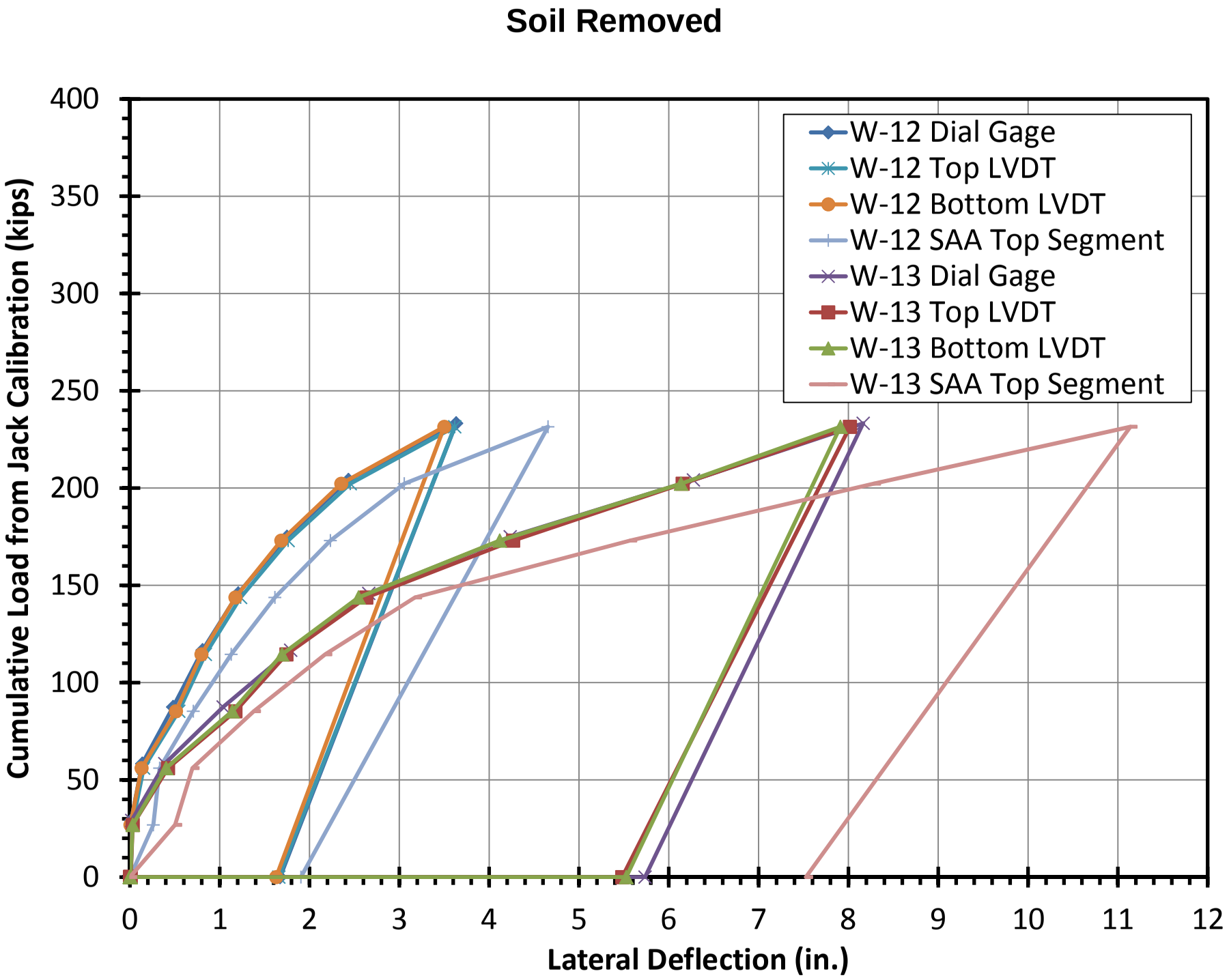

Soil Removed
Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
Lateral Deflection (in.)
W-6 Dial Gage
W-6 Top LVDT
W-6 Bottom LVDT
W-6 SAA Top Segment
W-7 Dial Gage
W-7 Top LVDT
W-7 Bottom LVDT
W-7 SAA Top Segment

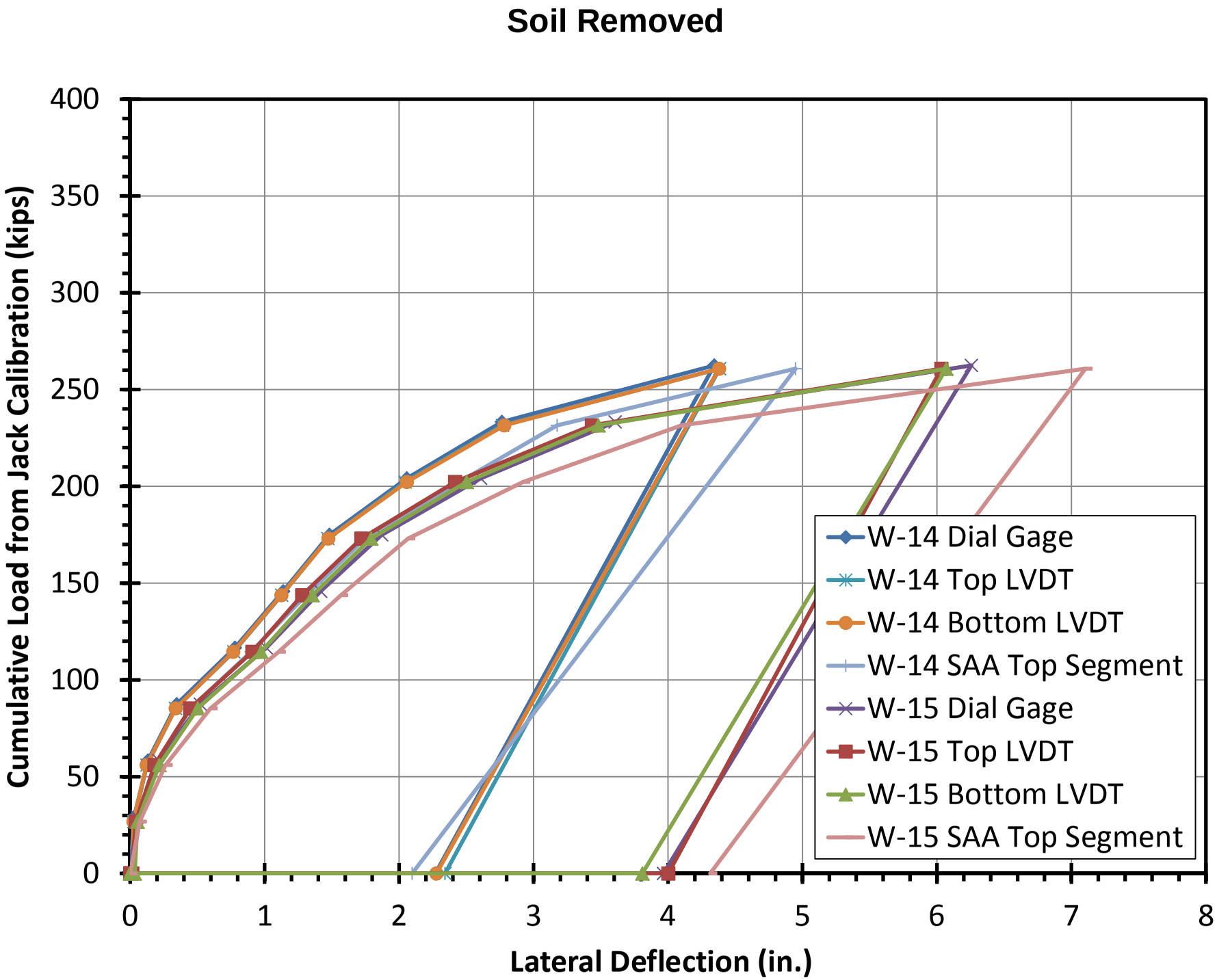

Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Lateral Deflection (in.)
W-8 Dial Gage
W-8 Top LVDT
W-8 Bottom LVDT
W-8 SAA Top Segment
W-9 Dial Gage
W-9 Top LVDT
W-9 Bottom LVDT
W-9 SAA Top Segment


Soil Removed
Cumulative Load from Jack Calibration (kips)
Lateral Deflection (in.)
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
6
7
8
W-8 Dial Gage
W-8 Top LVDT
W-8 Bottom LVDT
W-8 SAA Top Segment
W-9 Dial Gage
W-9 Top LVDT
W-9 Bottom LVDT
W-9 SAA Top Segment

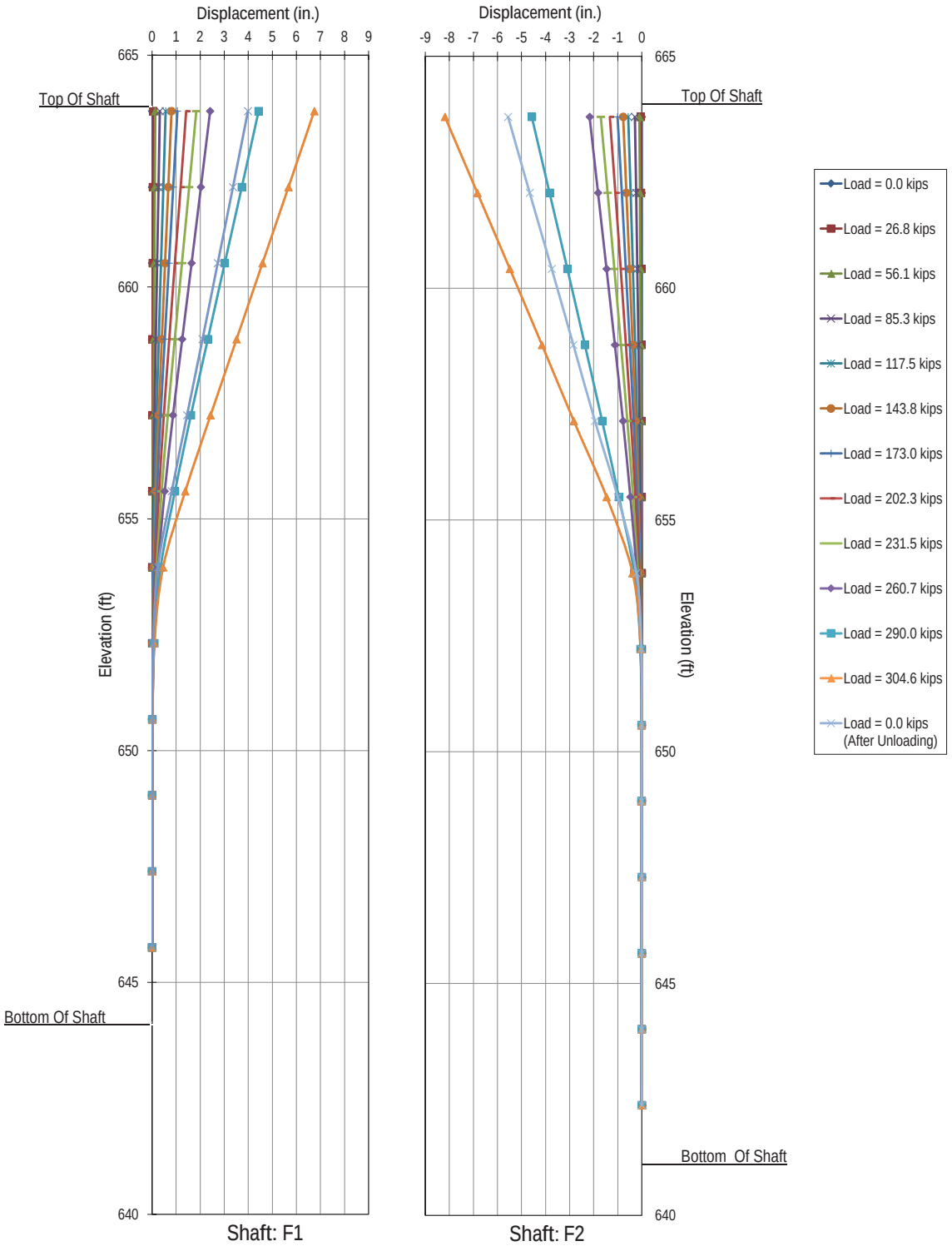

Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Lateral Deflection (in.)
W-10 Dial Gage
W-10 Top LVDT
W-10 Bottom LVDT
W-10 SAA Top Segment
W-11 Dial Gage
W-11 Top LVDT
W-11 Bottom LVDT
W-11 SAA Top Segment


Soil Removed
Cumulative Load from Jack Calibration (kips)
Lateral Deflection (in.)
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
6
7
8
W-10 Dial Gage
W-10 Top LVDT
W-10 Bottom LVDT
W-10 SAA Top Segment
W-11 Dial Gage
W-11 Top LVDT
W-11 Bottom LVDT
W-11 Top Segment

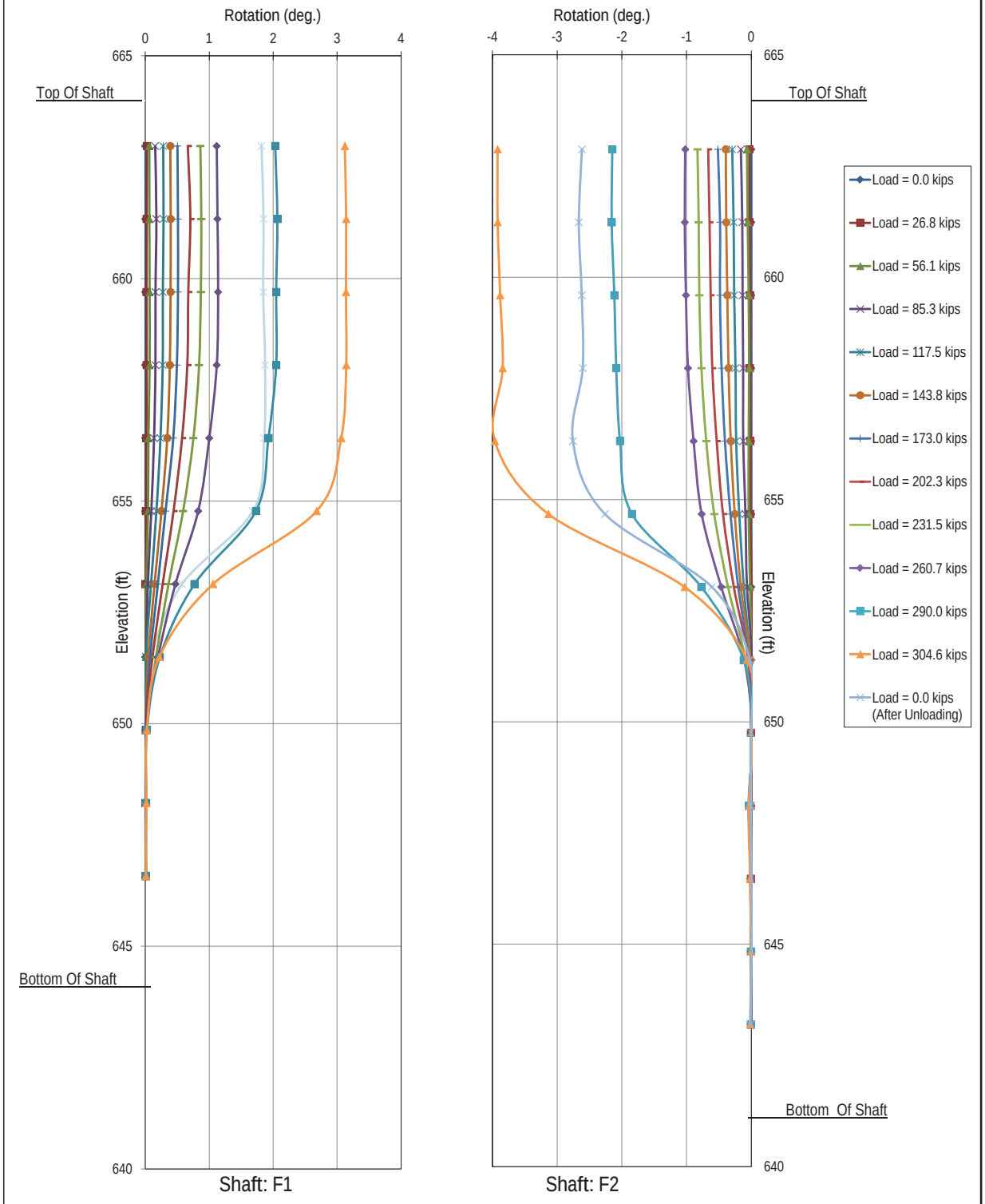

Soil Removed
Cumulative Load from Jack Calibration (kips)
Lateral Deflection (in.)
0
50
100
150
200
250
300
350
400
0
1
2
3
4
5
6
7
8
9
10
11
12
W-12 Dial Gage
W-12 Top LVDT
W-12 Bottom LVDT
W-12 SAA Top Segment
W-13 Dial Gage
W-13 Top LVDT
W-13 Bottom LVDT
W-13 SAA Top Segment


Soil Removed
Cumulative Load from Jack Calibration (kips)
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
Lateral Deflection (in.)
W-14 Dial Gage
W-14 Top LVDT
W-14 Bottom LVDT
W-14 SAA Top Segment
W-15 Dial Gage
W-15 Top LVDT
W-15 Bottom LVDT
W-15 SAA Top Segment

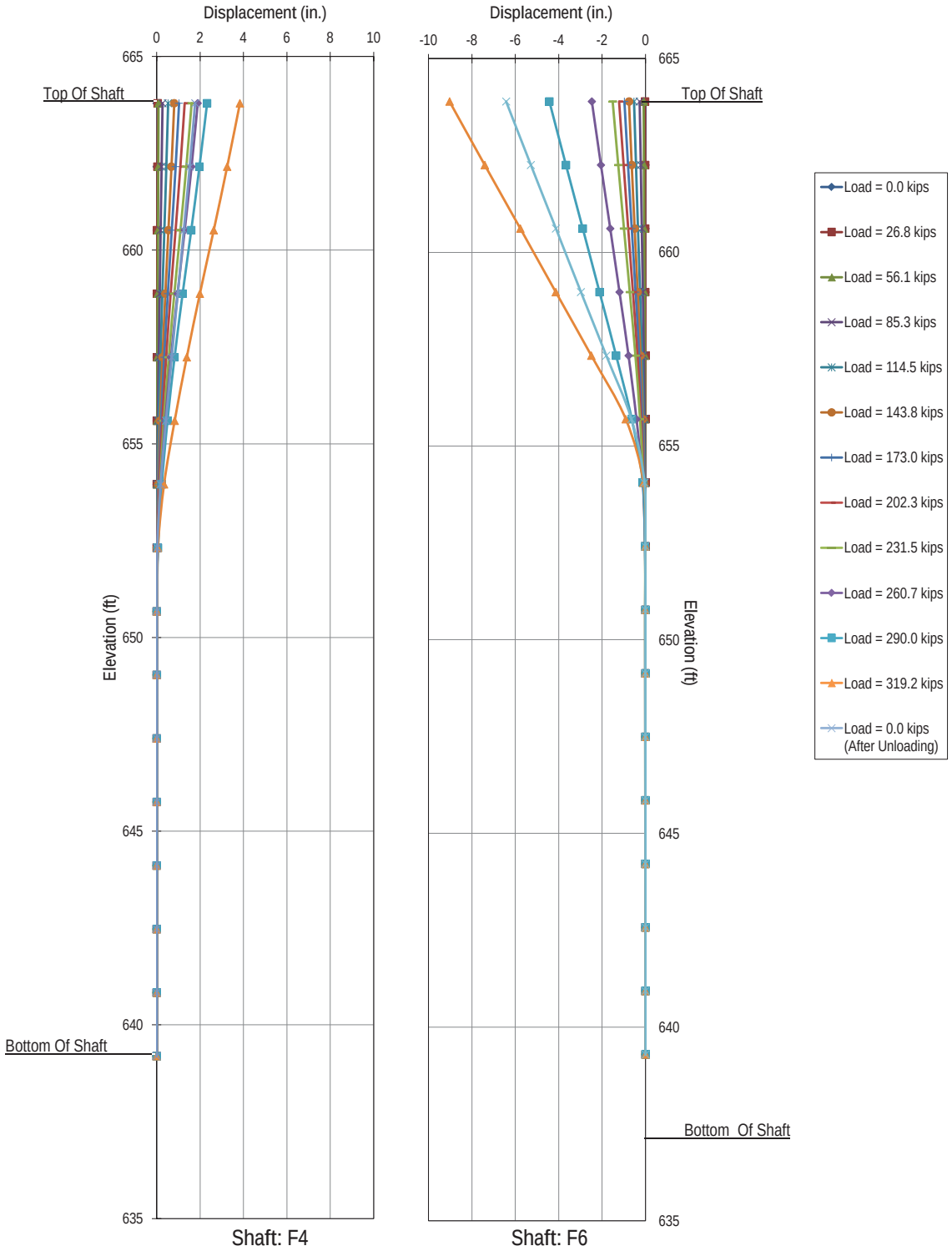
Appendix C – Test Displacement and Rotation Profiles



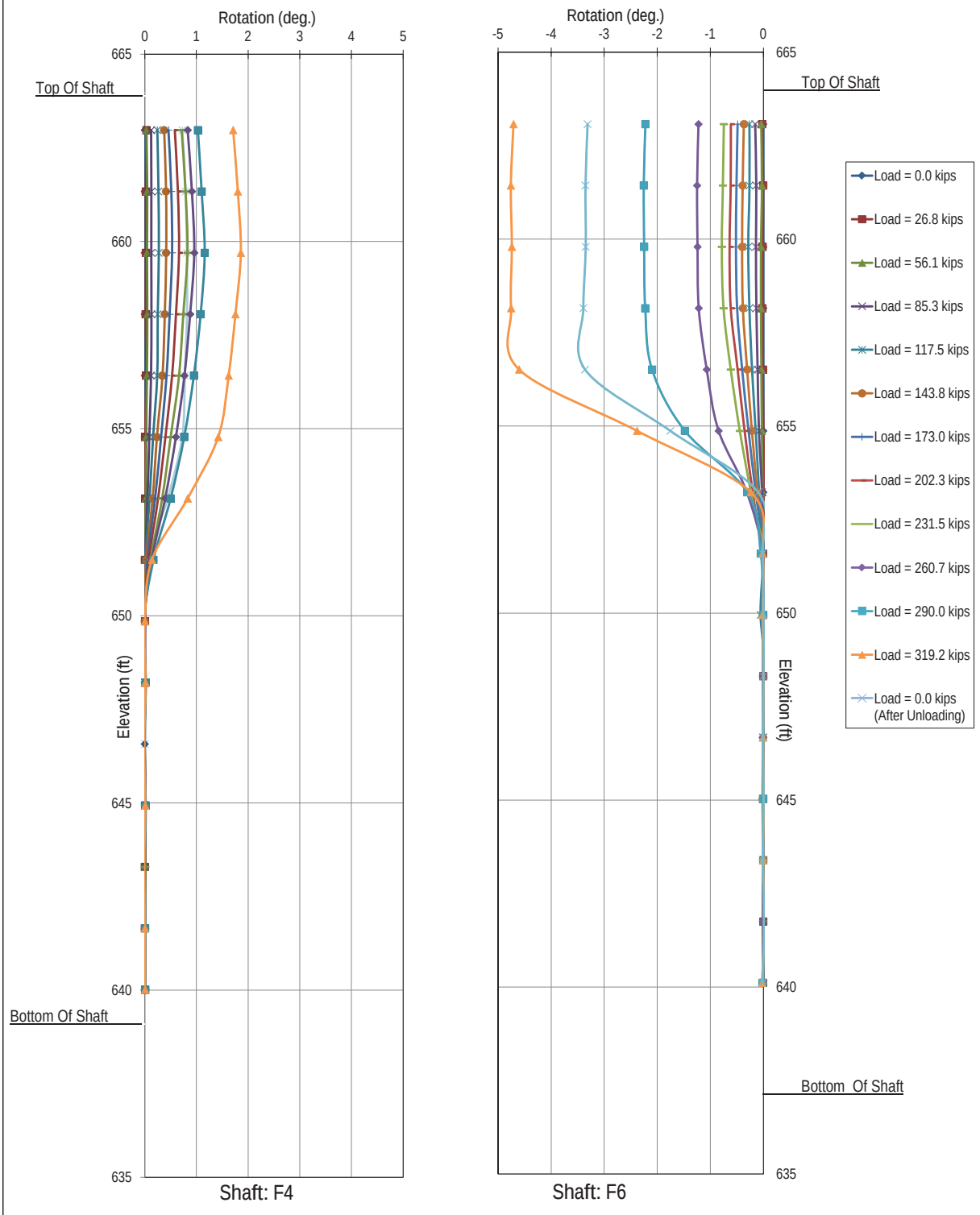
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Frankford Test: F1-F2 Test Date: 8/23/2012	



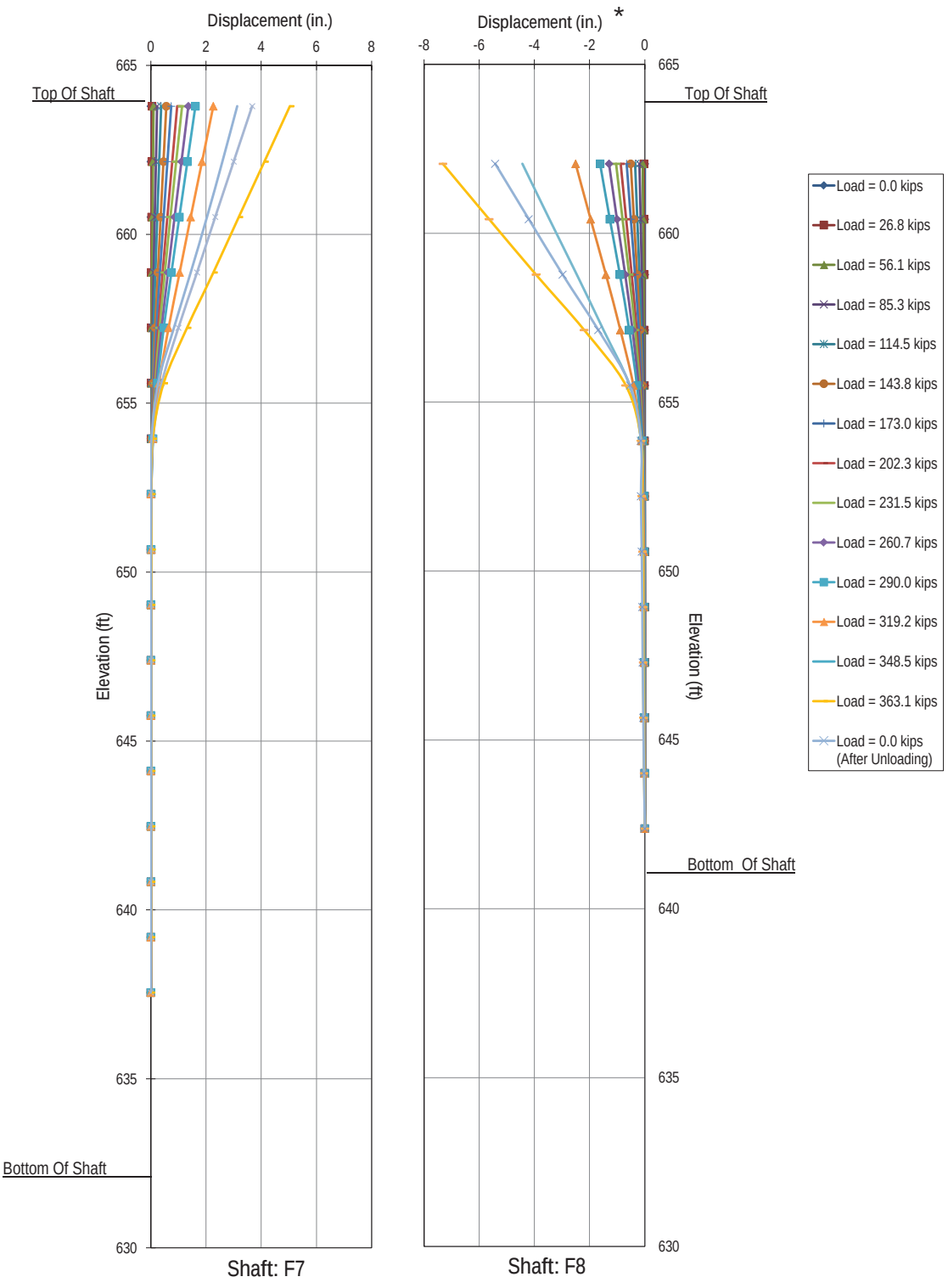
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Frankford Test: F1-F2 Test Date: 8/23/2012	



MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Frankford Test: F4-F6 Test Date: 8/29/2012	

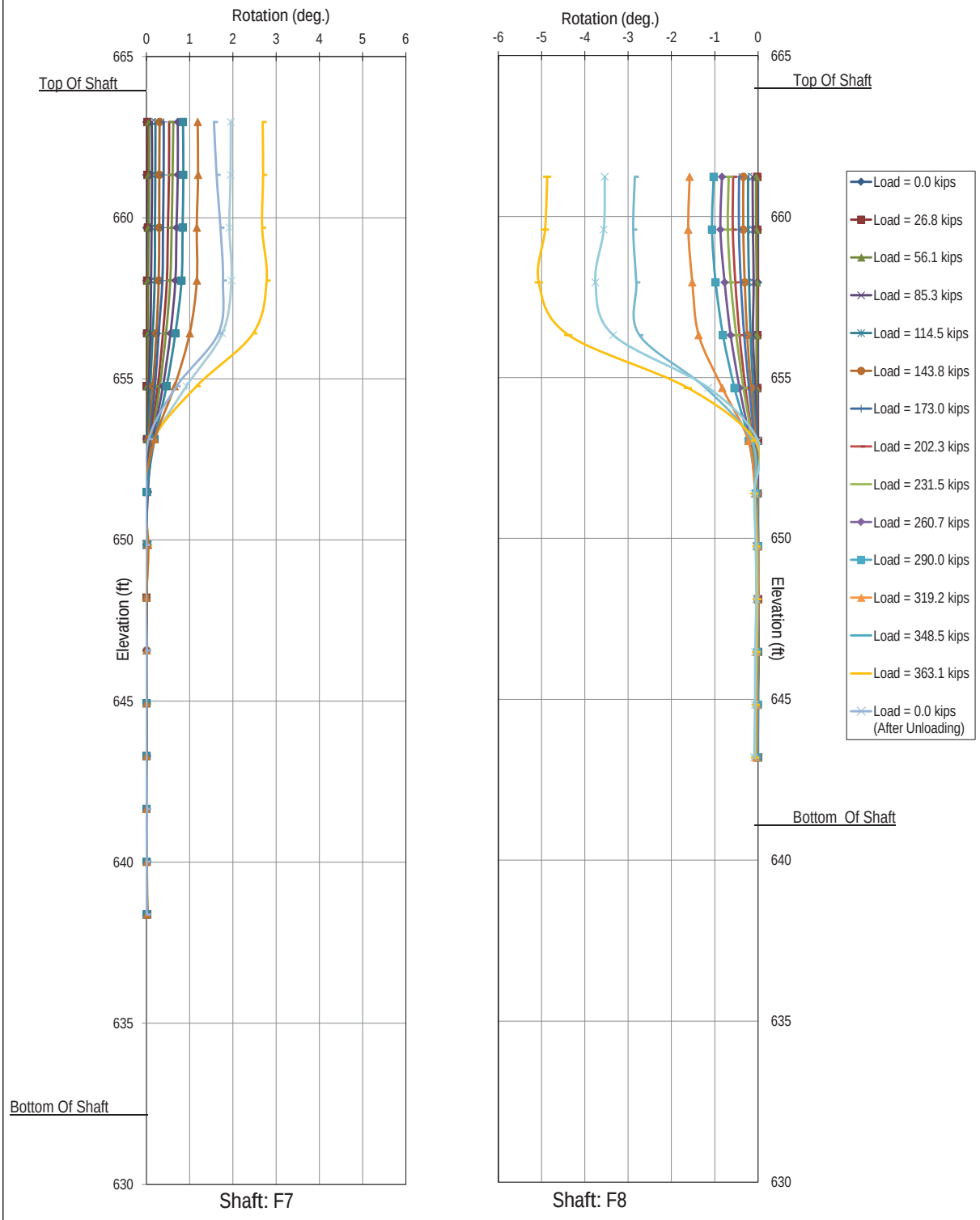


MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Frankford Test: F4-F6 Test Date: 8/29/2012	

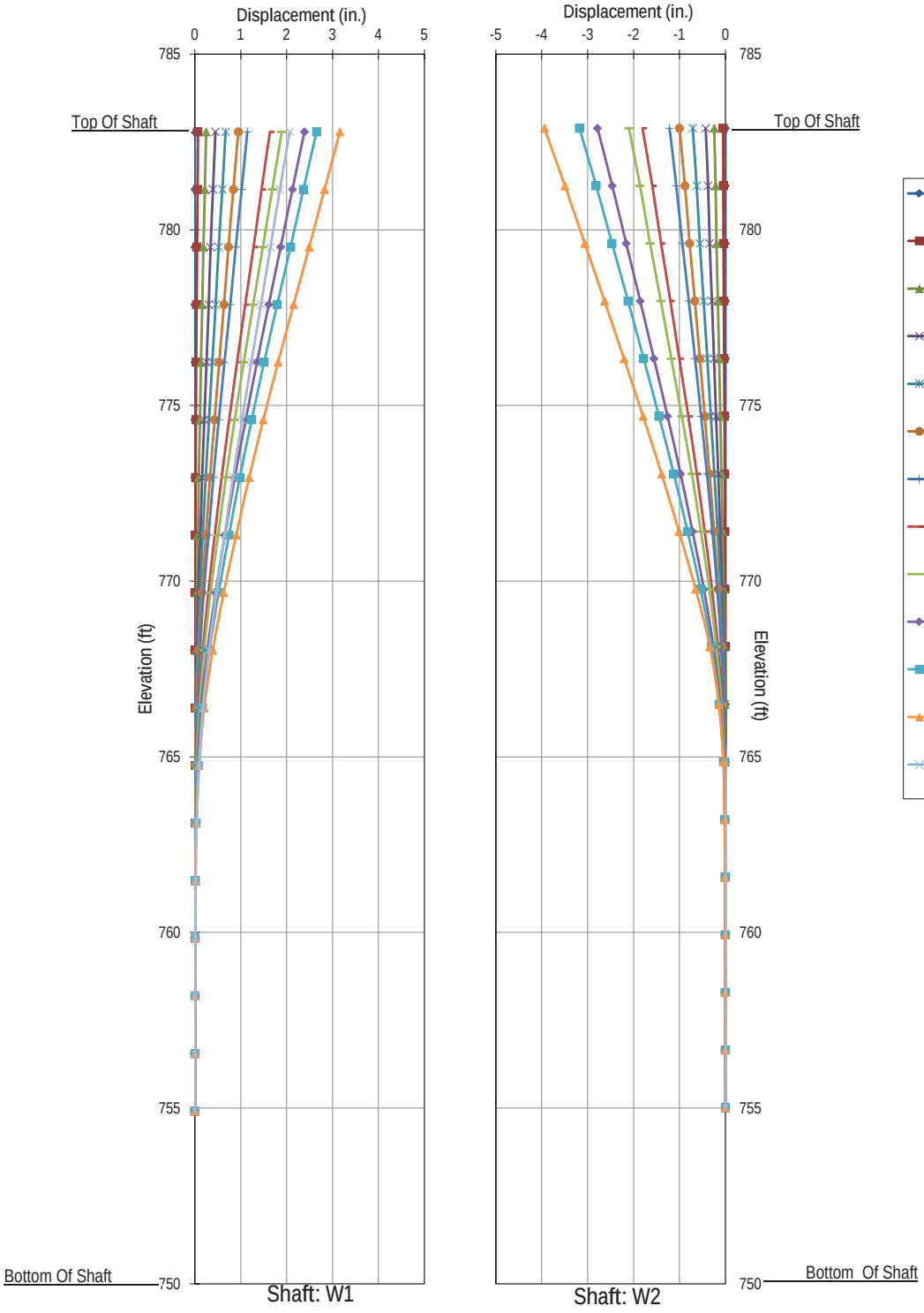


MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Frankford Test: F7-F8 Test Date: 8/27/2012	

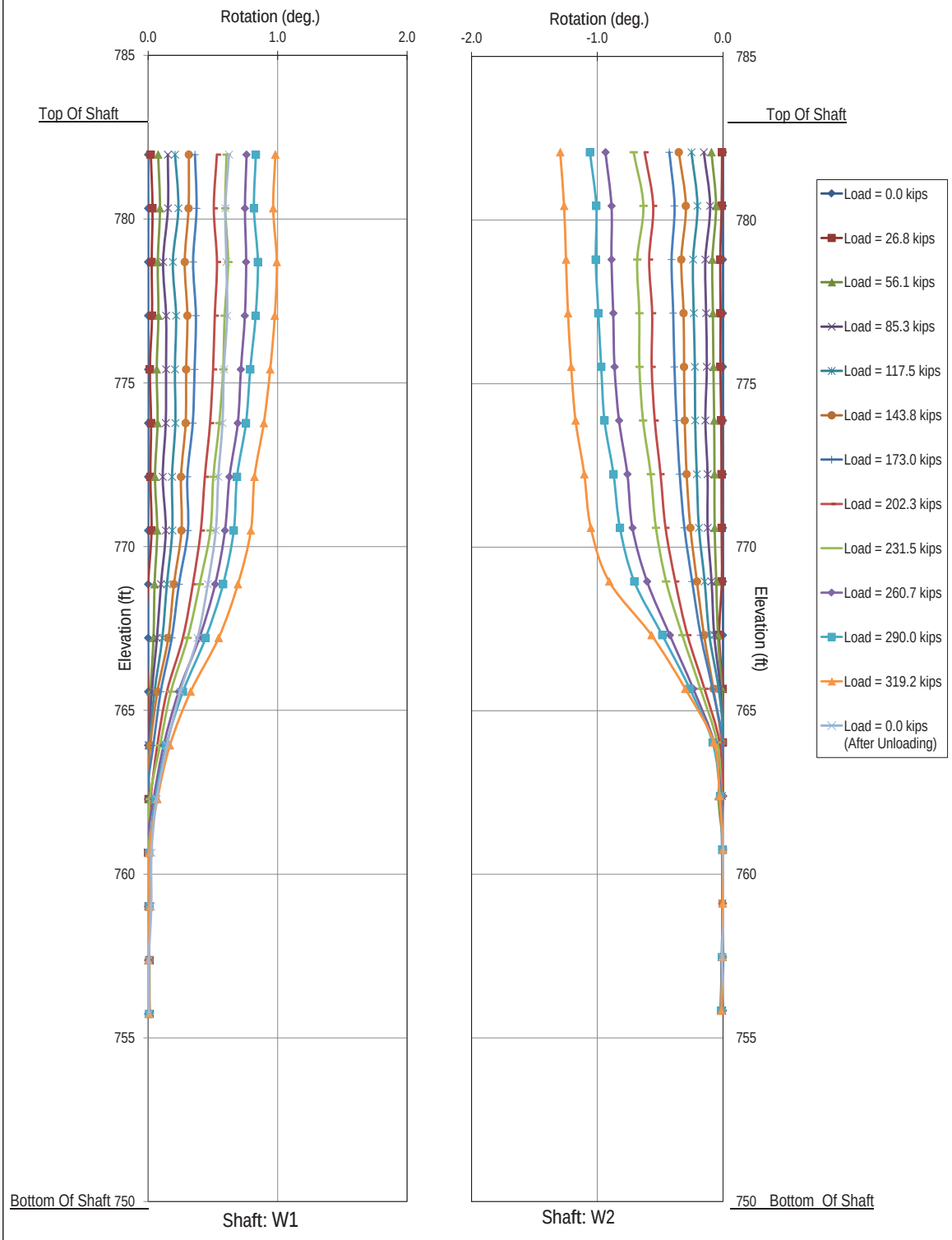
*SAA data for the top segment of F8 was neglected since it conflicted with LVDT and dial gage data.



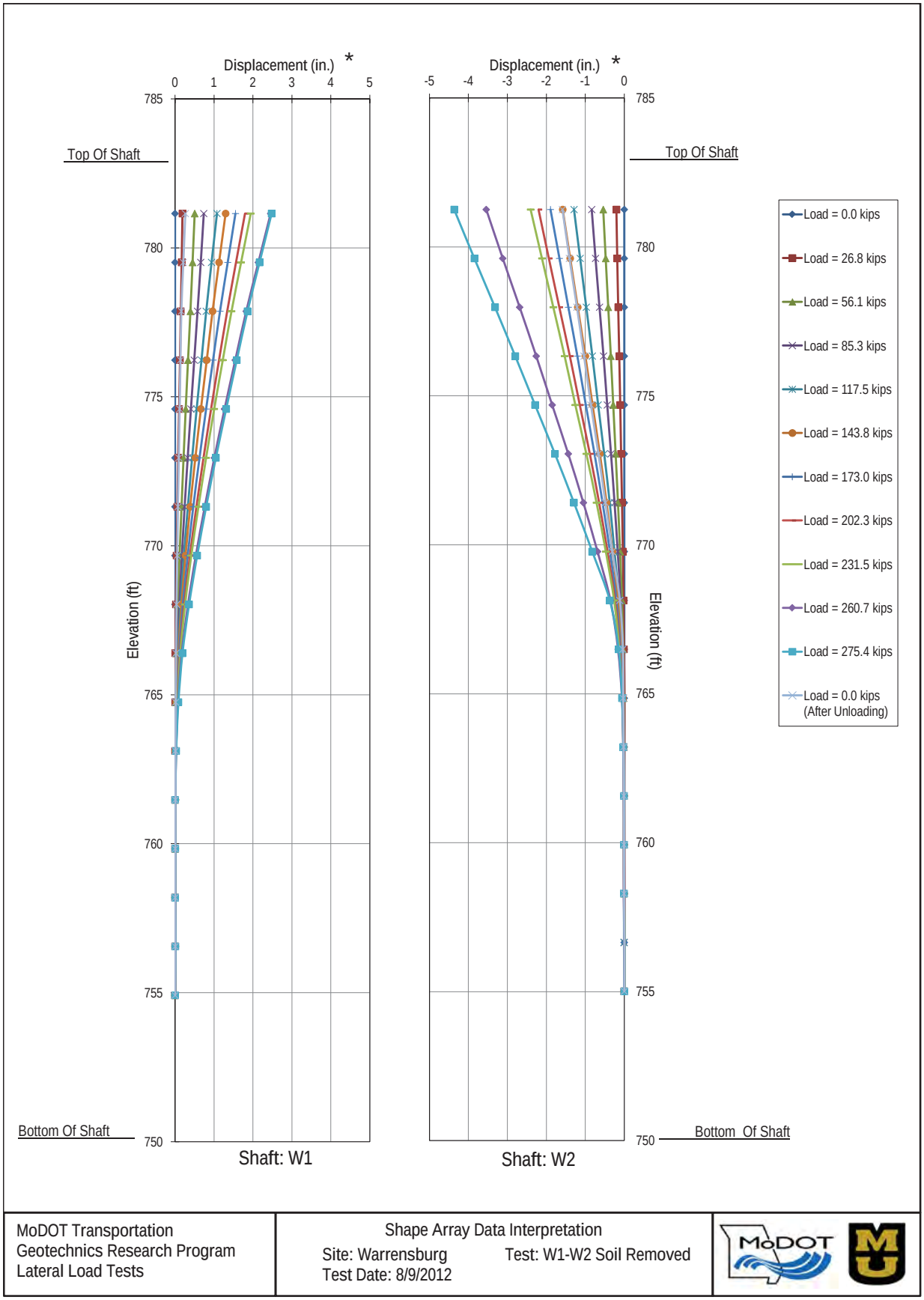
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Frankford Test: F7-F8 Test Date: 8/27/2012	



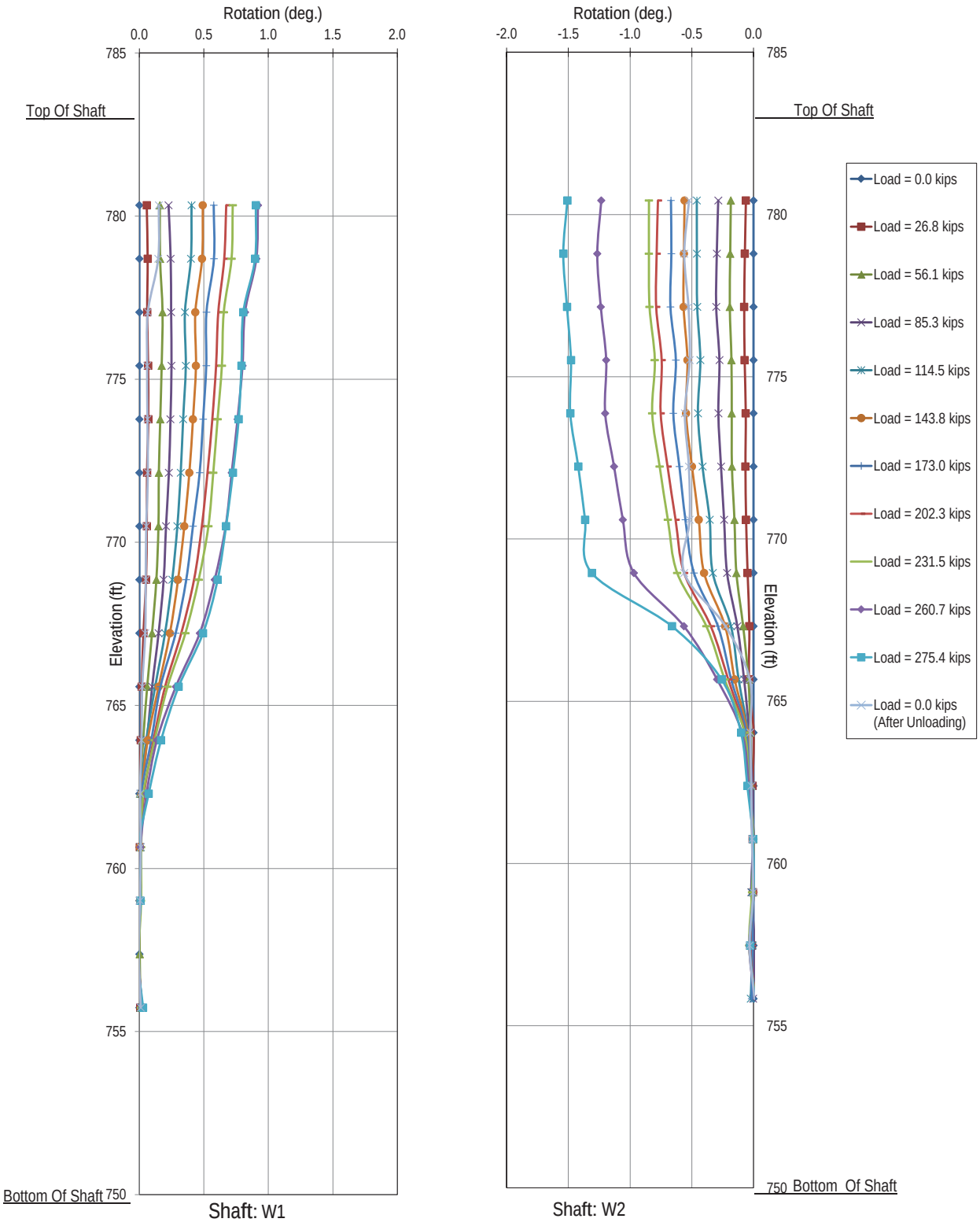
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W1-W2 Test Date: 8/1/2012	



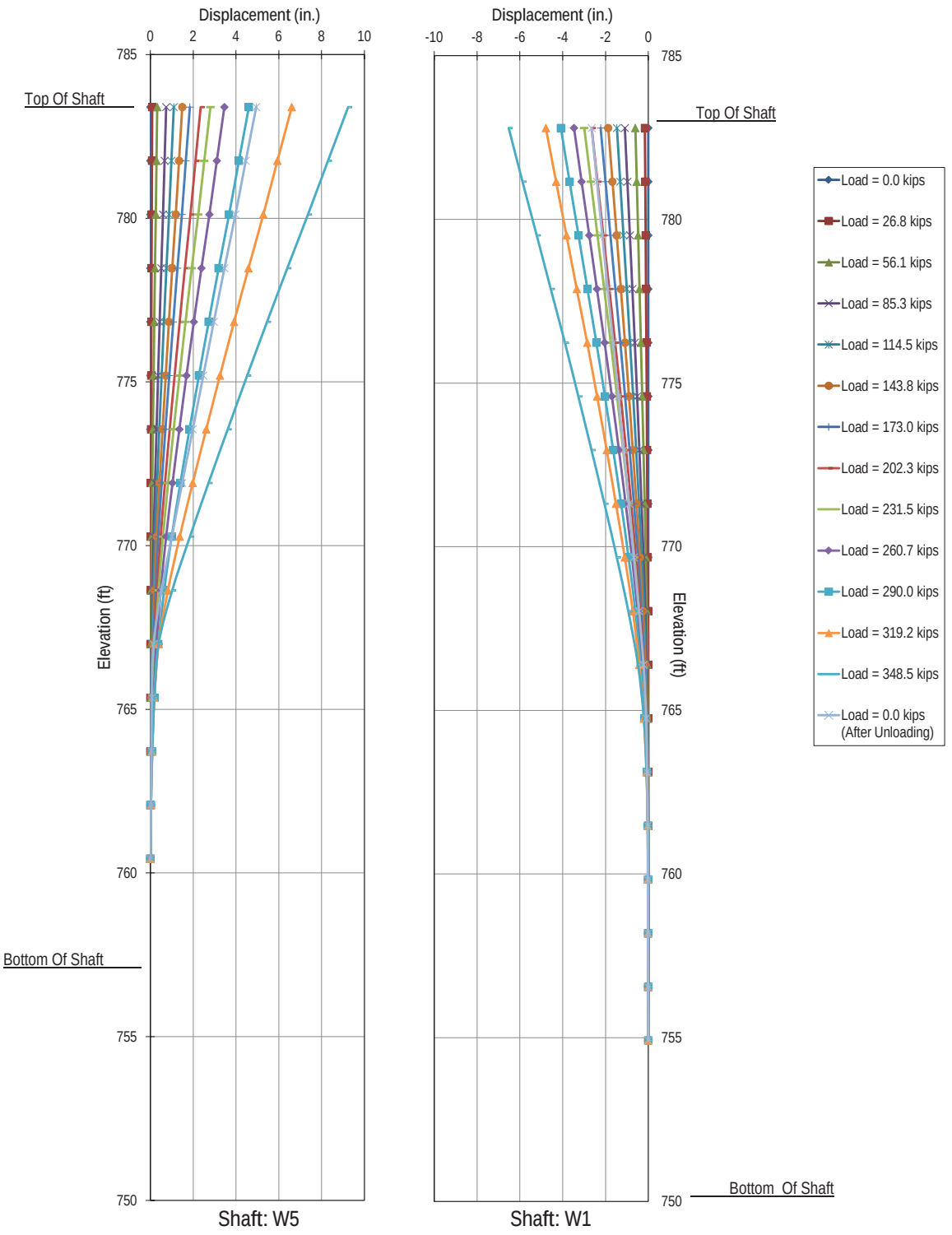
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W1-W2 Test Date: 8/1/2012	



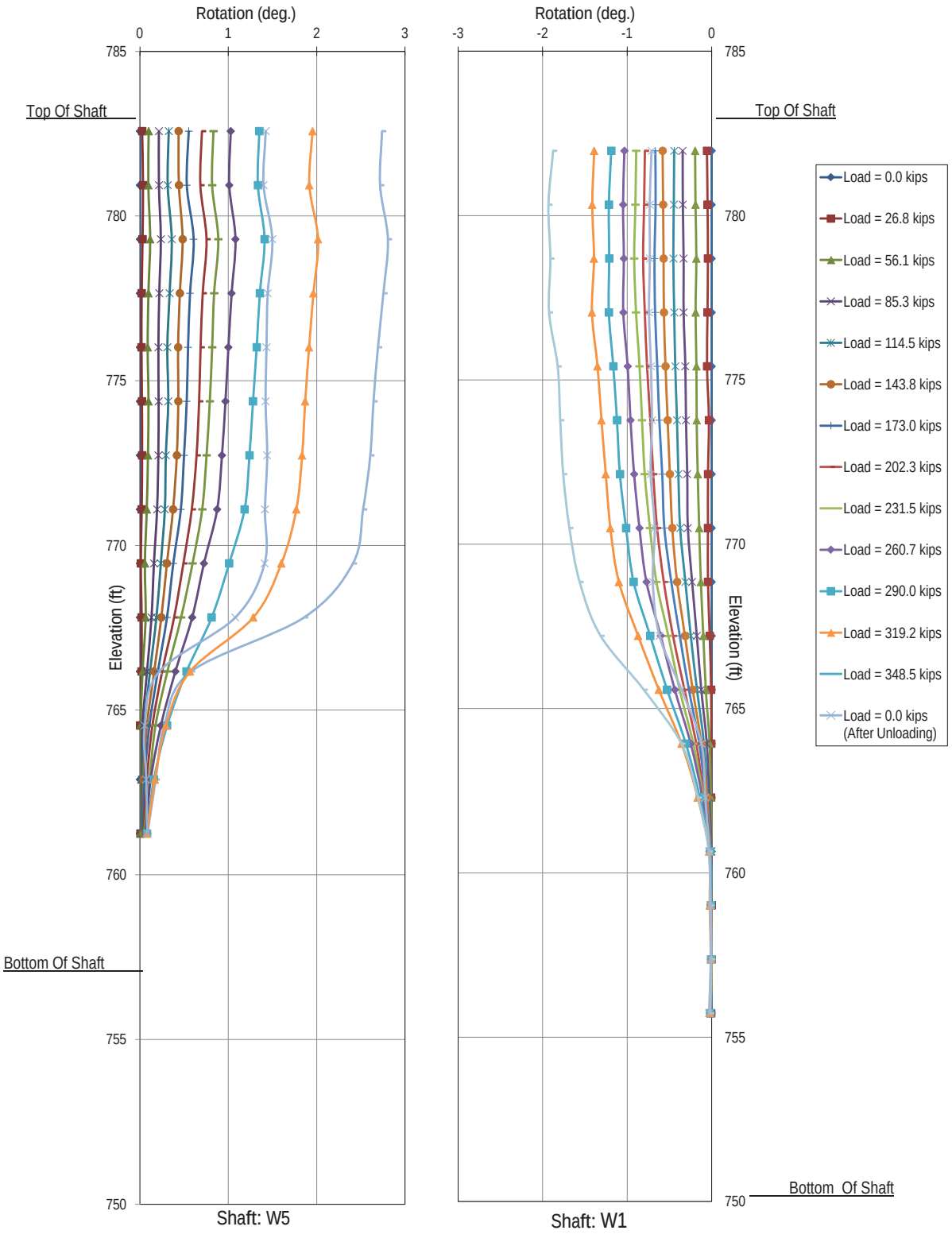
*SAA data for the top segments of W1 and W2 were neglected since they conflicted with LVDT and dial gage data.



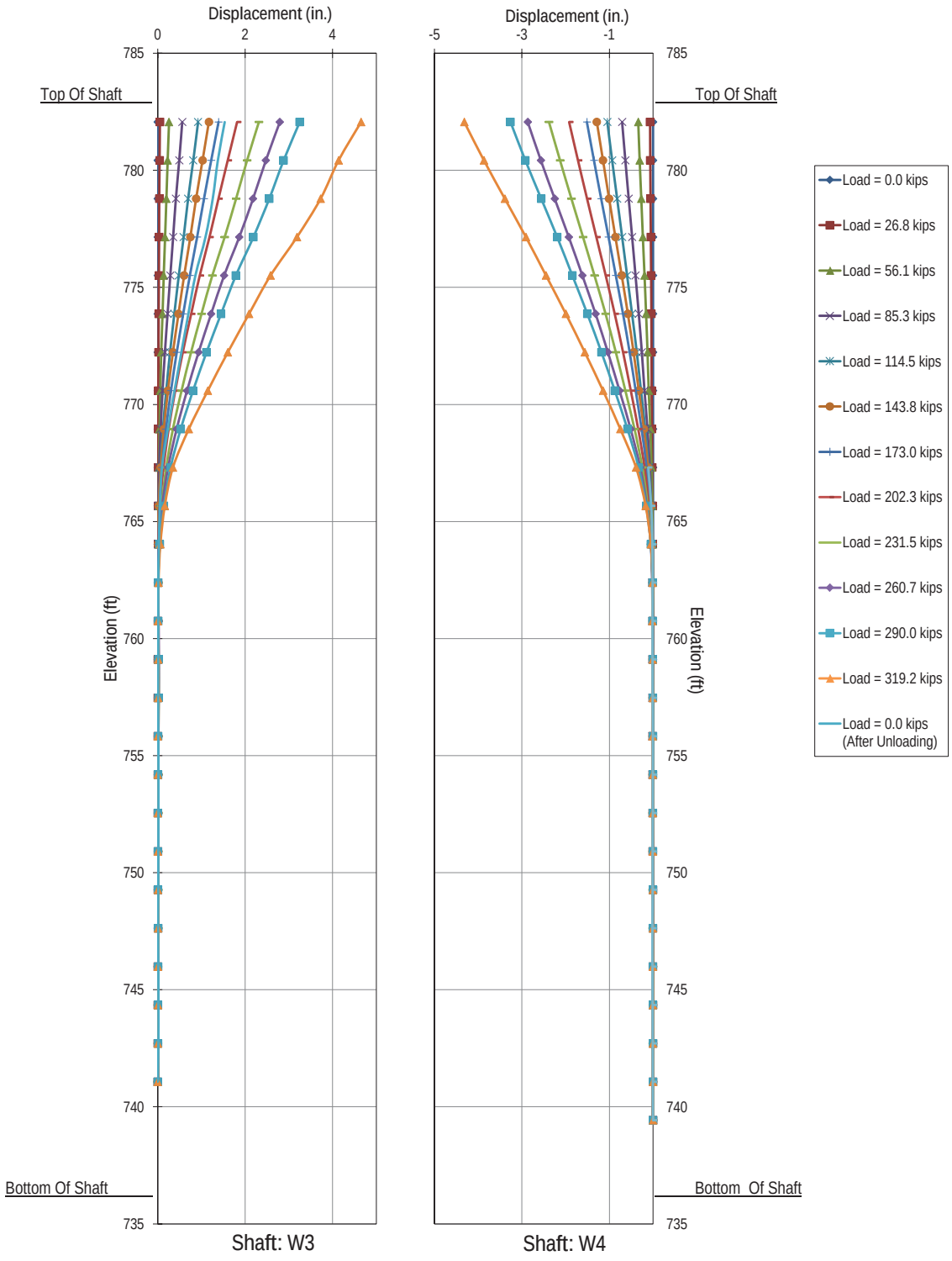
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W1-W2 Soil Removed Test Date: 8/9/2012	MoDOT



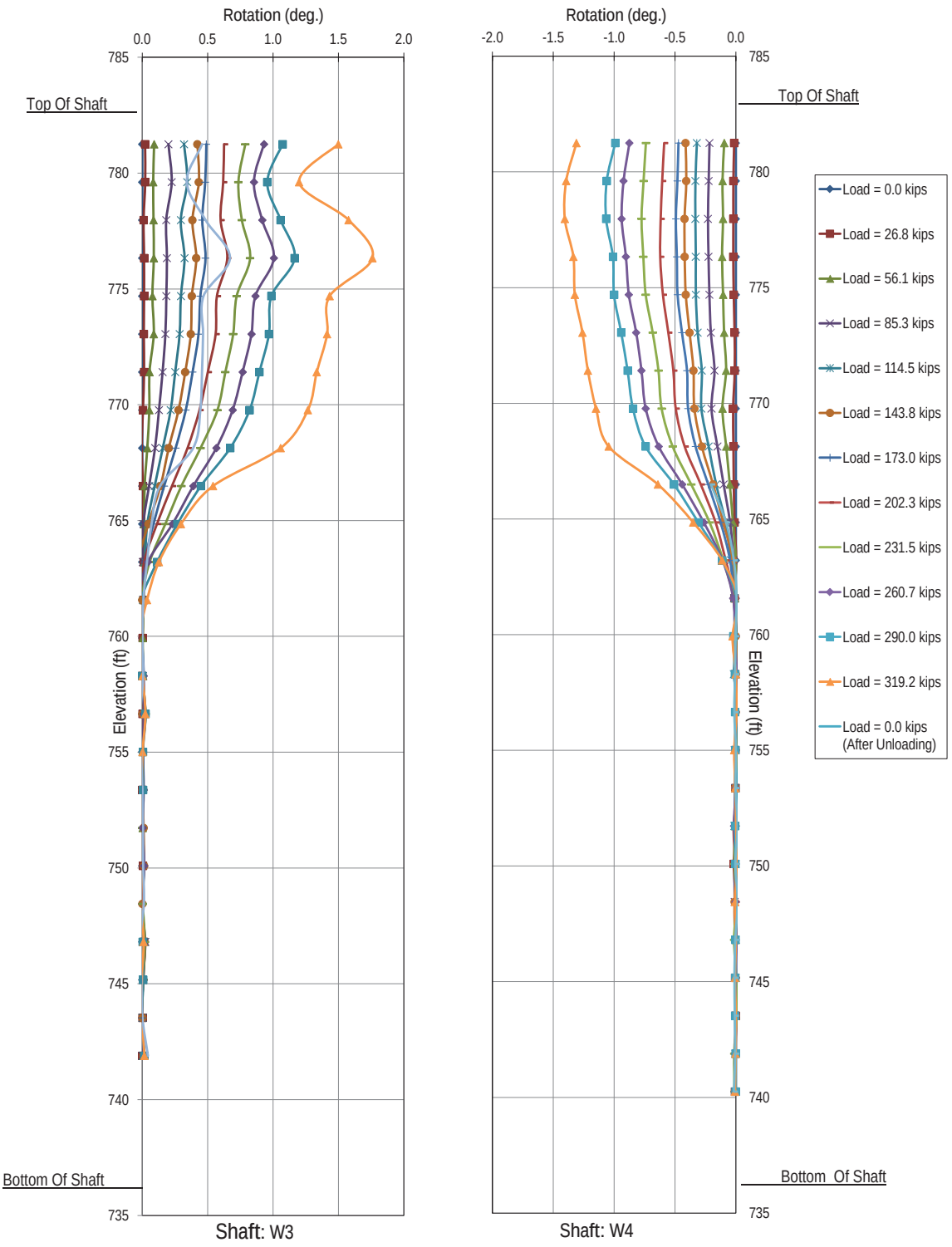
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W1-W5 Soil Removed Test Date: 8/20/2012	



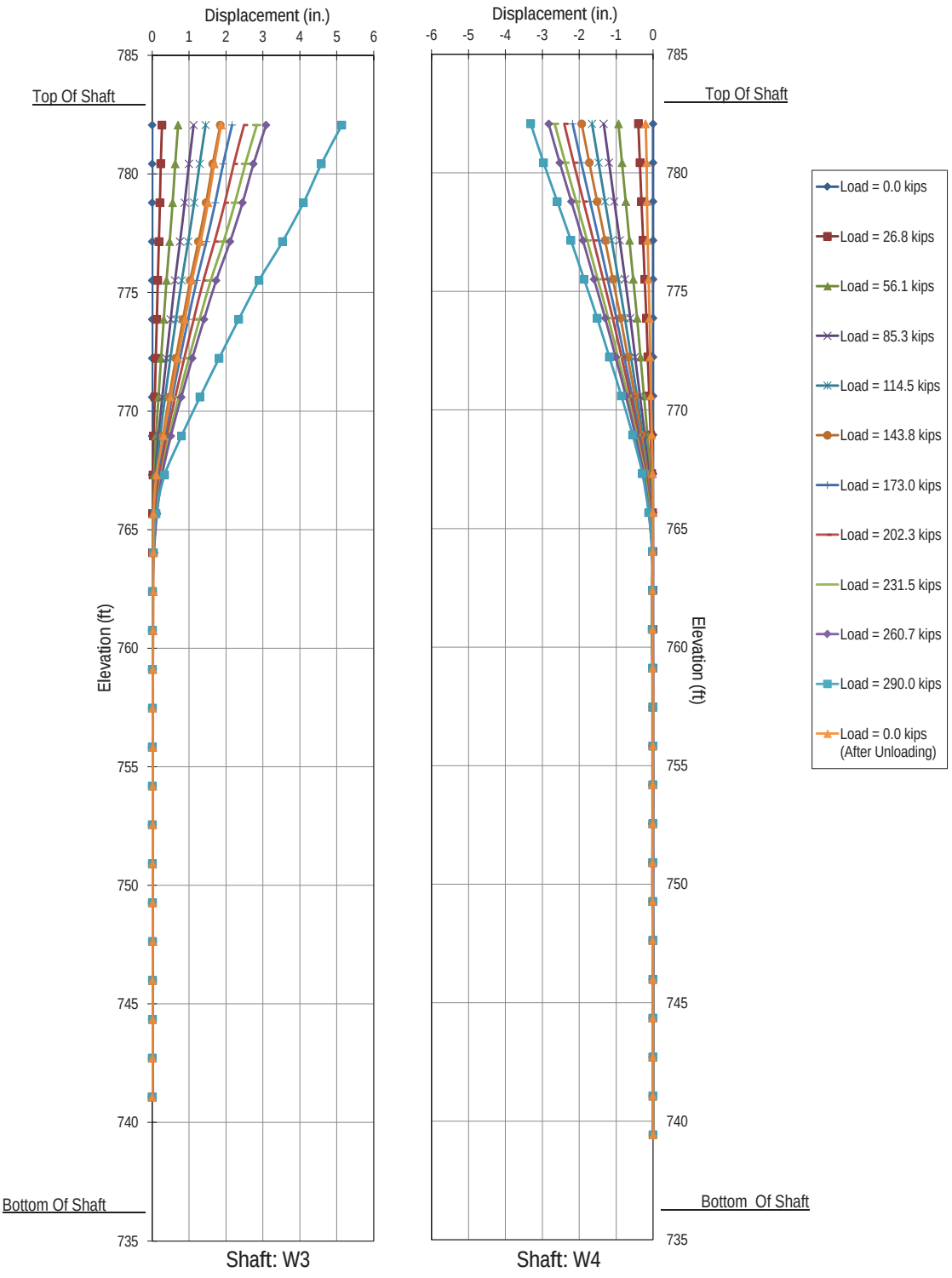
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W1-W5 Soil Removed Test Date: 8/20/2012	



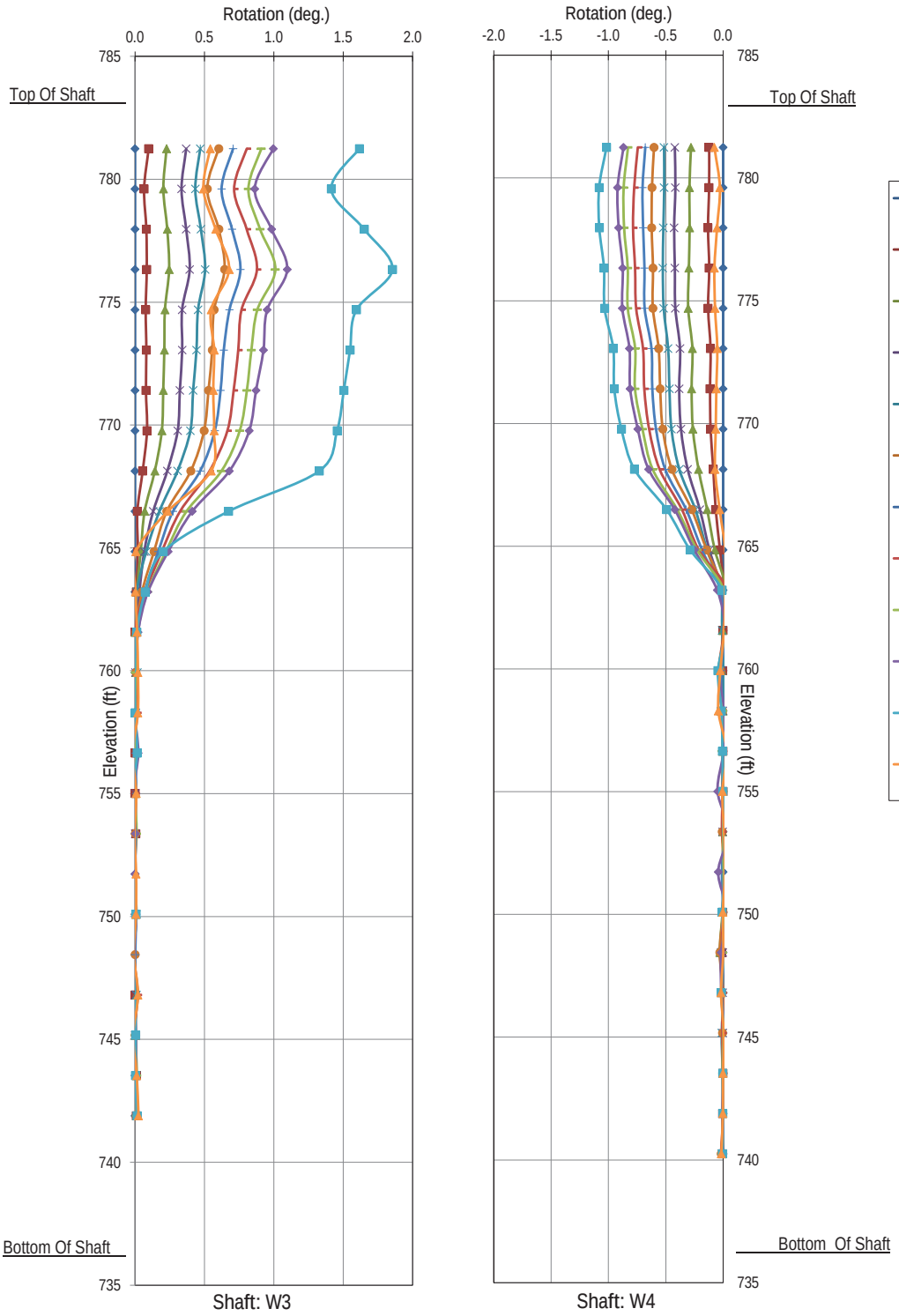
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W3-W4 Test Date: 8/6/2012	



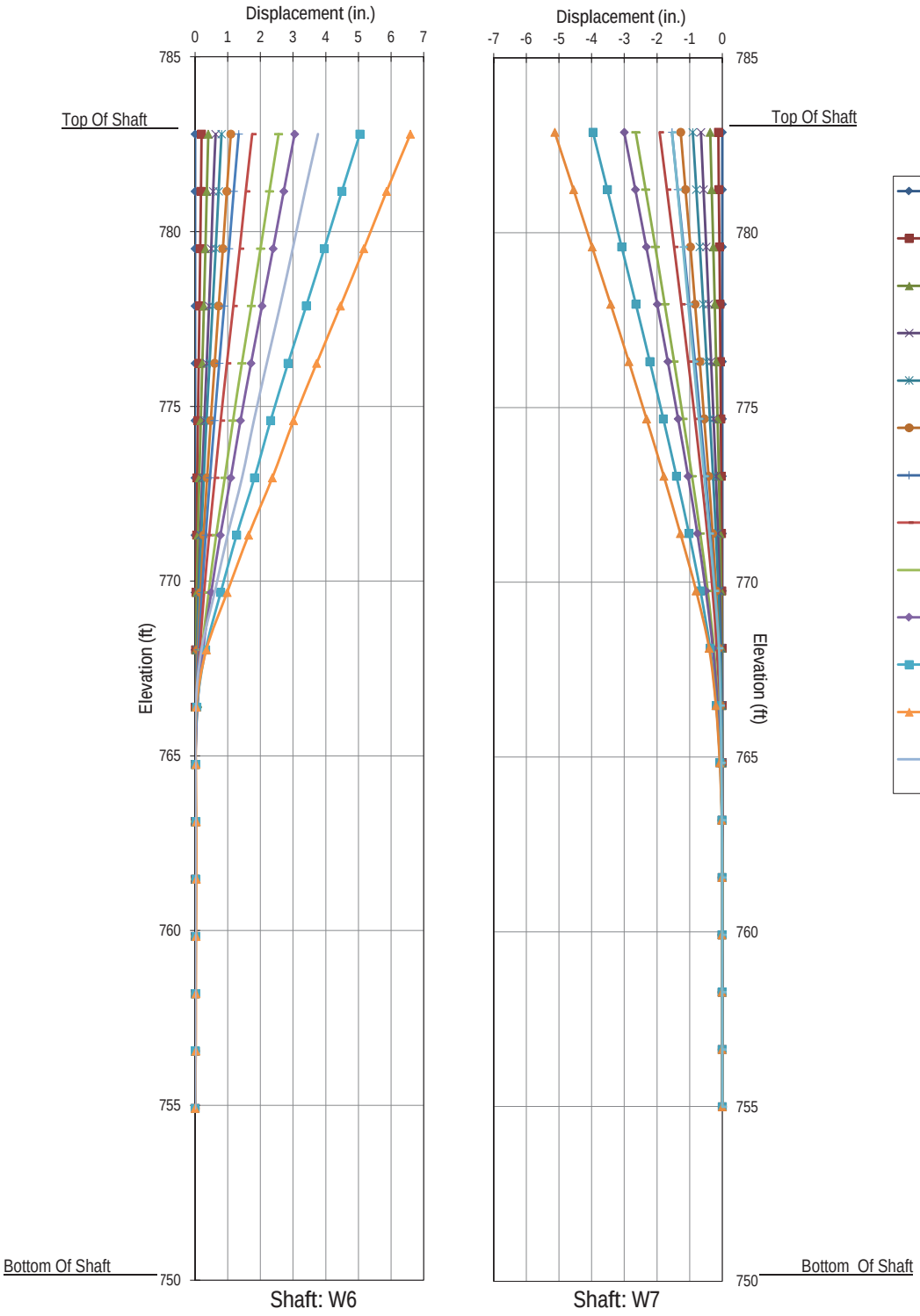
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W3-W4 Test Date: 8/6/2012	



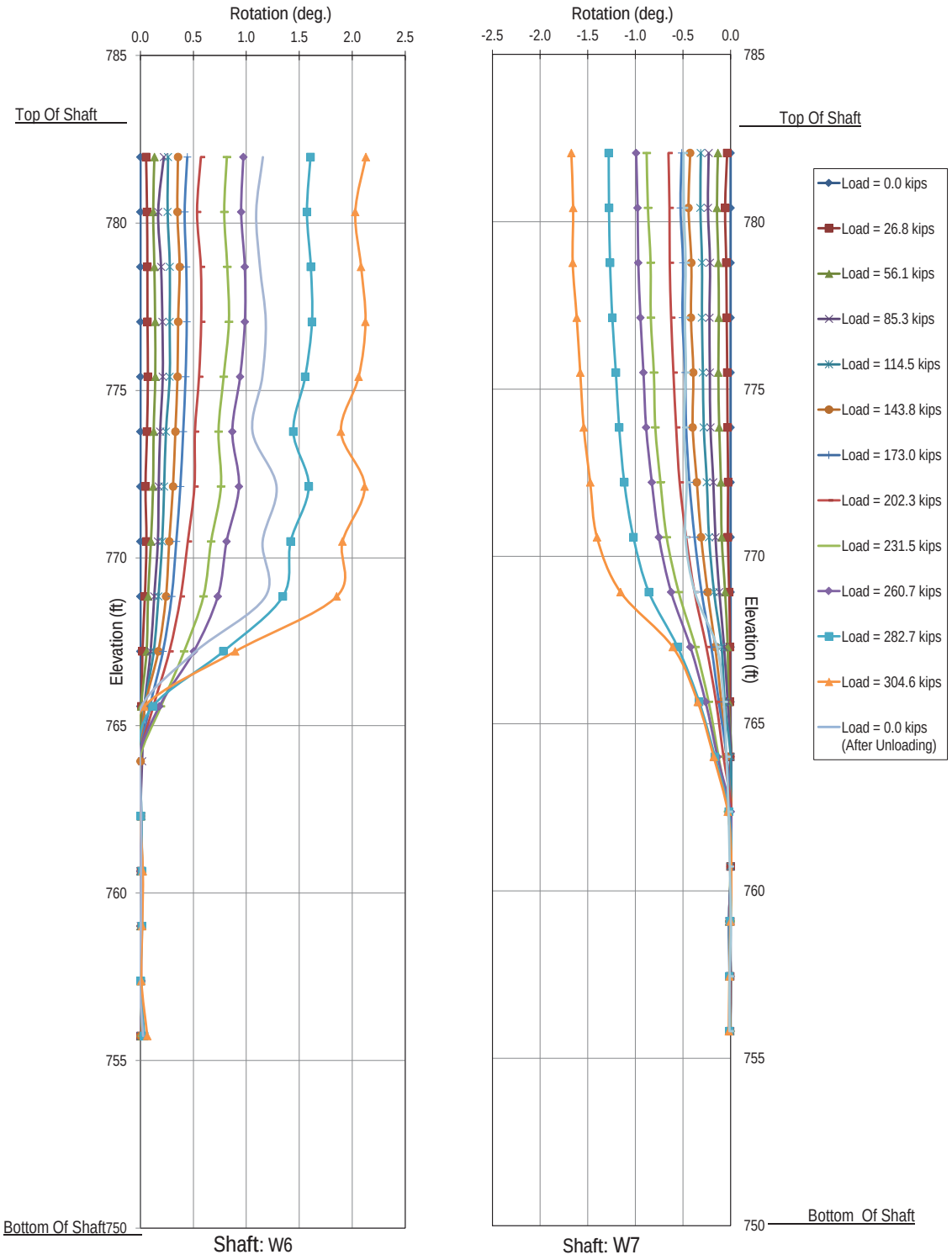
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W3-W4 Soil Removed Test Date: 8/7/2012	



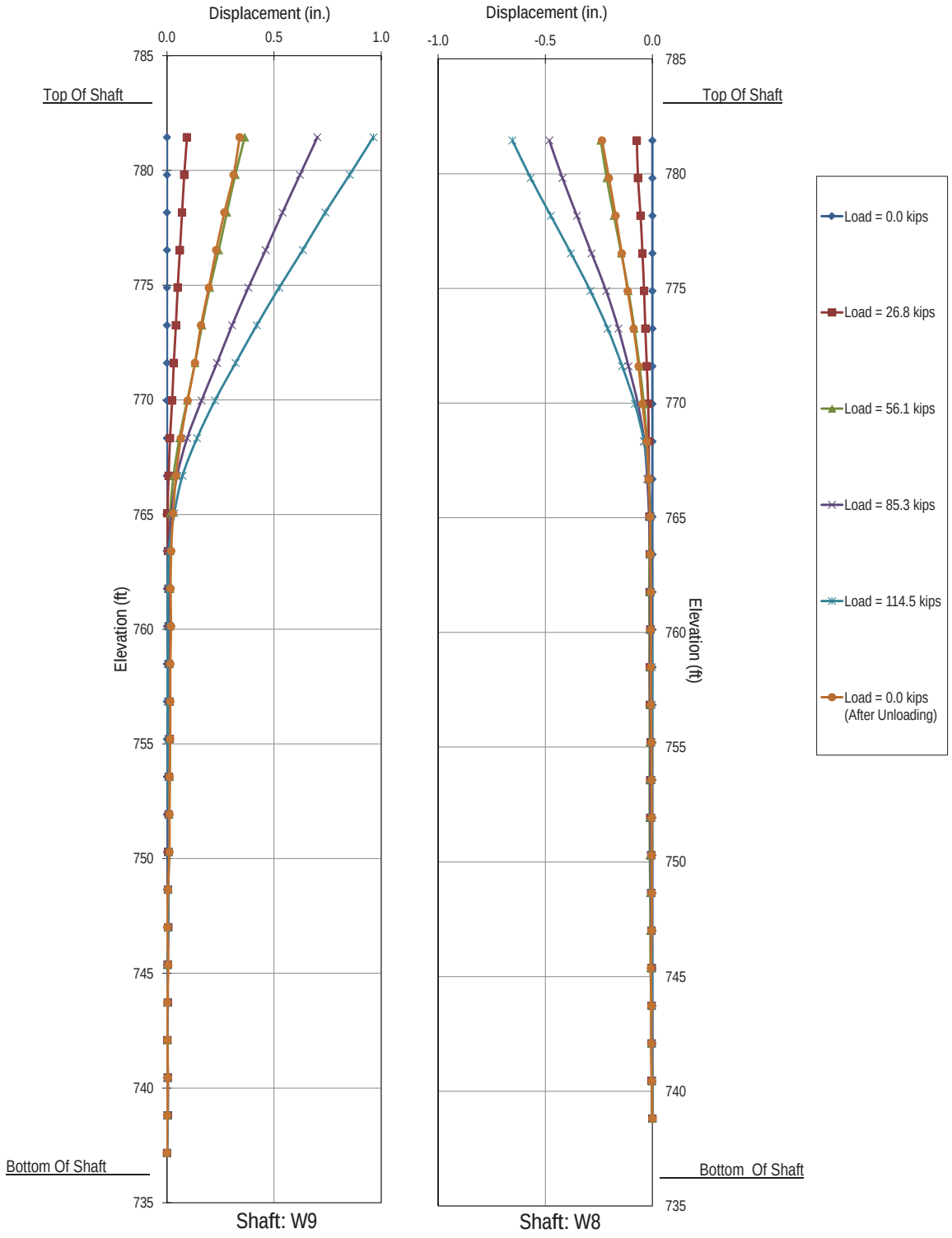
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W3-W4 Soil Removed Test Date: 8/7/2012	



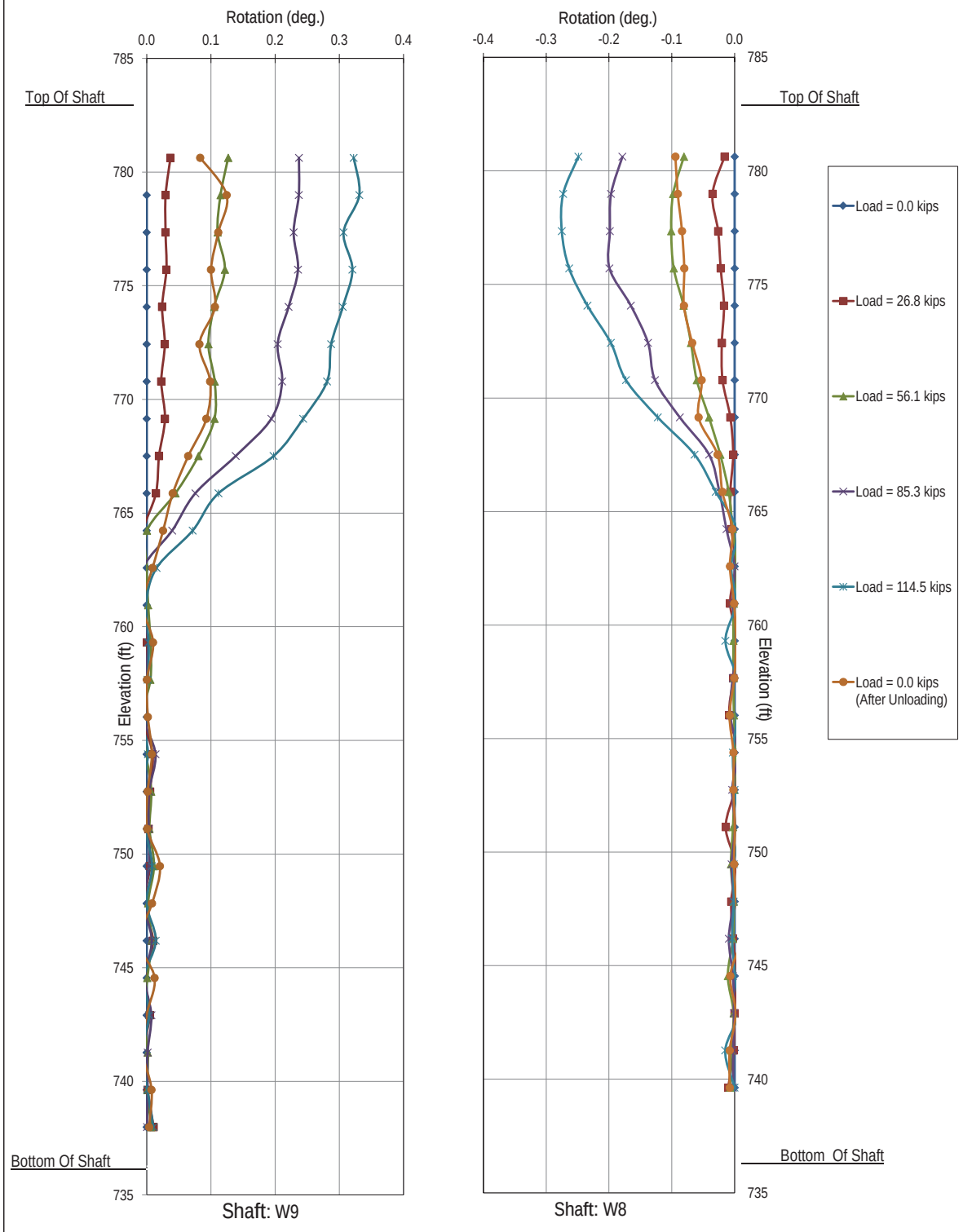
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W6-W7 Soil Removed Test Date: 8/11/2012	



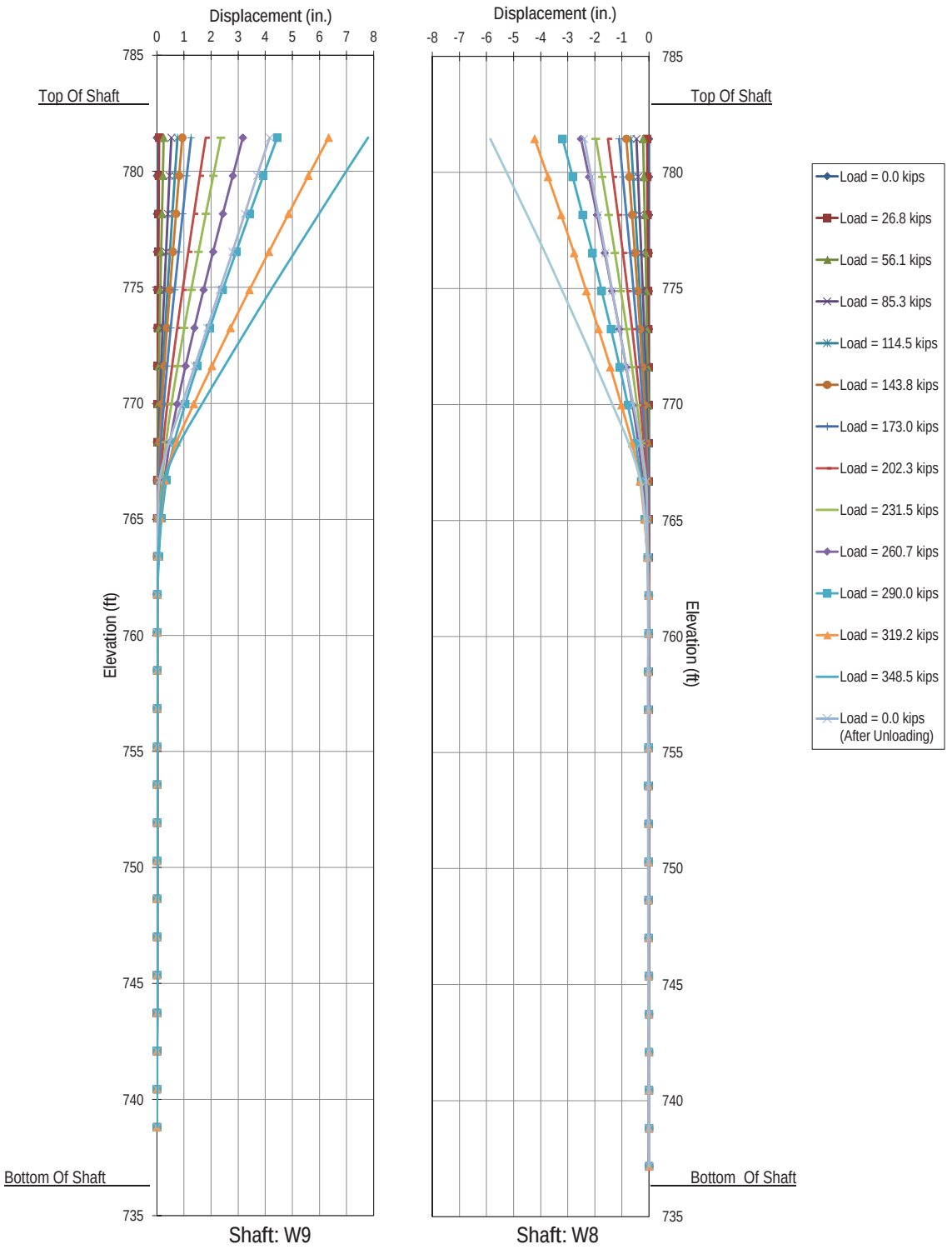
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W6-W7 Soil Removed Test Date: 8/11/2012	



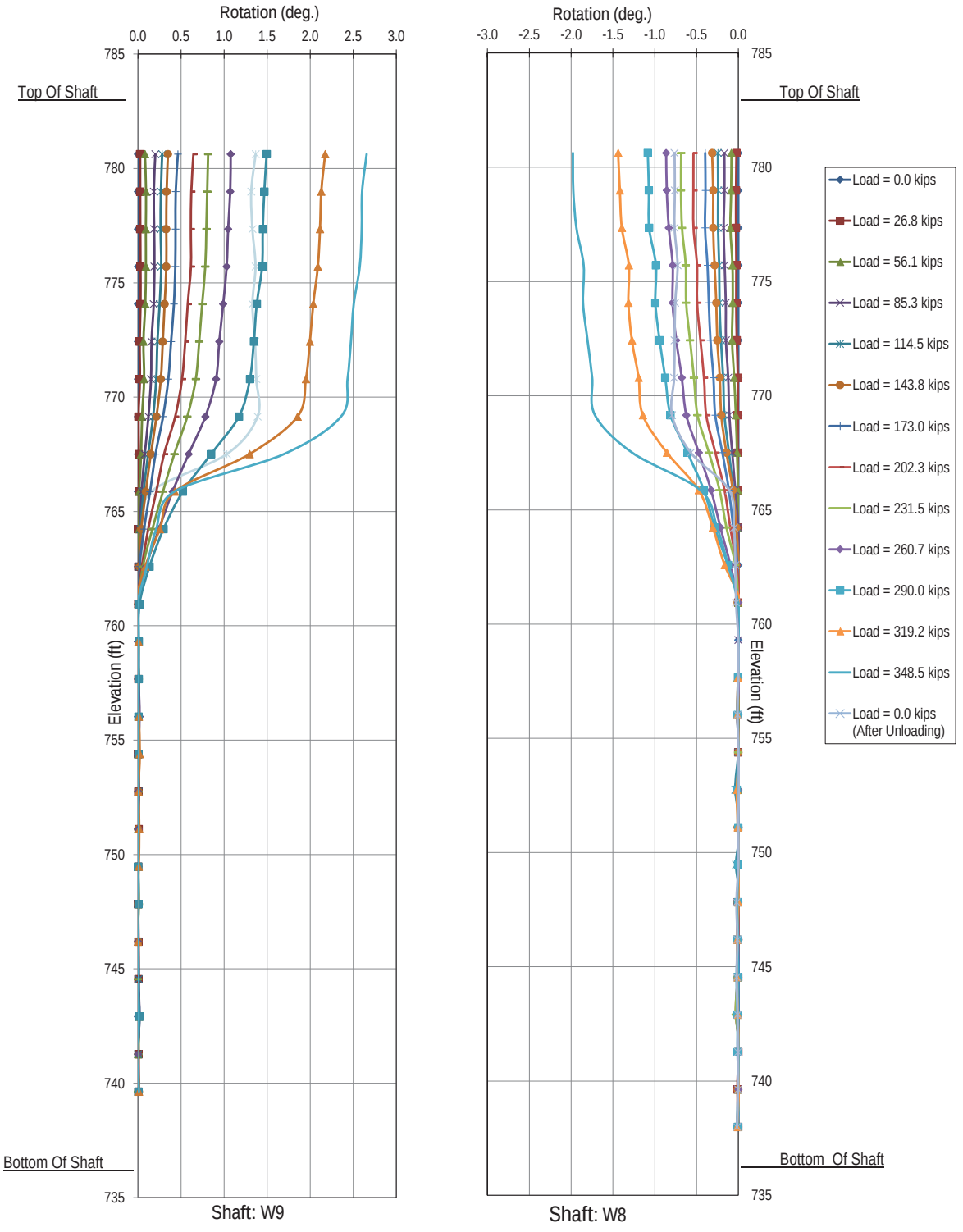
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W8-W9 Test Date: 7/24/2012	



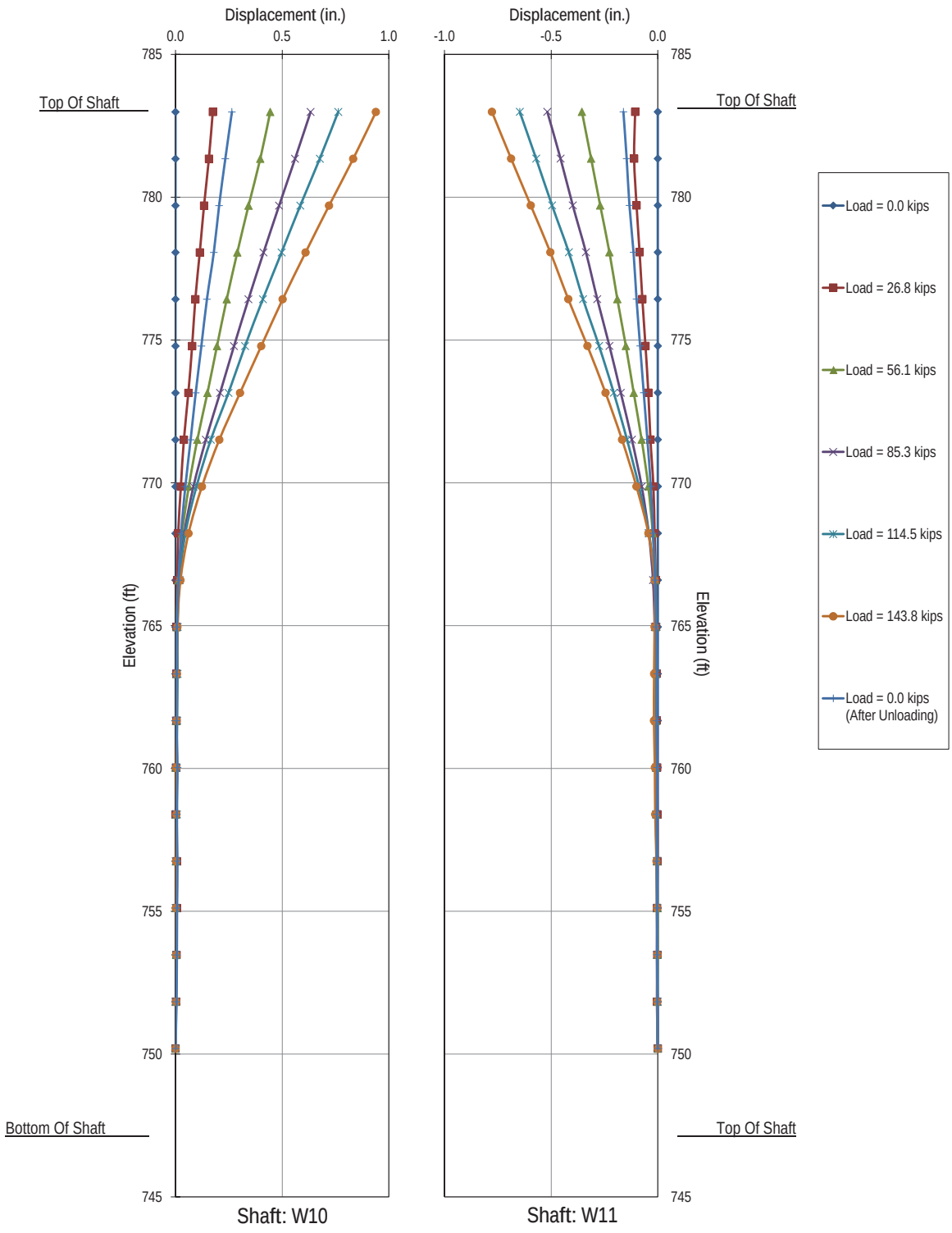
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W8-W9 Test Date: 7/24/2012	



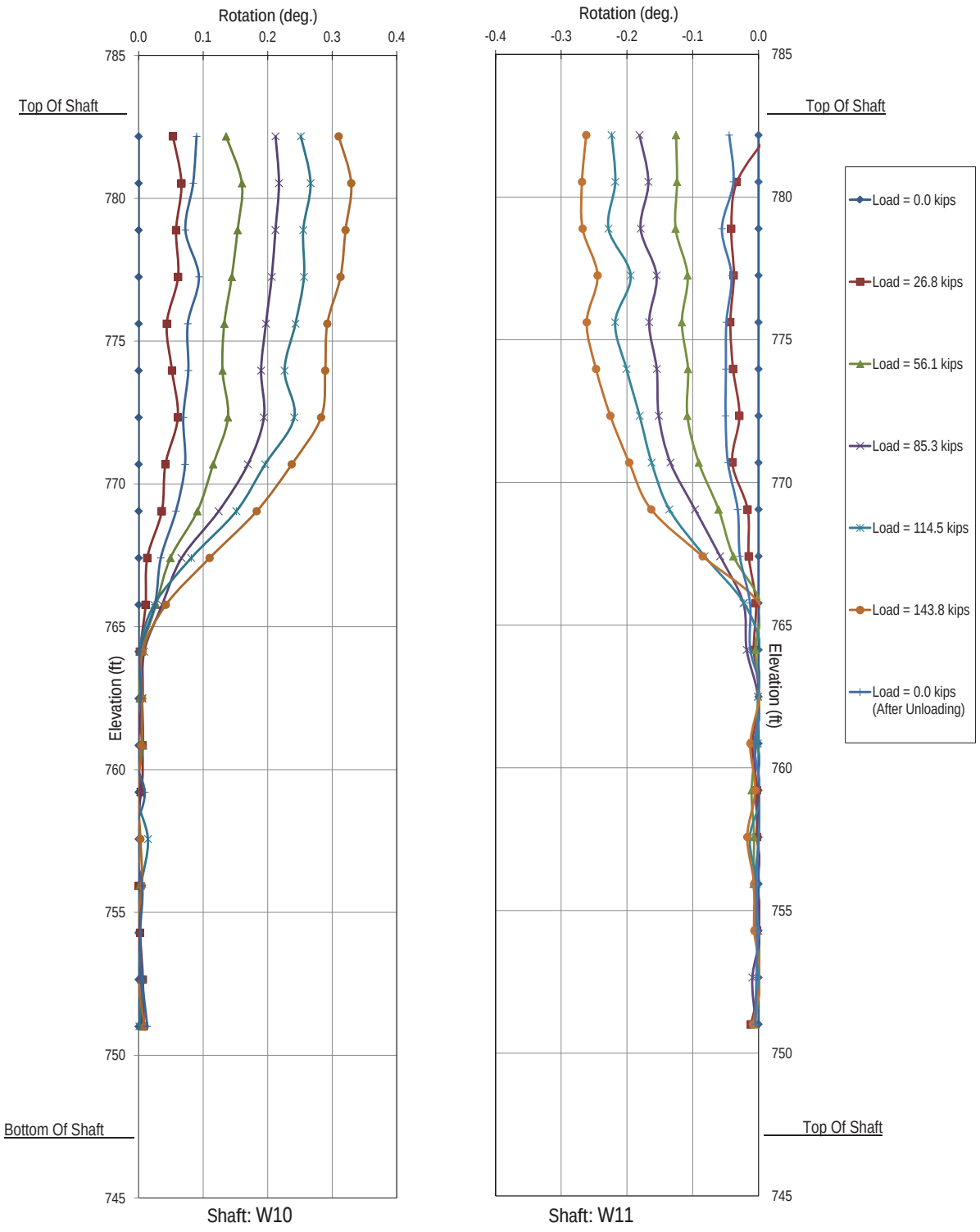
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W8-W9 Soil Removed Test Date: 8/15/2012	



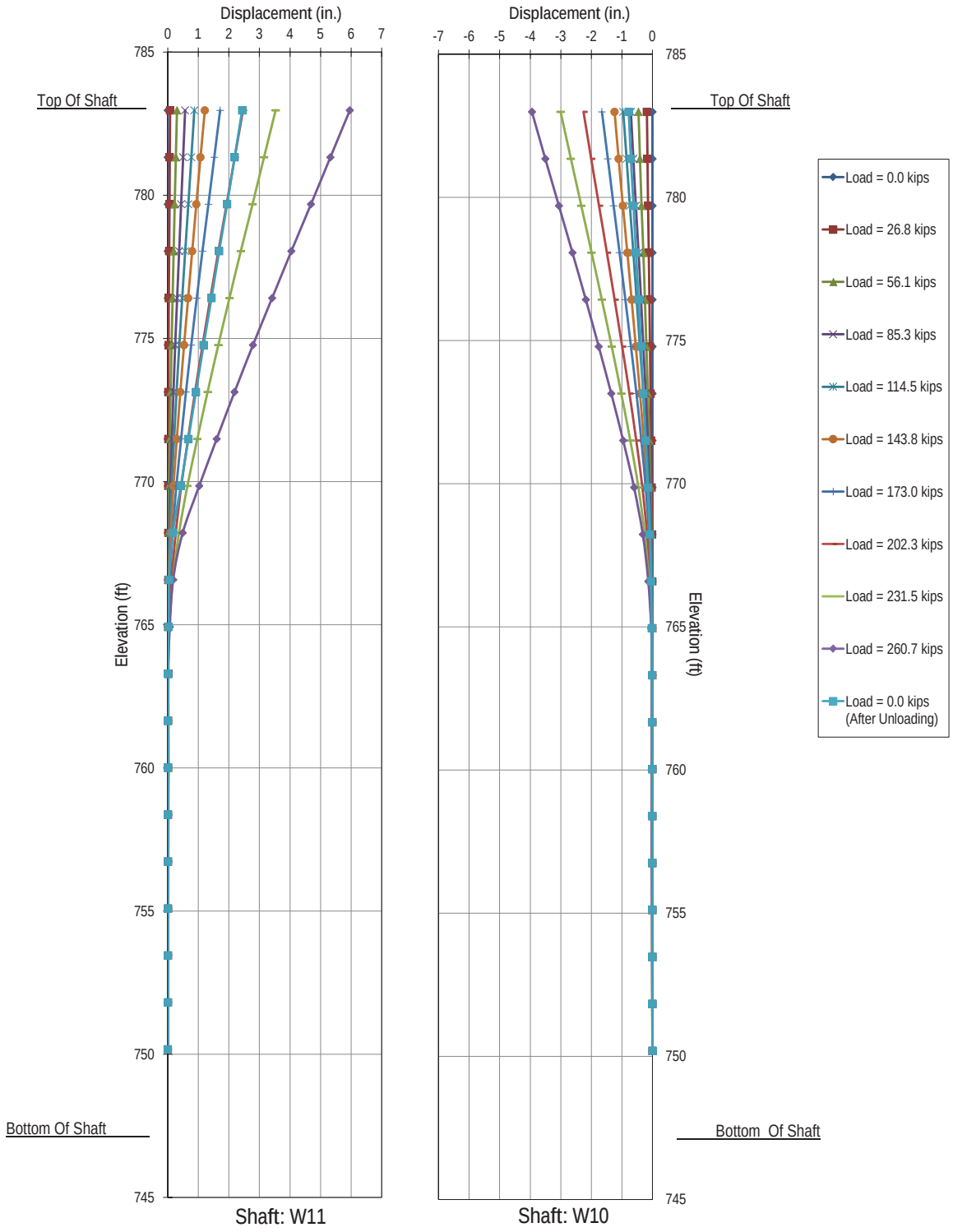
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W8-W9 Soil Removed Test Date: 8/15/2012	



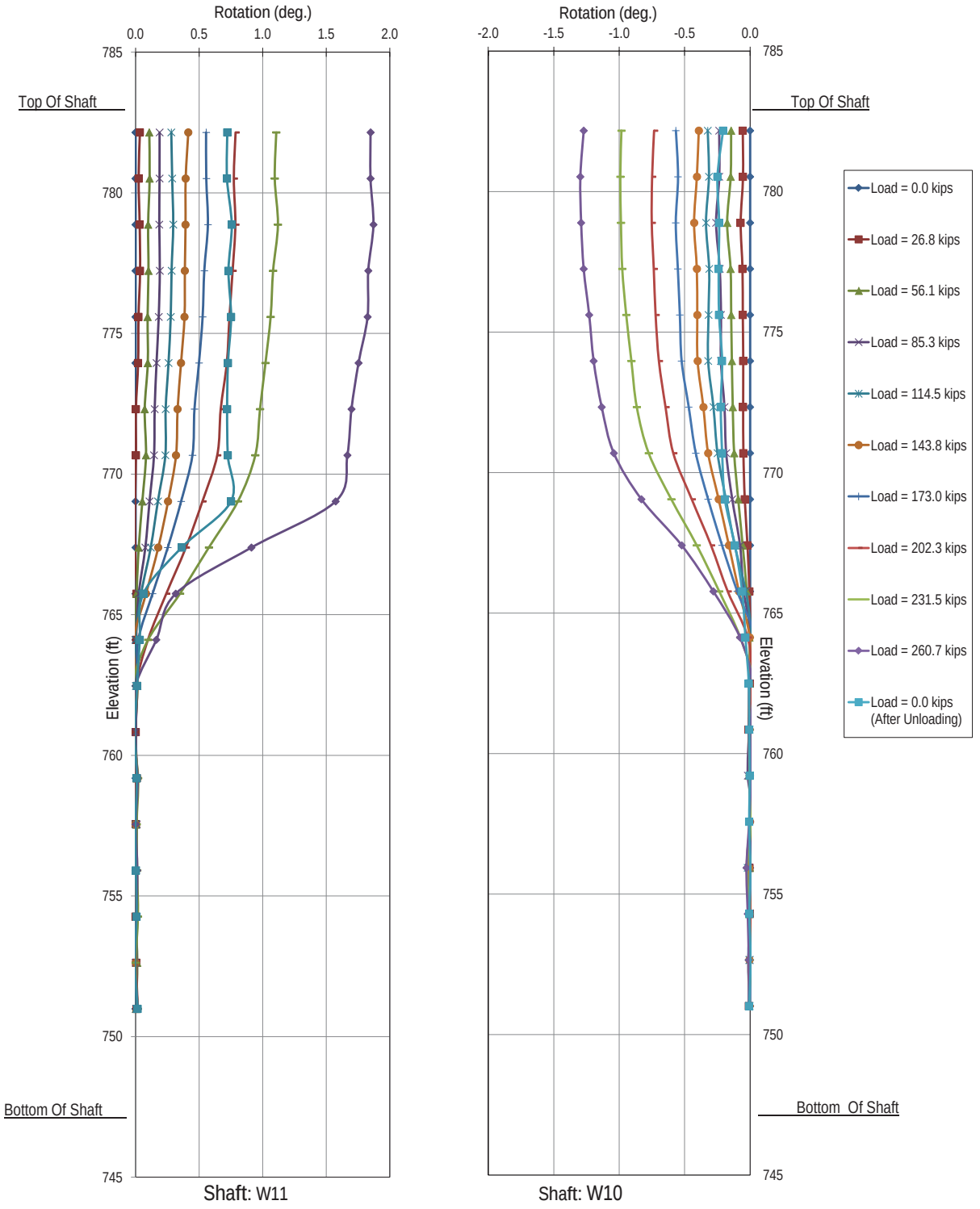
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W10-W11 Test Date: 7/27/2012	



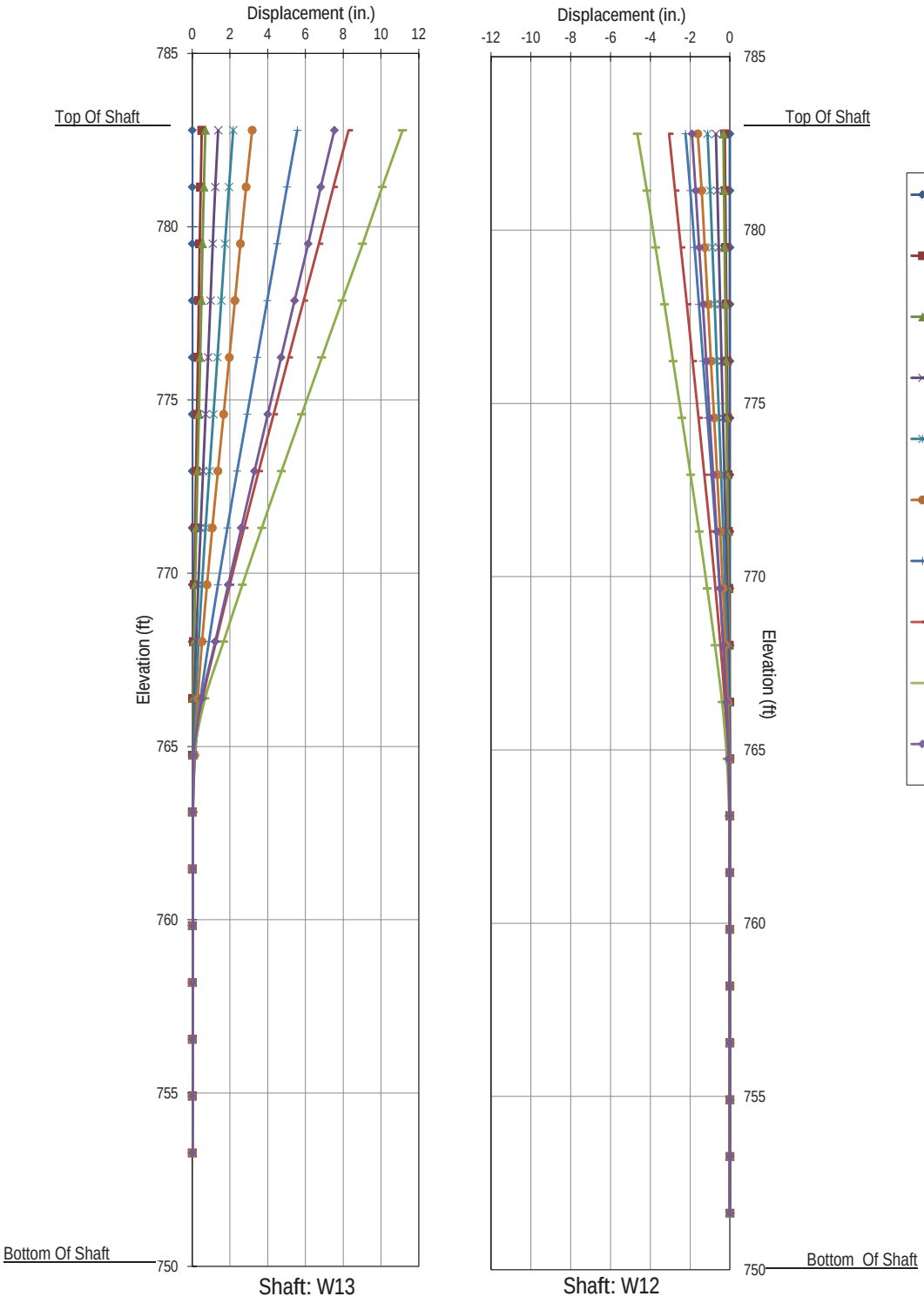
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W10-W11 Test Date: 7/27/2012	



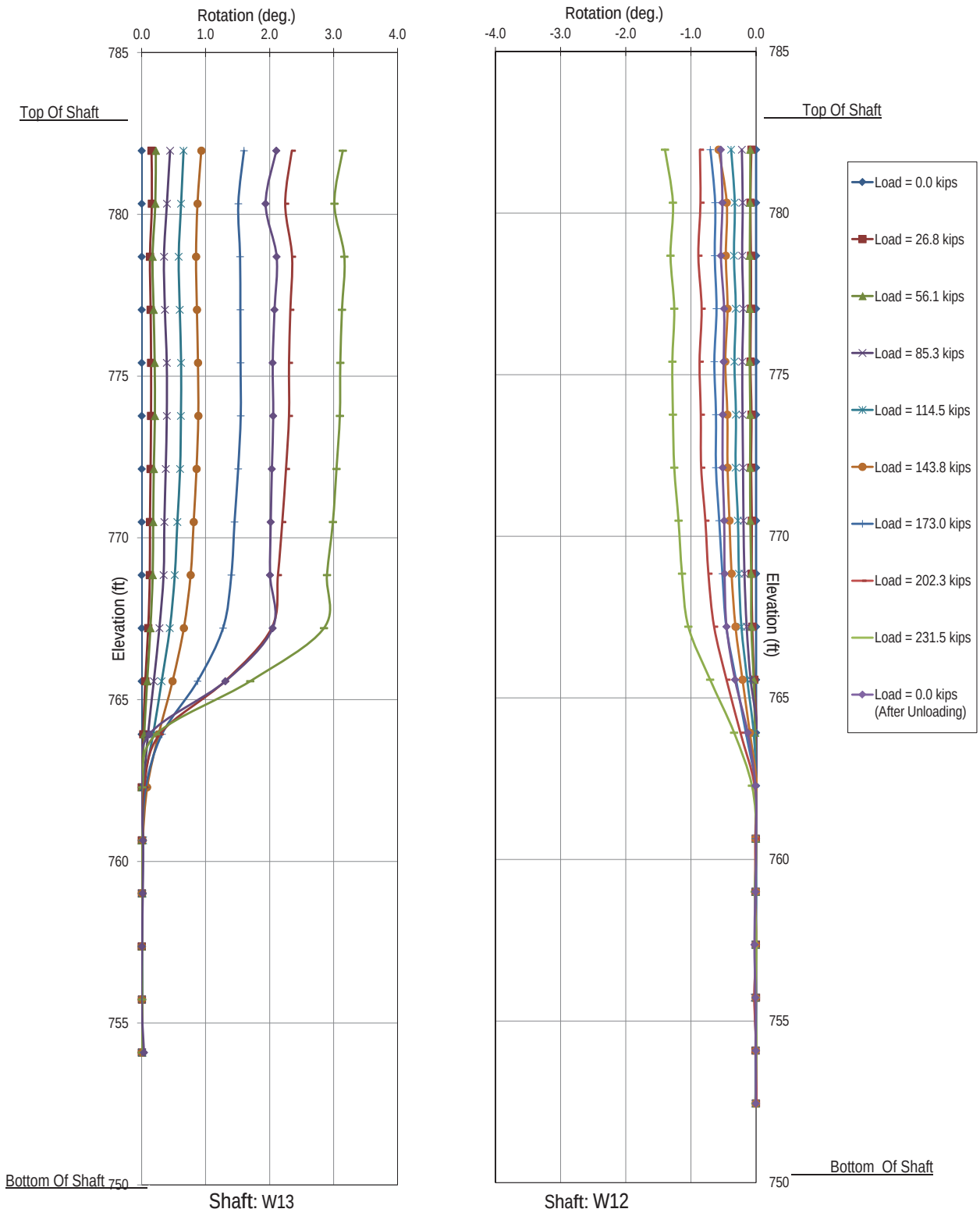
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W10-W11 Soil Removed Test Date: 8/13/2012	



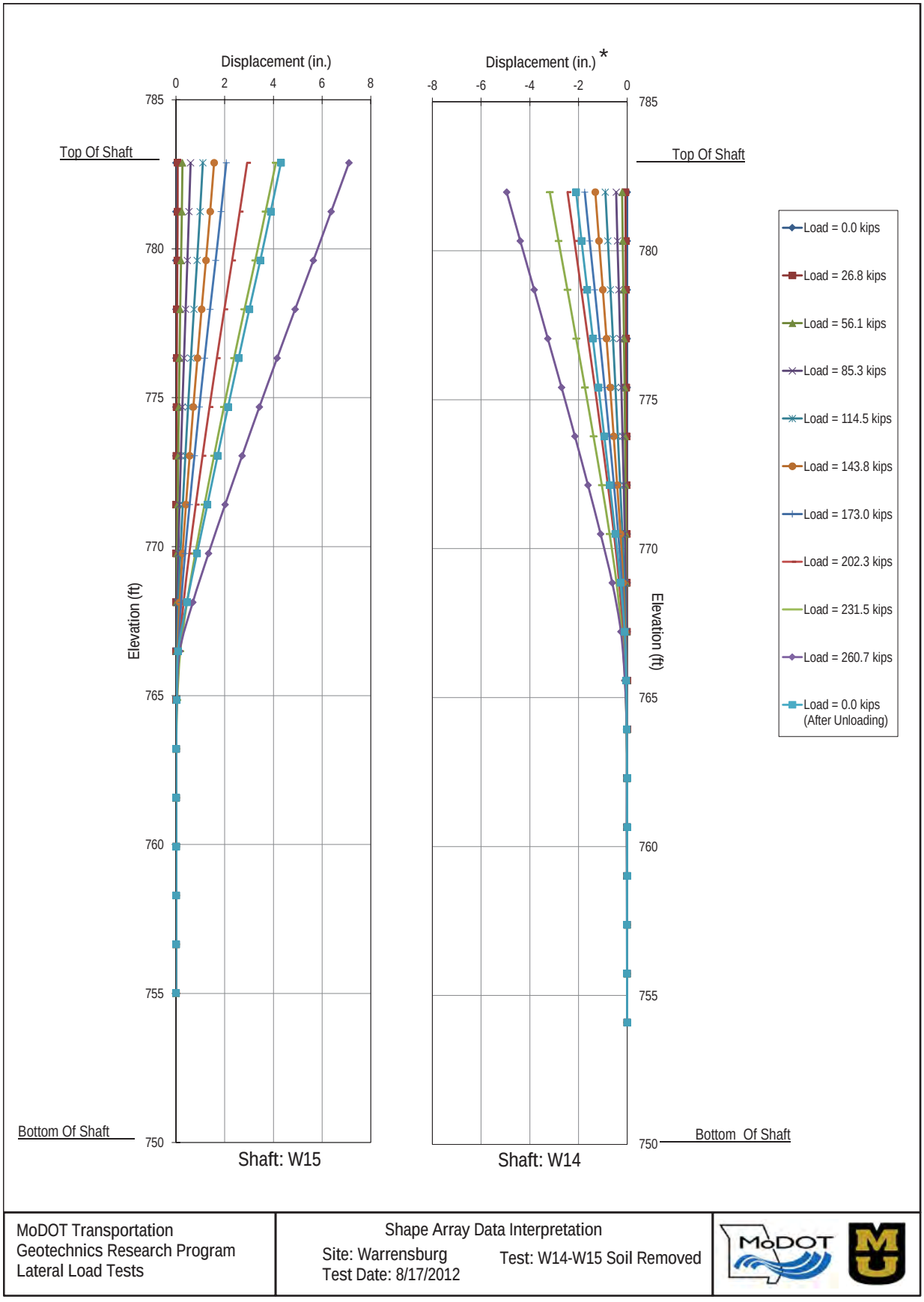
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W10-W11 Soil Removed Test Date: 8/13/2012	



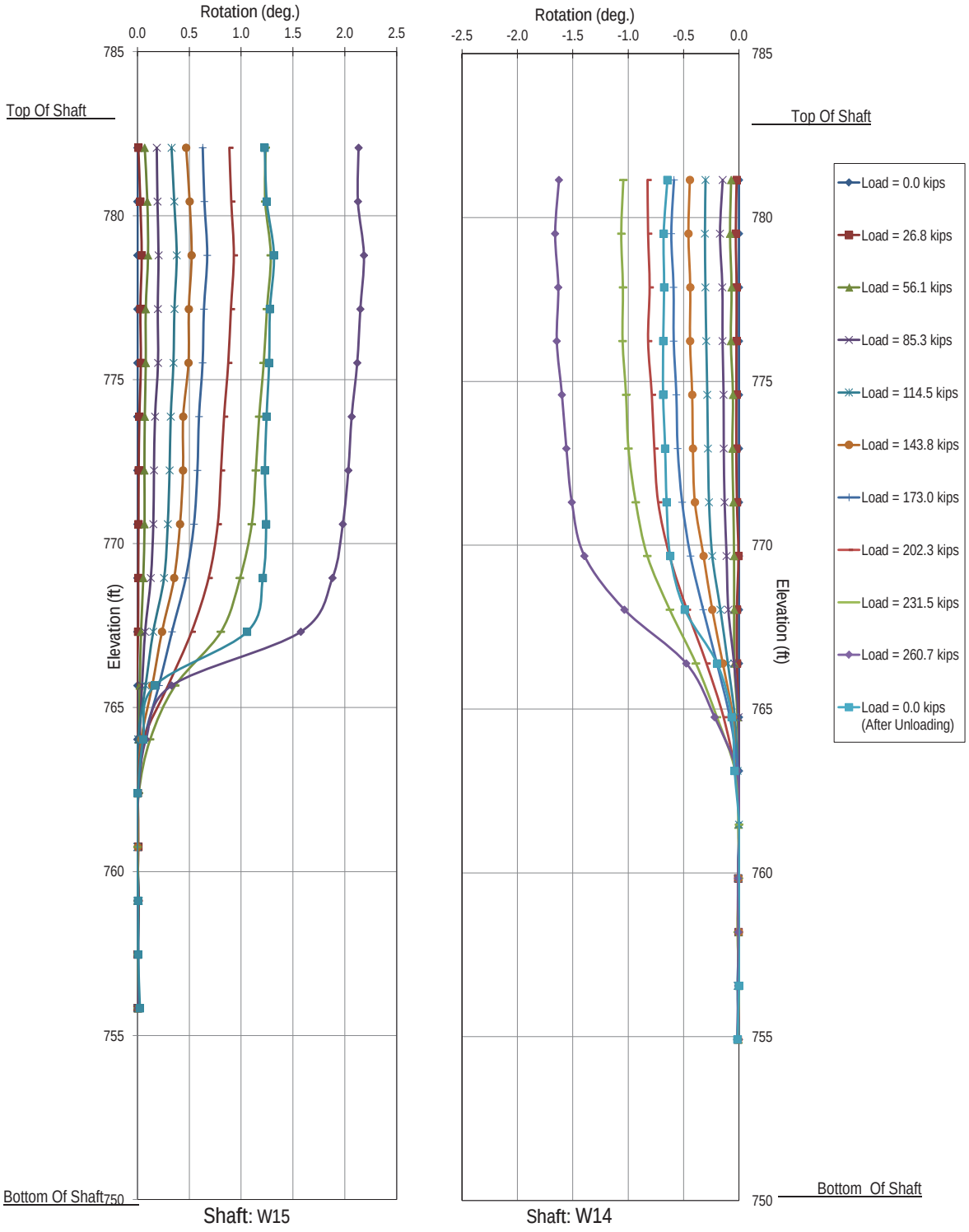
MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W12-W13 Soil Removed Test Date: 8/18/2012	



MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test: W12-W13 Soil Removed Test Date: 8/18/2012	

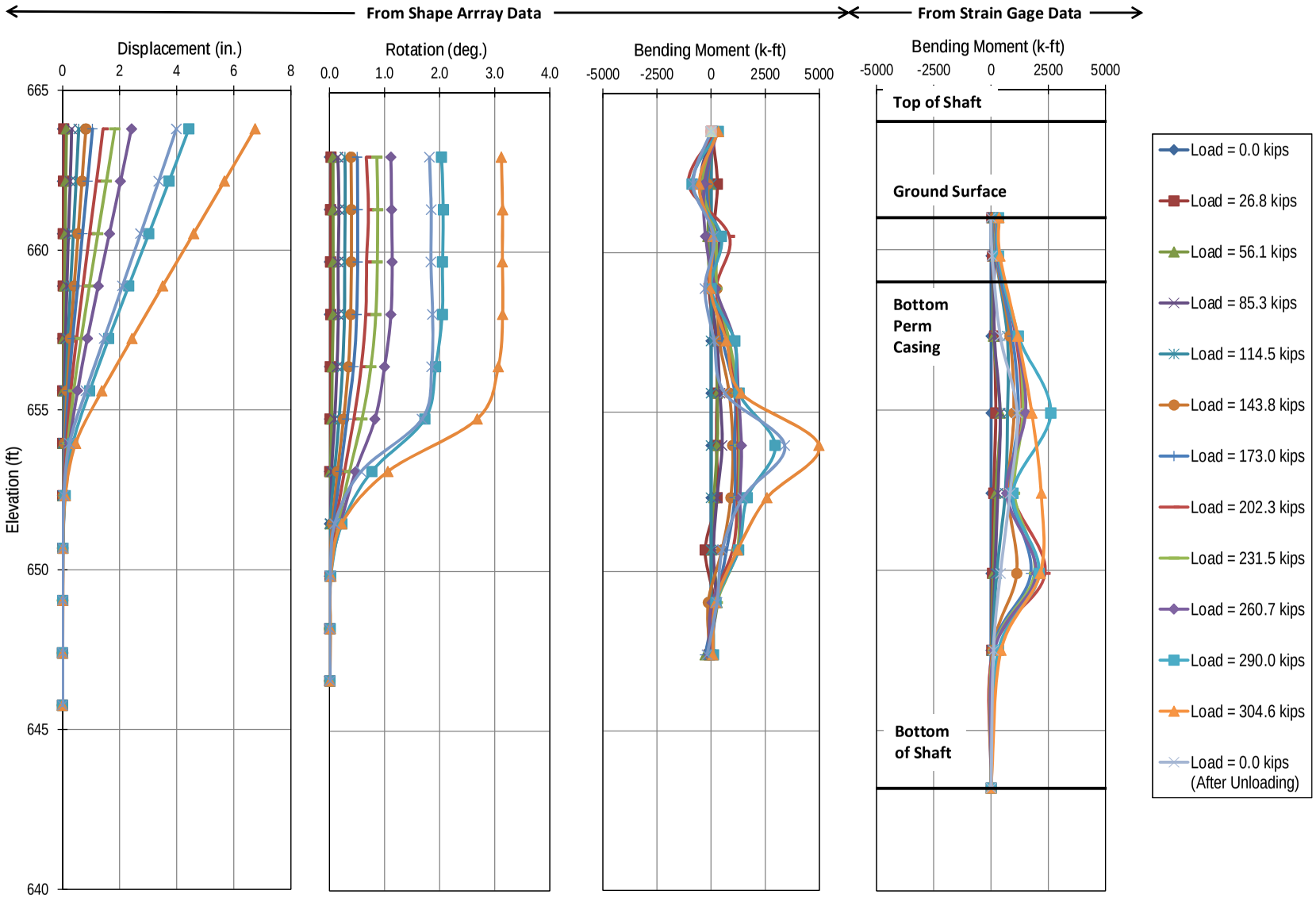


*SAA data for the top segment of W14 was neglected since it conflicted with LVDT and dial gage data.



MoDOT Transportation Geotechnics Research Program Lateral Load Tests	Shape Array Data Interpretation Site: Warrensburg Test Date: 8/17/2012 Test: W14-W15 Soil Removed	

Appendix D – Measured Drilled Shaft Response Profile Plots

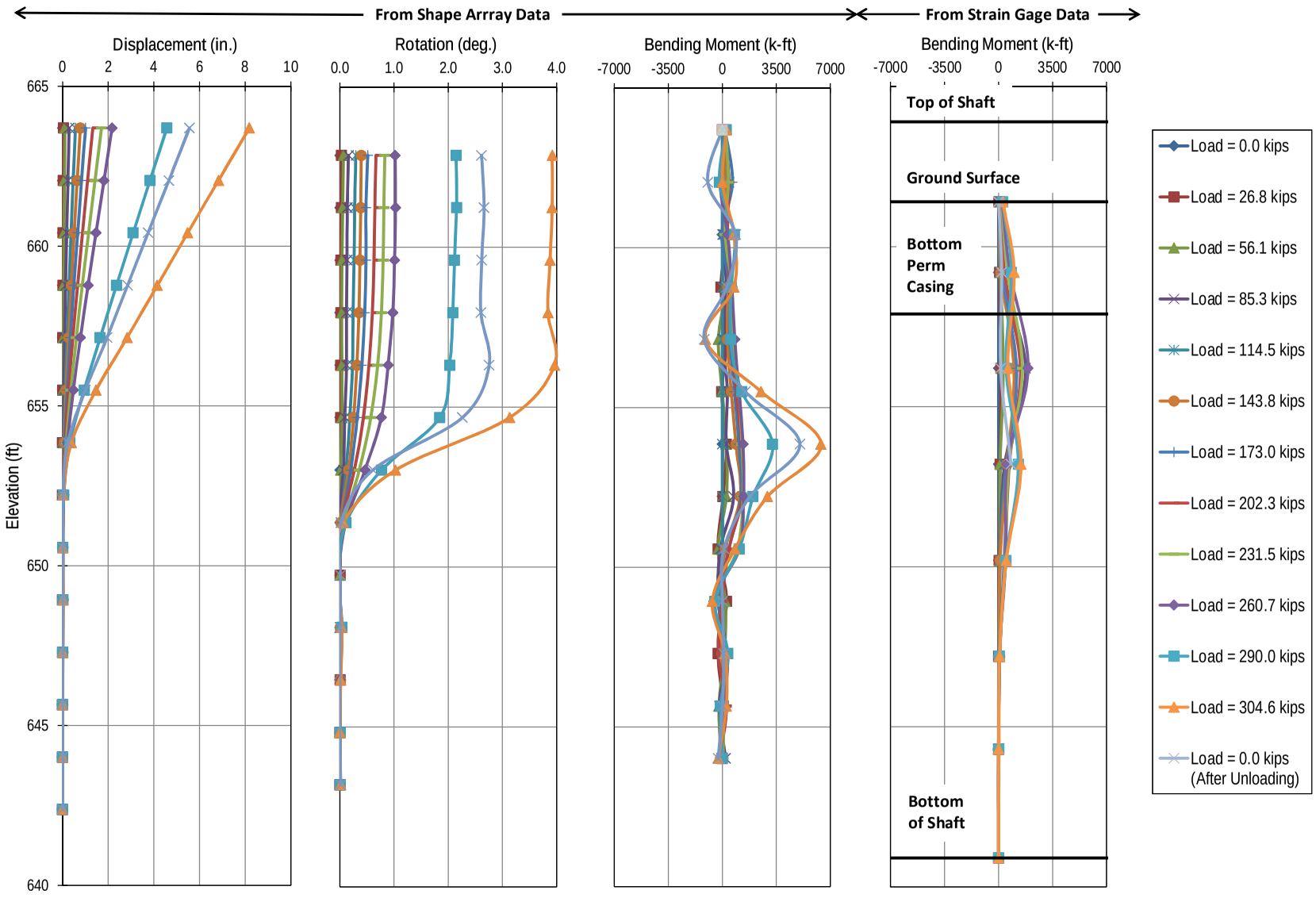


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Frankford
Test Date: 8/23/2012

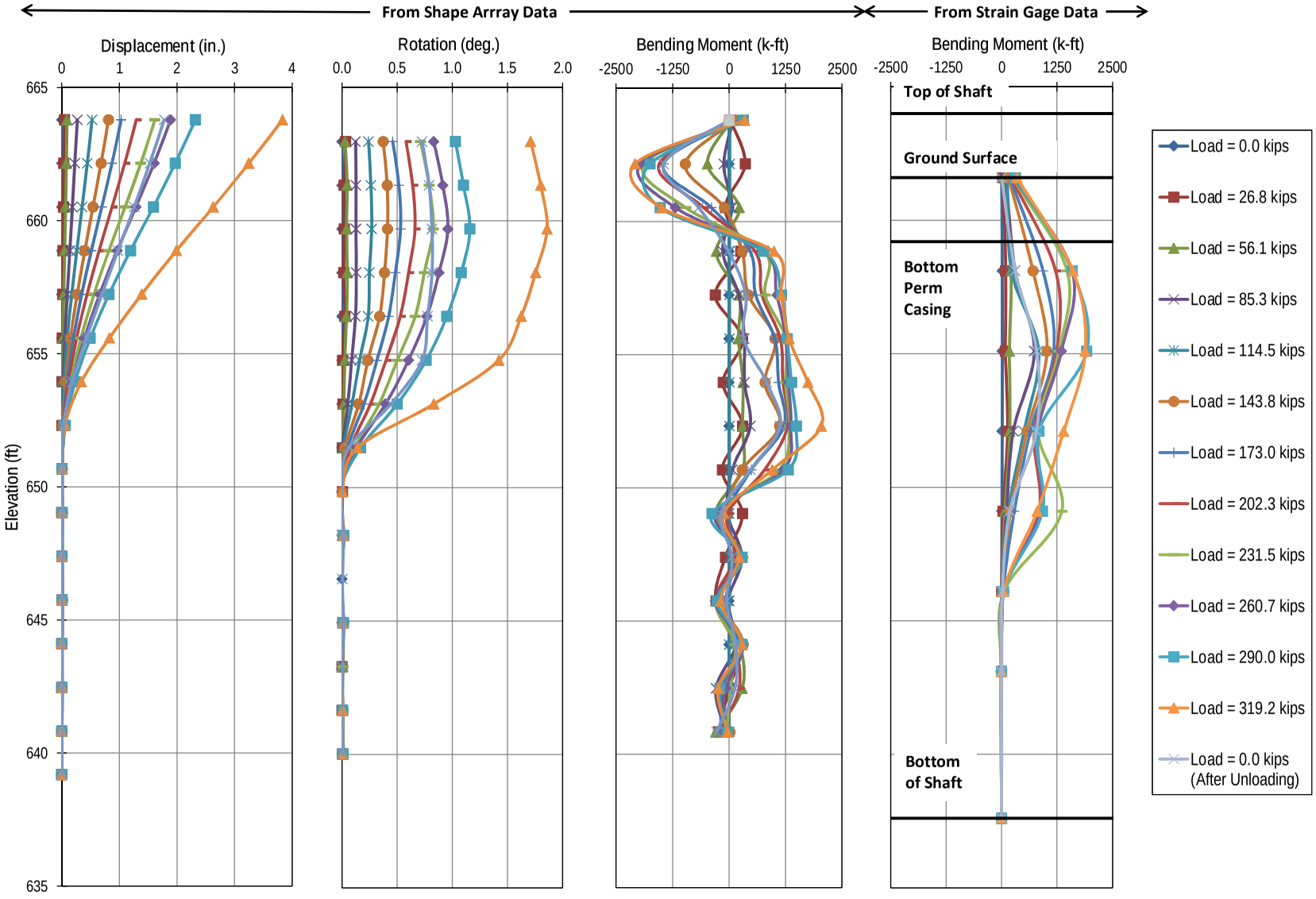
Test: F1-F2
Shaft: F1



MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Frankford
Test Date: 8/23/2012
Test: F1-F2
Shaft: F2

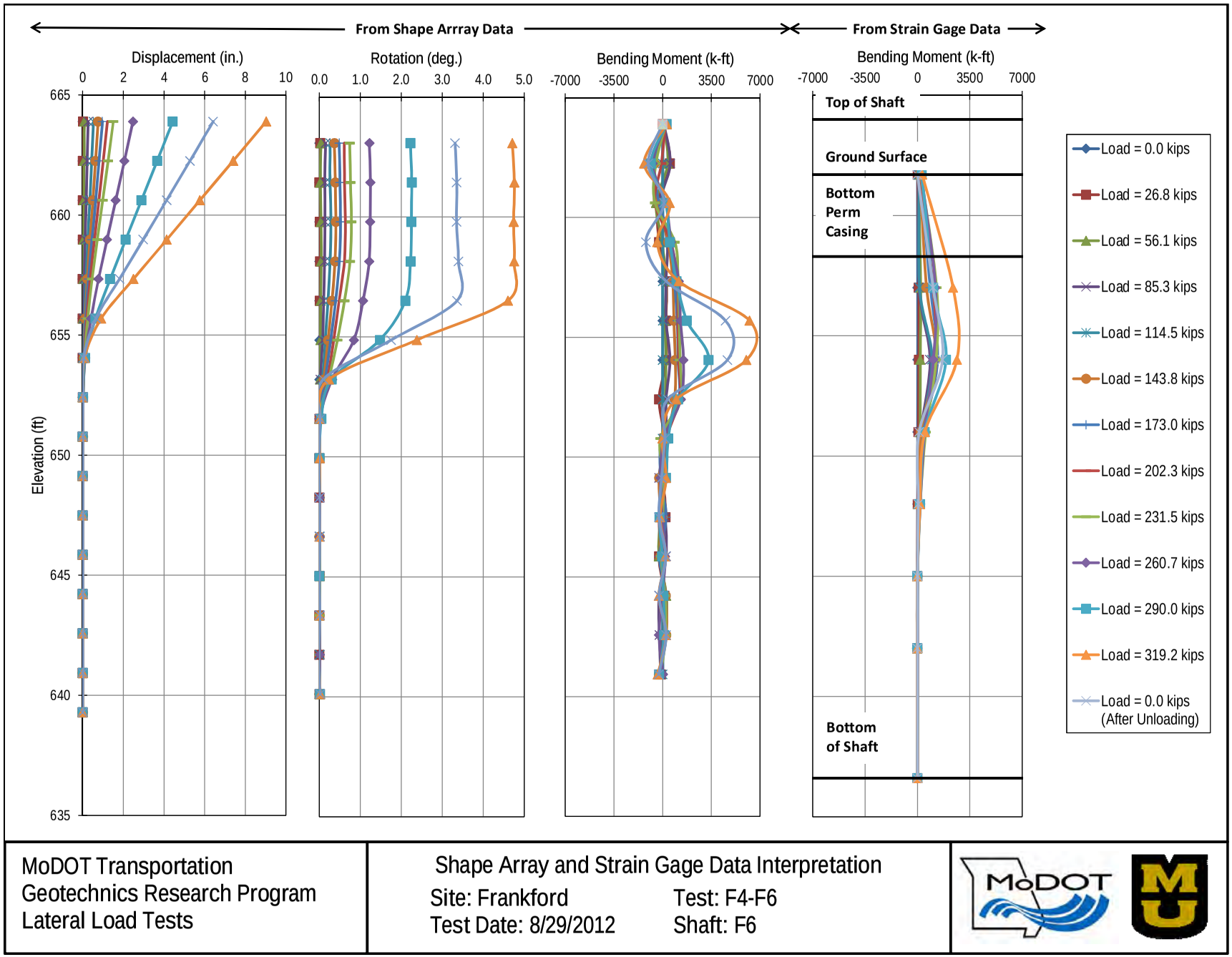


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Frankford Test: F4-F6

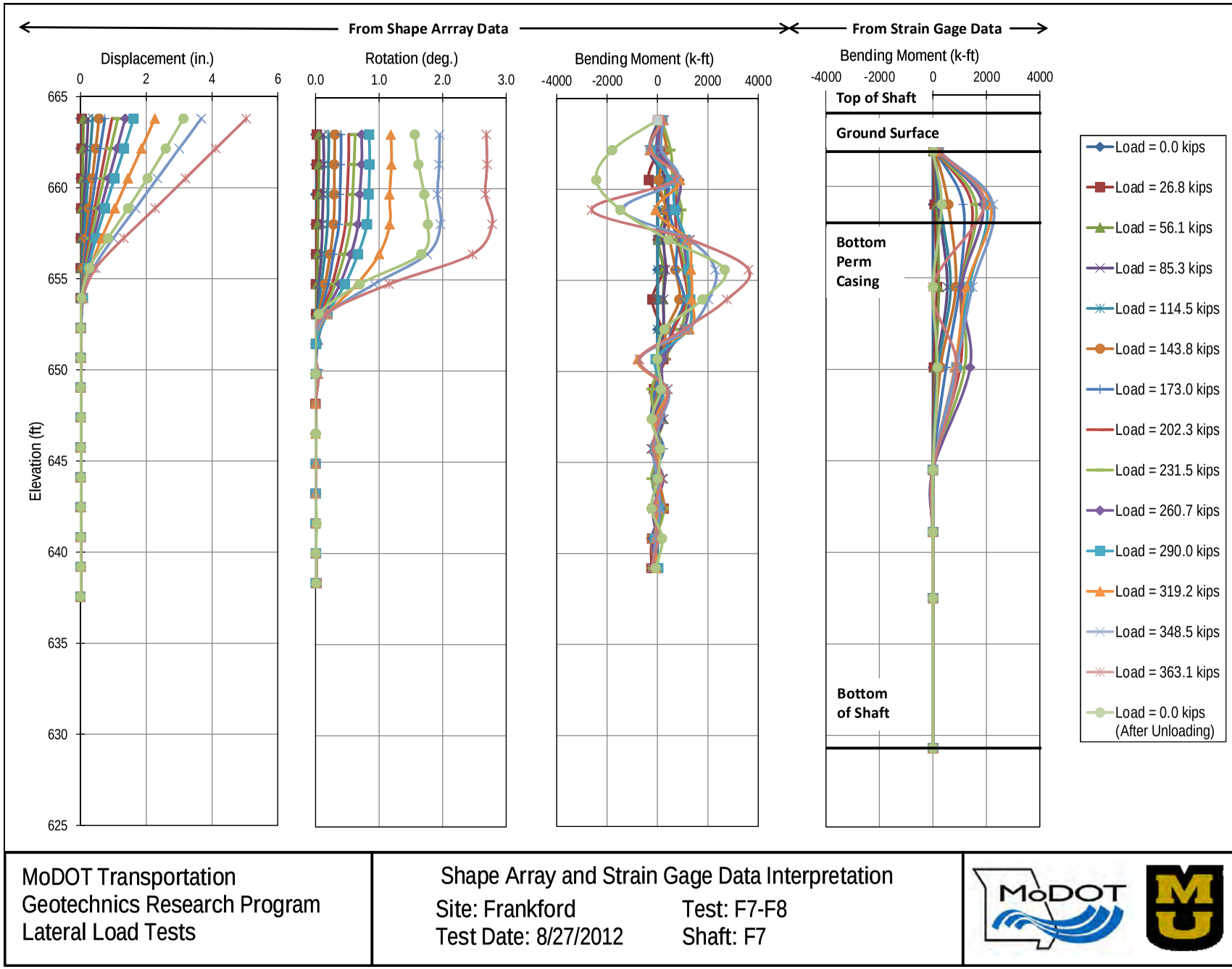
Test Date: 8/29/2012 Shaft: F4



MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Frankford
Test Date: 8/29/2012
Test: F4-F6
Shaft: F6

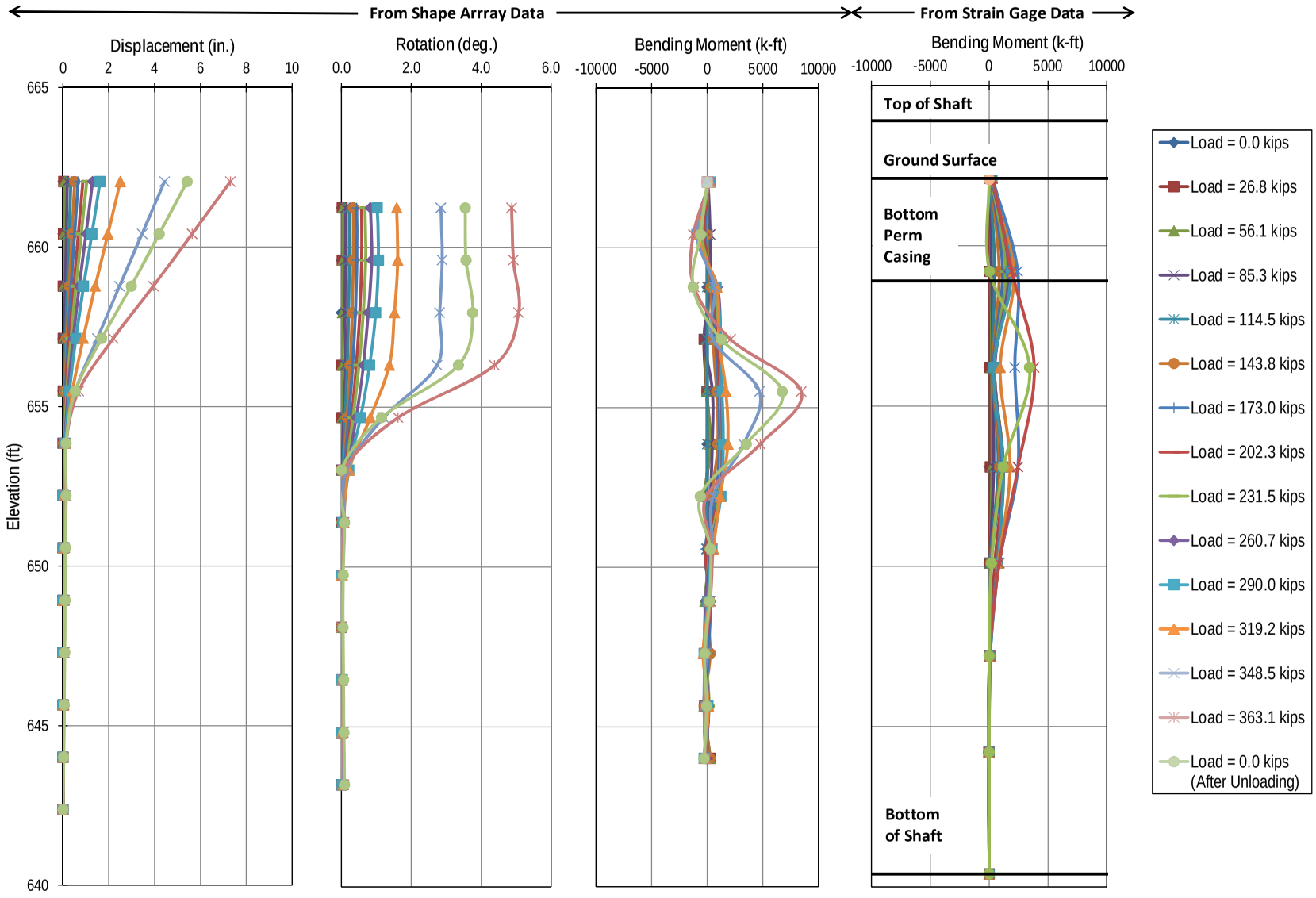


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Frankford
Test Date: 8/27/2012

Test: F7-F8
Shaft: F7

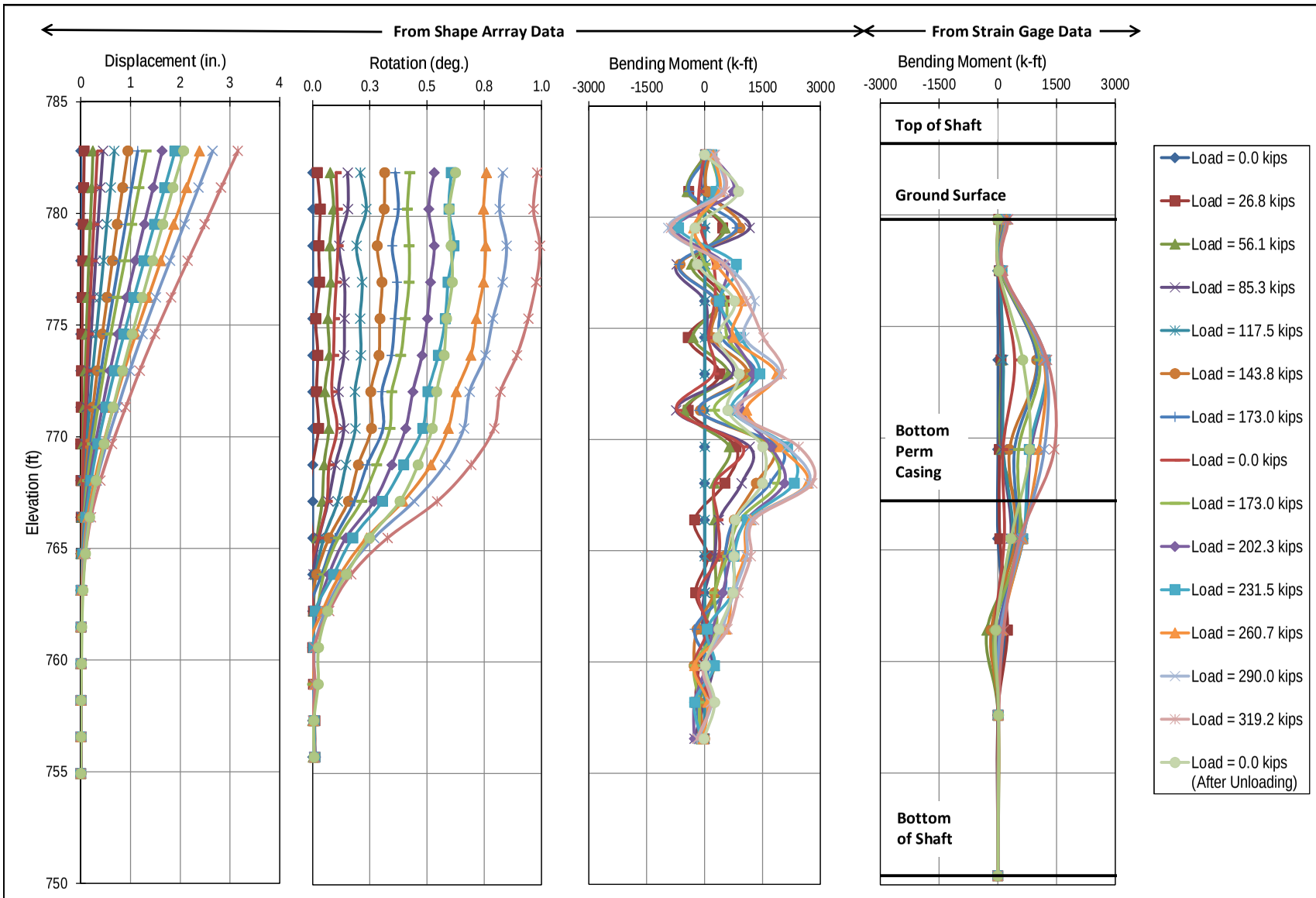


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Frankford
Test Date: 8/27/2012

Test: F7-F8
Shaft: F8

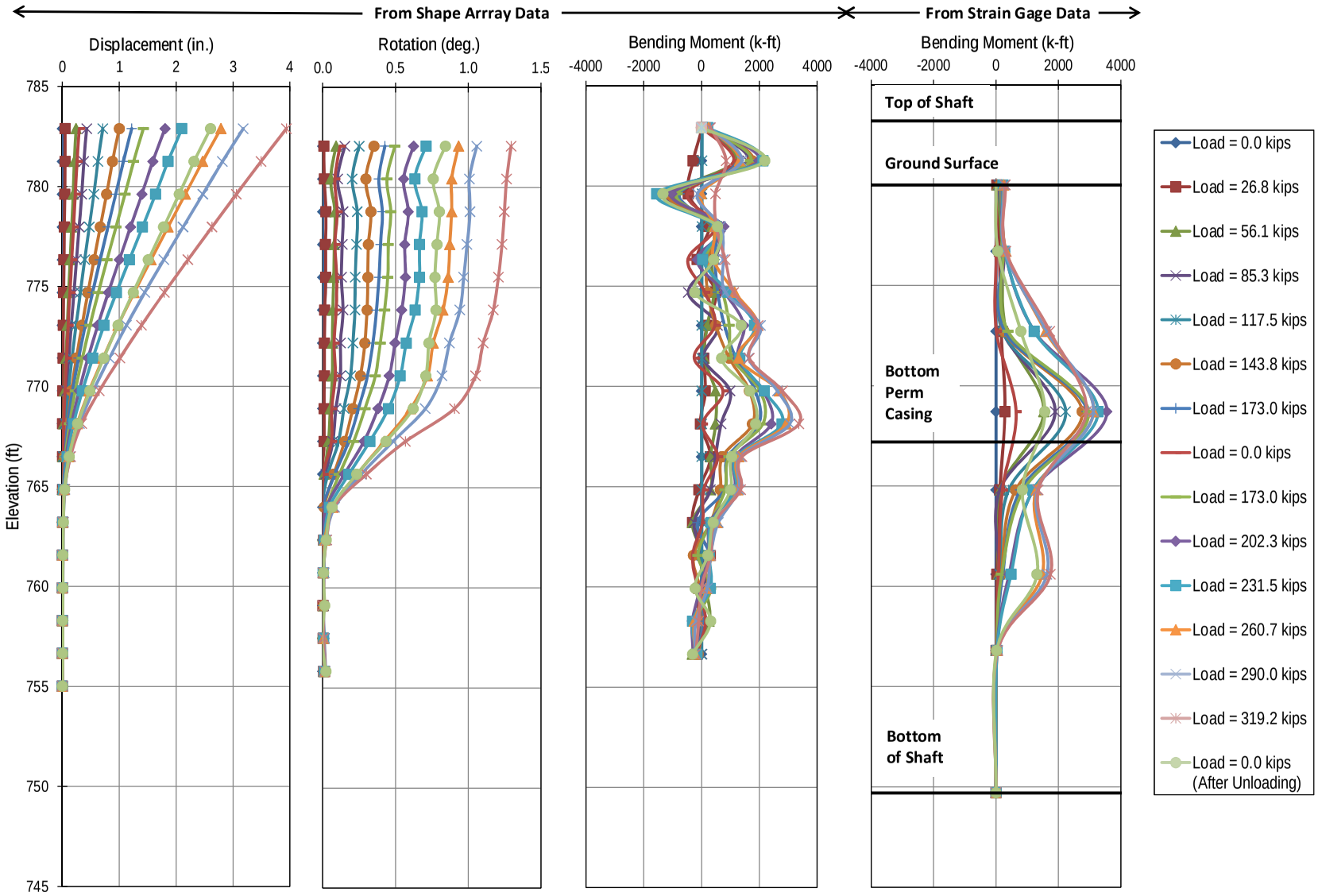


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg Test: W1-W2

Test Date: 8/1/2012 Shaft: W1

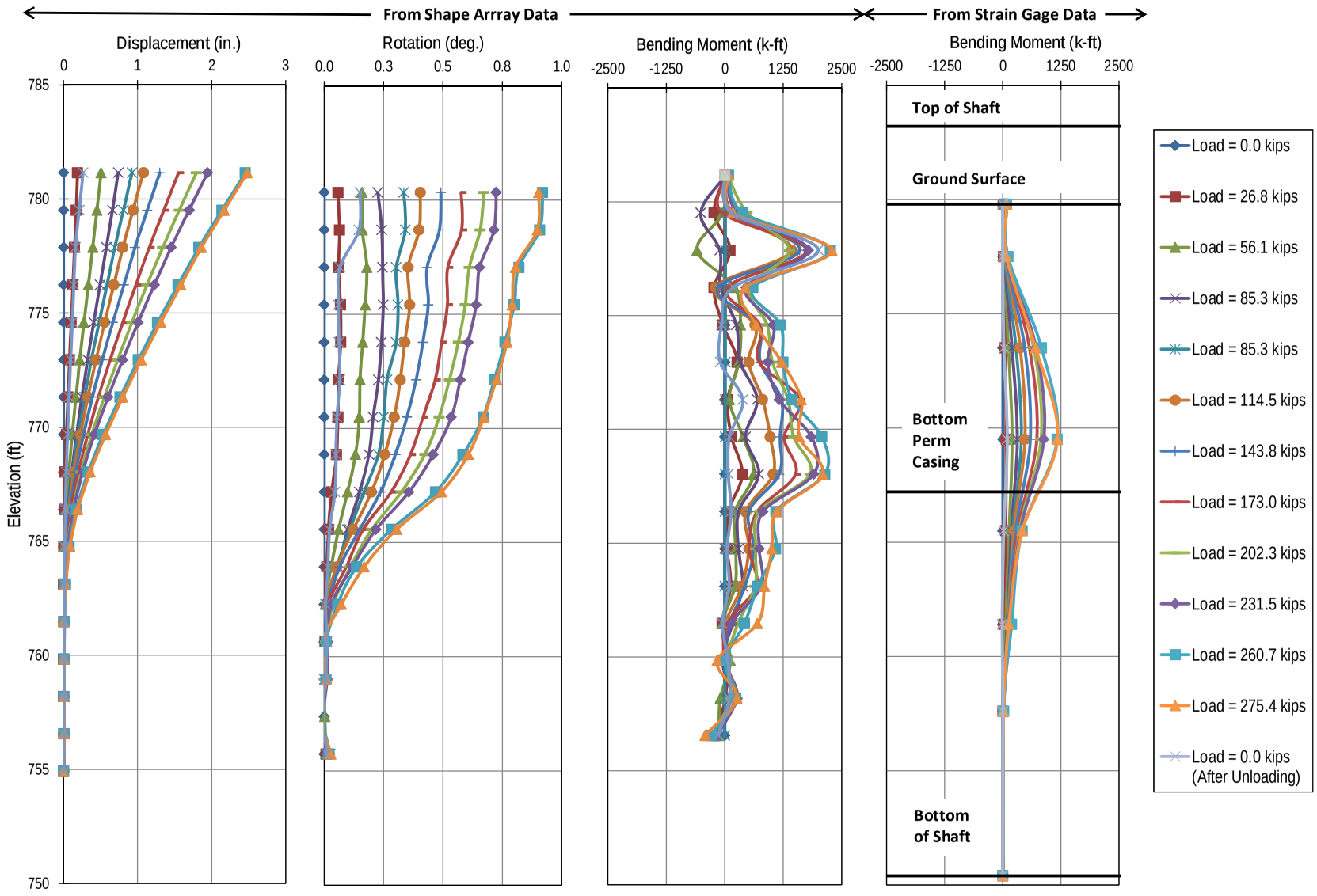


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg Test: W1-W2

Test Date: 8/1/2012 Shaft: W2

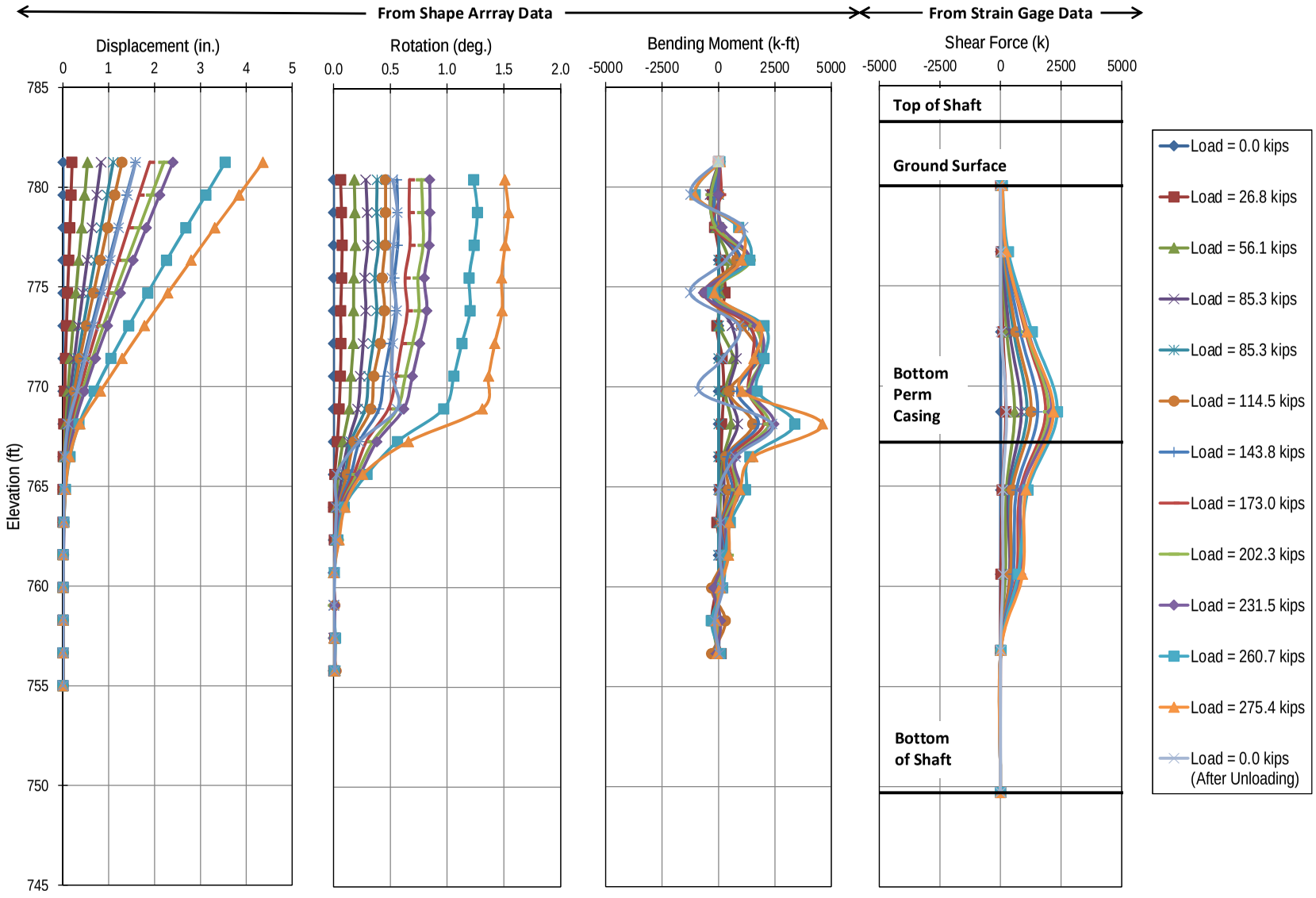


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/9/2012

Test: W1-W2 Soil Removed
Shaft: W1

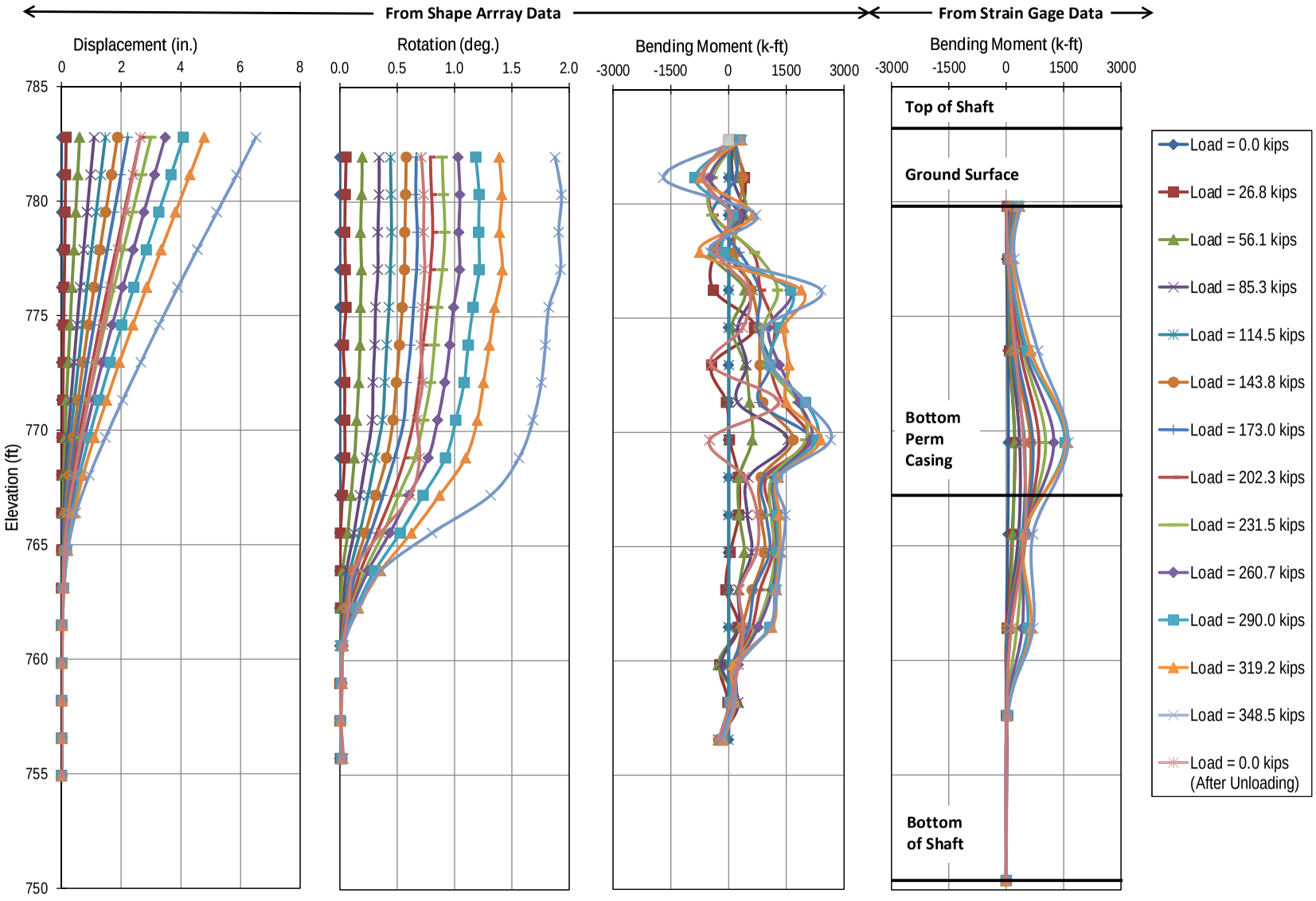


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/9/2012

Test: W1-W2 Soil Removed
Shaft: W2

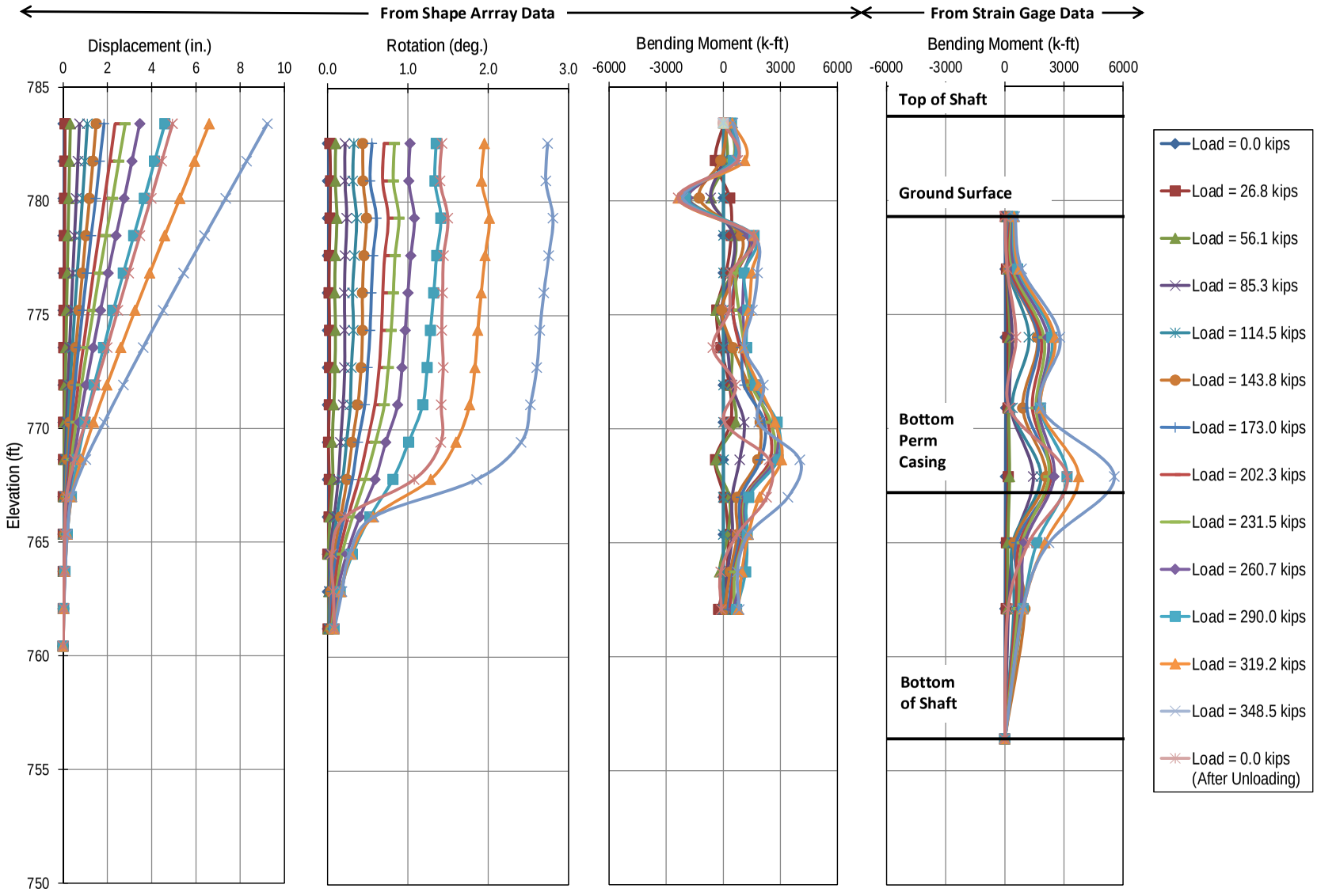


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/20/2012

Test: W1-W5 Soil Removed
Shaft: W1

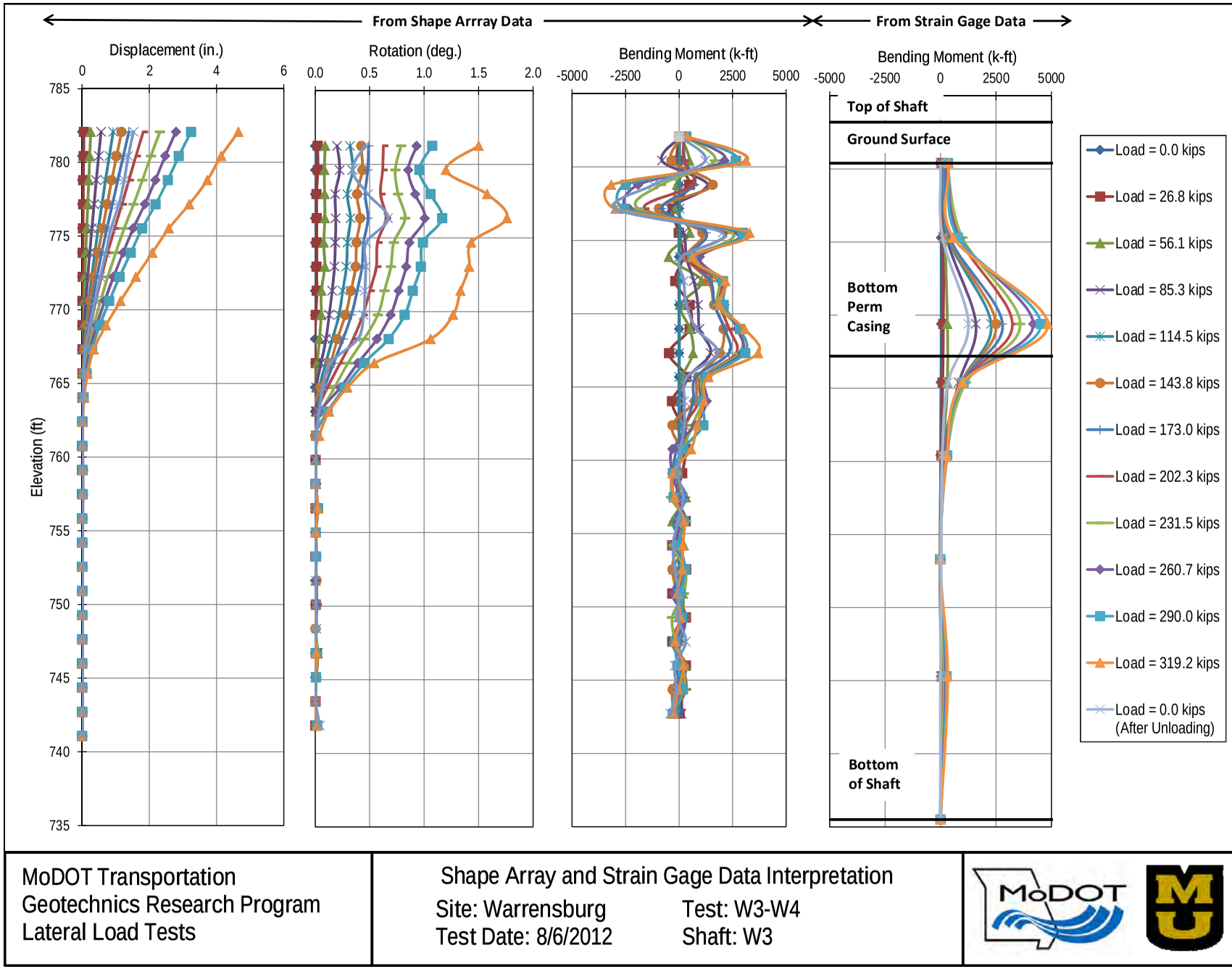


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/20/2012

Test: W1-W5 Soil Removed
Shaft: W5

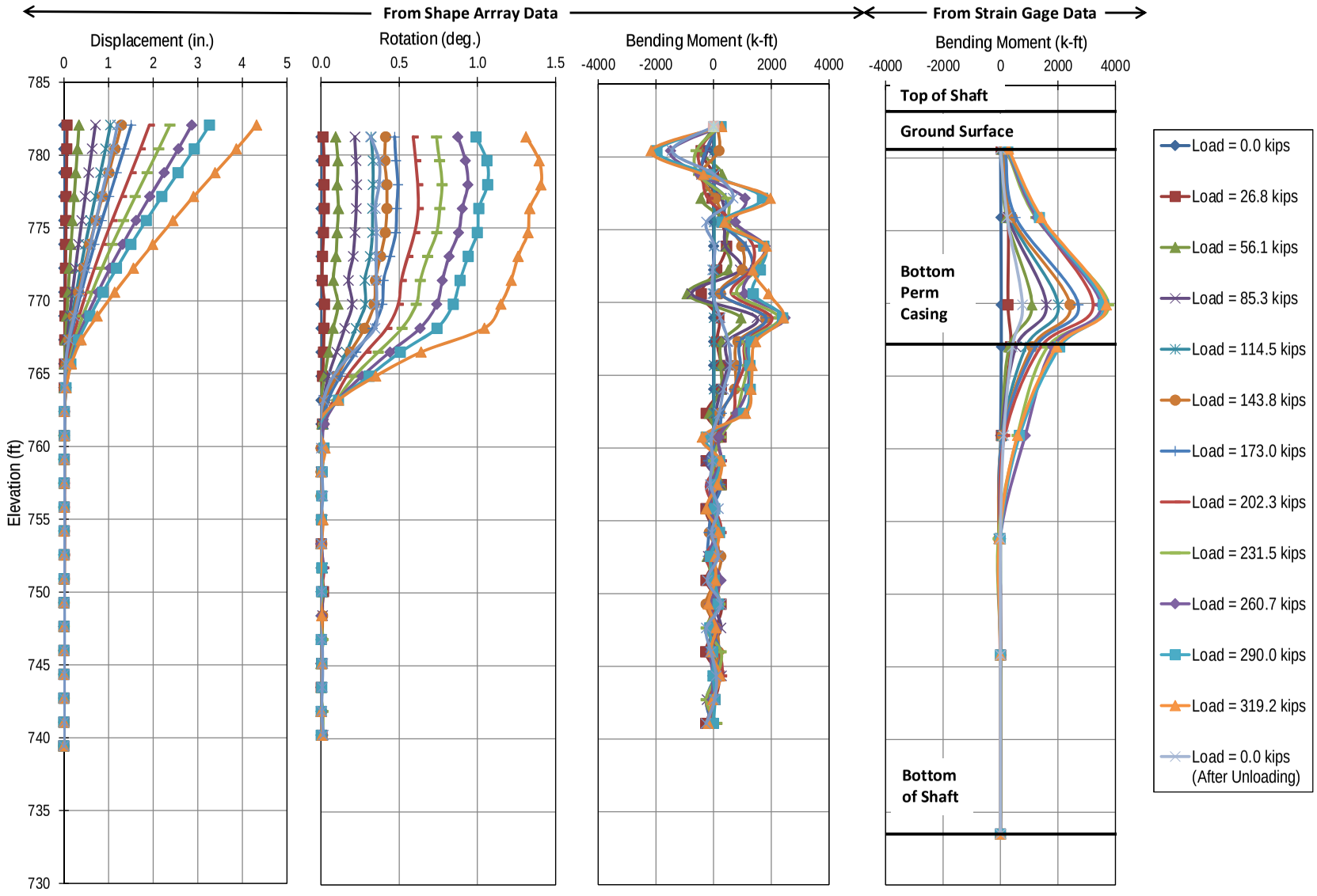


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg Test: W3-W4

Test Date: 8/6/2012 Shaft: W3

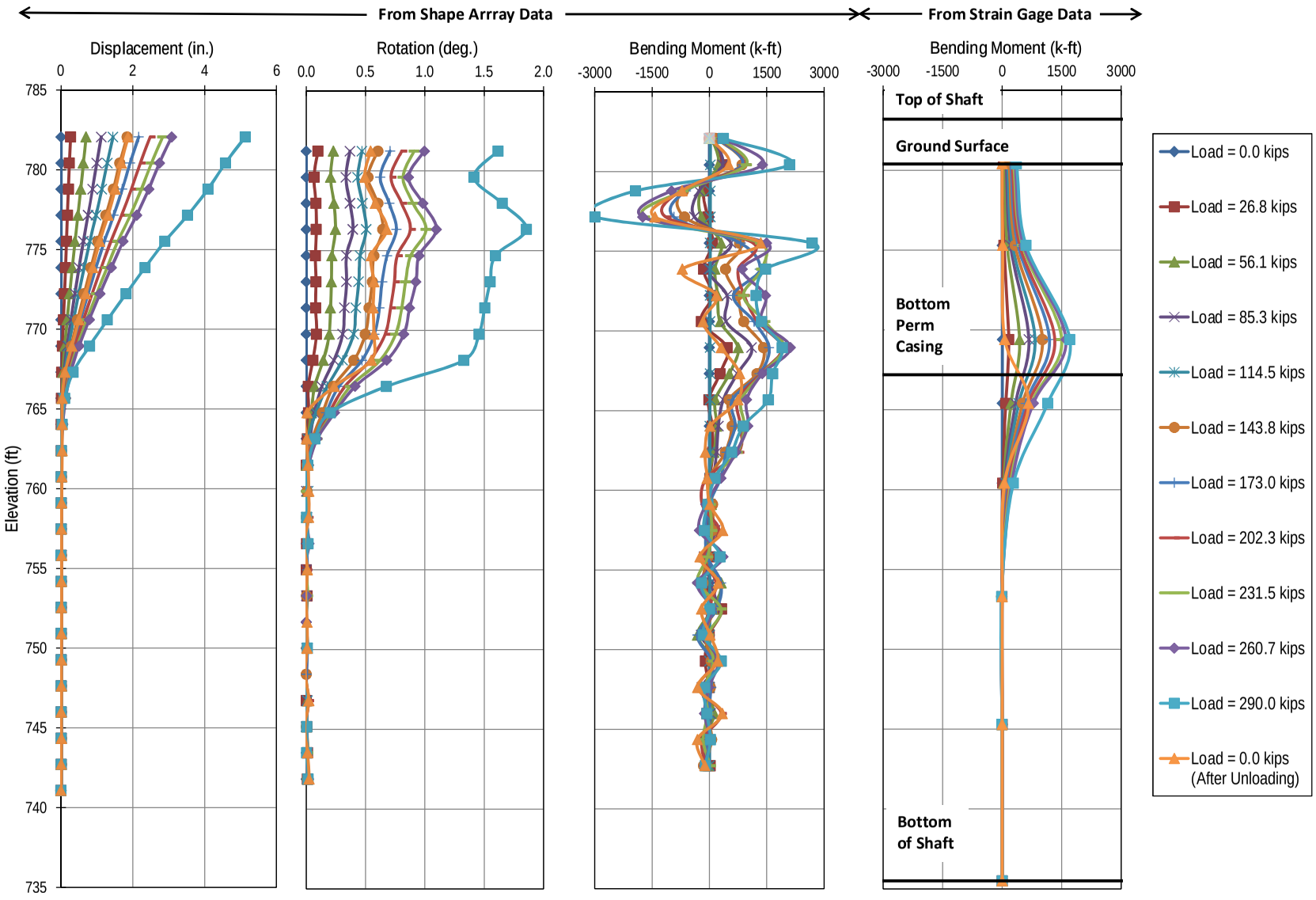


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg Test: W3-W4

Test Date: 8/6/2012 Shaft: W4

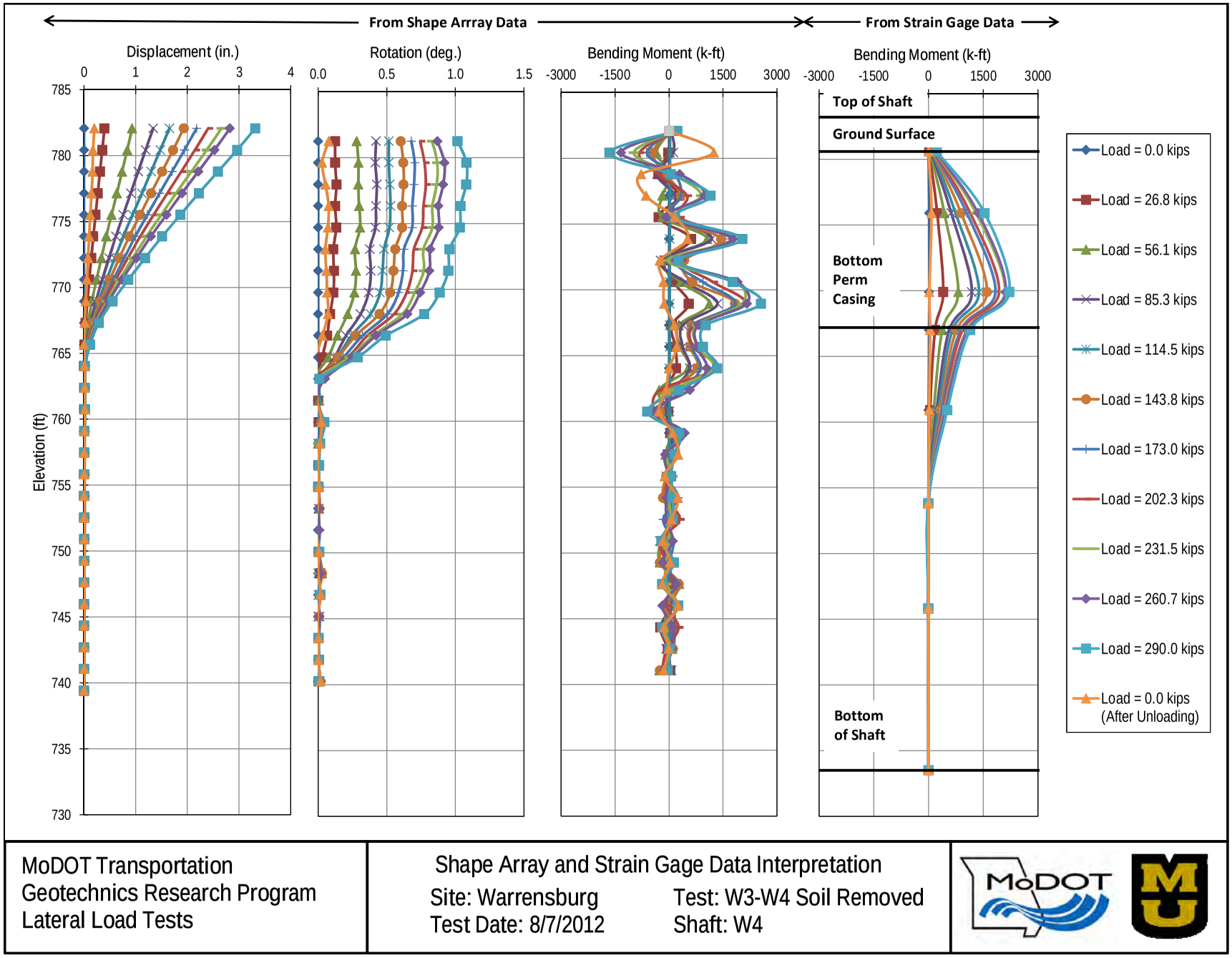


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/7/2012

Test: W3-W4 Soil Removed
Shaft: W3

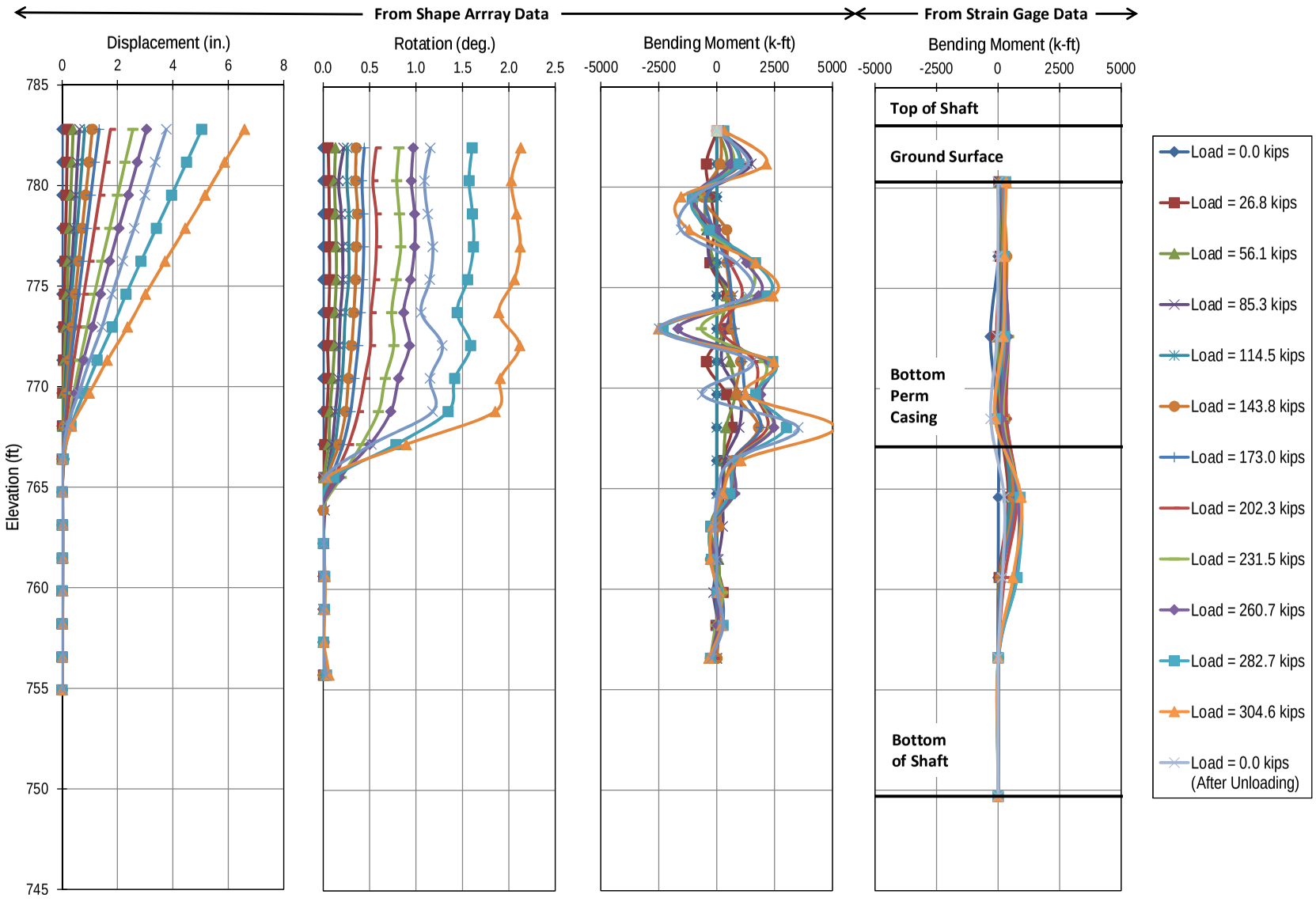


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/7/2012

Test: W3-W4 Soil Removed
Shaft: W4

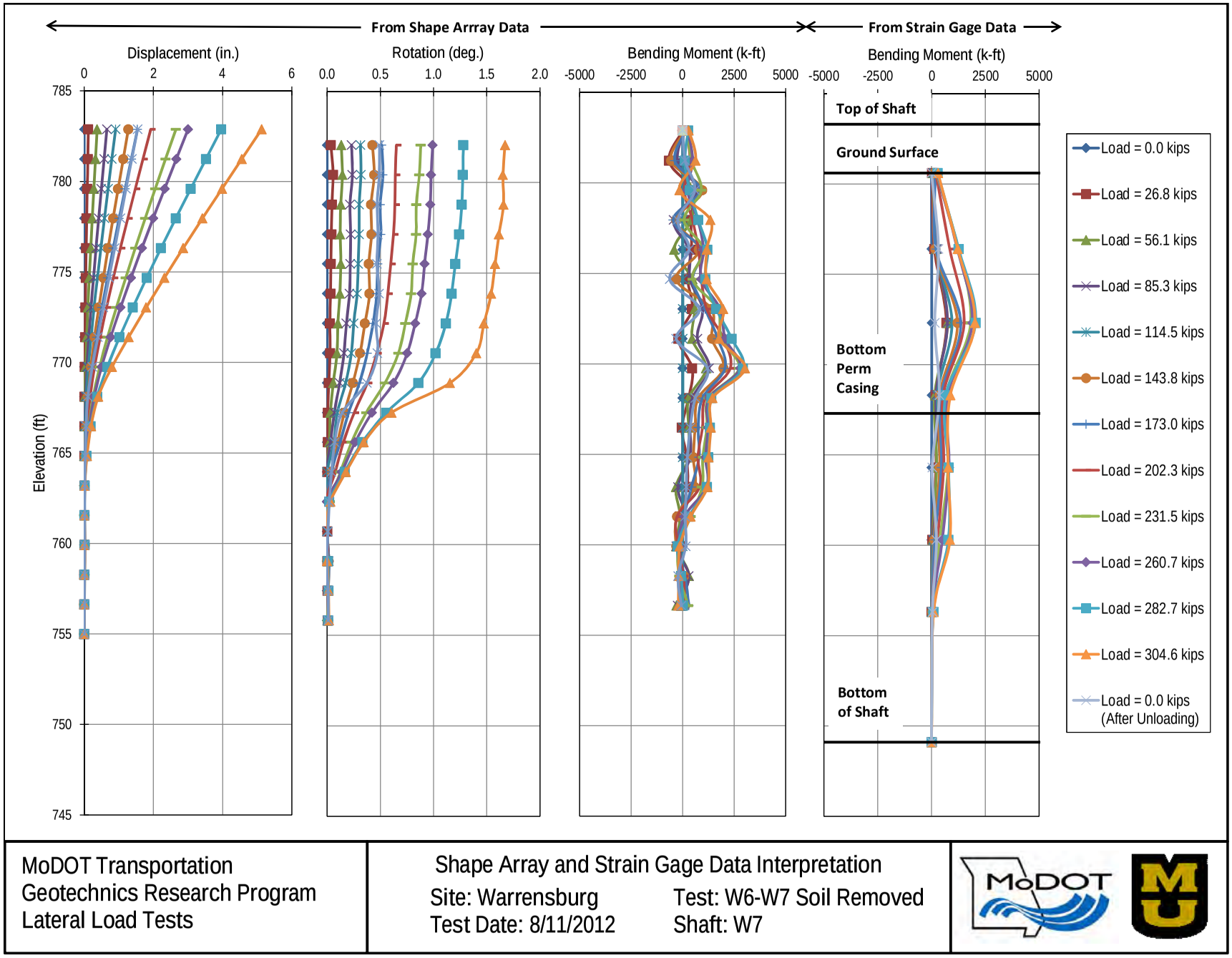


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/11/2012

Test: W6-W7 Soil Removed
Shaft: W6

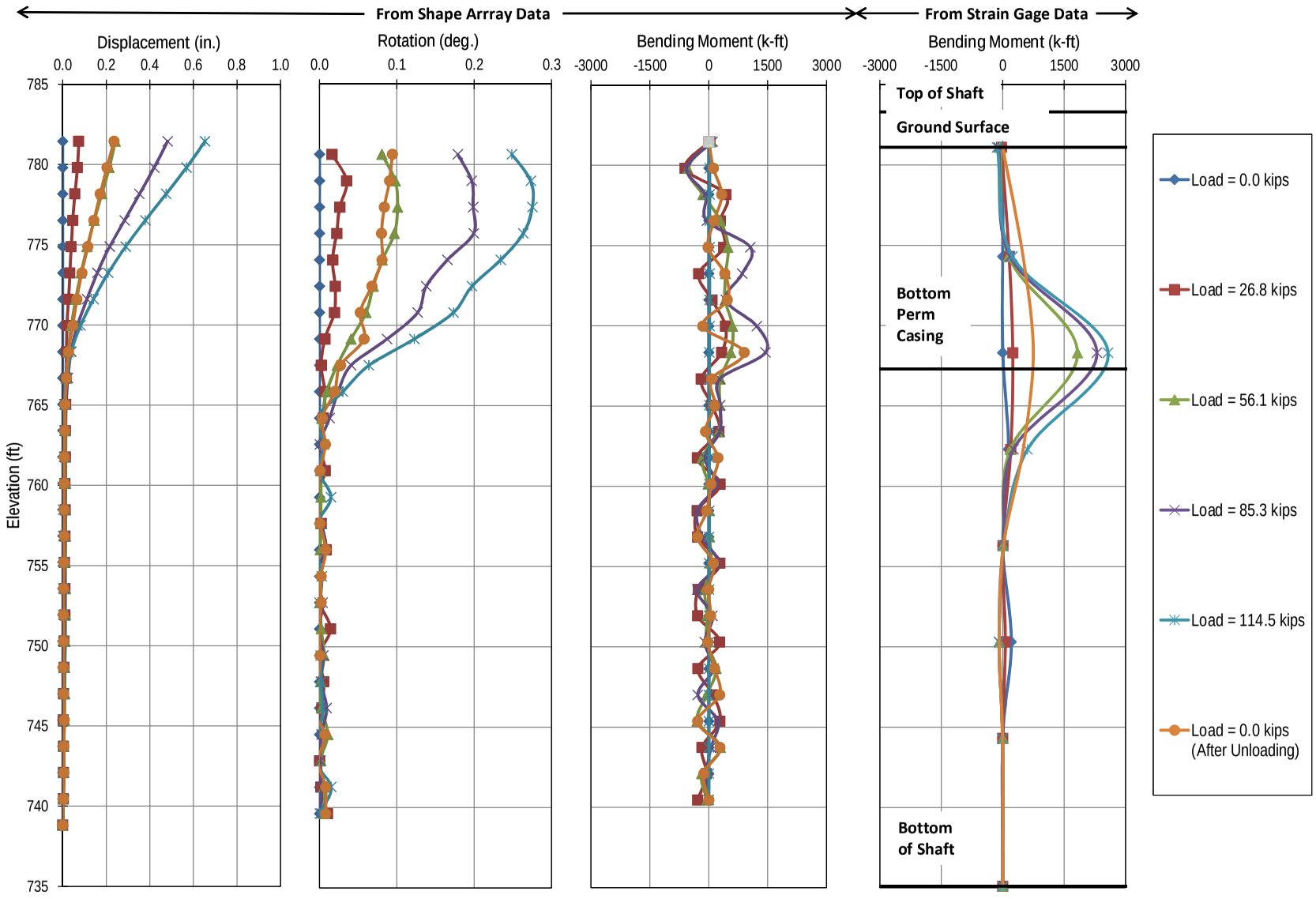


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/11/2012

Test: W6-W7 Soil Removed
Shaft: W7

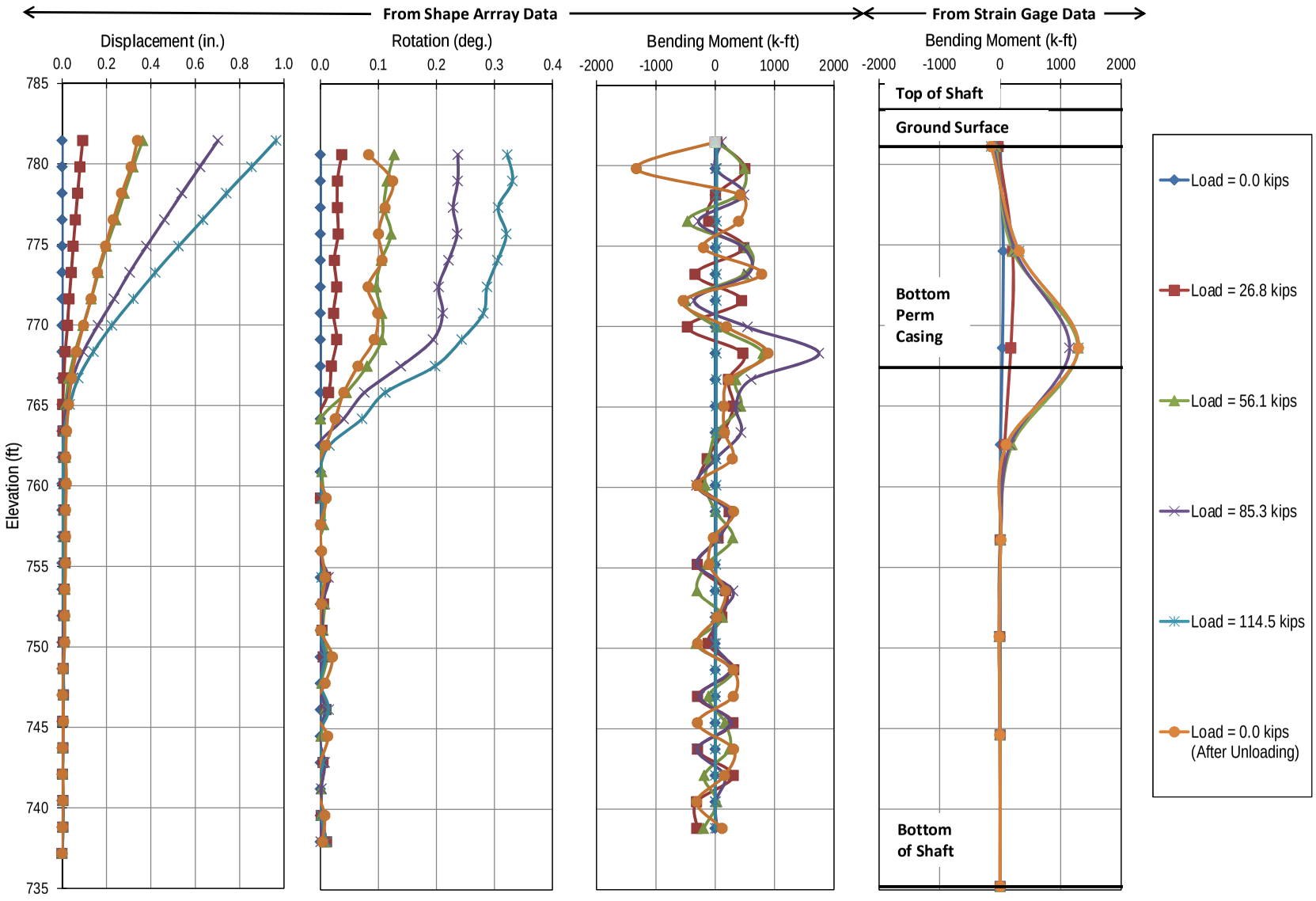


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg Test: W8-W9

Test Date: 7/24/2012 Shaft: W8

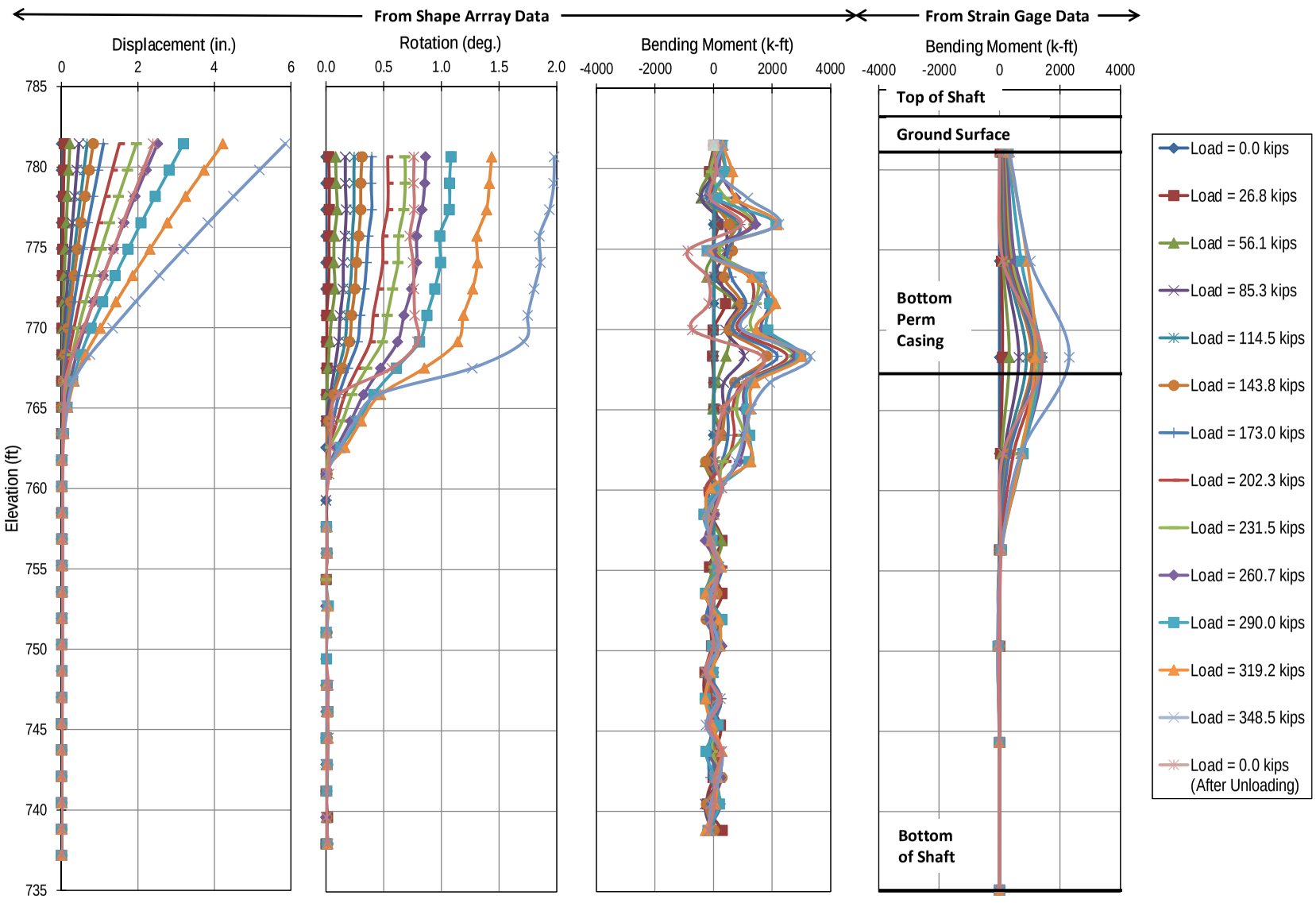


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg Test: W8-W9

Test Date: 7/24/2012 Shaft: W9

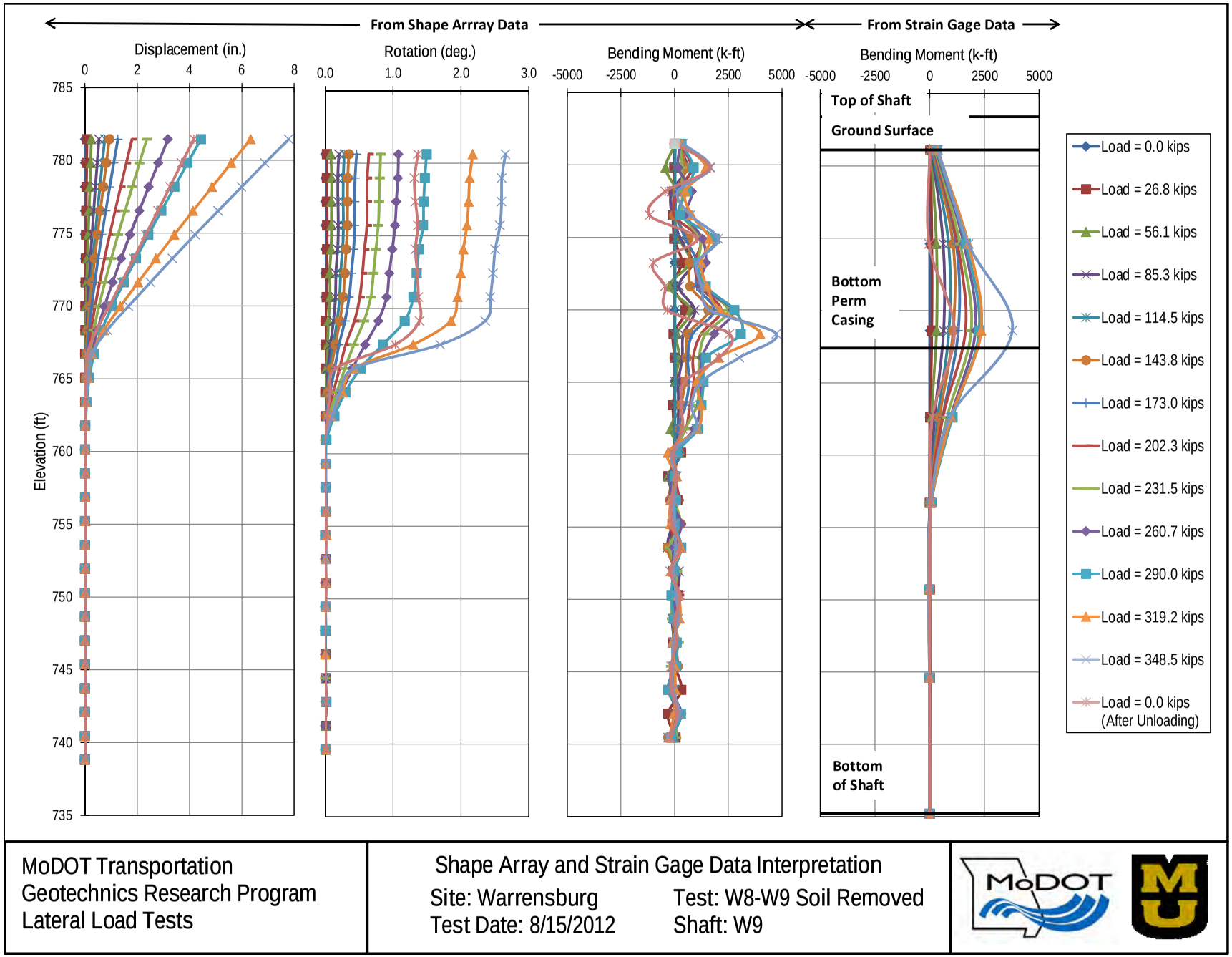


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/15/2012

Test: W8-W9 Soil Removed
Shaft: W8

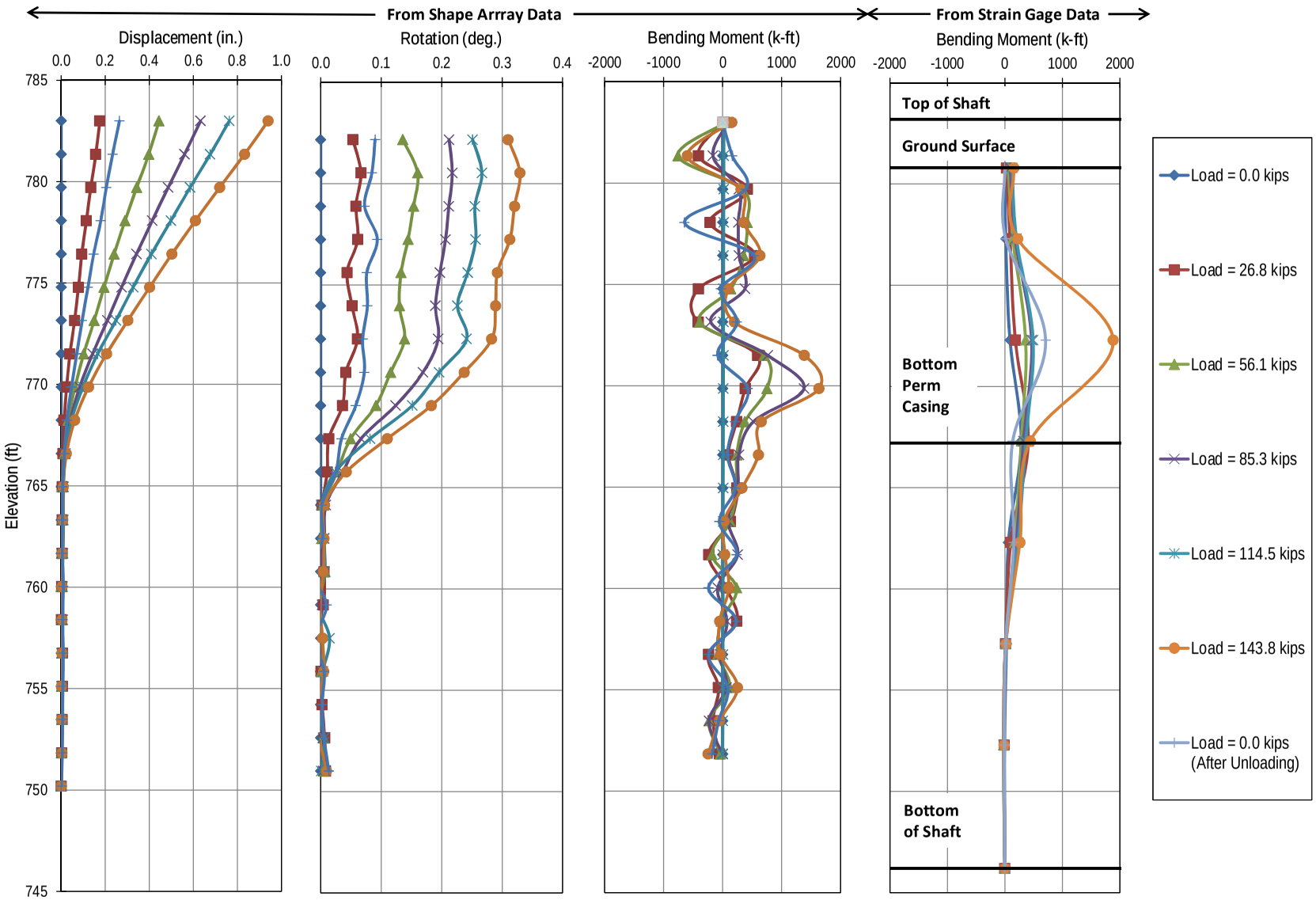


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/15/2012

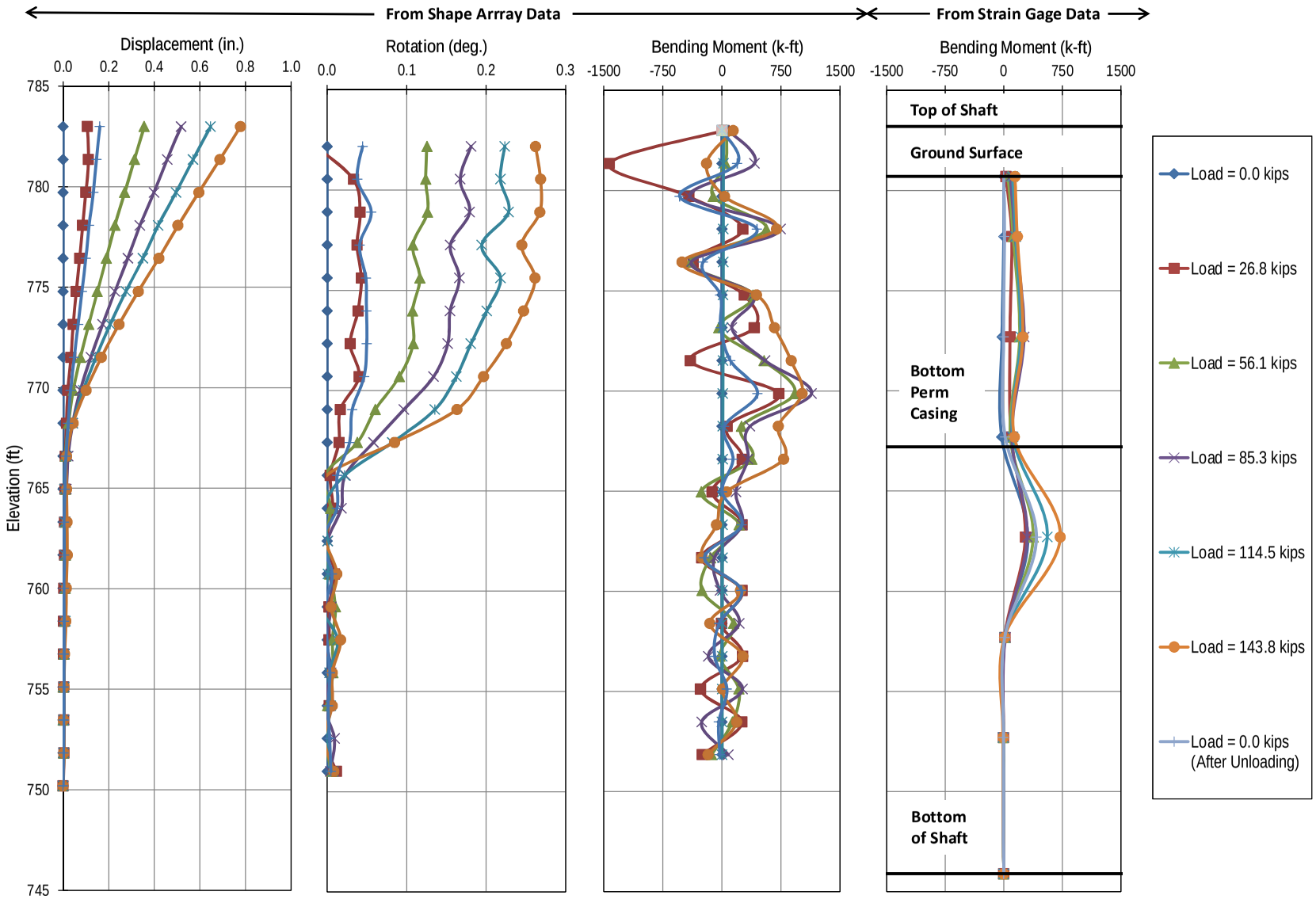
Test: W8-W9 Soil Removed
Shaft: W9



MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 7/27/2012
Test: W10-W11
Shaft: W10

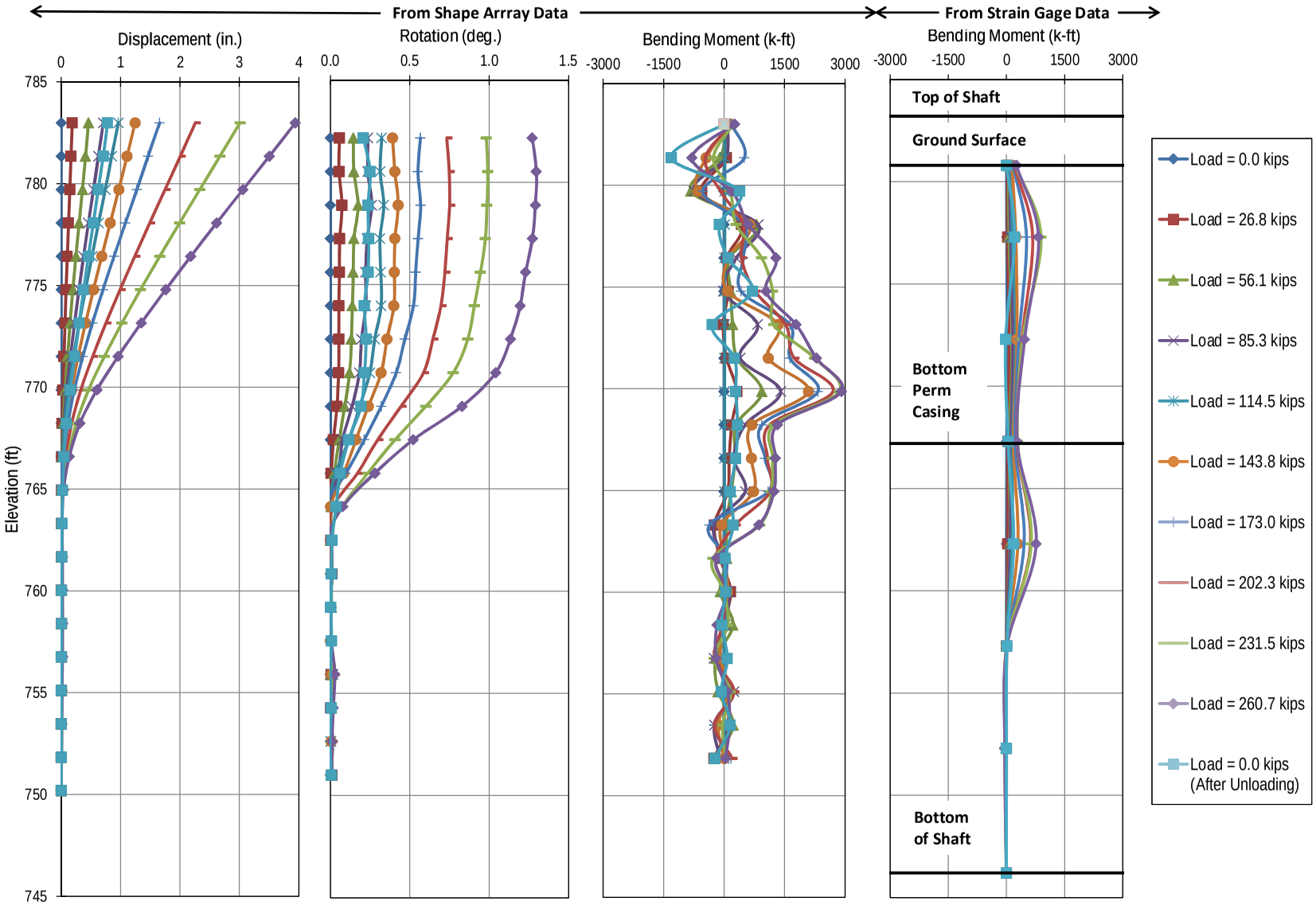


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg Test: W10-W11

Test Date: 7/27/2012 Shaft: W11

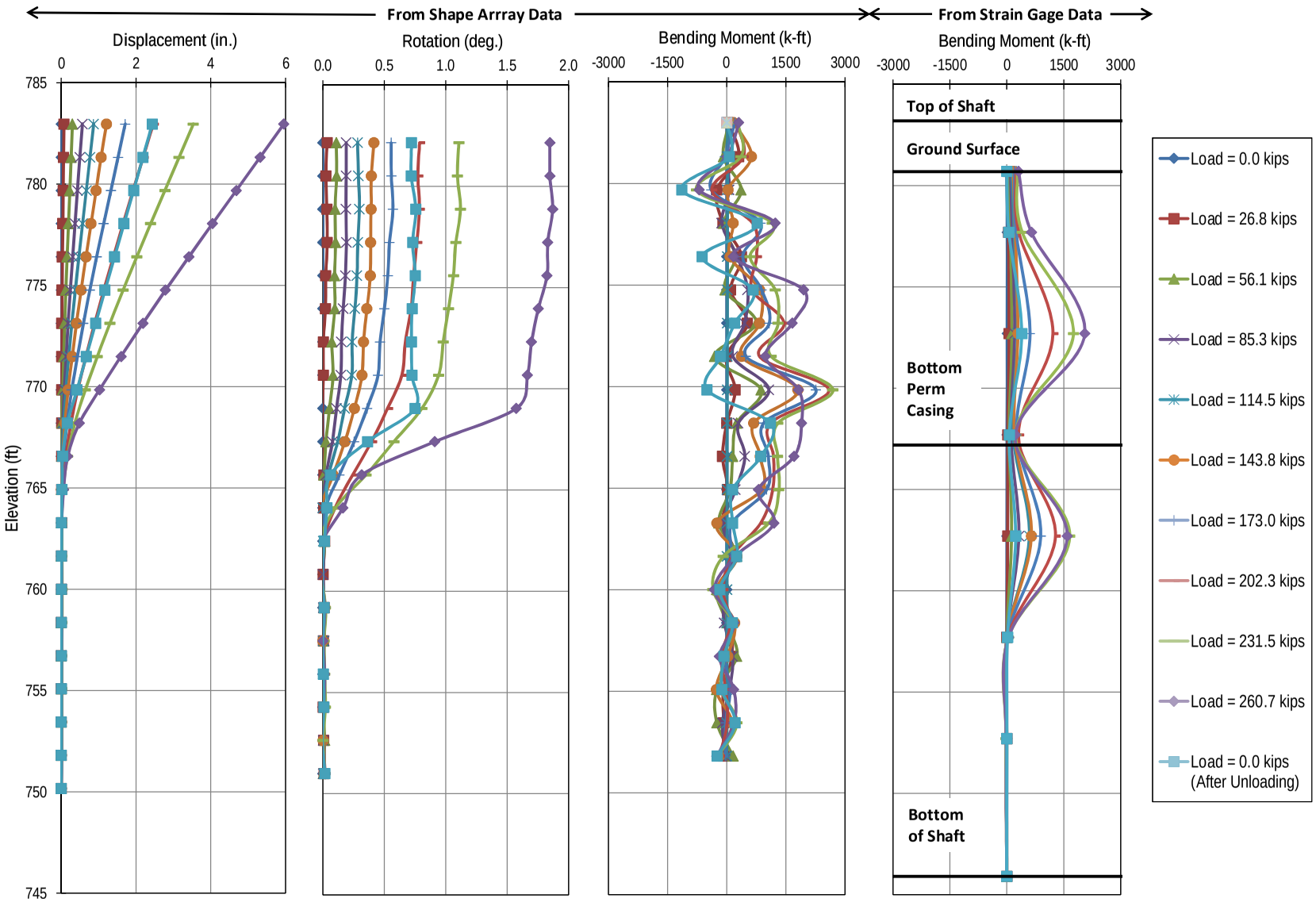


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/13/2012

Test: W10-W11 Soil Removed
Shaft: W10

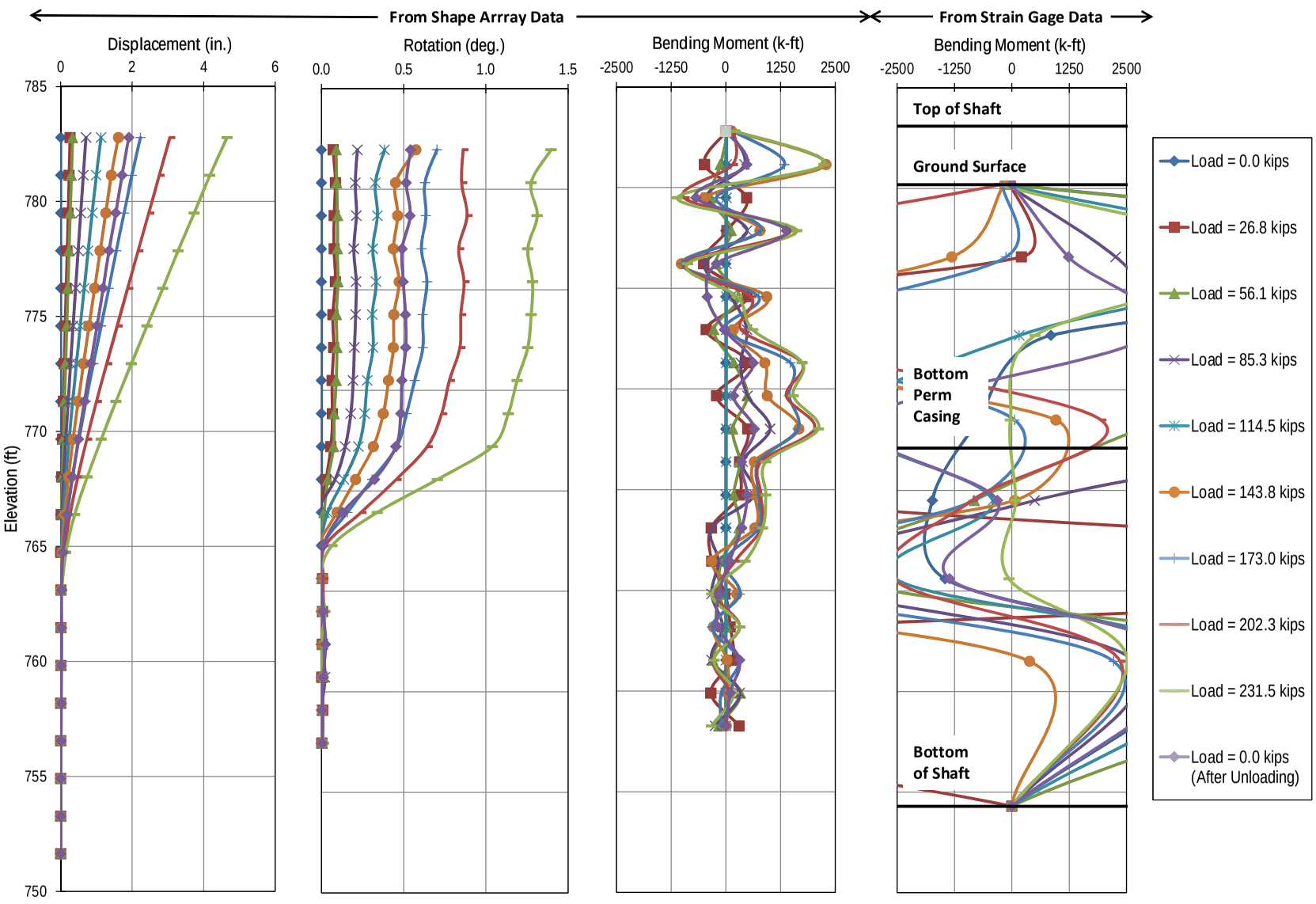


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/13/2012

Test: W10-W11 Soil Removed
Shaft: W11

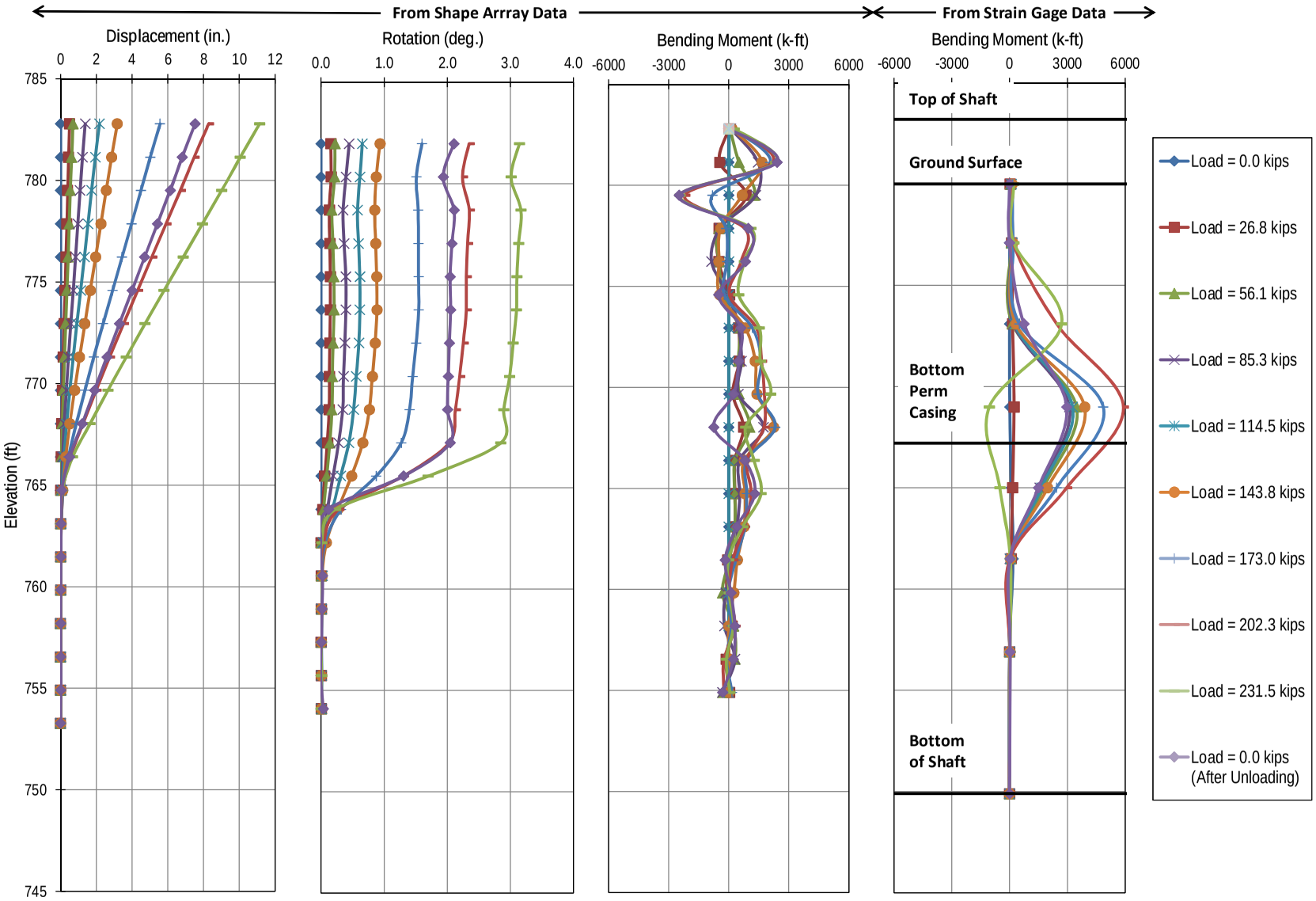


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/18/2012

Test: W12-W13 Soil Removed
Shaft: W12

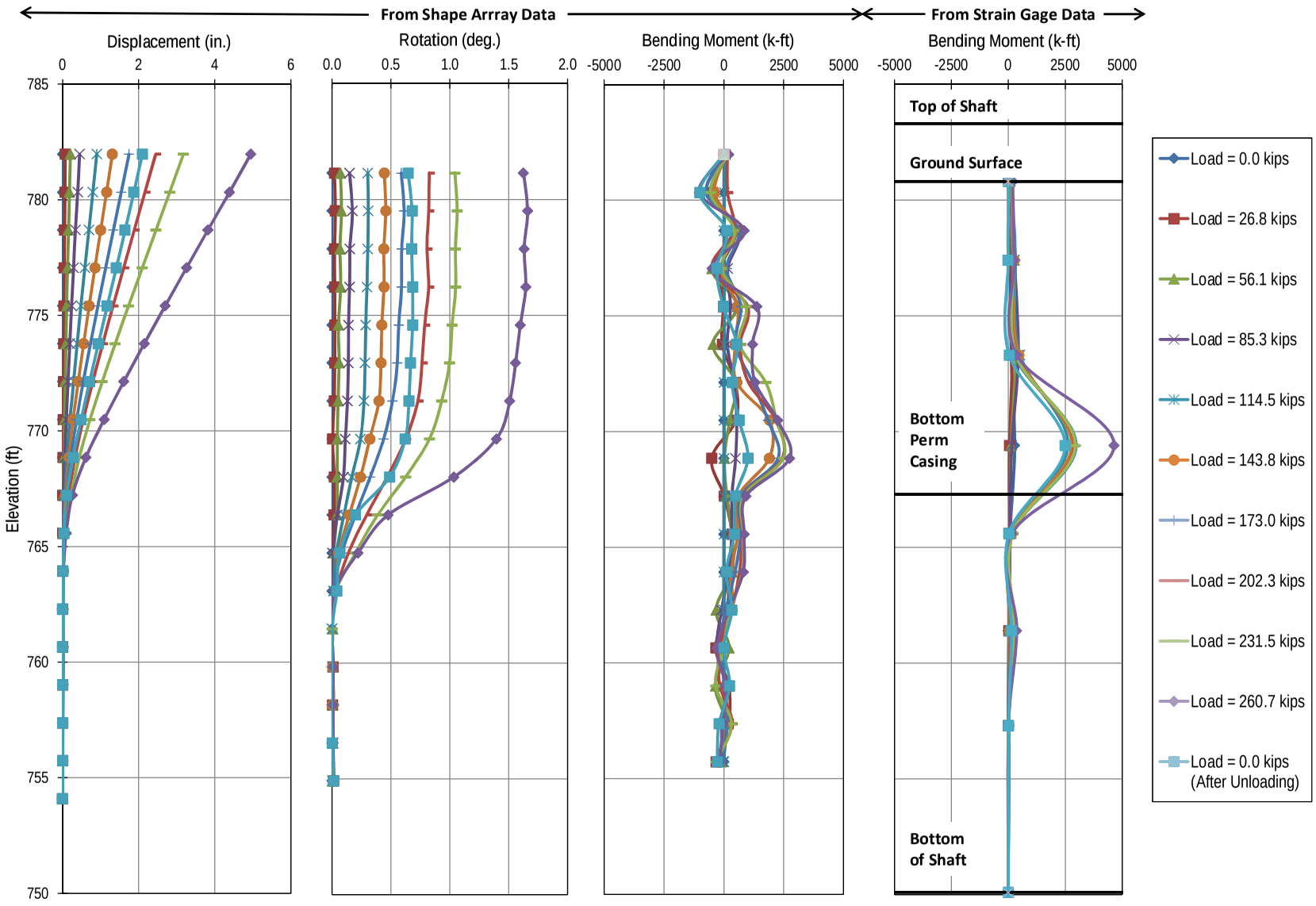


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/18/2012

Test: W12-W13 Soil Removed
Shaft: W13

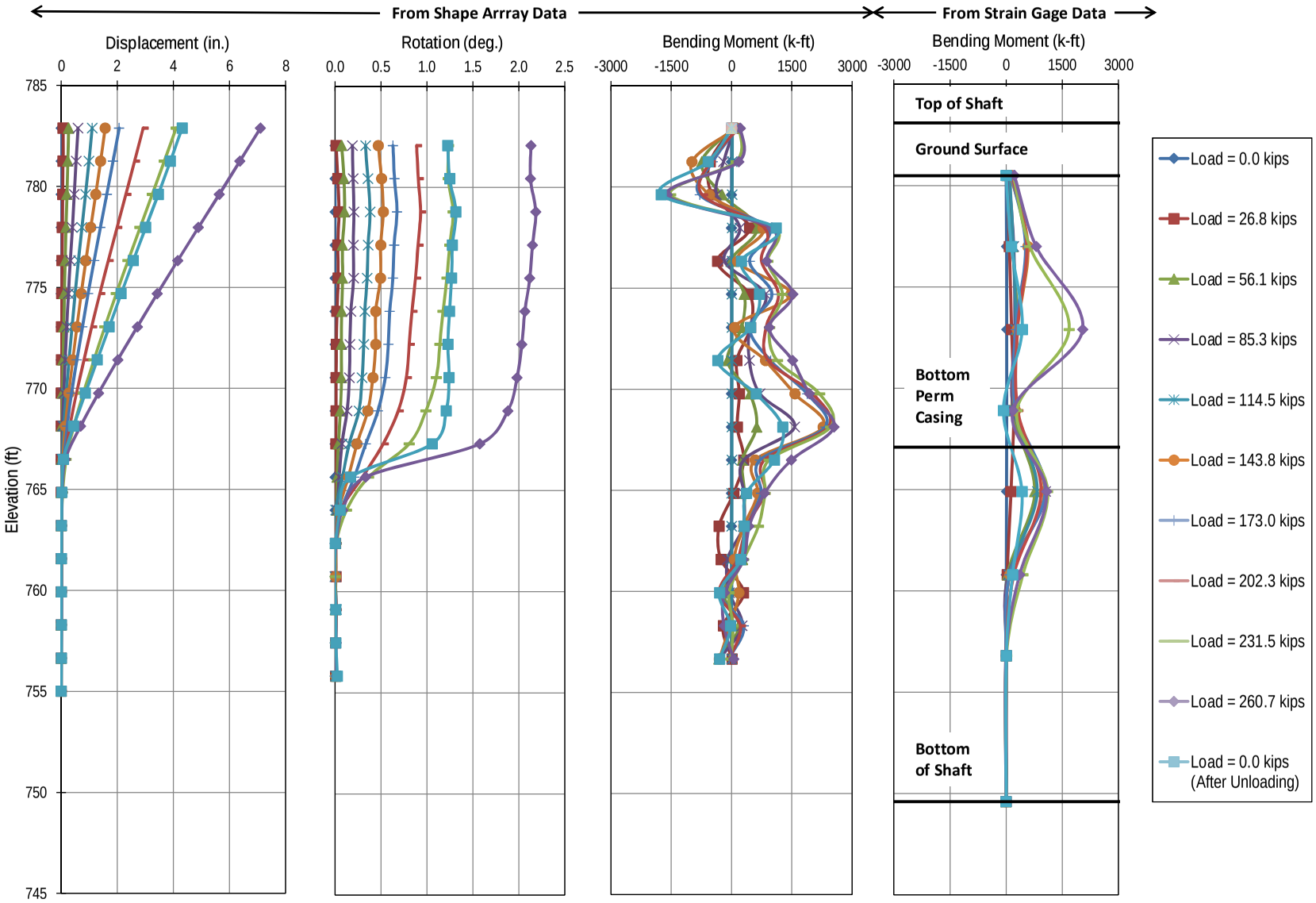


MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

Shape Array and Strain Gage Data Interpretation

Site: Warrensburg
Test Date: 8/17/2012

Test: W14-W15 Soil Removed
Shaft: W14



MoDOT Transportation
Geotechnics Research Program
Lateral Load Tests

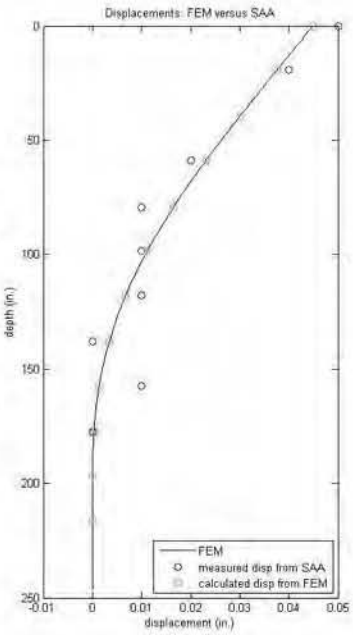
Shape Array and Strain Gage Data Interpretation

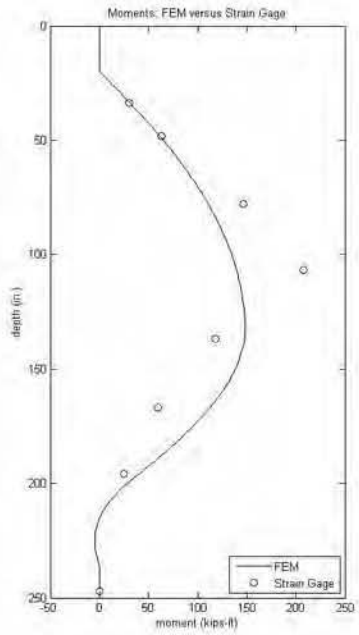
Site: Warrensburg
Test Date: 8/17/2012

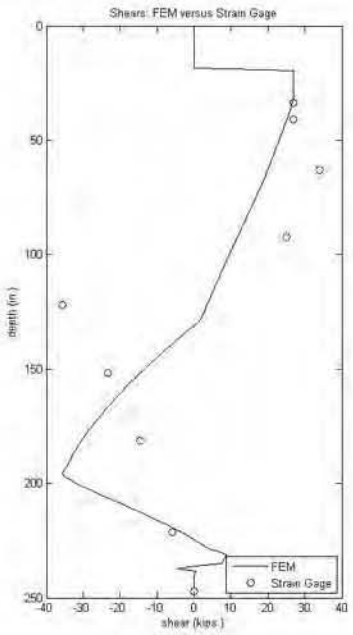
Test: W14-W15 Soil Removed
Shaft: W15

Appendix E – MATLAB Drilled Shaft Response Plots

F1 26.8 kips







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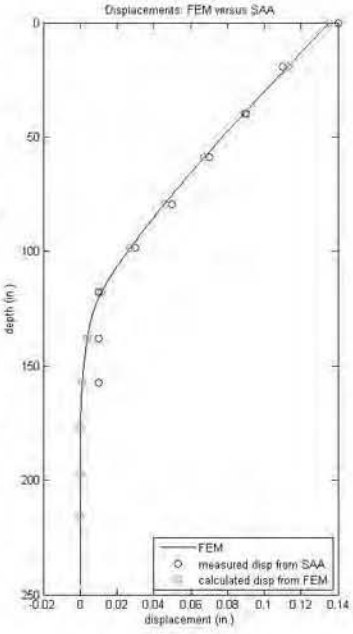

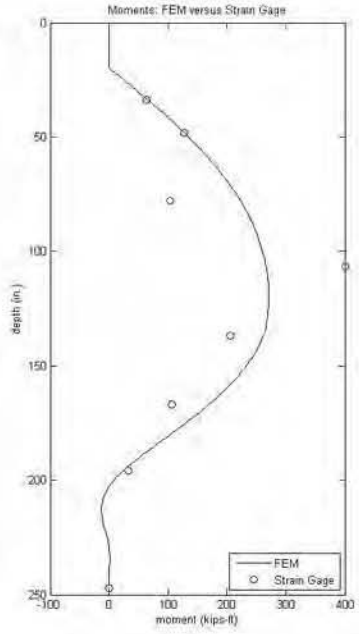

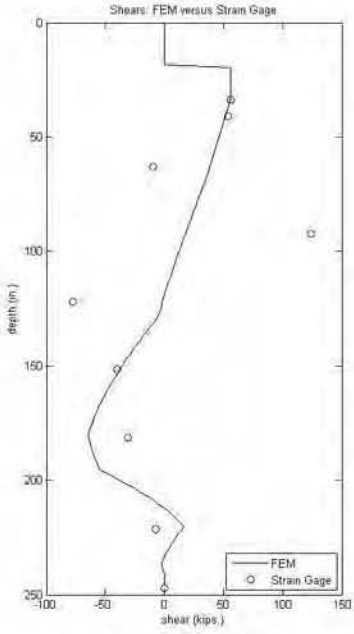

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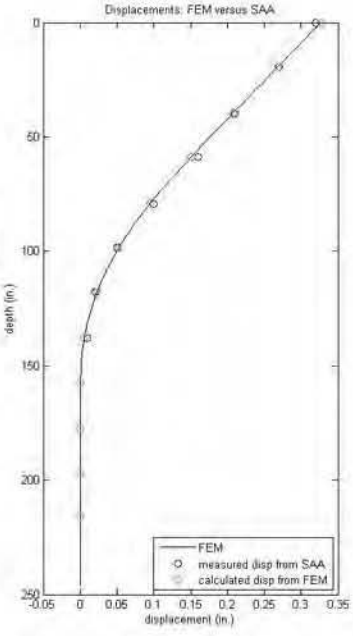

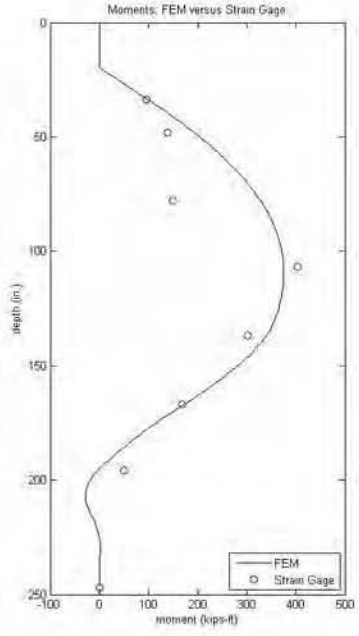

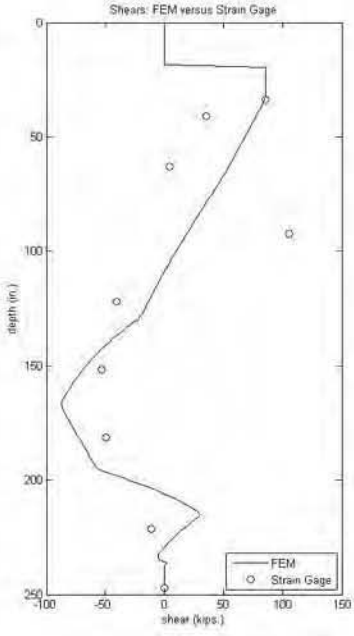

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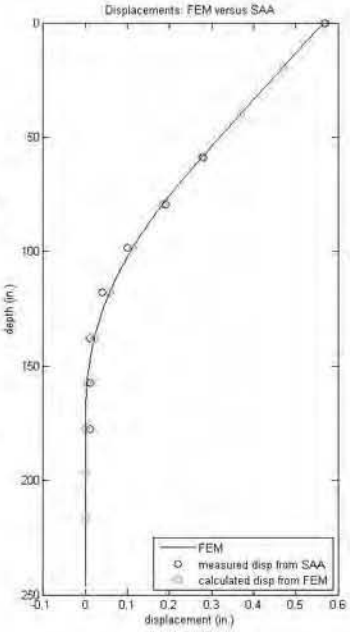

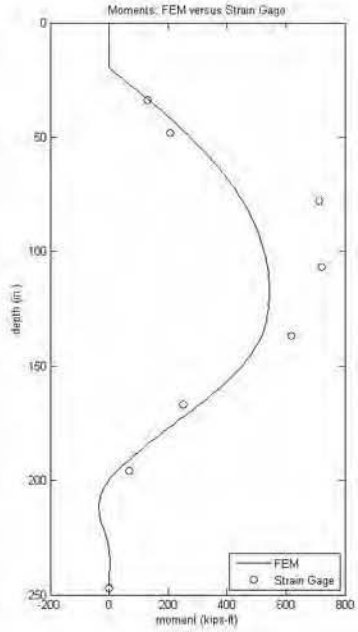

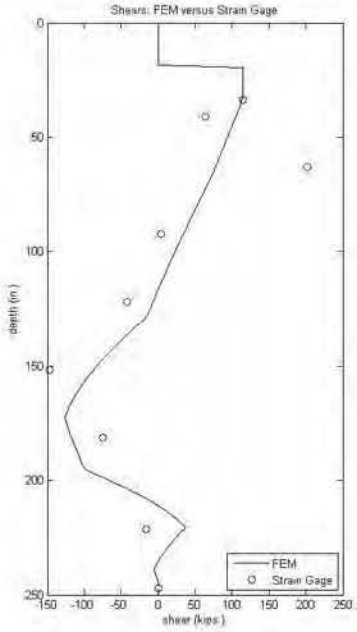

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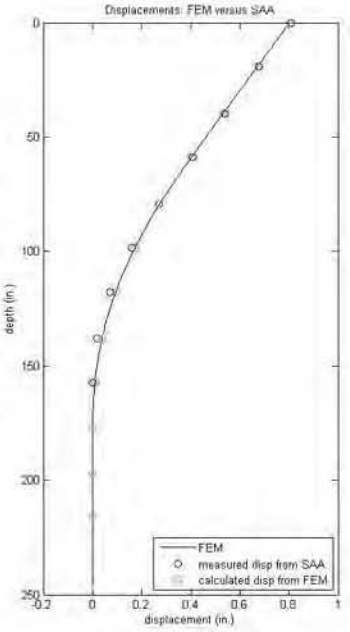

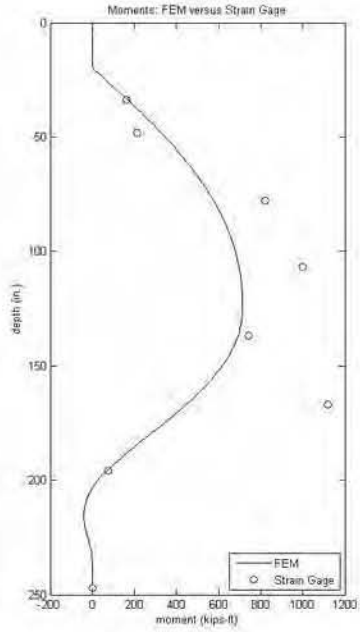

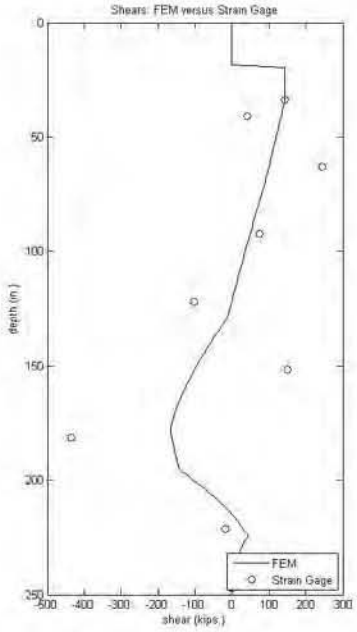

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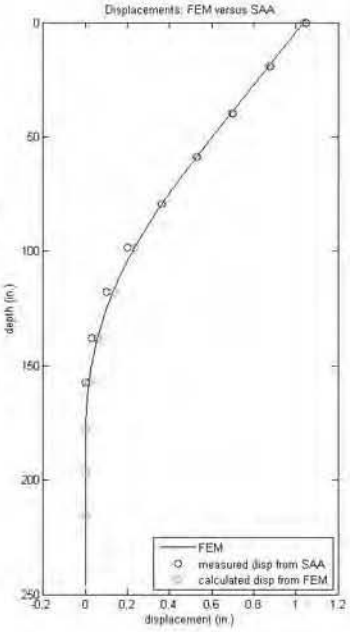

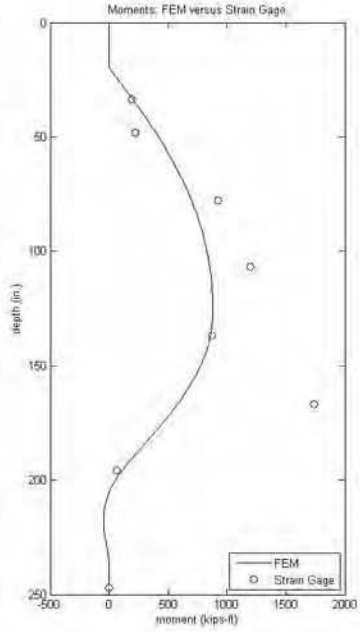

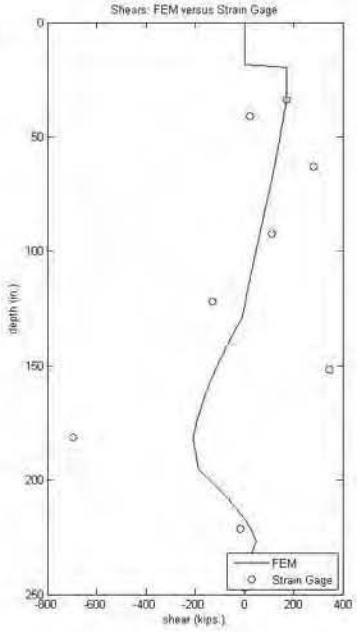

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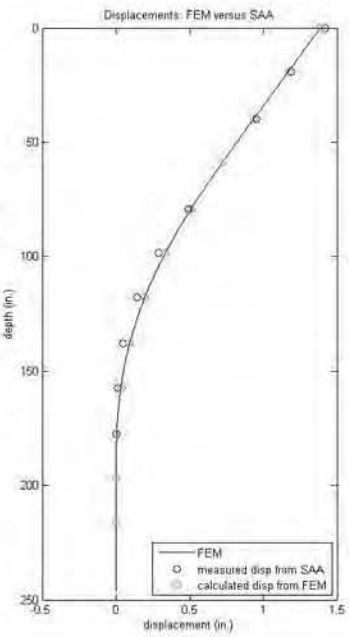

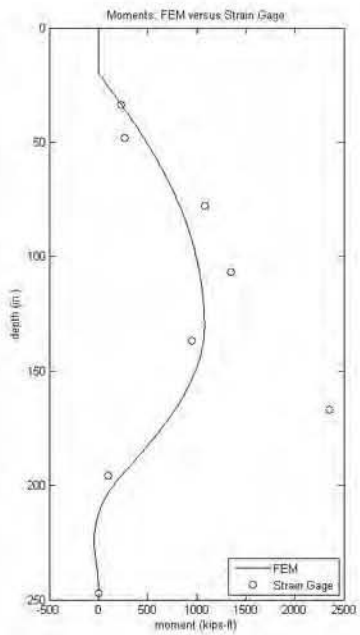

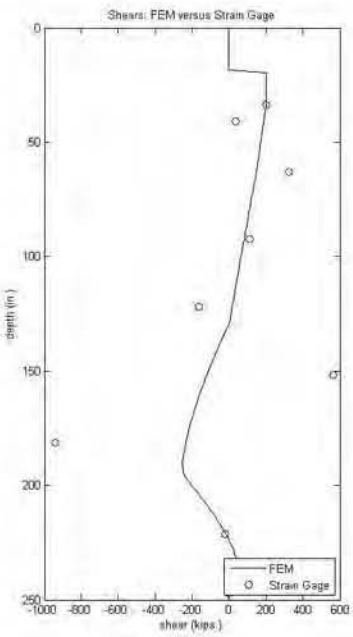

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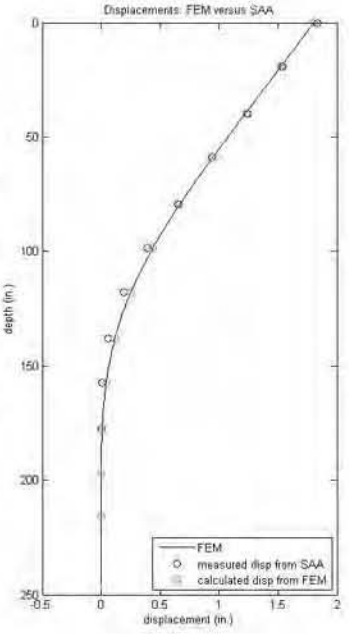

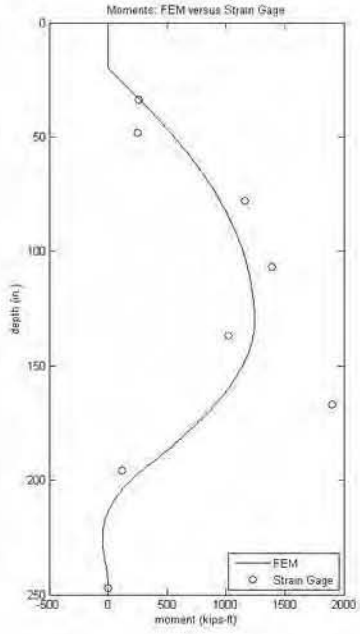

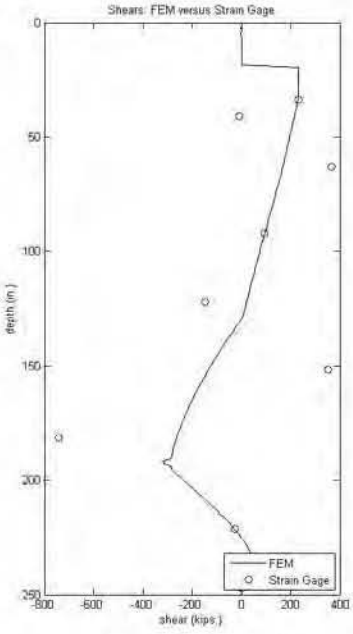

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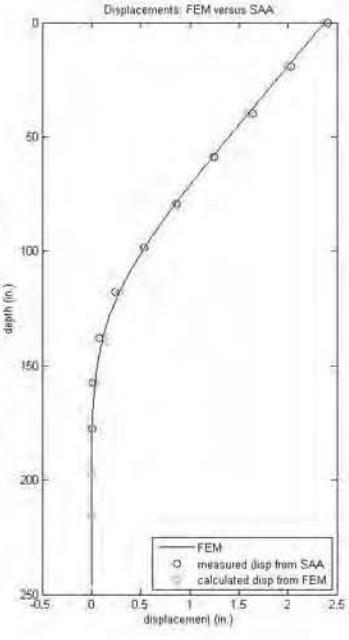

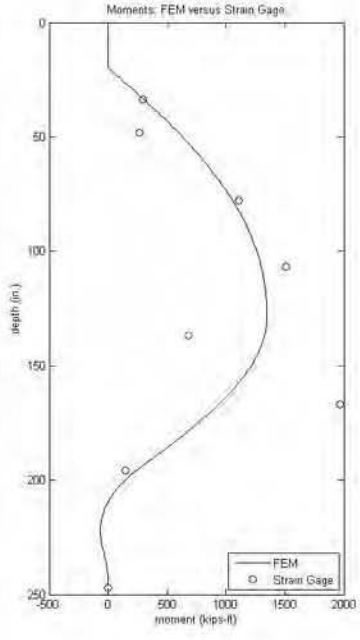

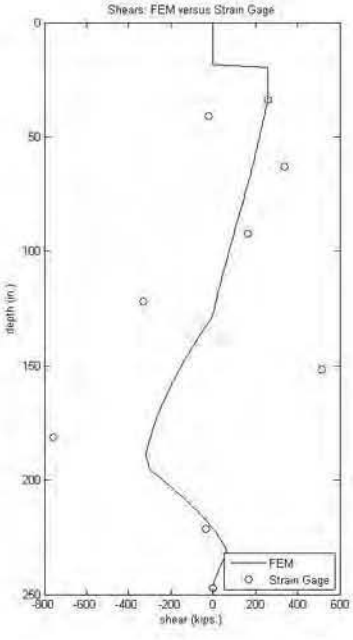

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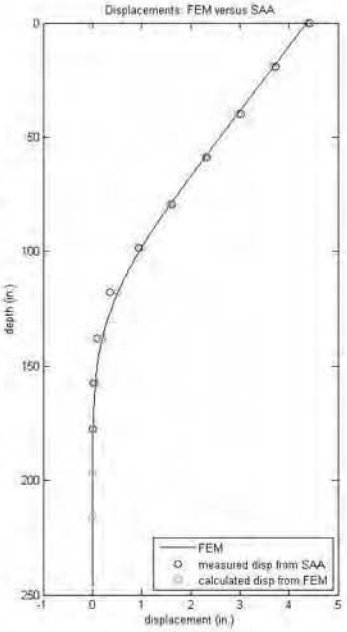

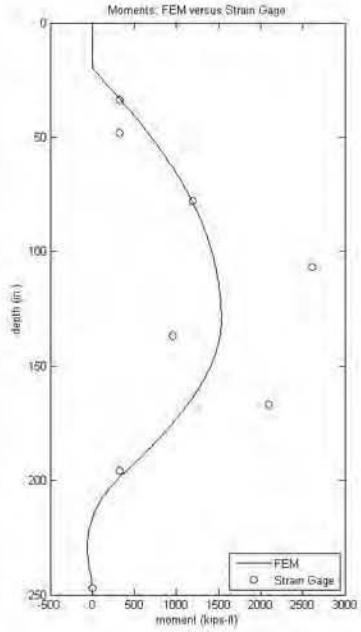

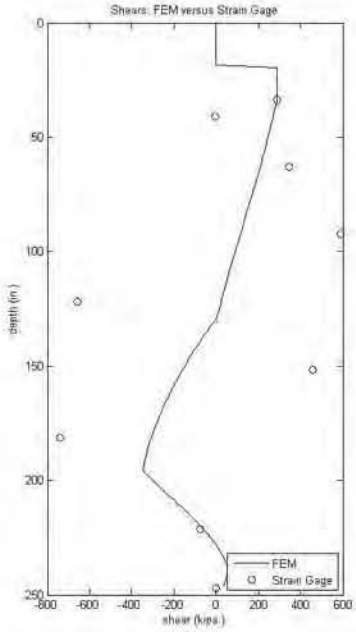

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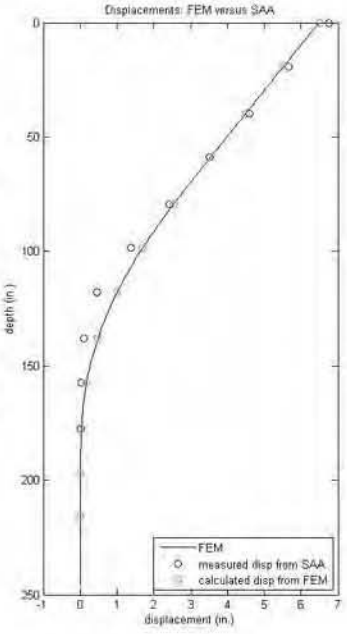

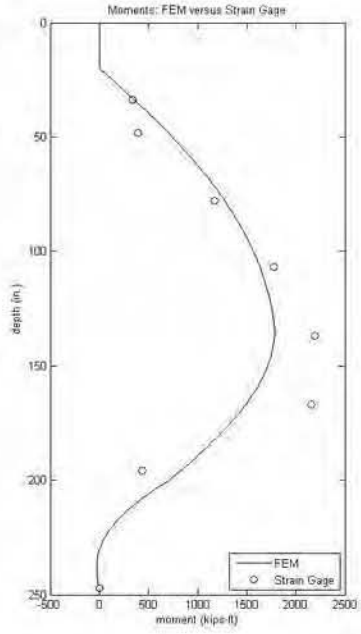

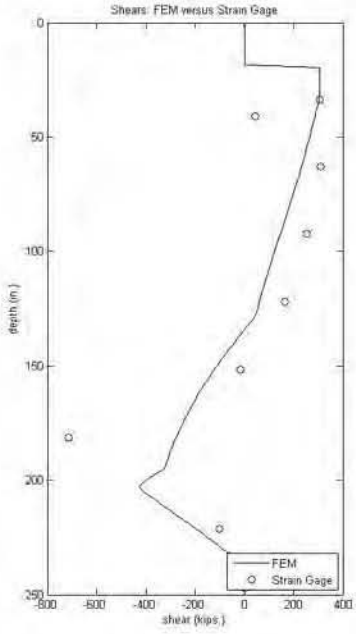

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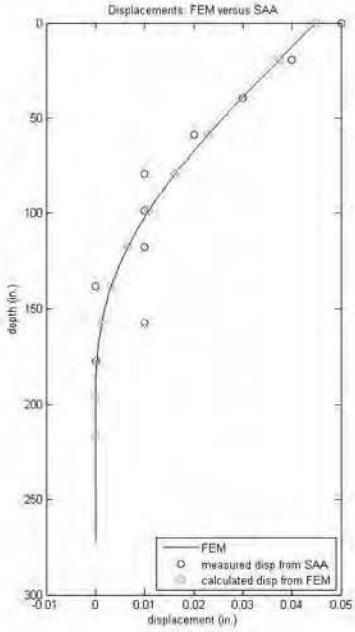

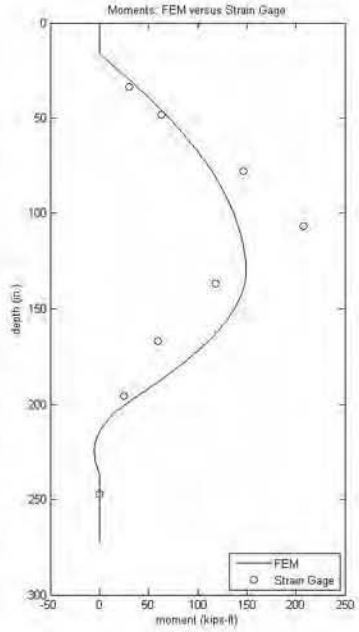

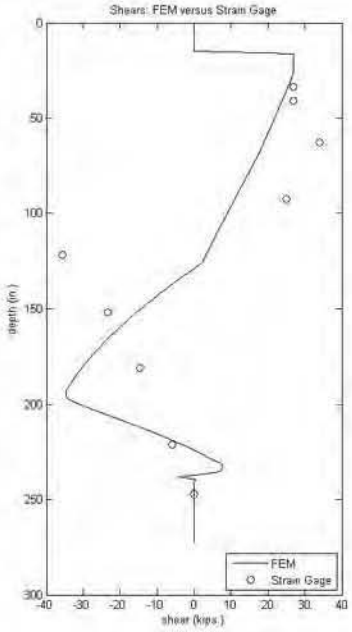

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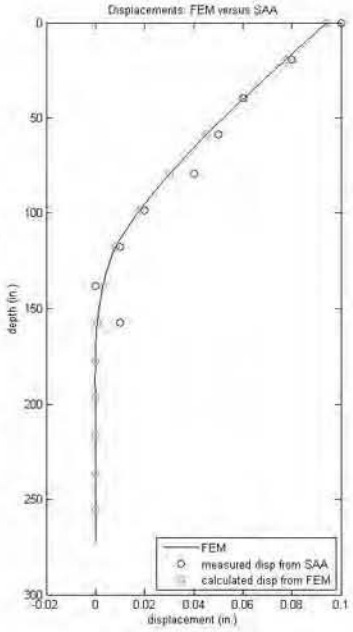

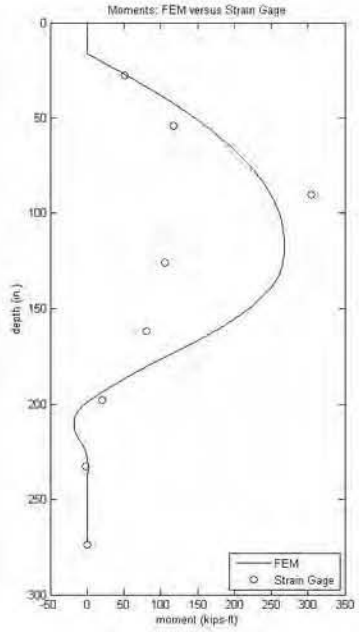

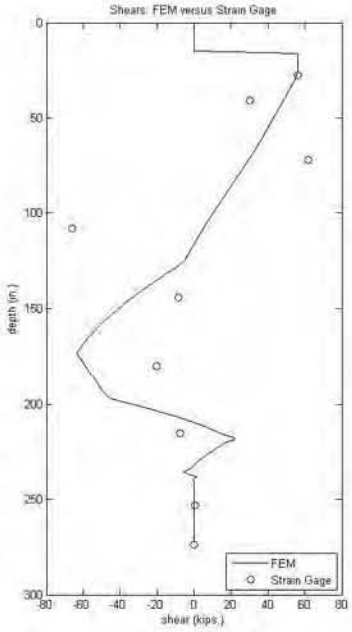

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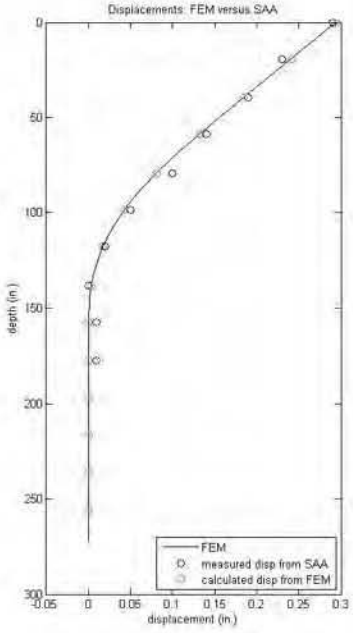

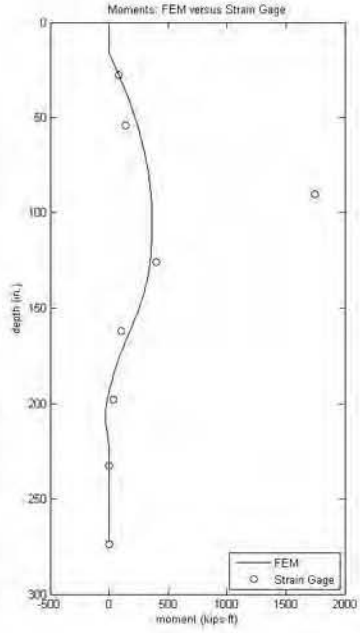

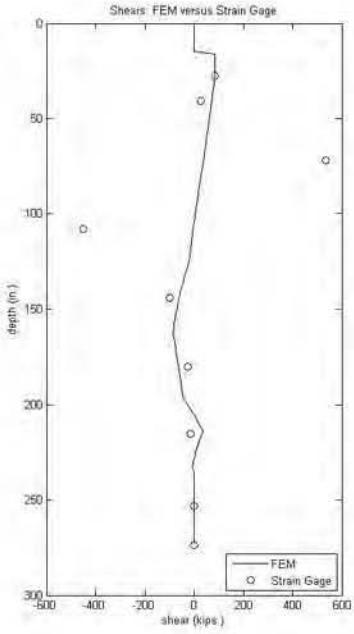

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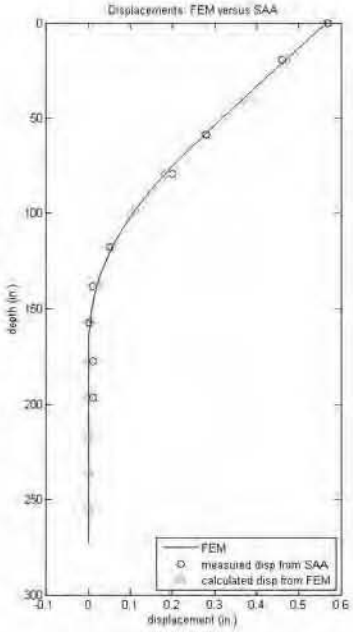

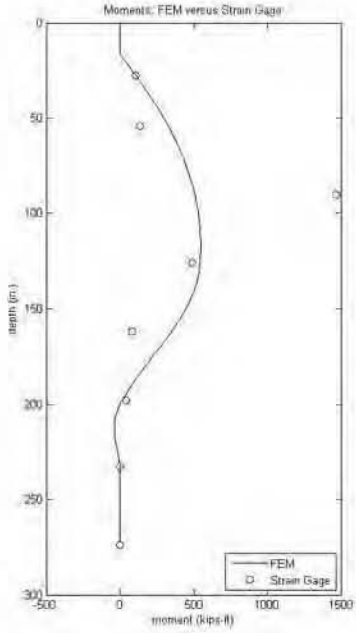

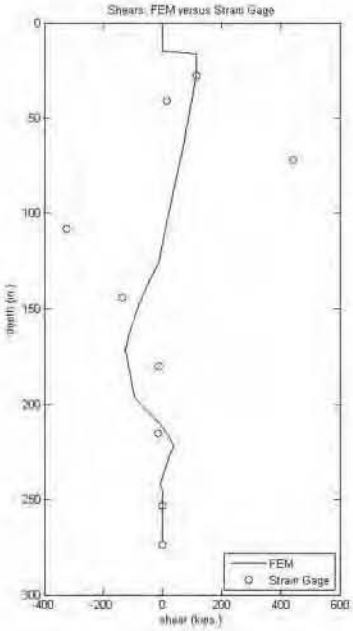

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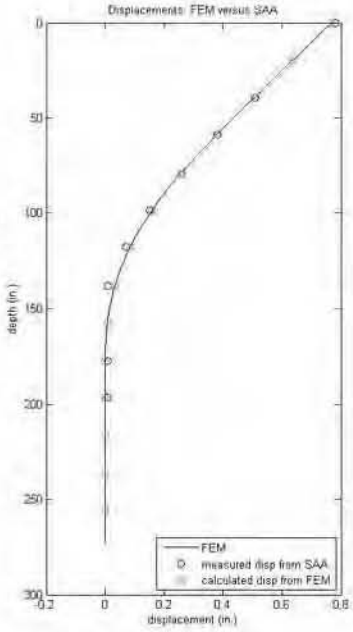

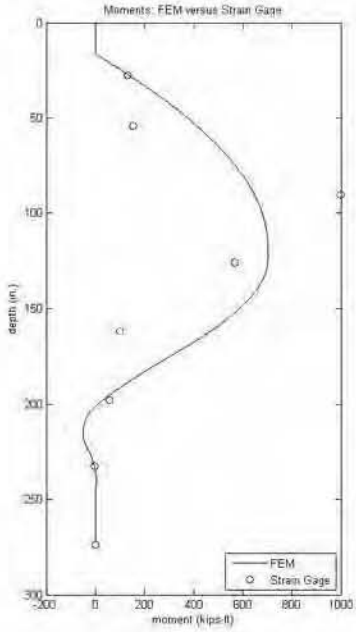

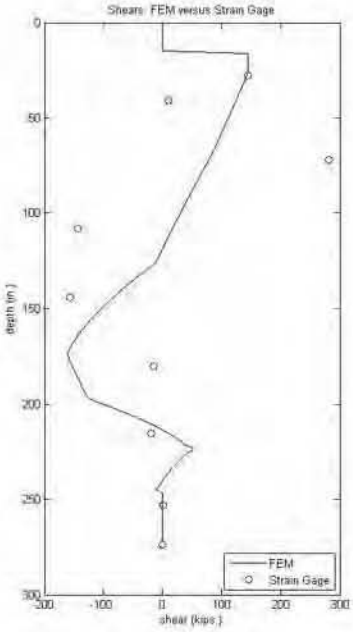

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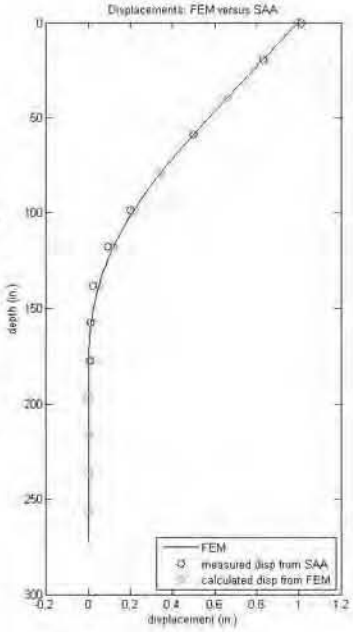

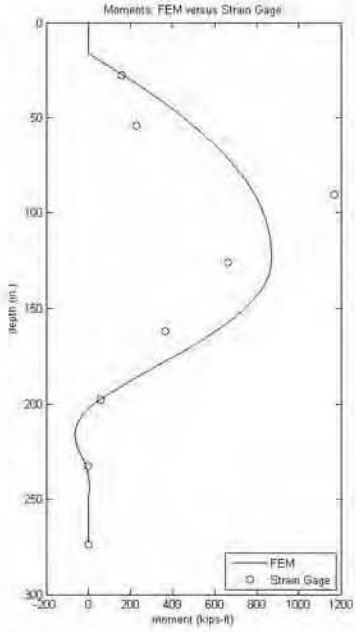

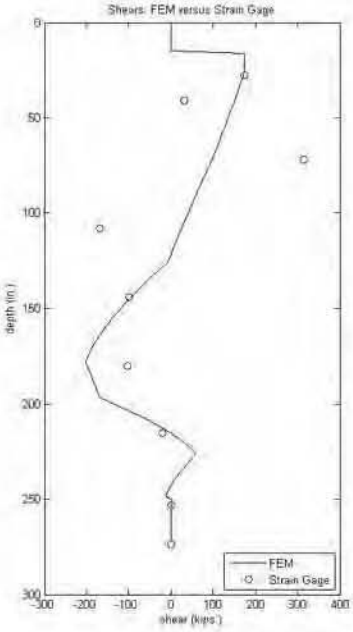

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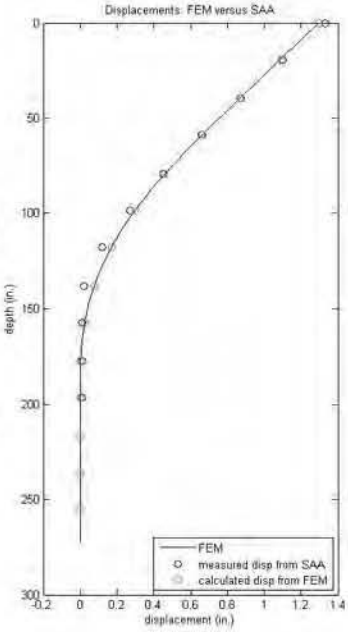

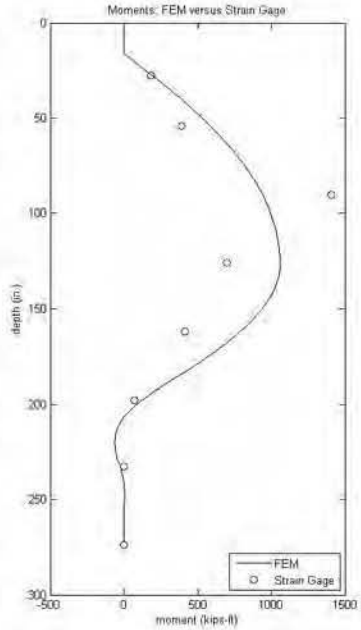

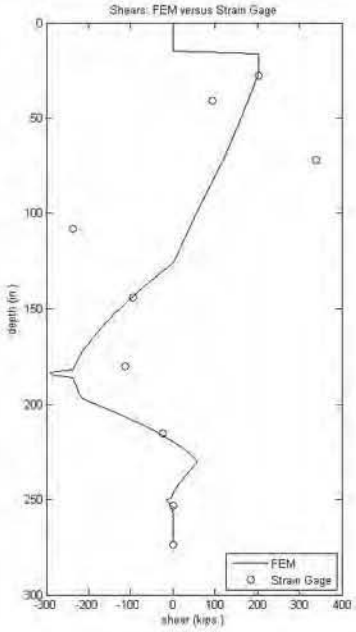

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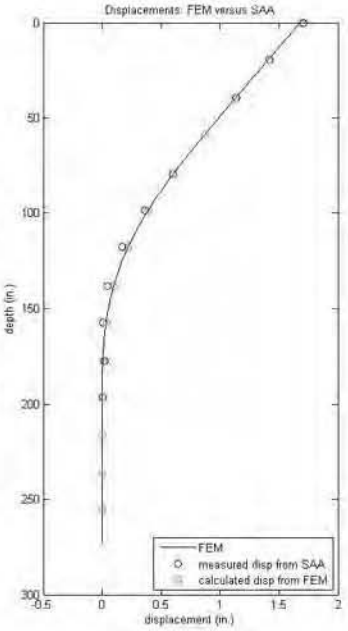

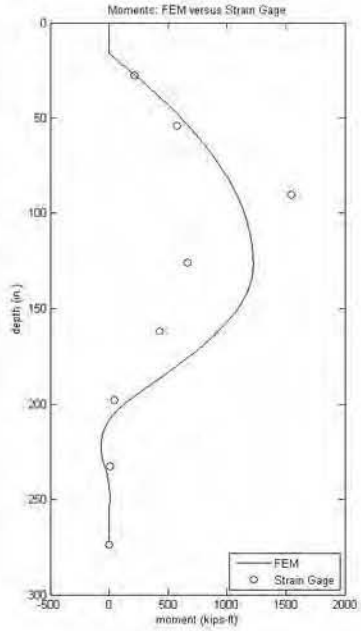

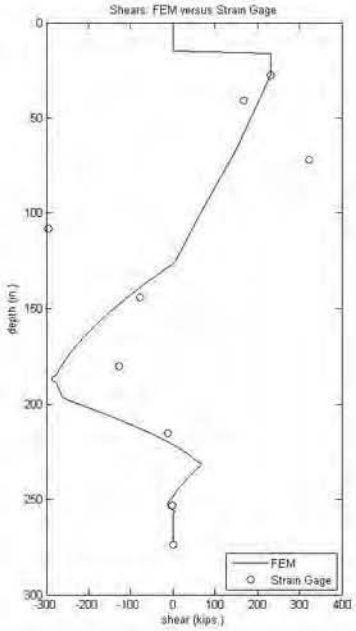

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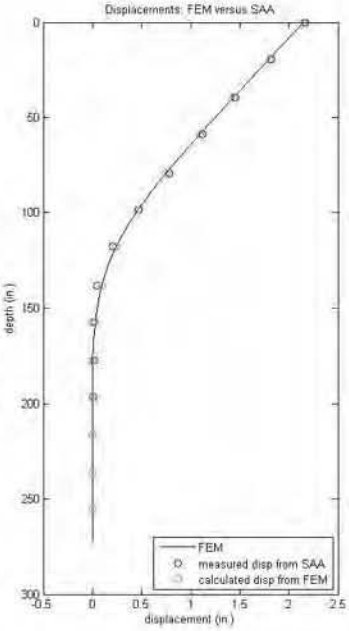

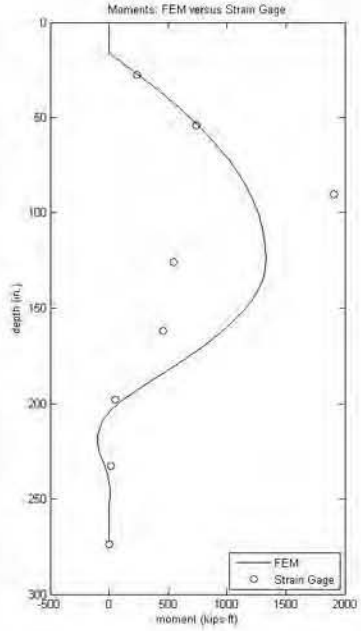

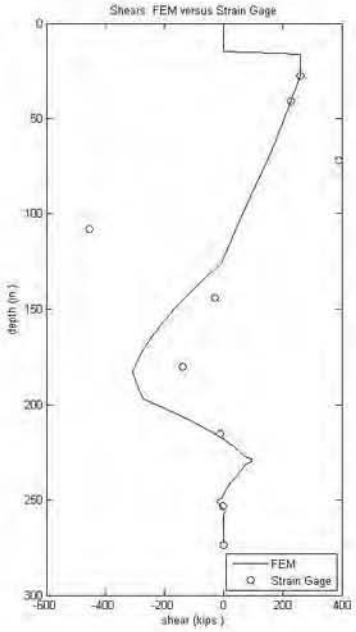

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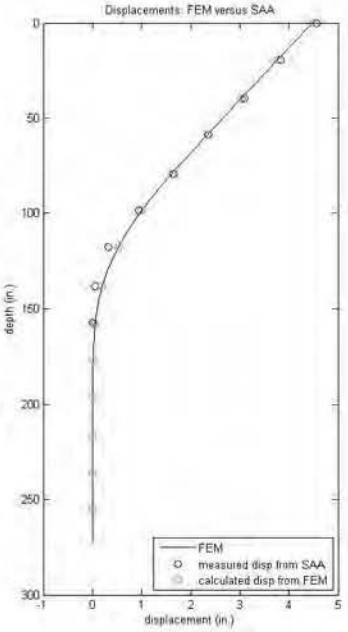

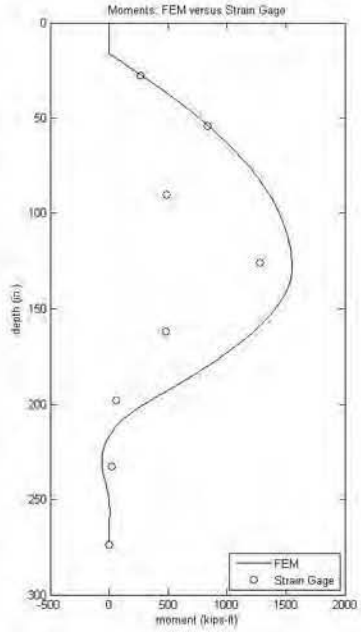

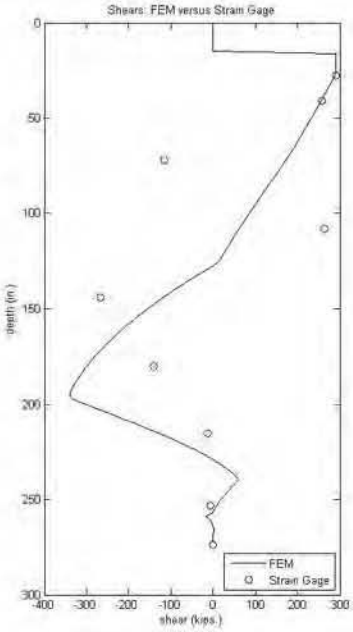

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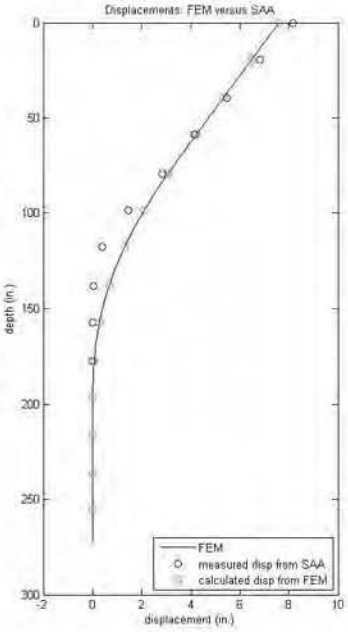

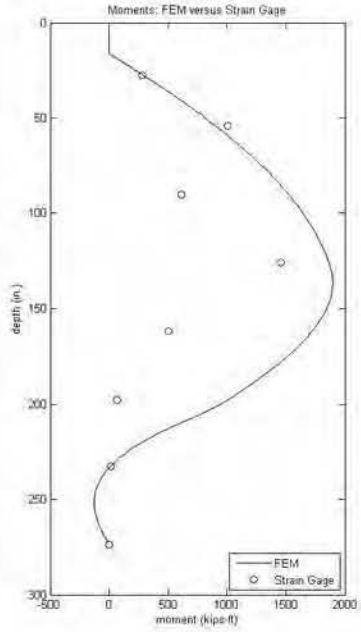

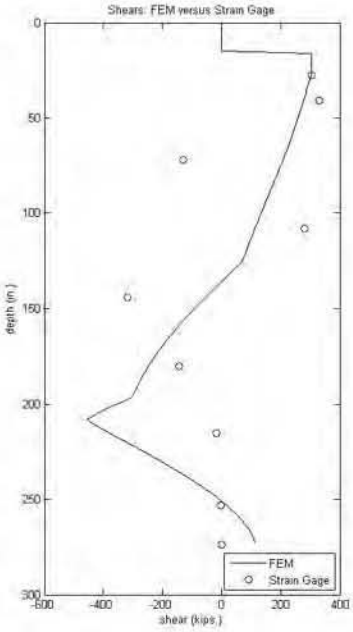

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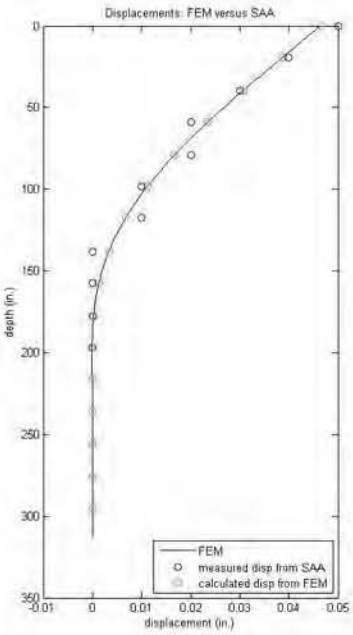

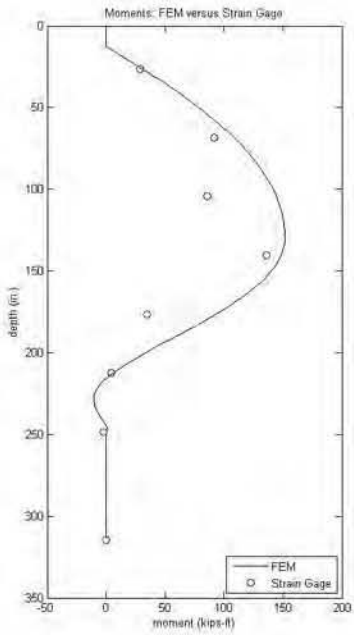

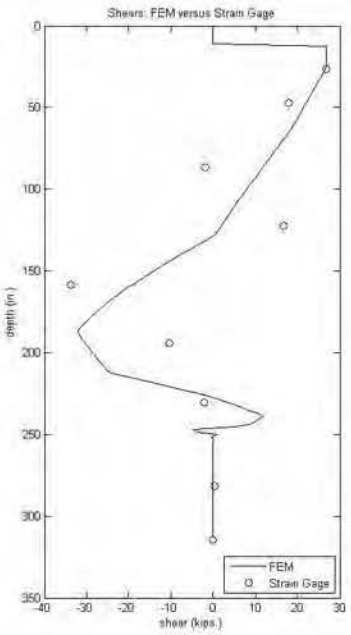

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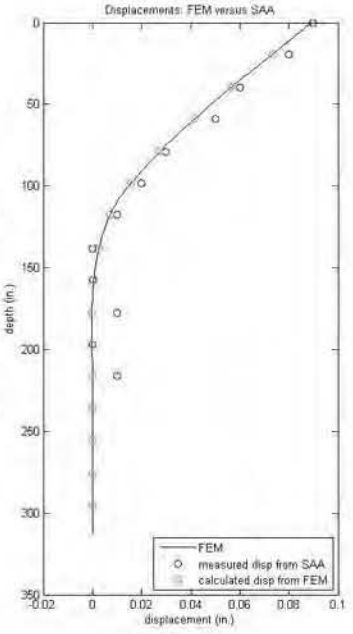

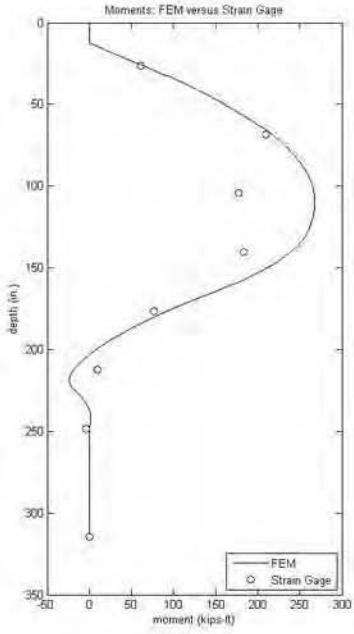

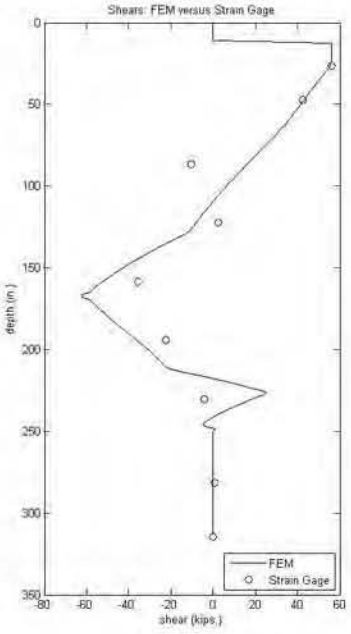

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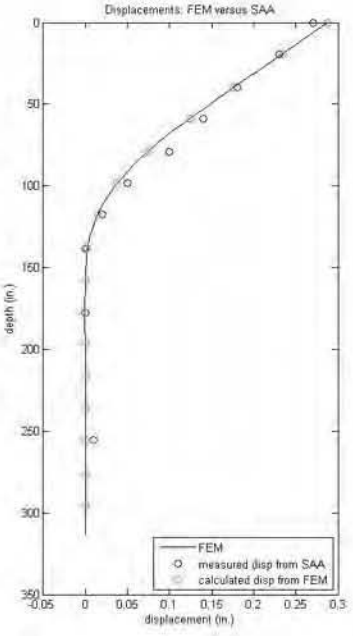

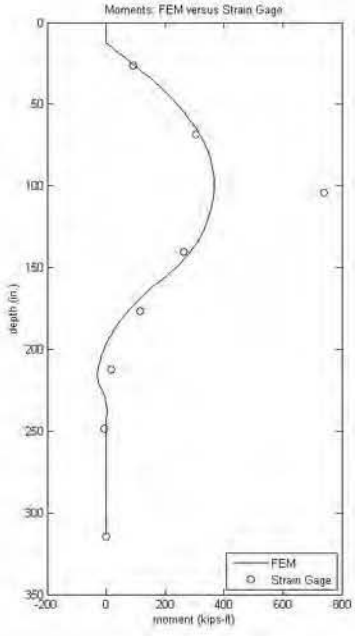

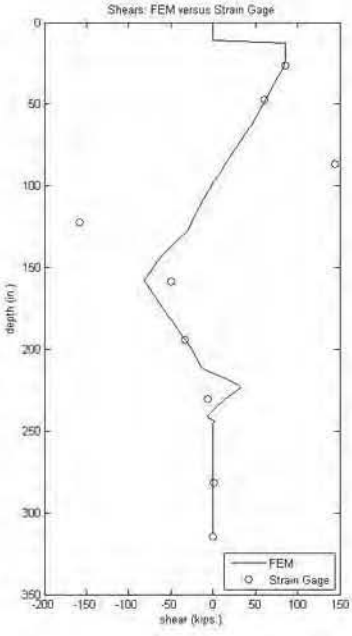

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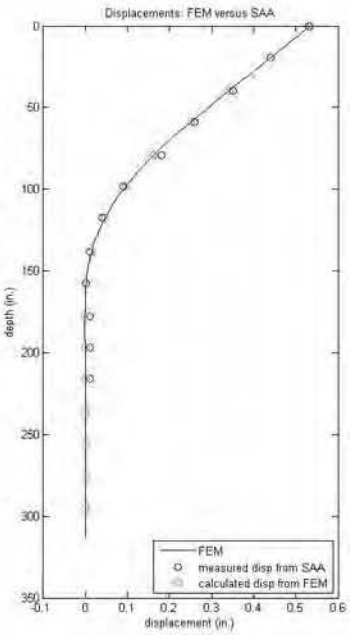

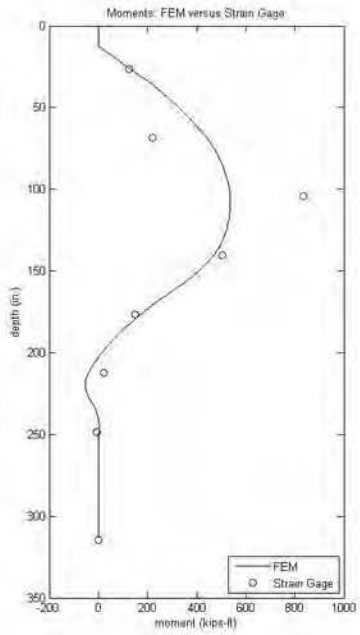

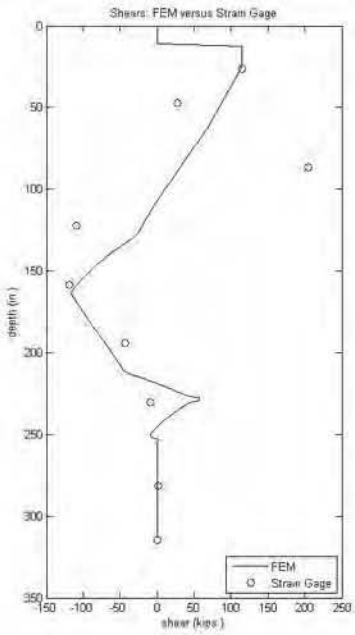

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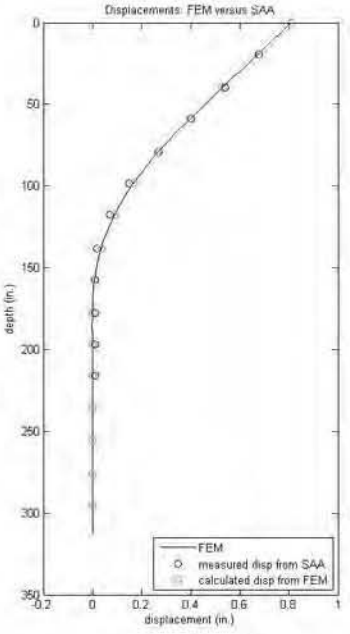

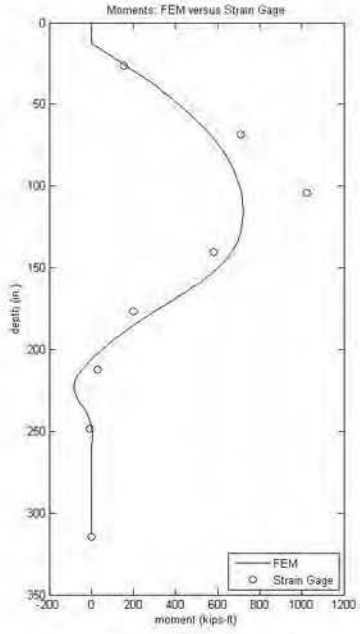

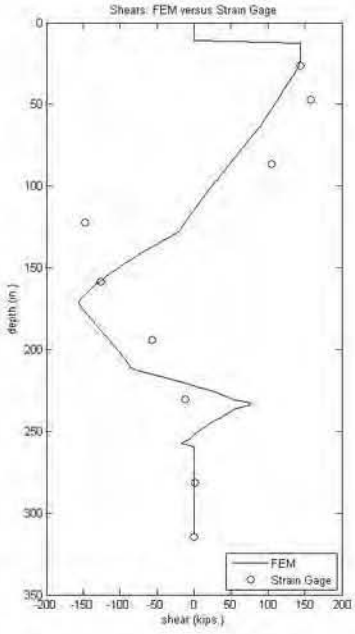

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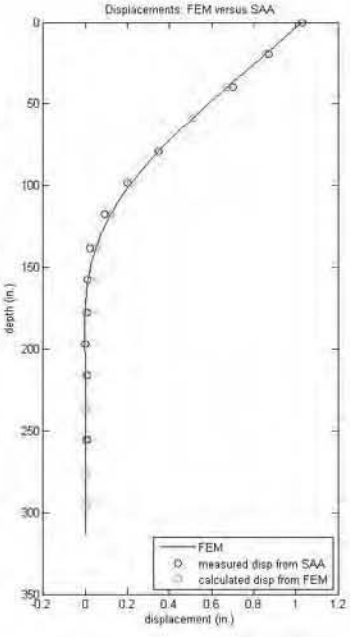

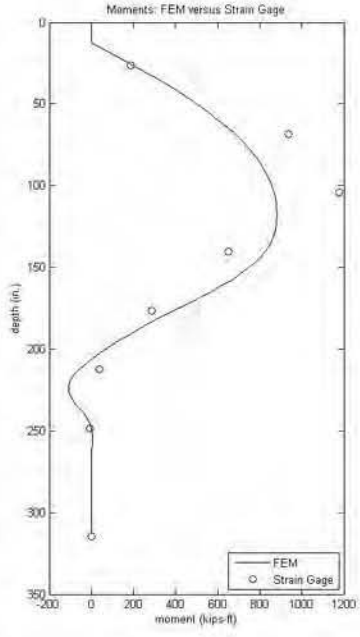

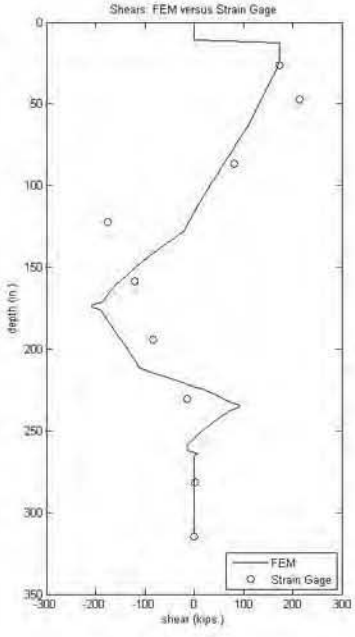

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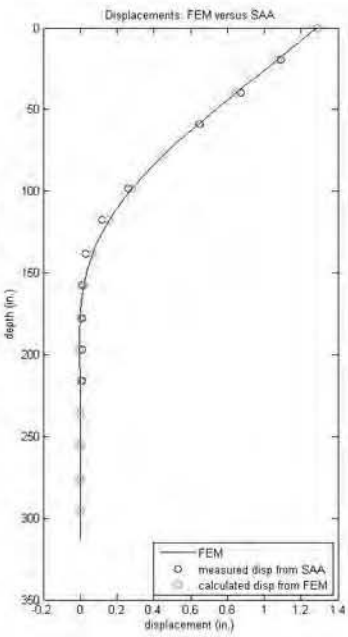

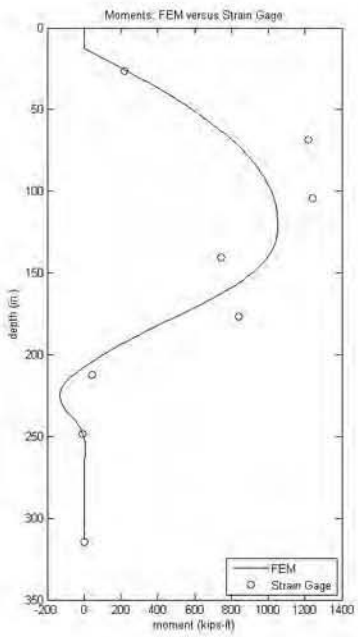

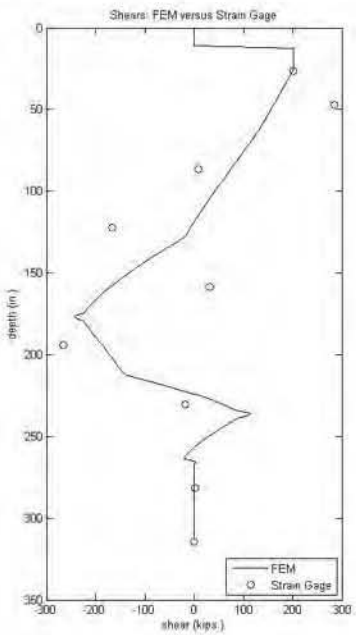

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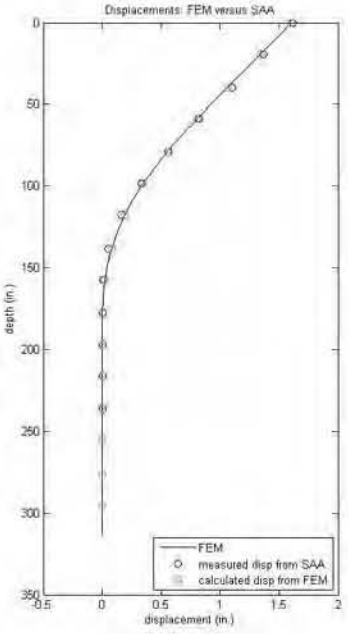

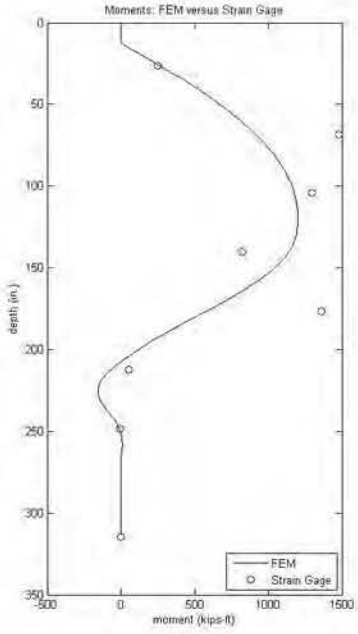

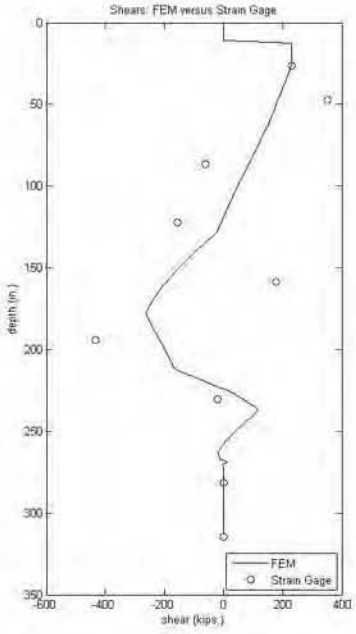

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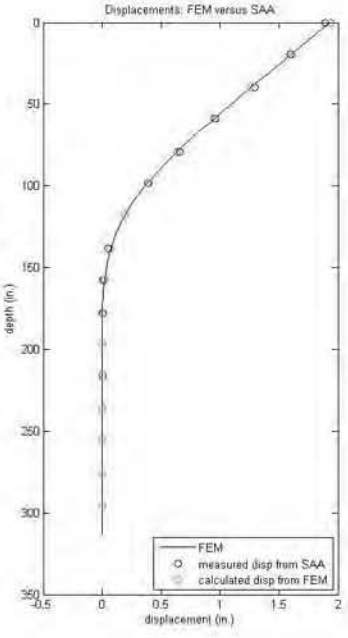

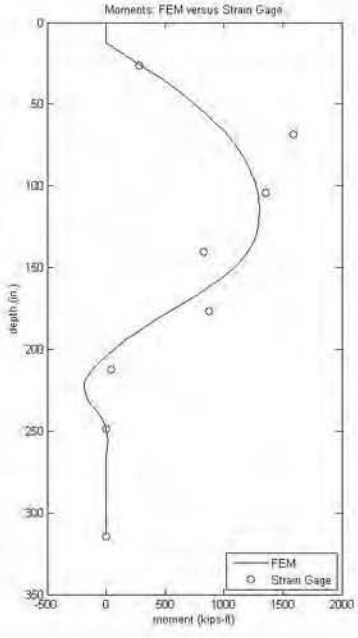

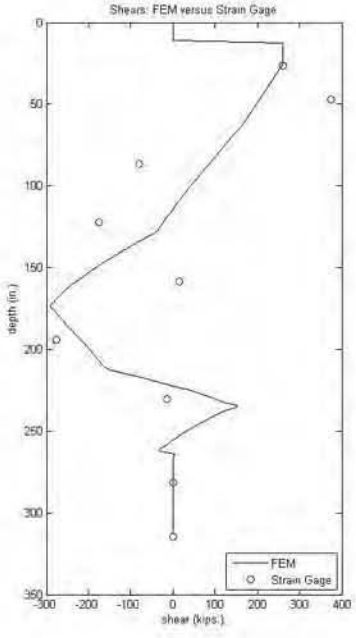

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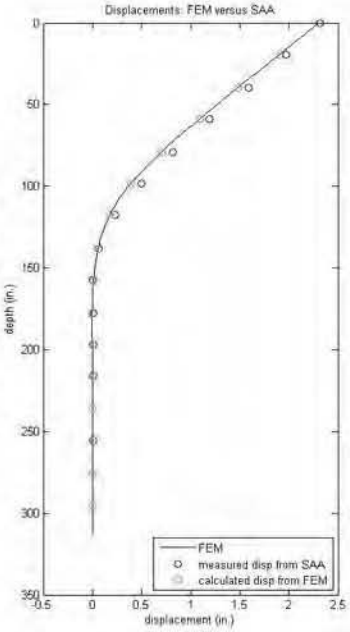

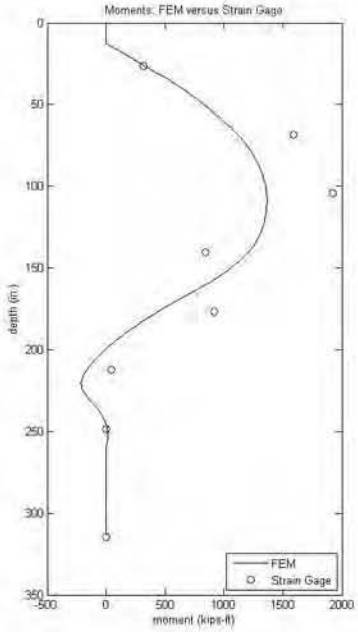

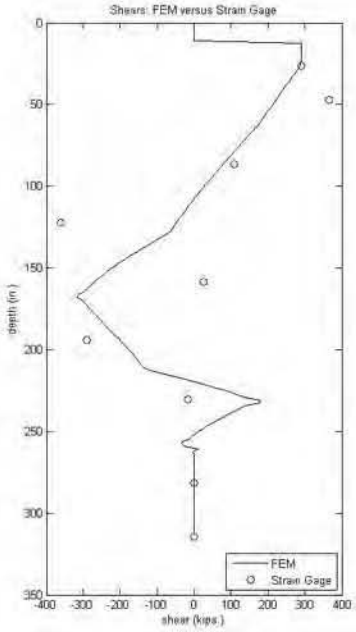

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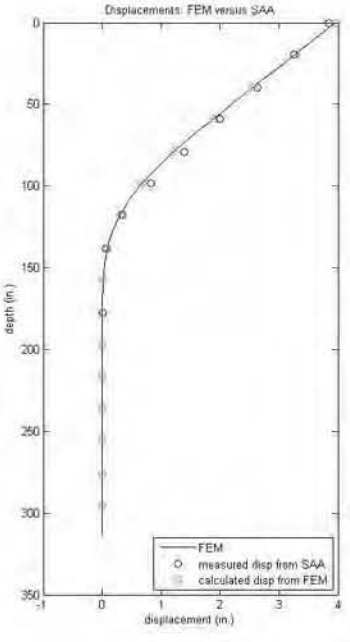
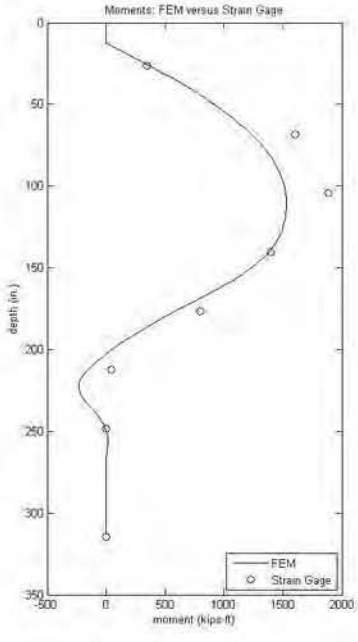
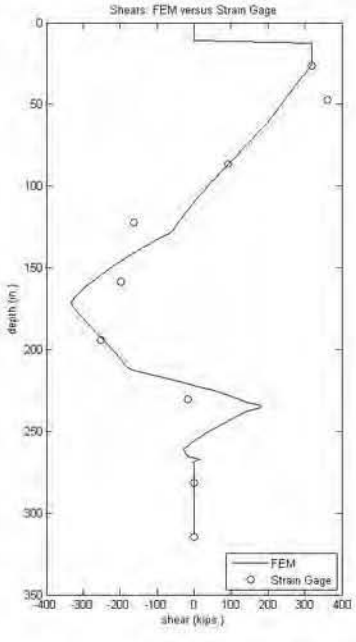
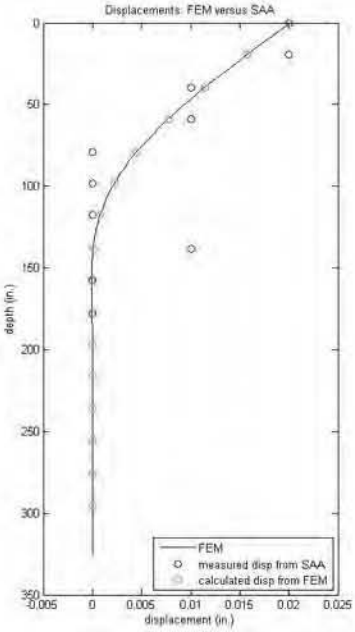
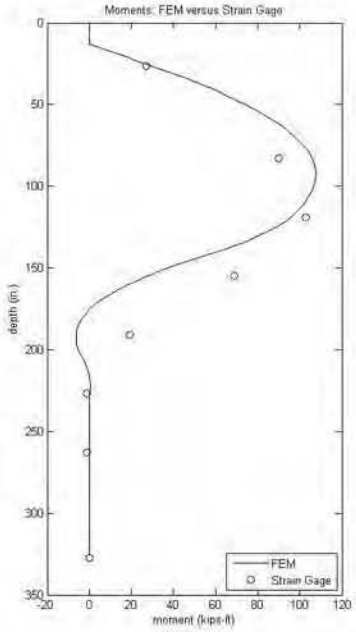


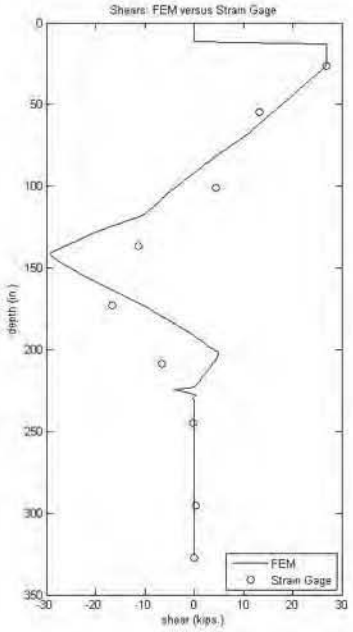




F6 26.8 kips







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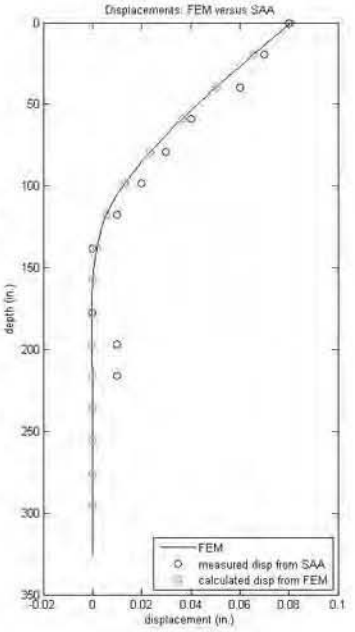
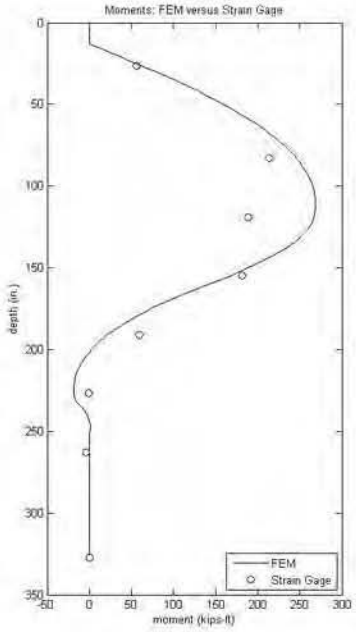
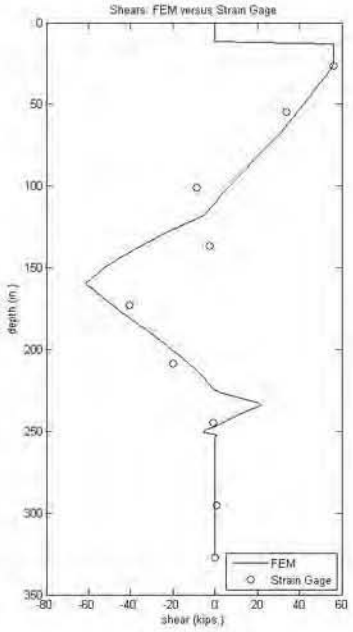
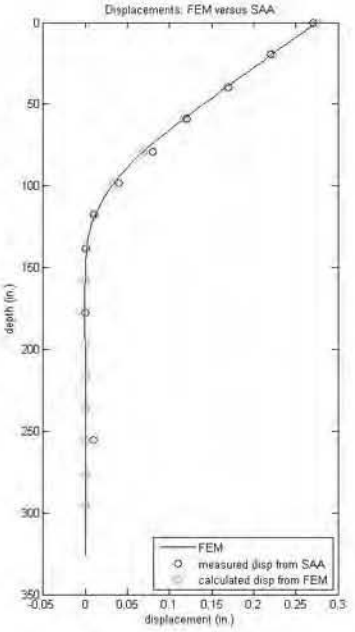
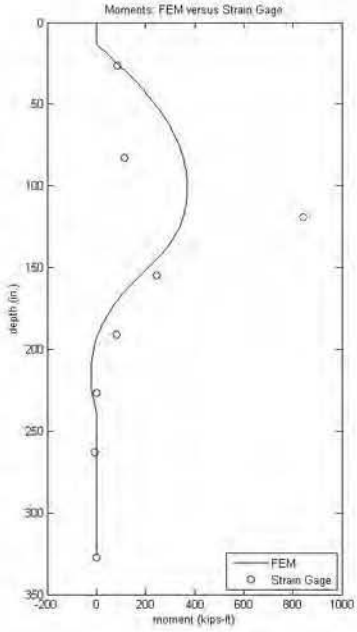


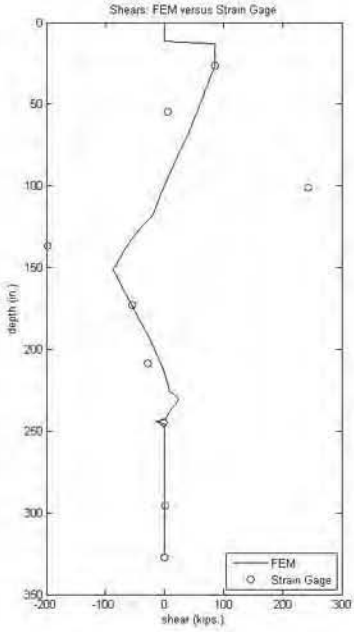




F6 85.3 kips







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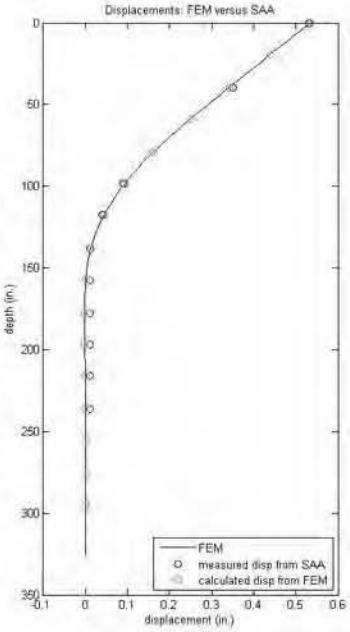

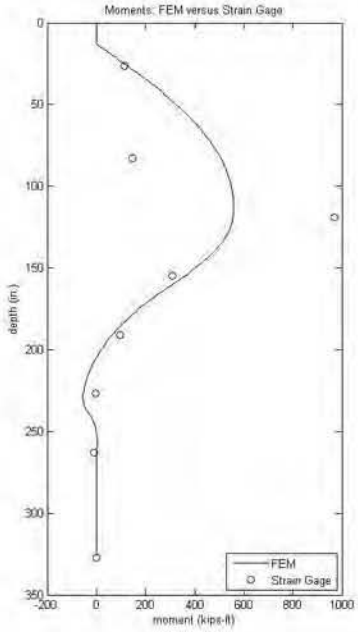

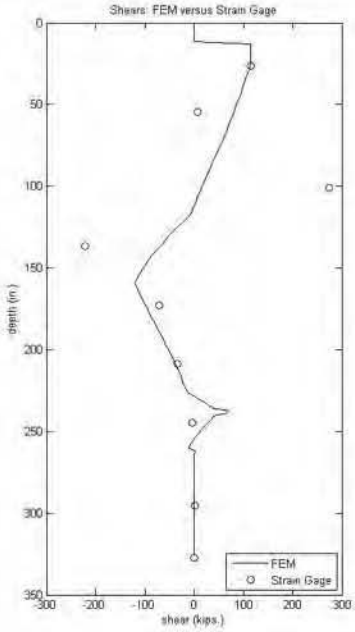

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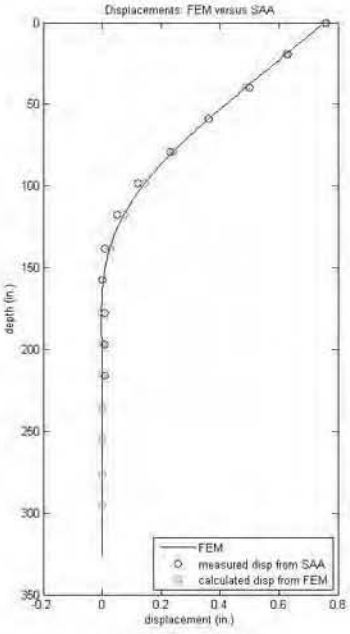

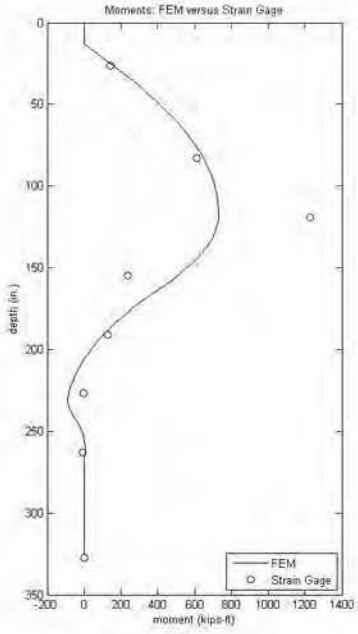

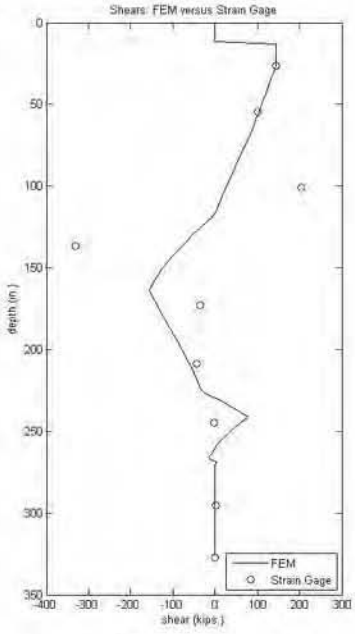

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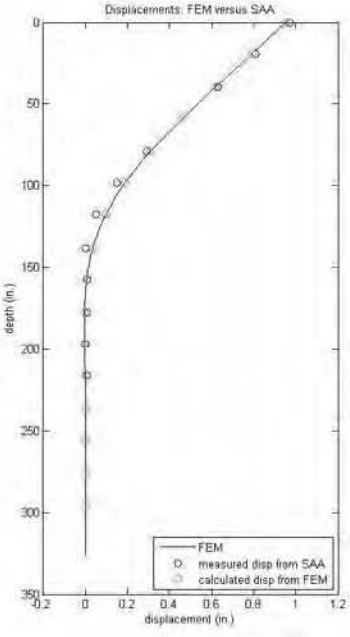

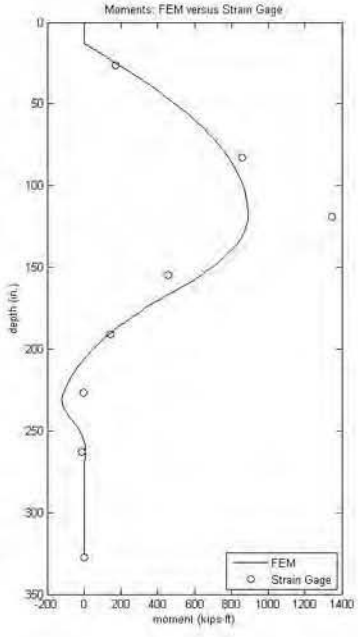

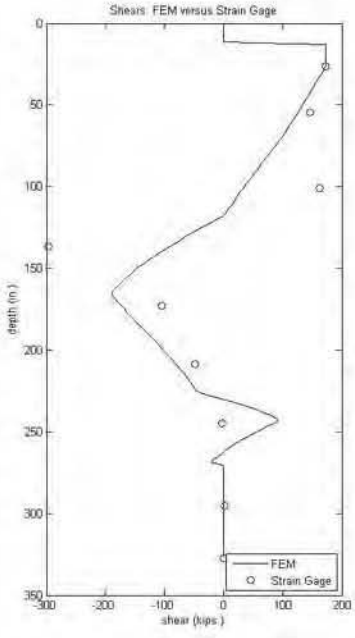

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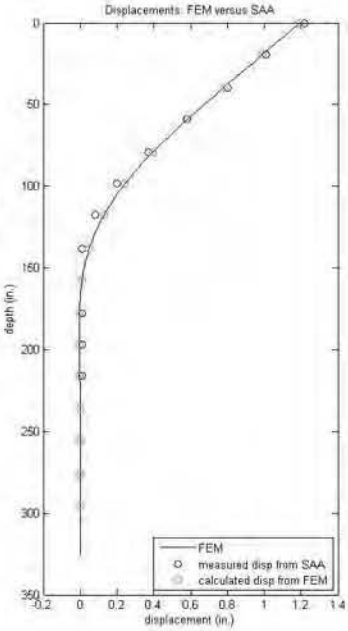

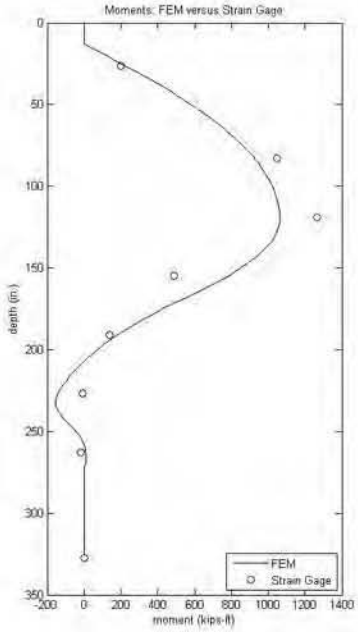

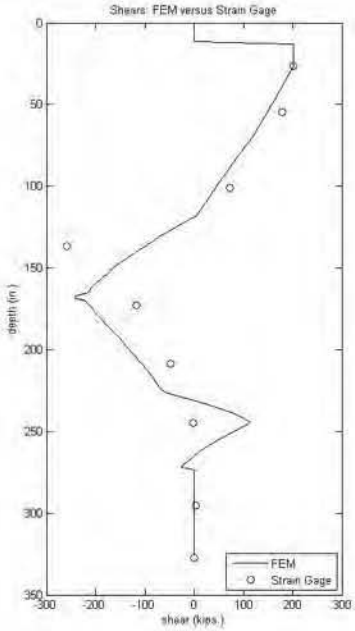

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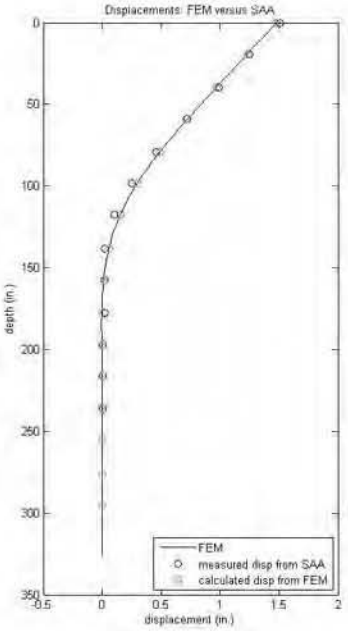

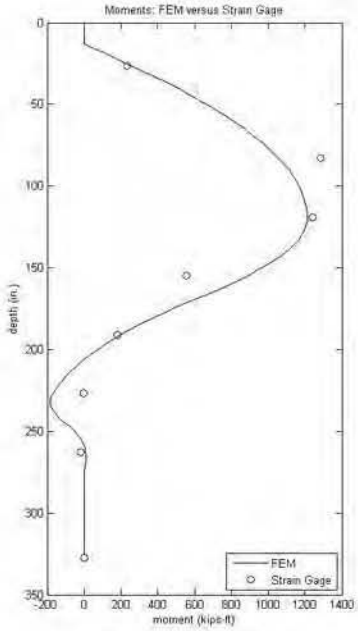

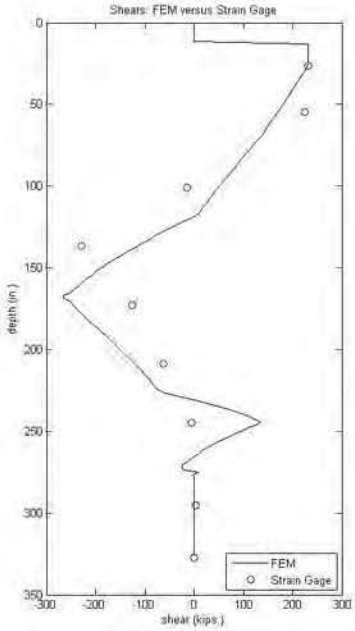

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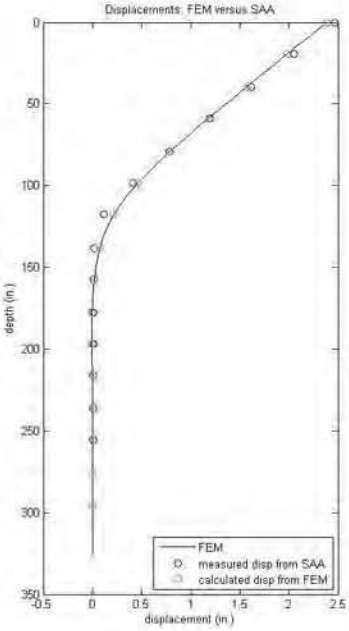

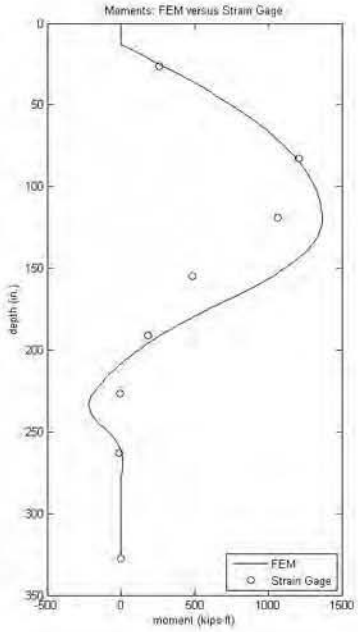

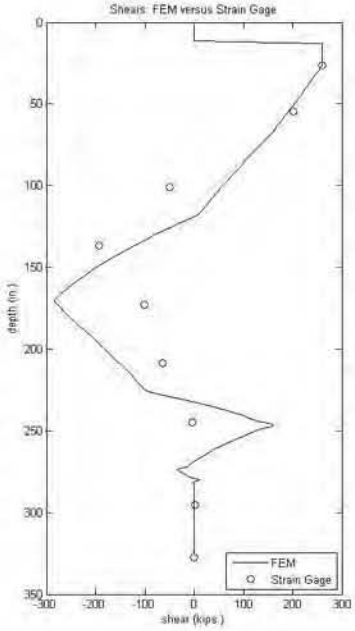

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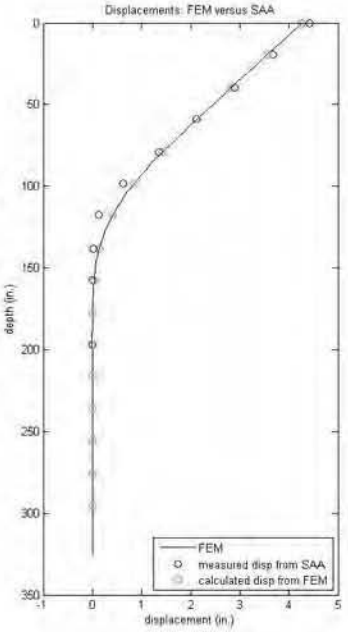

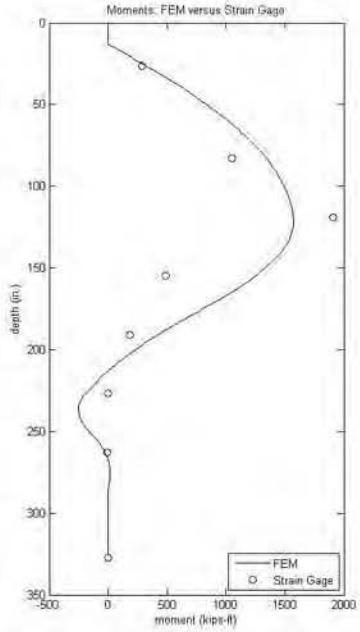

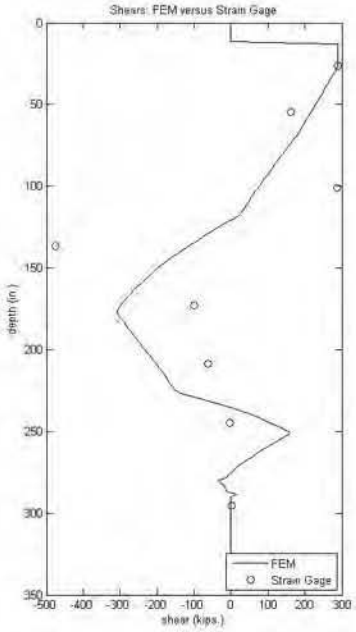

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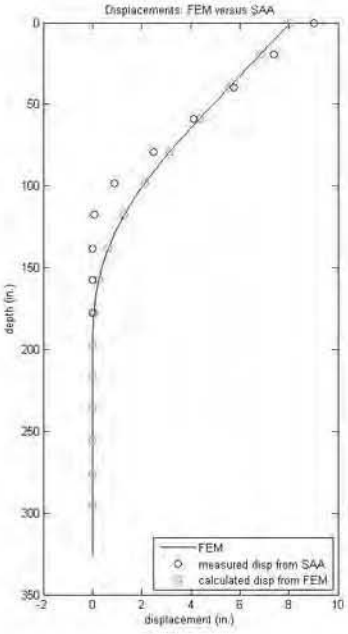

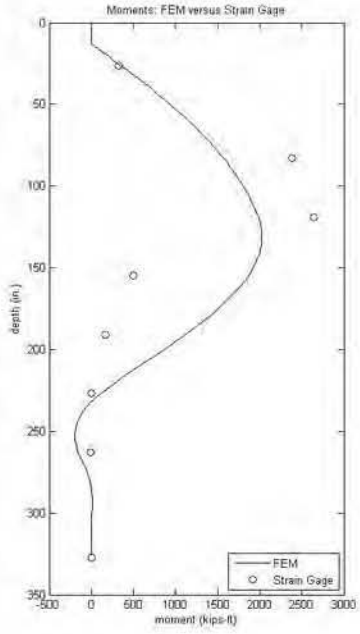

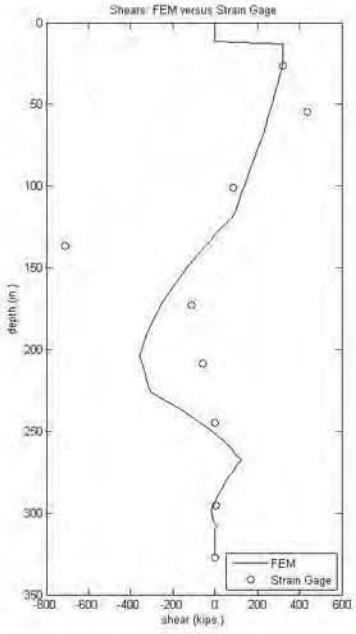

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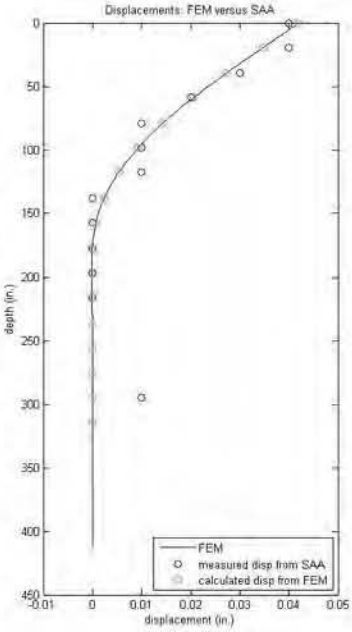

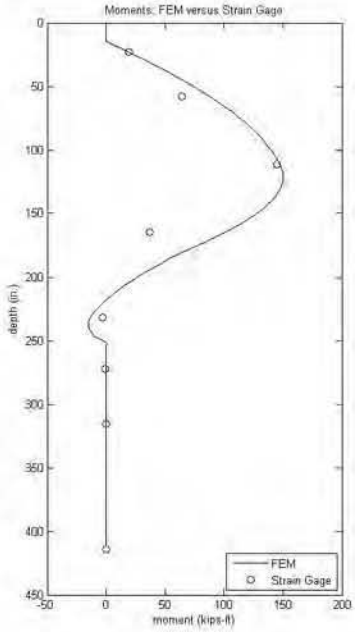

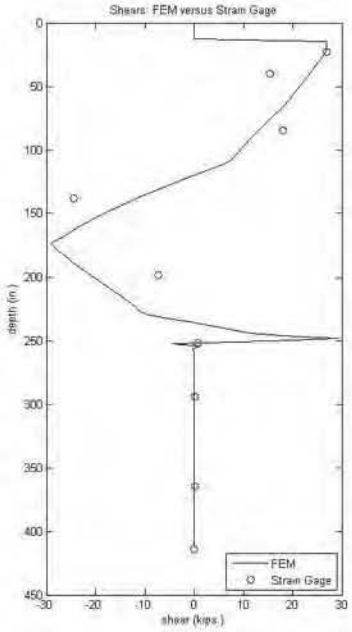

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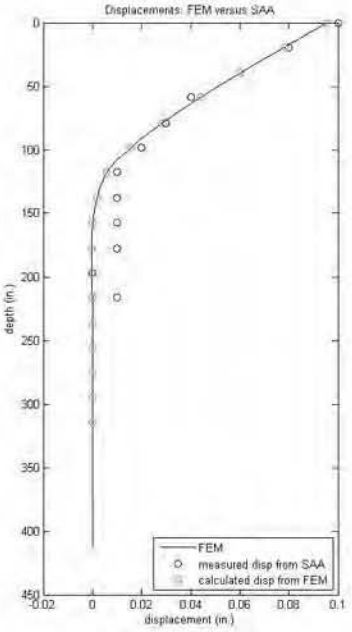

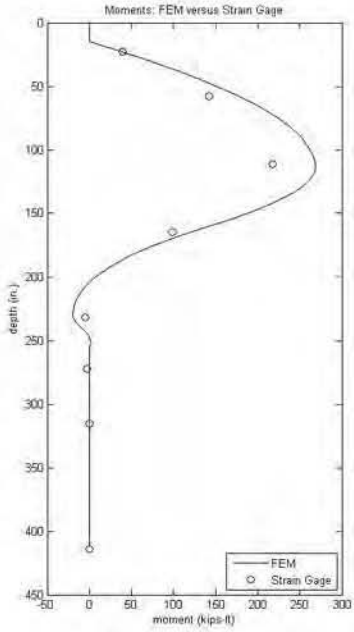

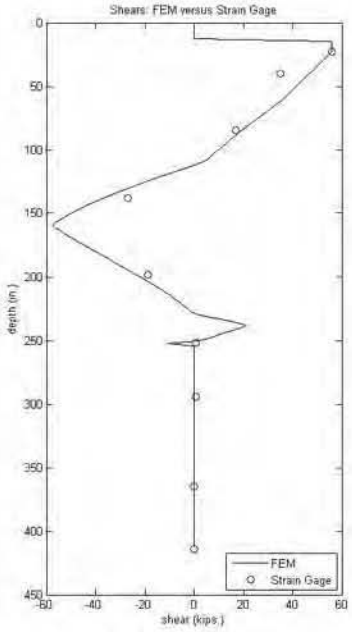

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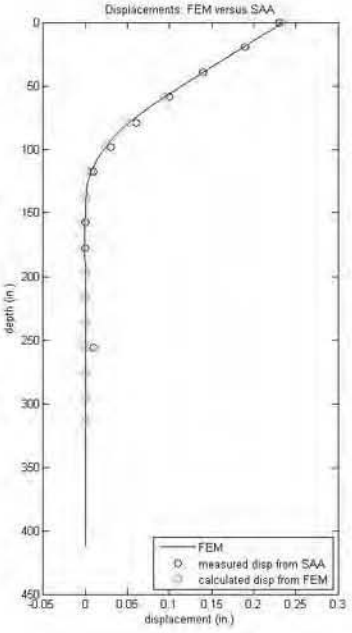
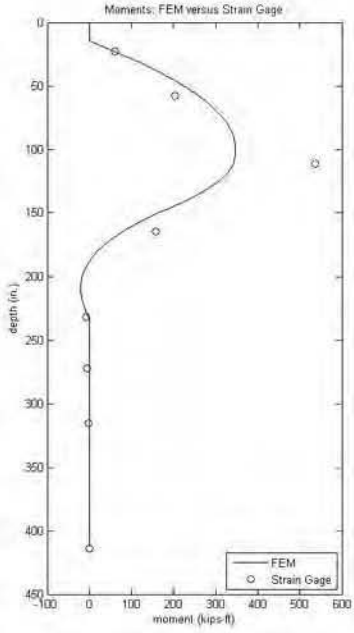
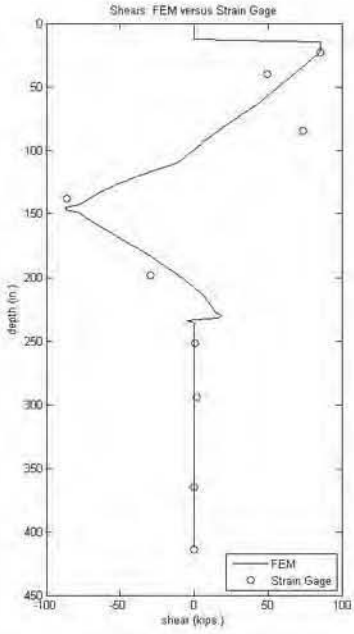
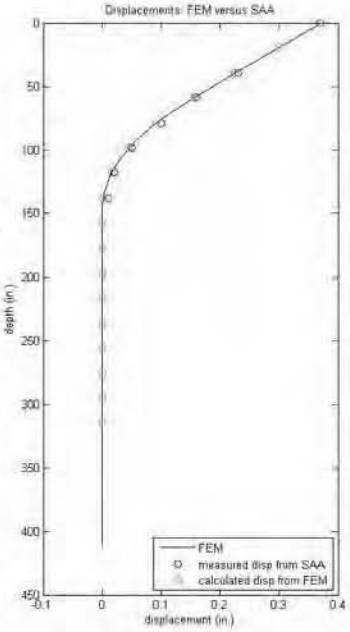
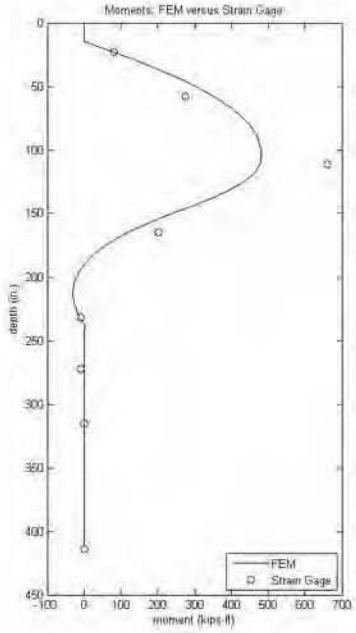


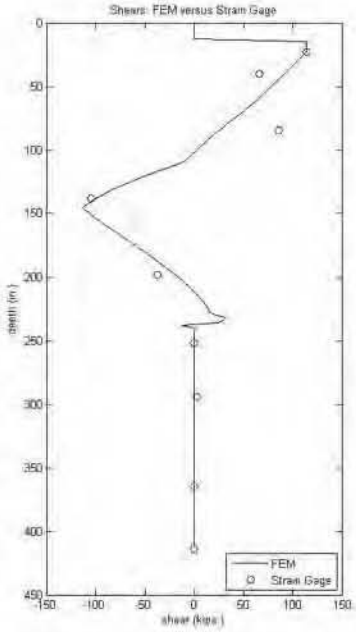




F7 114.5 kips







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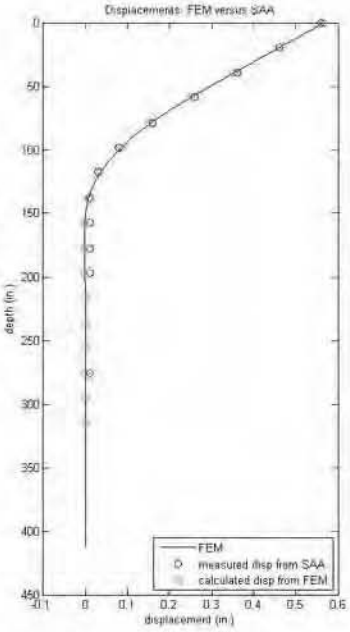

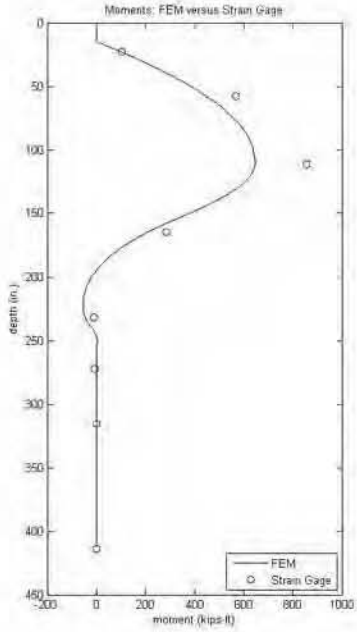

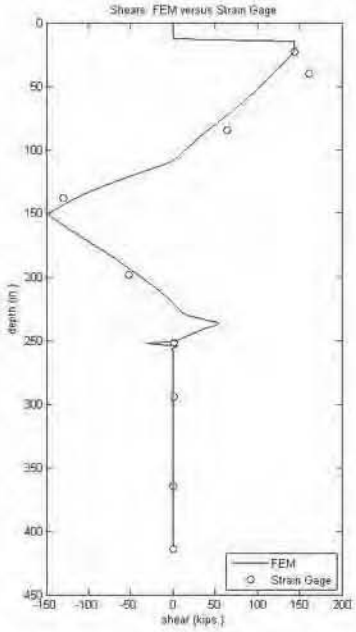

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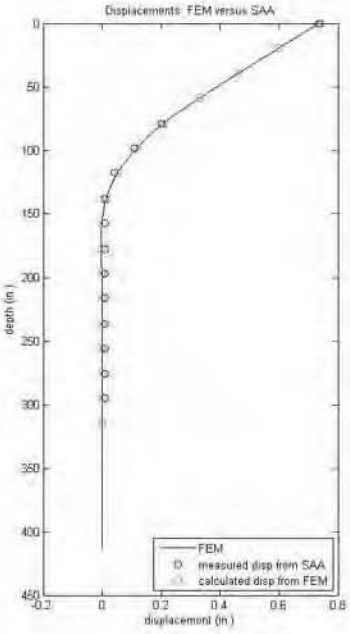

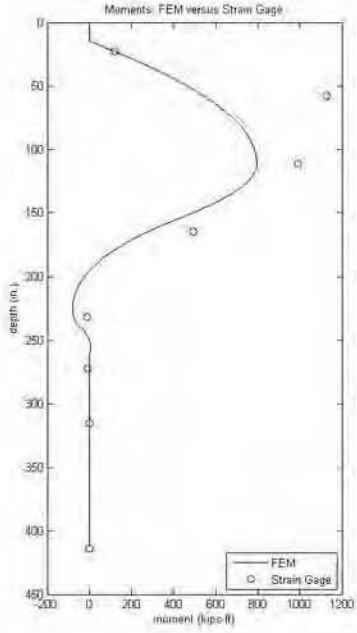

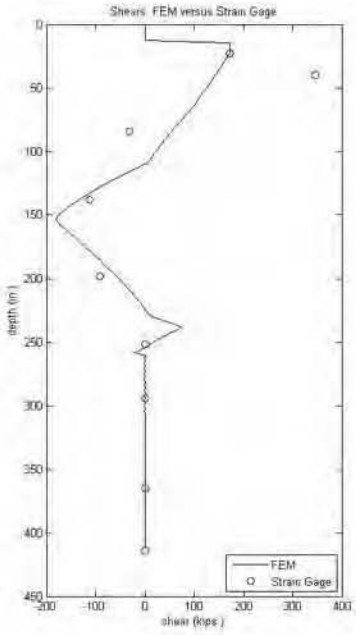

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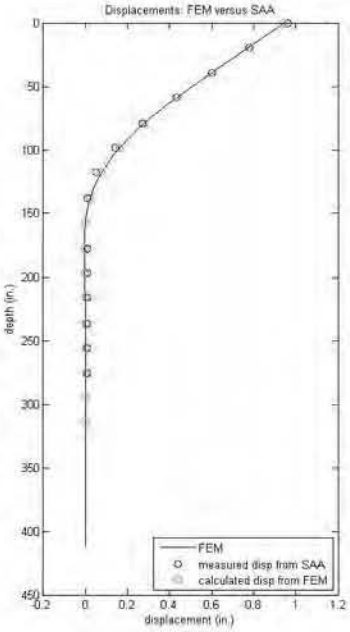

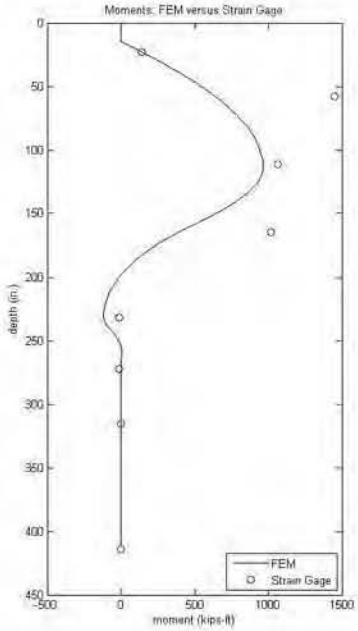

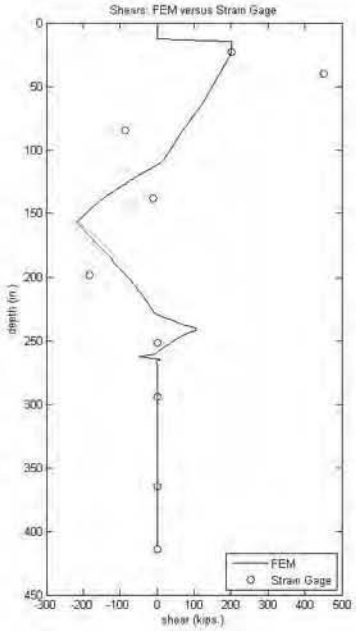

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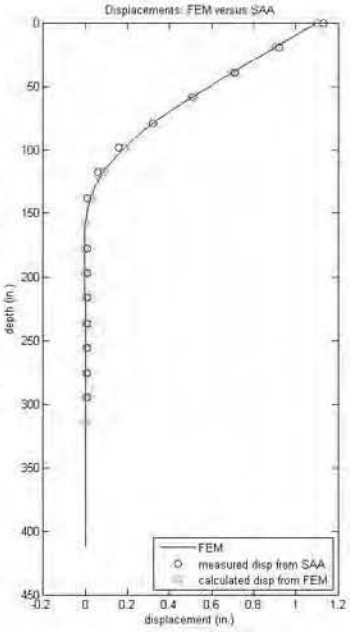

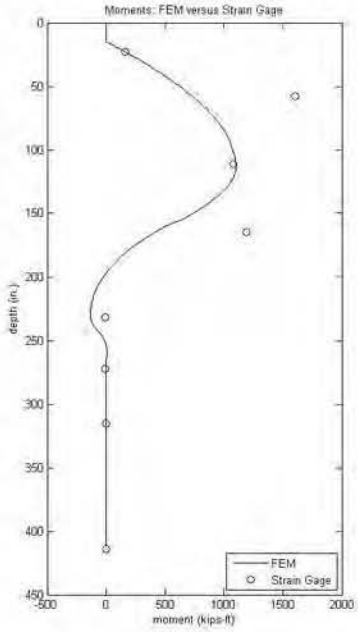

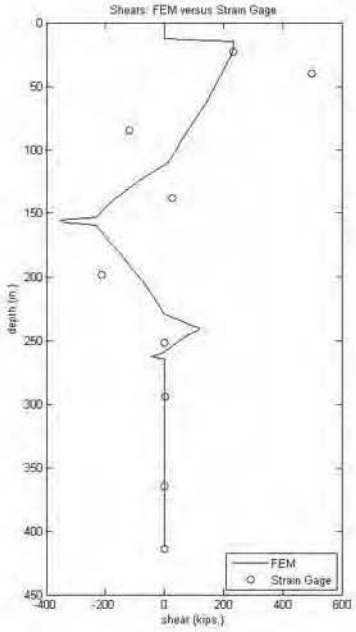

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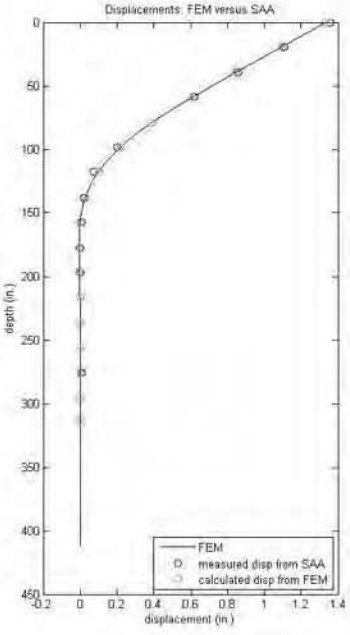
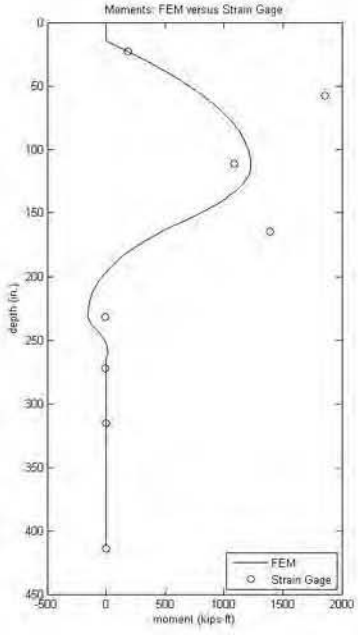
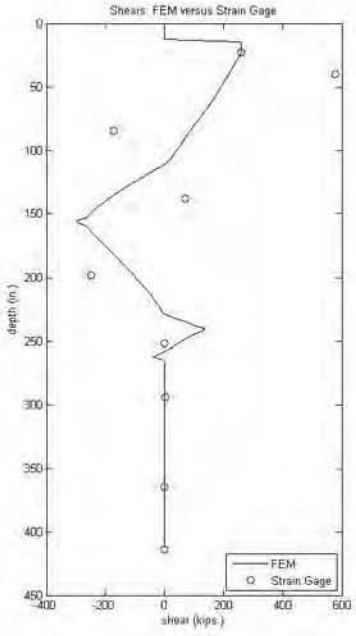
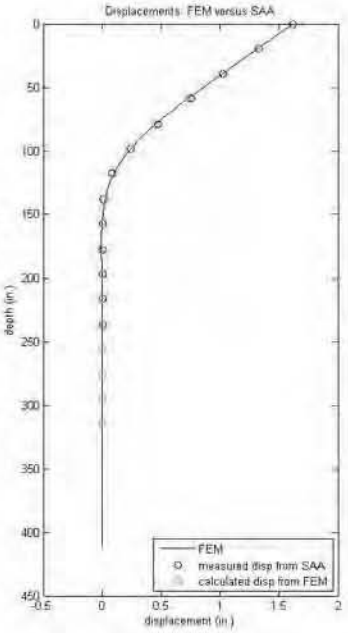
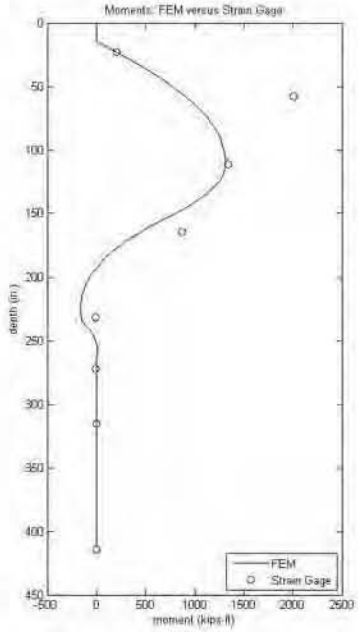


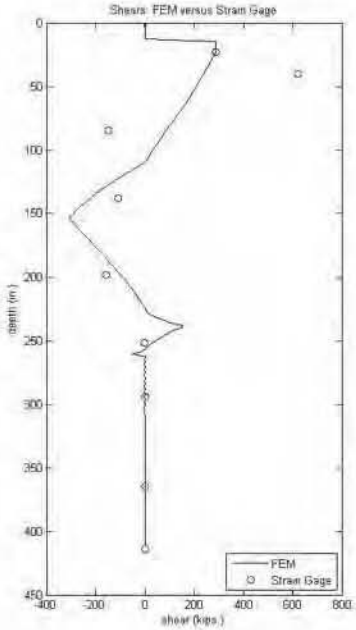




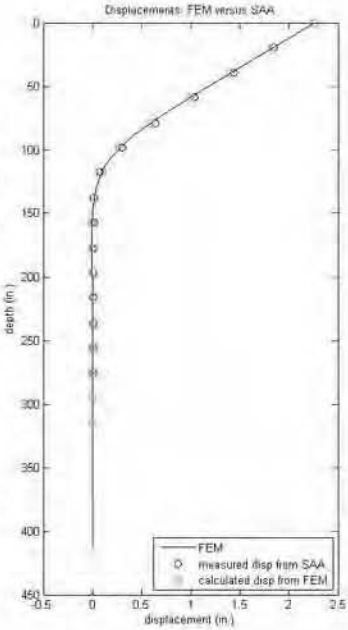
F7 290.0 kips

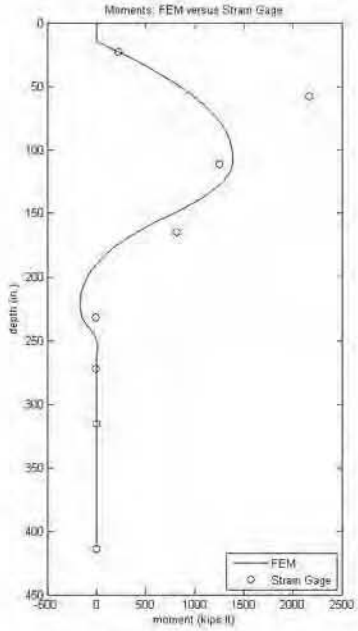


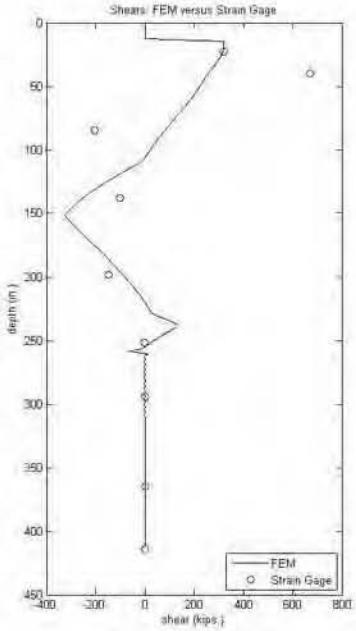




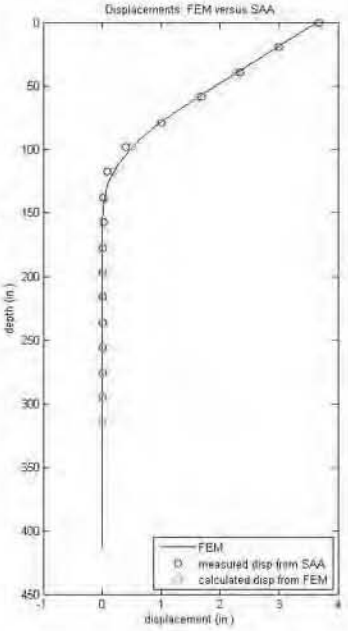
F7 319.2 kips

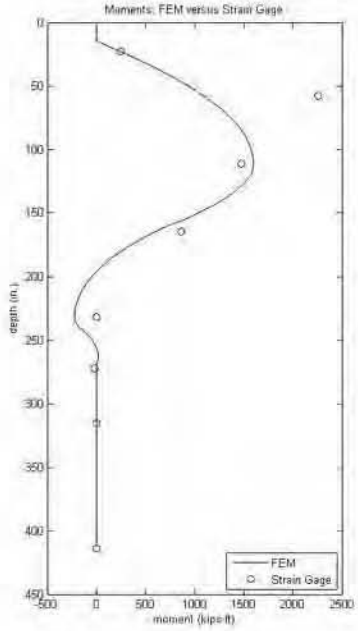


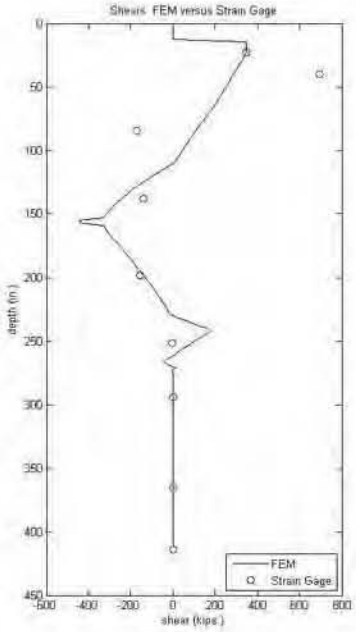




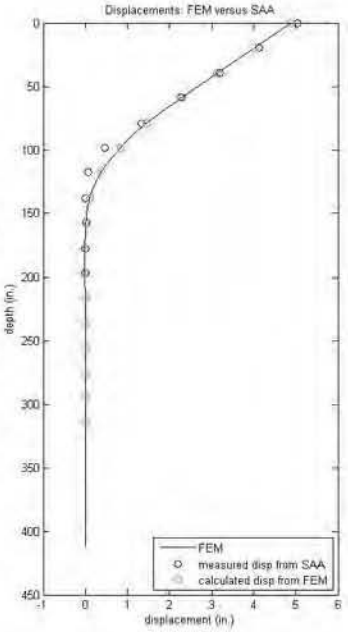
F7 348.5 kips

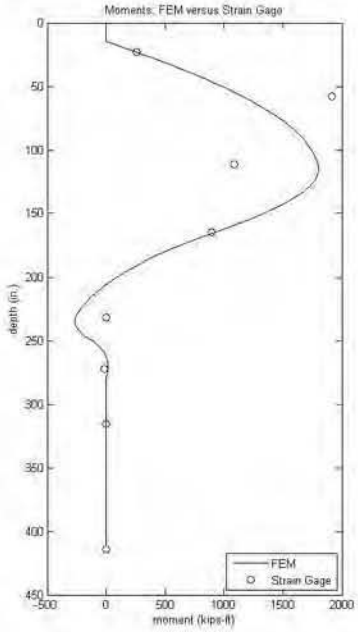


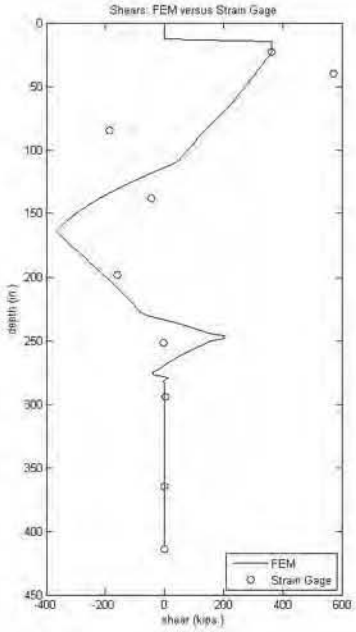




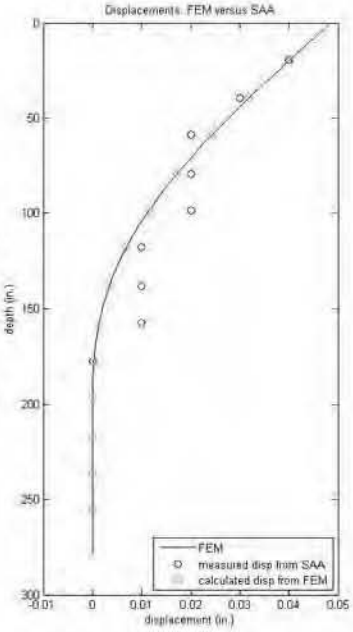
F7 363.1 kips

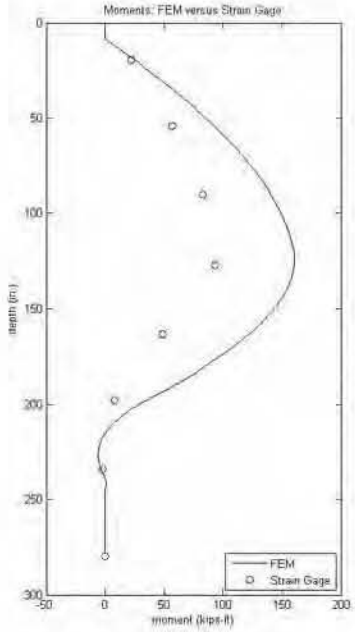

Displacements: FEM versus SAA
depth (in.)
displacement (in.)
FEM
measured disp from SAA
calculated disp from FEM

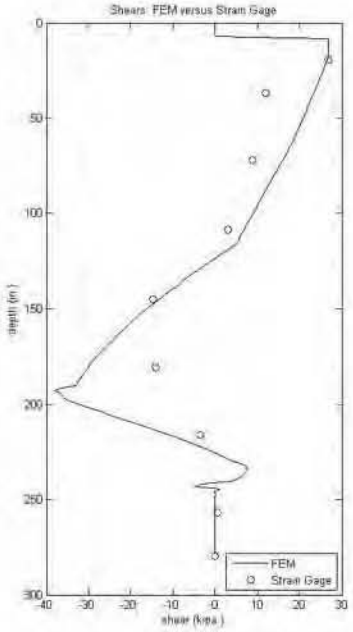

Moments: FEM versus Strain Gage
depth (in.)
moment (kips-ft)
FEM
Strain Gage


Shears: FEM versus Strain Gage
depth (in.)
shear (kips)
FEM
Strain Gage

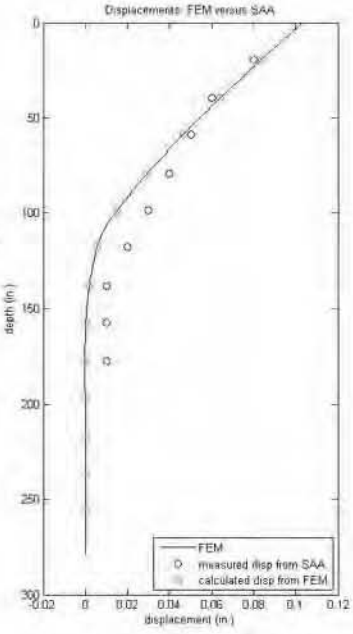
F8 26.8 kips

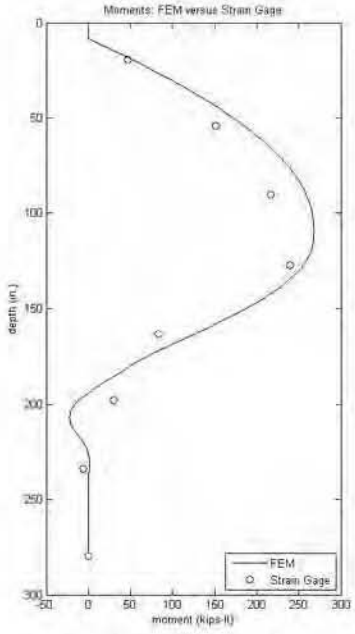


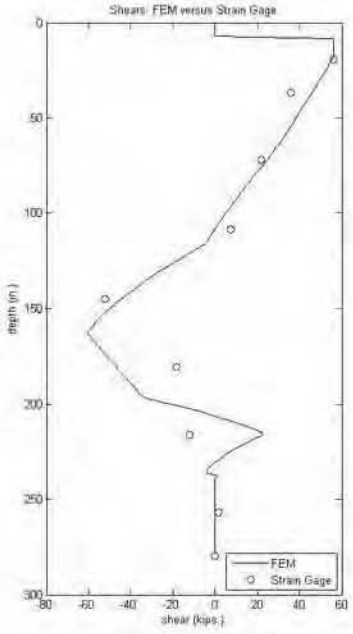




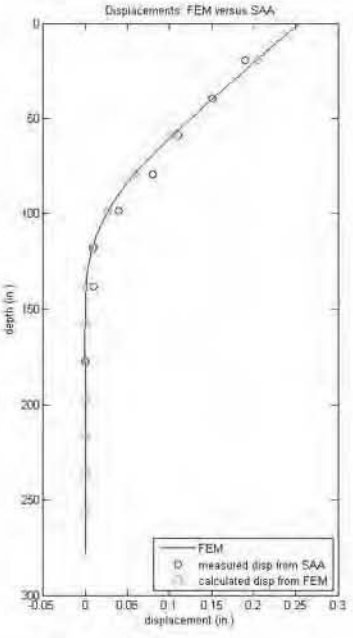
F8 56.1 kips

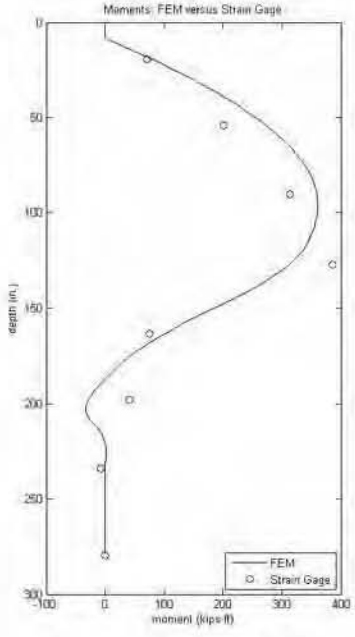


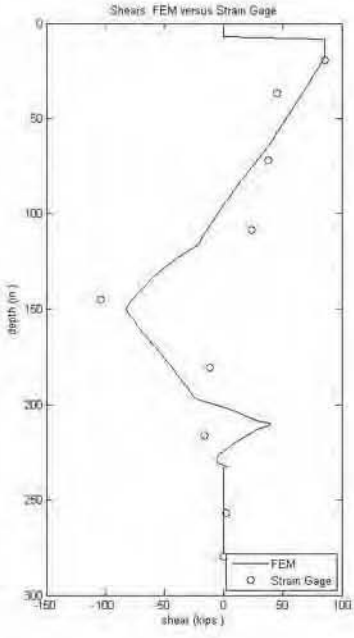




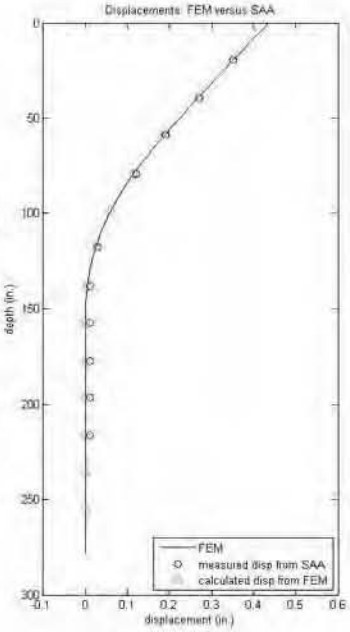
F8 85.3 kips

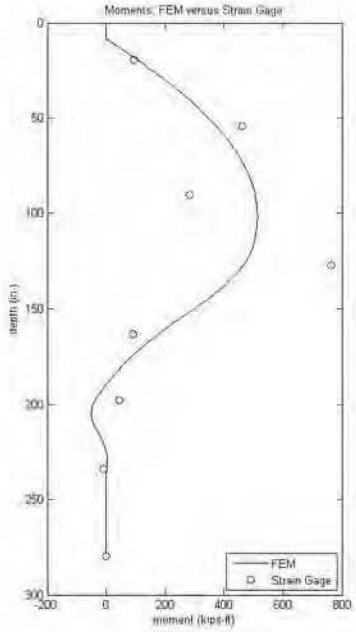


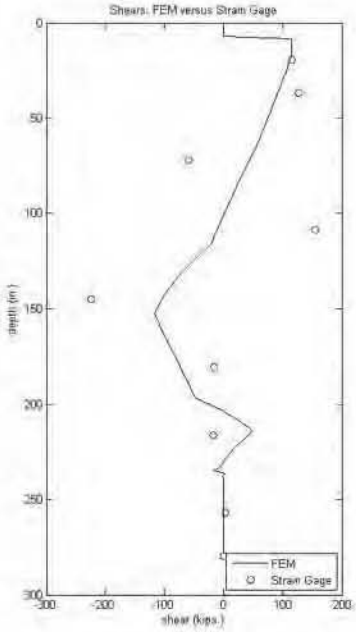




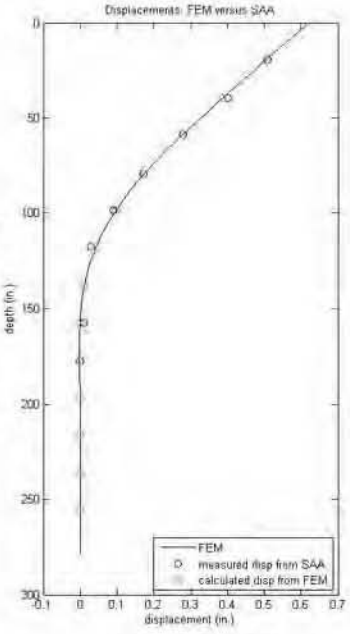
F8 114.5 kips

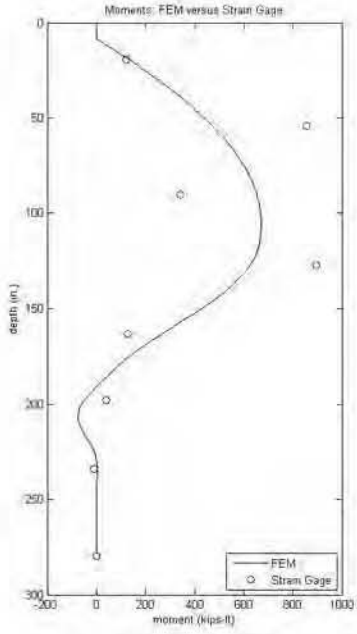


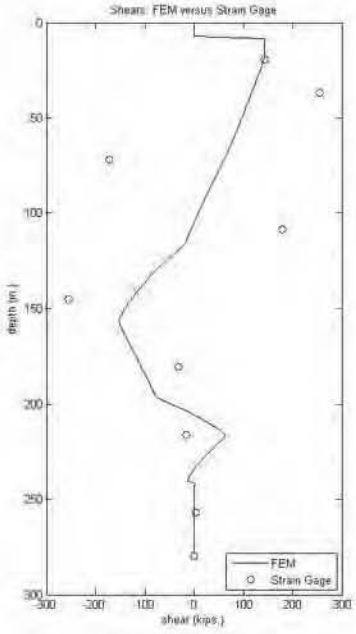




F8 143.8 kips







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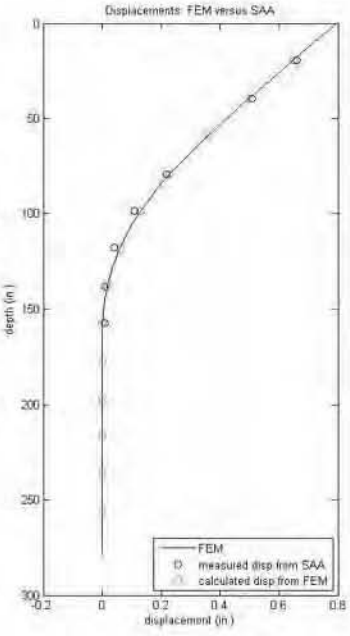
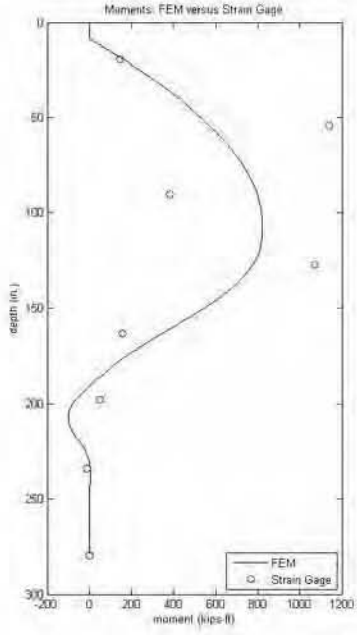
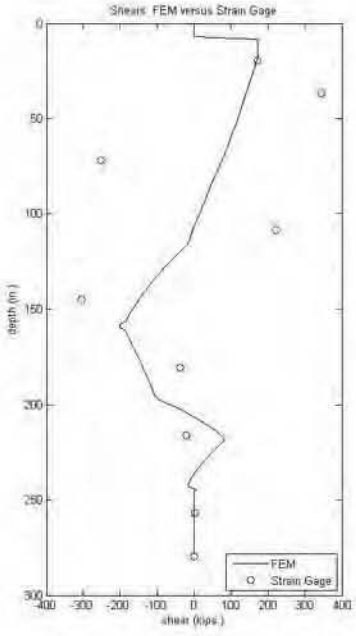
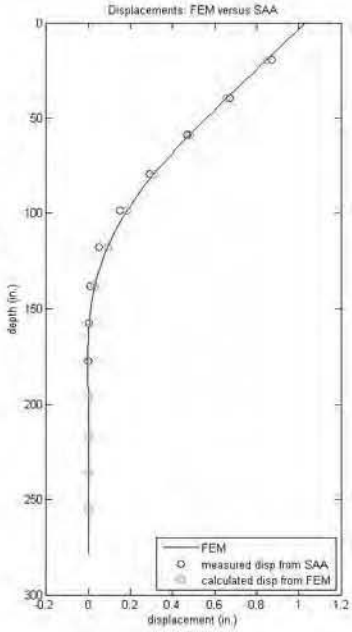
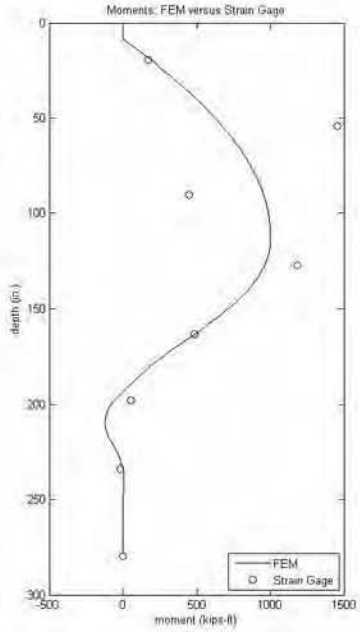


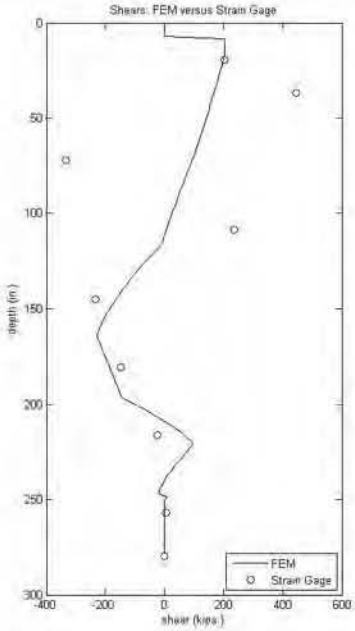




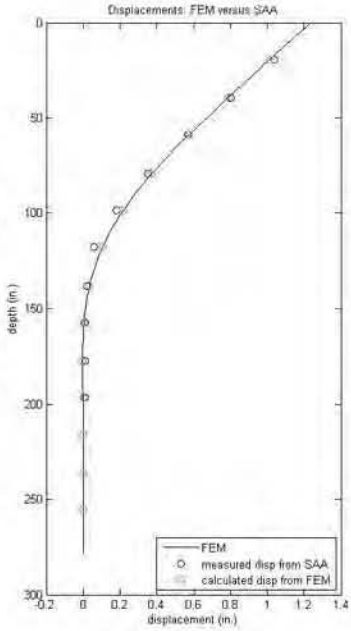
F8 202.3 kips

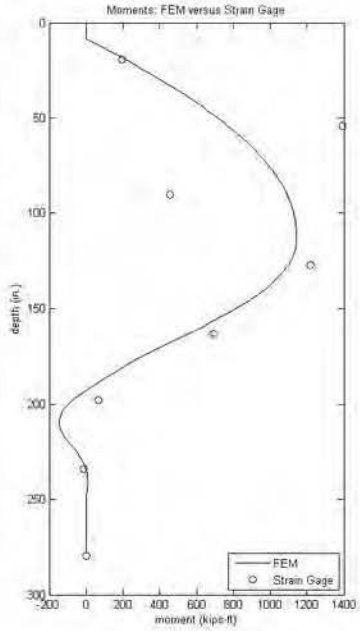


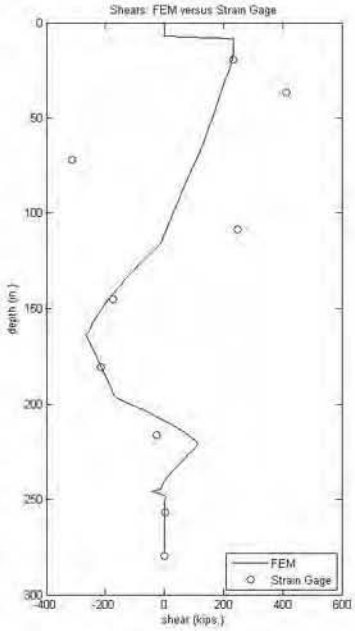




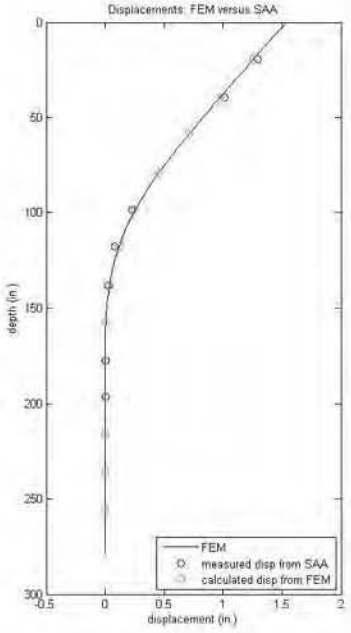
F8 231.5 kips

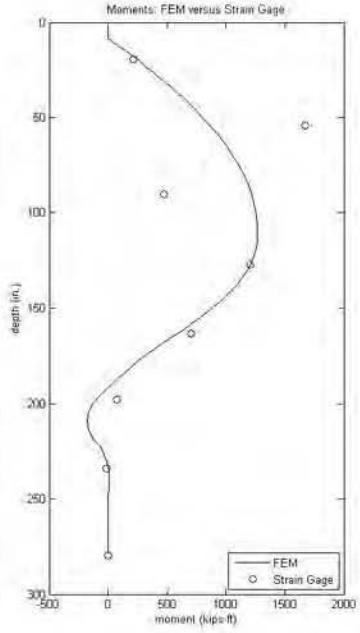


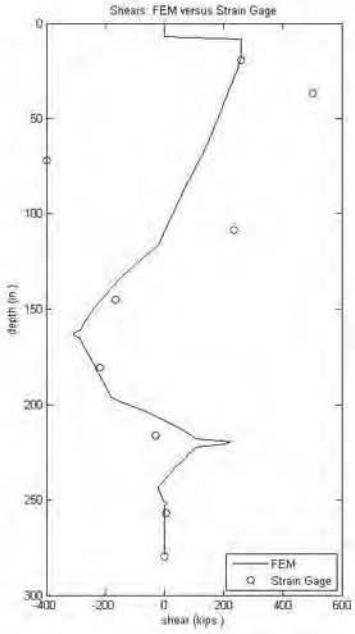




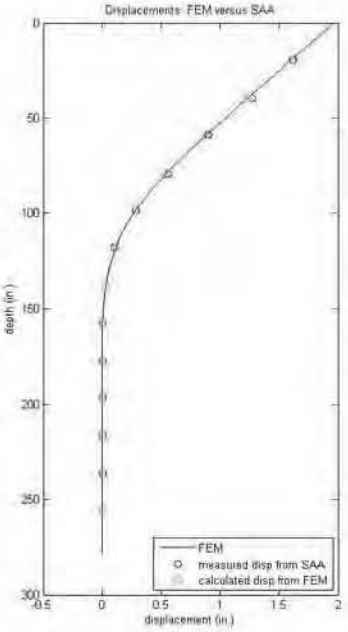
F8 260.7 kips

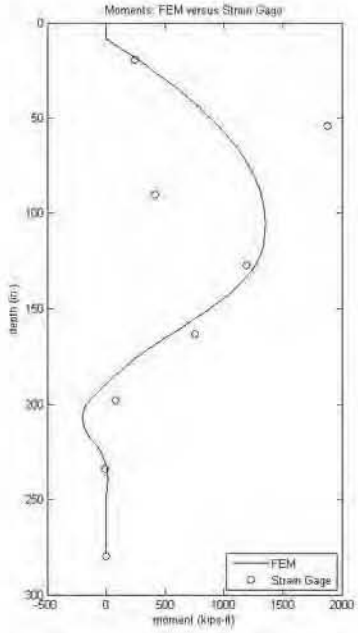


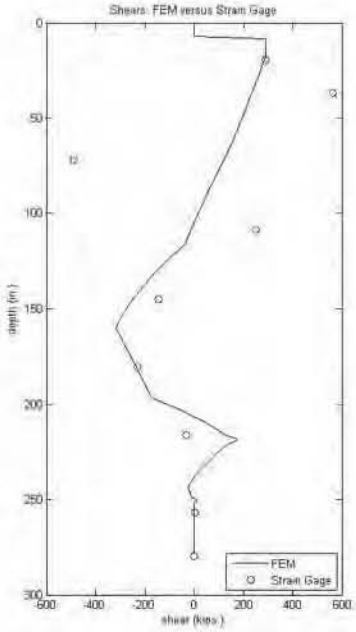




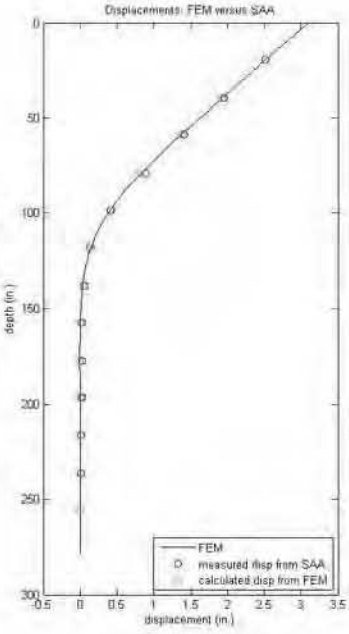
F8 290.0 kips

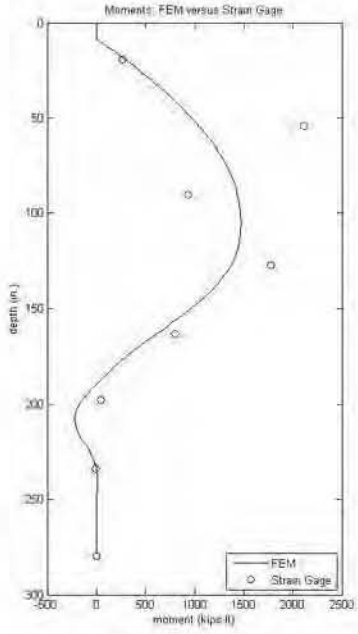


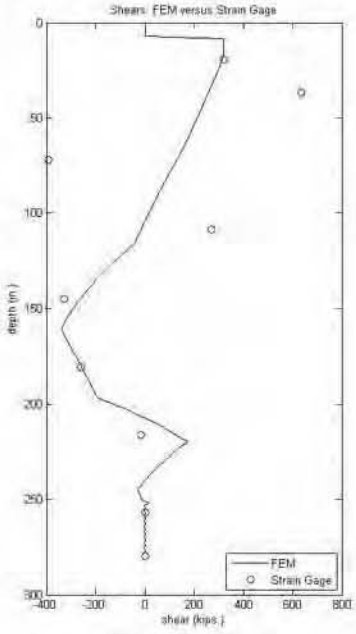




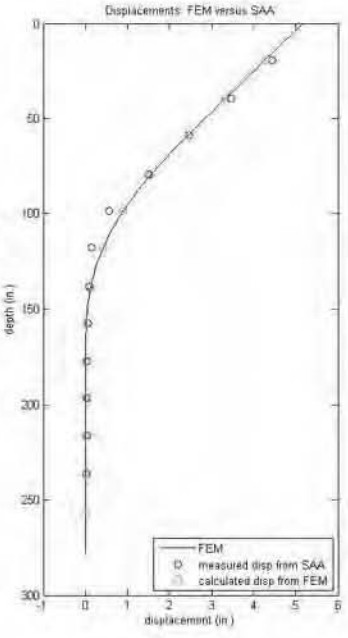
F8 319.2 kips

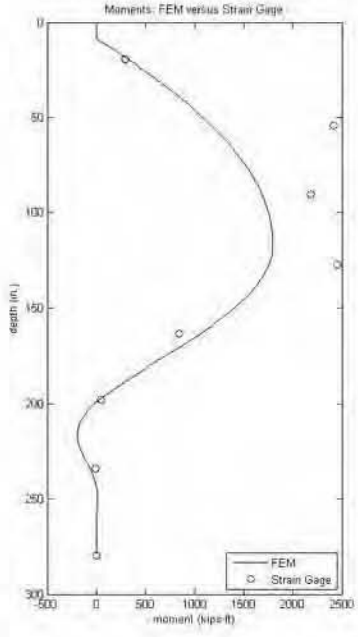


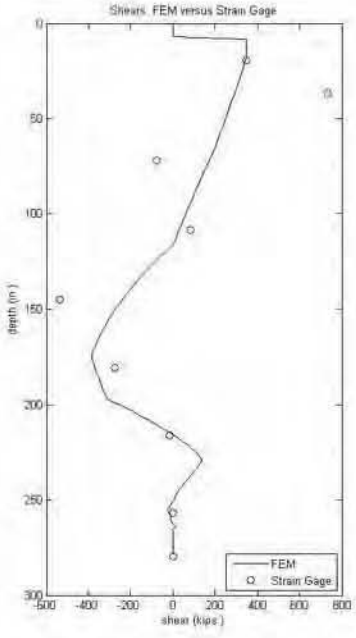




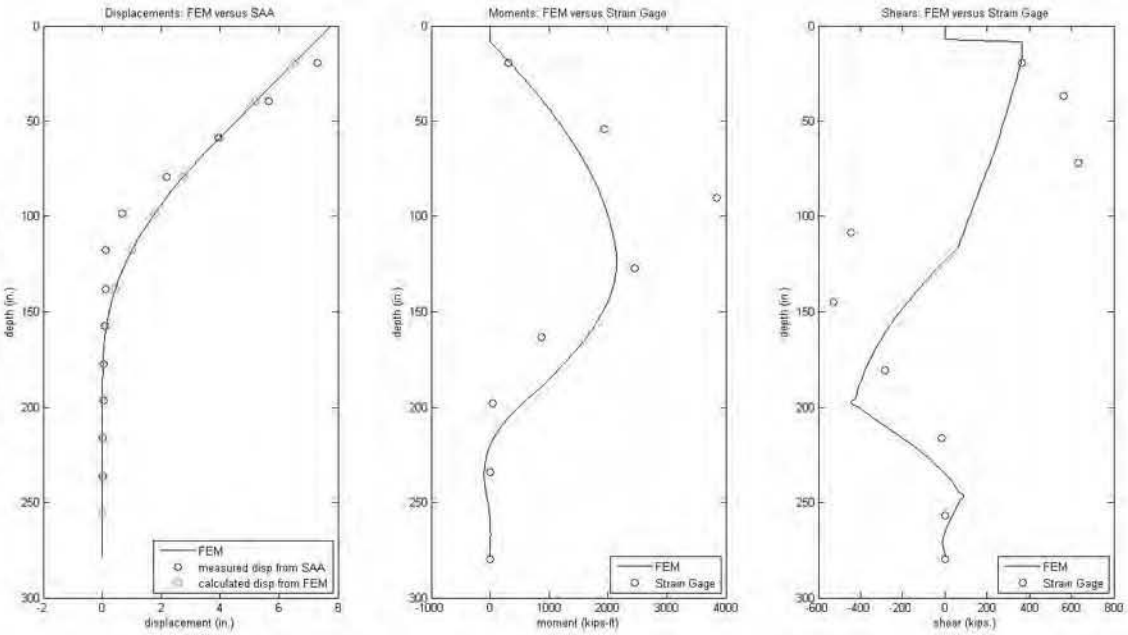
F8 348.5 kips



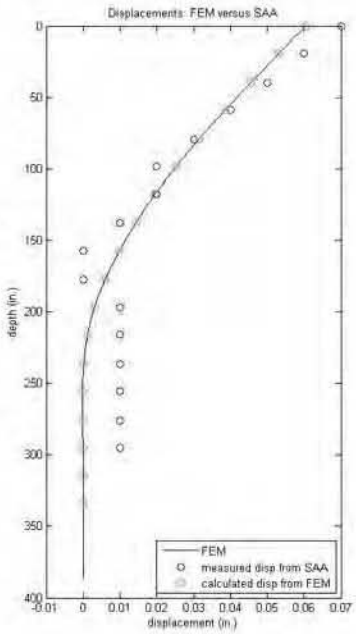


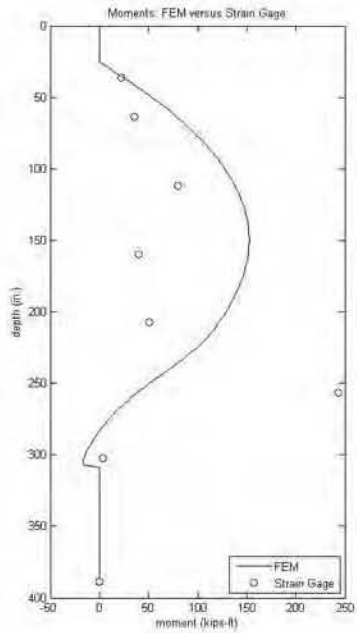


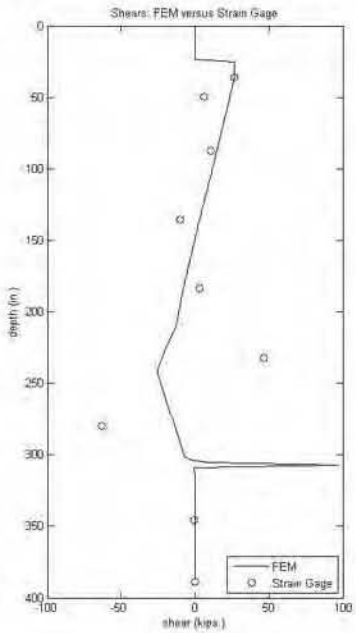
F8 363.1 kips


Displacements: FEM versus SAA
depth (in.)
displacement (in.)
FEM
measured disp from SAA
calculated disp from FEM
Moments: FEM versus Strain Gage
depth (in.)
moment (kips-ft)
FEM
Strain Gage
Shears: FEM versus Strain Gage
depth (in.)
shear (kips.)
FEM
Strain Gage

W1 26.8 kips







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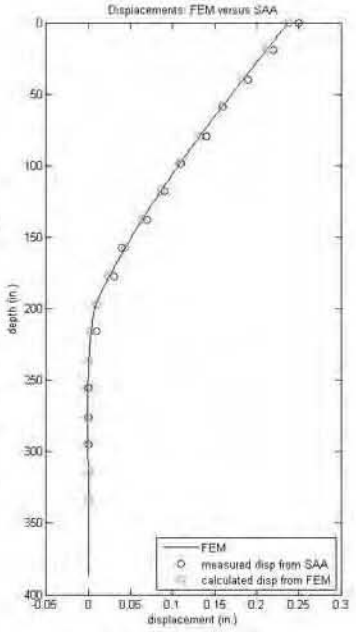

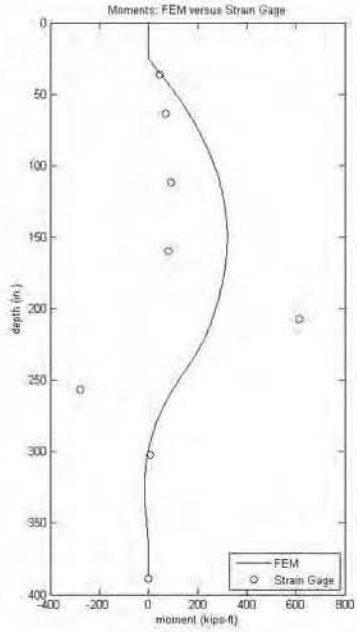

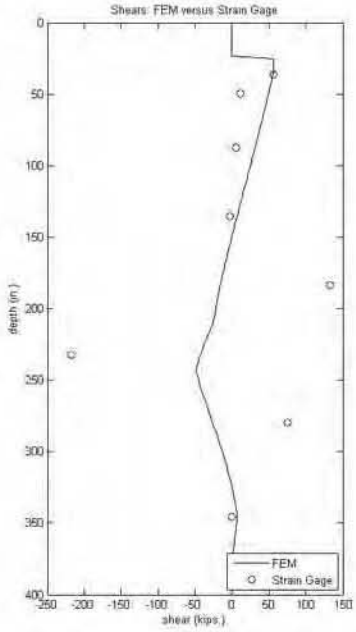

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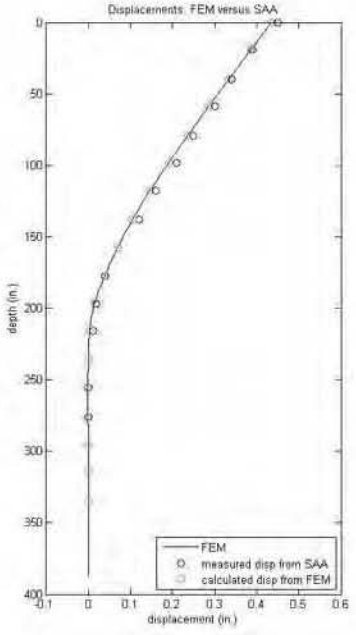

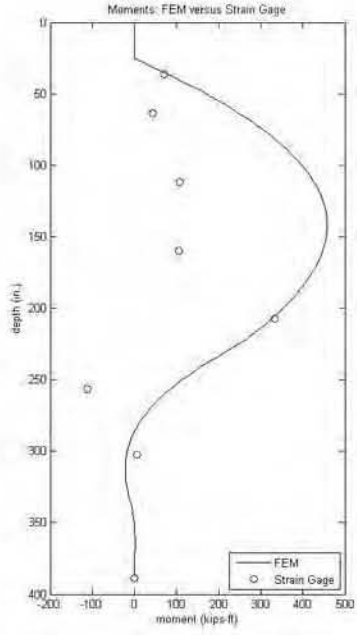

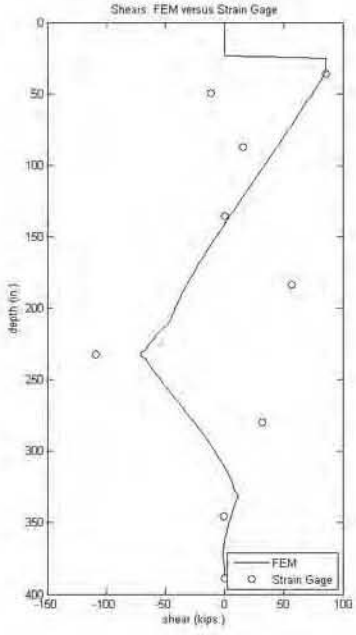

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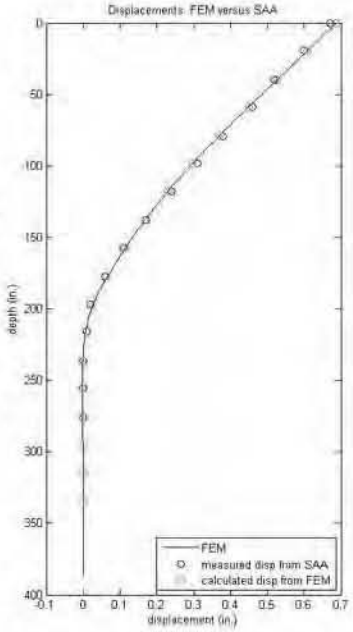

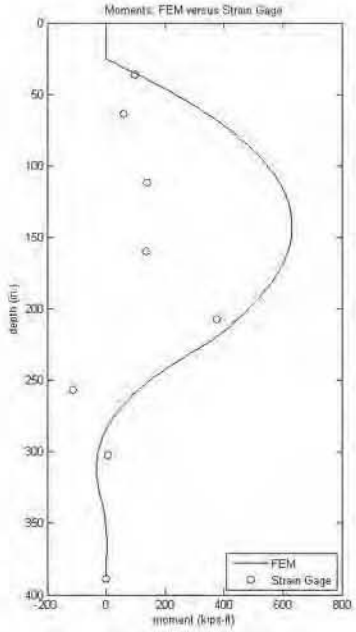

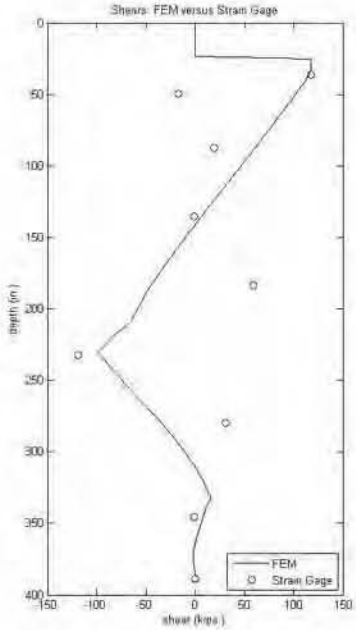

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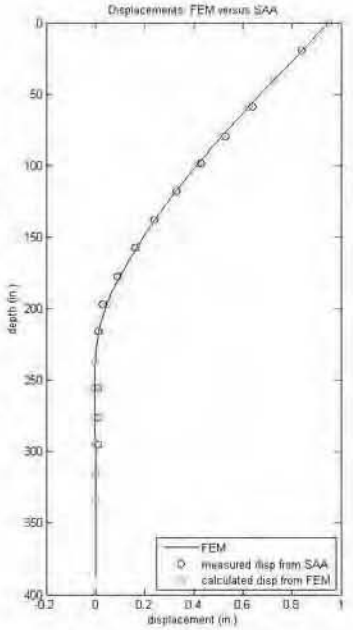

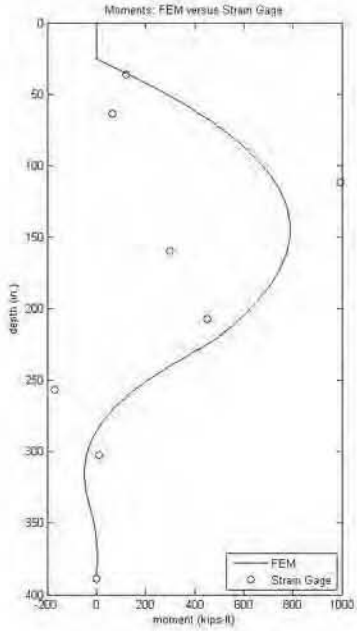

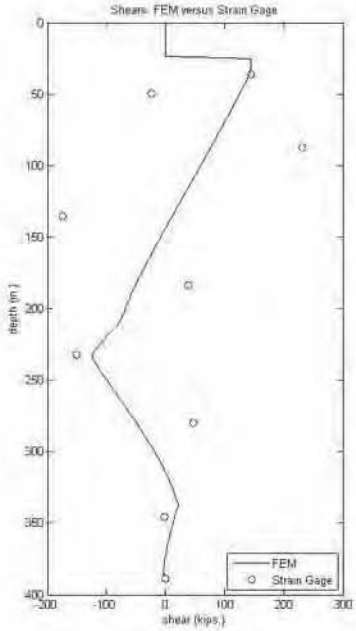

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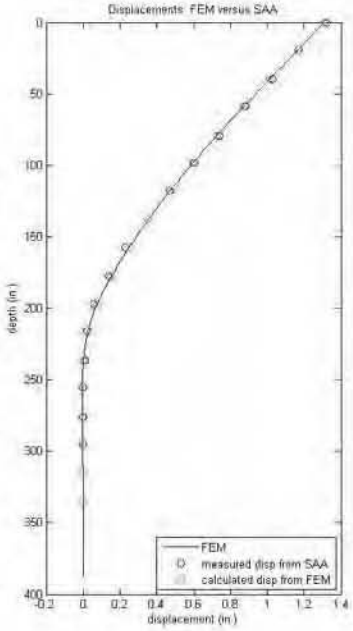

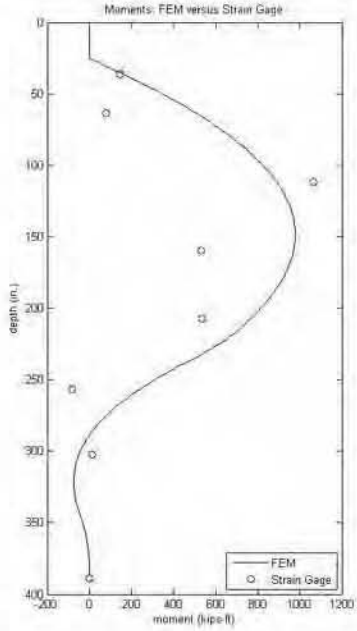

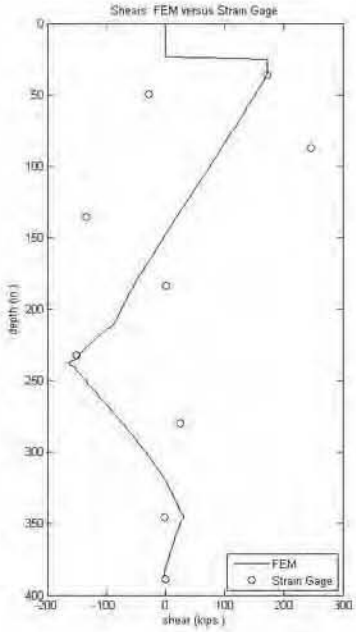

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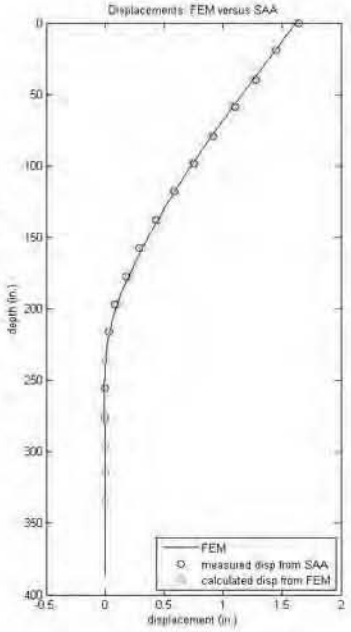

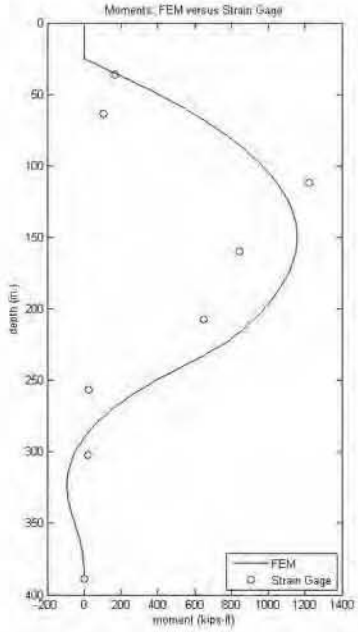

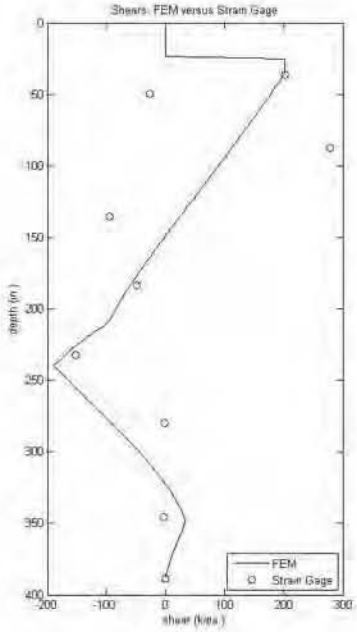

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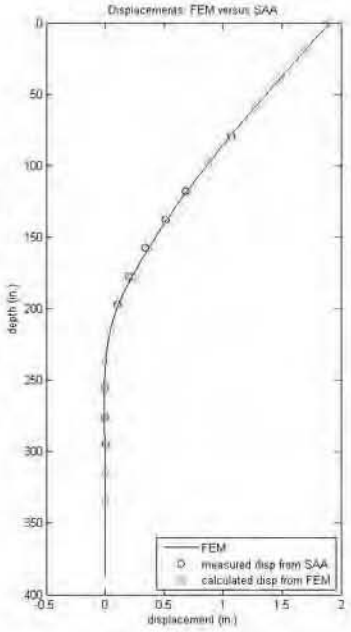

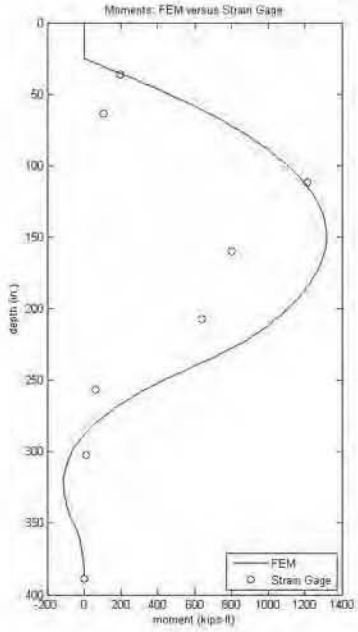

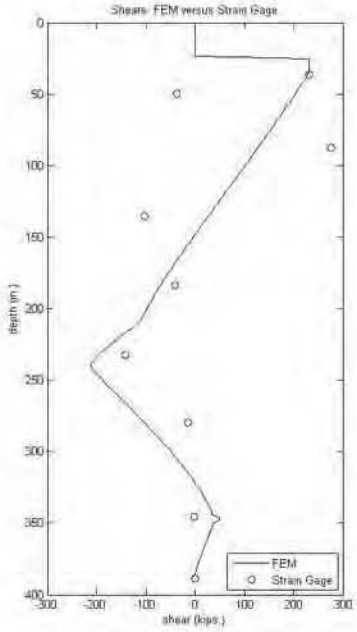

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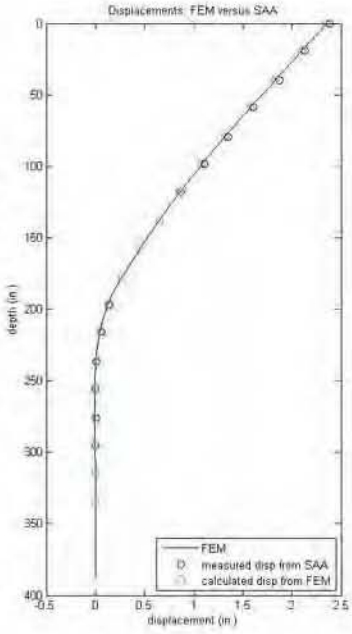

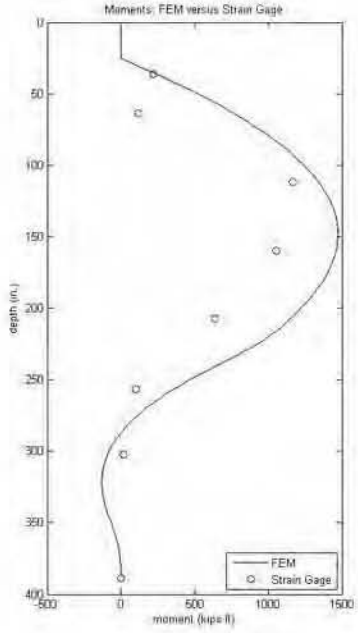

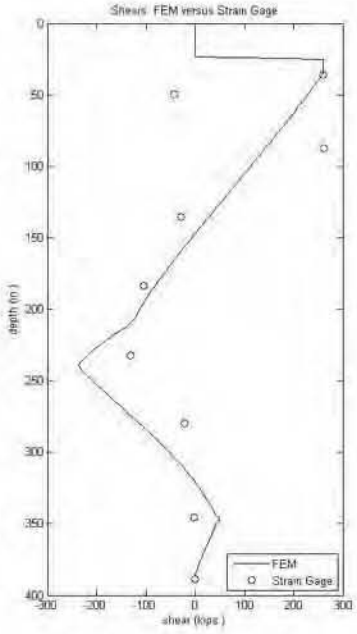

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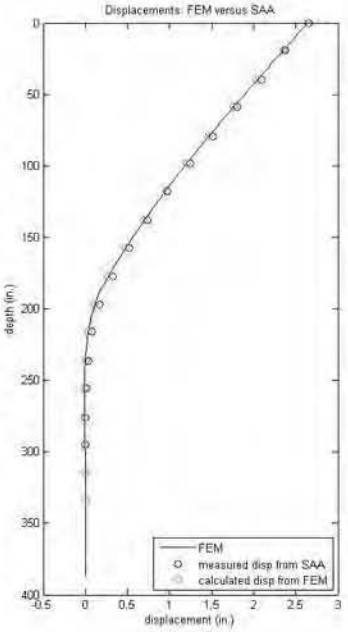

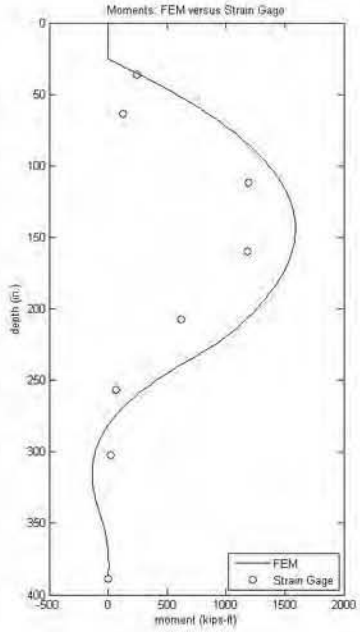

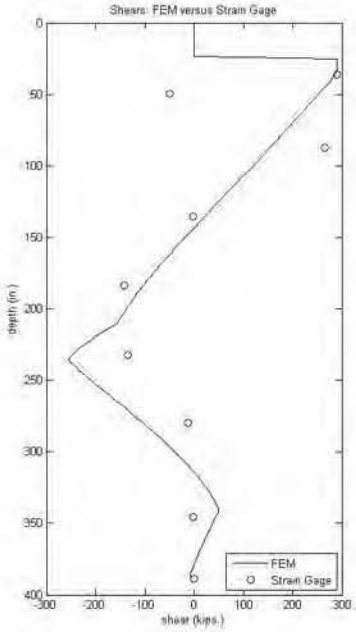

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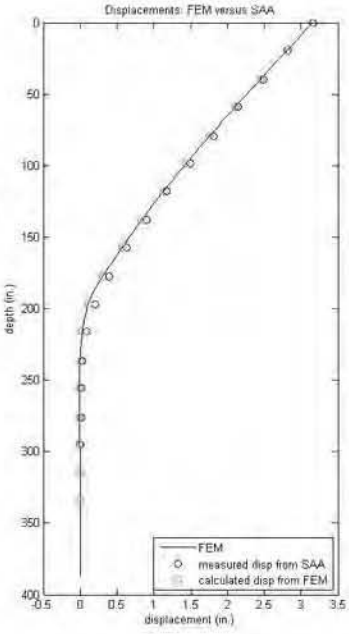

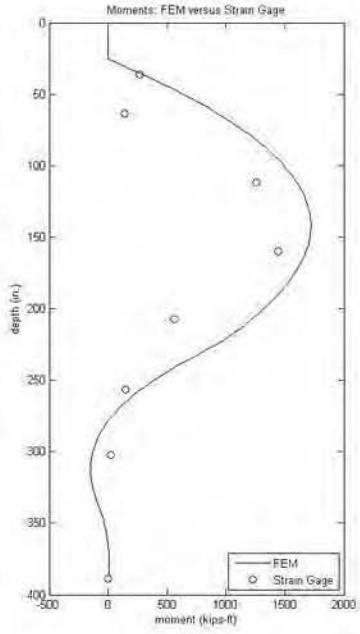

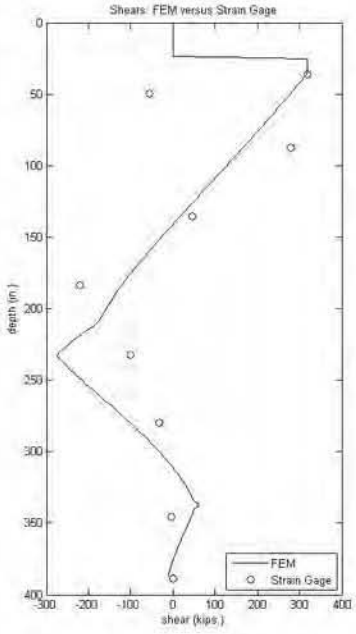

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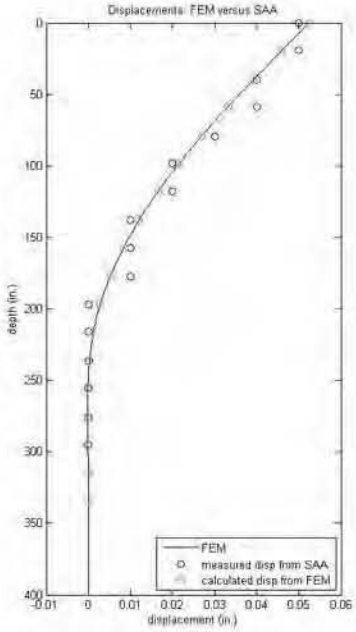

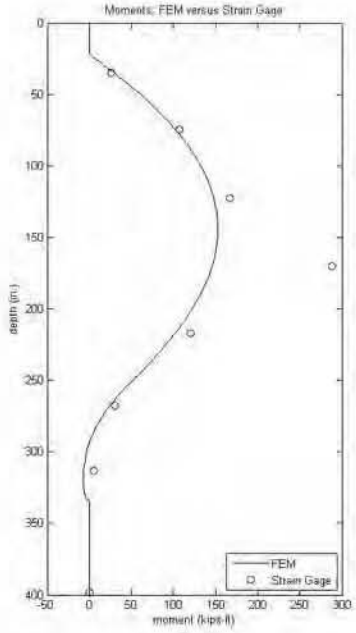

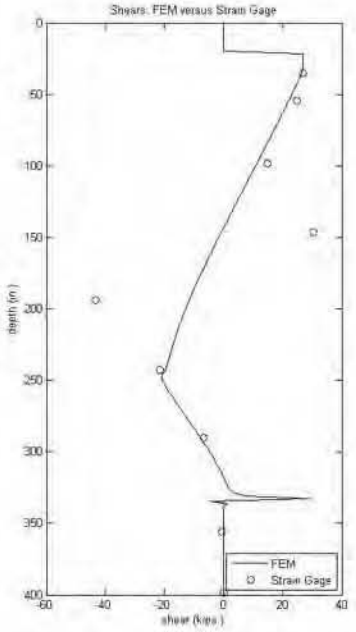

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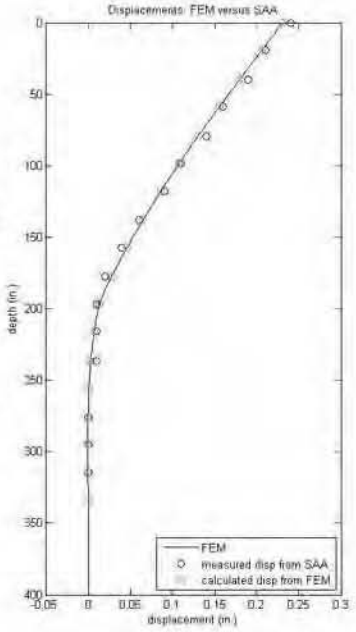

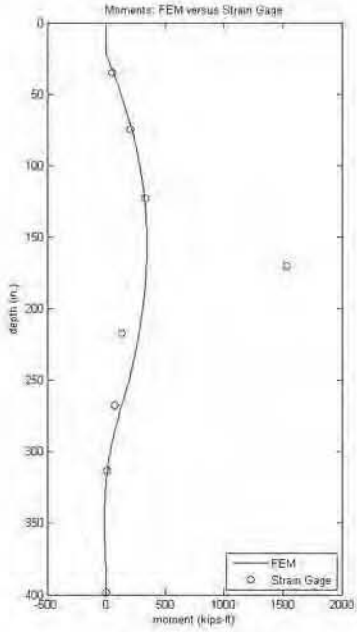

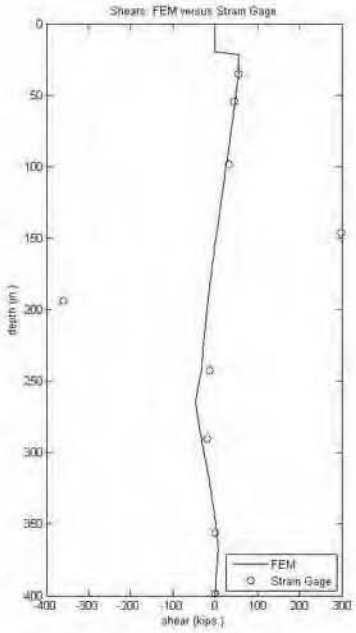

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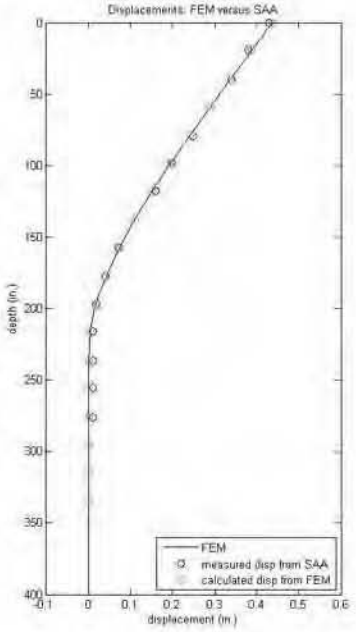
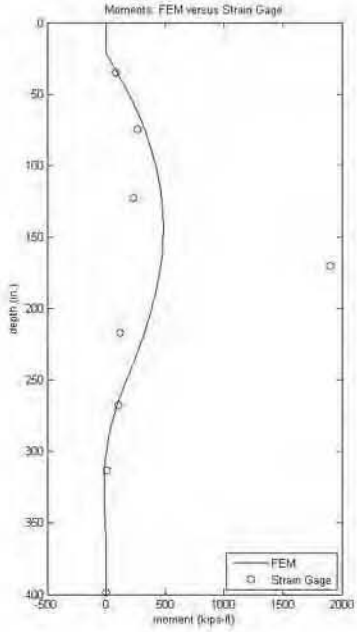
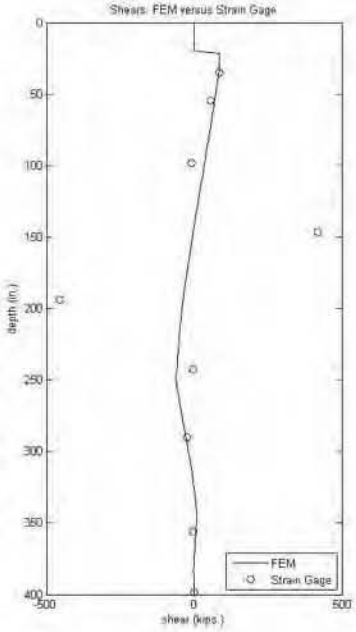
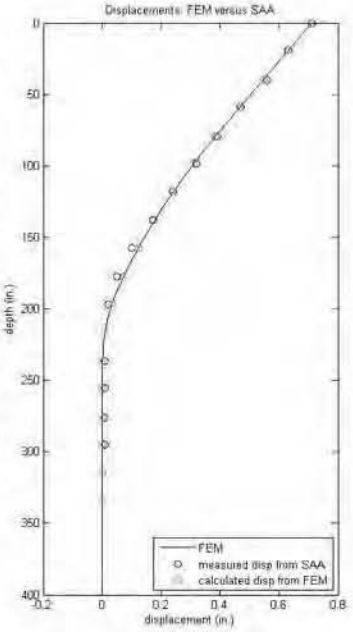
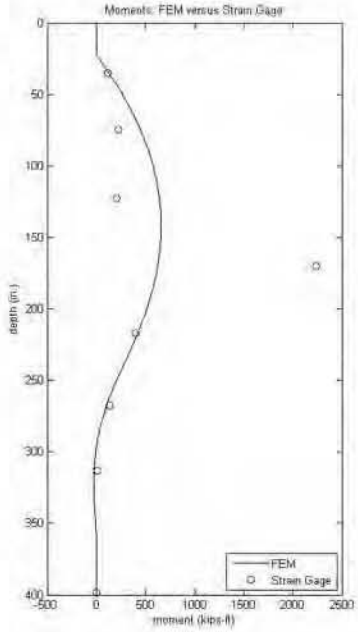


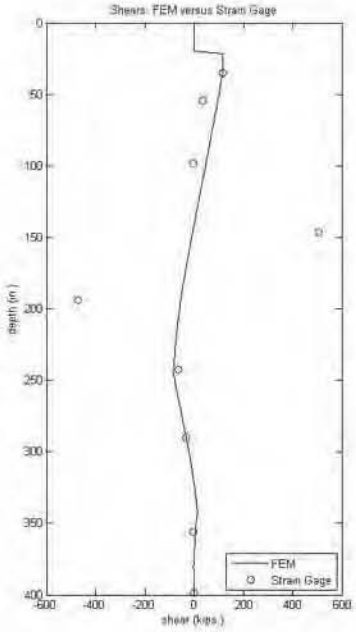




W2 117.5 kips







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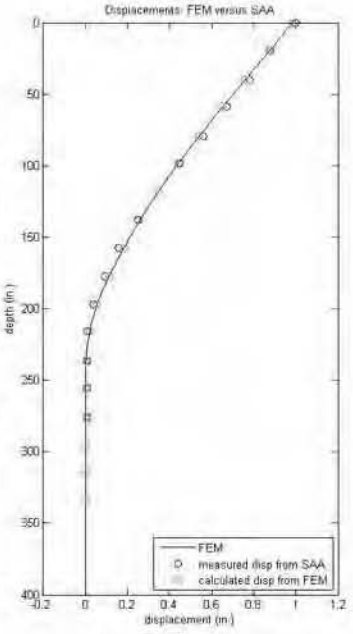

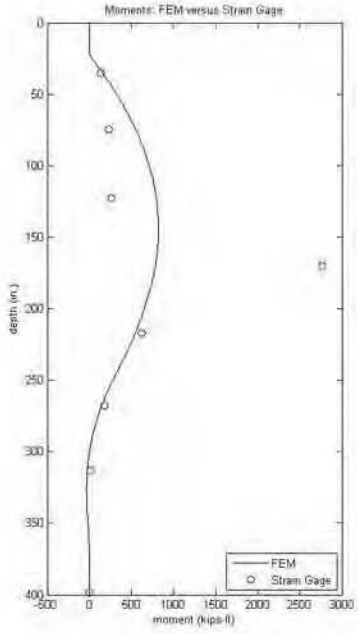

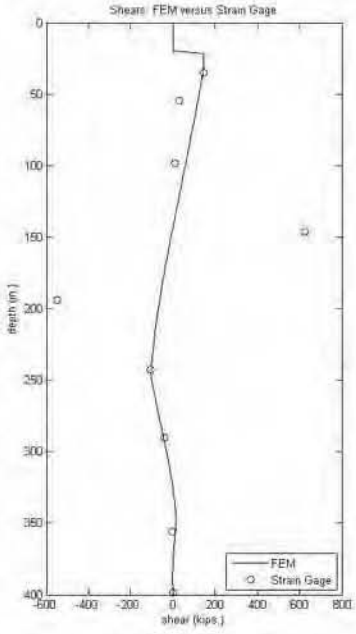

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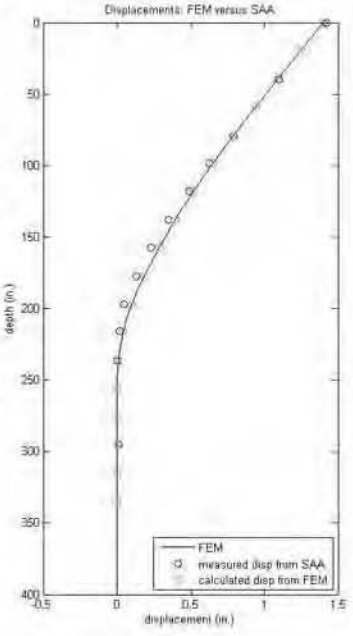
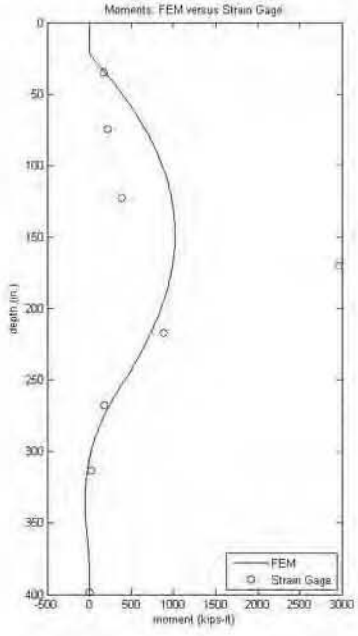
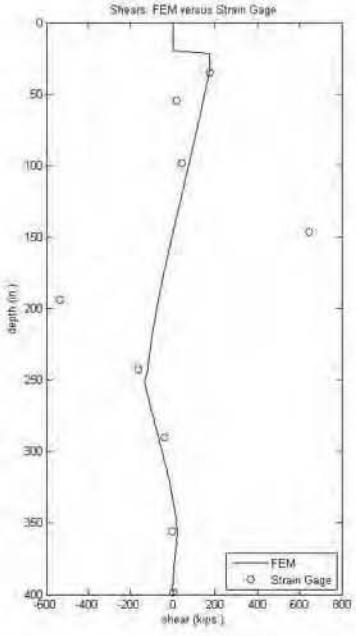
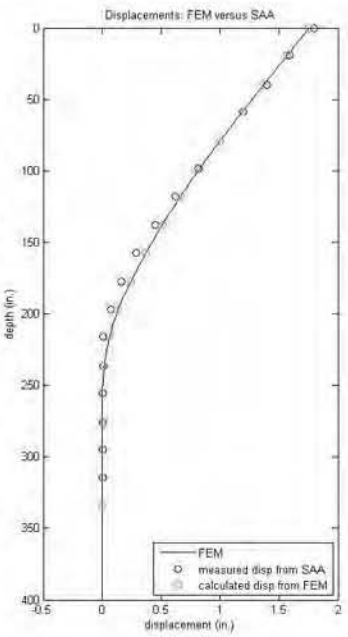
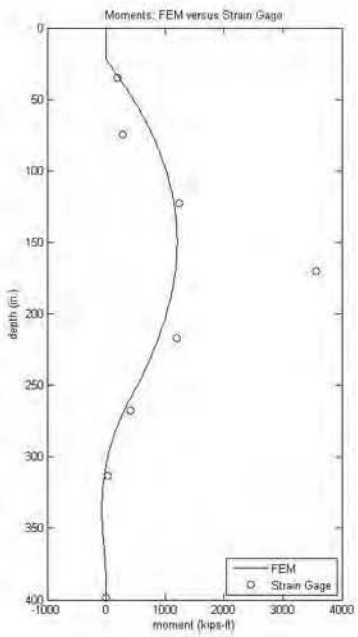


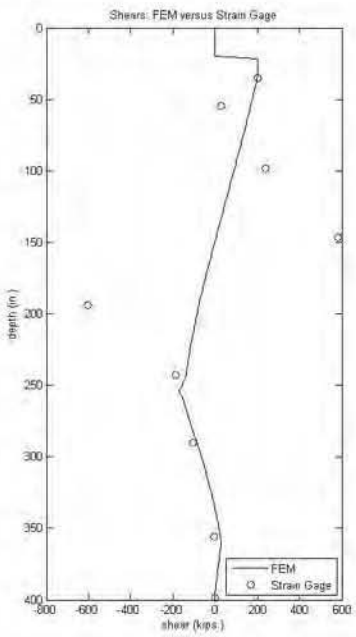




W2 202.3 kips







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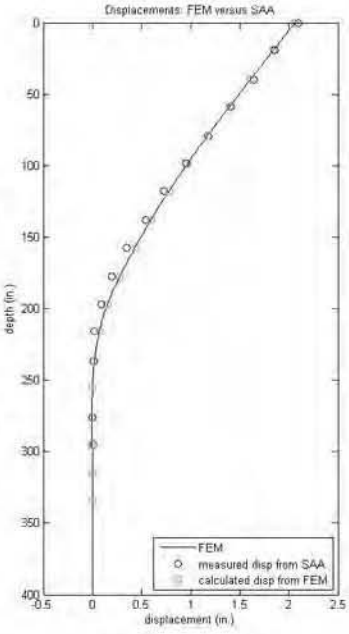
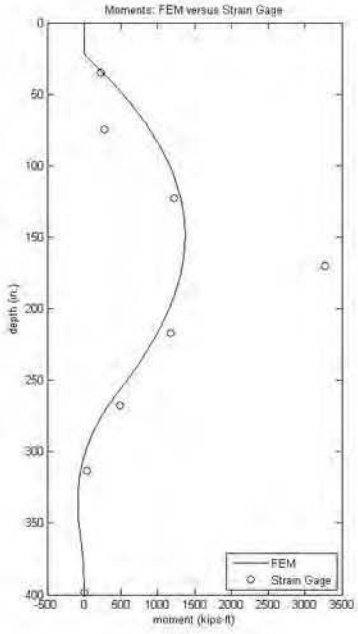
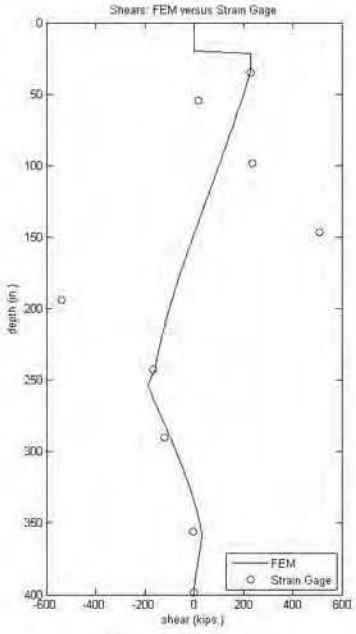
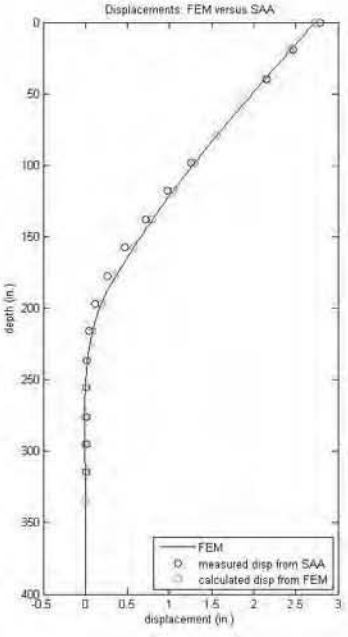
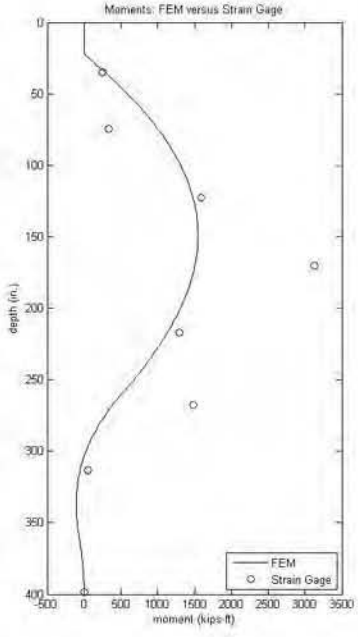


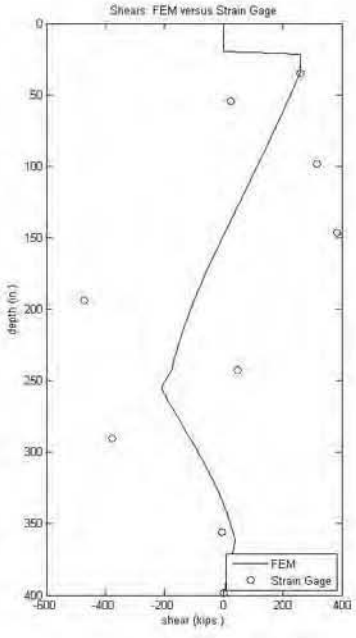




W2 260.7 kips







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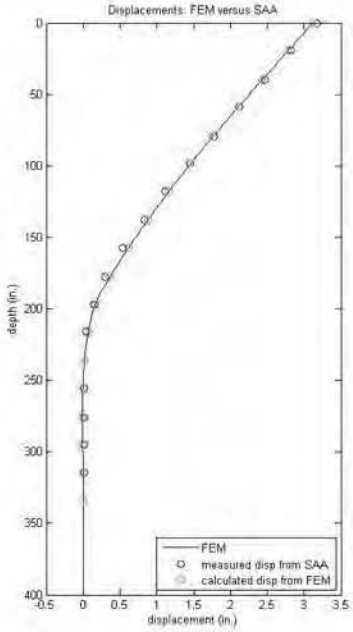
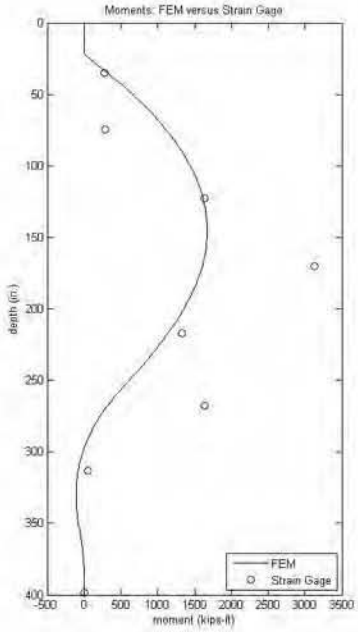
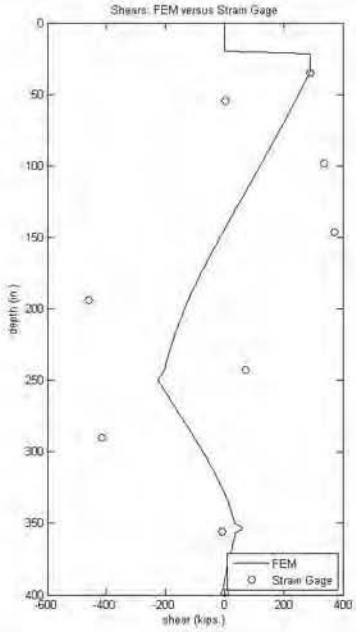
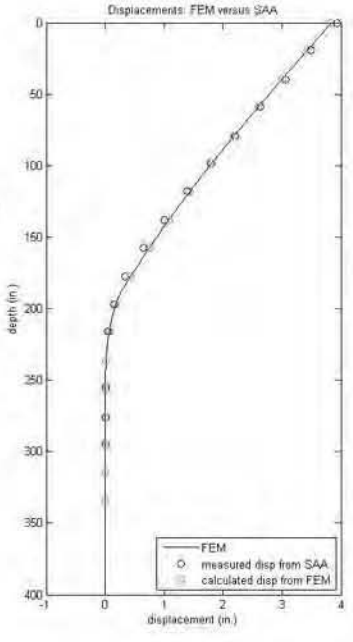
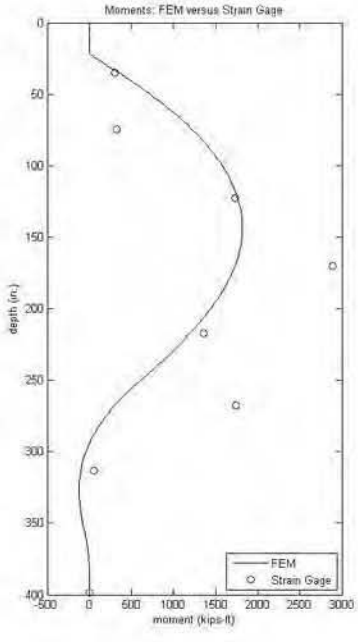


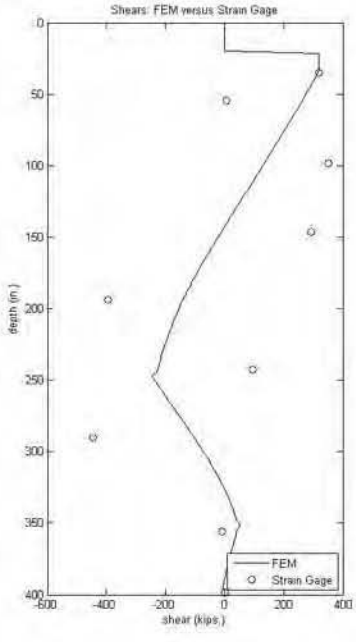




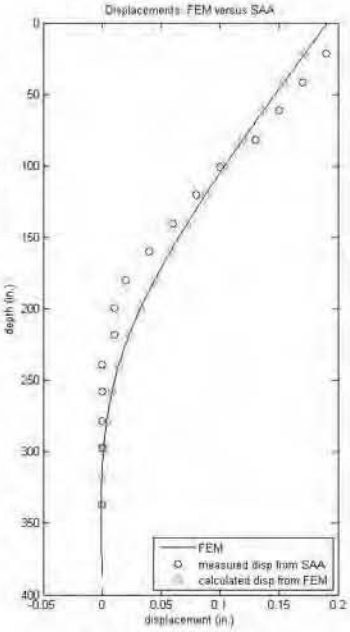
W2 319.2 kips

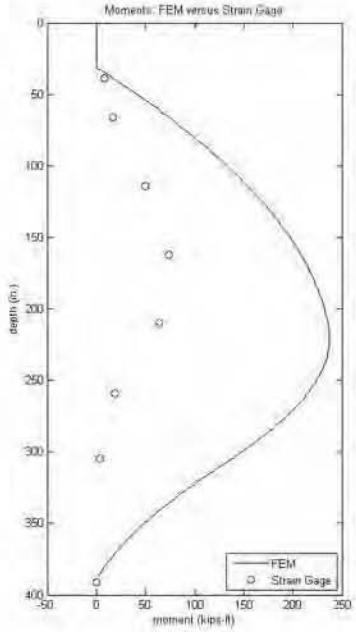


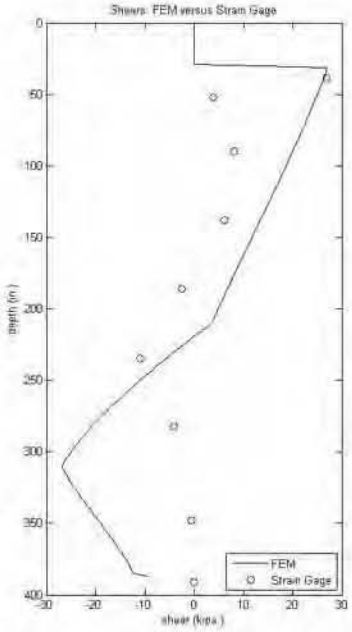




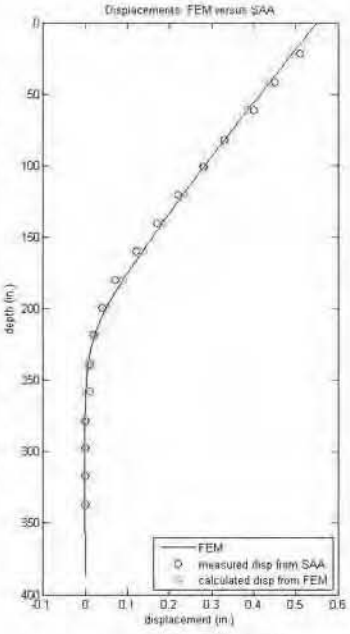
W1 Soil Removed 26.8 kips

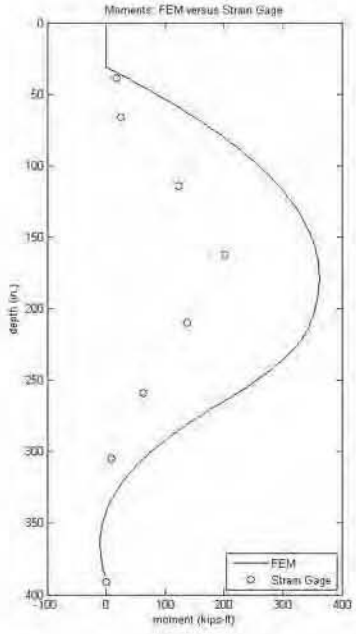


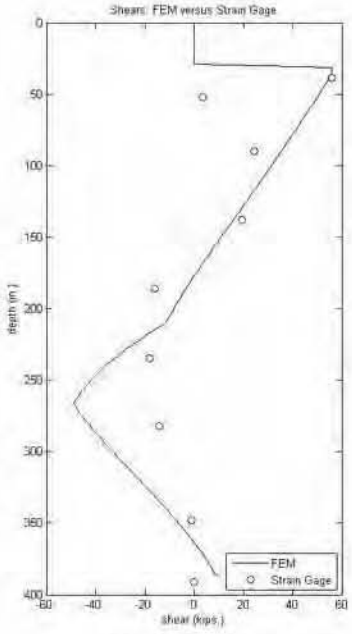




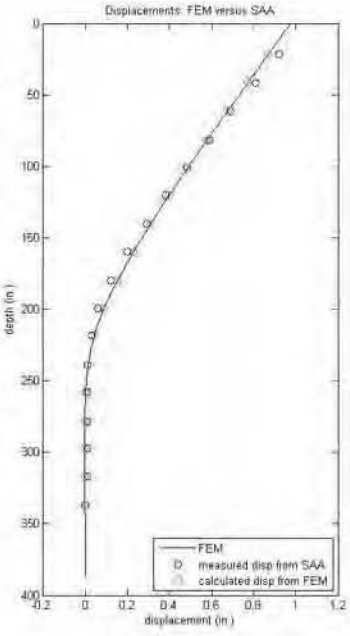
W1 Soil Removed 56.1 kips

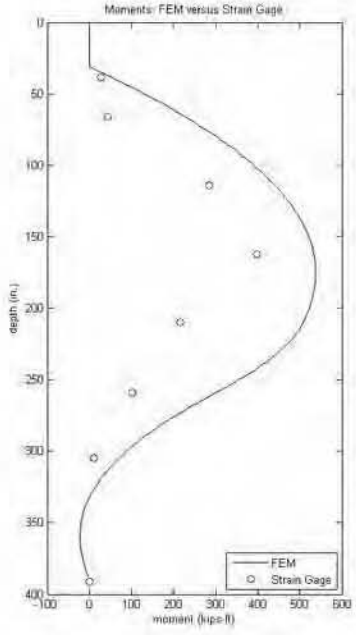


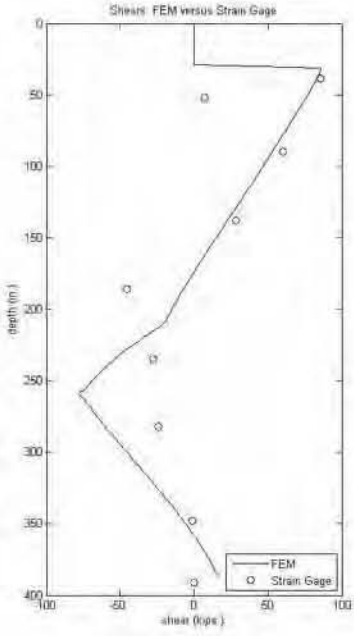




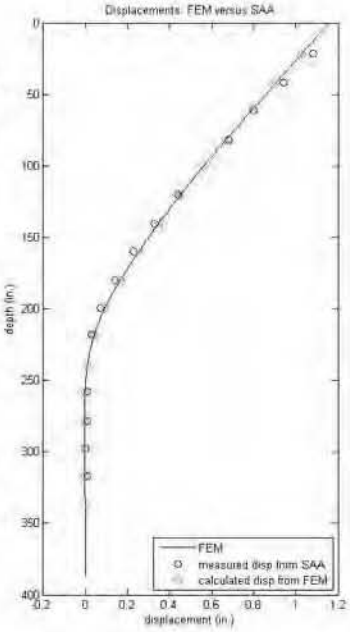
W1 Soil Removed 85.3 kips

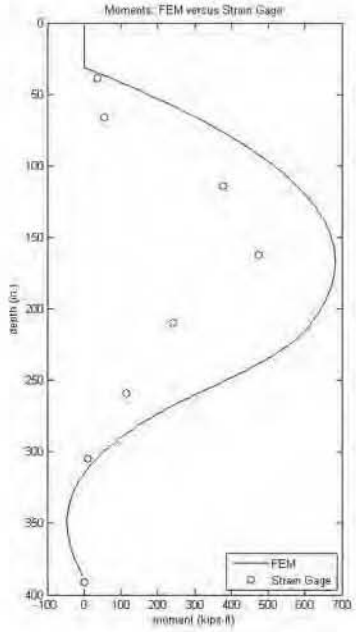


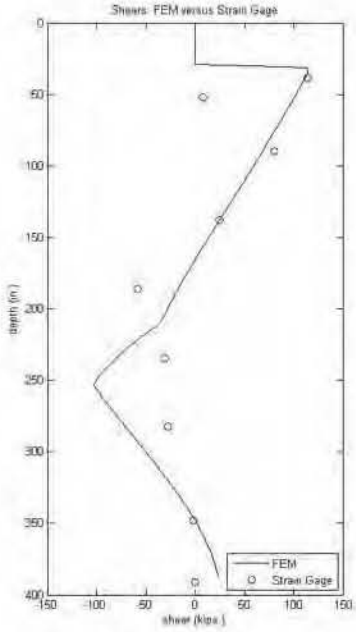




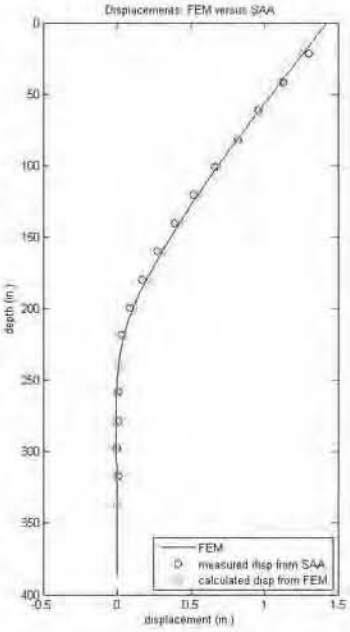
W1 Soil Removed 114.5 kips

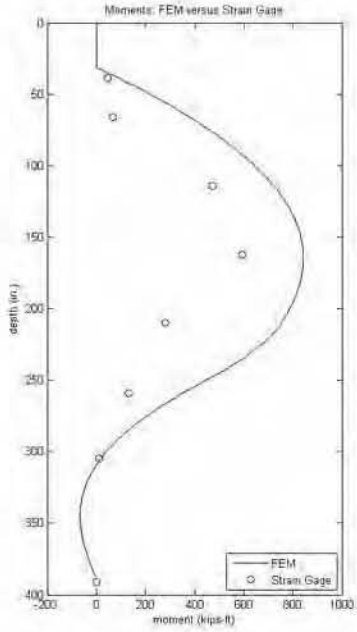


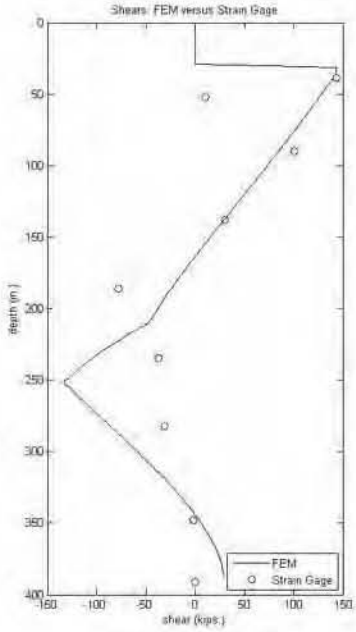




W1 Soil Removed 143.8 kips







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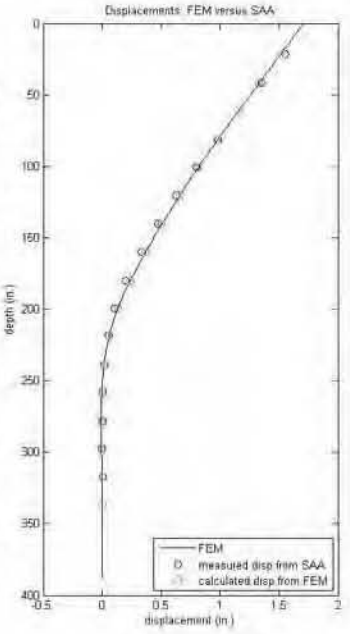
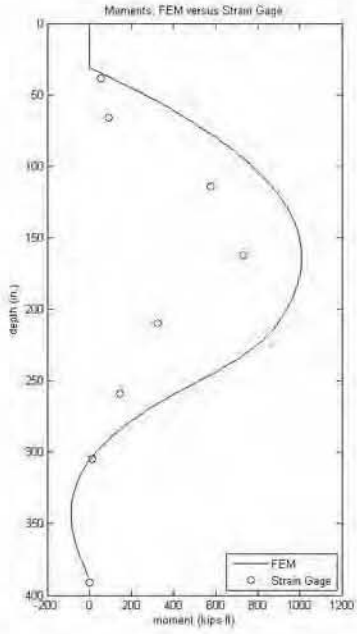
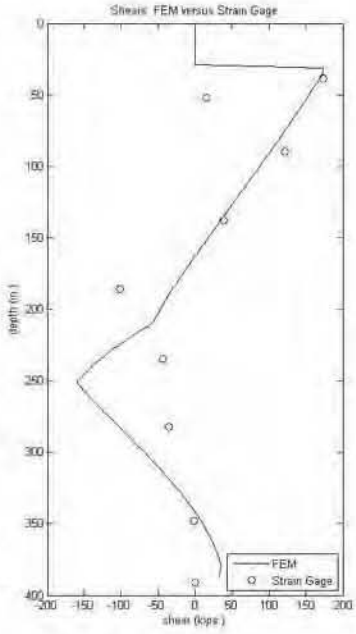
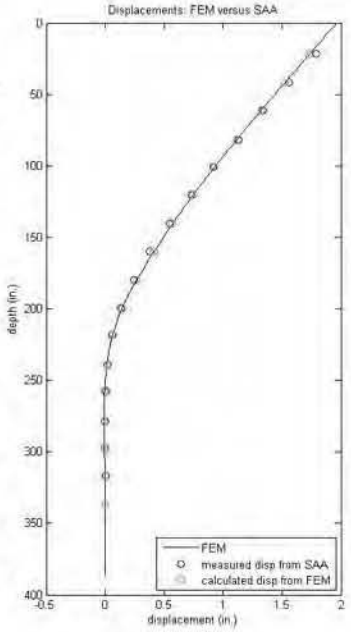
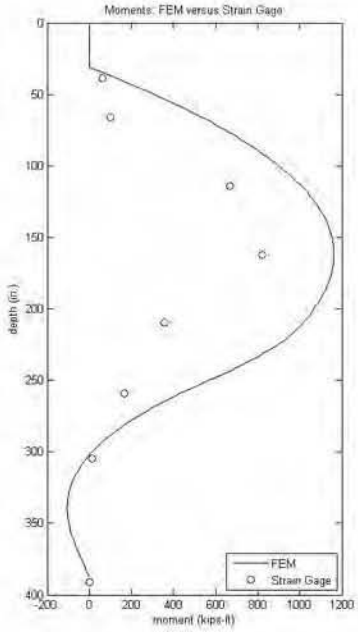


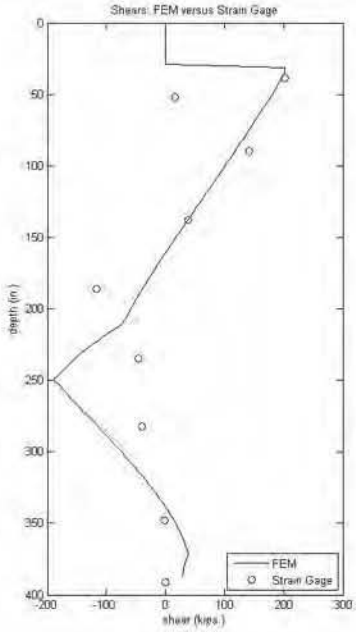




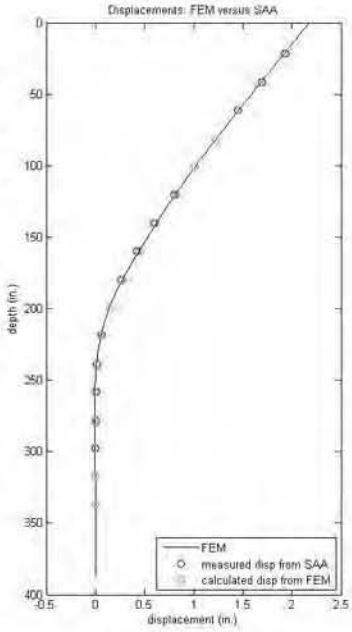
W1 Soil Removed 202.3 kips

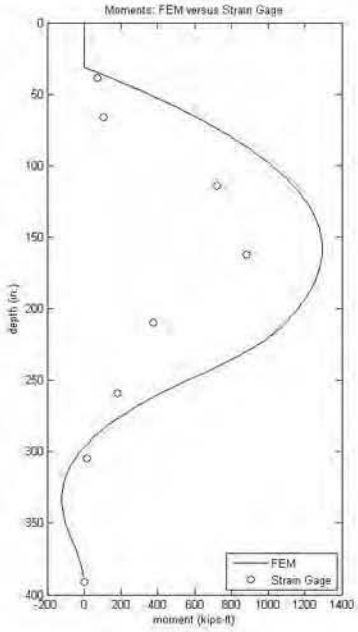


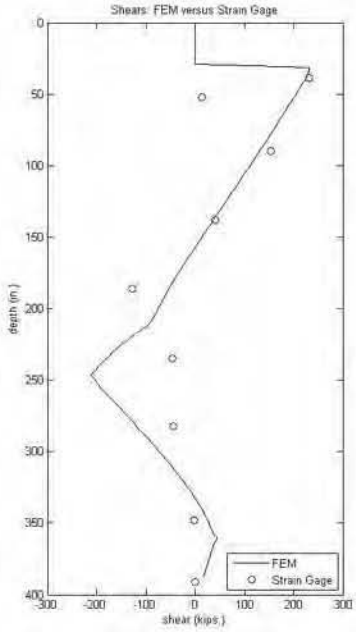




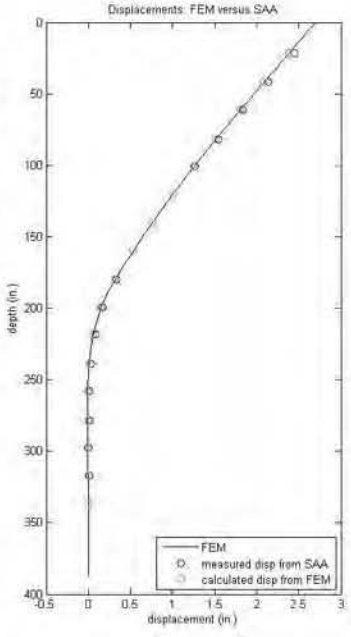
W1 Soil Removed 231.5 kips

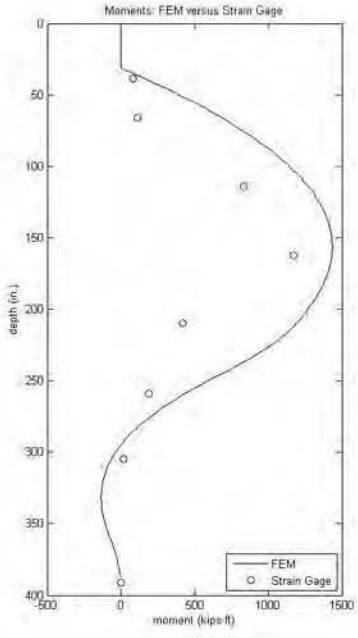


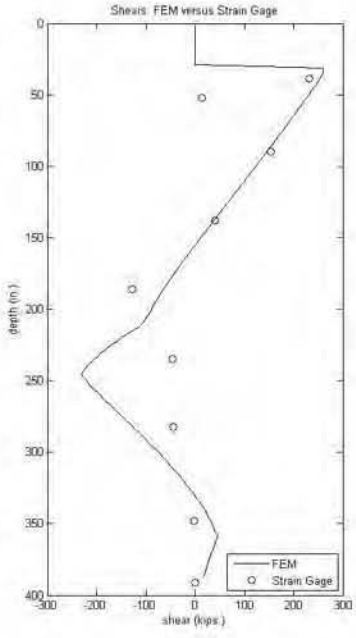




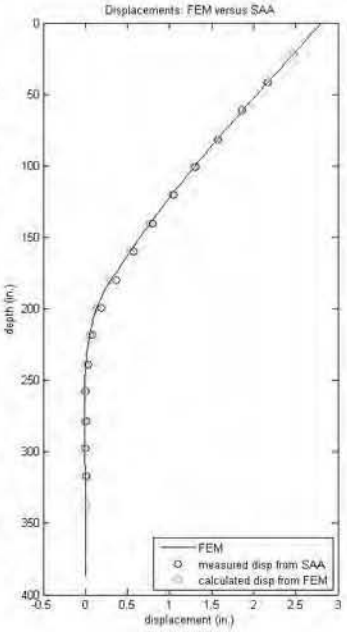
W1 Soil Removed 260.7 kips

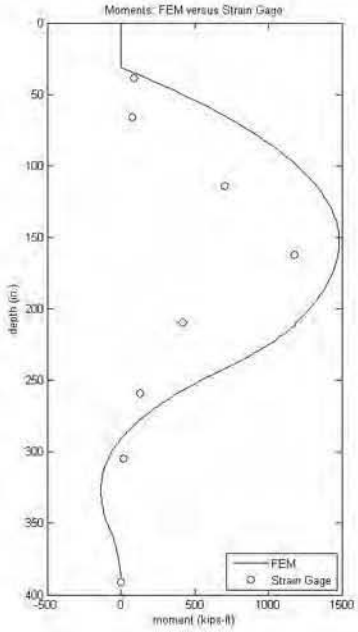


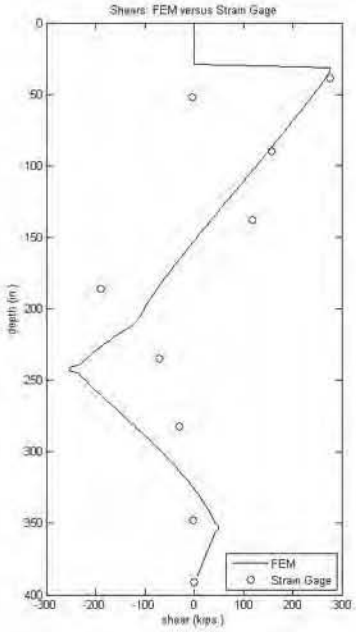




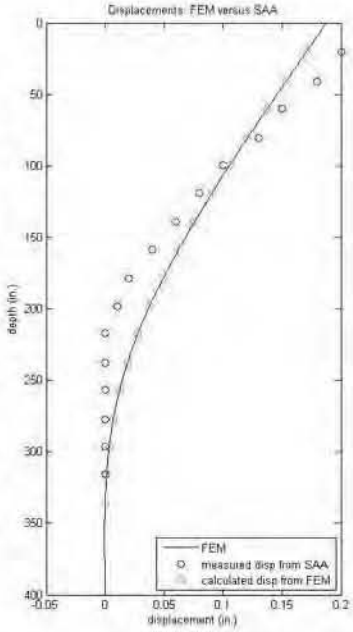
W1 Soil Removed 275.4 kips

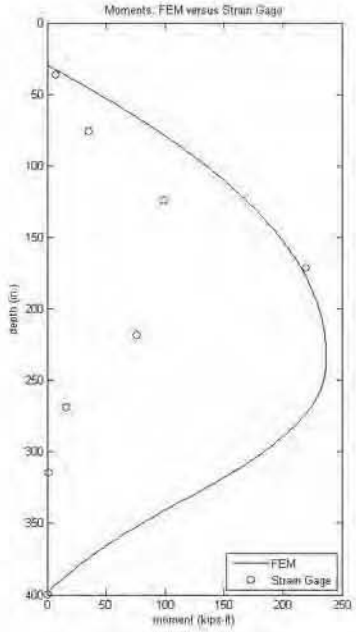


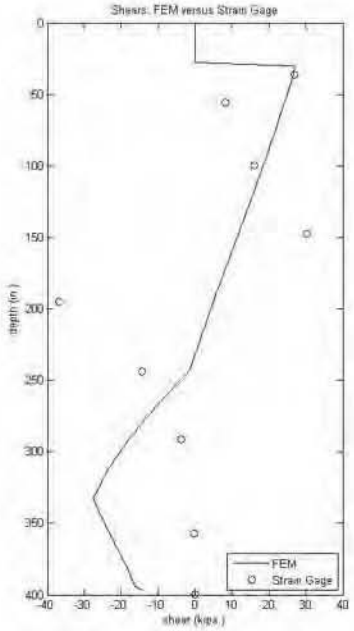




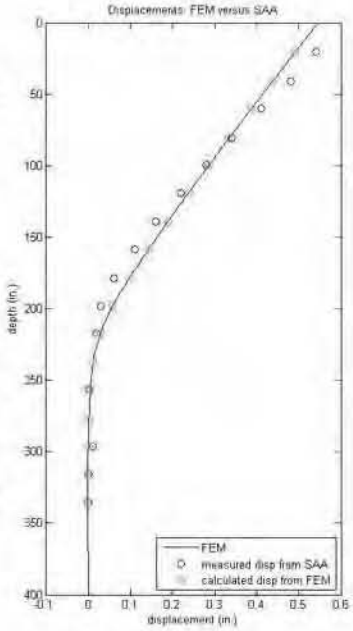
W2 Soil Removed 26.8 kips

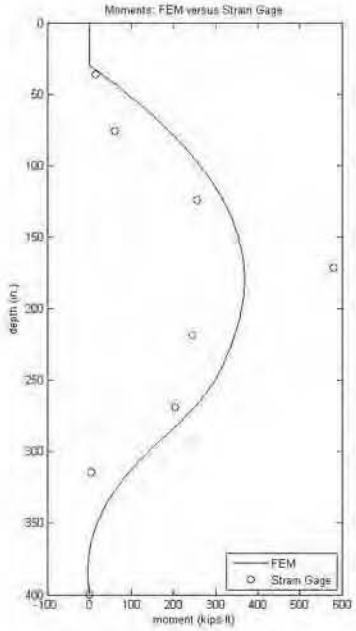


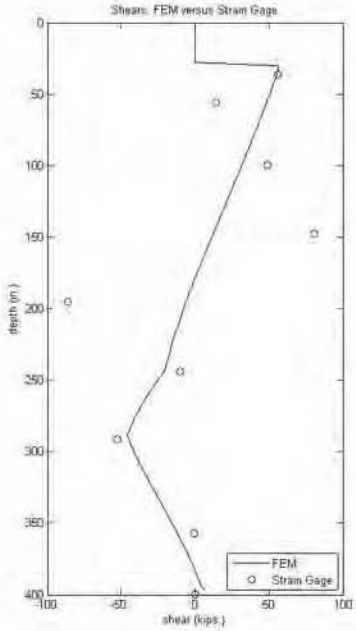




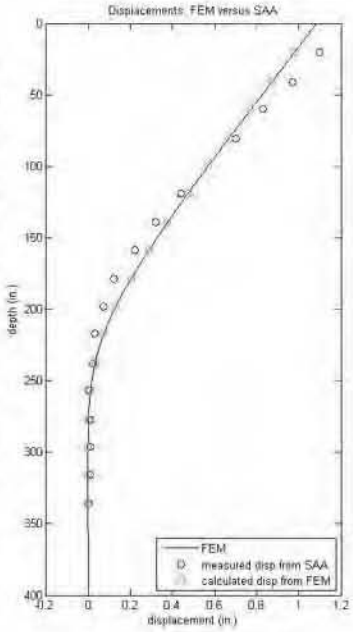
W2 Soil Removed 56.1 kips

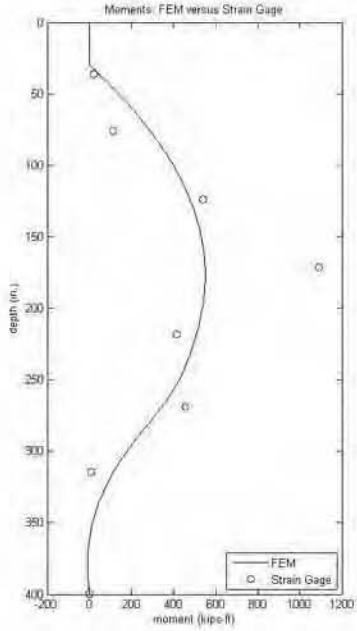


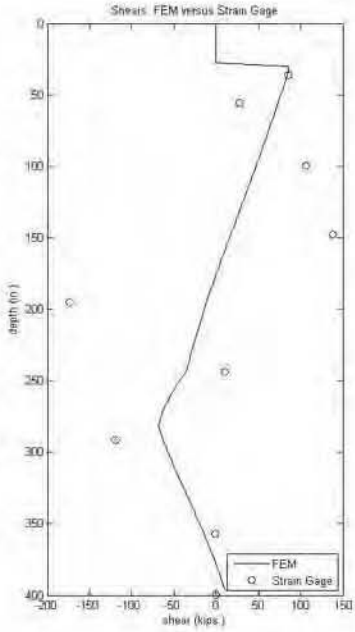




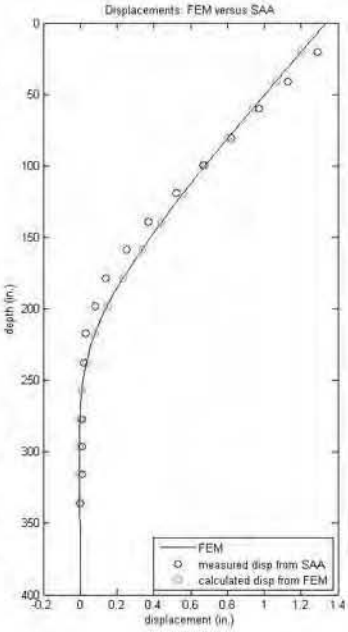
W2 Soil Removed 85.3 kips

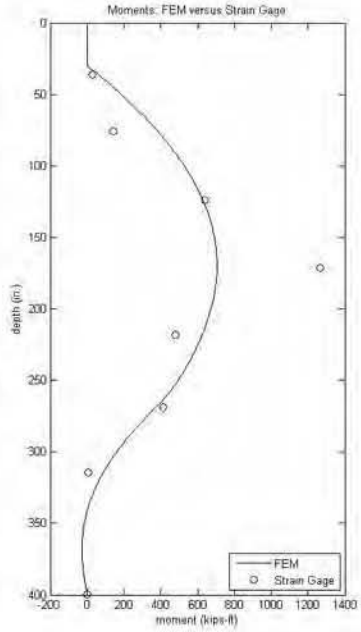


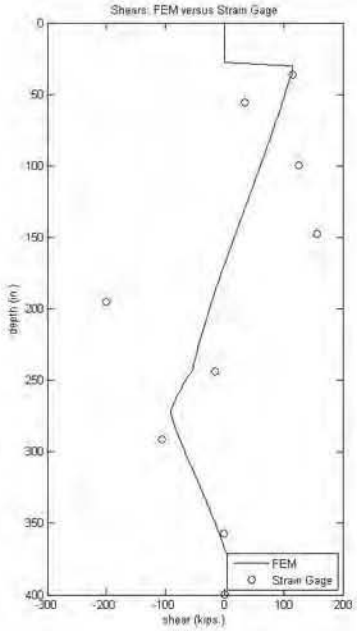




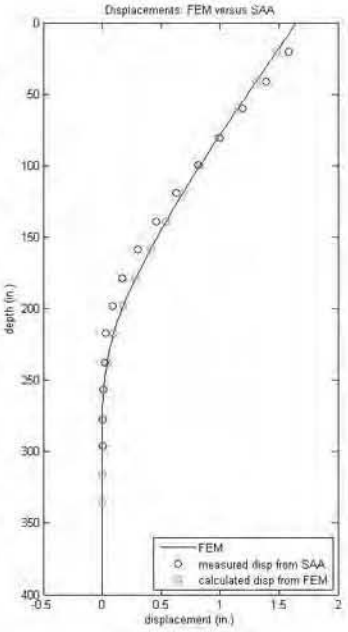
W2 Soil Removed 114.5 kips

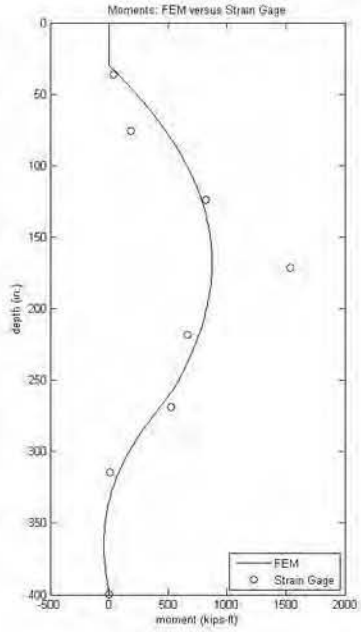


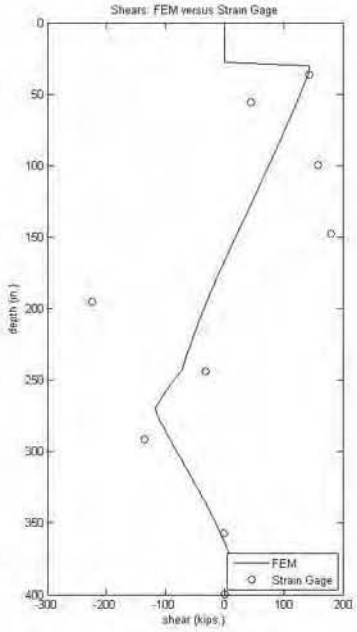




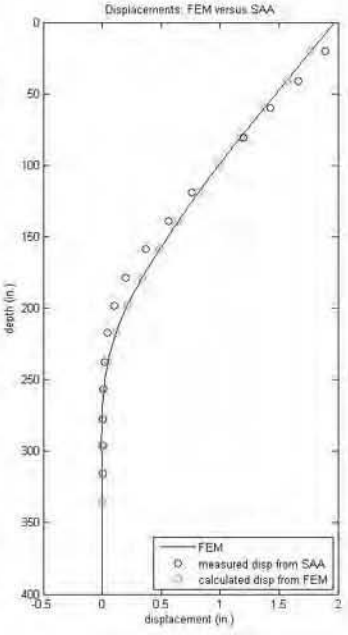
W2 Soil Removed 143.8 kips

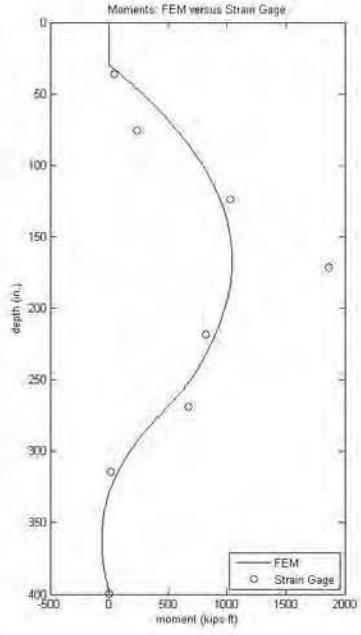


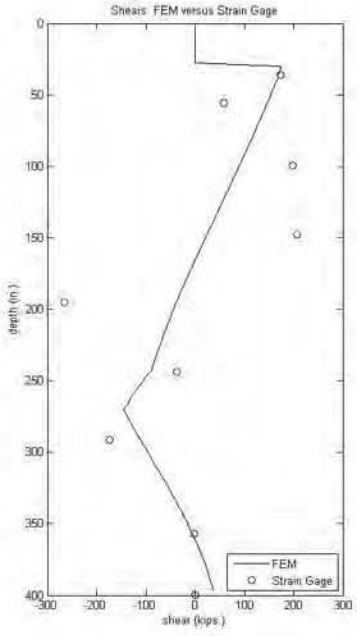




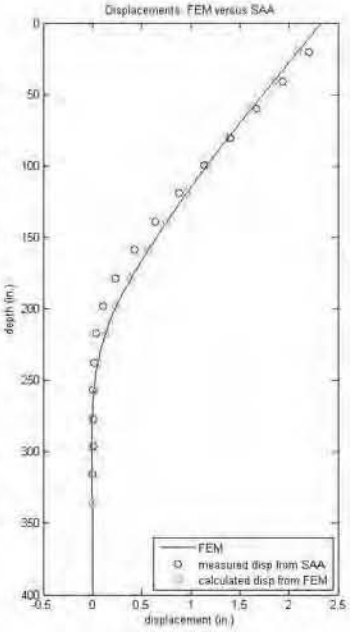
W2 Soil Removed 173.0 kips

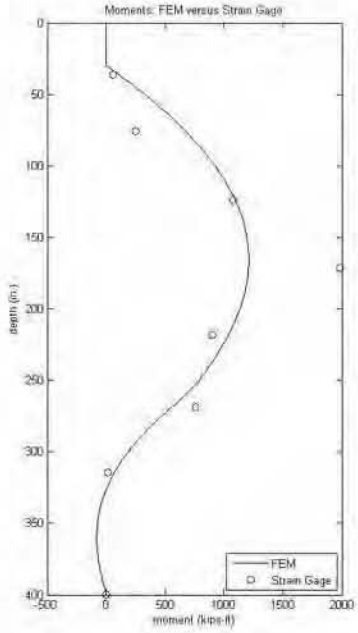


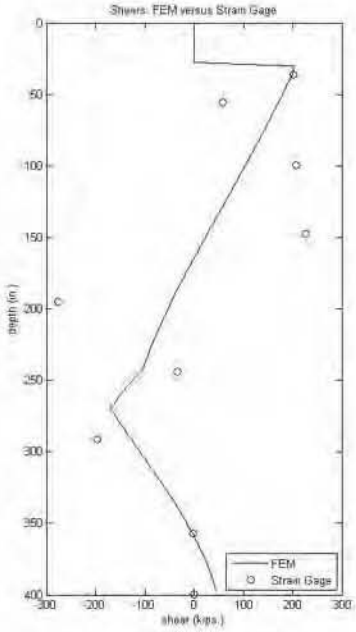




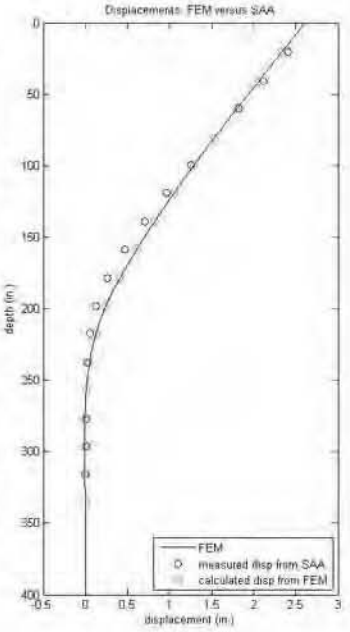
W2 Soil Removed 202.3 kips

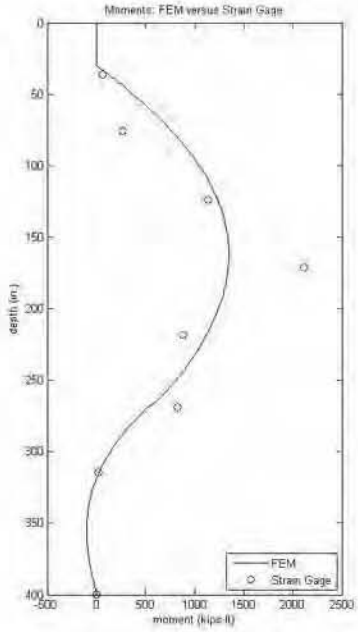


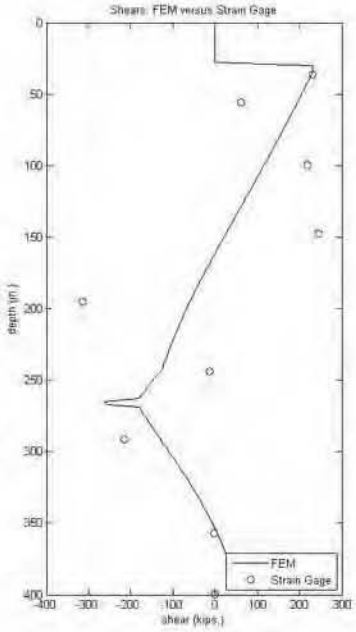




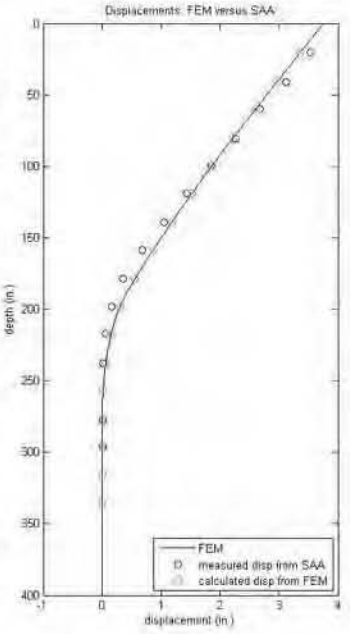
W2 Soil Removed 231.5 kips

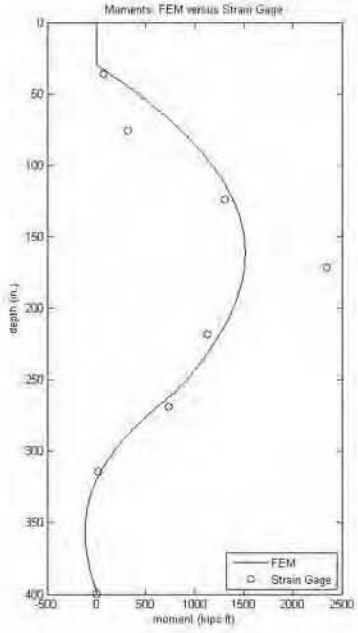


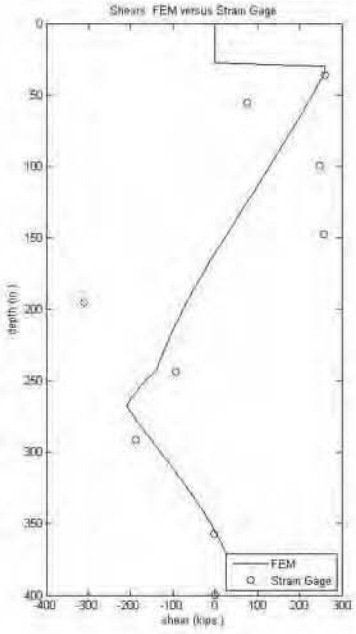




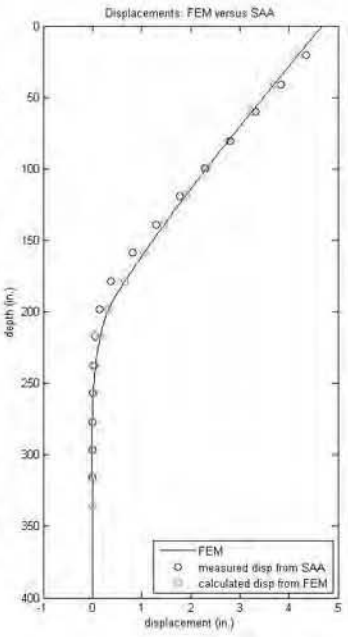
W2 Soil Removed 260.7 kips

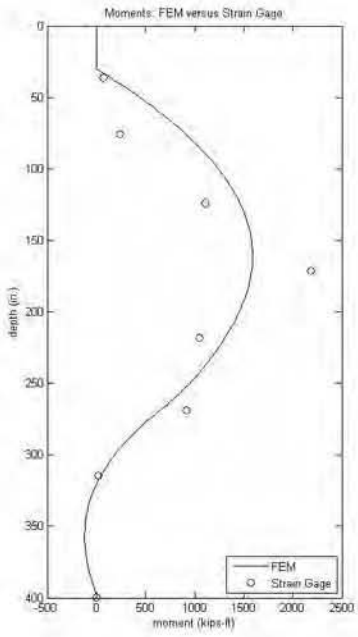


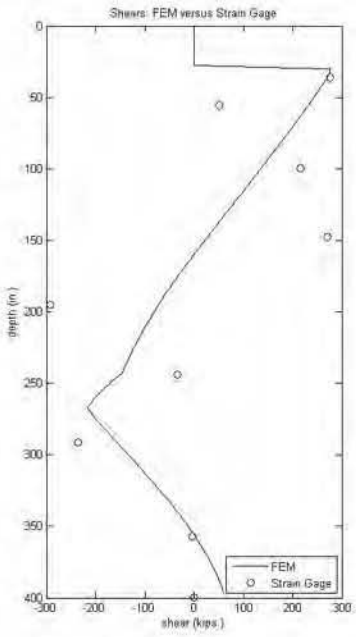




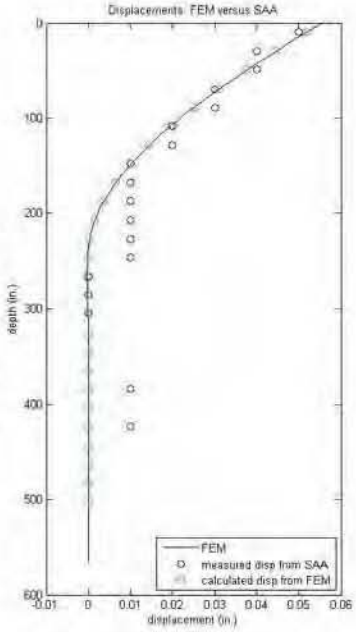
W2 Soil Removed 275.4 kips

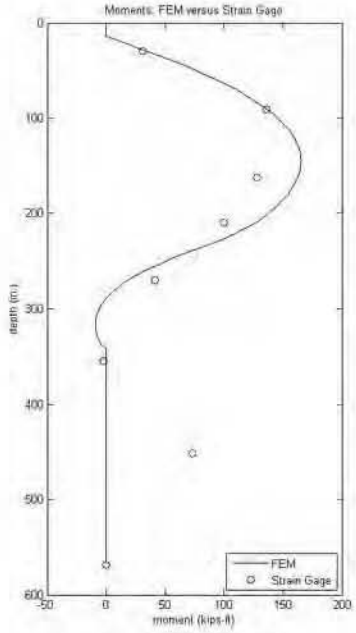


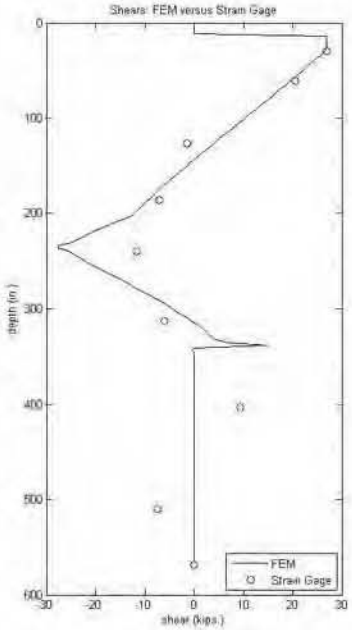




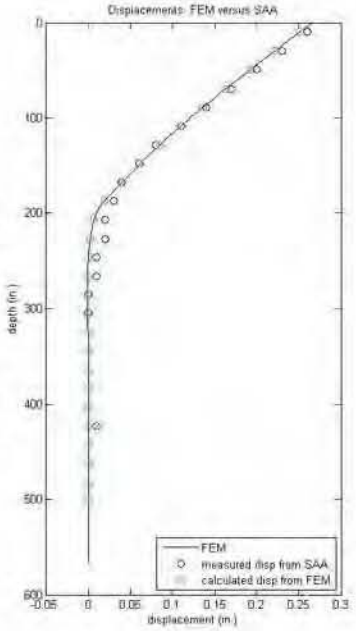
W3 26.8 kips

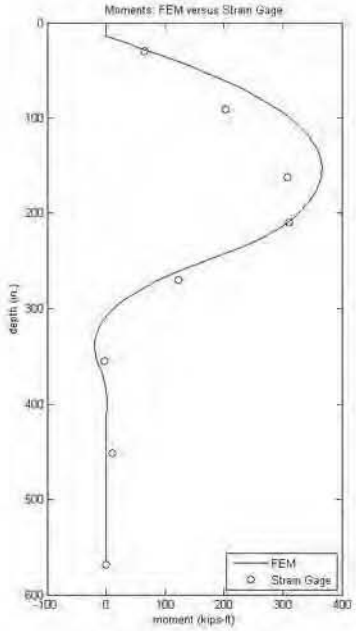


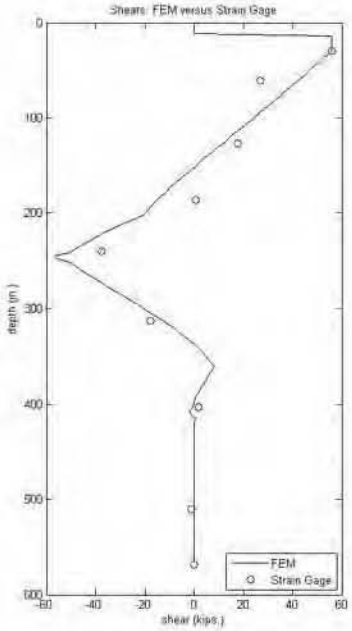




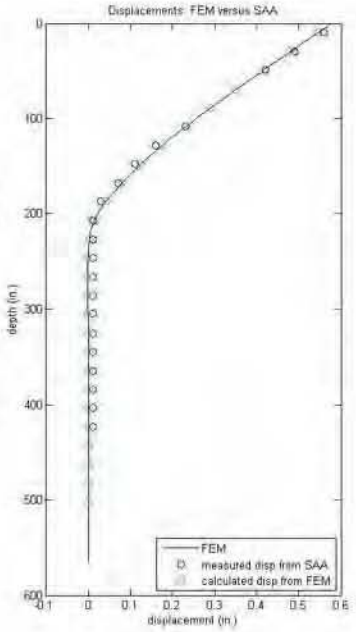
W3 56.1 kips

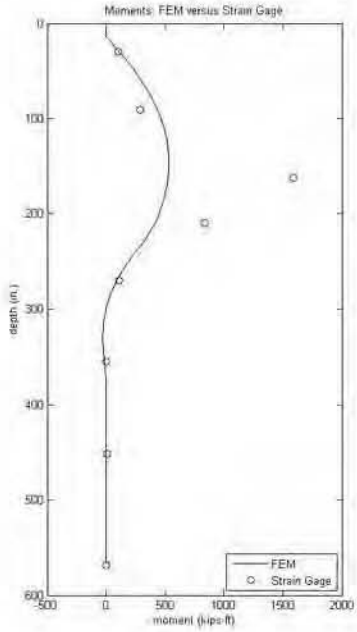


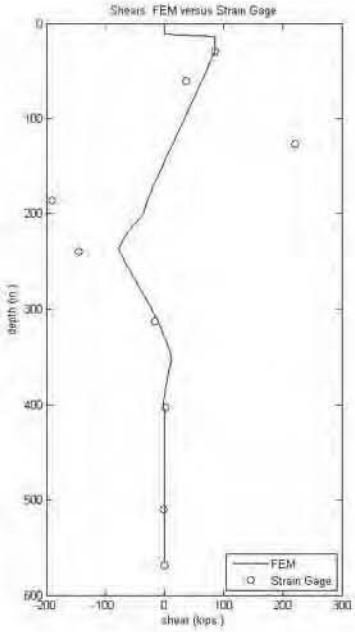




W3 85.3 kips







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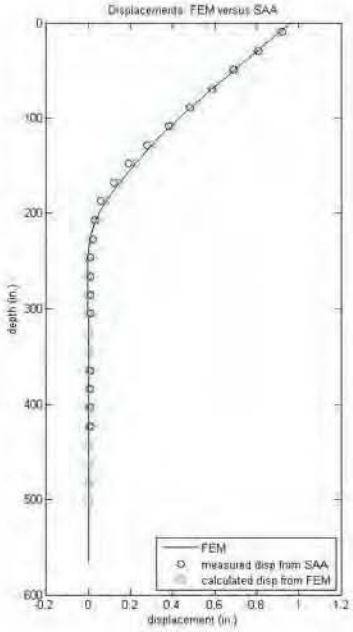

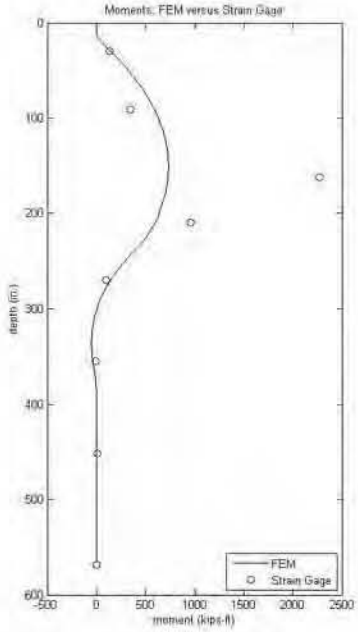

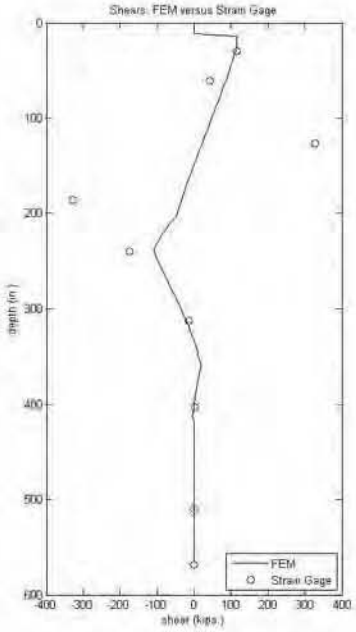

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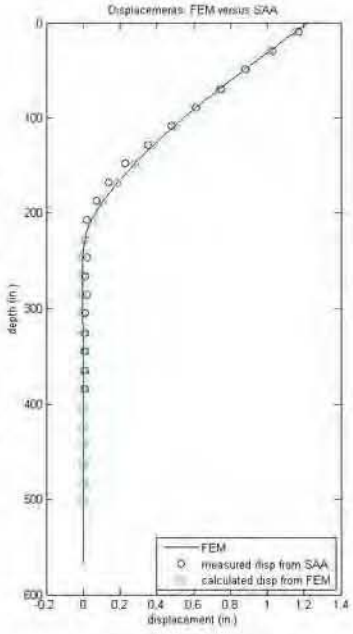
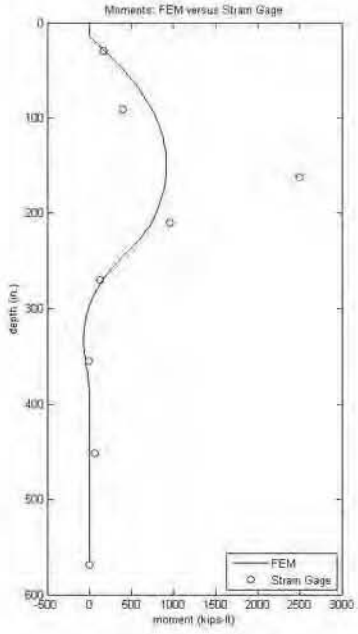
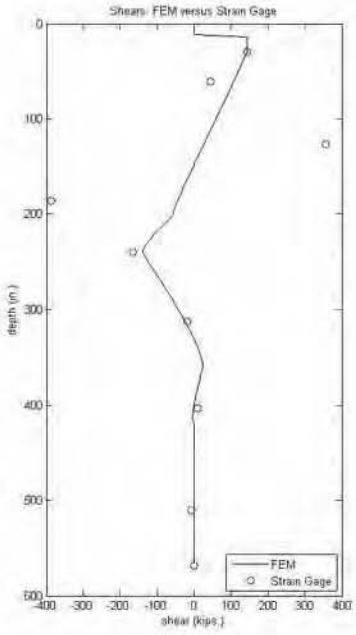
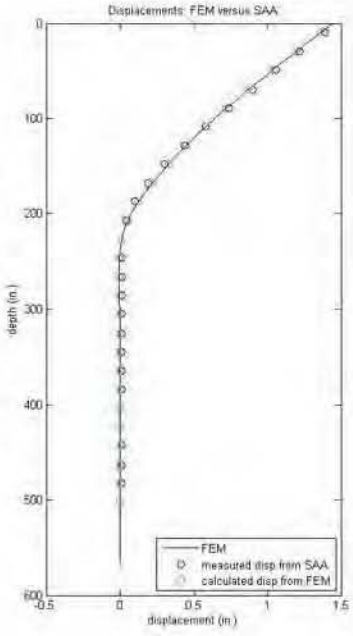
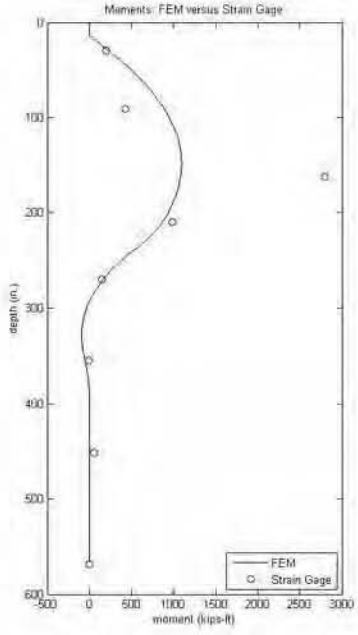


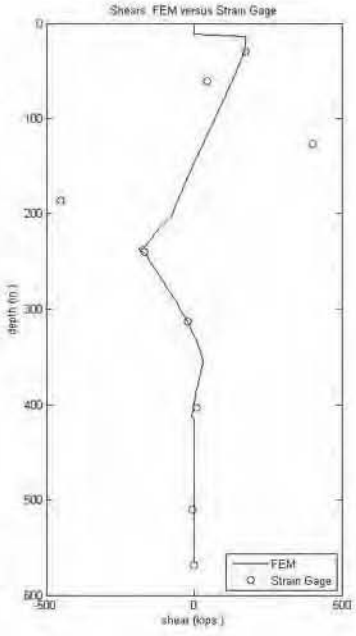




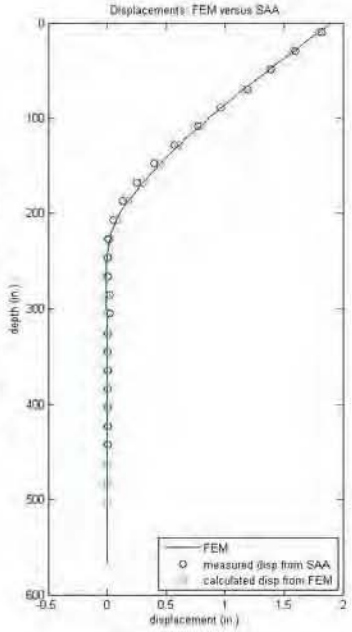
W3 173.0 kips

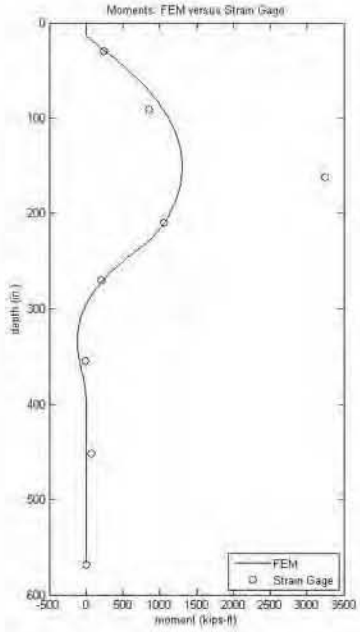


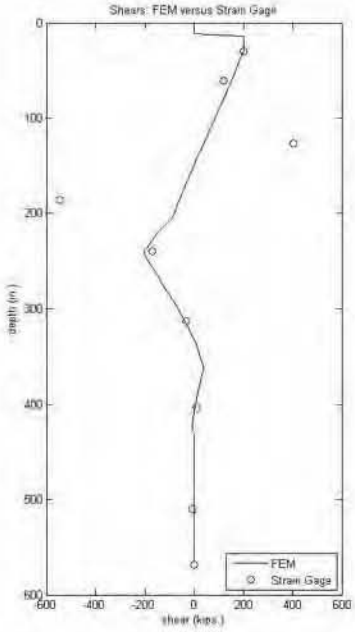




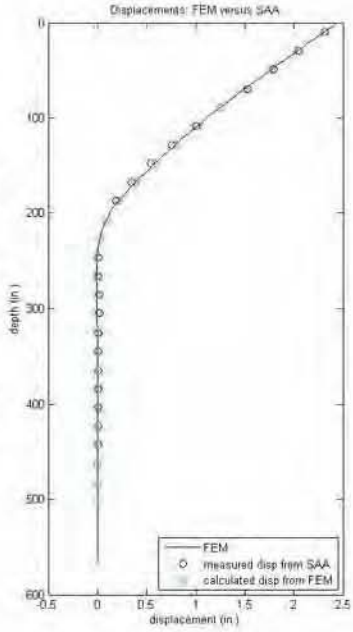
W3 202.3 kips

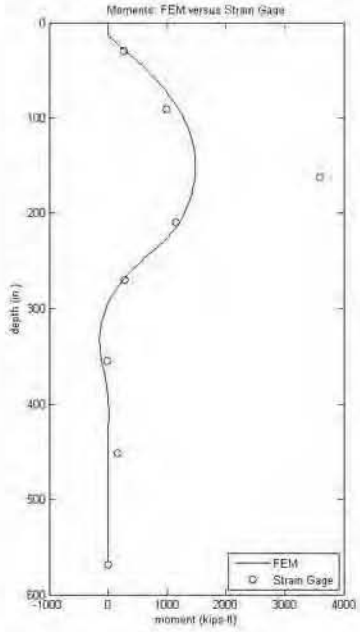


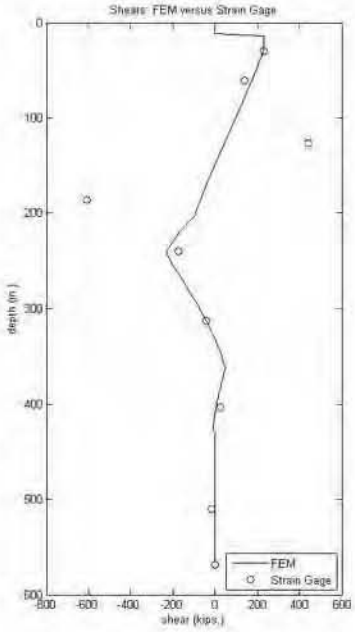




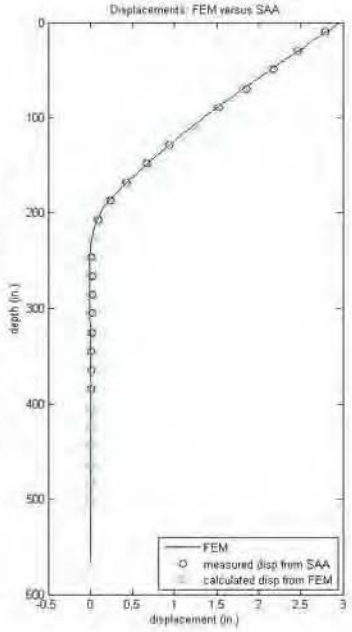
W3 231.5 kips

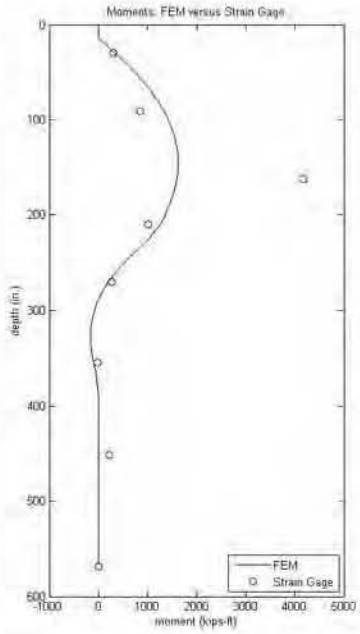


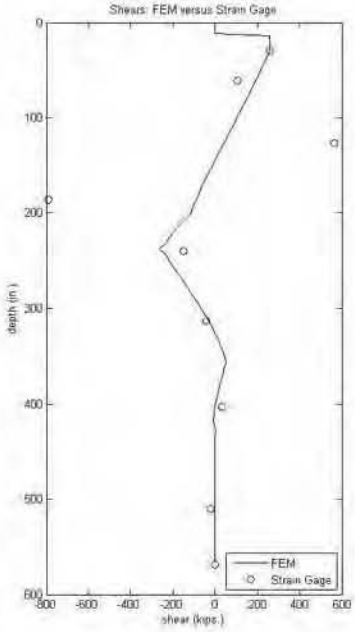




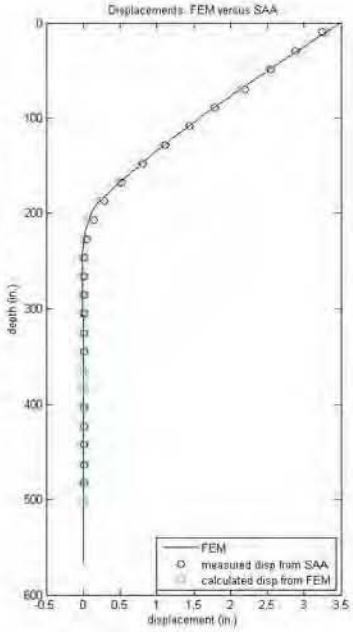
W3 260.7 kips

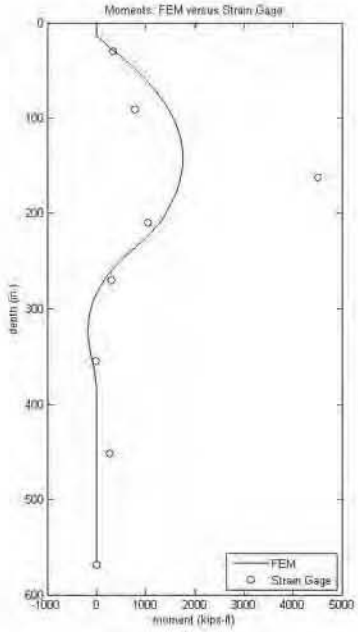


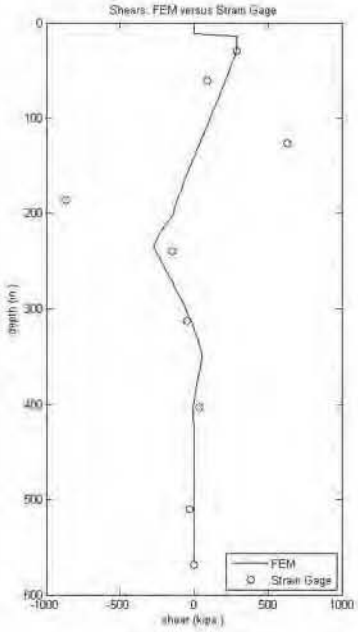




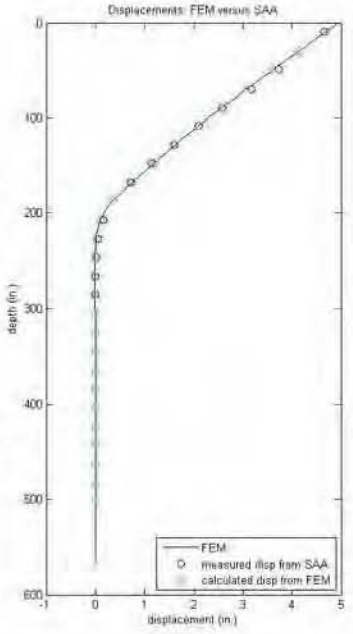
W3 290.0 kips

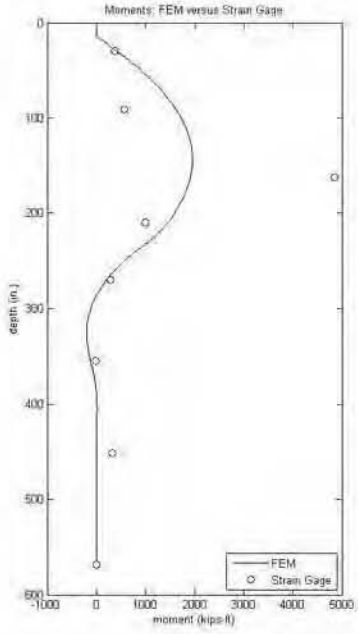


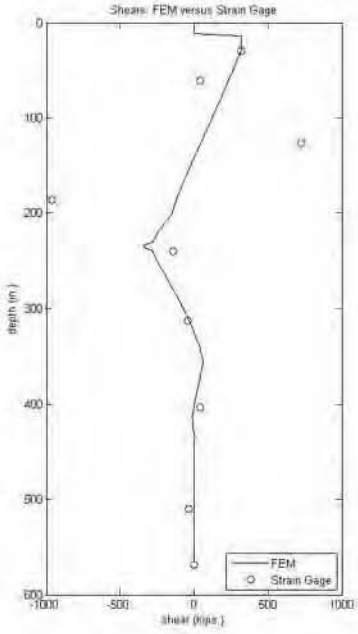




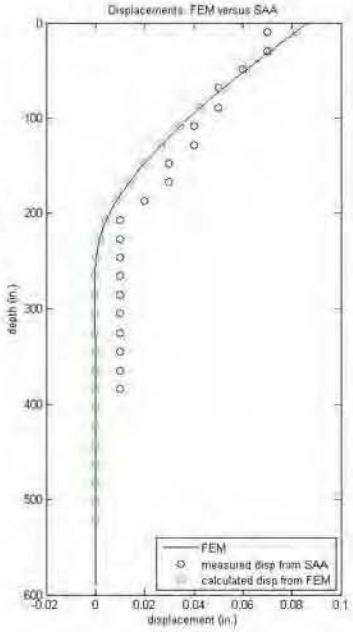
W3 319.2 kips

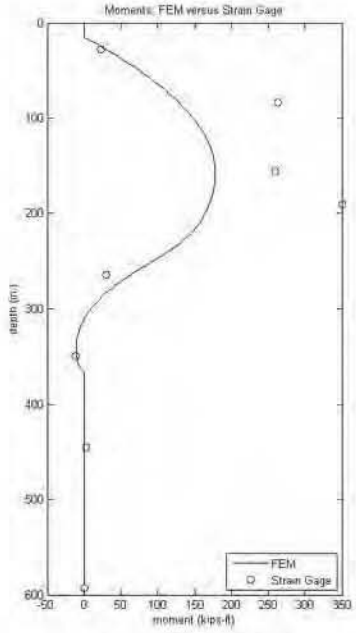


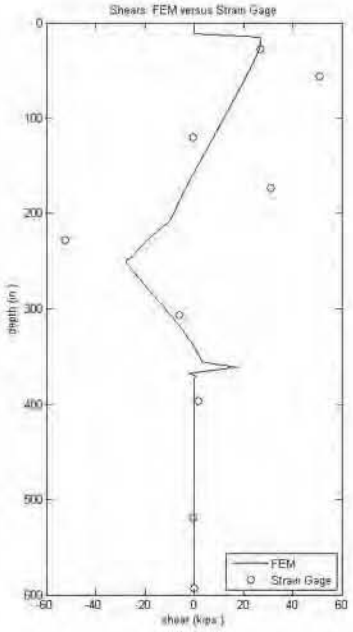




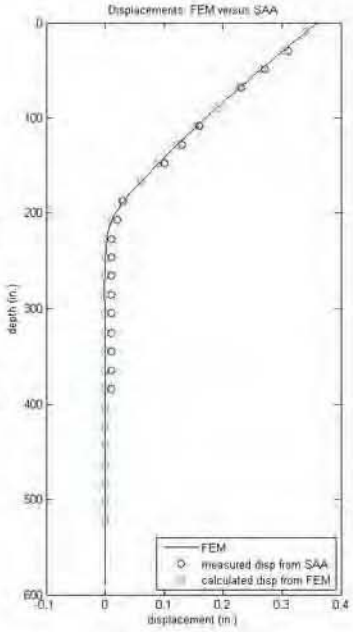
W4 26.8 kips

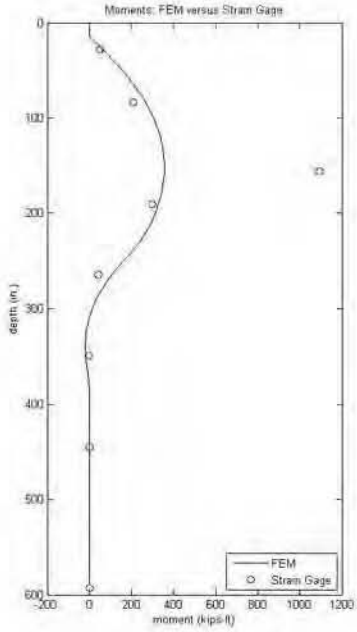


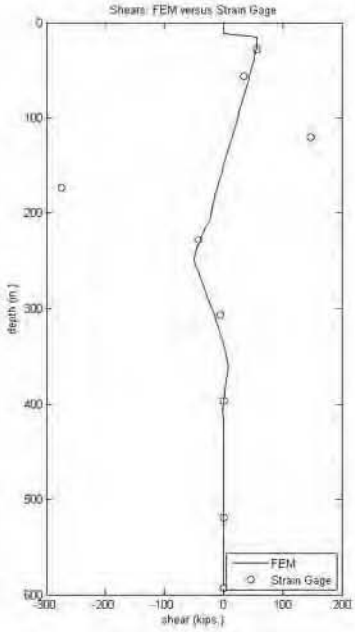




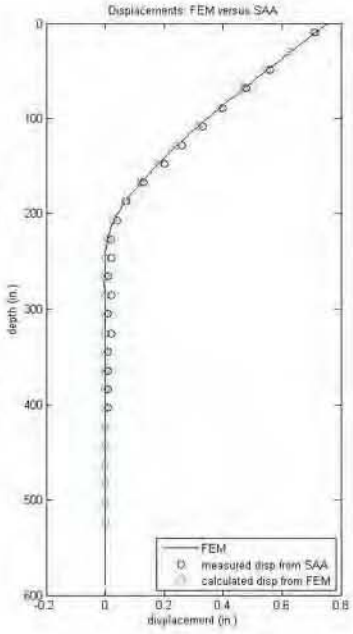
W4 56.1 kips

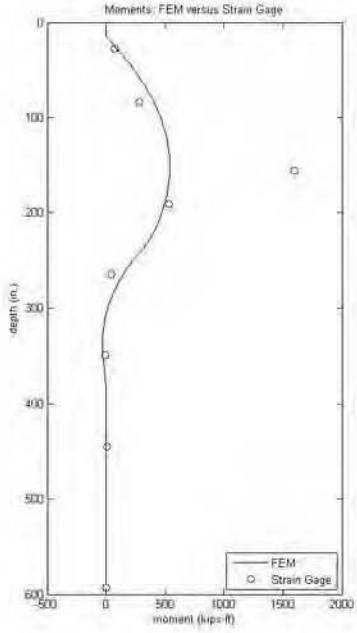


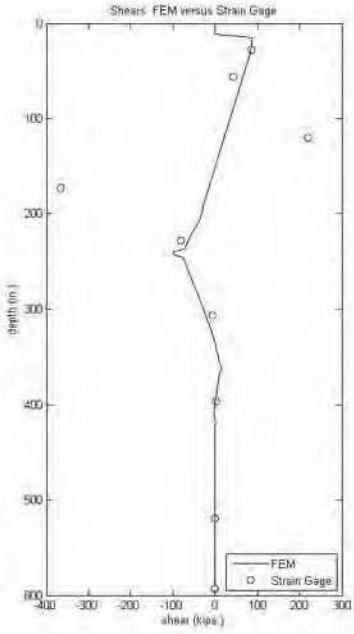




W4 85.3 kips







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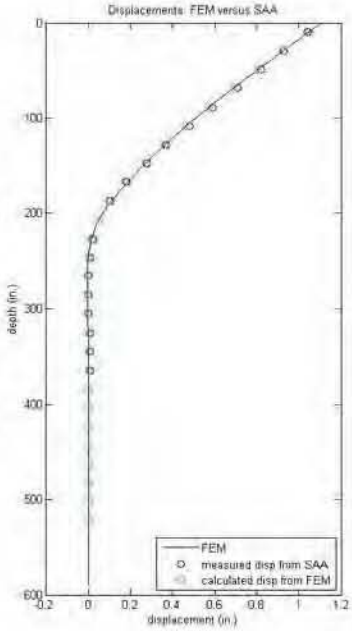

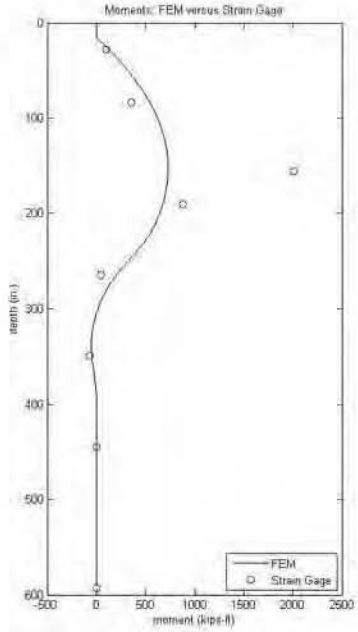

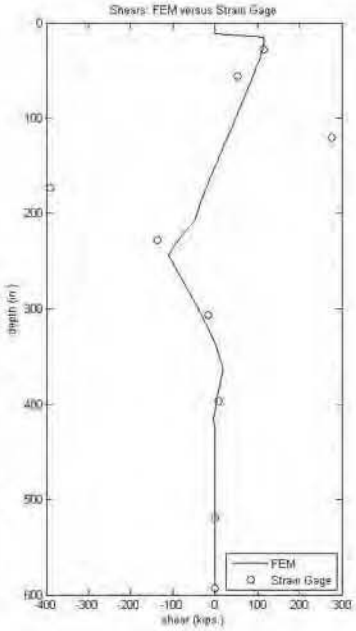

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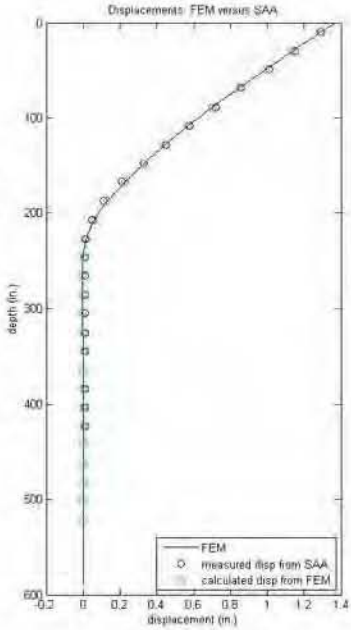

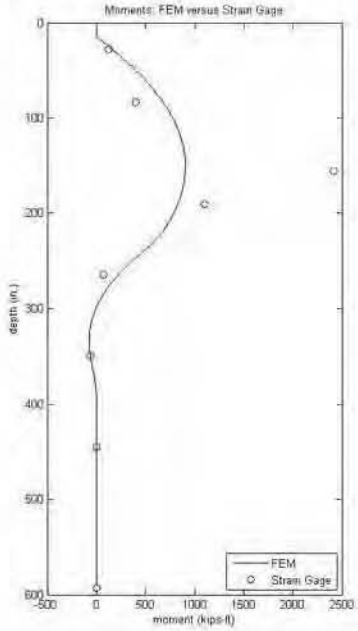

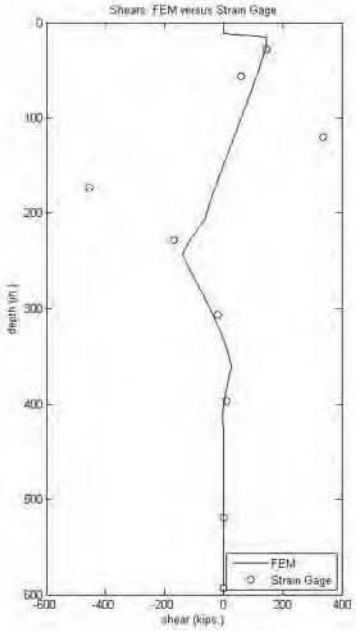

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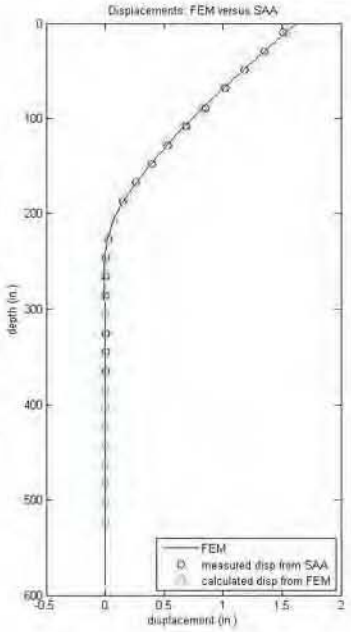
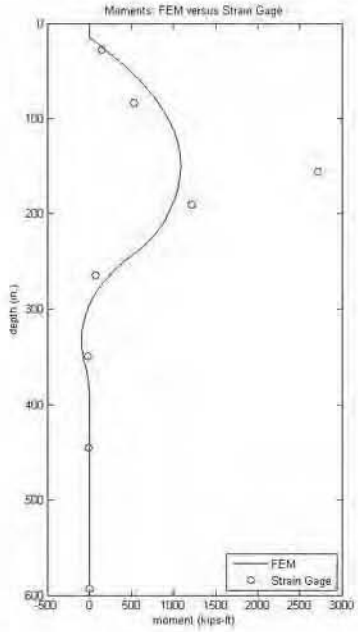
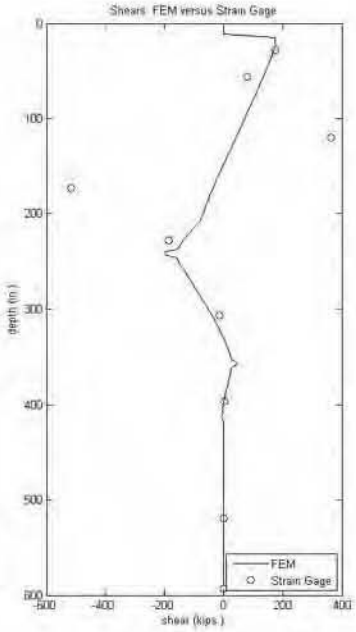
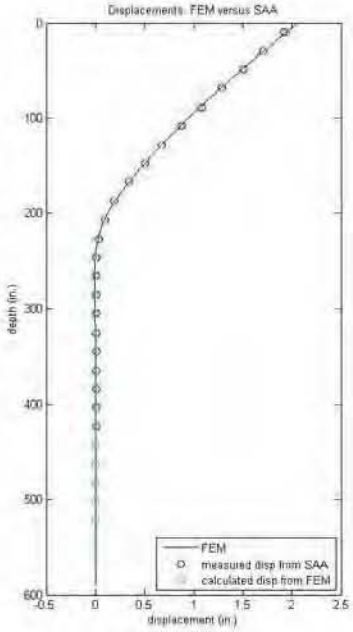
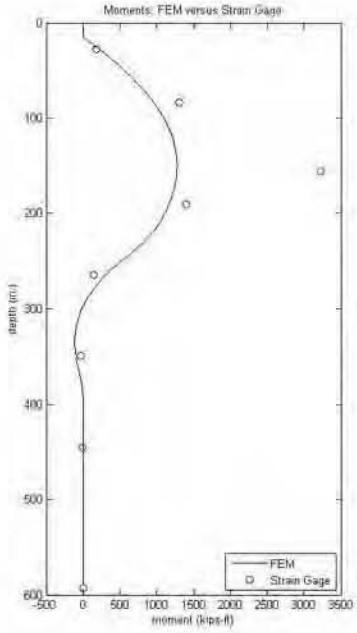


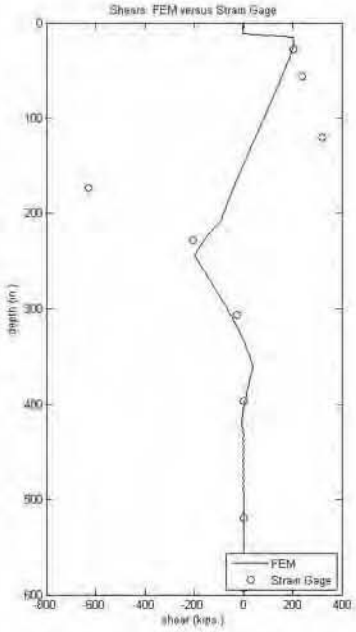




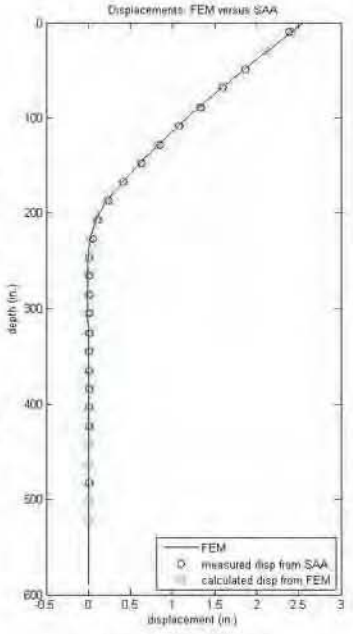
W4 202.3 kips

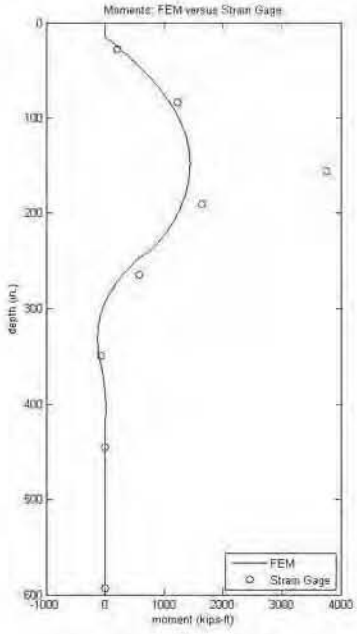


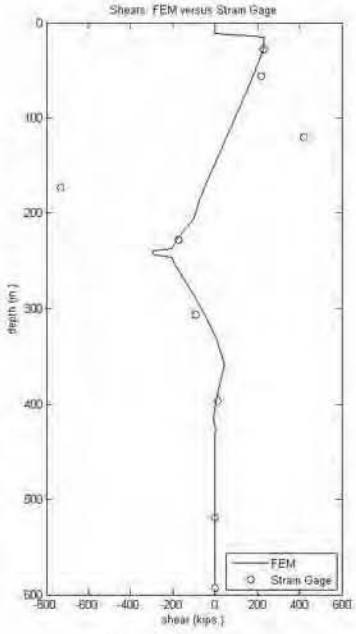




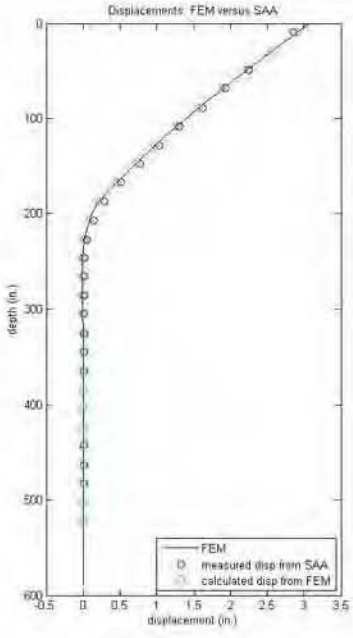
W4 231.5 kips

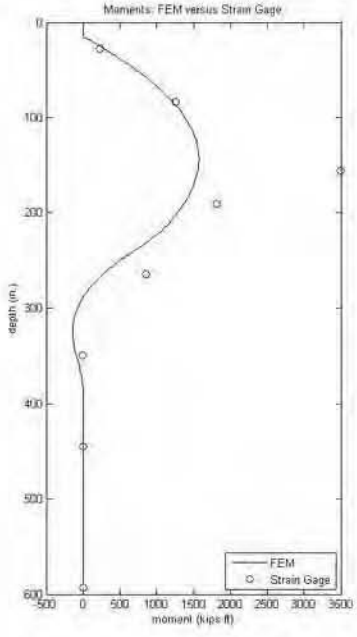


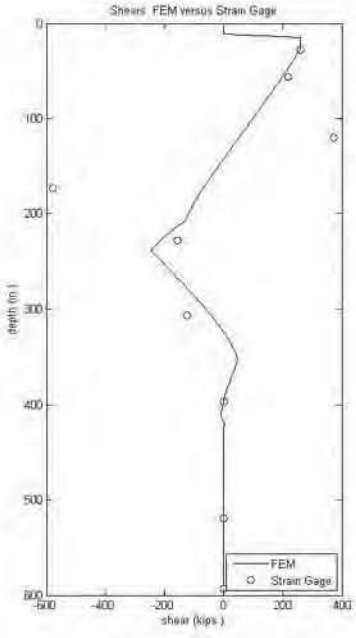




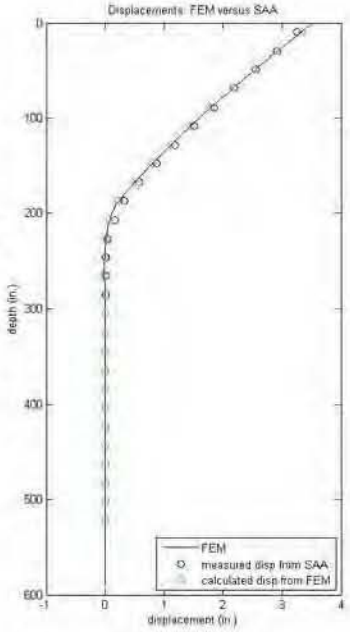
W4 260.7 kips

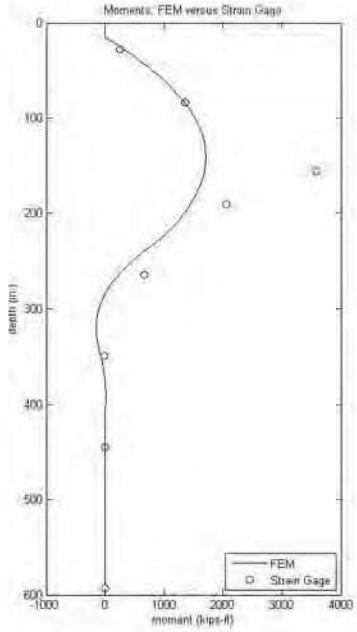


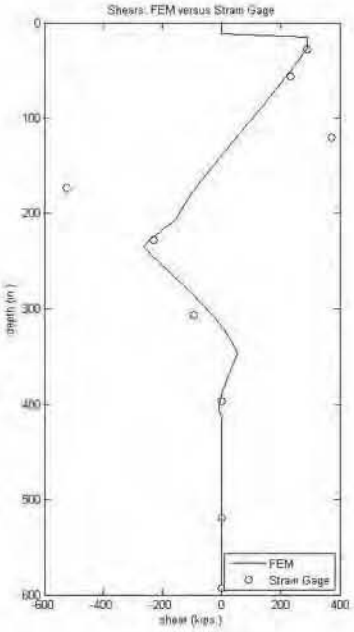




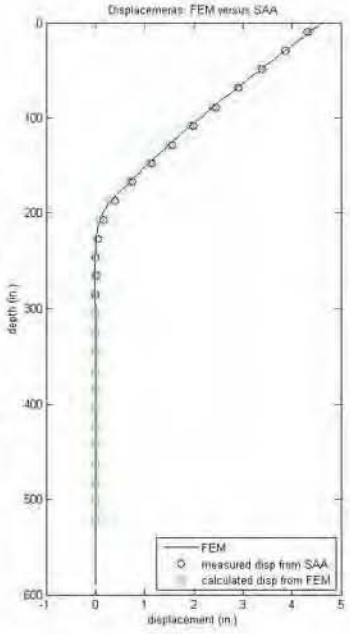
W4 290.0 kips

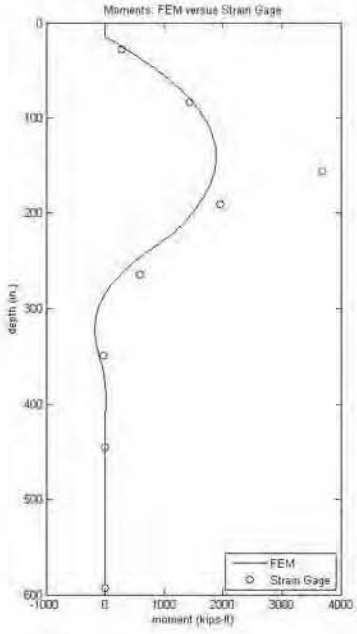


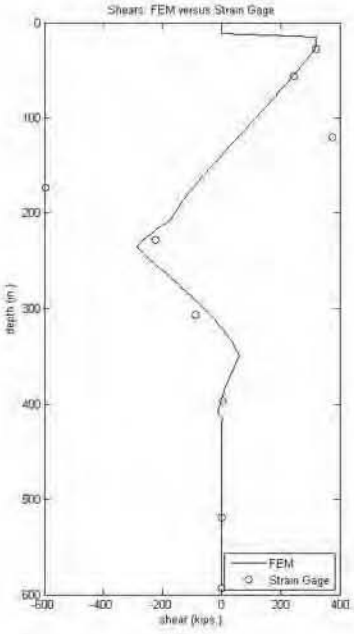




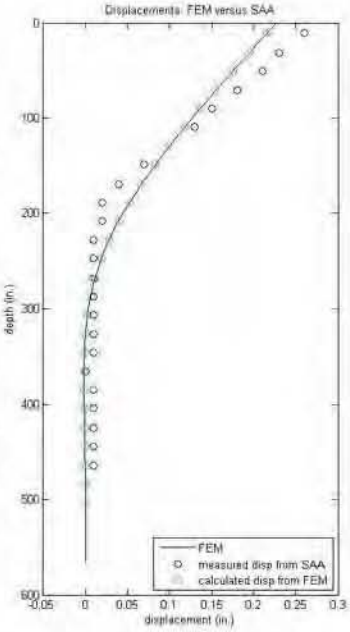
W4 319.2 kips

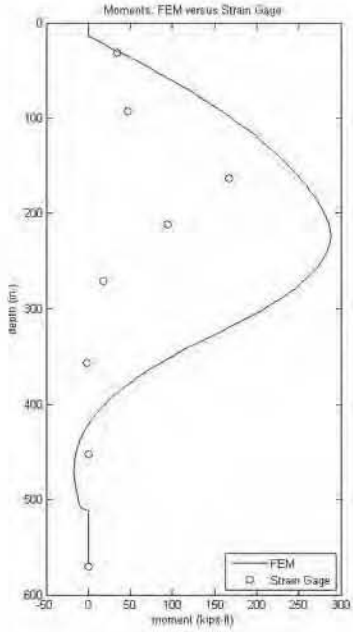


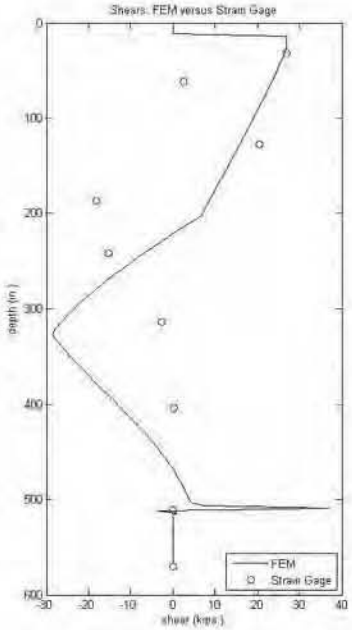




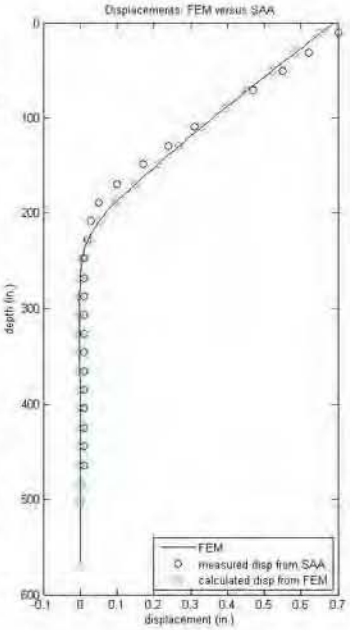
W3 Soil Removed 26.8 kips

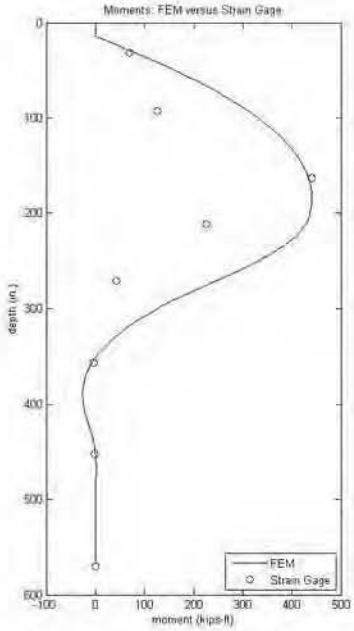


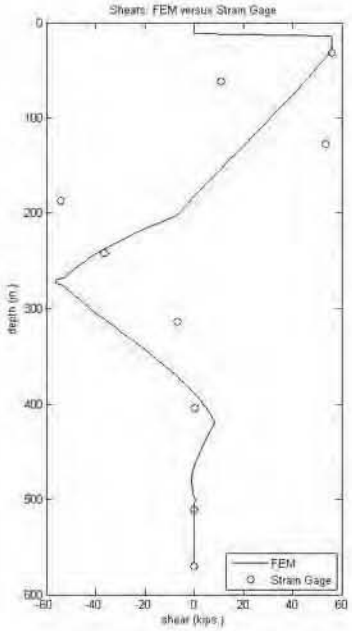




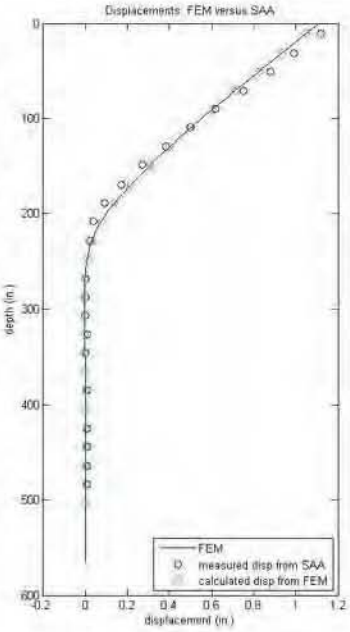
W3 Soil Removed 56.1 kips

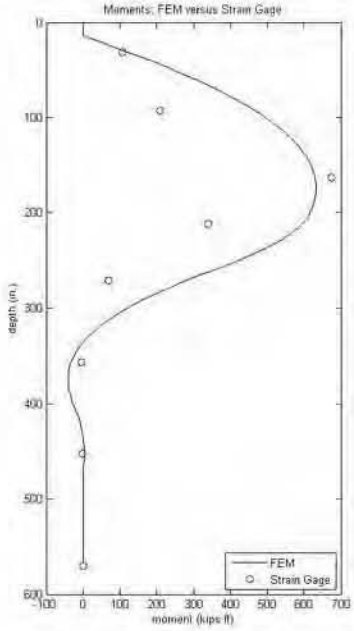


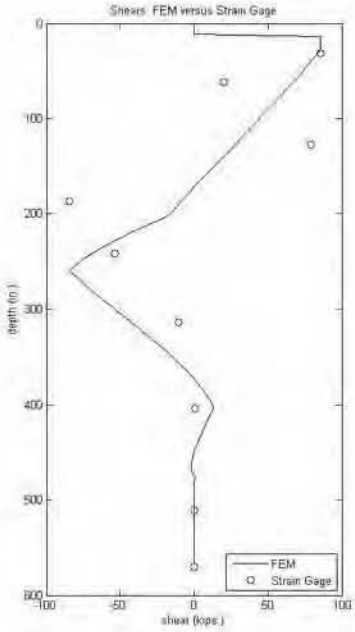




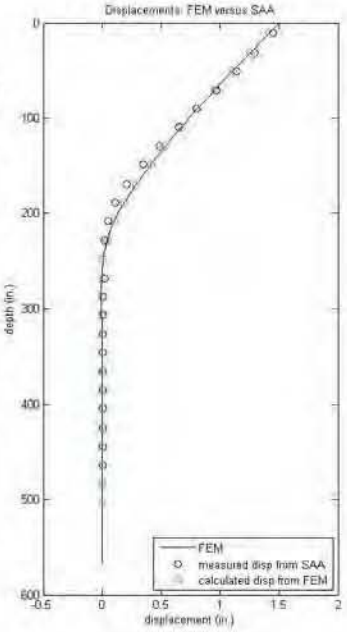
W3 Soil Removed 85.3 kips

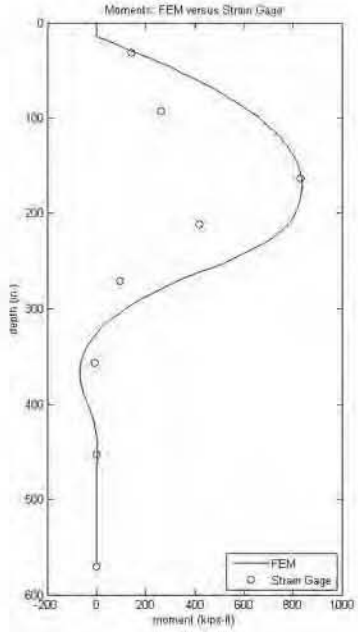


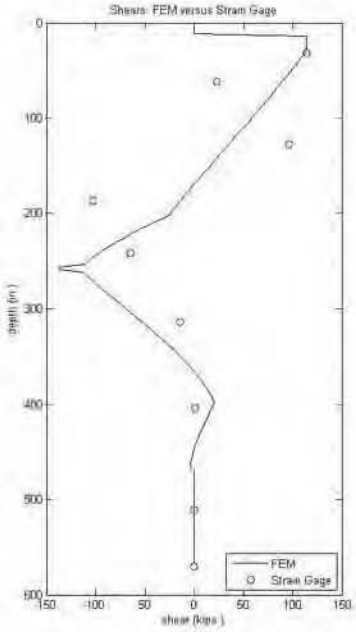




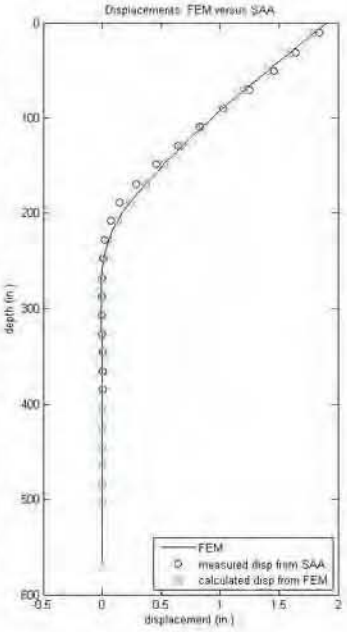
W3 Soil Removed 114.5 kips

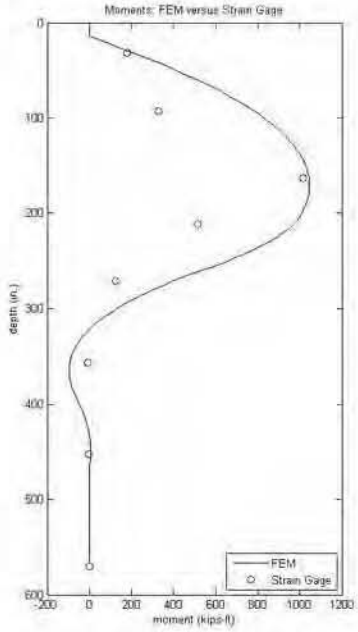


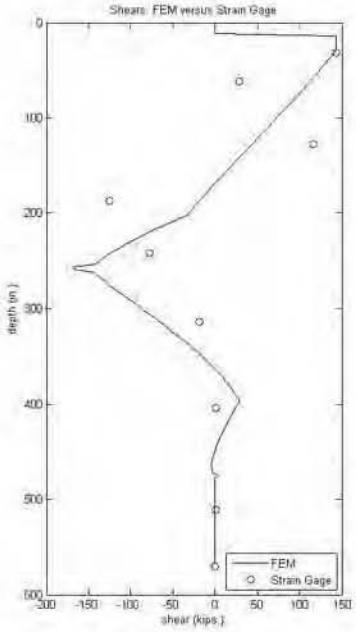




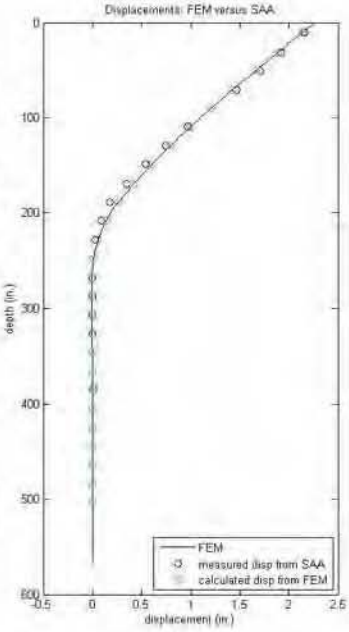
W3 Soil Removed 143.8 kips

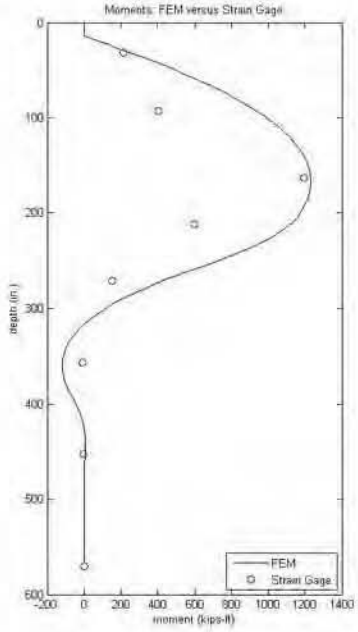


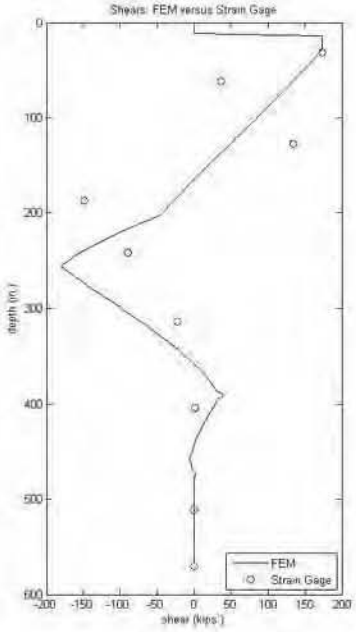




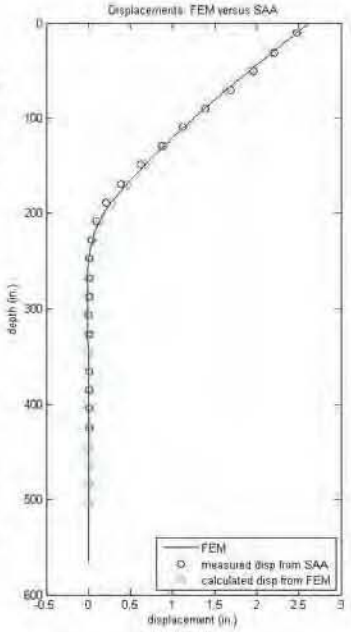
W3 Soil Removed 173.0 kips

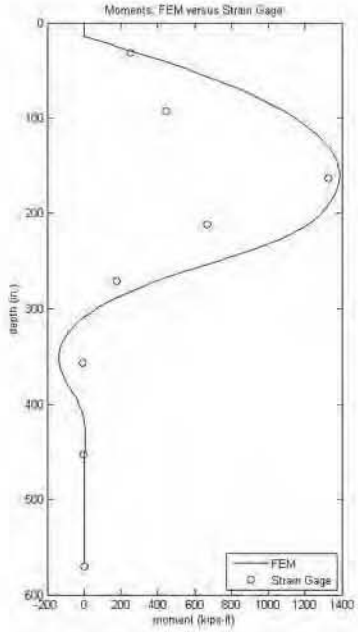


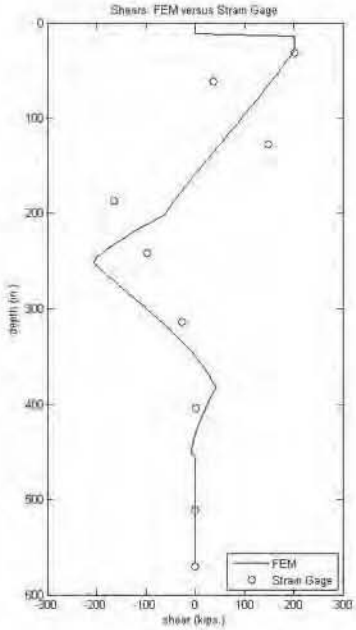




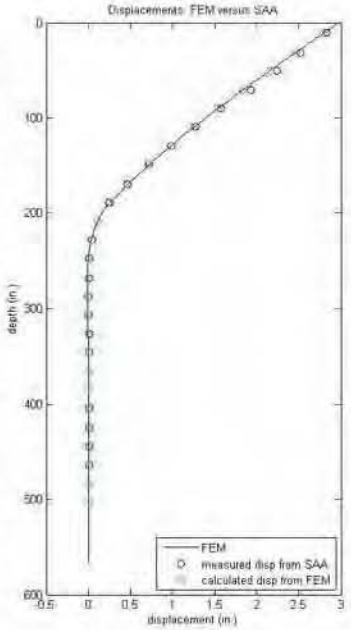
W3 Soil Removed 202.3 kips

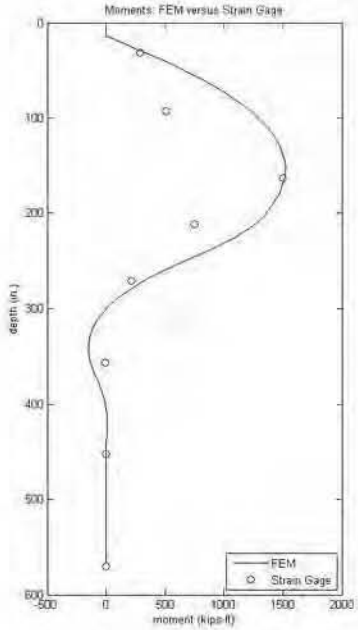


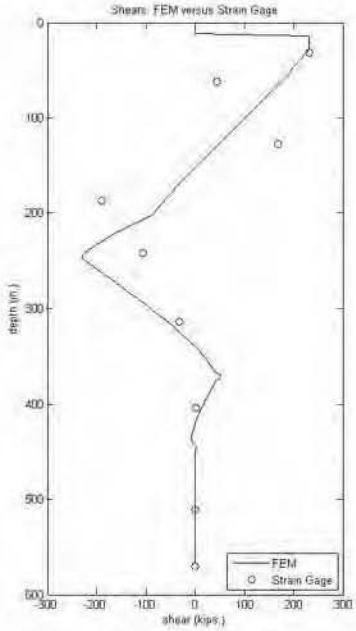




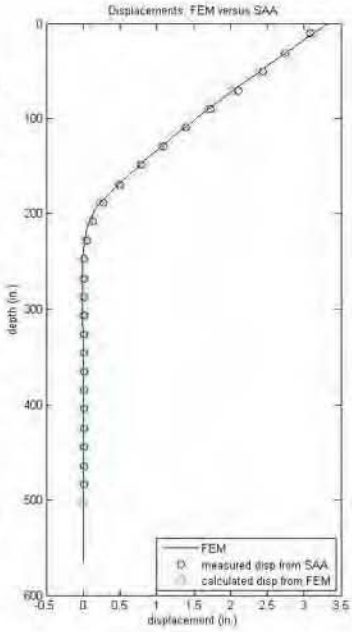
W3 Soil Removed 231.5 kips

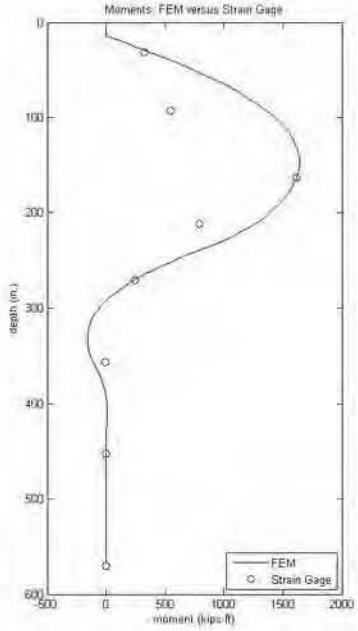


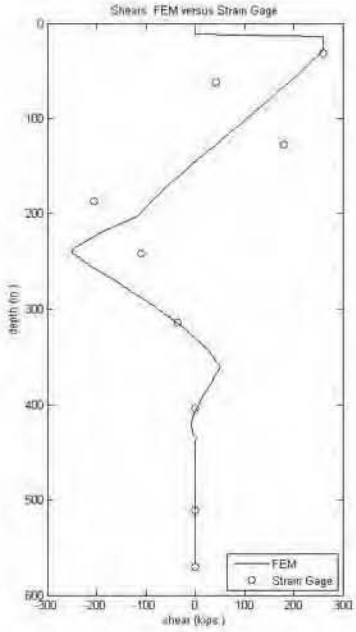




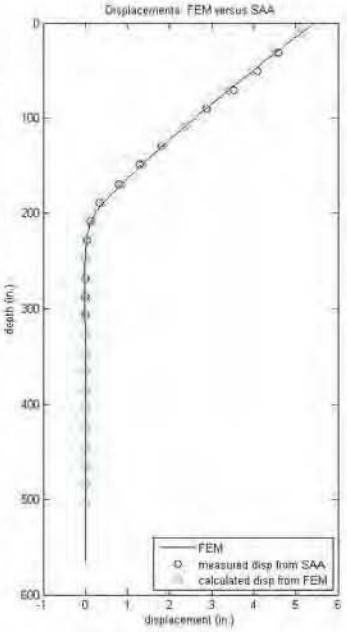
W3 Soil Removed 260.7 kips

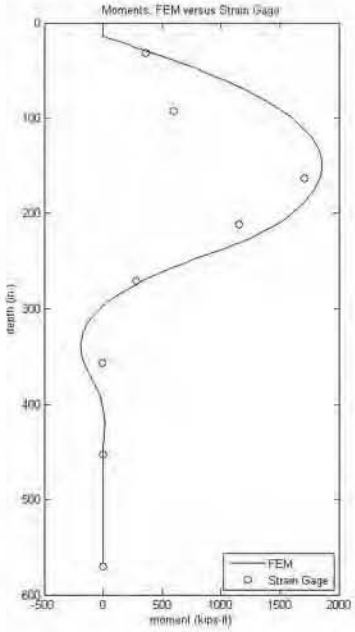


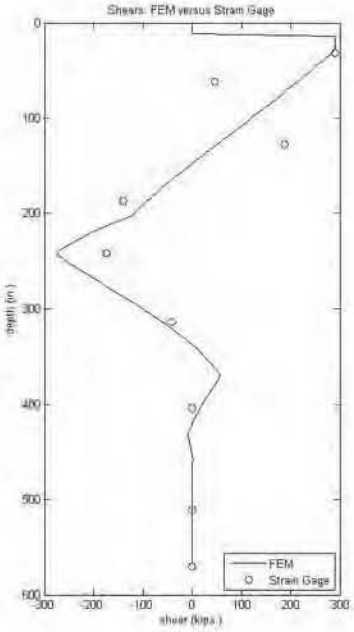




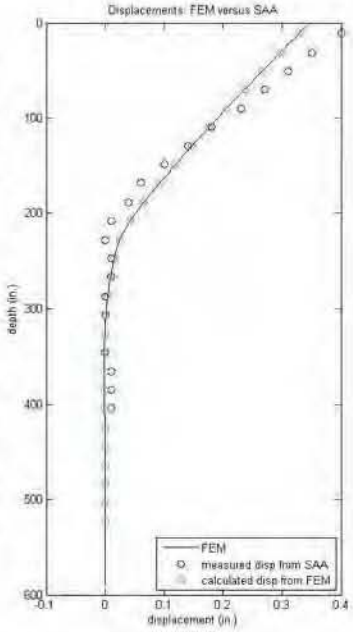
W3 Soil Removed 290.0 kips

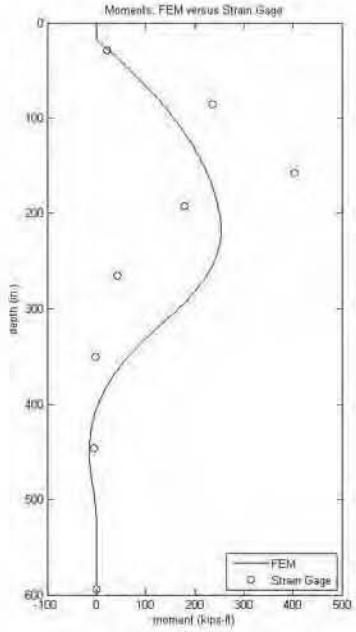


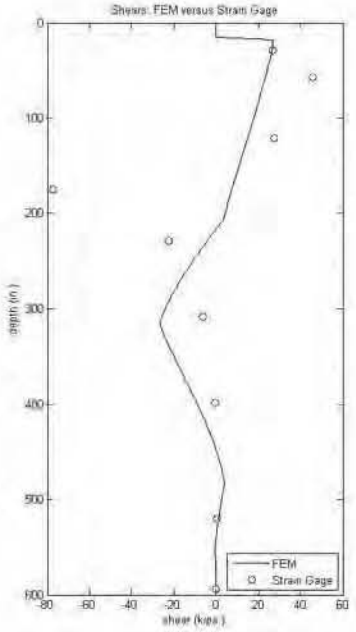




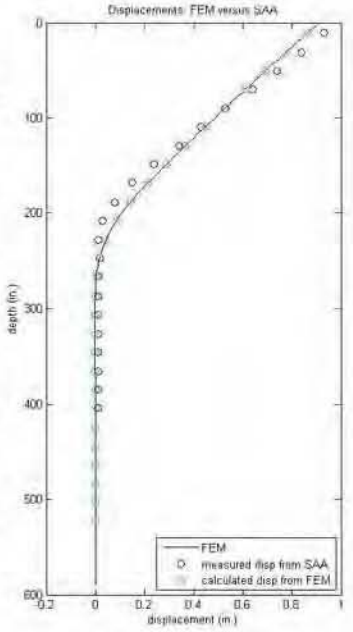
W4 Soil Removed 26.8 kips

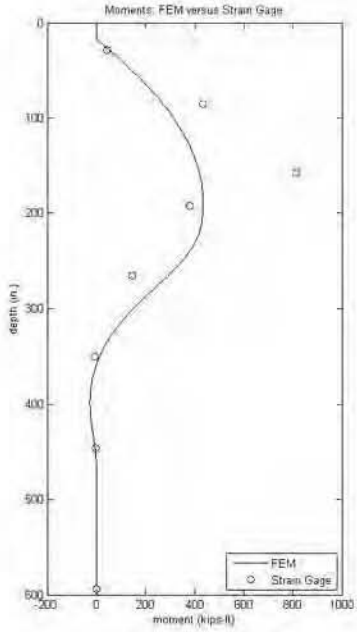


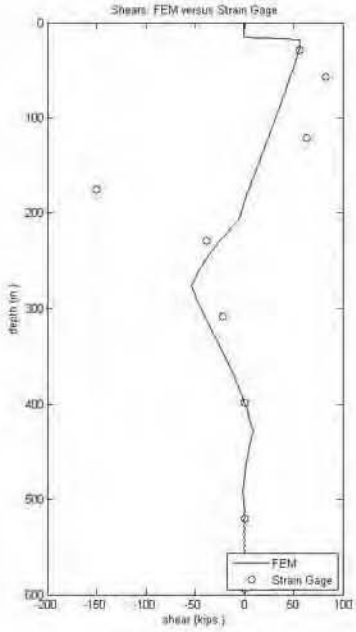




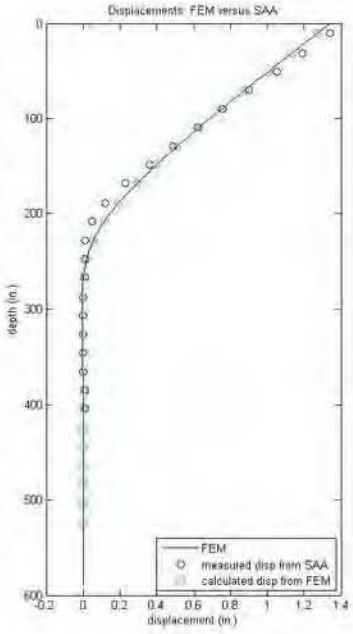
W4 Soil Removed 56.1 kips

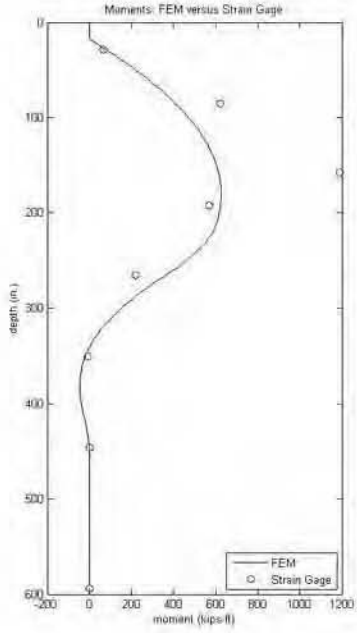


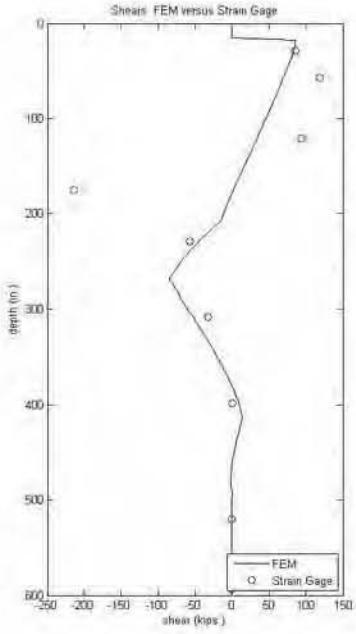




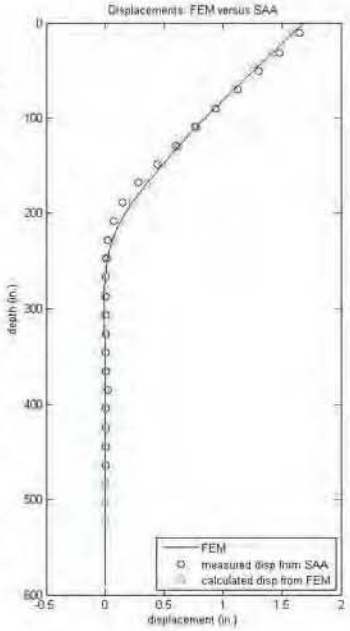
W4 Soil Removed 85.3 kips

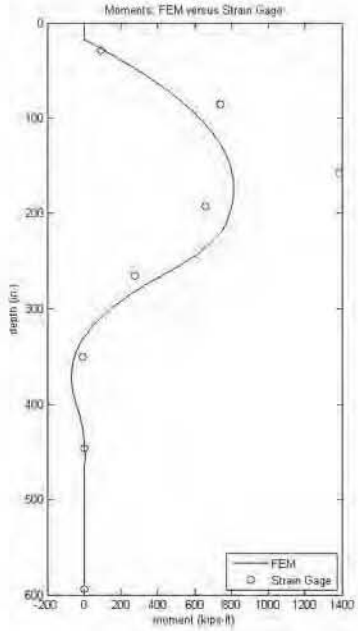


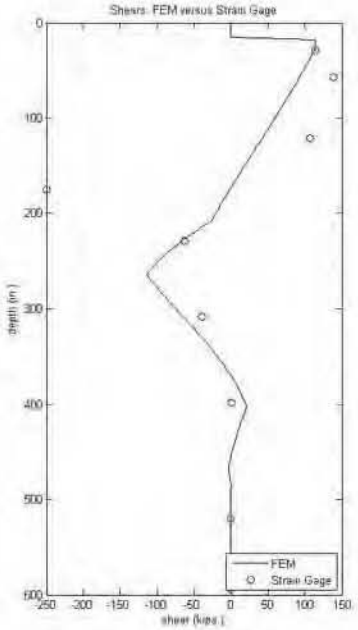




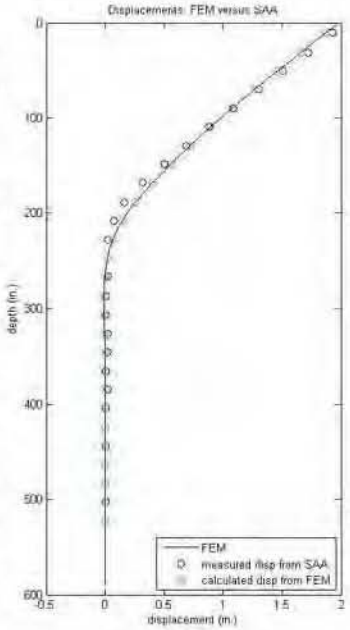
W4 Soil Removed 114.5 kips

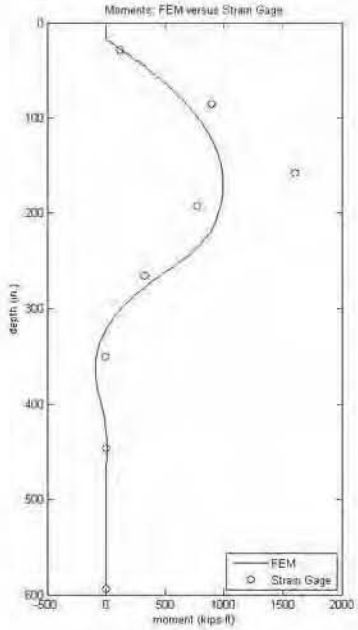


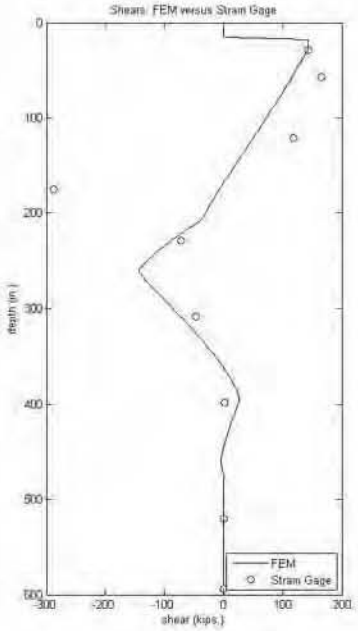




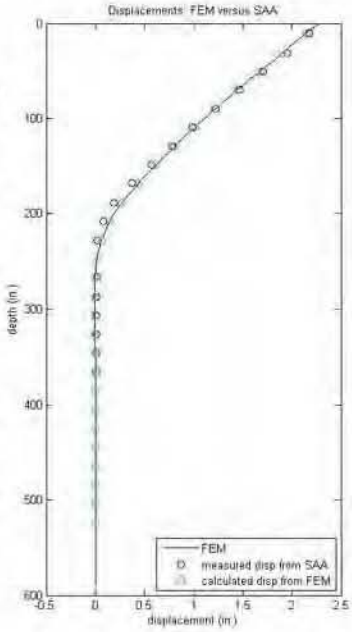
W4 Soil Removed 143.8 kips

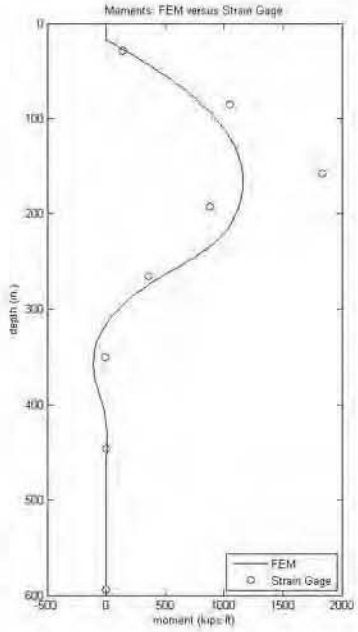


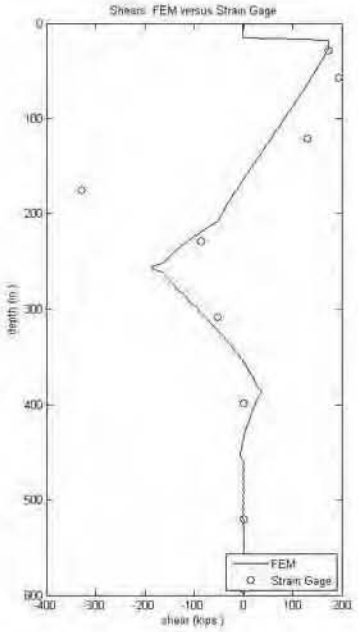




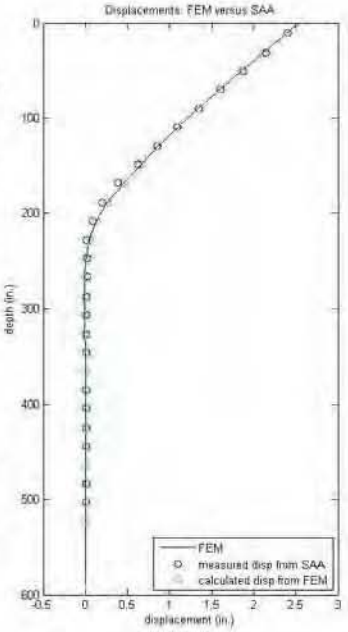
W4 Soil Removed 173.0 kips

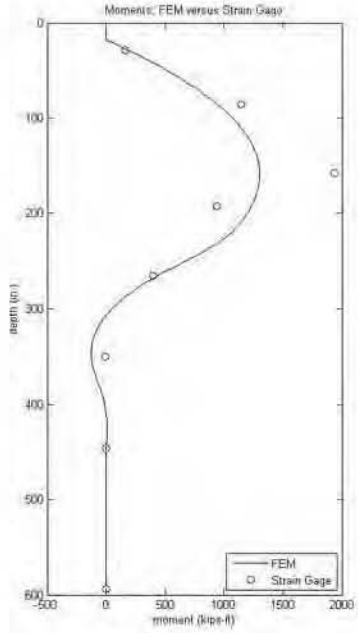


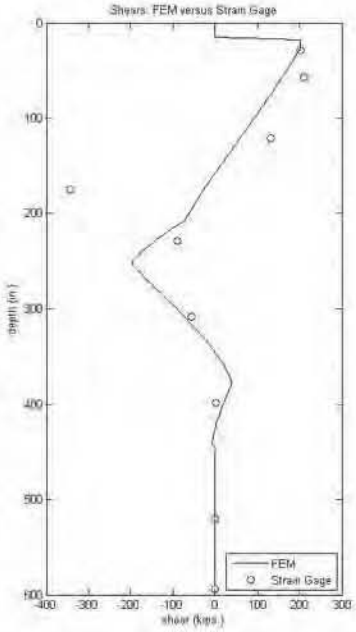




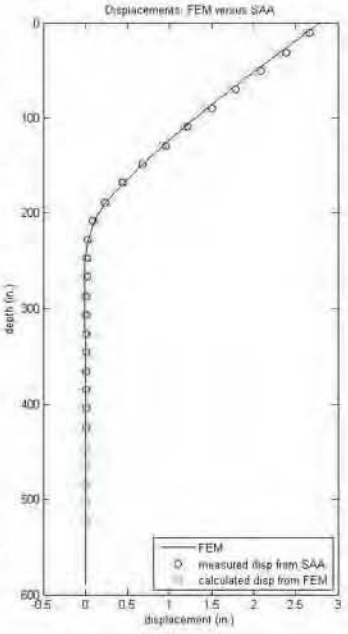
W4 Soil Removed 202.3 kips

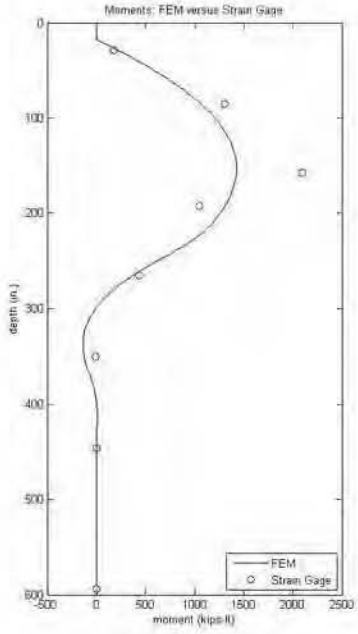


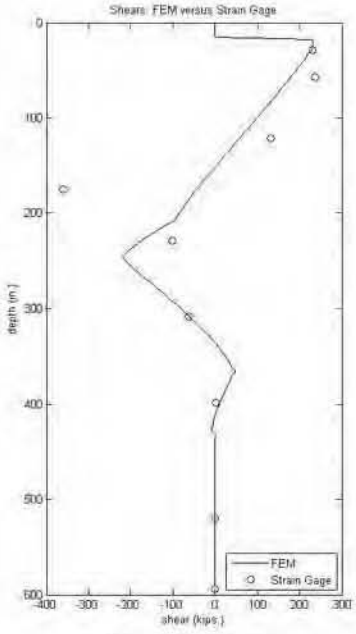




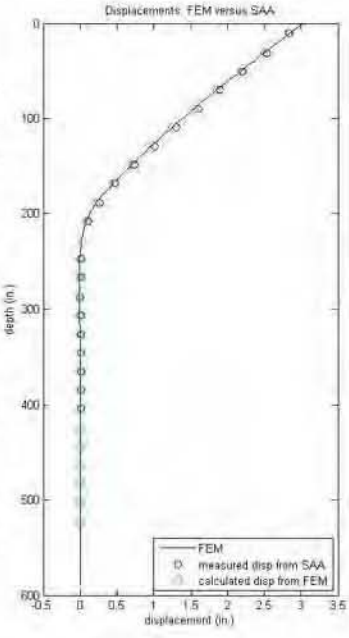
W4 Soil Removed 231.5 kips

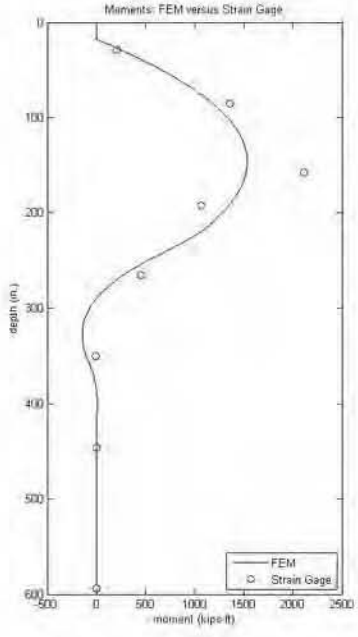


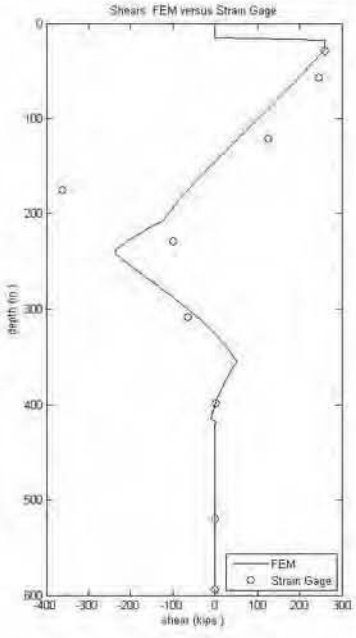




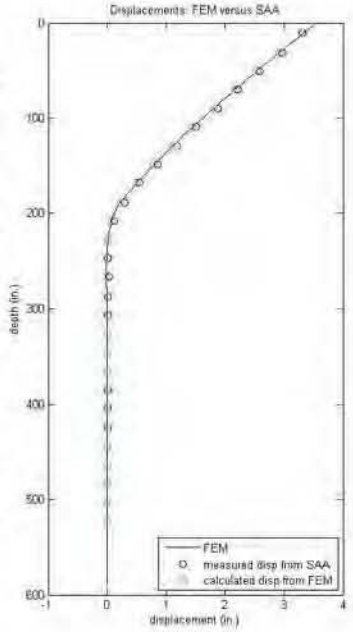
W4 Soil Removed 260.7 kips

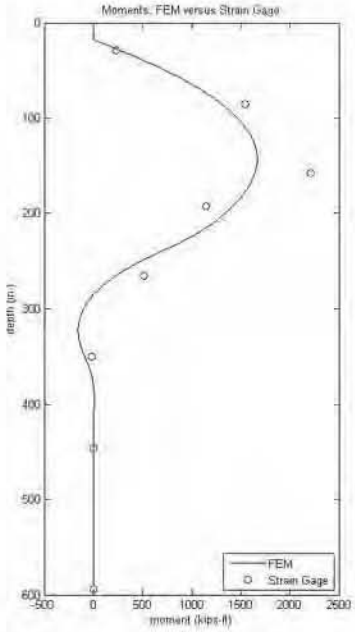


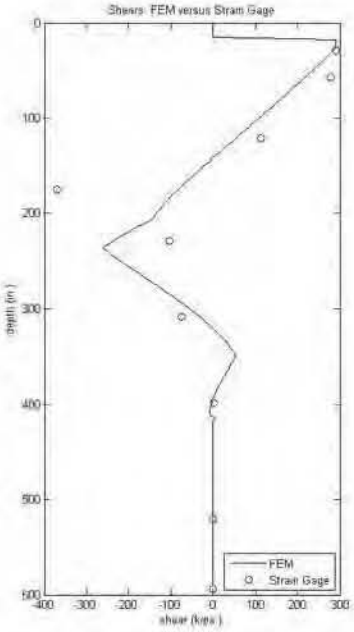




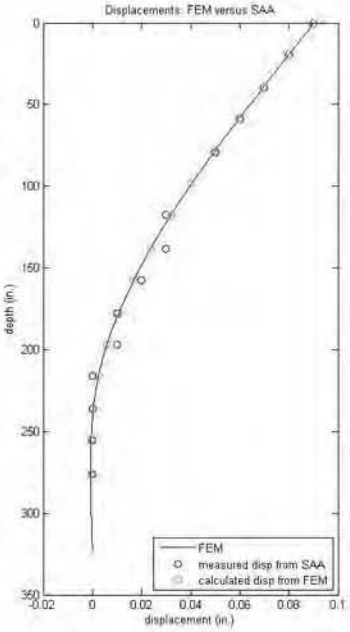
W4 Soil Removed 290.0 kips

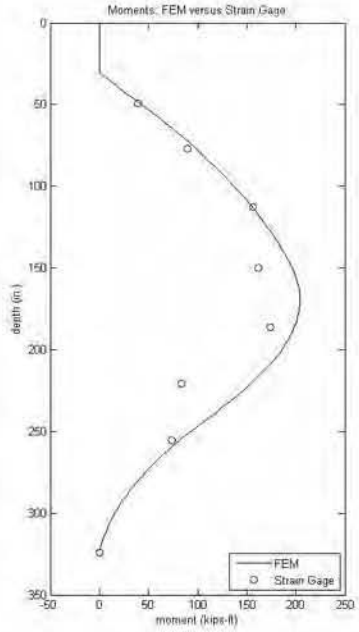


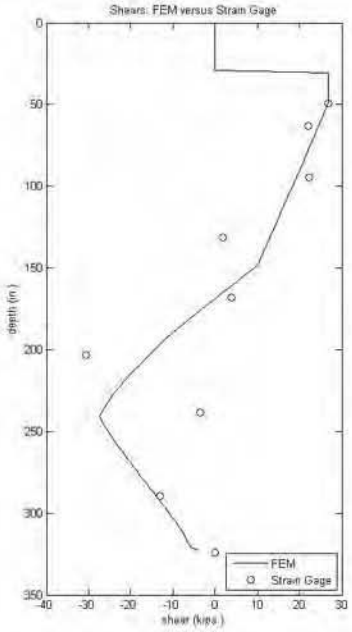




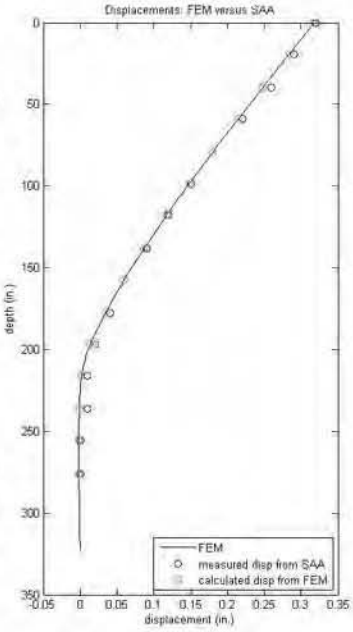
W5 Soil Removed 26.8 kips

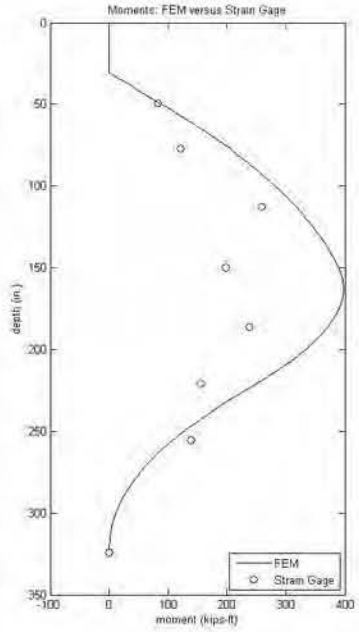


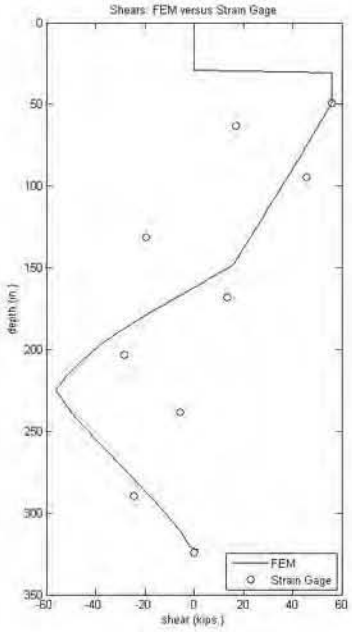




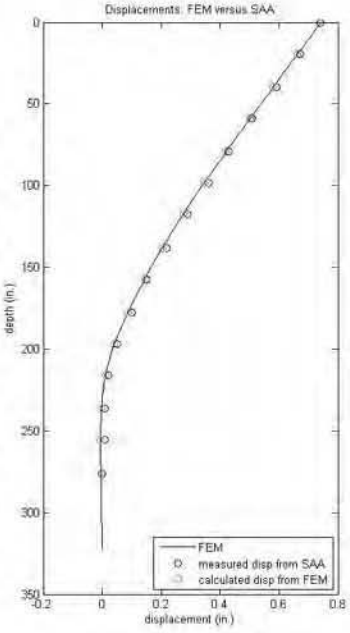
W5 Soil Removed 56.1 kips

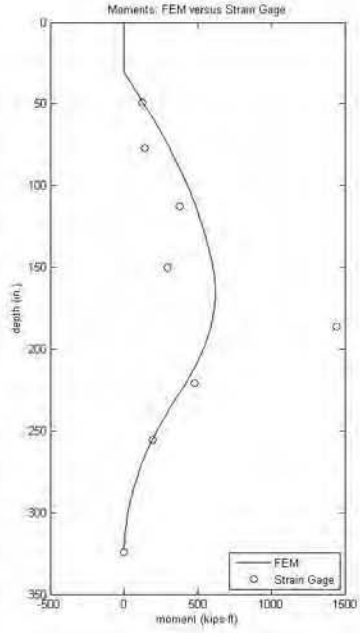


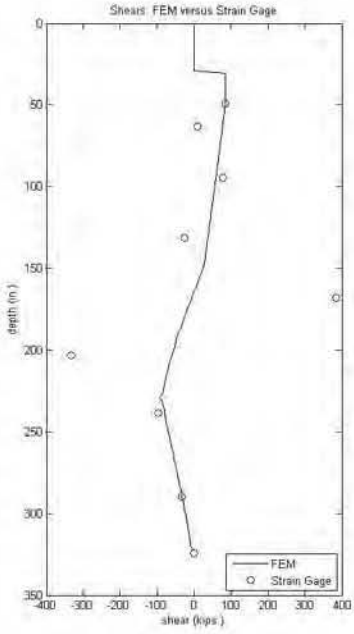




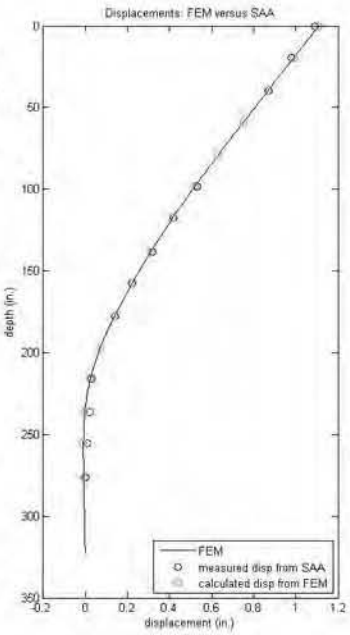
W5 Soil Removed 85.3 kips

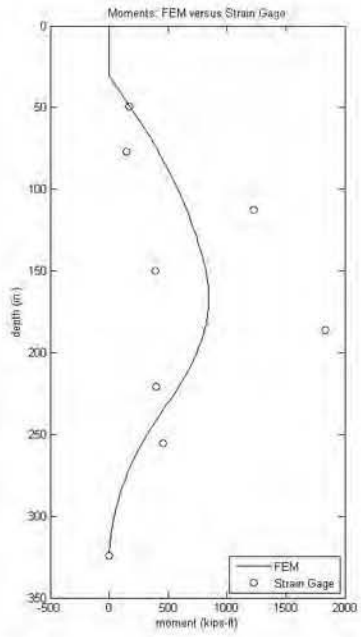


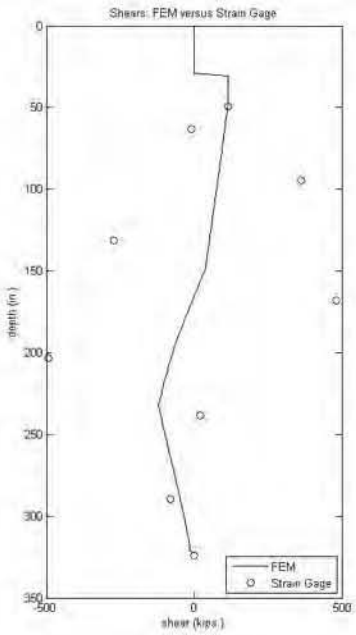




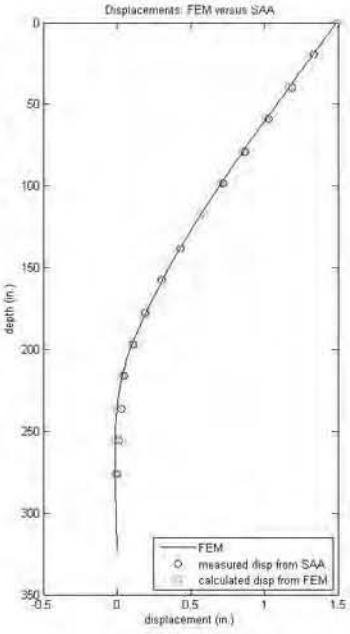
W5 Soil Removed 114.5 kips

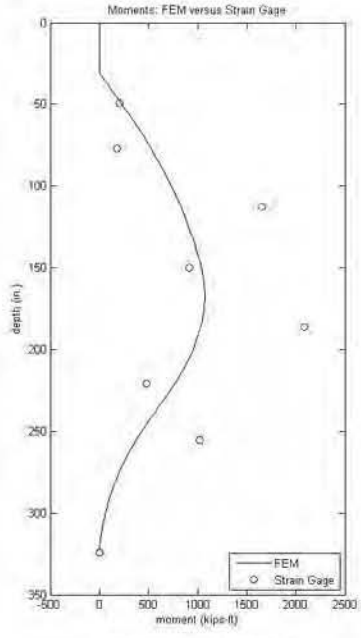


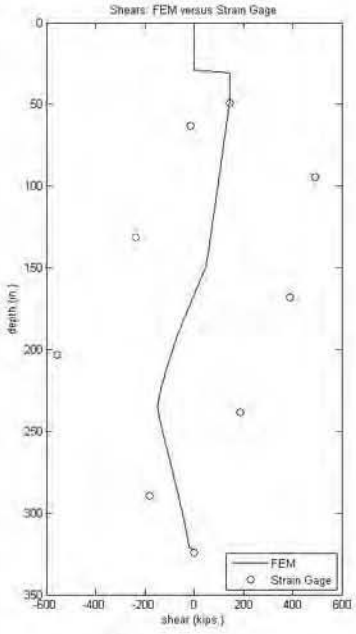




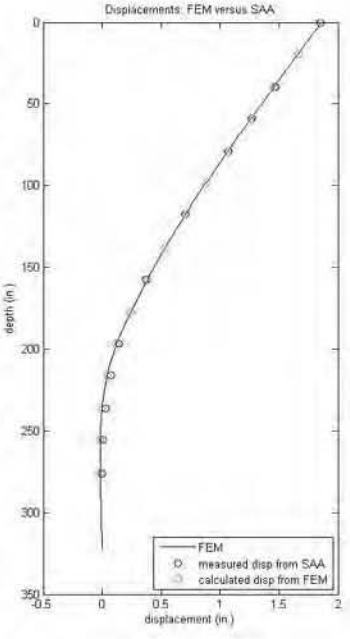
W5 Soil Removed 143.8 kips

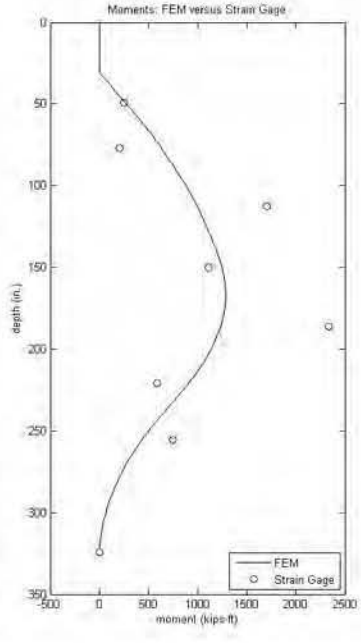


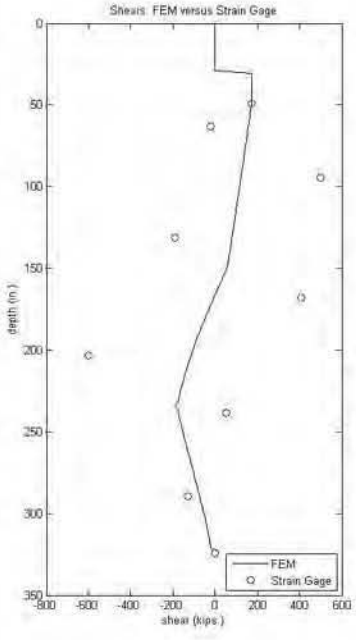




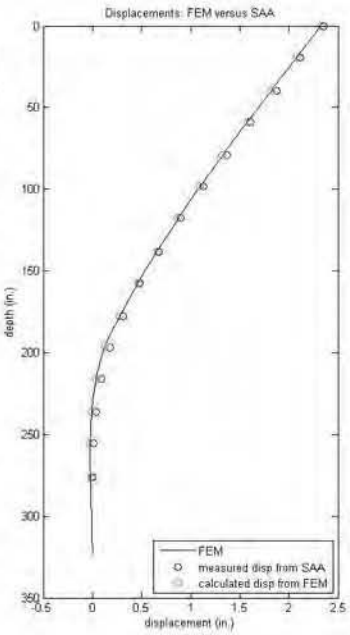
W5 Soil Removed 173.0 kips

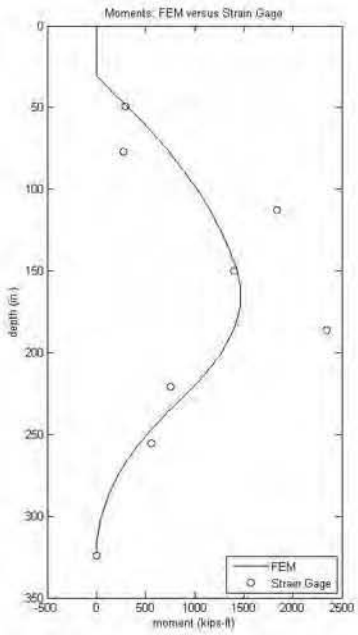


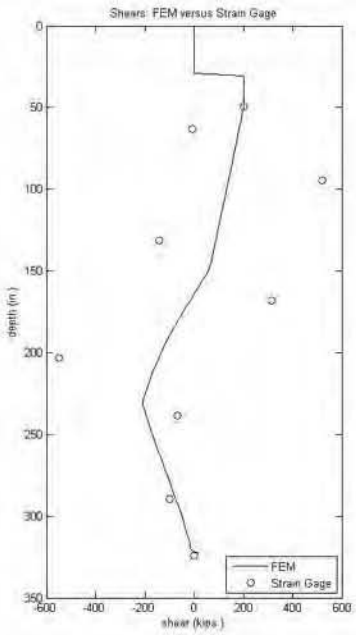




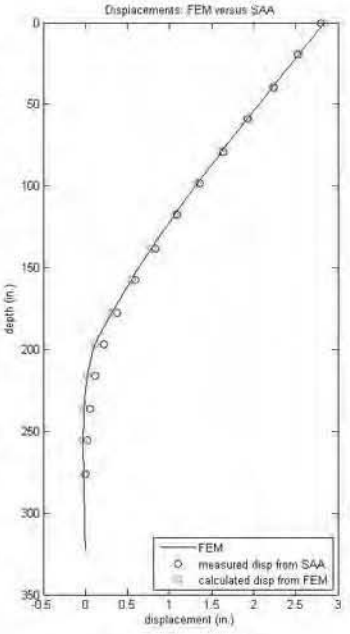
W5 Soil Removed 202.3 kips

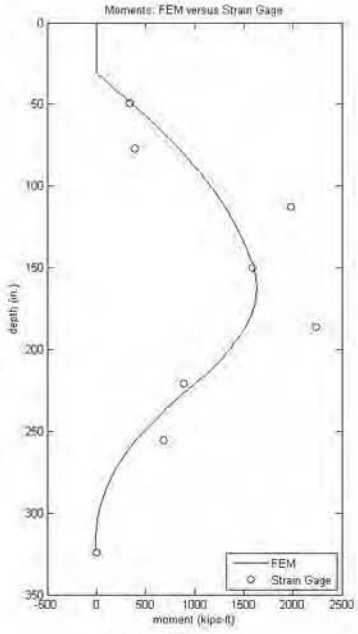


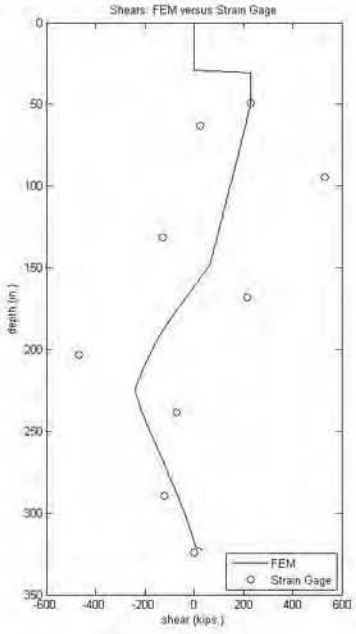




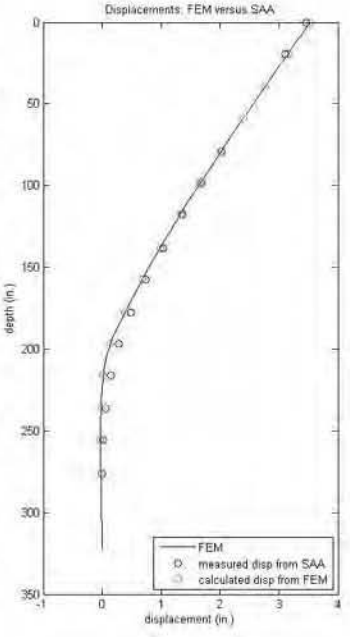
W5 Soil Removed 231.5 kips

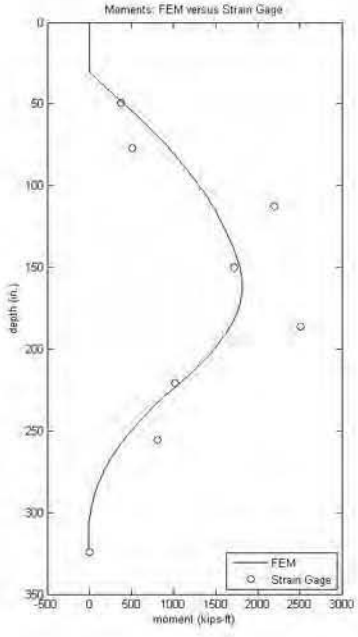


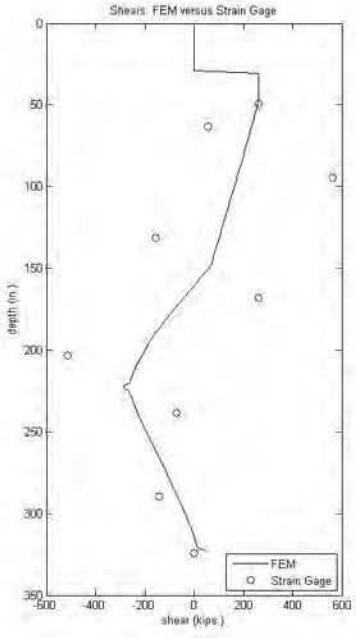




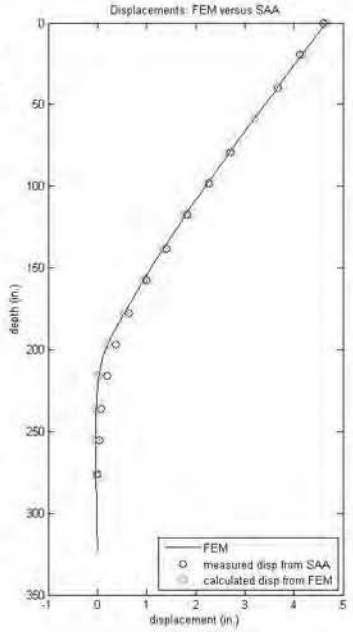
W5 Soil Removed 260.7 kips

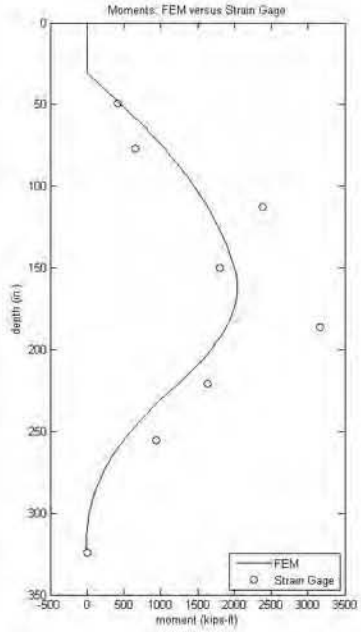


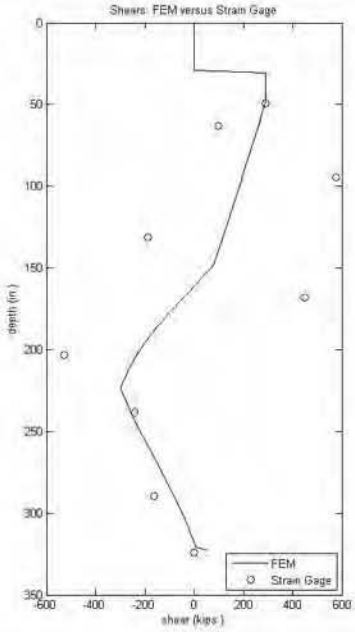




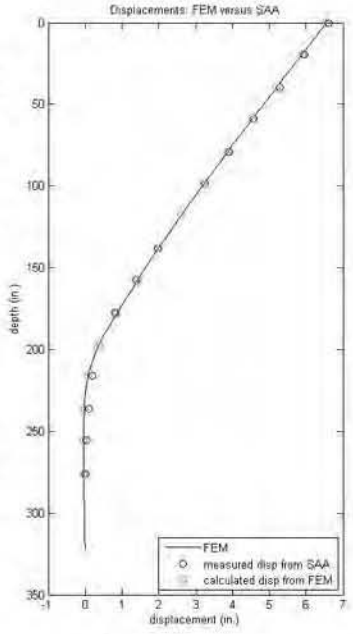
W5 Soil Removed 290.0 kips

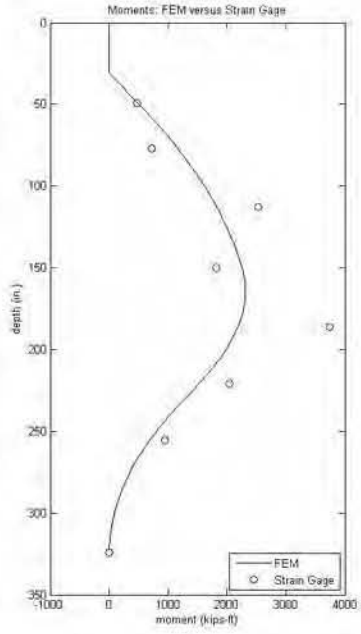


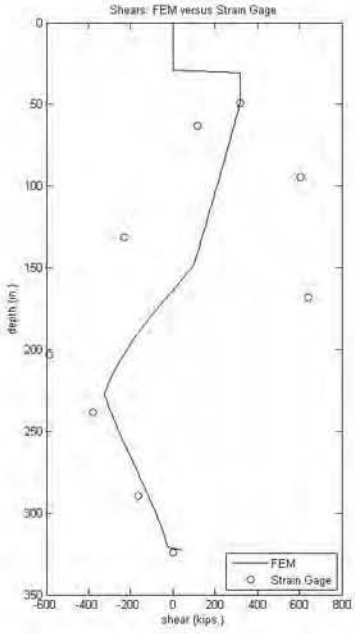




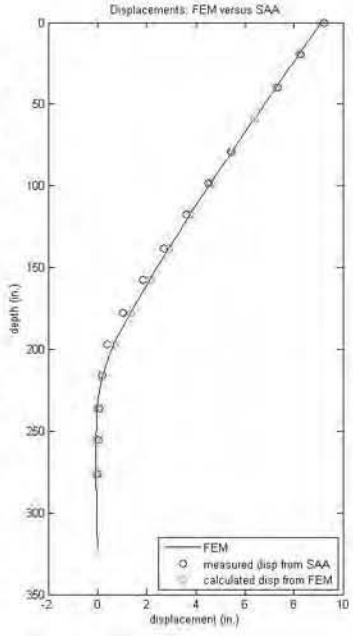
W5 Soil Removed 319.2 kips

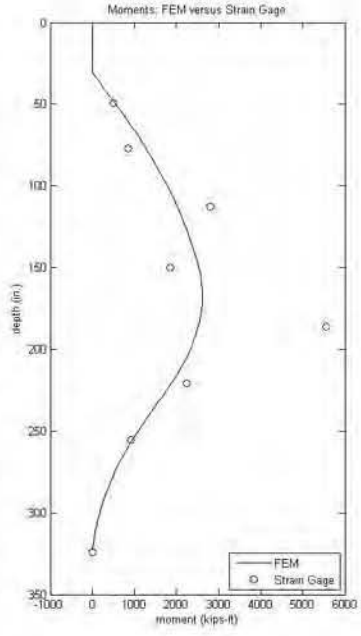


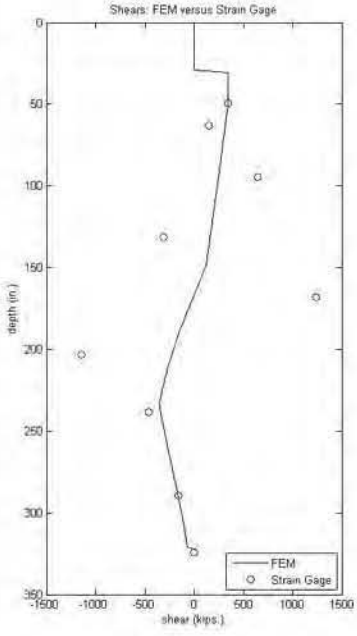




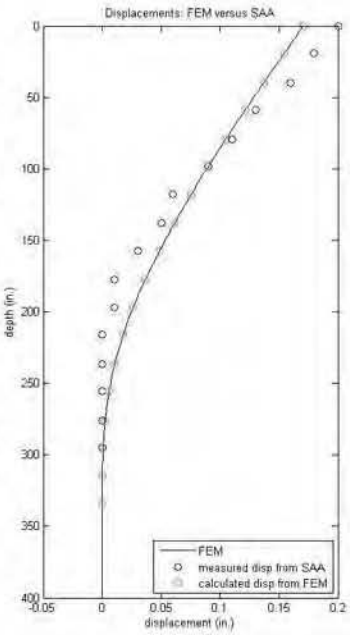
W5 Soil Removed 348.5 kips

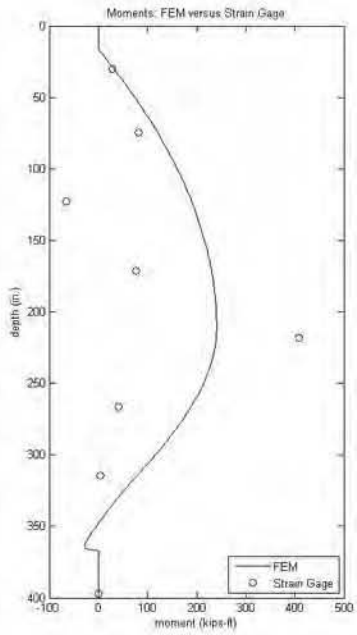


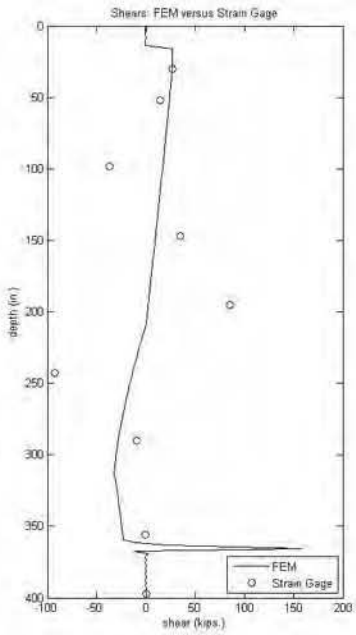




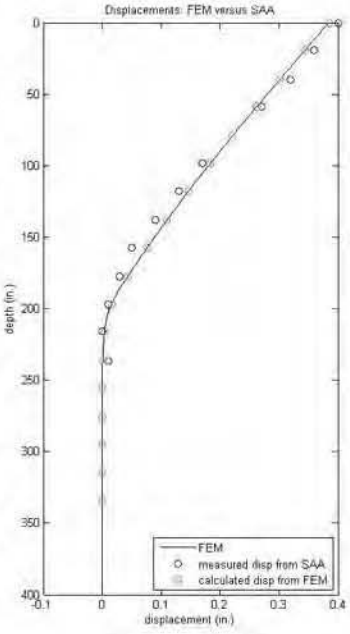
W6 Soil Removed 26.8 kips

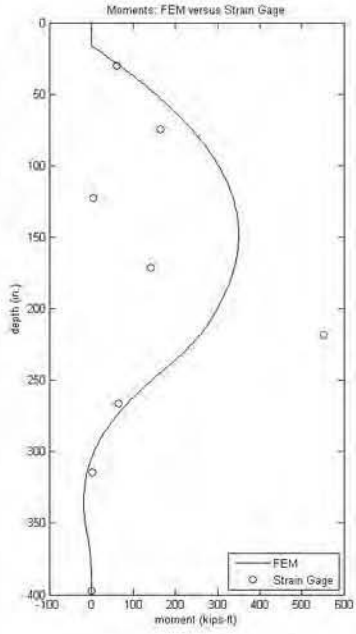


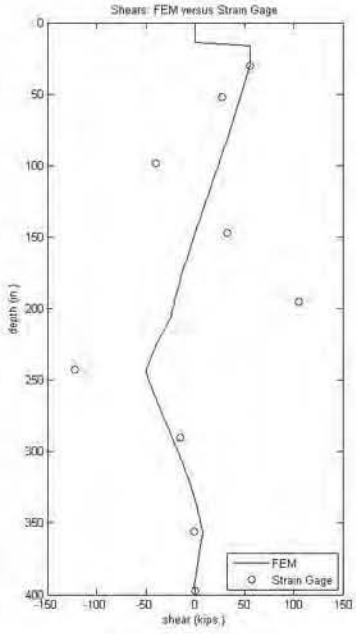




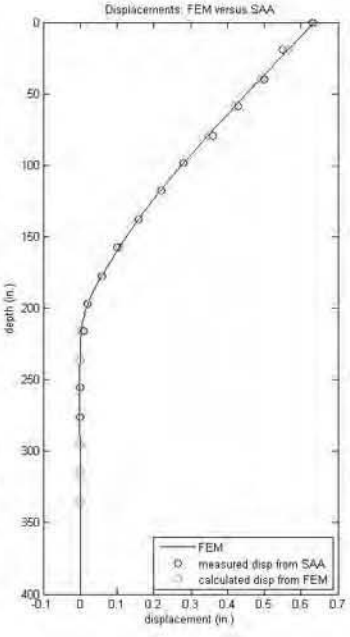
W6 Soil Removed 56.1 kips

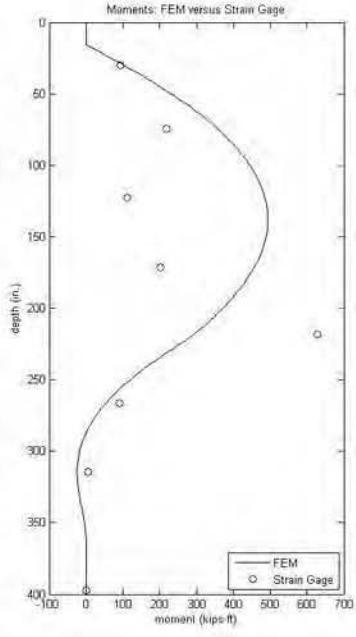


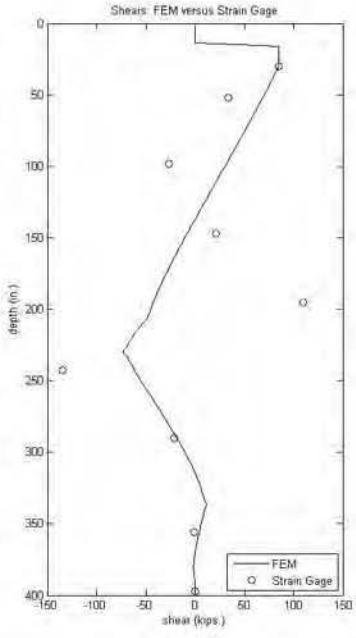




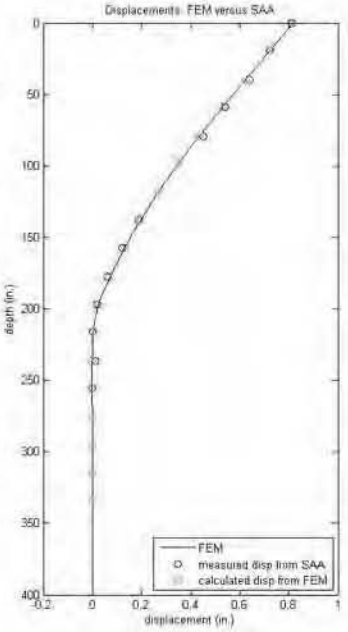
W6 Soil Removed 85.3 kips

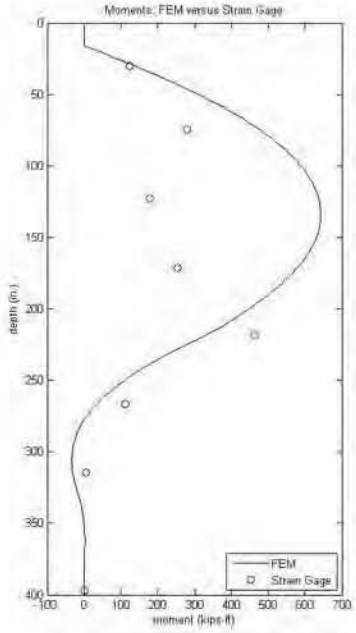


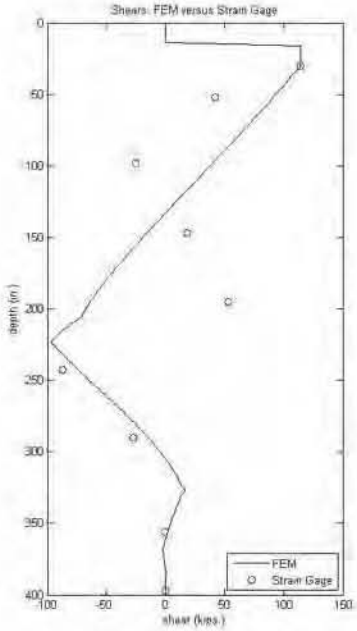




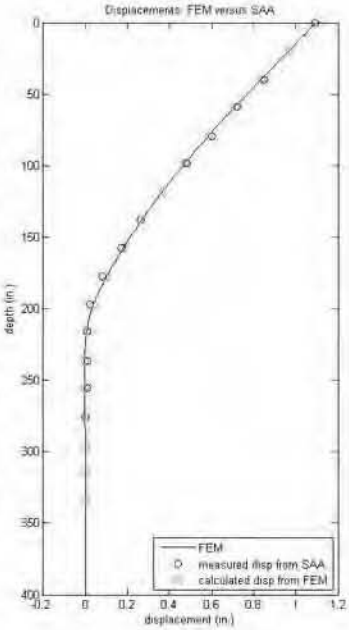
W6 Soil Removed 114.5 kips

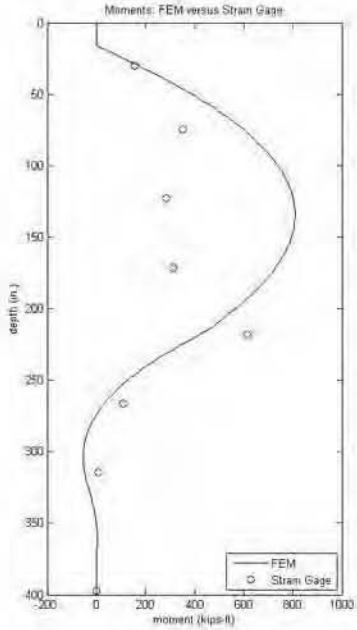


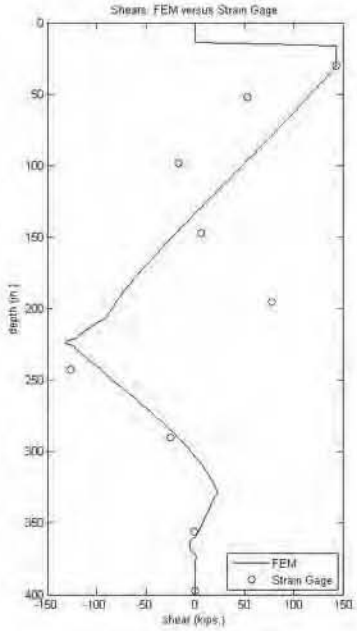




W6 Soil Removed 143.8 kips







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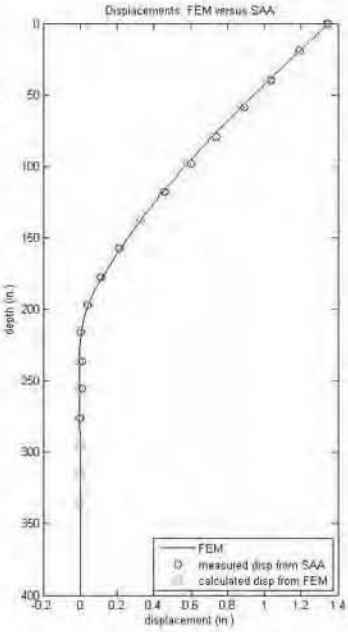
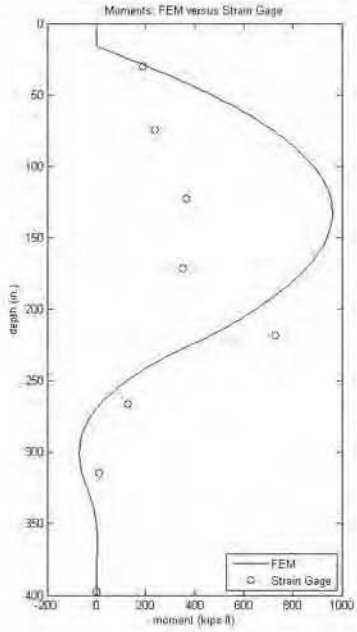
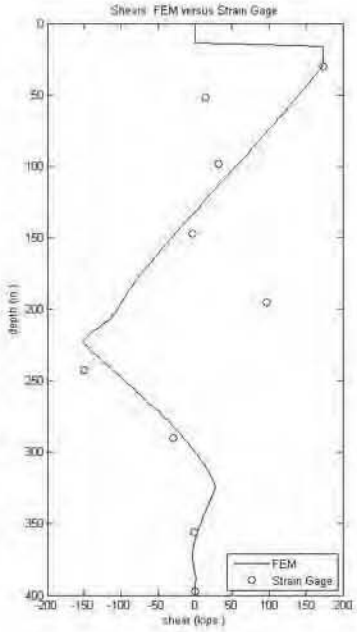
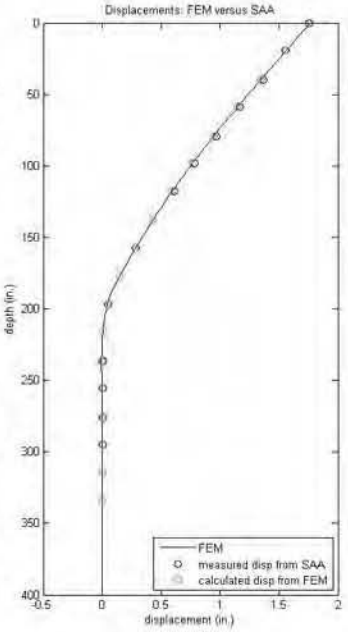
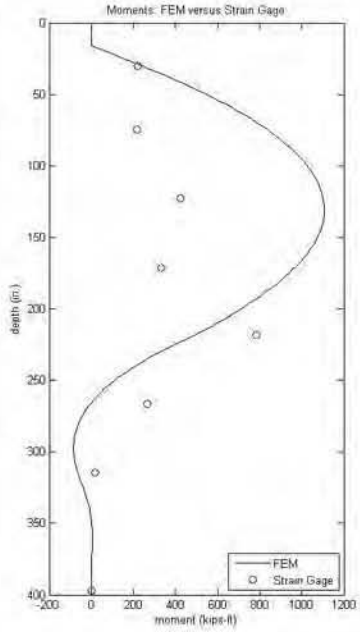


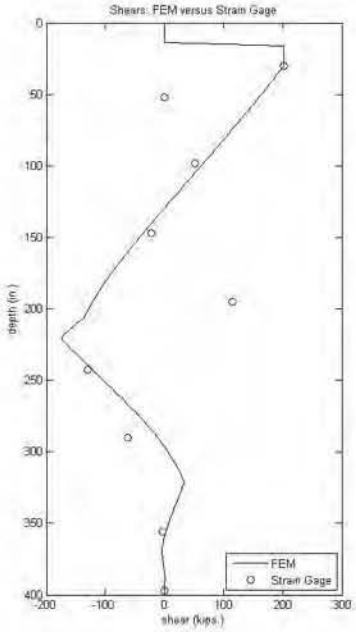




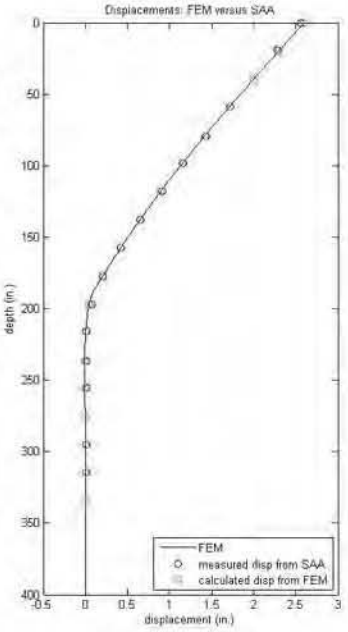
W6 Soil Removed 202.3 kips

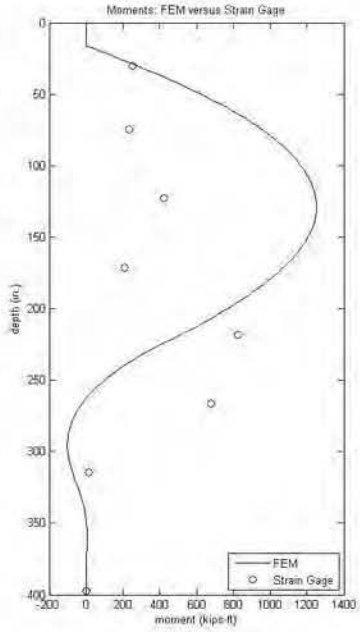


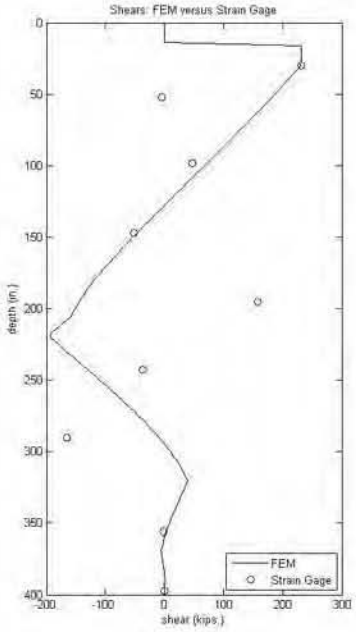




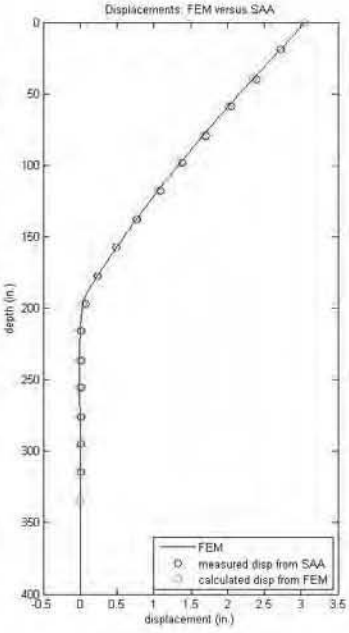
W6 Soil Removed 231.5 kips

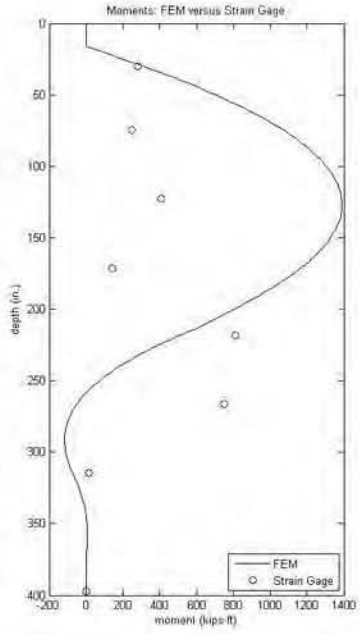


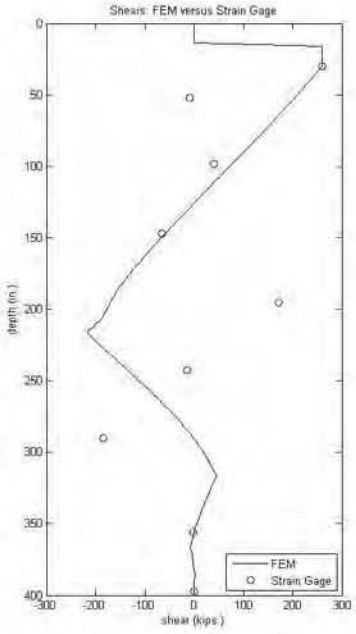




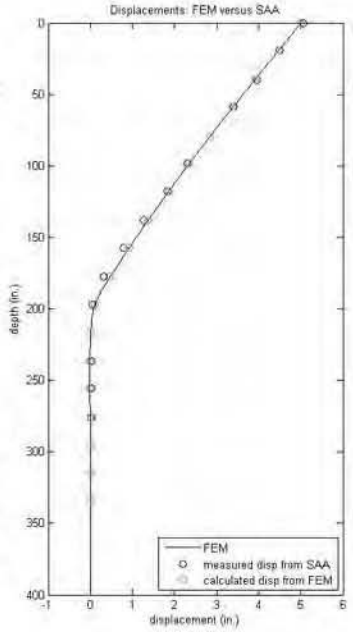
W6 Soil Removed 260.7 kips

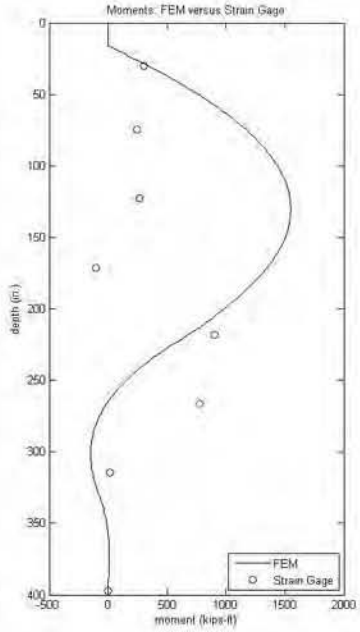


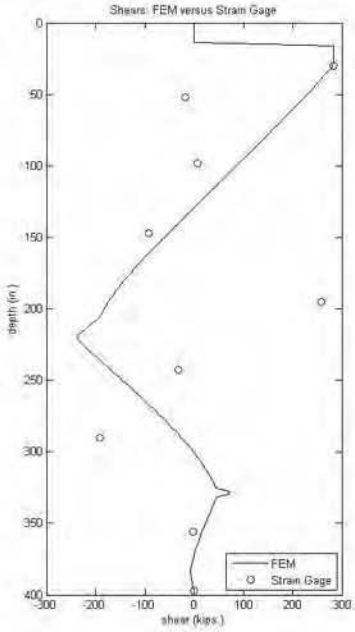




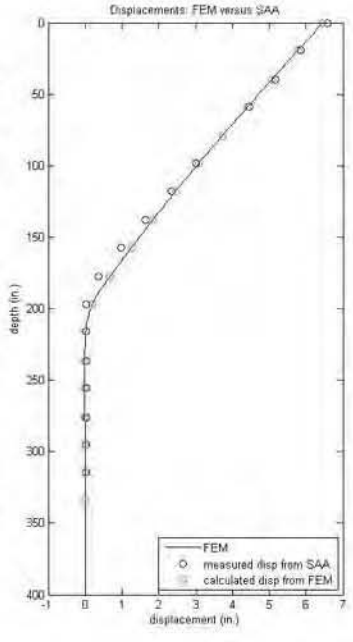
W6 Soil Removed 282.7 kips

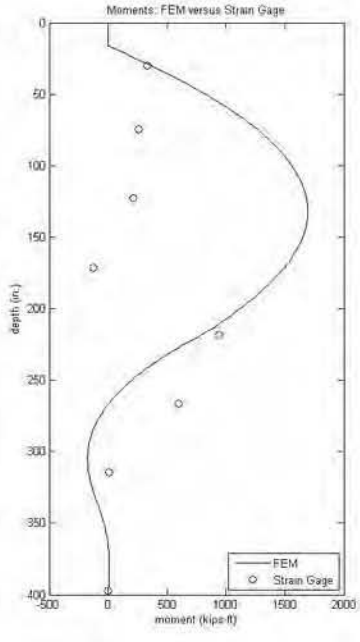


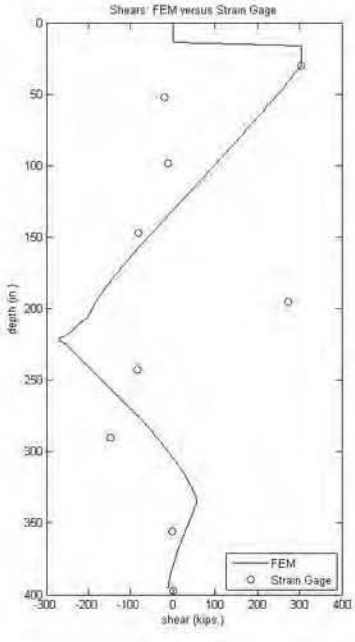




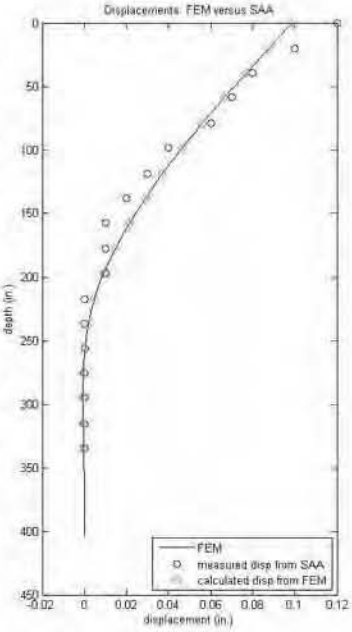
W6 Soil Removed 304.6 kips

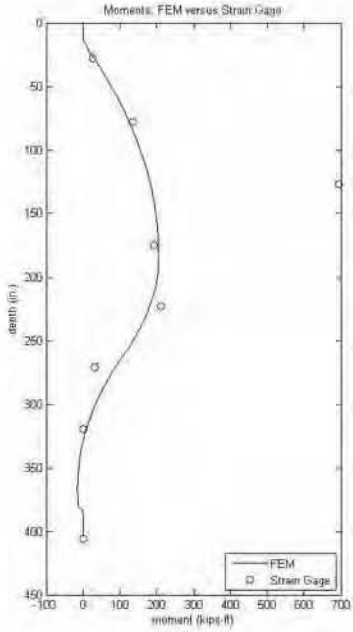


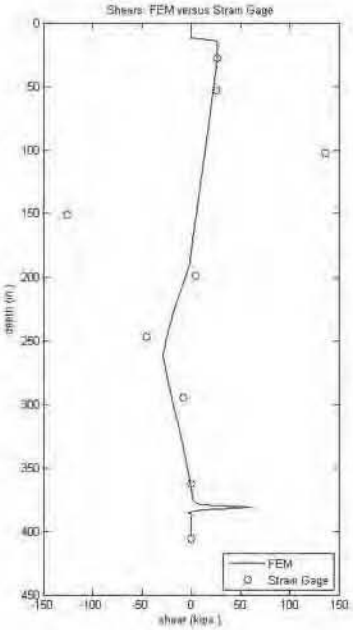




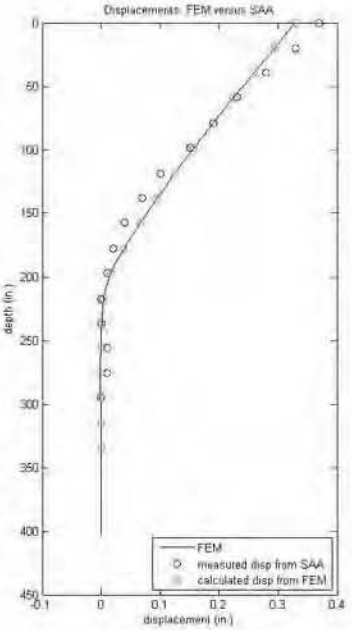
W7 Soil Removed 26.8 kips

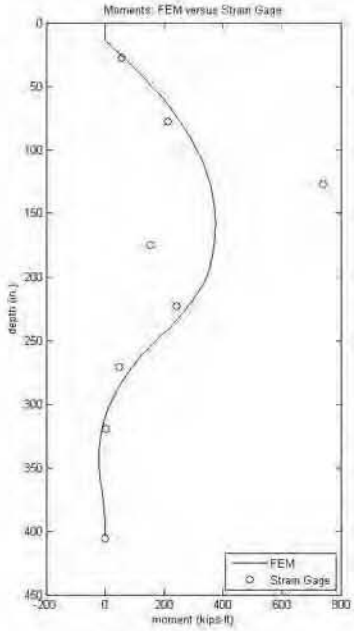


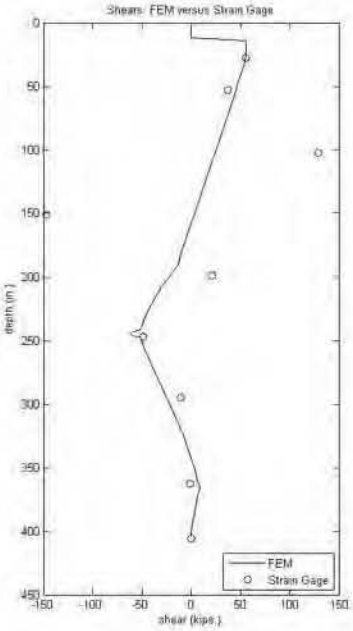




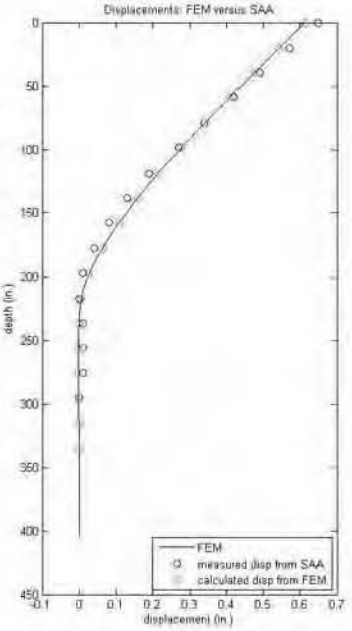
W7 Soil Removed 56.1 kips

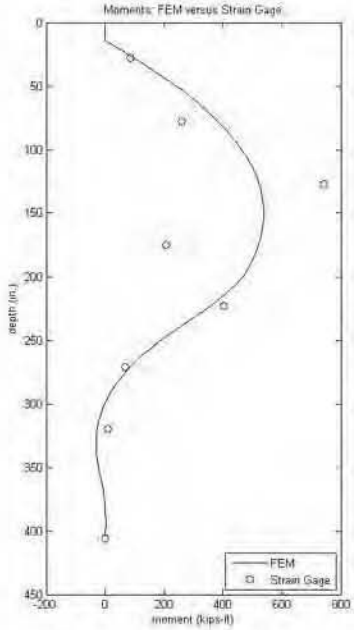


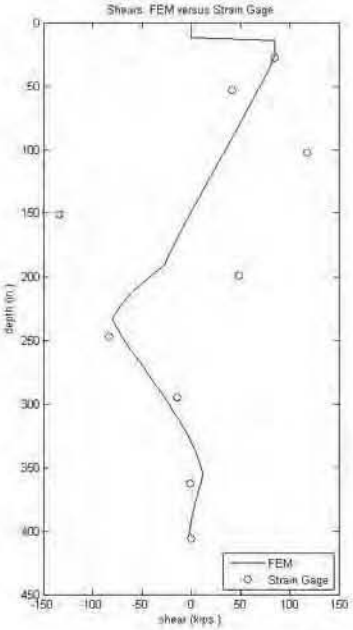




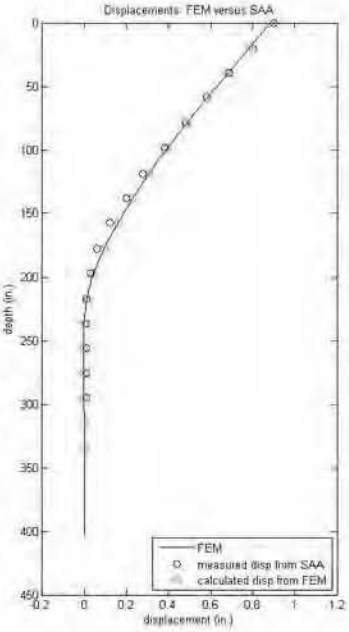
W7 Soil Removed 85.3 kips

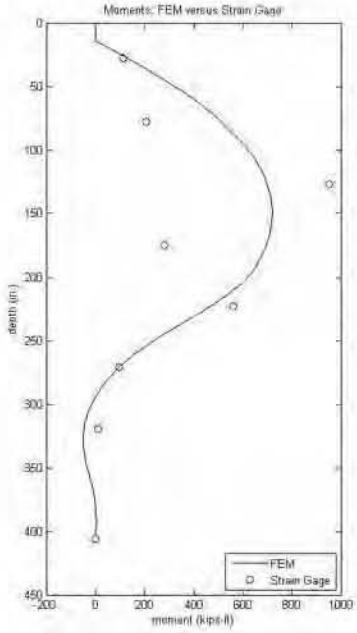


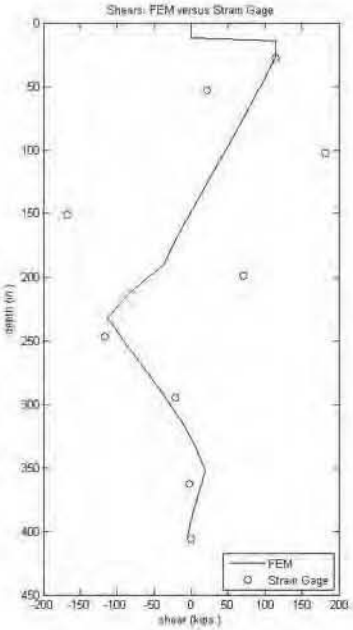




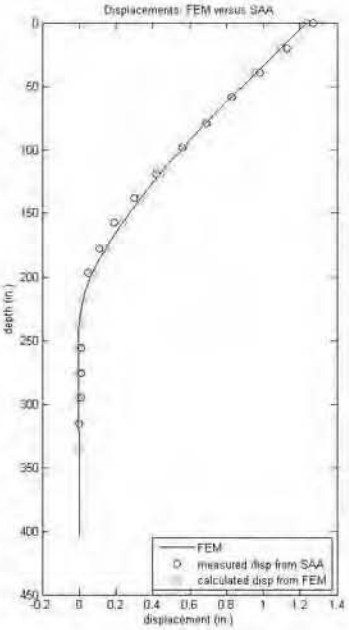
W7 Soil Removed 114.5 kips

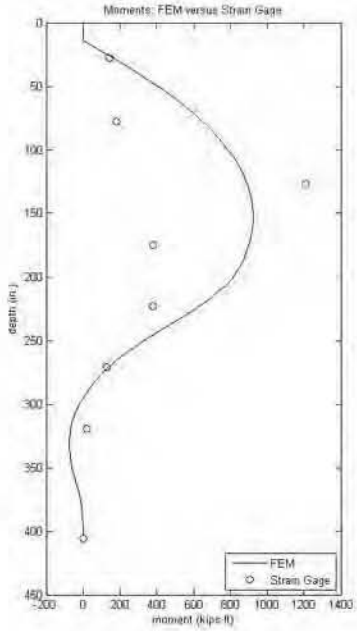


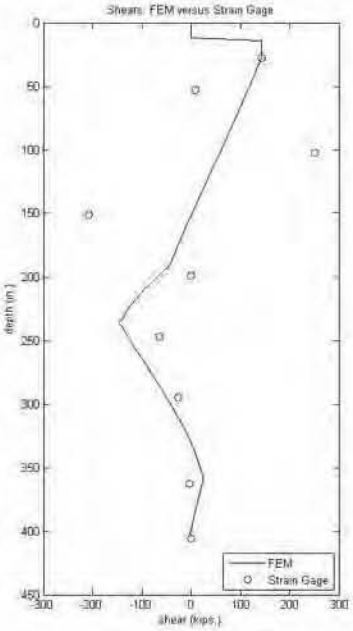




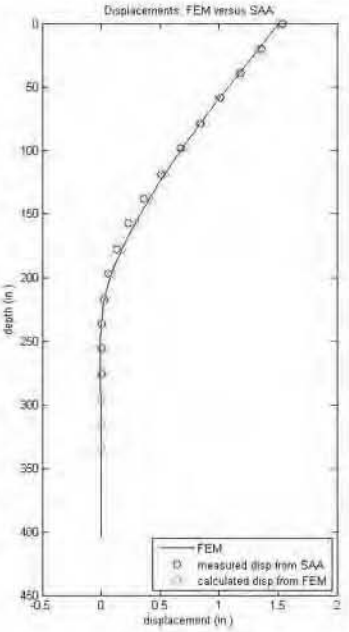
W7 Soil Removed 143.8 kips

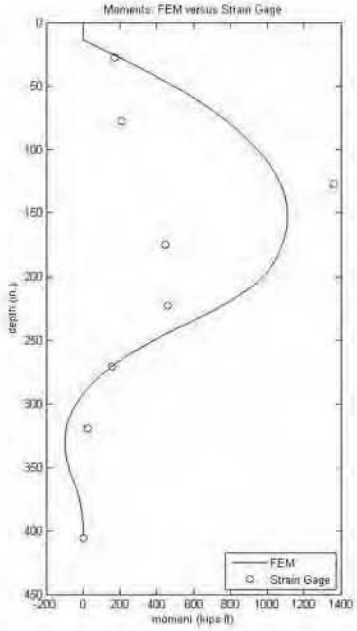


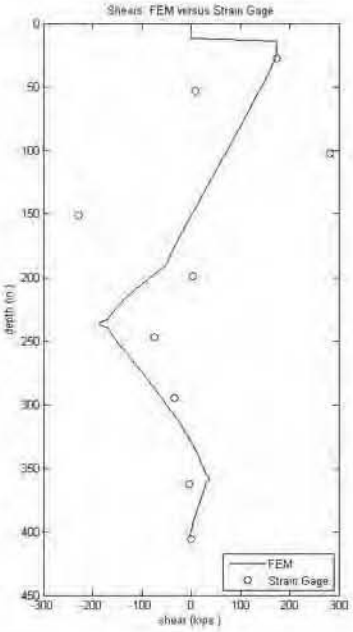




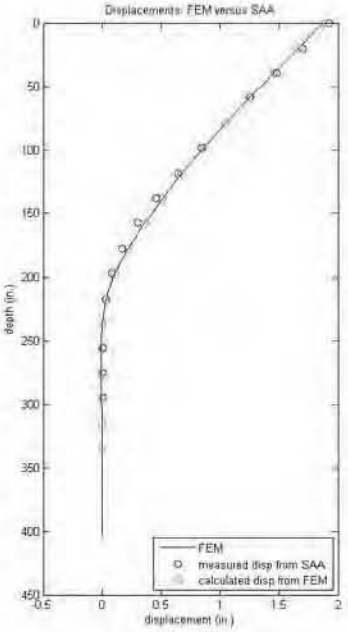
W7 Soil Removed 173.0 kips

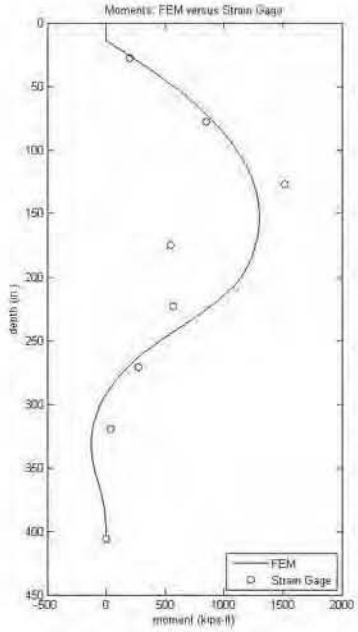


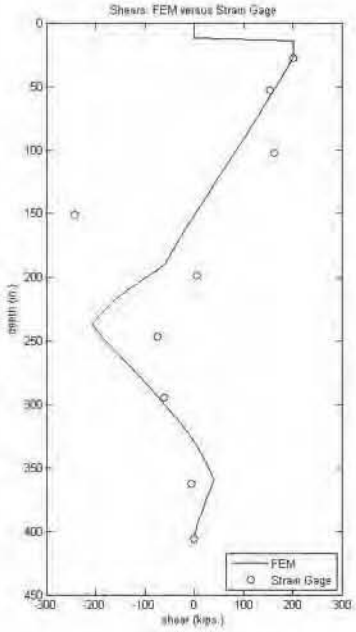




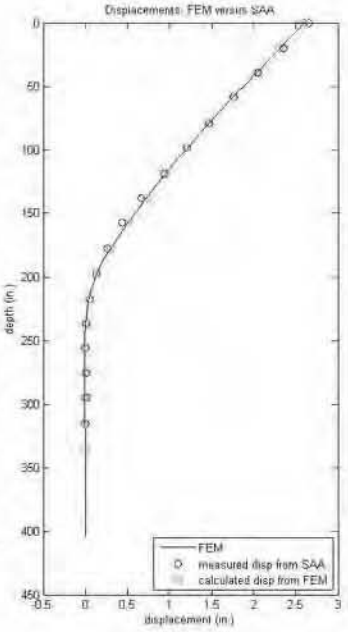
W7 Soil Removed 202.3 kips

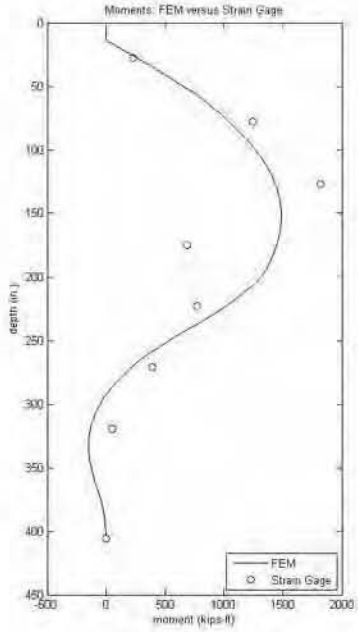


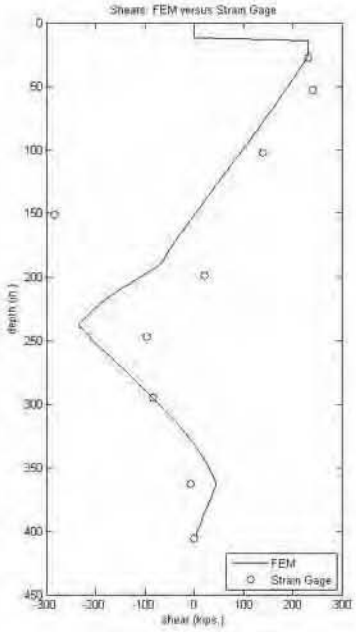




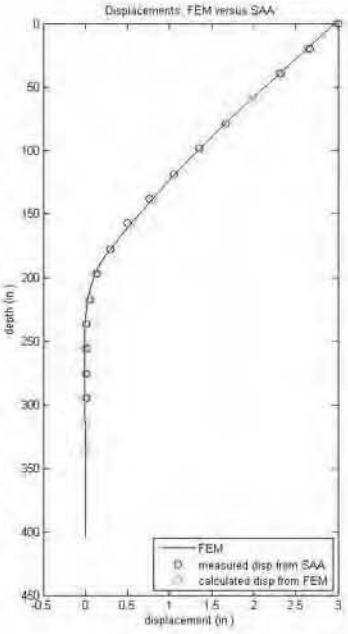
W7 Soil Removed 231.5 kips

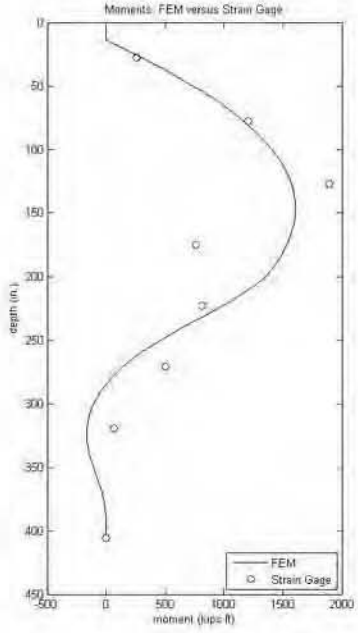


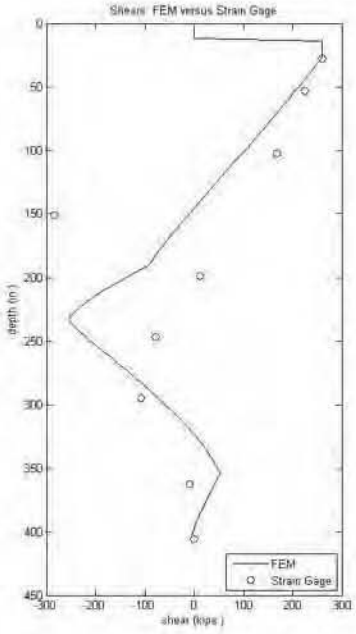




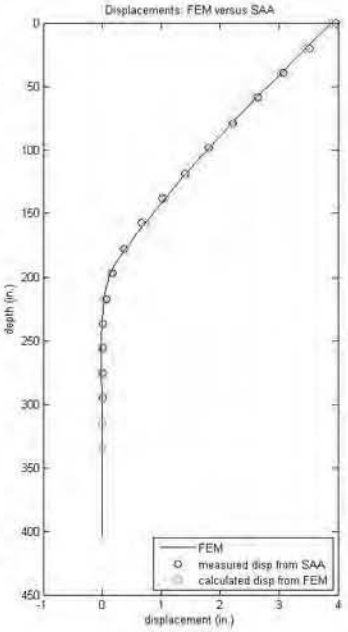
W7 Soil Removed 260.7 kips

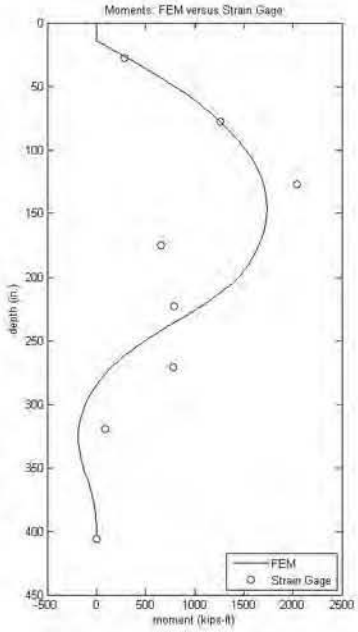


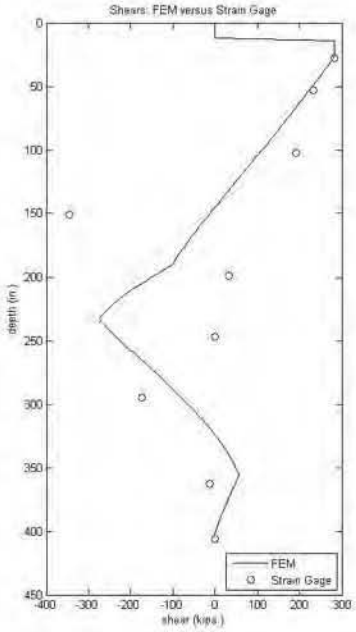




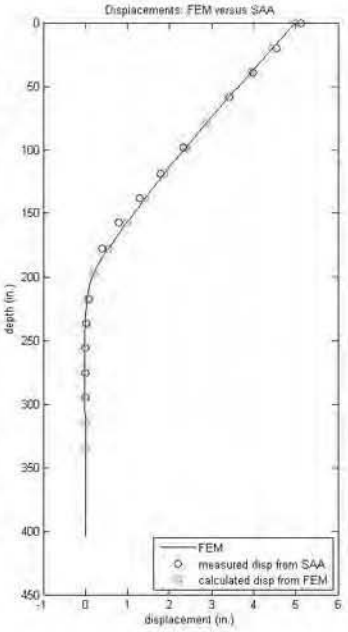
W7 Soil Removed 282.7 kips

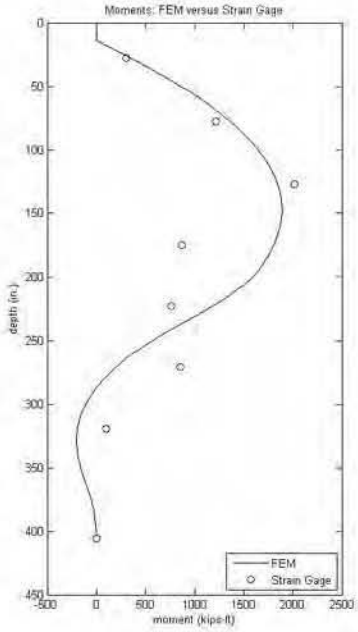


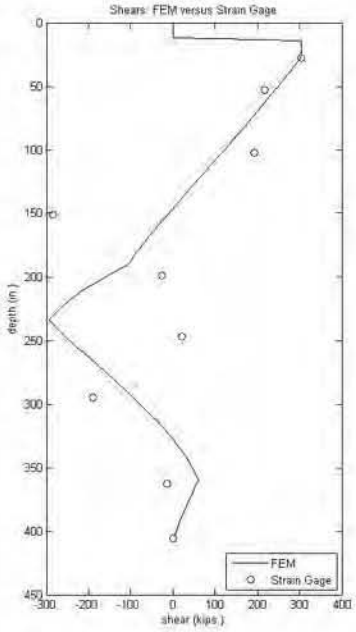




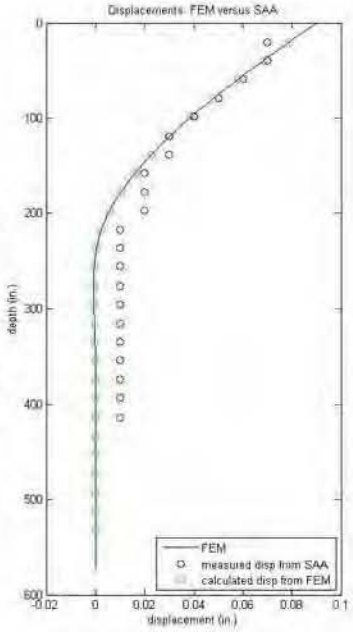
W7 Soil Removed 304.6 kips

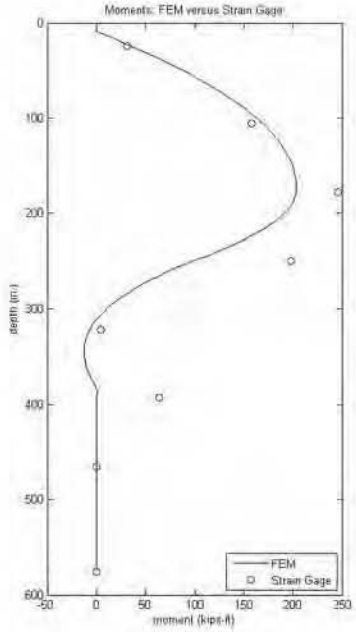


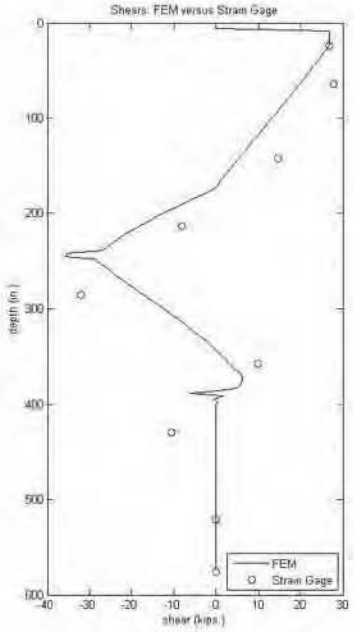




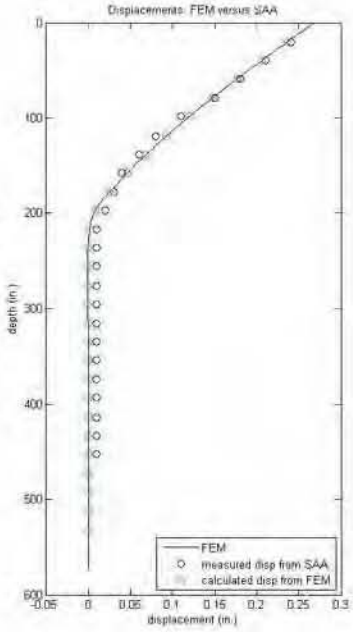
W8 26.8 kips

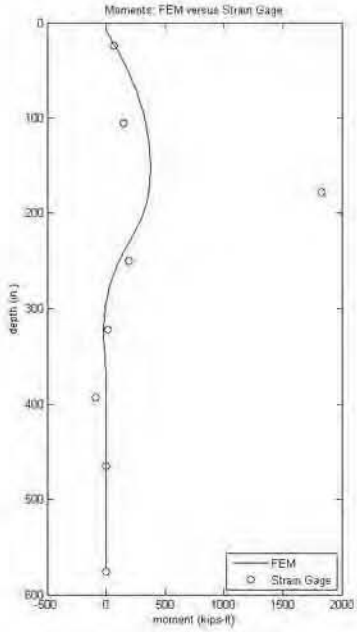


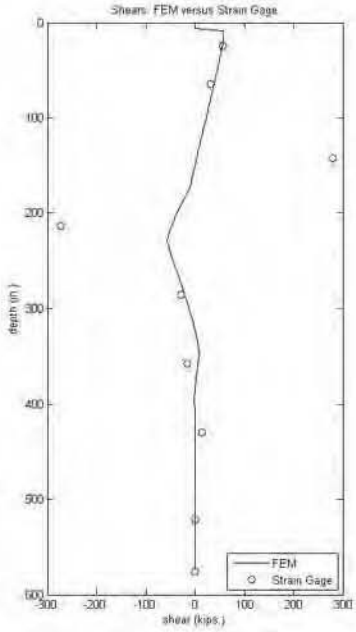




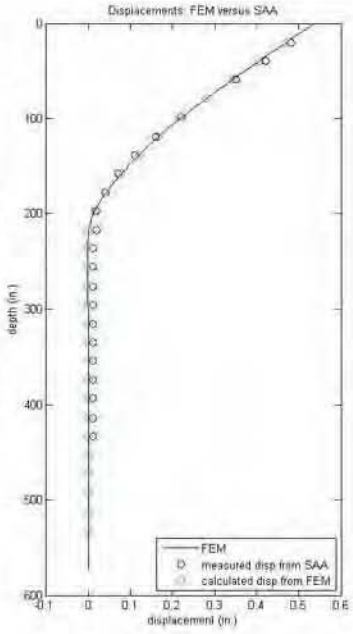
W8 56.1 kips

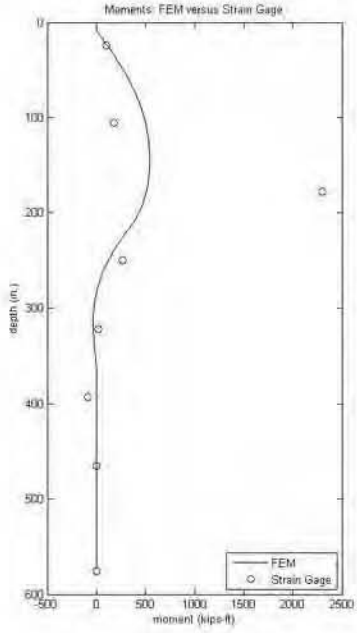


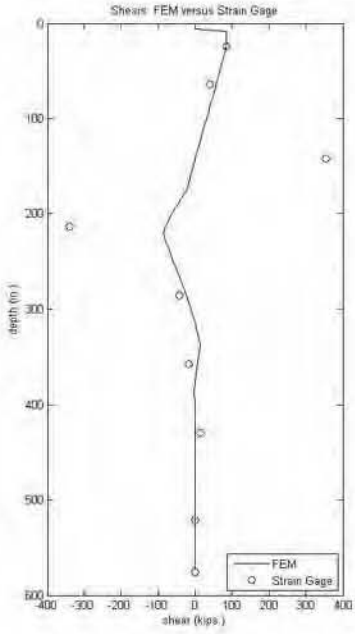




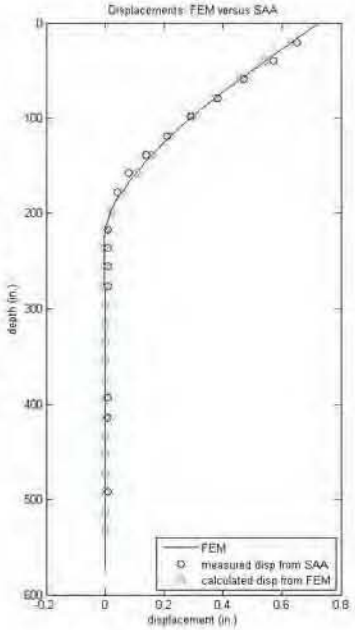
W8 85.3 kips

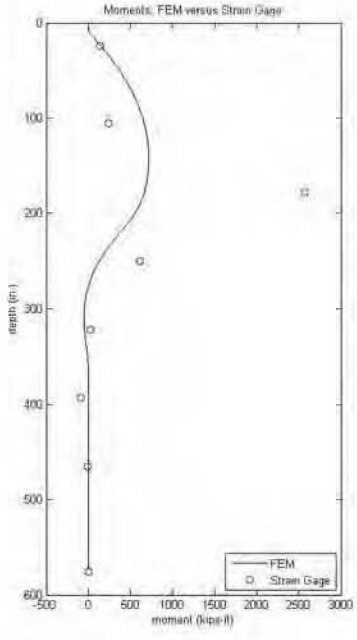


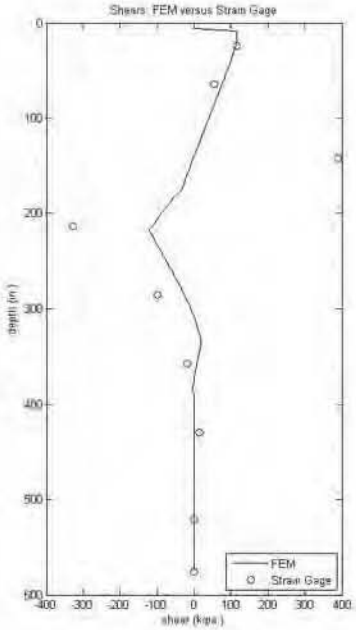




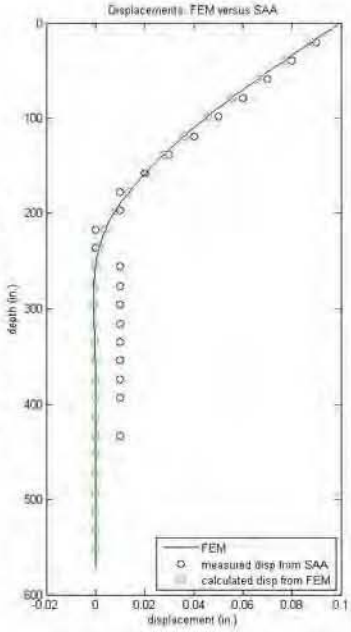
W8 114.5 kips

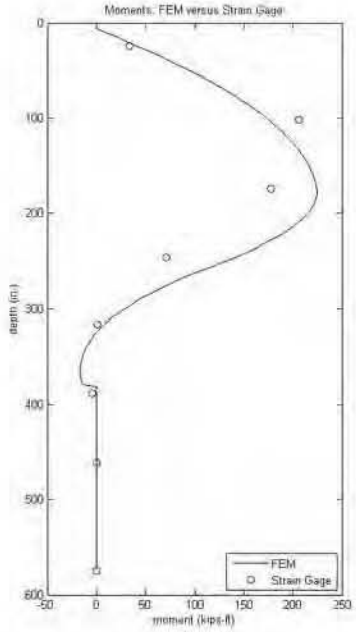

Displacements: FEM versus SAA
depth (in.)
displacement (in.)
FEM
measured disp from SAA
calculated disp from FEM

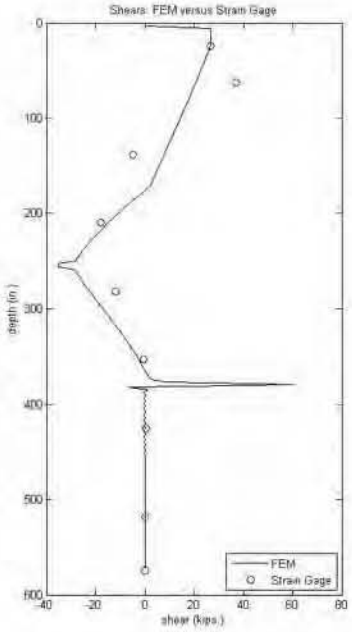

Moments: FEM versus Strain Gage
depth (in.)
moment (kips-ft)
FEM
Strain Gage


Shears: FEM versus Strain Gage
depth (in.)
shear (kips)
FEM
Strain Gage

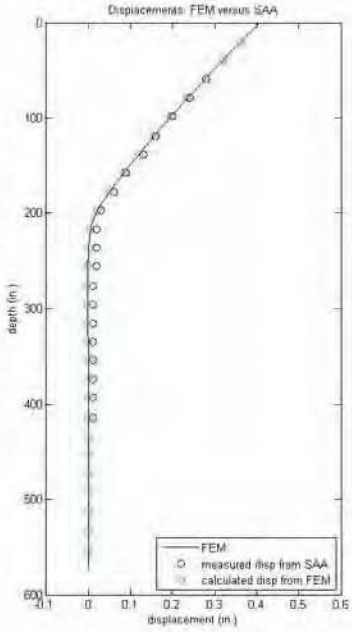
W9 26.8 kips

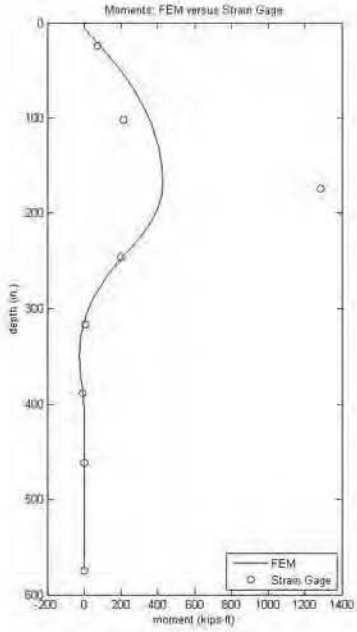


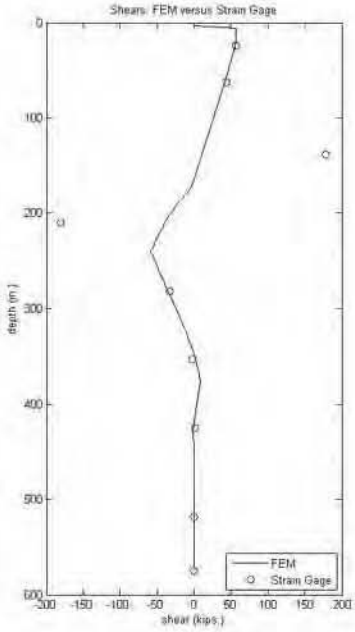




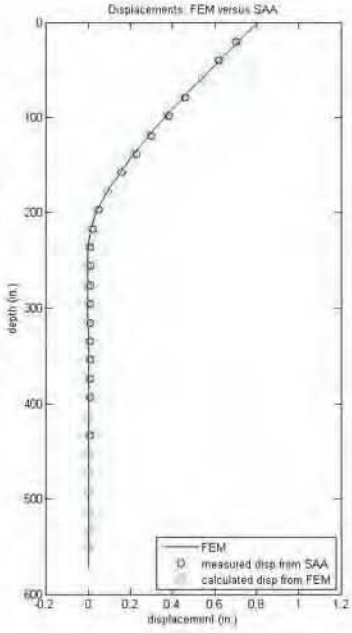
W9 56.1 kips

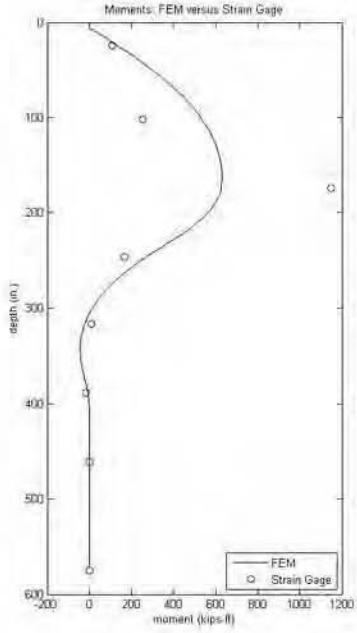


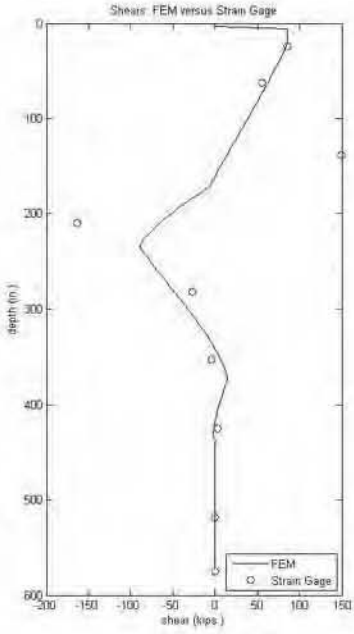




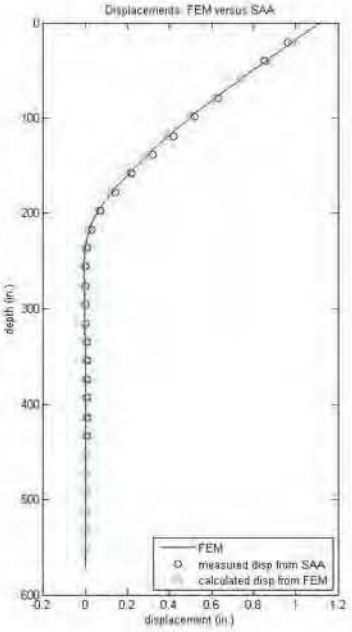
W9 85.3 kips

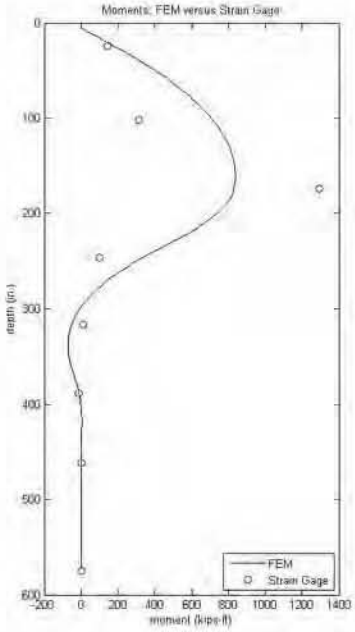


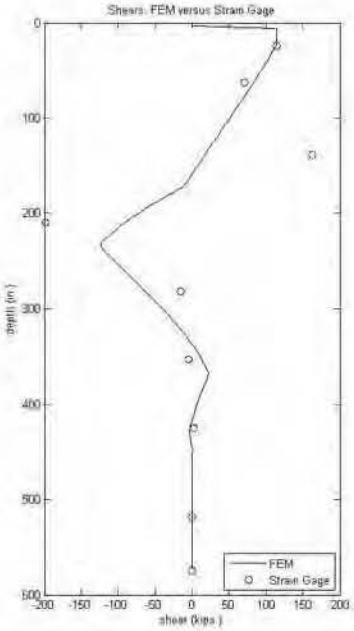




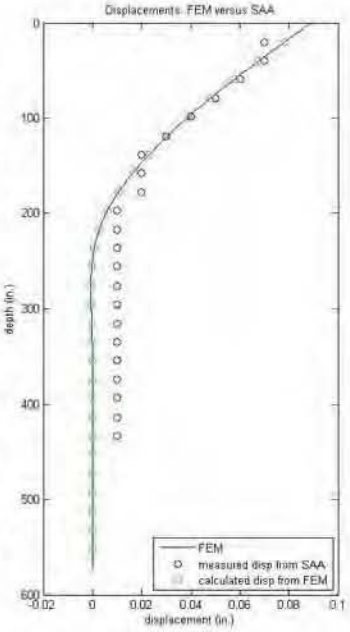
W9 114.5 kips

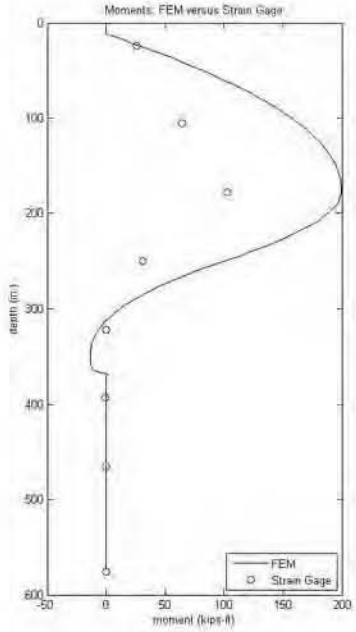

Displacements: FEM versus SAA
depth (in.)
displacement (in.)
FEM
measured disp from SAA
calculated disp from FEM

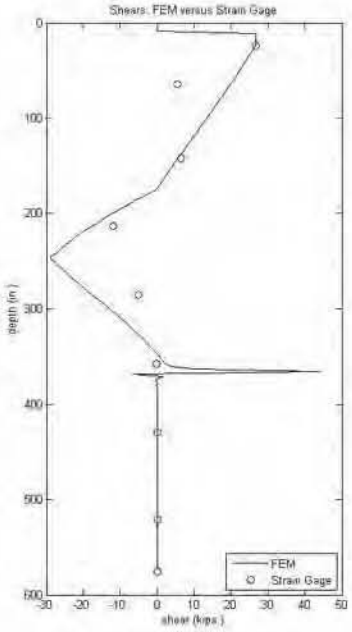

Moments: FEM versus Strain Gage
depth (in.)
moment (kips-ft)
FEM
Strain Gage


Shears: FEM versus Strain Gage
depth (in.)
shear (kips)
FEM
Strain Gage

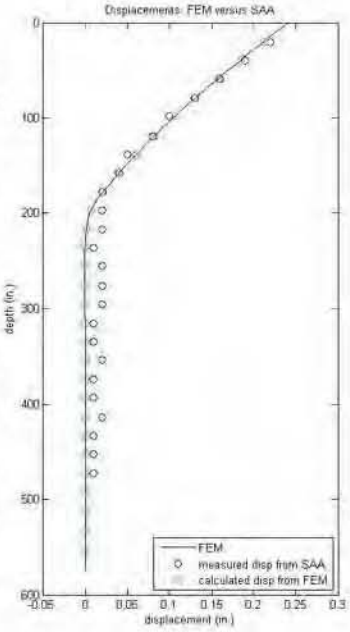
W8 Soil Removed 26.8 kips

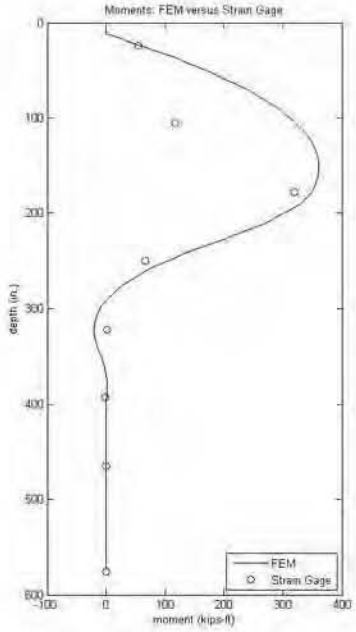


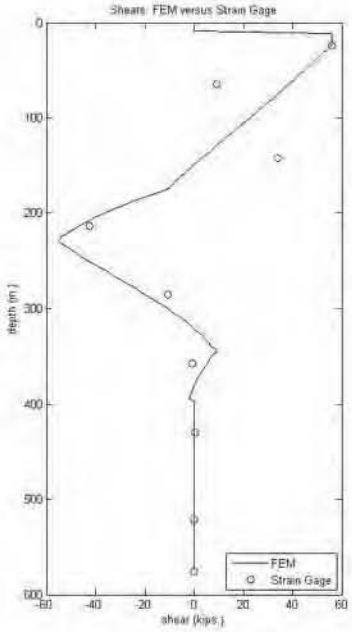




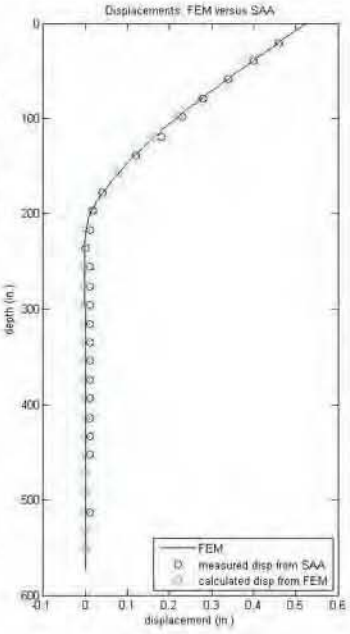
W8 Soil Removed 56.1 kips

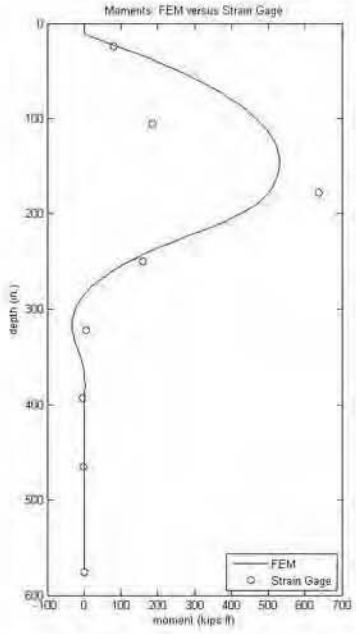


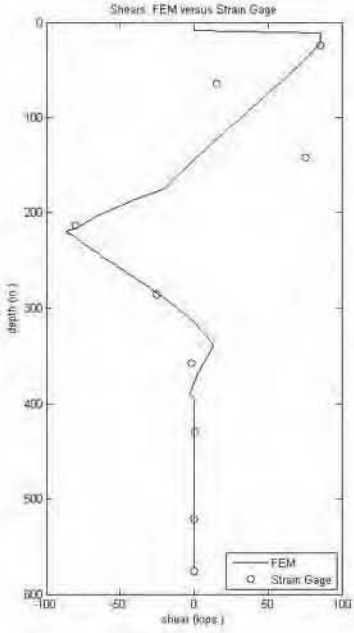




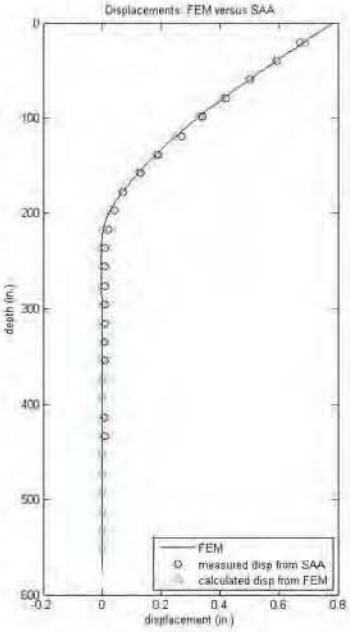
W8 Soil Removed 85.3 kips

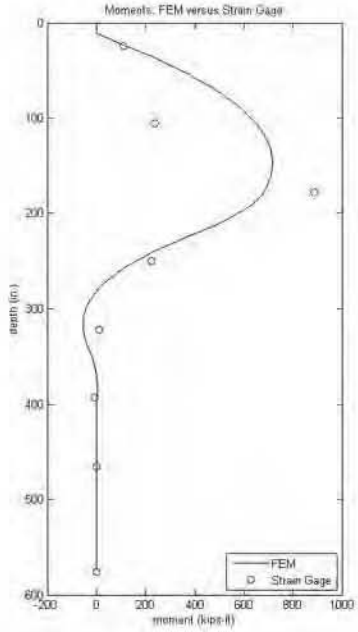


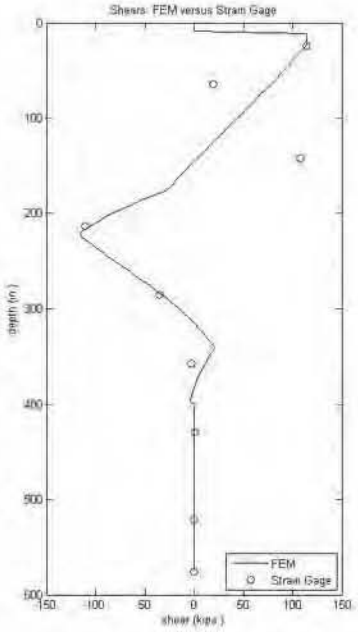




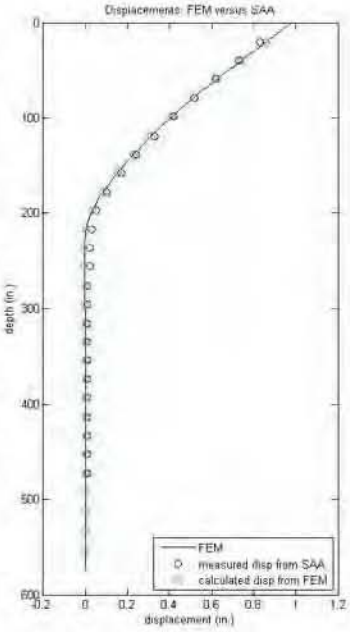
W8 Soil Removed 114.5 kips

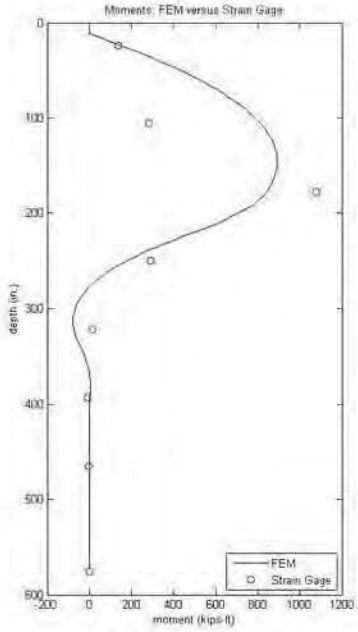


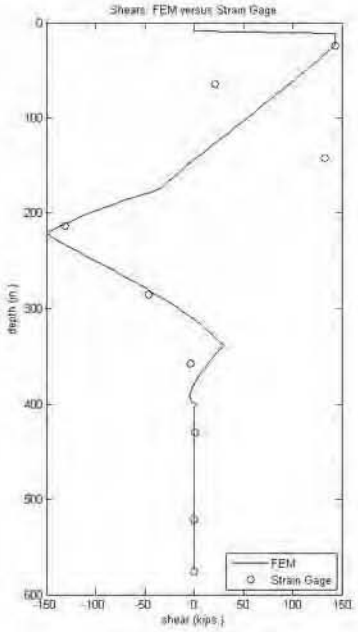




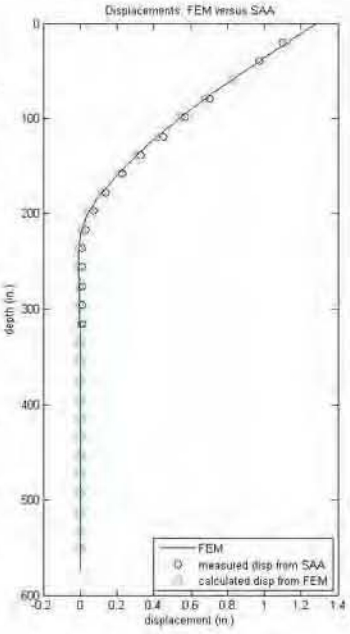
W8 Soil Removed 143.8 kips

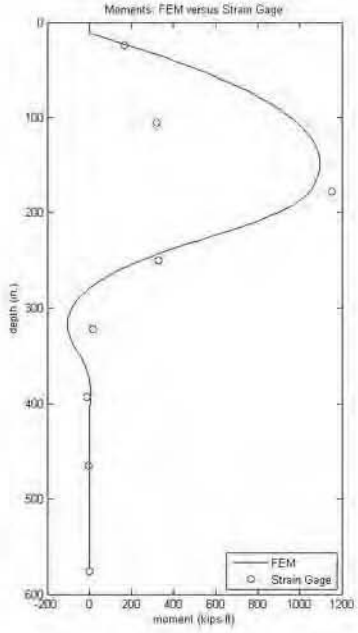


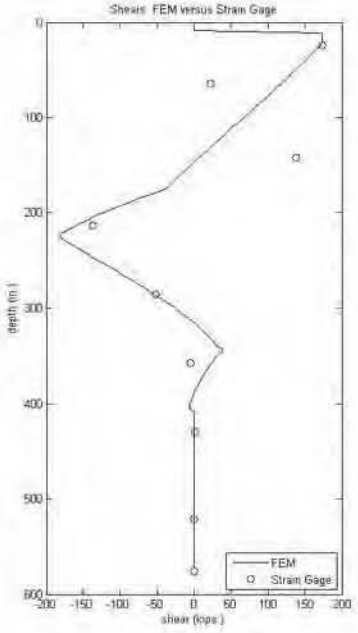




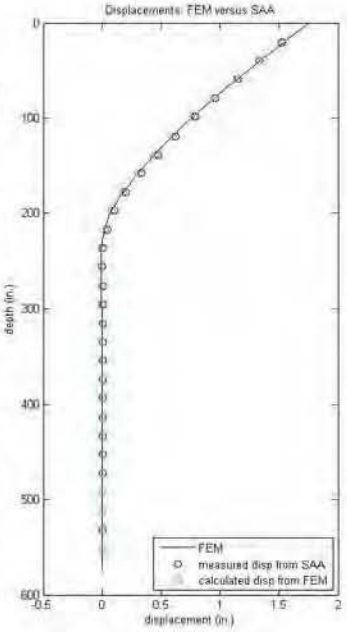
W8 Soil Removed 173.0 kips

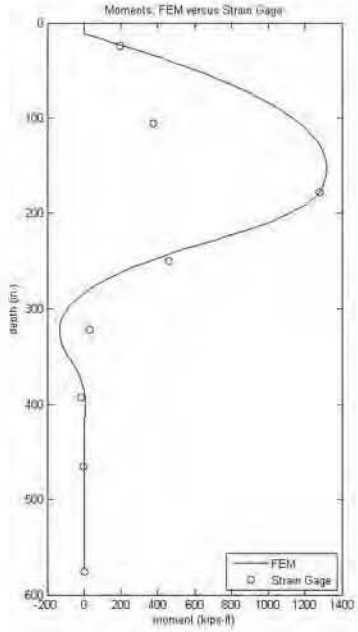


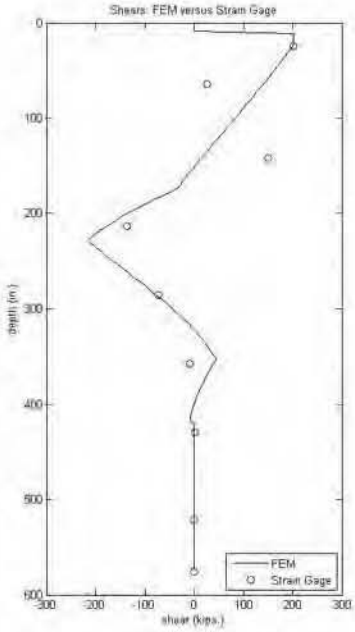




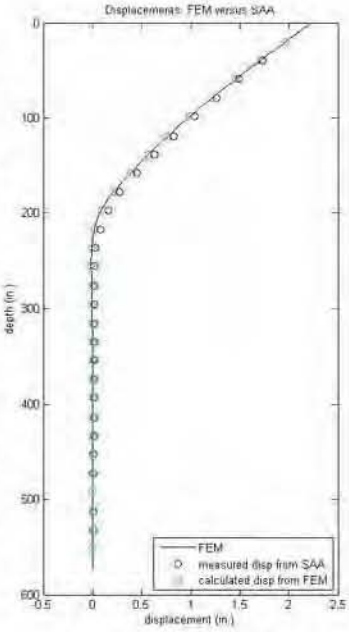
W8 Soil Removed 202.3 kips

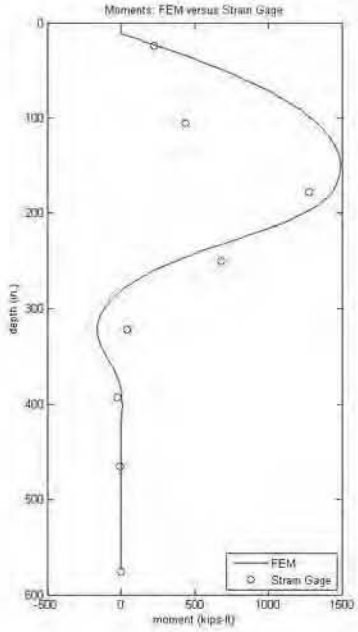


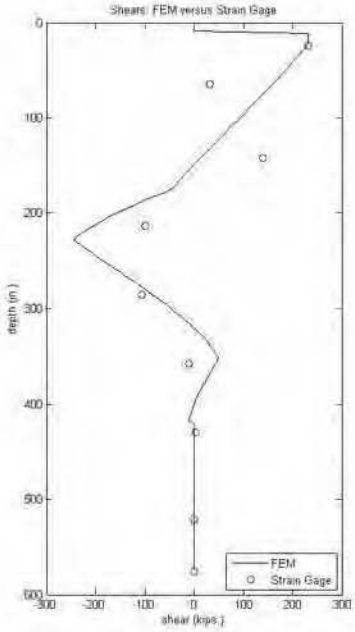




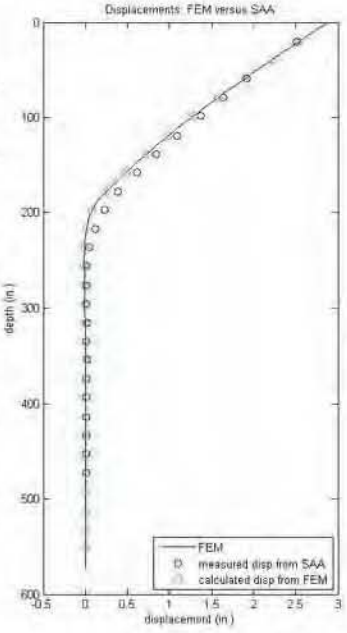
W8 Soil Removed 231.5 kips

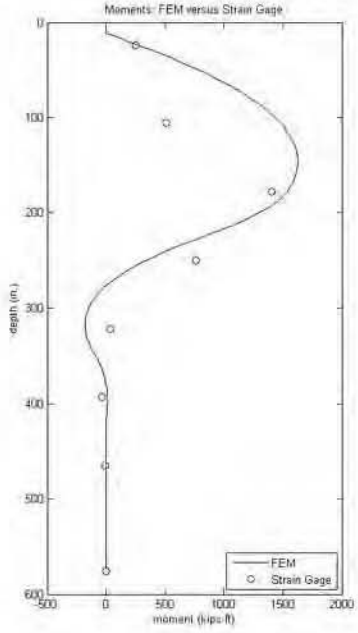


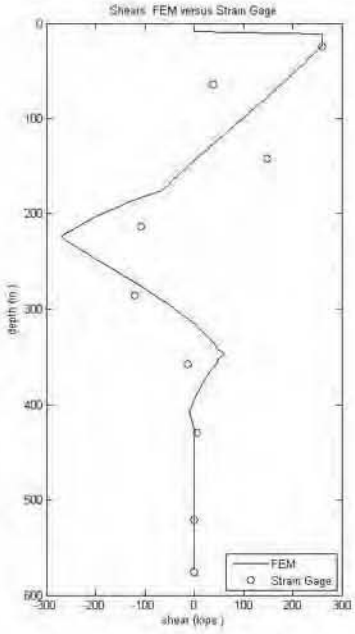




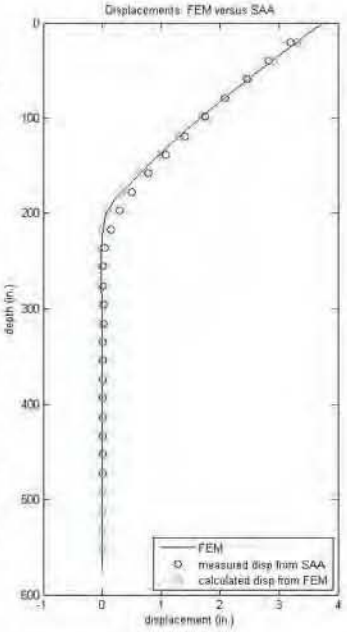
W8 Soil Removed 260.7 kips

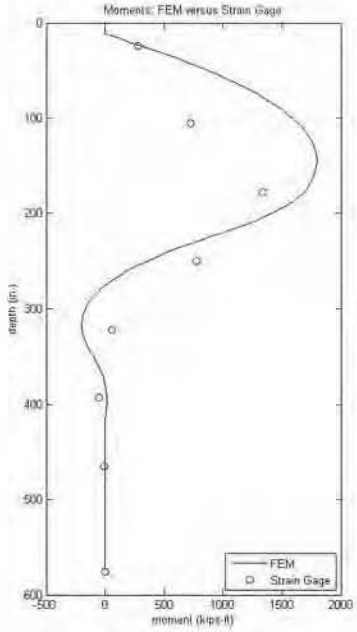


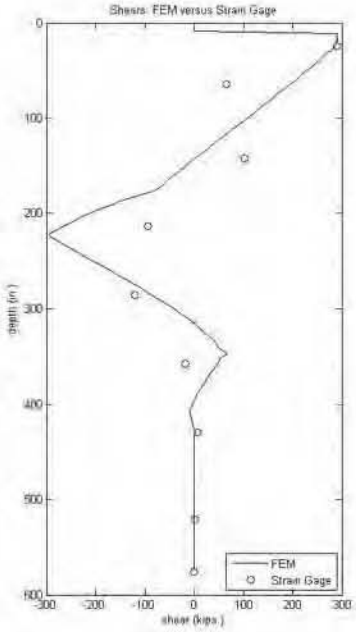




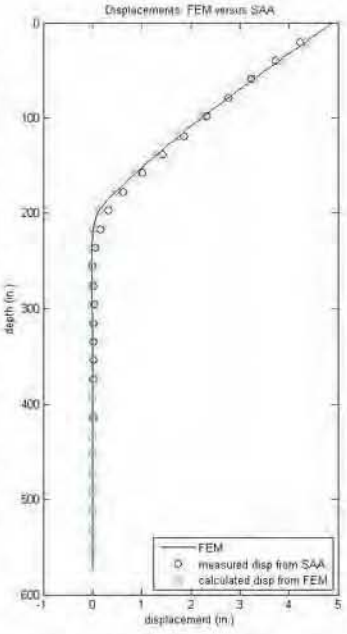
W8 Soil Removed 290.0 kips

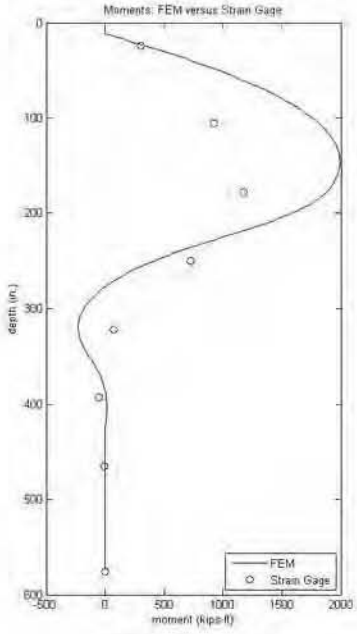


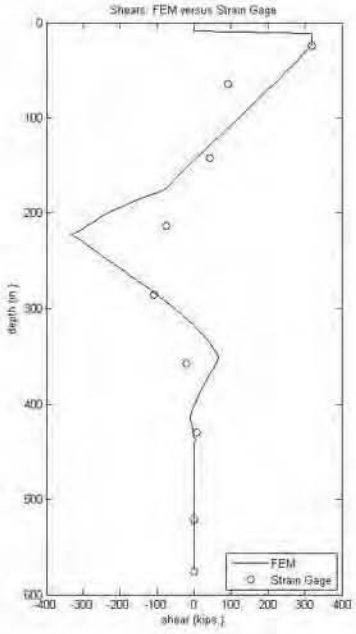




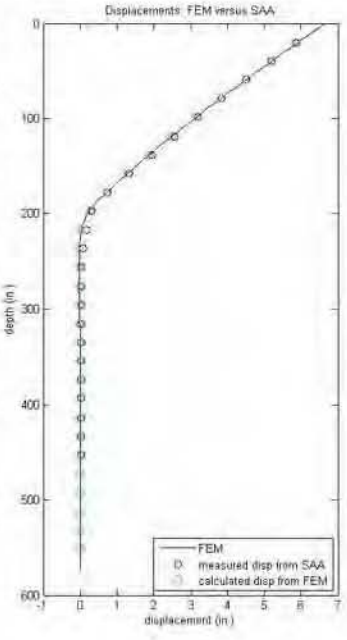
W8 Soil Removed 319.2 kips

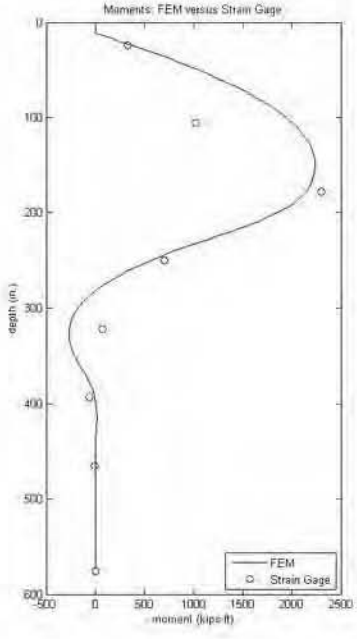


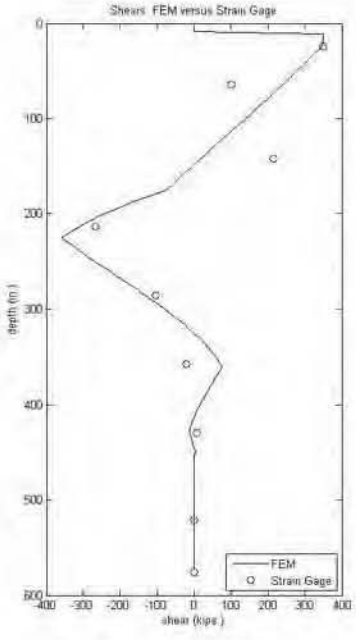




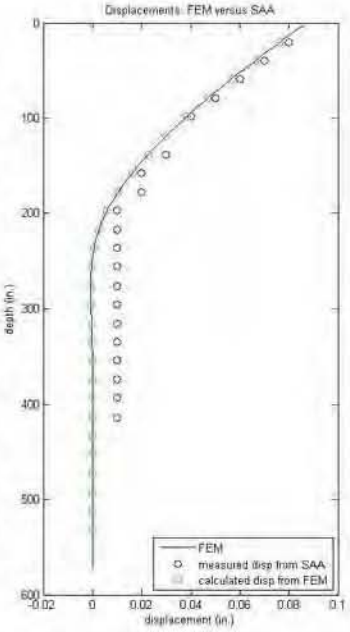
W8 Soil Removed 348.5 kips

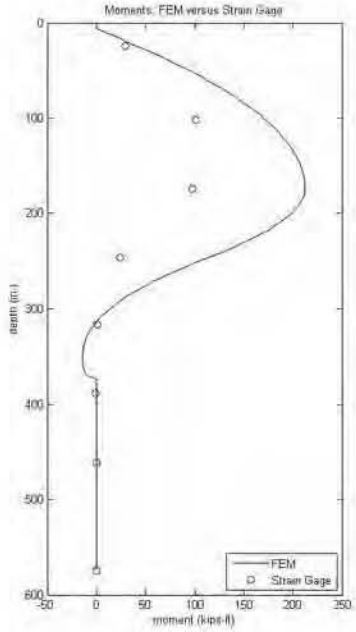


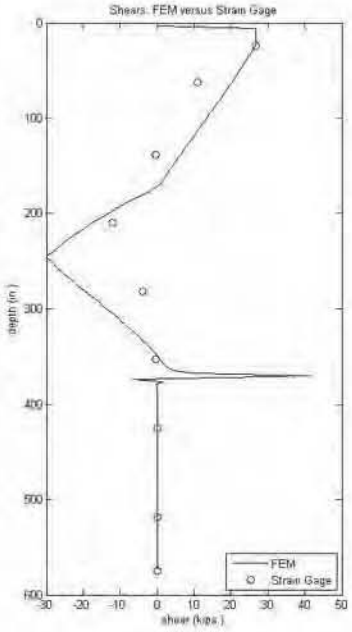




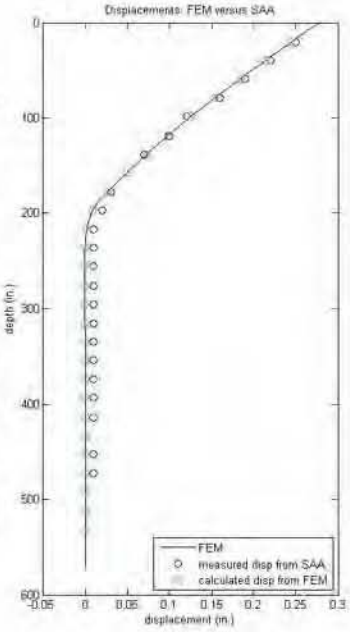
W9 Soil Removed 26.8 kips

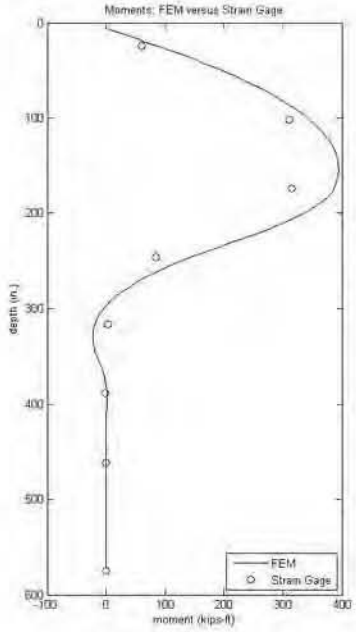


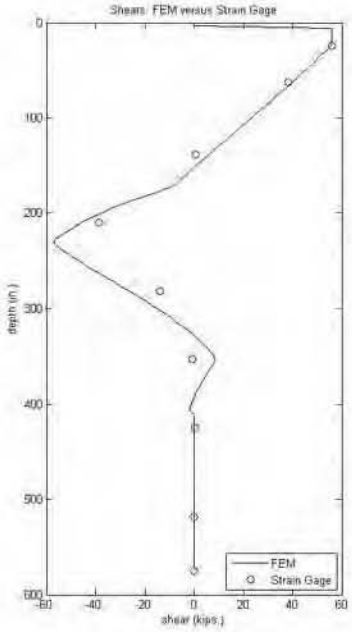




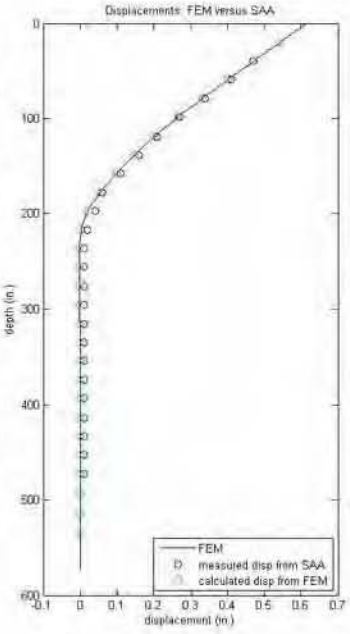
W9 Soil Removed 56.1 kips

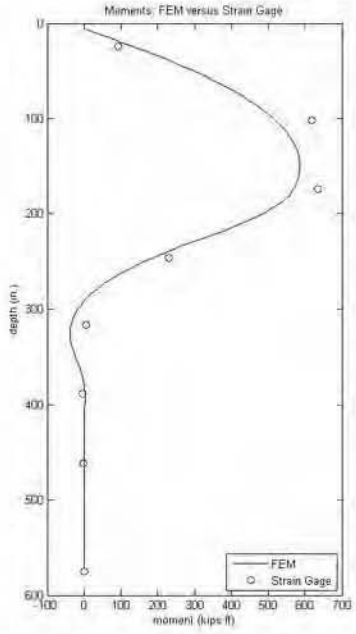


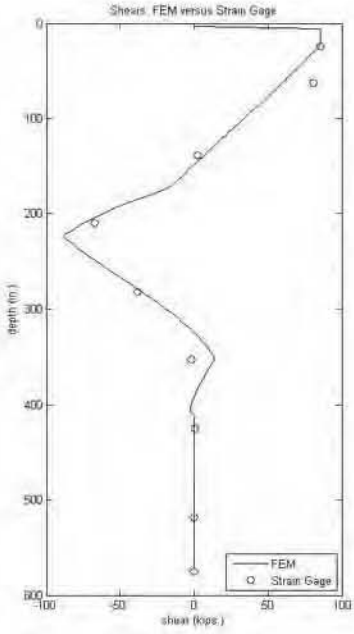




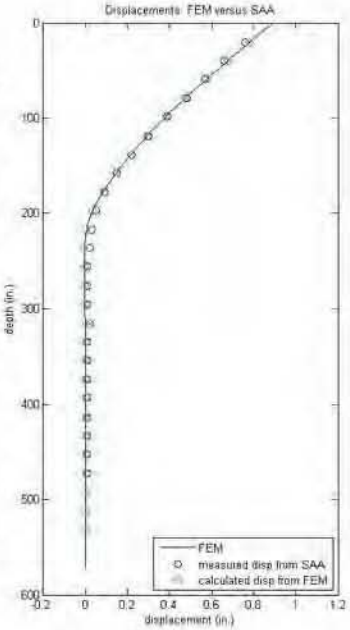
W9 Soil Removed 85.3 kips

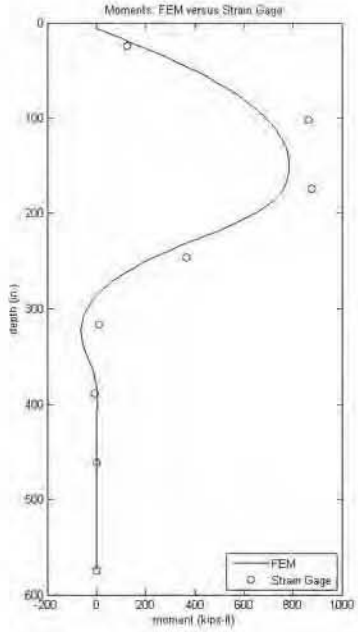


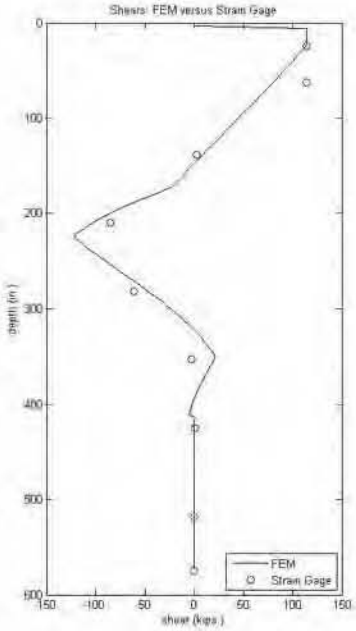




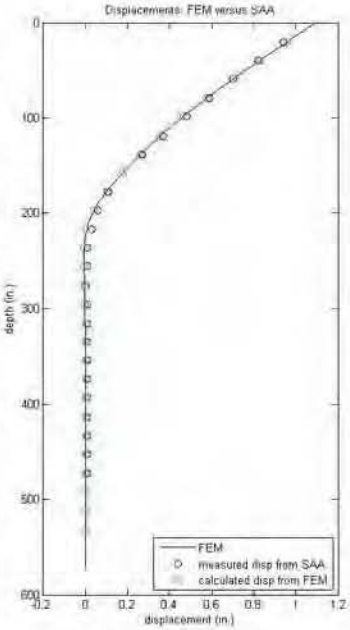
W9 Soil Removed 114.5 kips

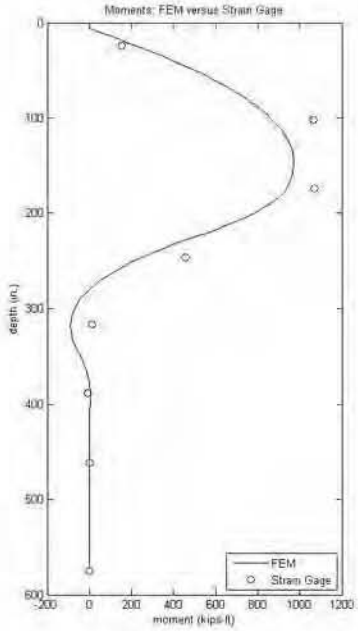


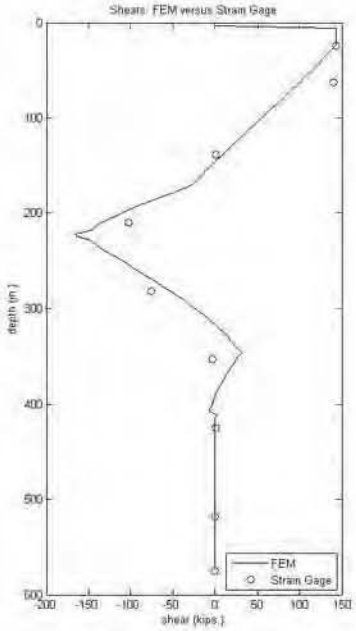




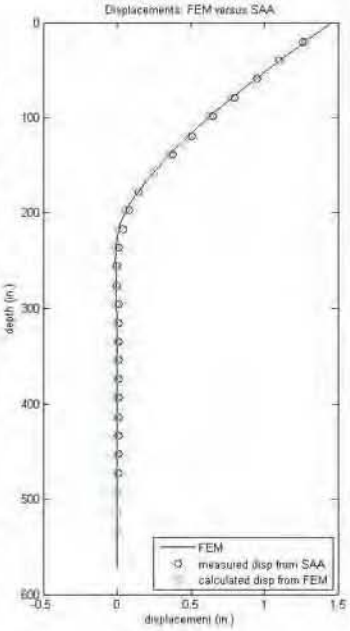
W9 Soil Removed 143.8 kips

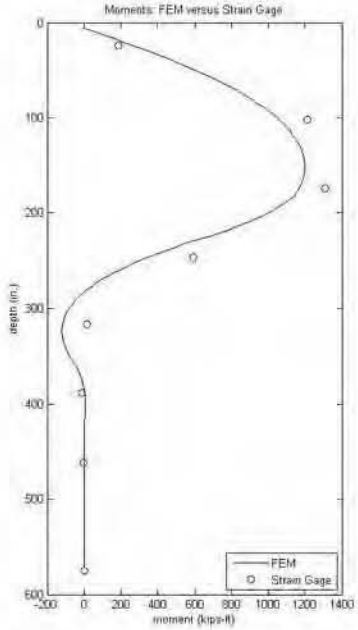


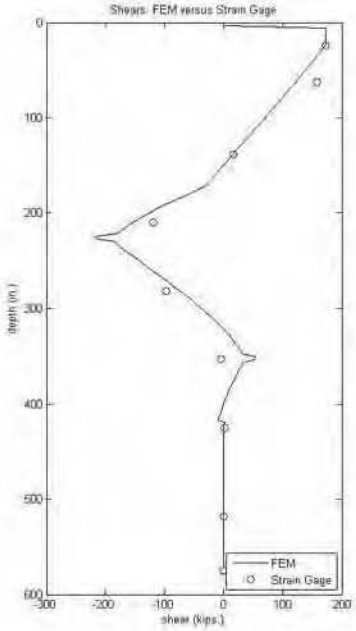




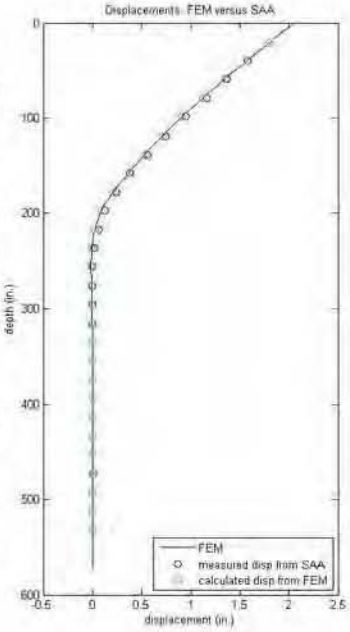
W9 Soil Removed 173.0 kips

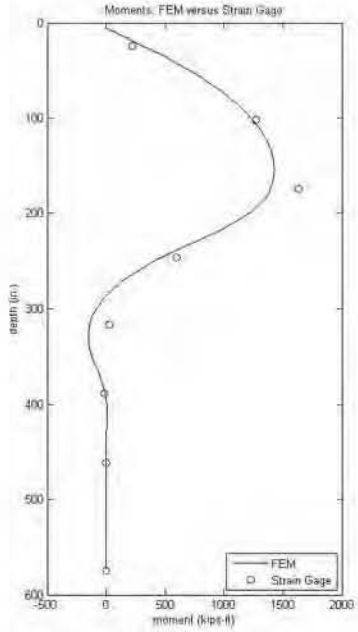


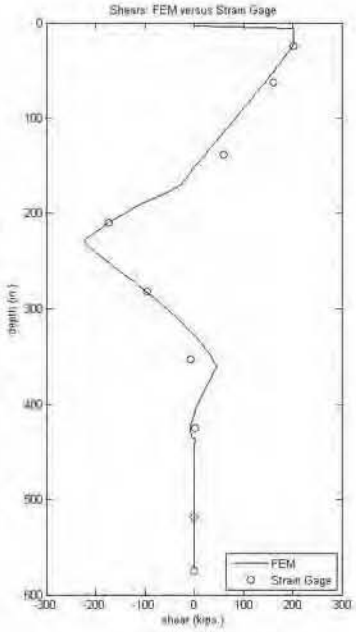




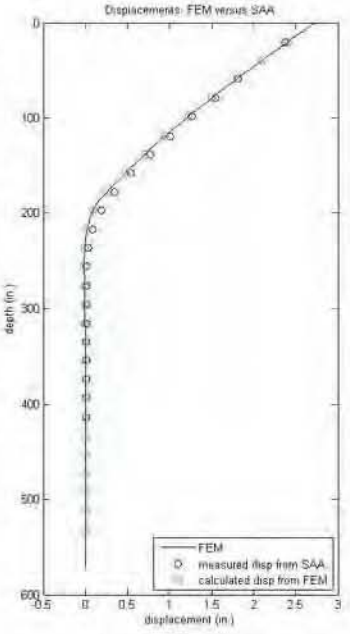
W9 Soil Removed 202.3 kips

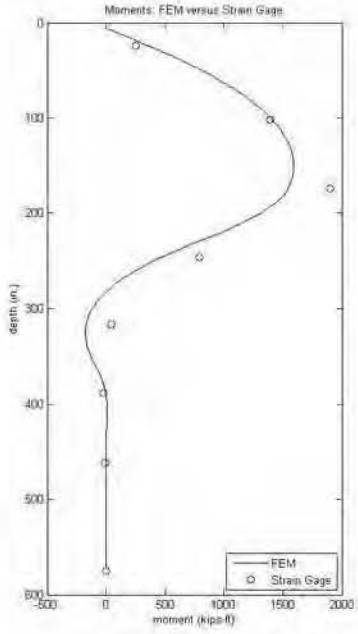


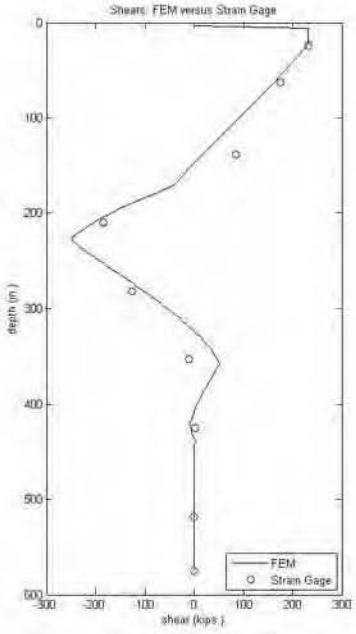




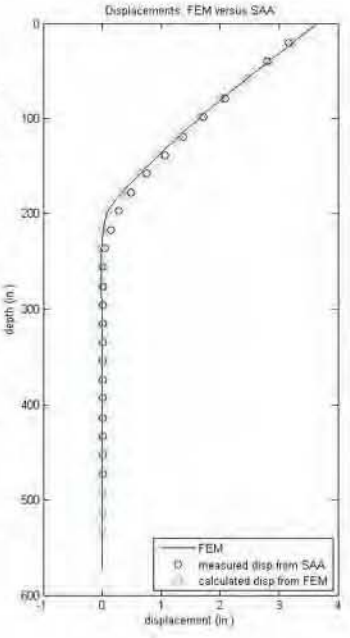
W9 Soil Removed 231.5 kips

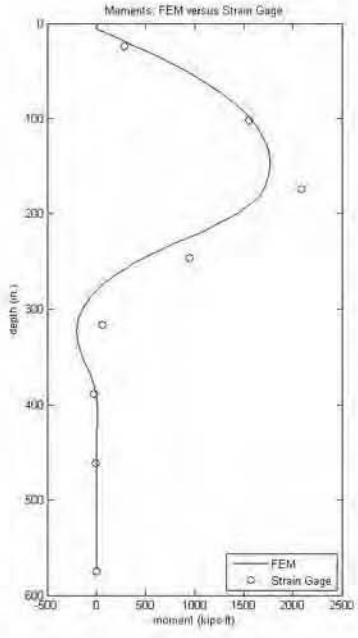


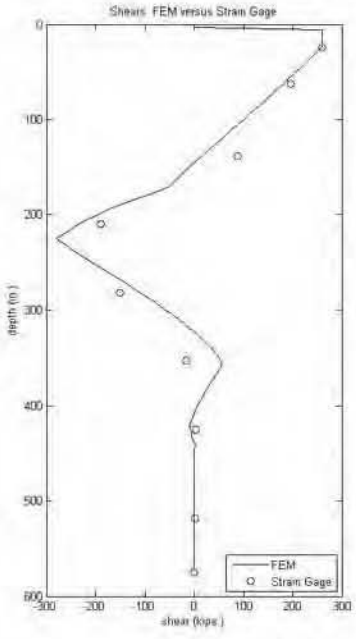




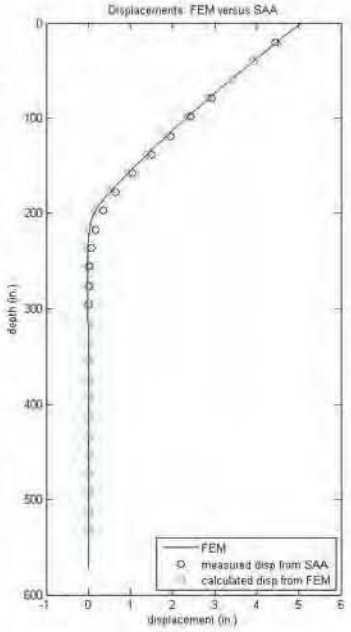
W9 Soil Removed 260.7 kips

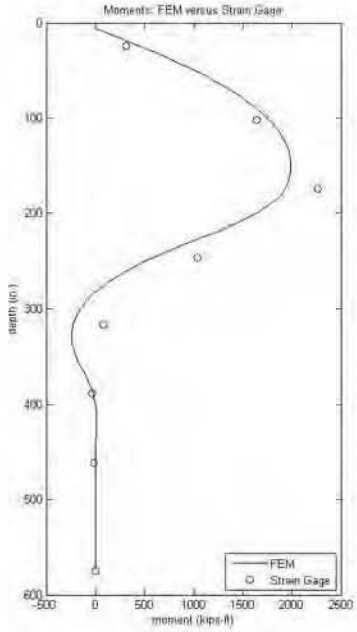


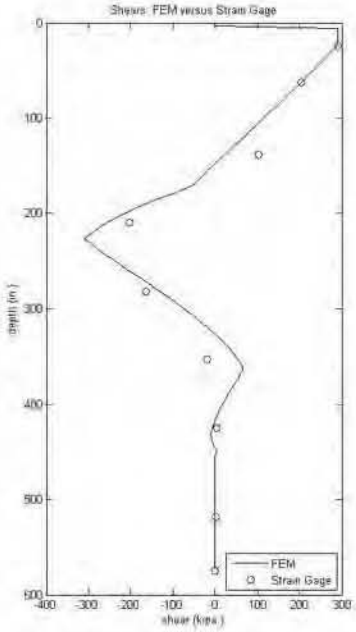




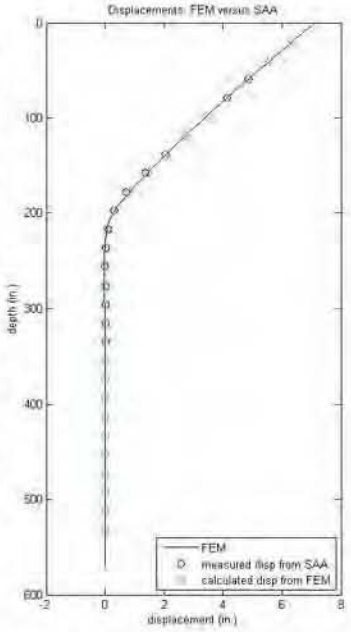
W9 Soil Removed 290.0 kips

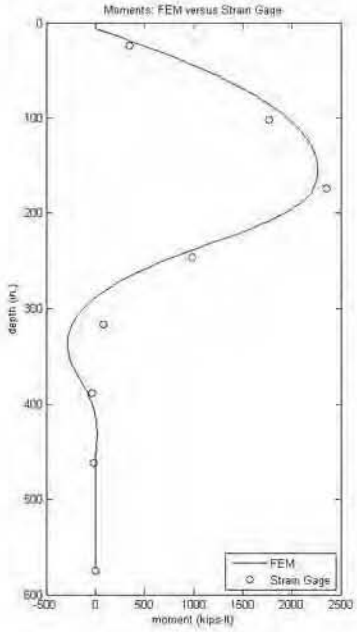


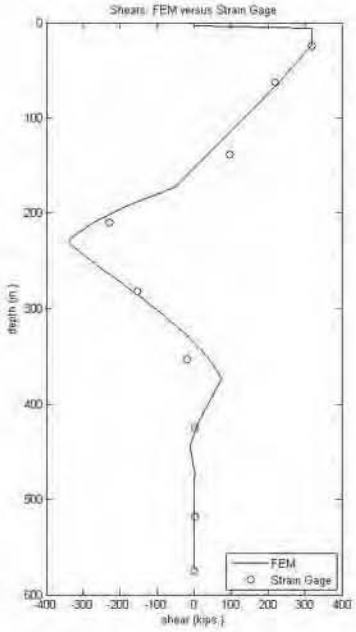




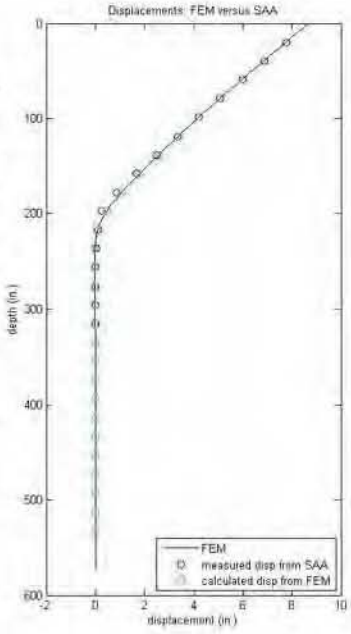
W9 Soil Removed 319.2 kips

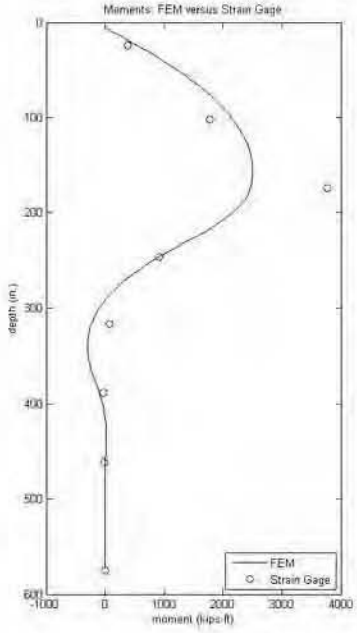


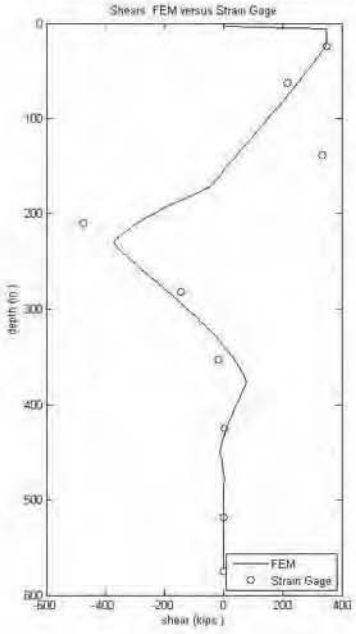




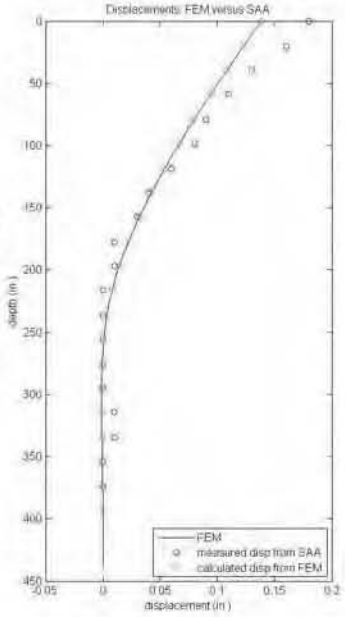
W9 Soil Removed 348.5 kips

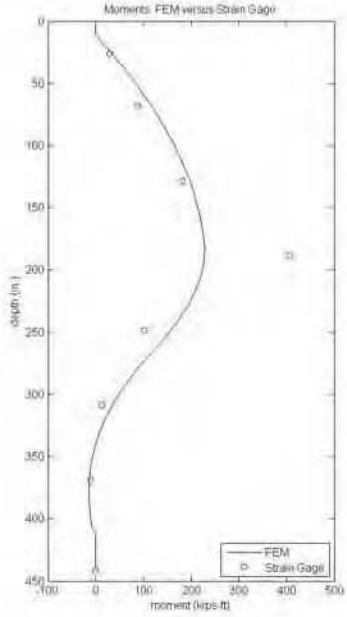


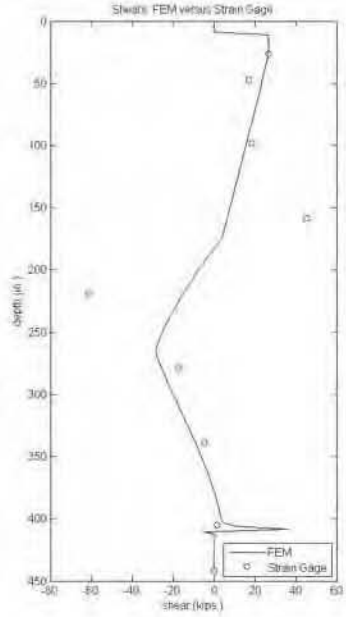




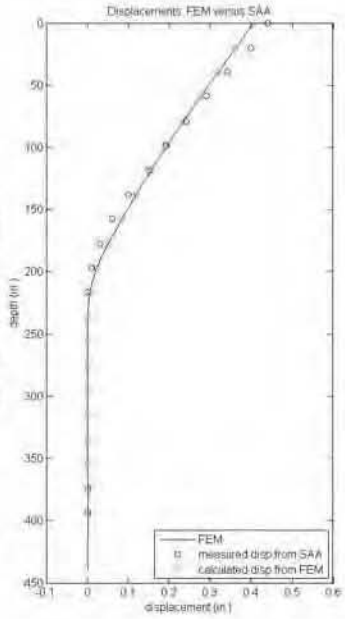
W10 26.8 kips

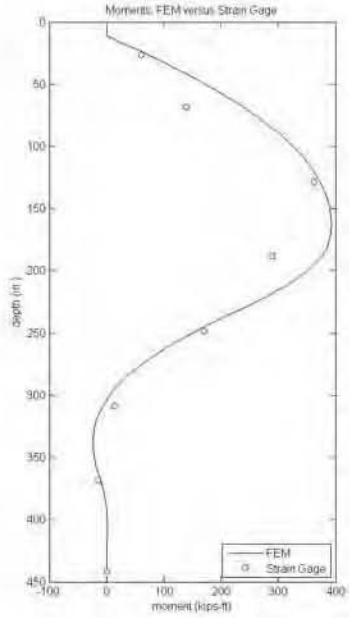


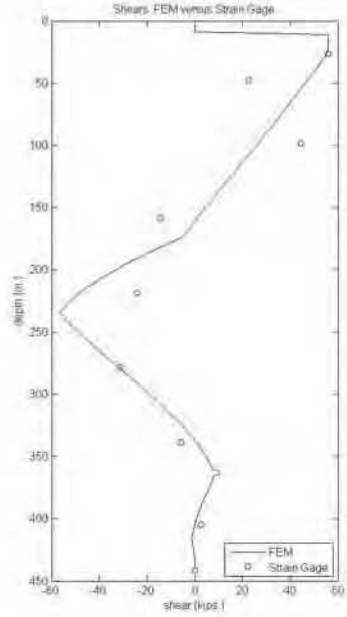




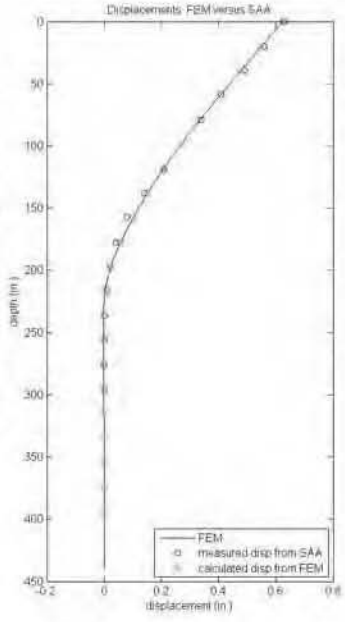
W10 56.1 kips

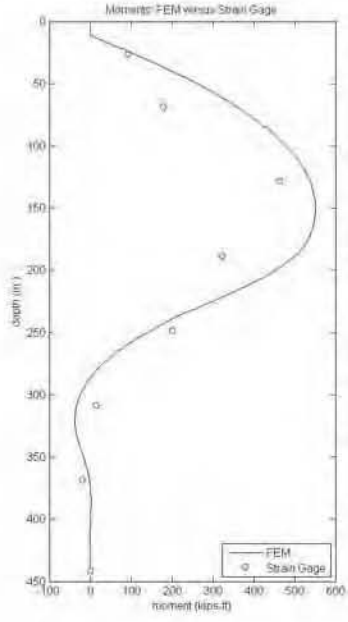


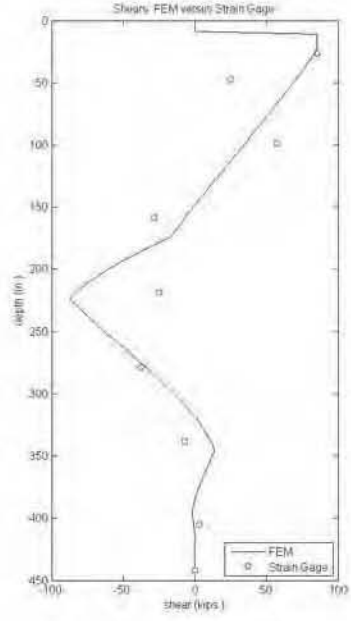




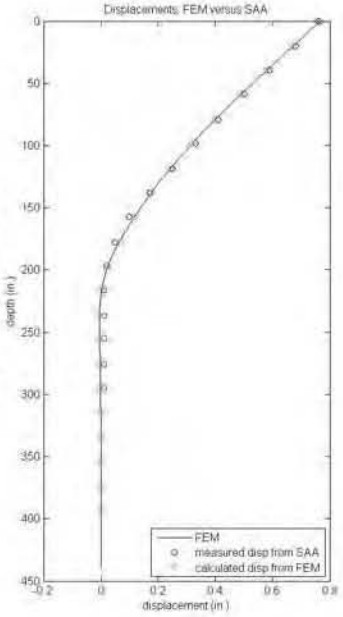
W10 85.3 kips

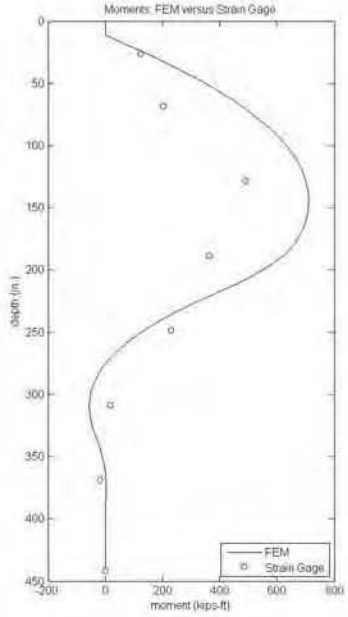


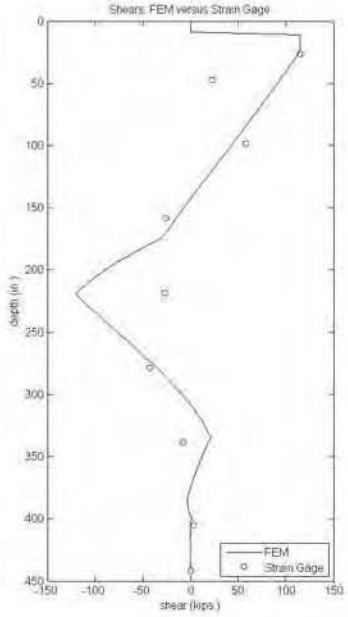




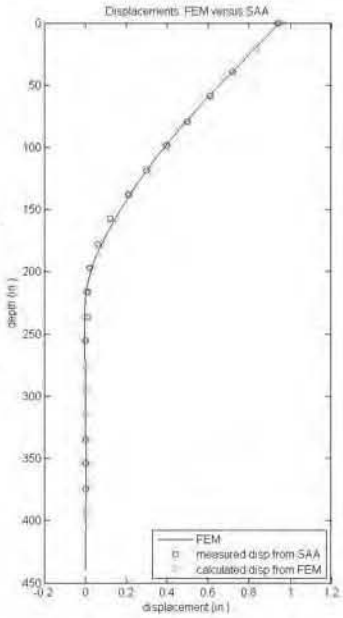
W10 114.5 kips

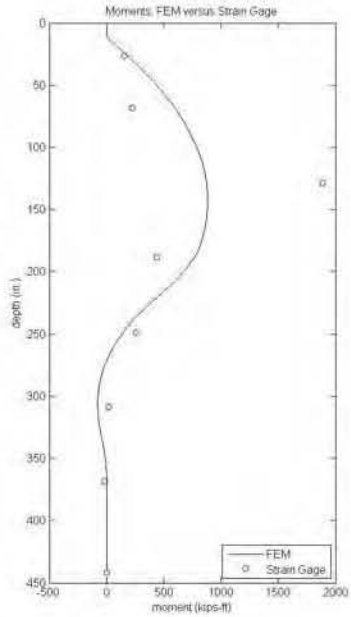


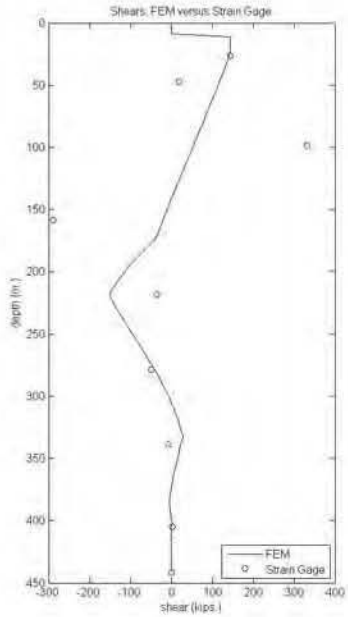




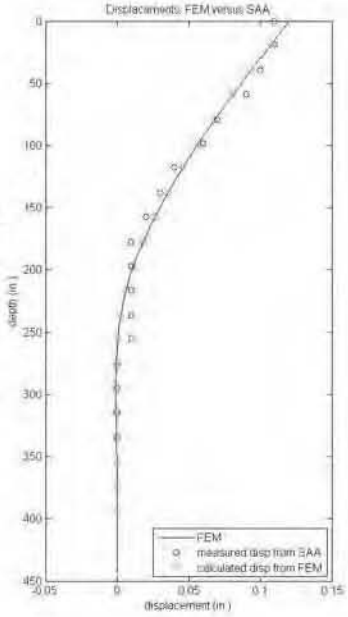
W10 143.8 kips

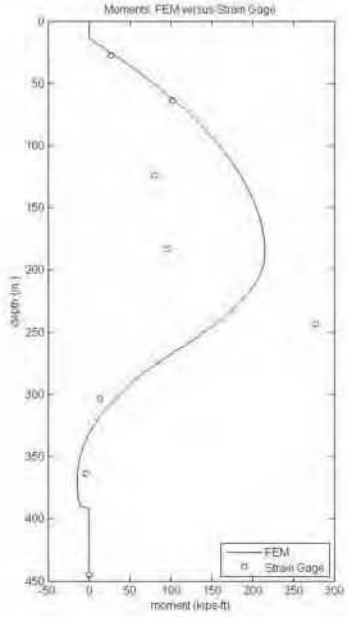


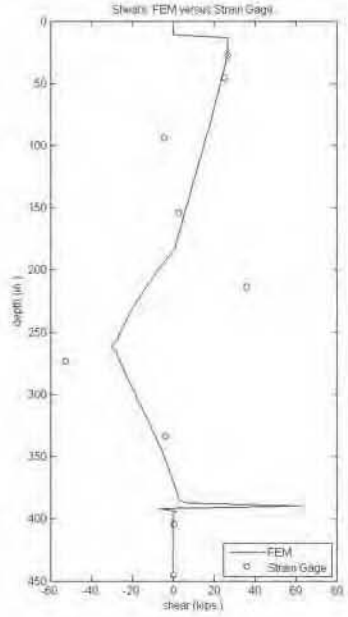




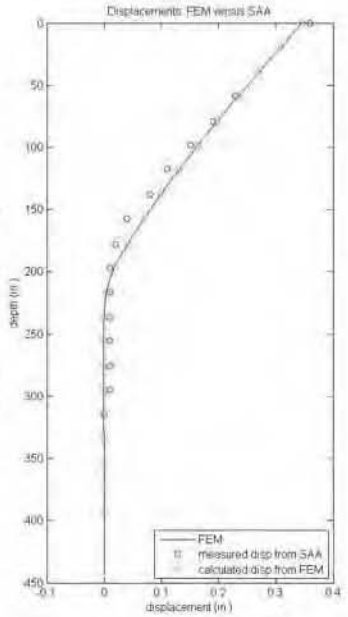
W11 26.8 kips

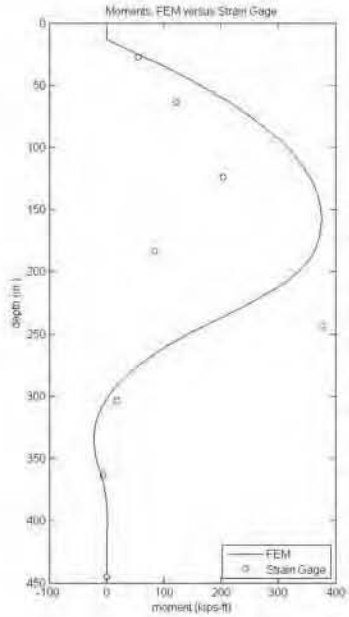


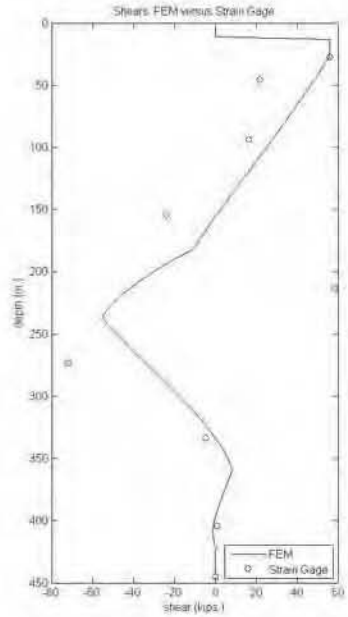




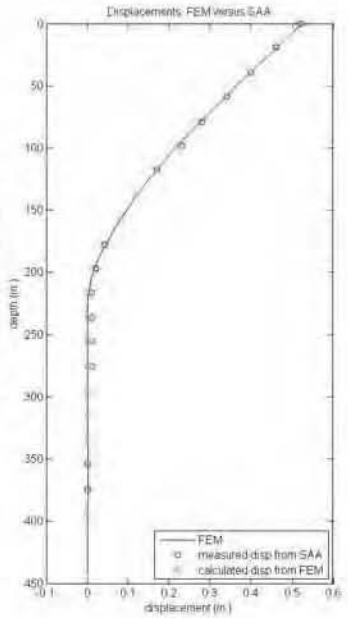
W11 56.1 kips

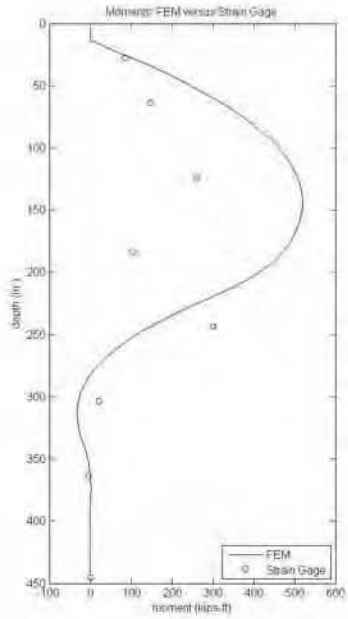


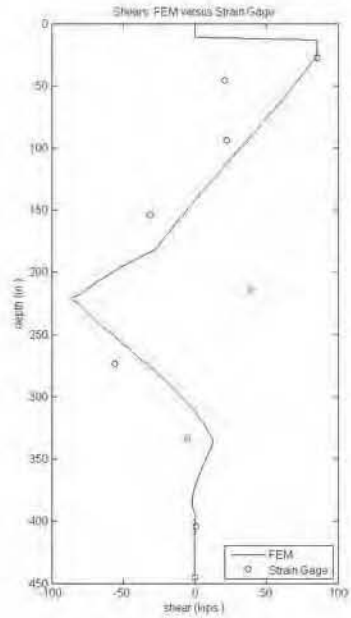




W11 85.3 kips







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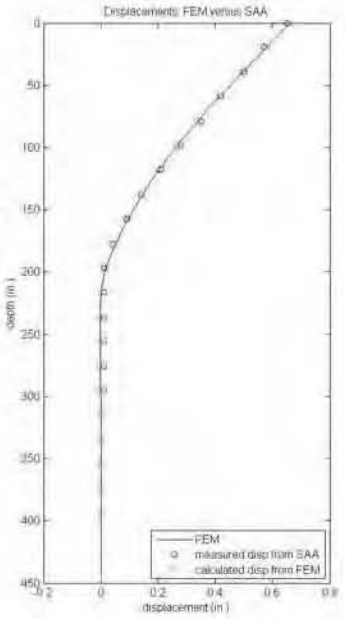
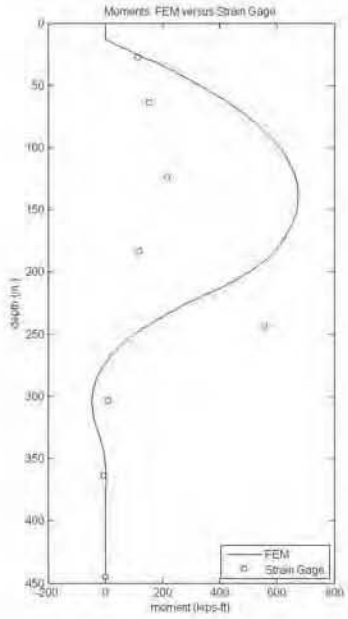
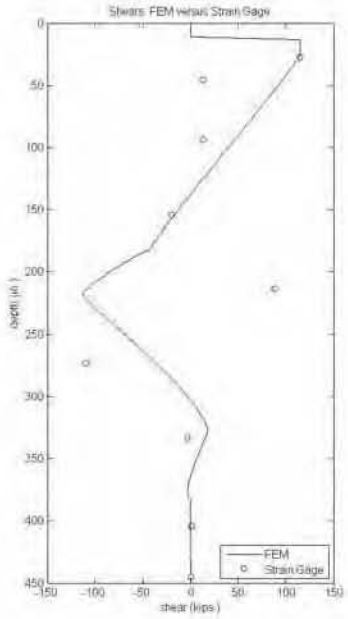
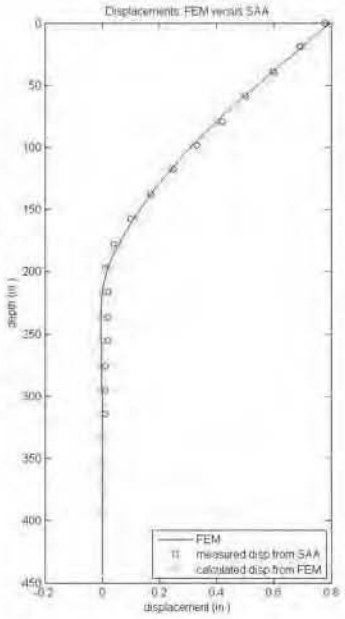
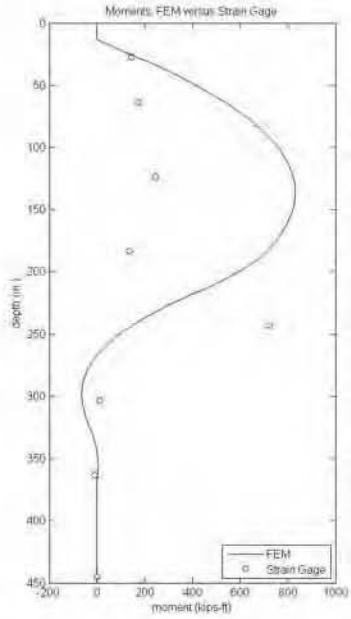


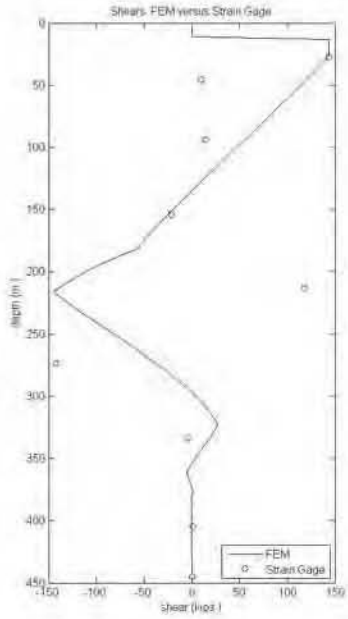




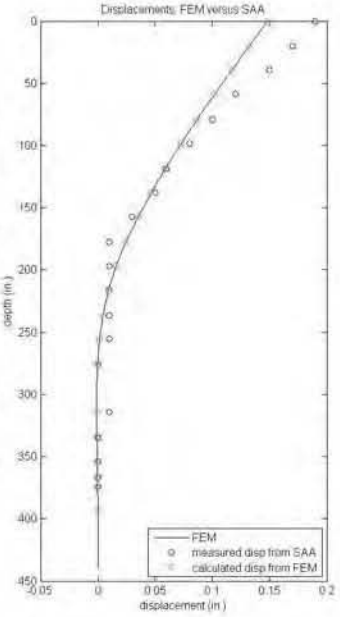
W11 143.8 kips

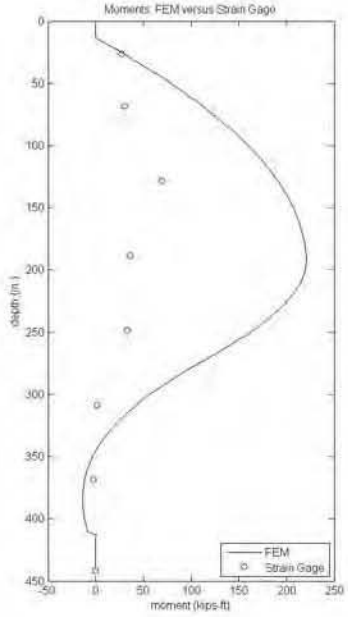


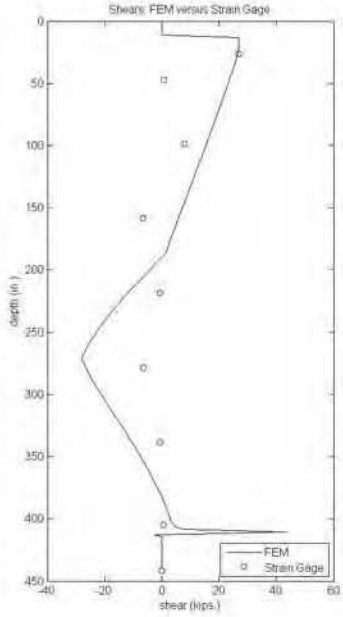




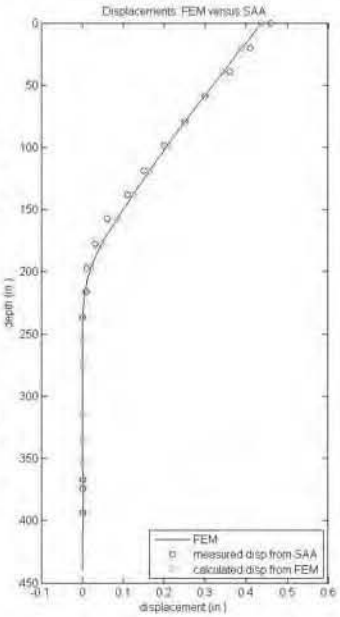
W10 Soil Removed 26.8 kips

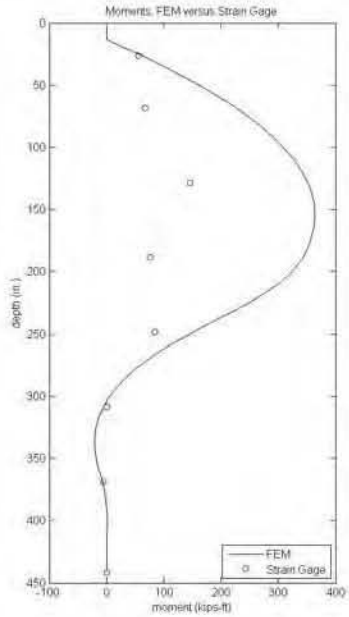


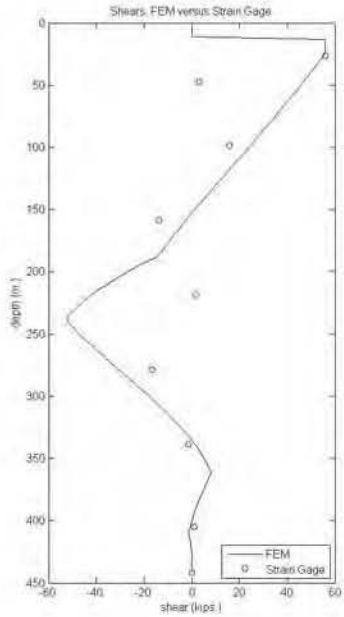




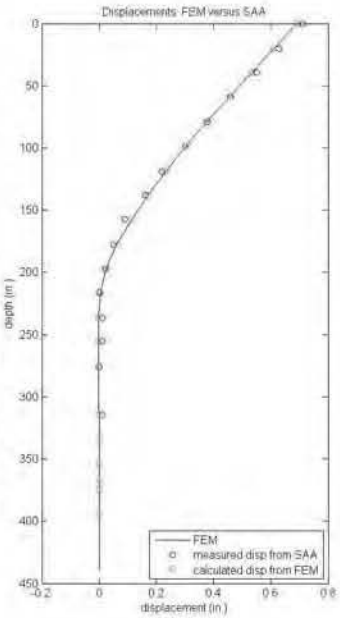
W10 Soil Removed 56.1 kips

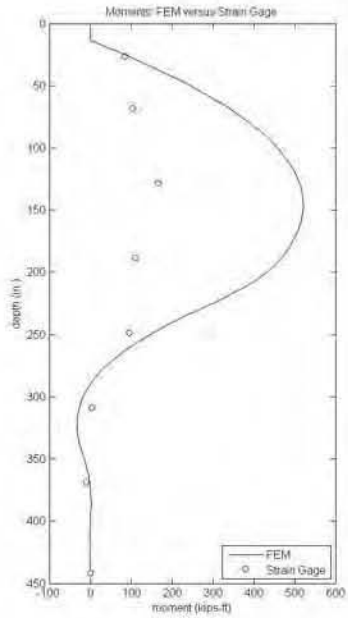


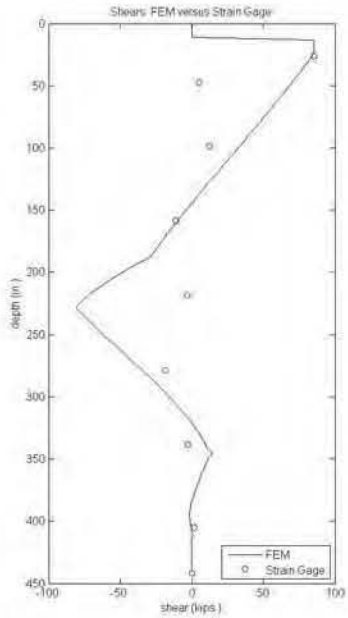




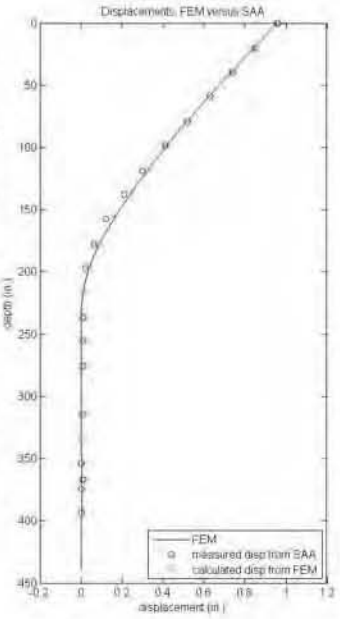
W10 Soil Removed 85.3 kips

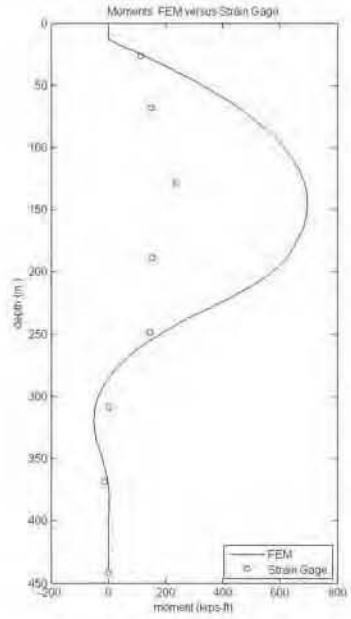


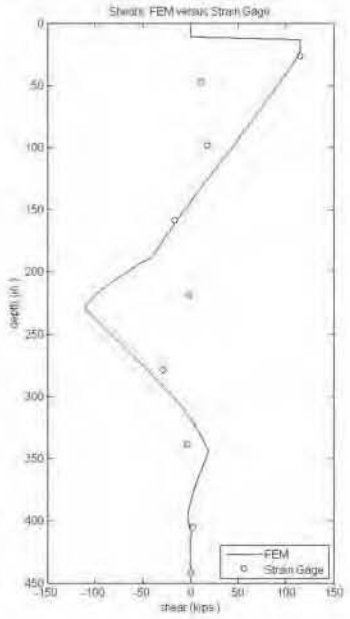




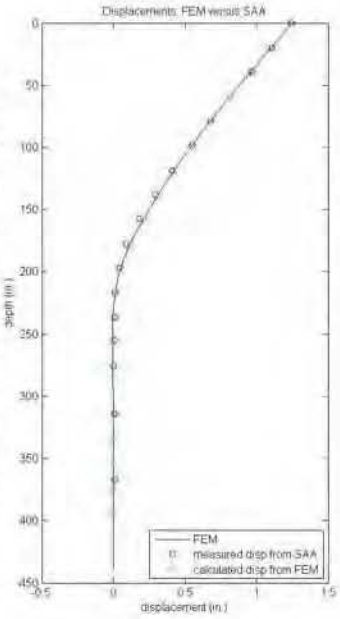
W10 Soil Removed 114.5 kips

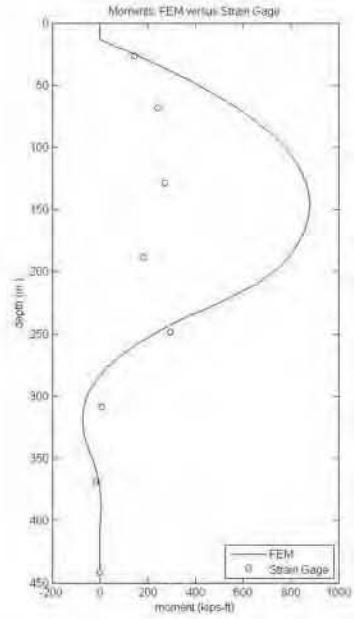


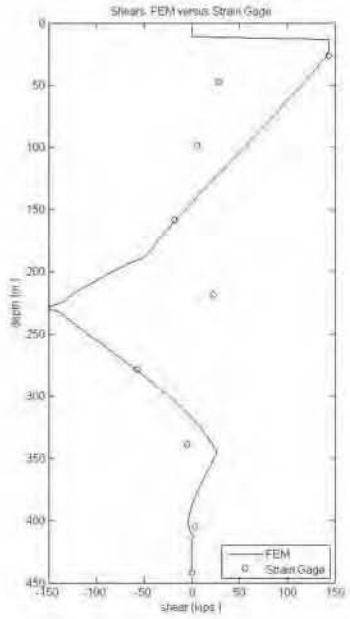




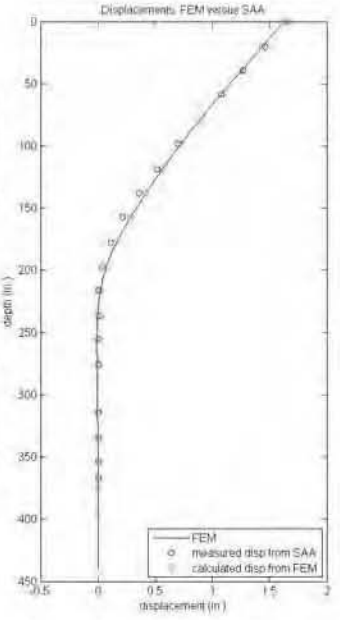
W10 Soil Removed 143.8 kips

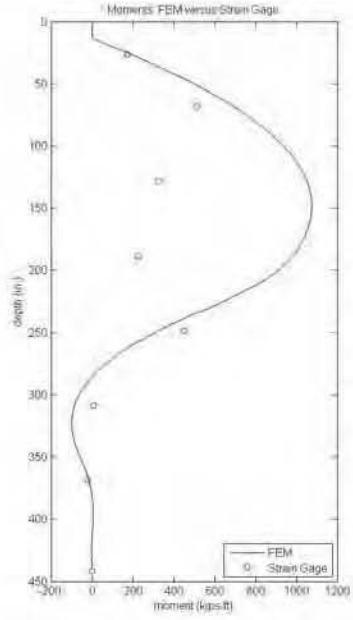


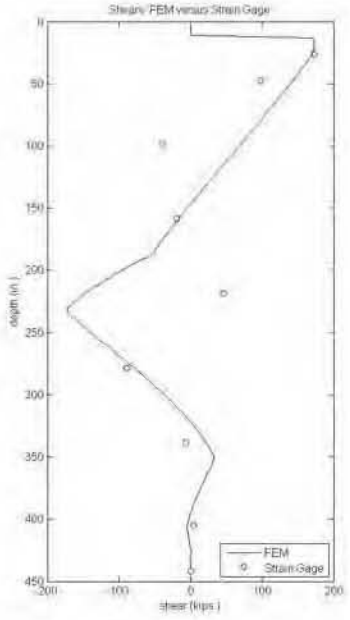




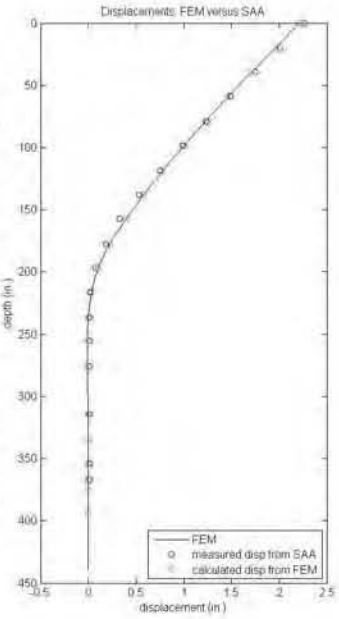
W10 Soil Removed 173.0 kips

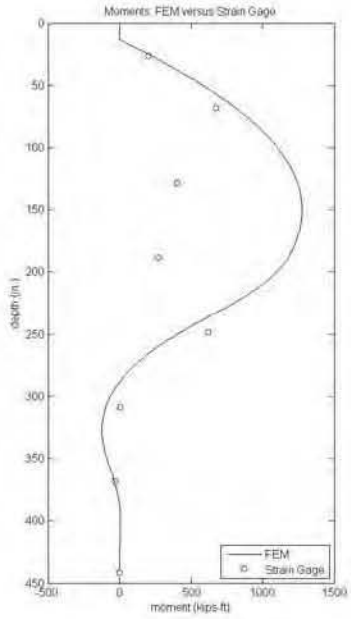


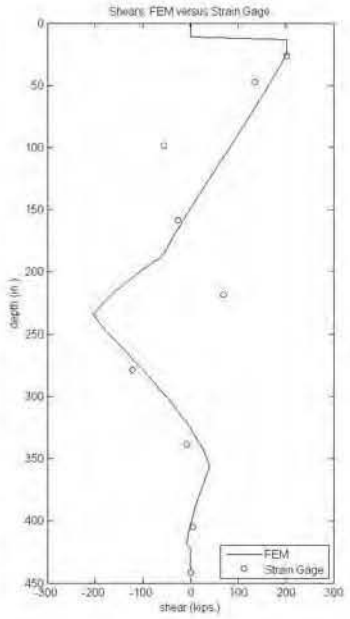




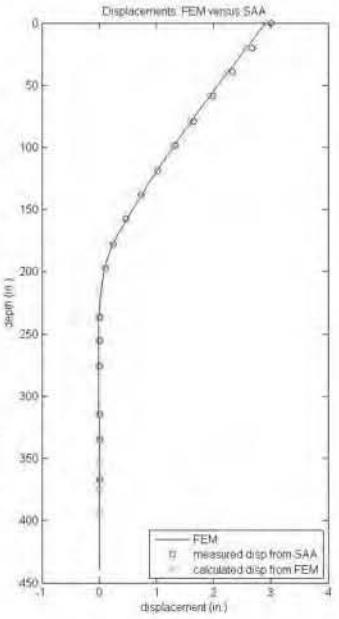
W10 Soil Removed 202.3 kips

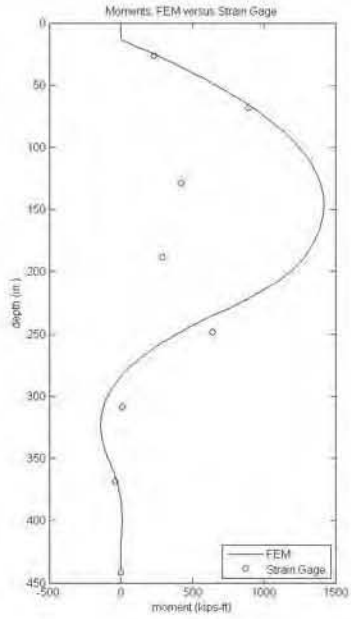


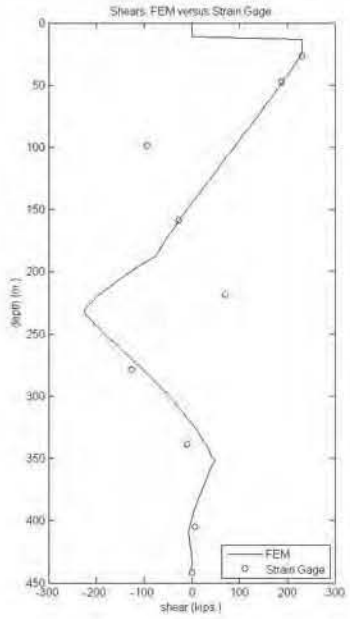




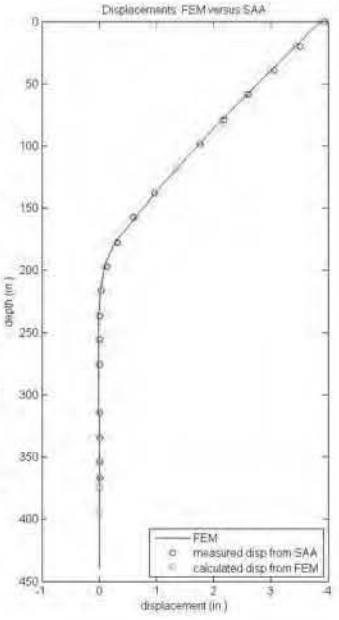
W10 Soil Removed 231.5 kips

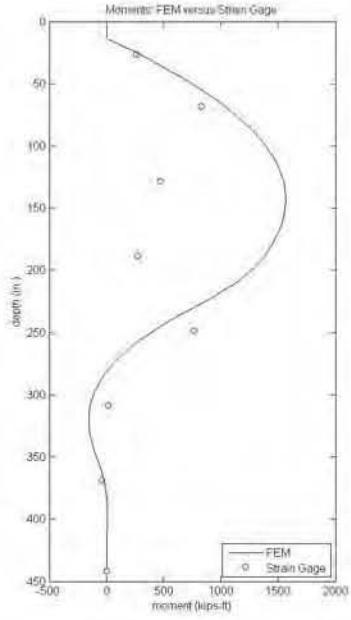


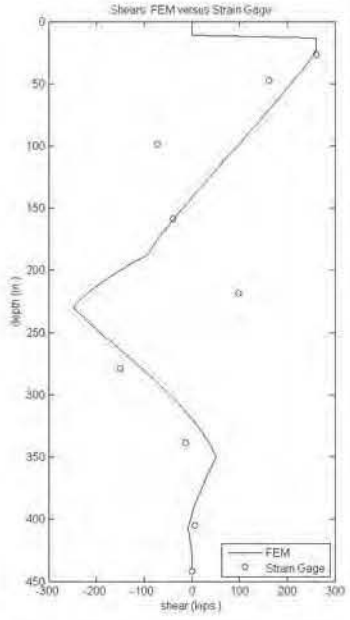




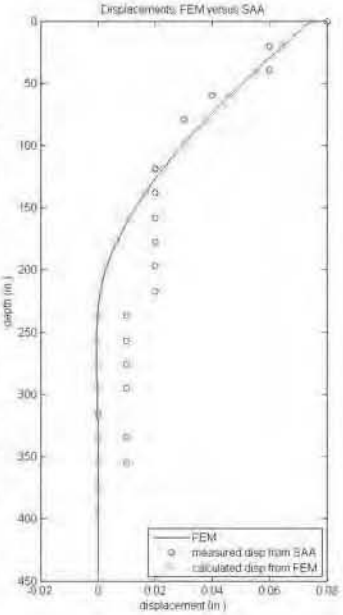
W10 Soil Removed 260.7 kips

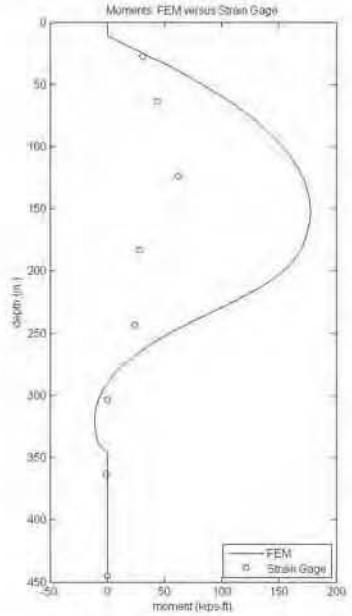


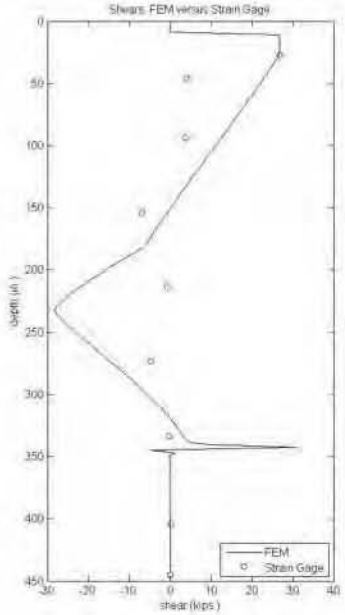




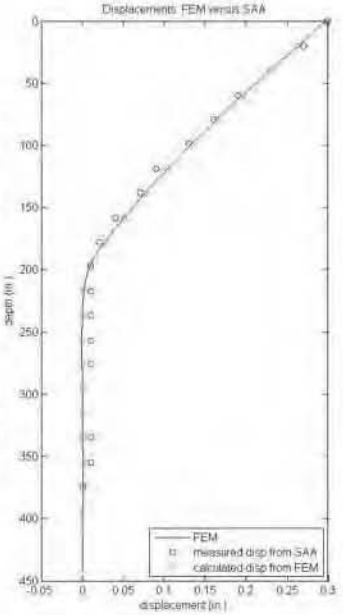
W11 Soil Removed 26.8 kips

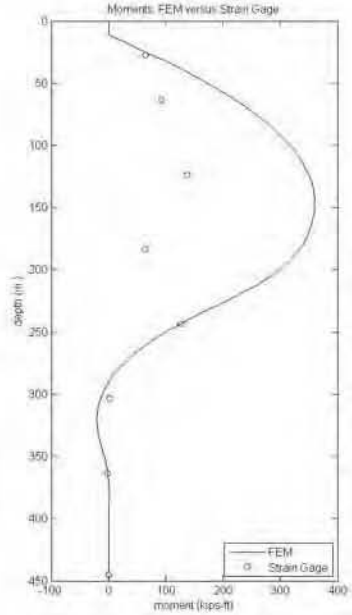


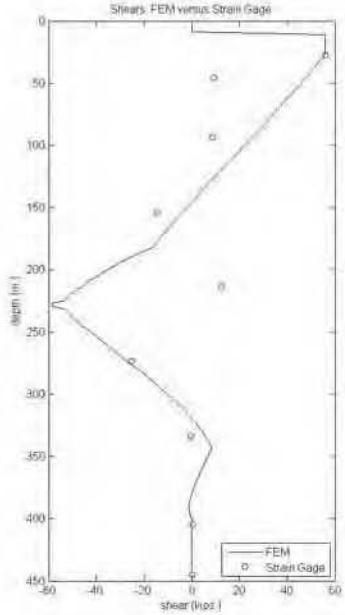




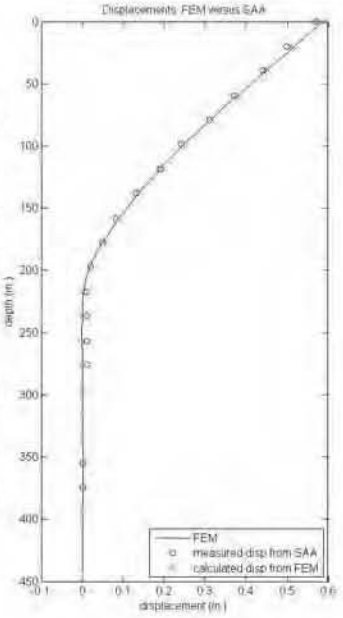
W11 Soil Removed 56.1 kips

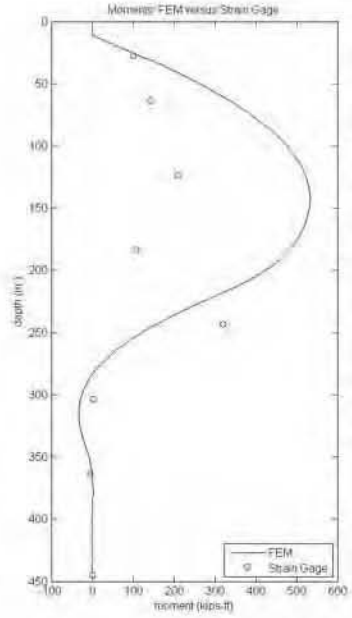


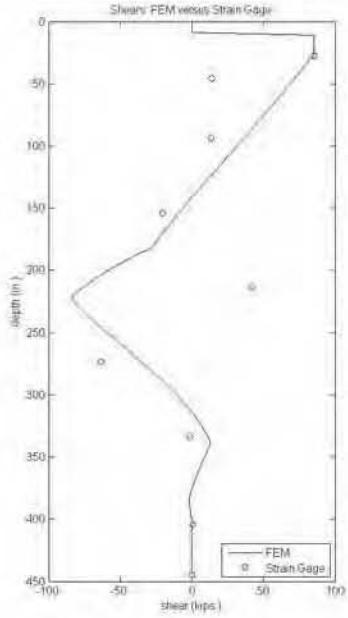




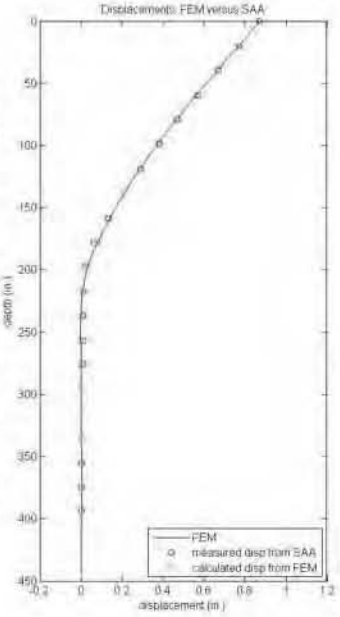
W11 Soil Removed 85.3 kips

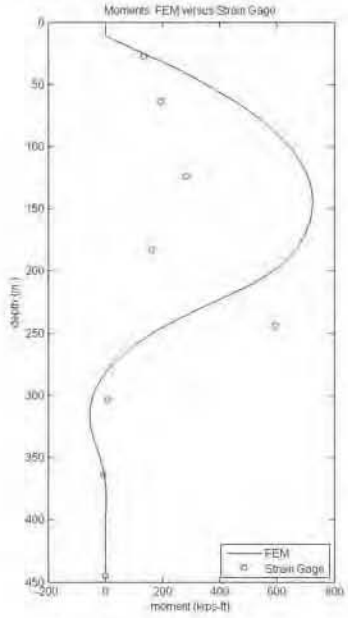


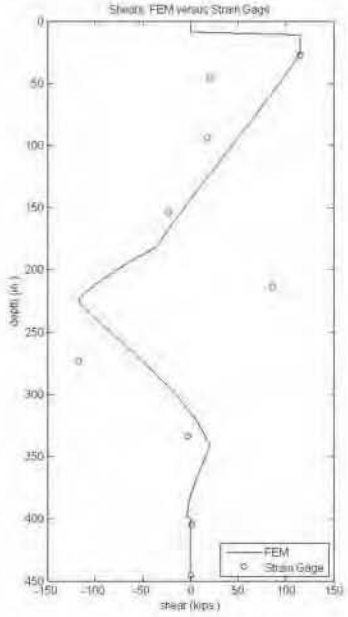




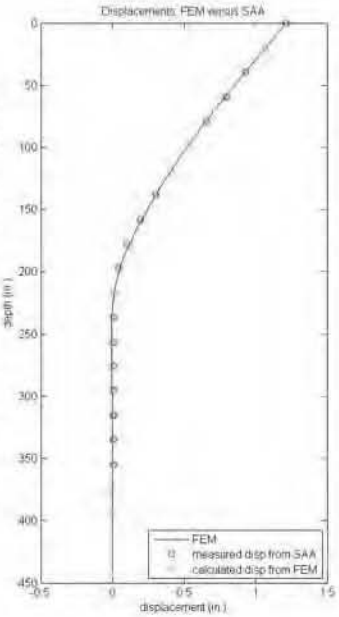
W11 Soil Removed 114.5 kips

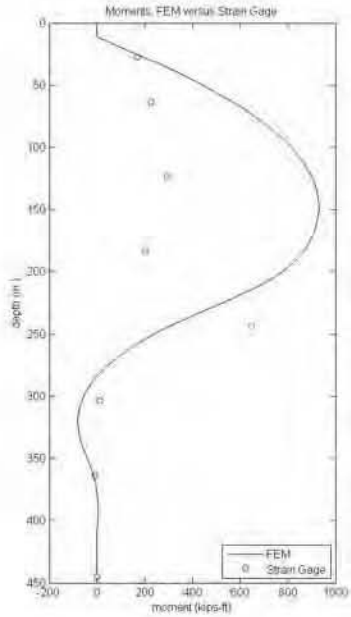


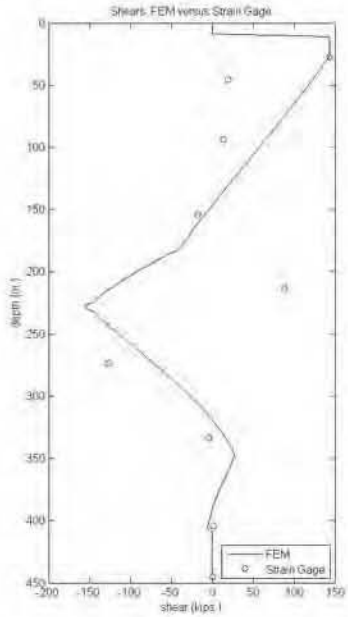




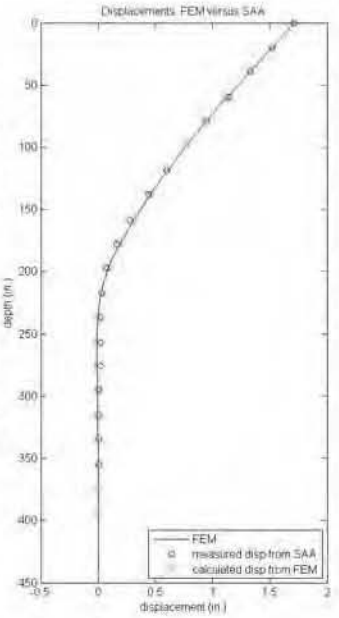
W11 Soil Removed 143.8 kips

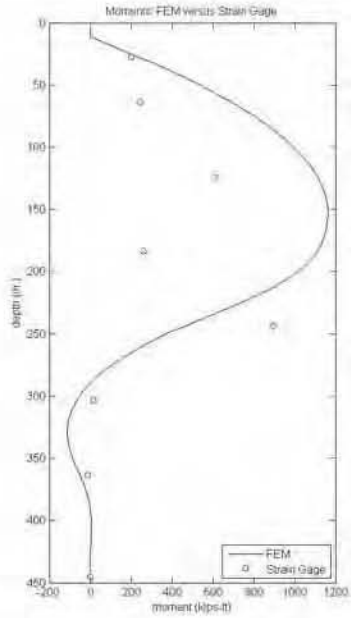


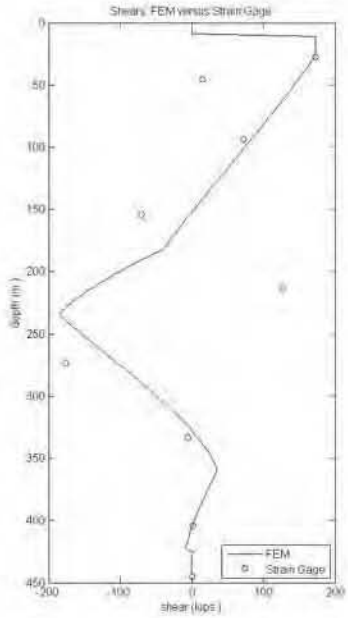




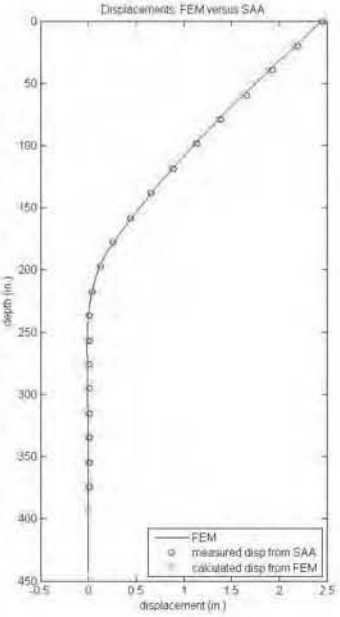
W11 Soil Removed 173.0 kips

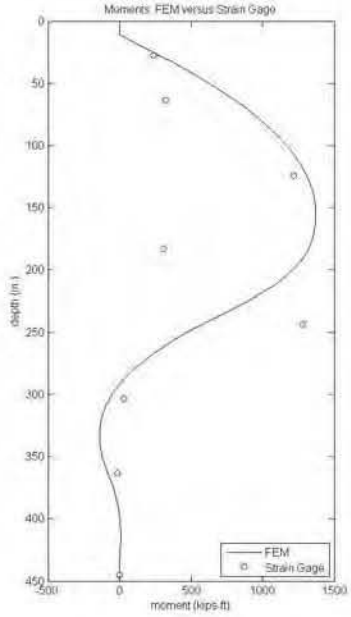


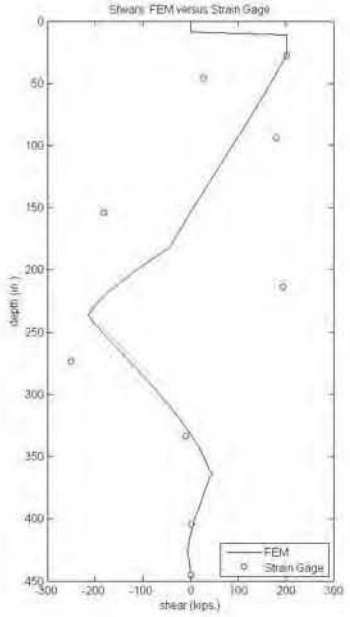




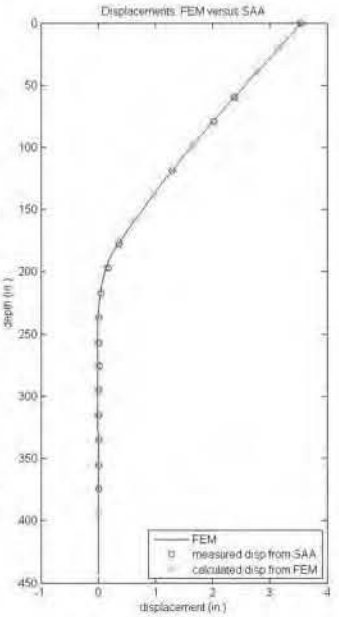
W11 Soil Removed 202.3 kips

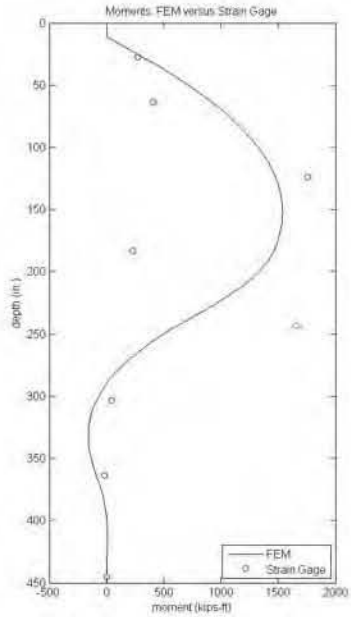


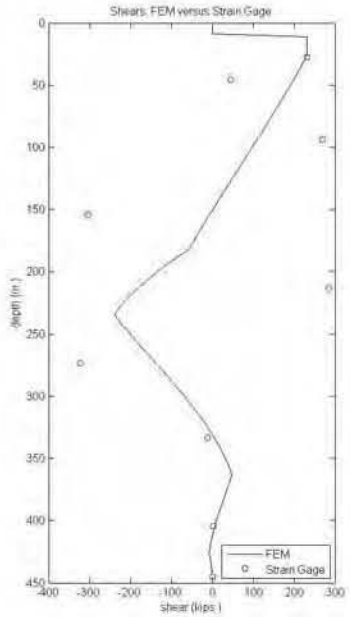




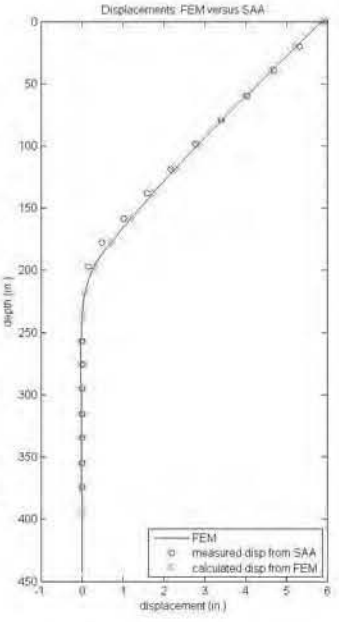
W11 Soil Removed 231.5 kips

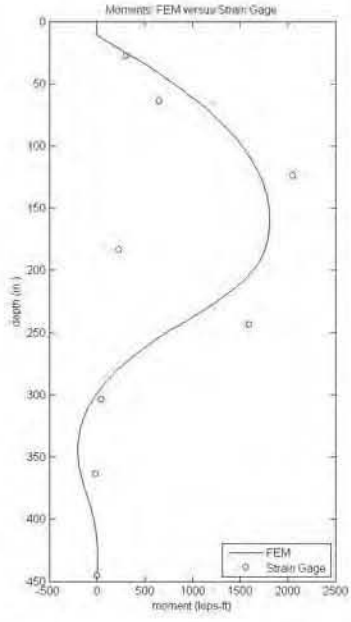


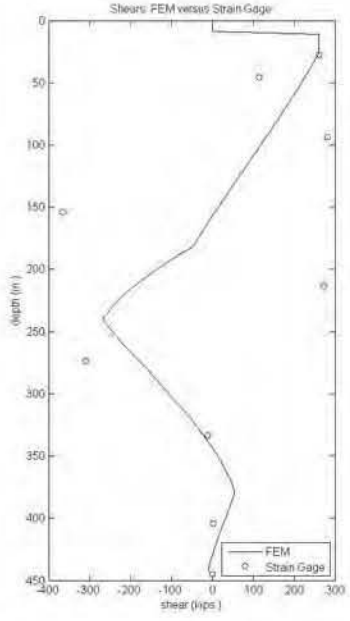




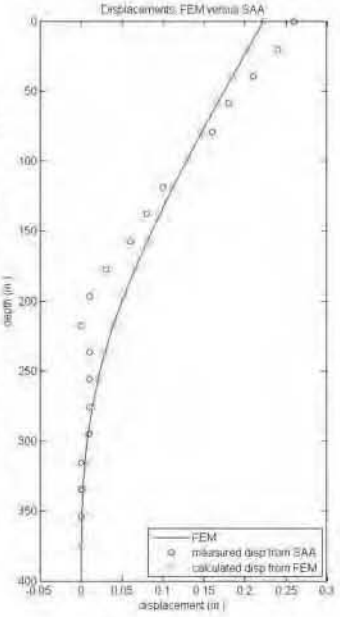
W11 Soil Removed 260.7 kips

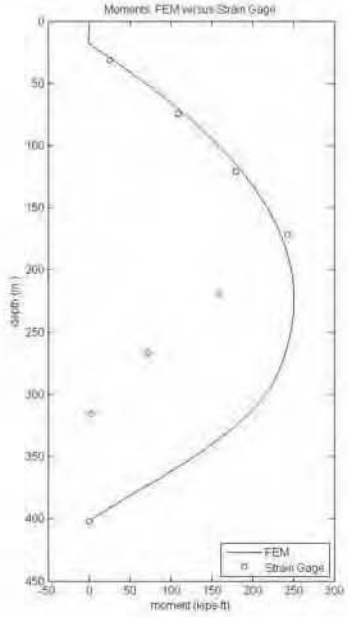


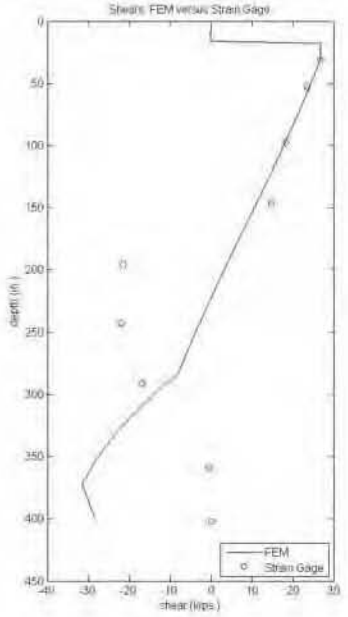




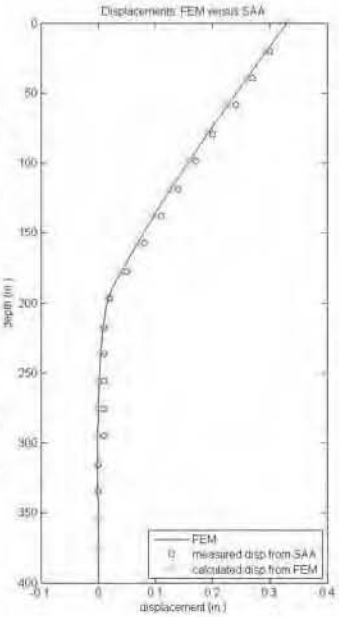
W12 Soil Removed 26.8 kips

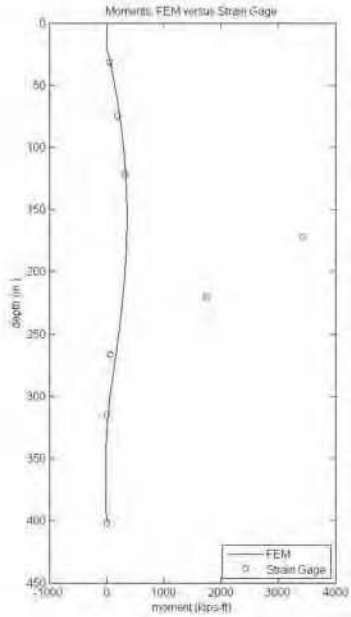


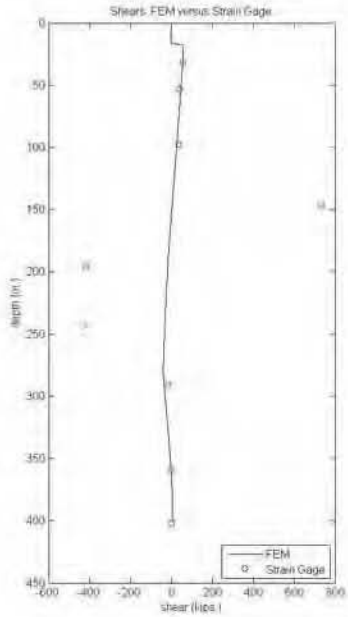




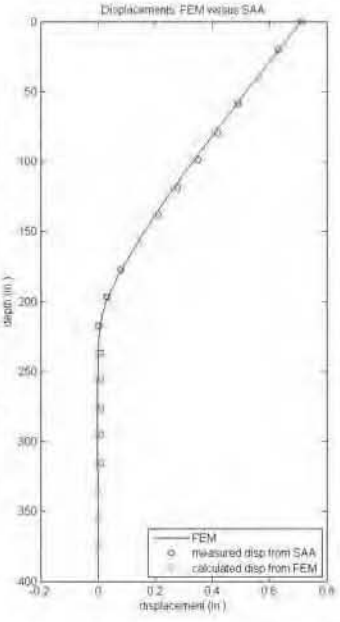
W12 Soil Removed 56.1 kips

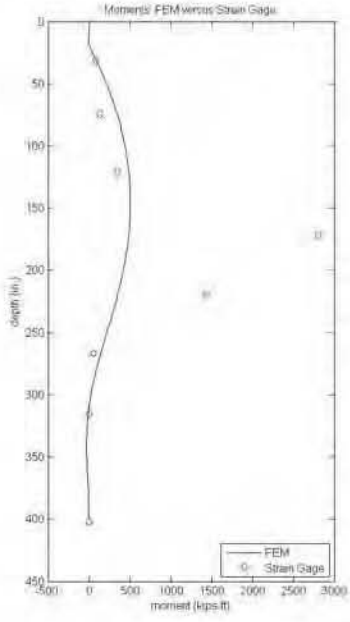


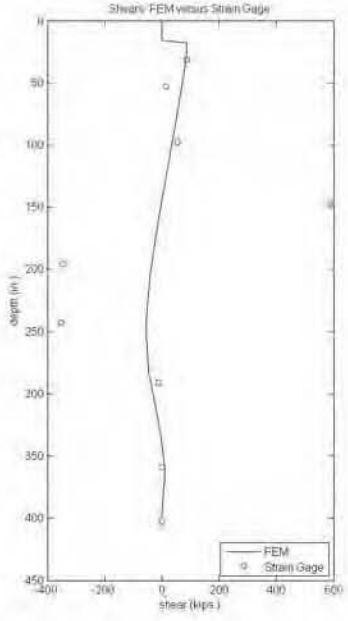




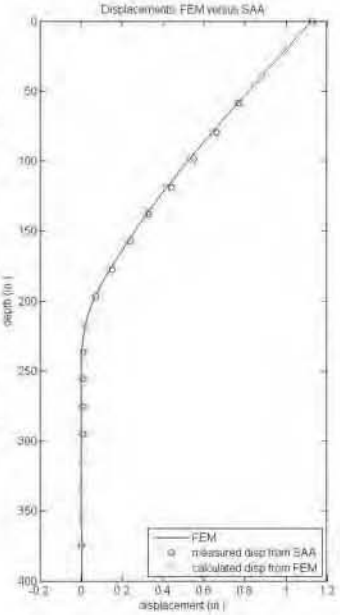
W12 Soil Removed 85.3 kips

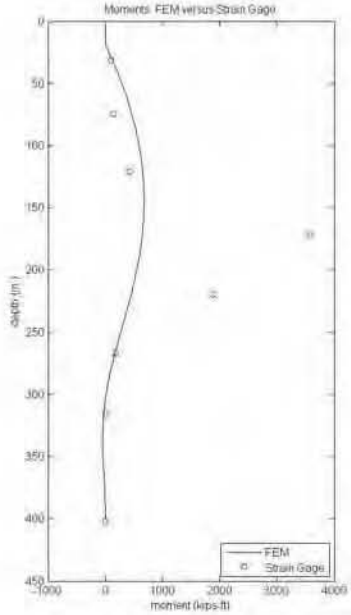


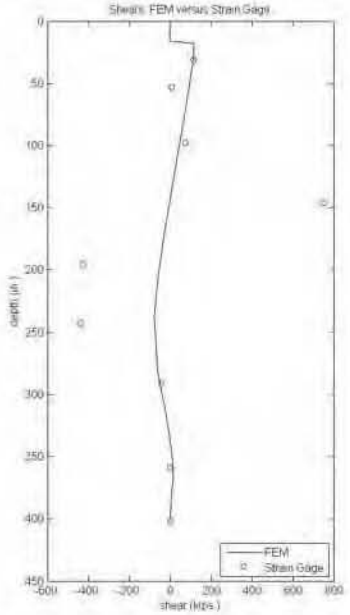




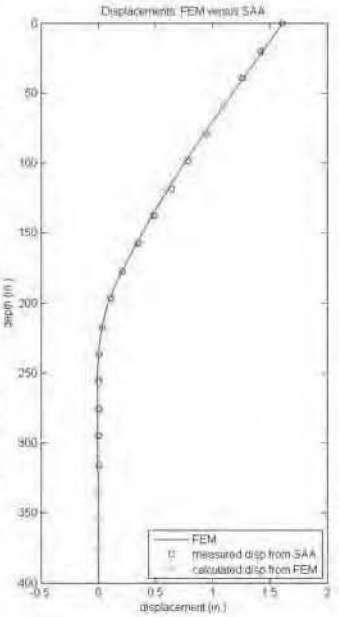
W12 Soil Removed 114.5 kips

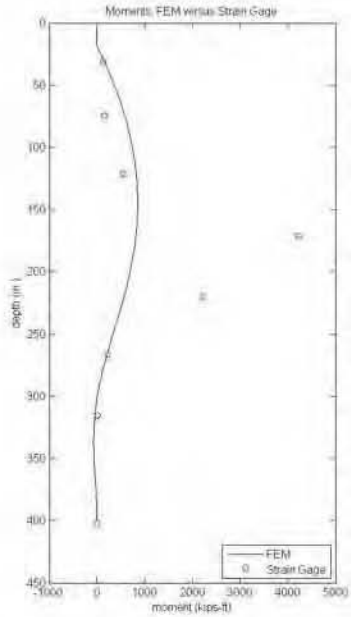


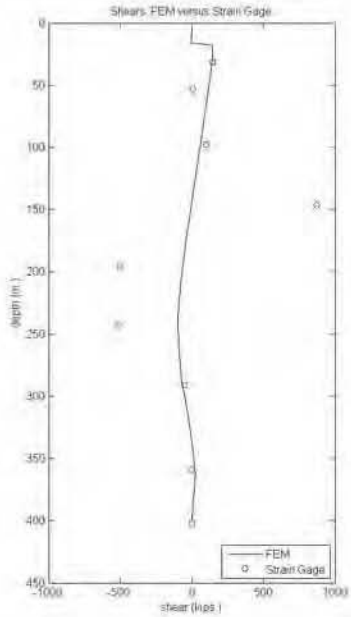




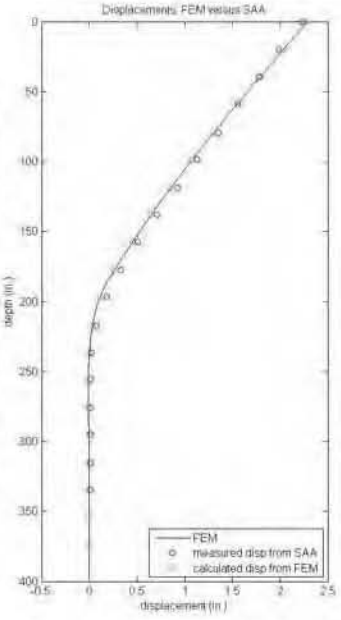
W12 Soil Removed 143.8 kips

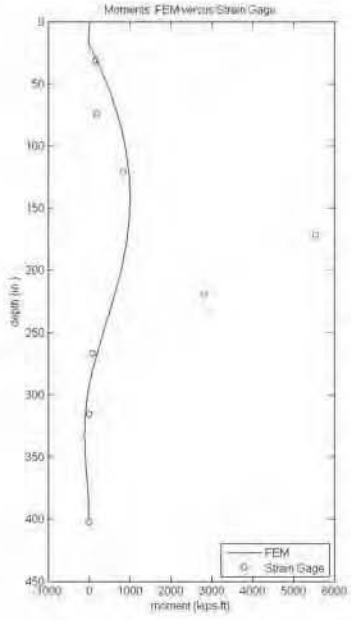


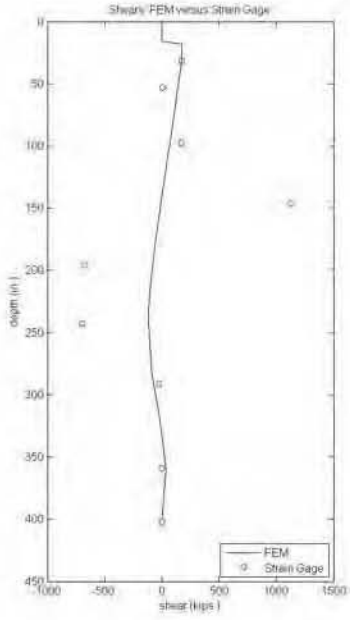




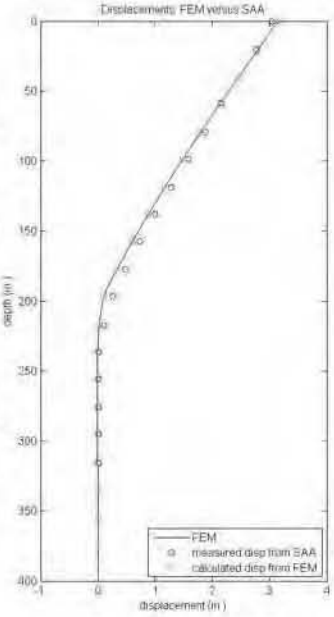
W12 Soil Removed 173.0 kips

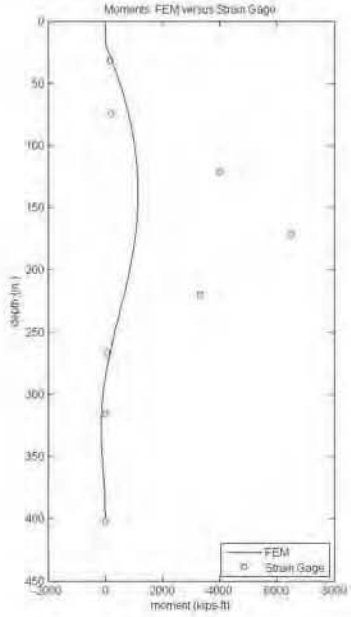


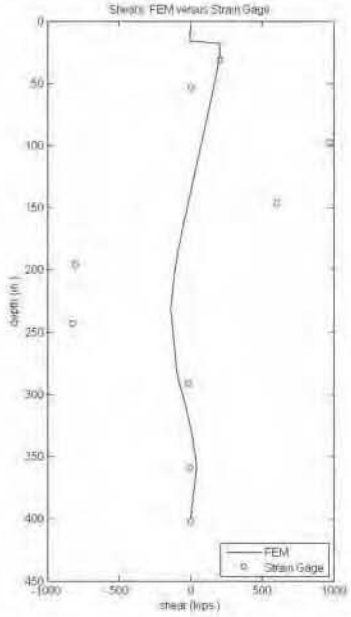




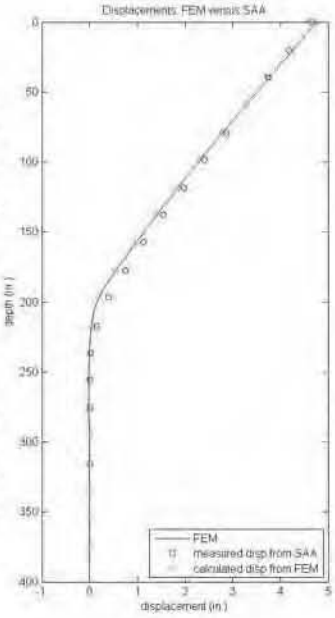
W12 Soil Removed 202.3 kips

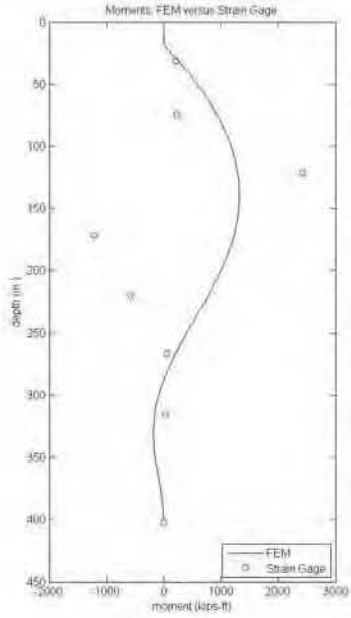


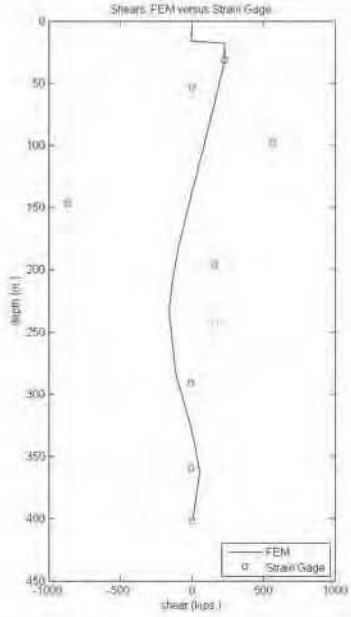




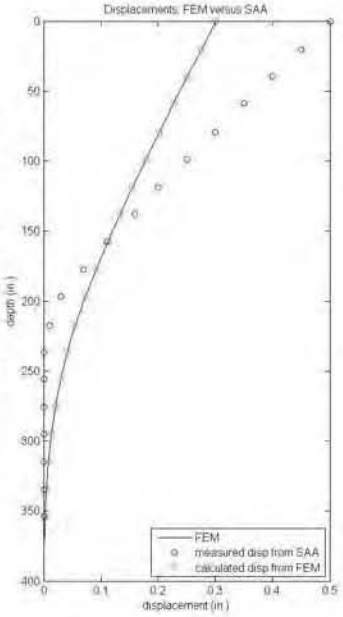
W12 Soil Removed 231.5 kips

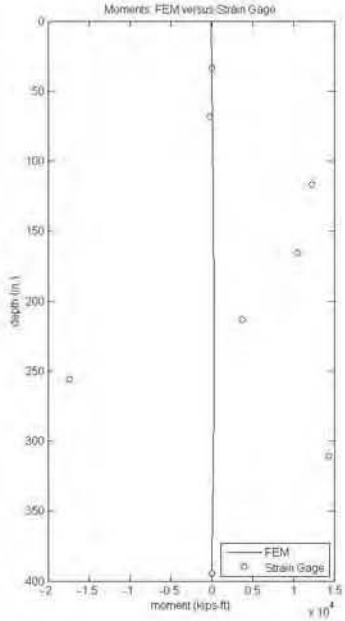


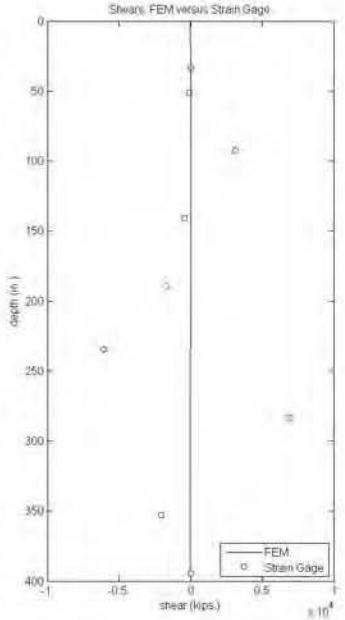




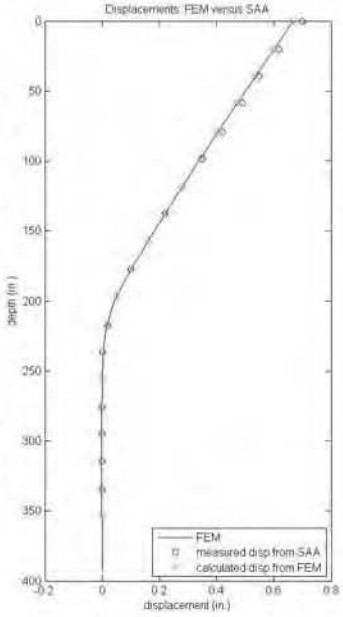
W13 Soil Removed 26.8 kips

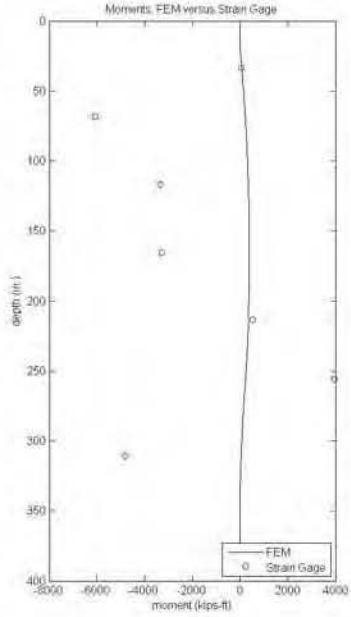


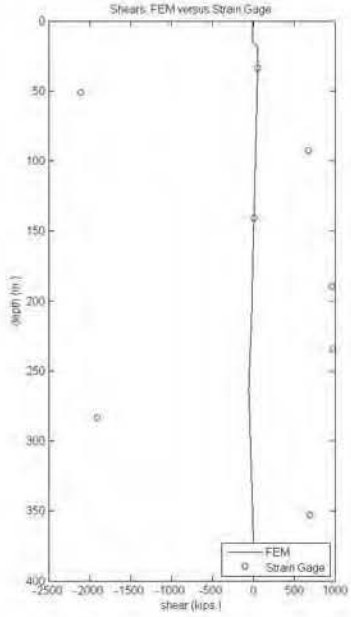




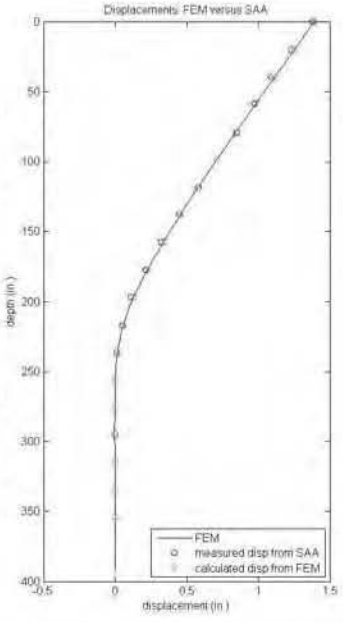
W13 Soil Removed 56.1 kips

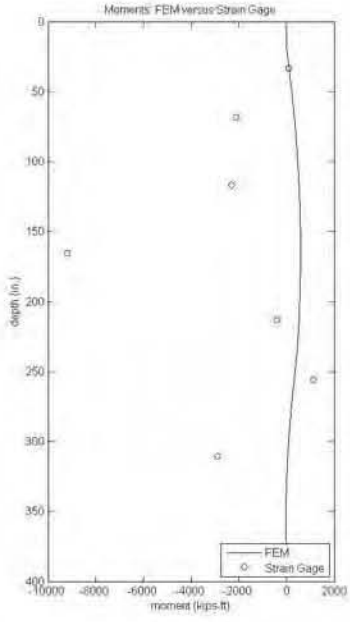


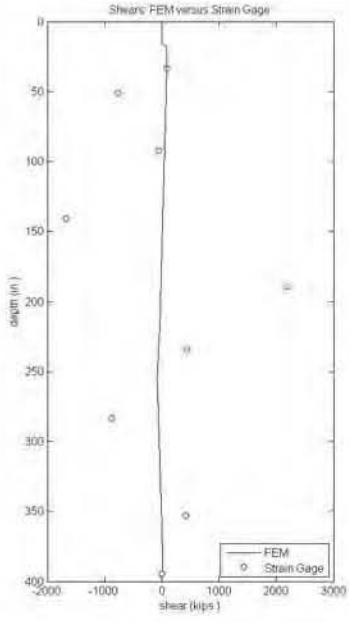




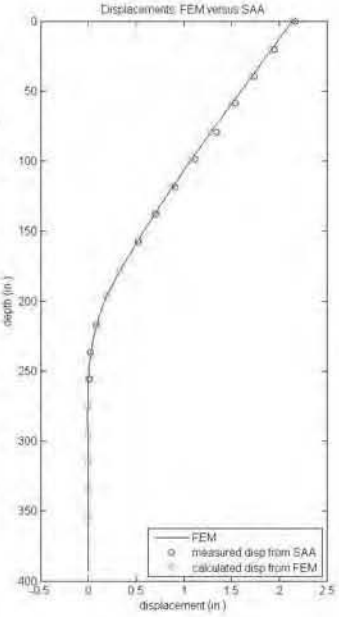
W13 Soil Removed 85.3 kips

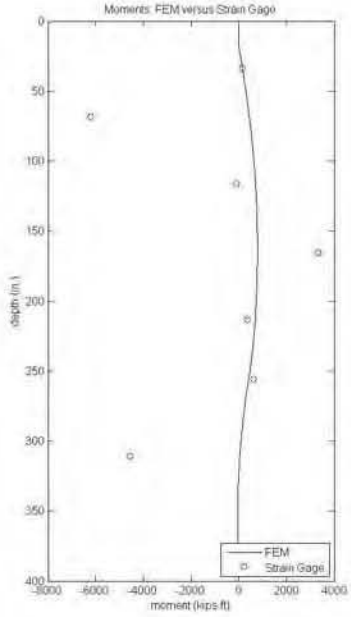


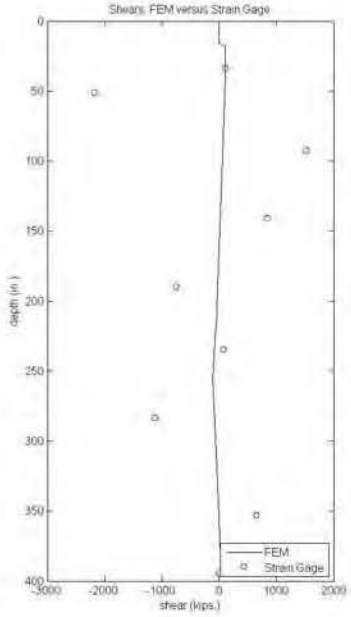




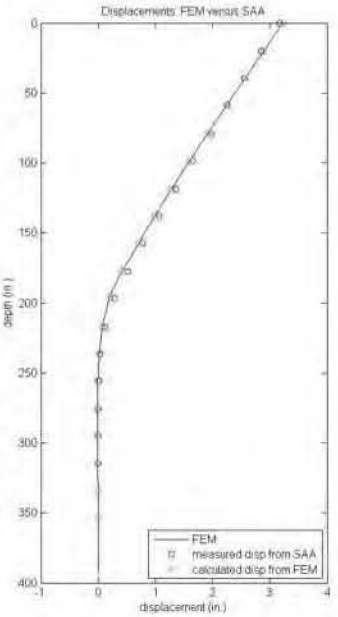
W13 Soil Removed 114.5 kips

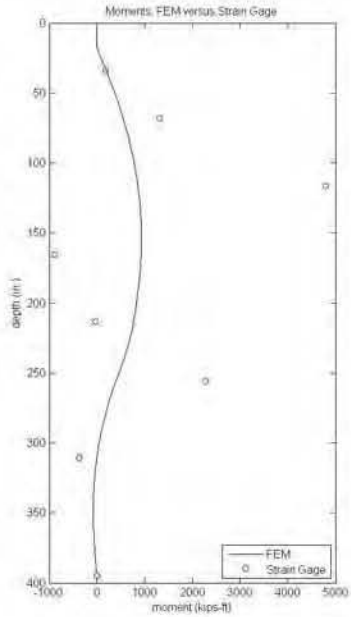


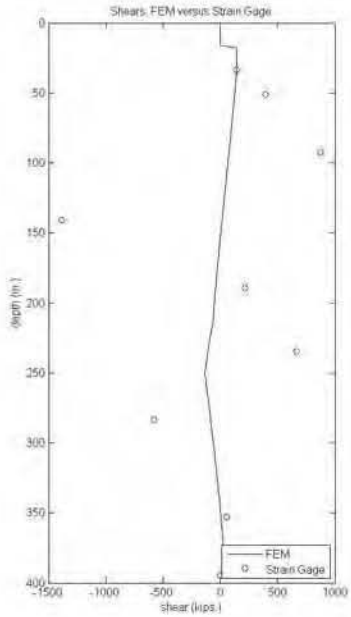




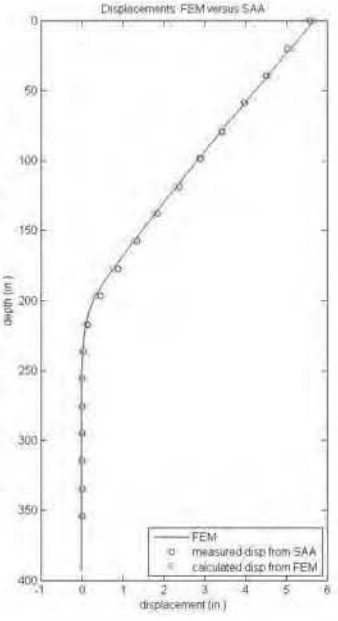
W13 Soil Removed 143.8 kips

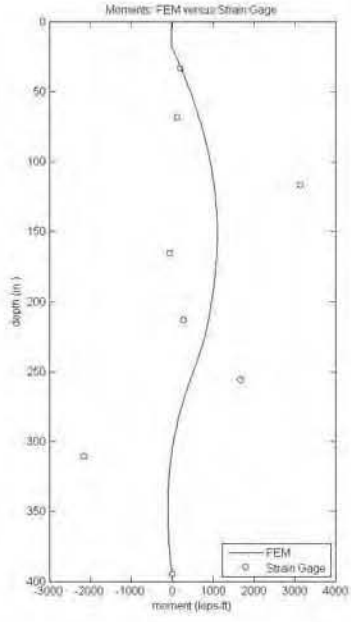


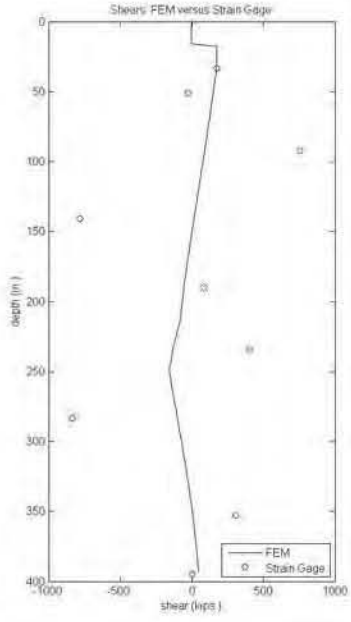




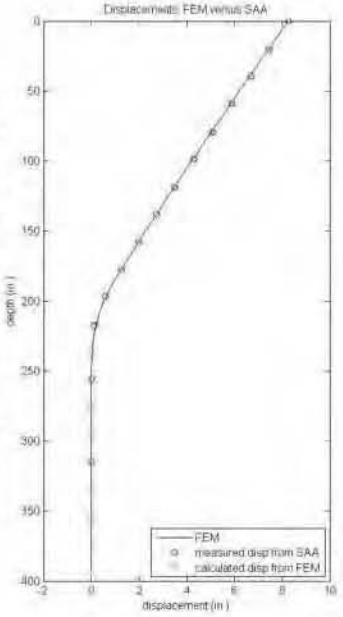
W13 Soil Removed 173.0 kips

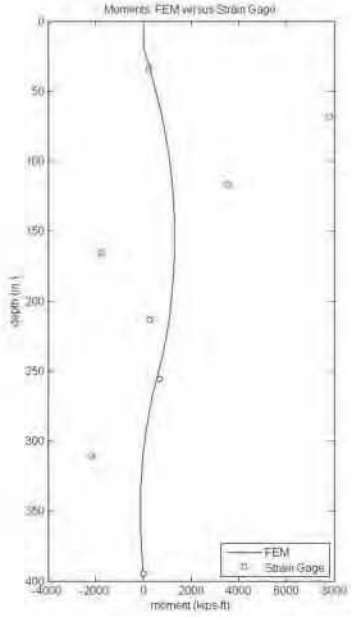


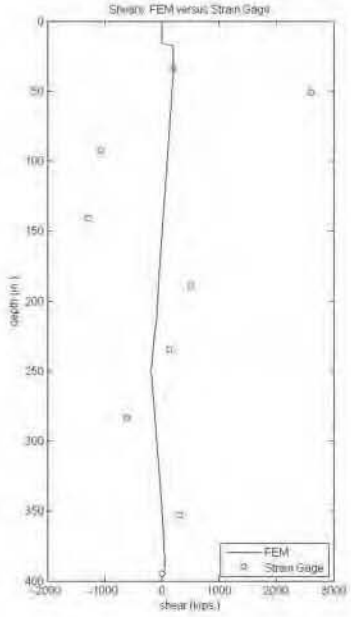




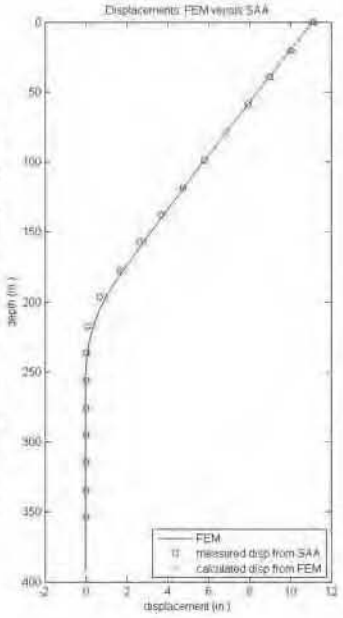
W13 Soil Removed 202.3 kips

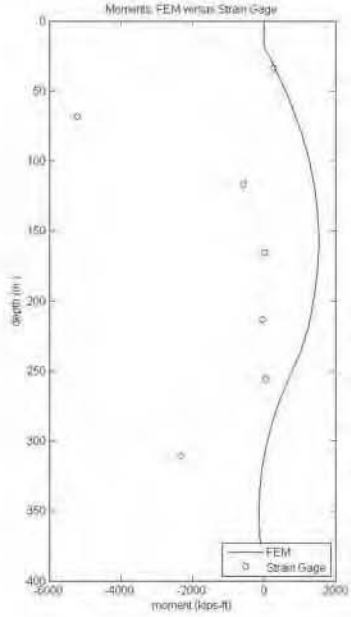


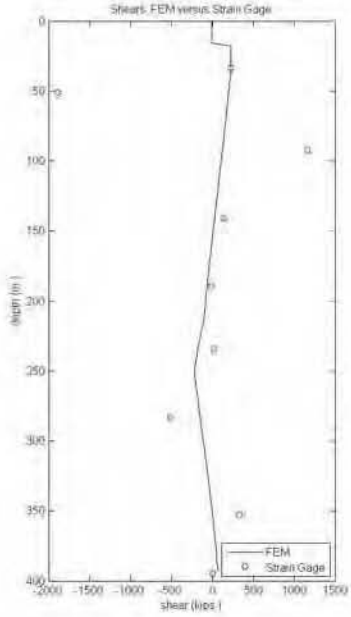




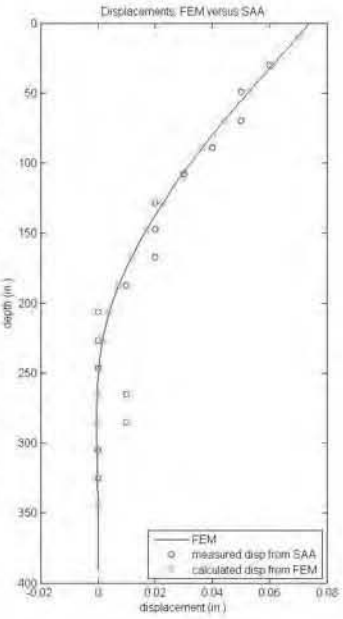
W13 Soil Removed 231.5 kips

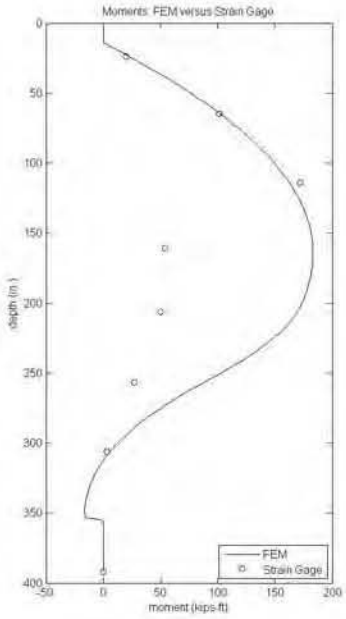


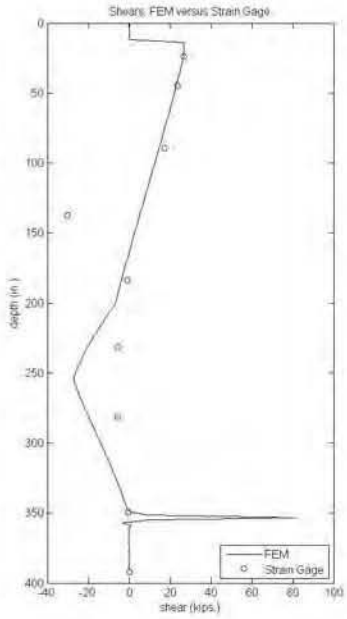




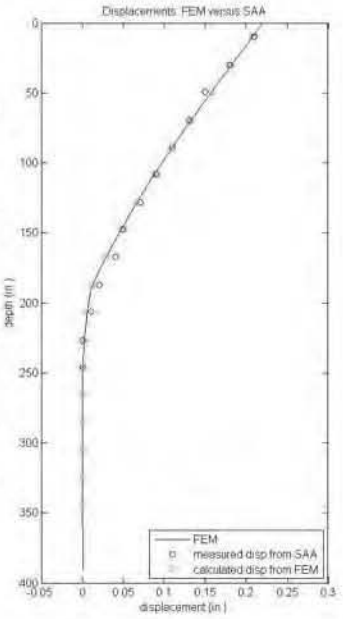
W14 Soil Removed 26.8 kips

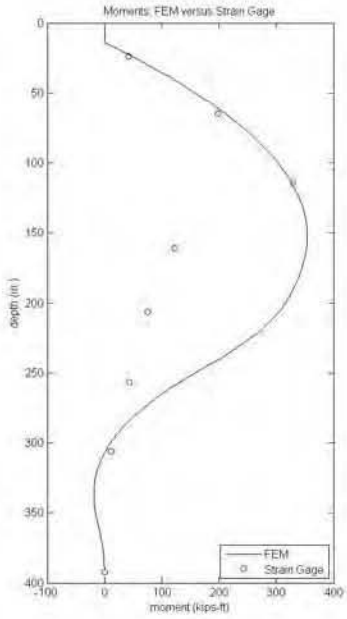


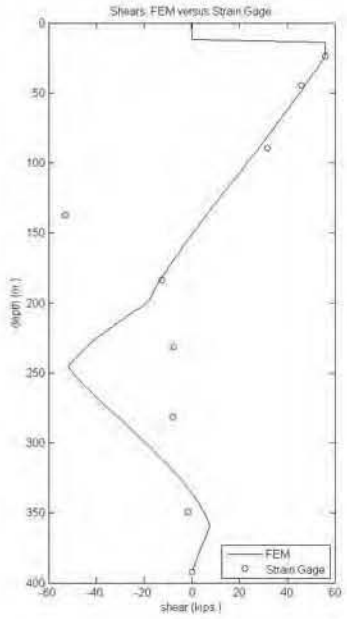




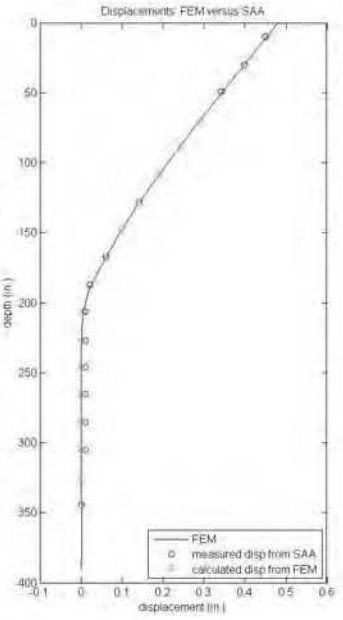
W14 Soil Removed 56.1 kips

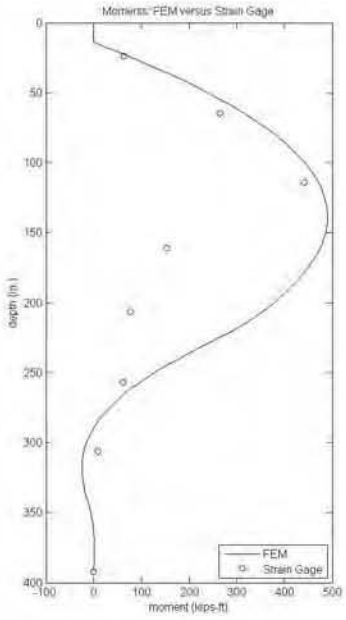


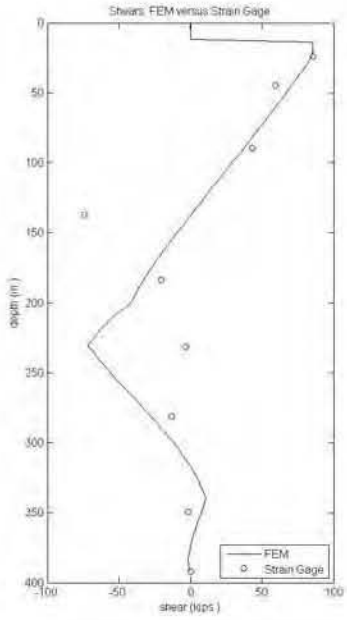




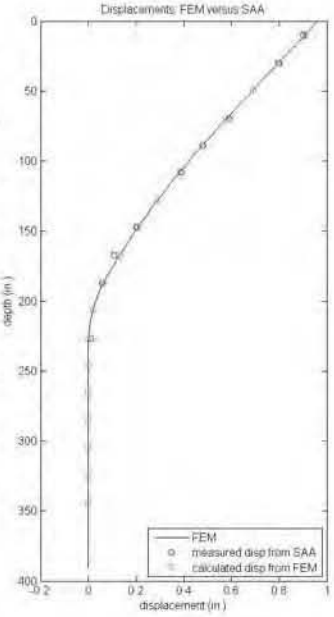
W14 Soil Removed 85.3 kips

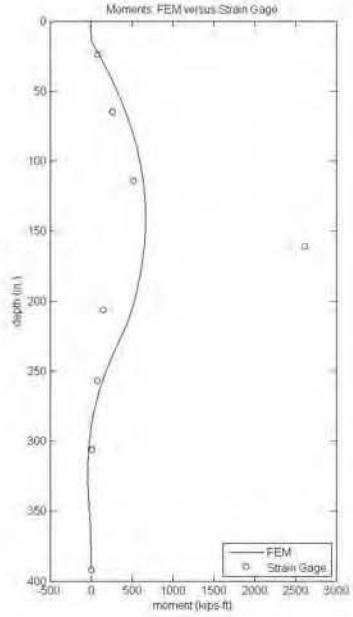


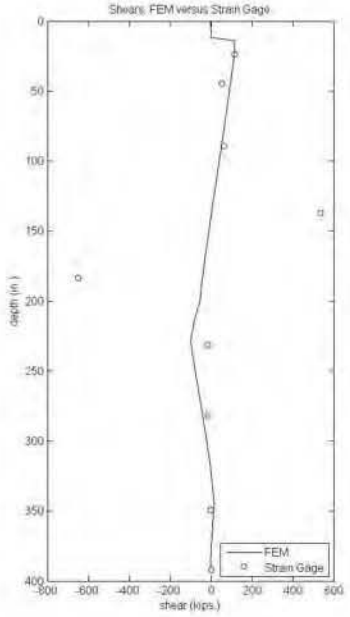




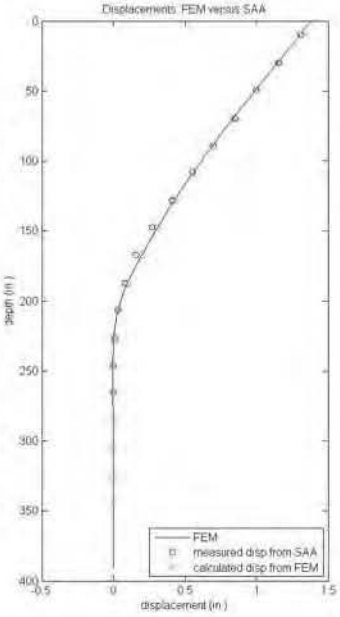
W14 Soil Removed 114.5 kips

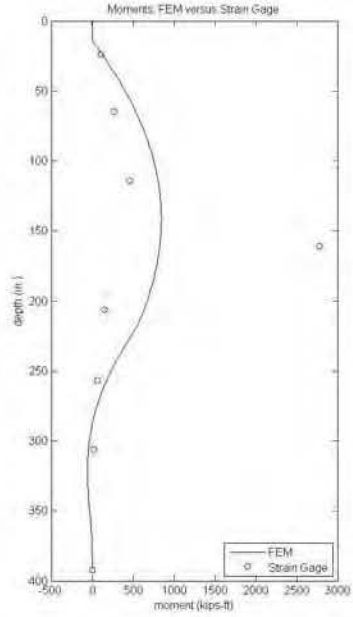


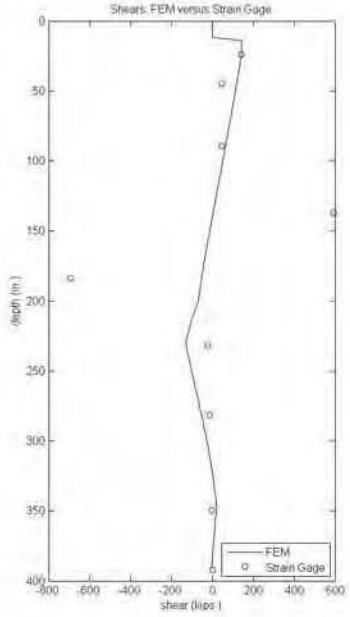




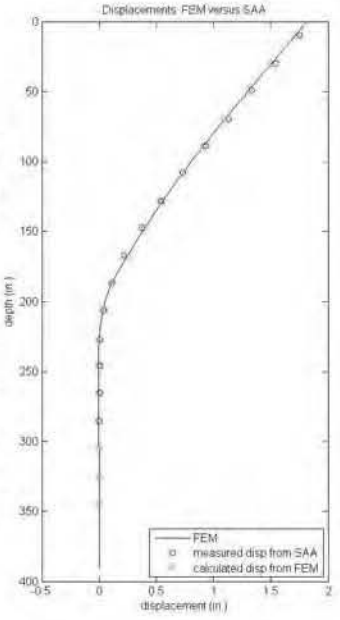
W14 Soil Removed 143.8 kips

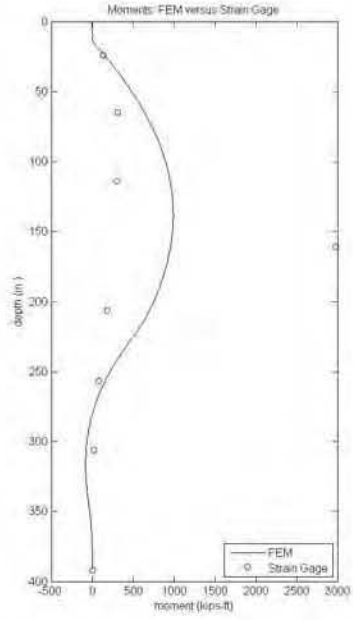


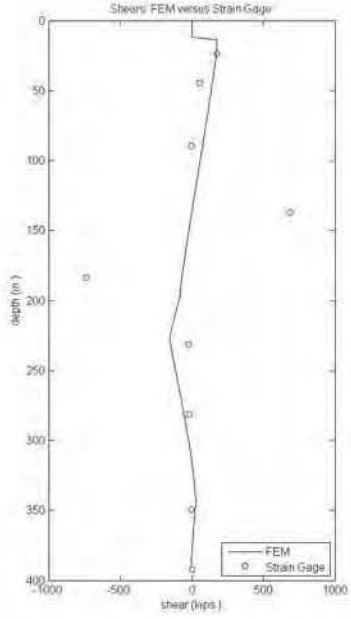




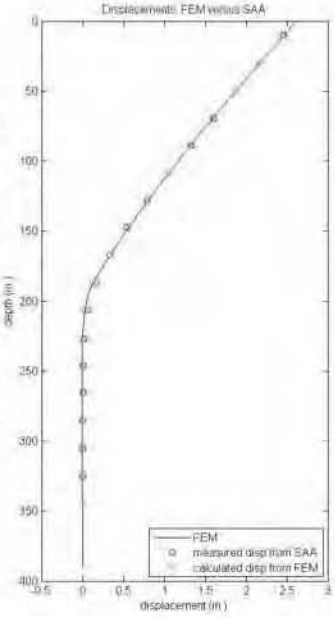
W14 Soil Removed 173.0 kips

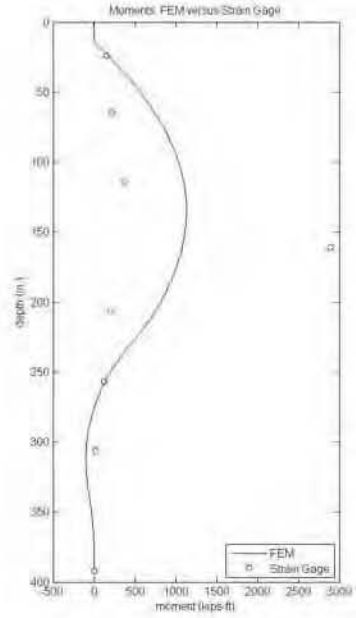


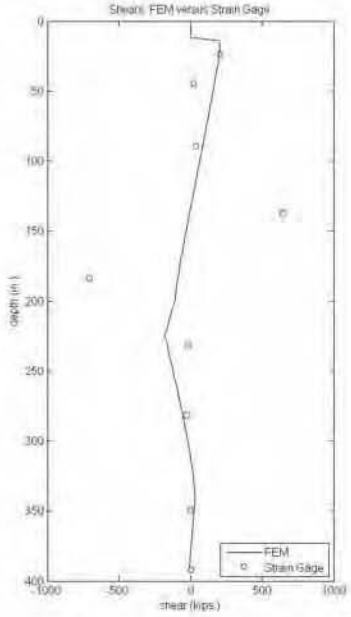




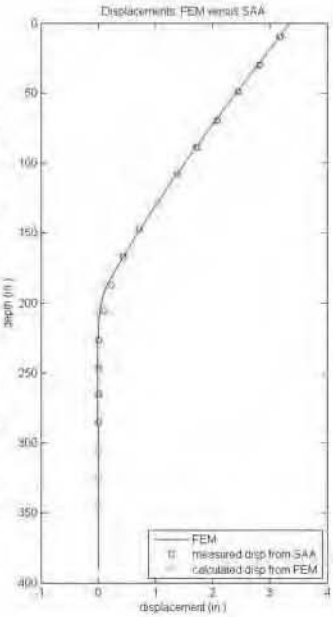
W14 Soil Removed 202.3 kips

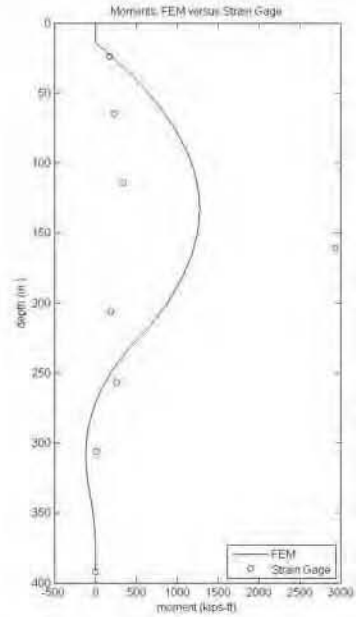


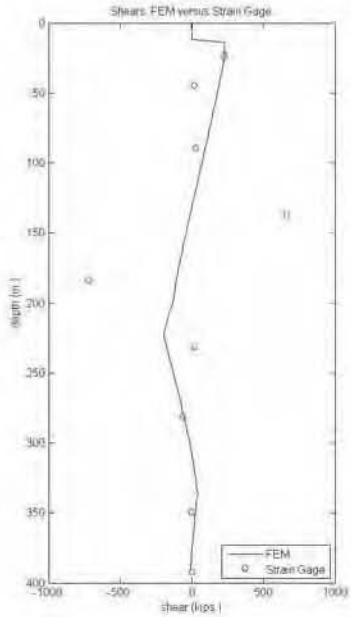




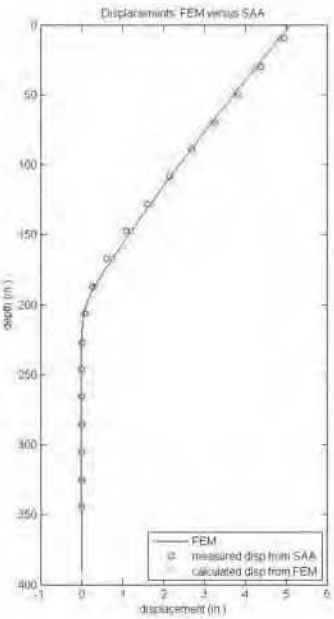
W14 Soil Removed 231.5 kips

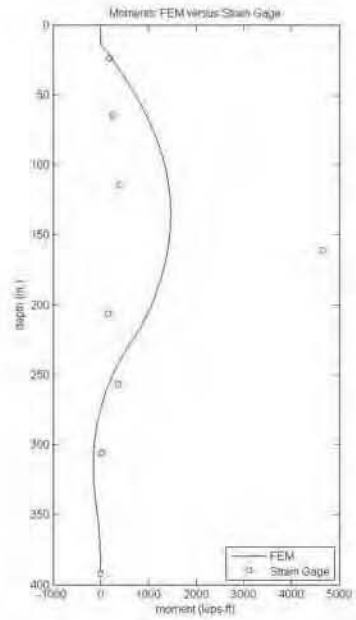


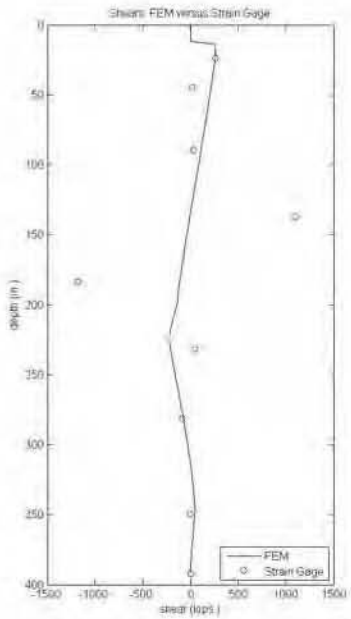




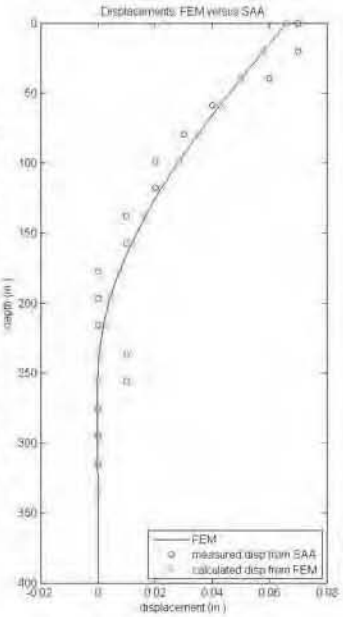
W14 Soil Removed 260.7 kips

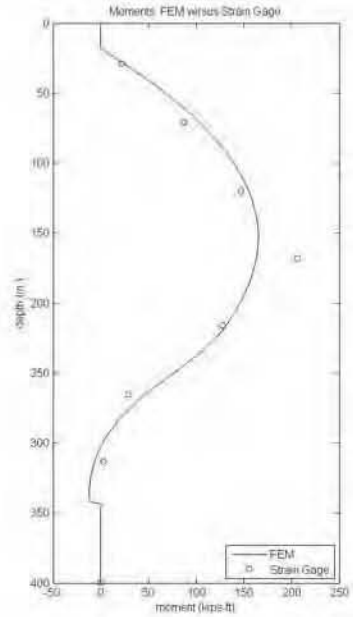


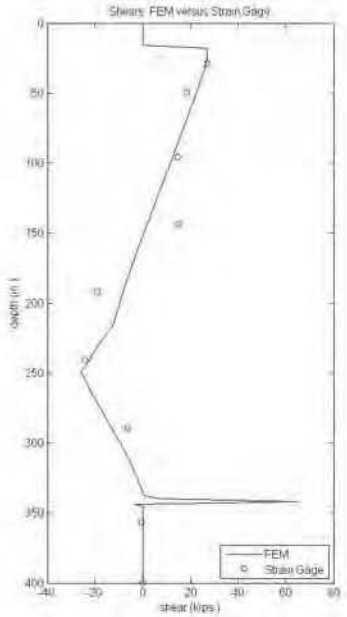




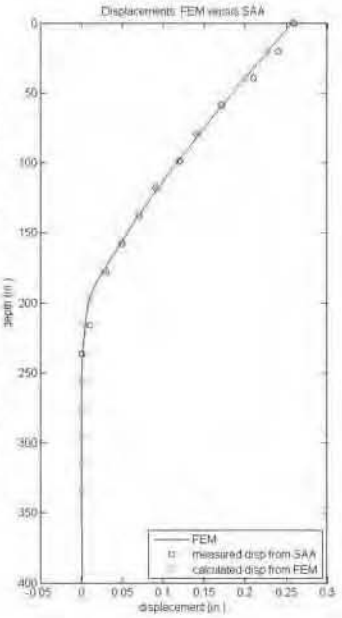
W15 Soil Removed 26.8 kips

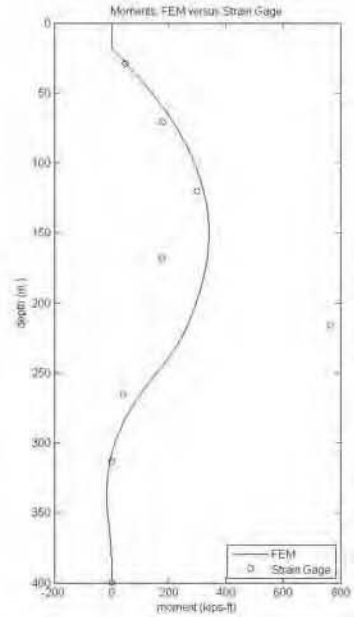


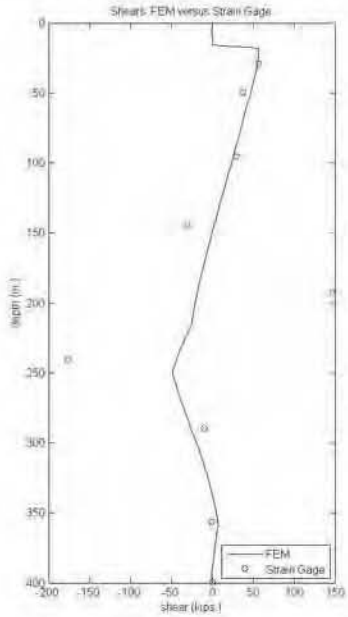




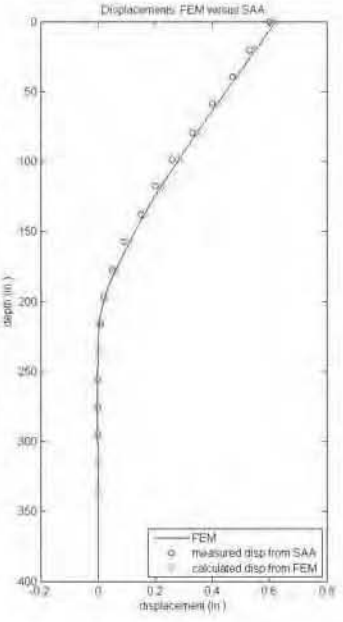
W15 Soil Removed 56.1 kips

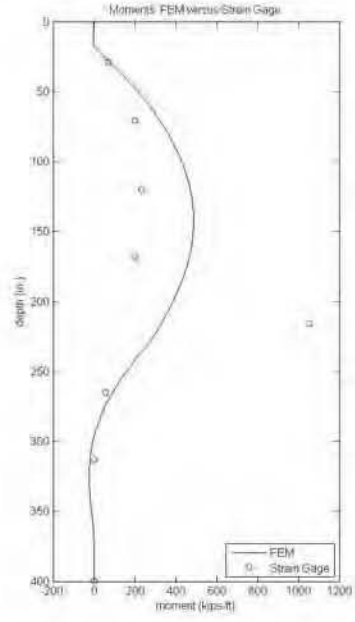


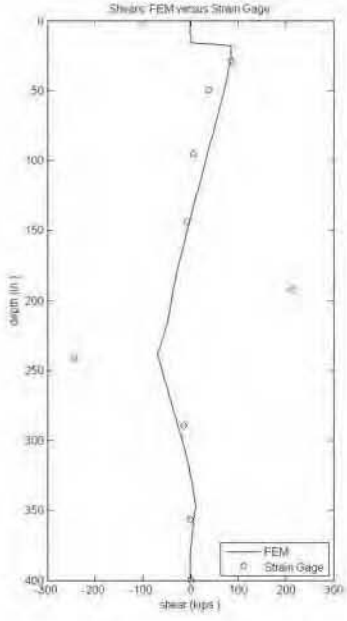




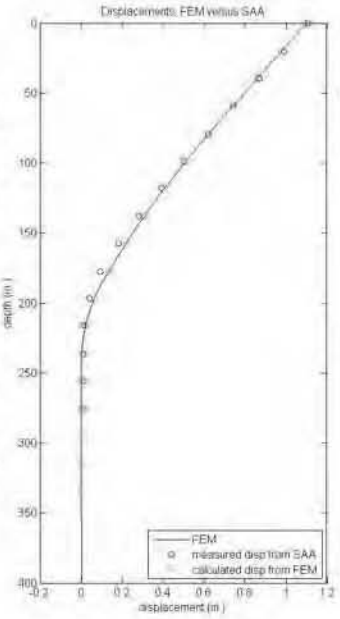
W15 Soil Removed 85.3 kips

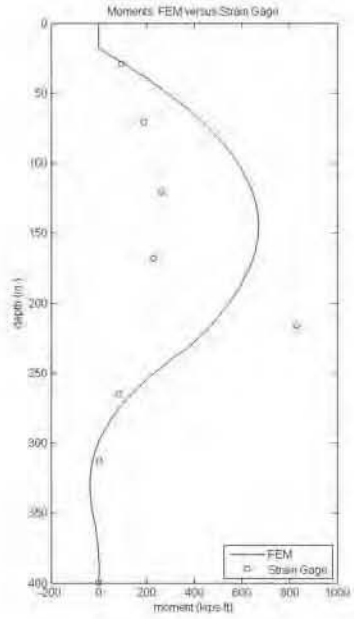


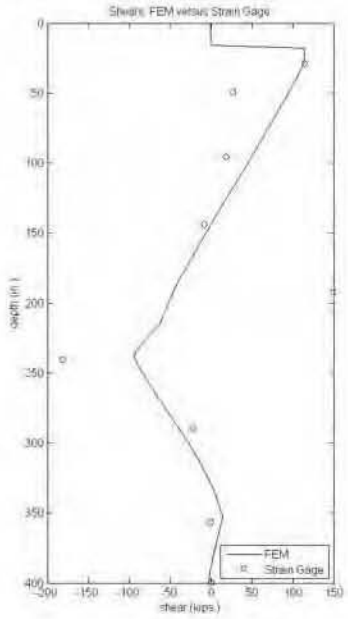




W15 Soil Removed 114.5 kips







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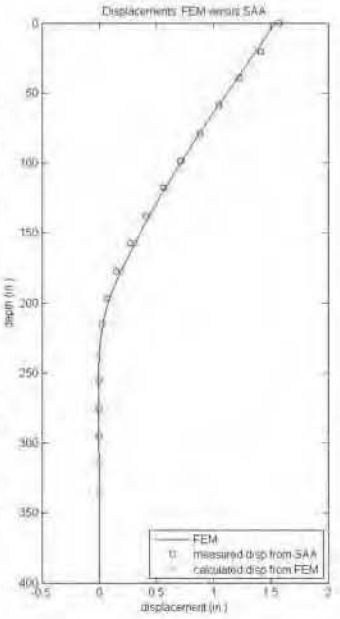
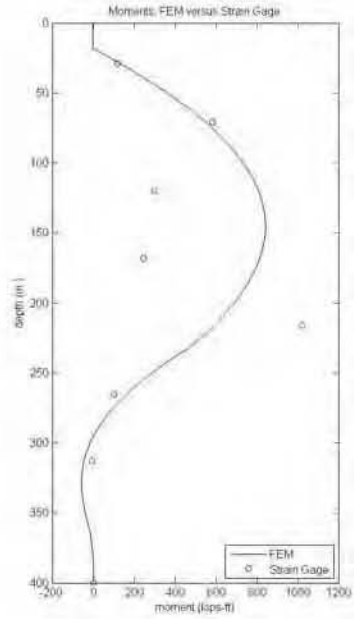
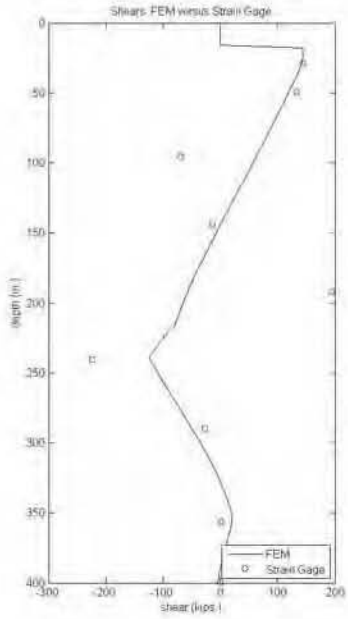
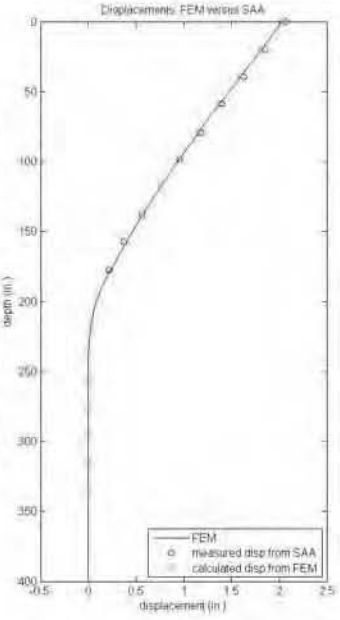
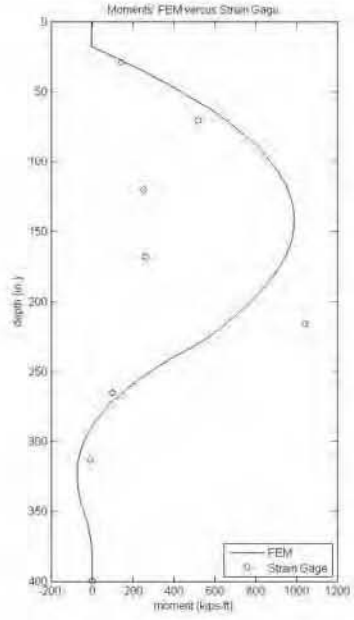


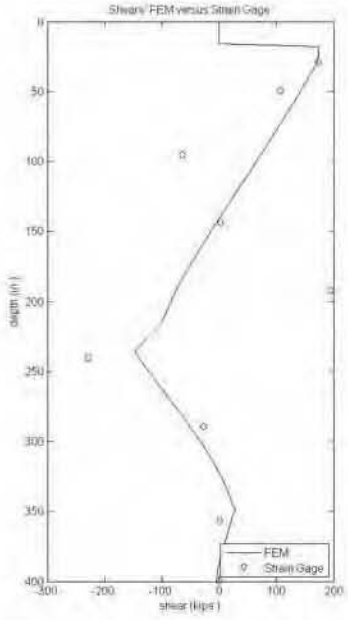




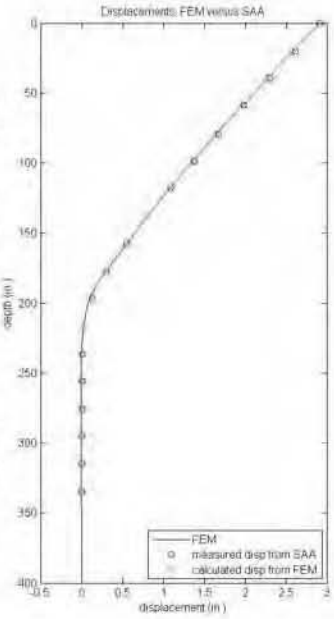
W15 Soil Removed 173.0 kips

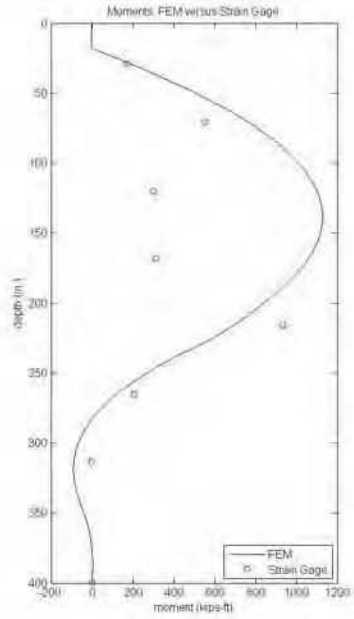


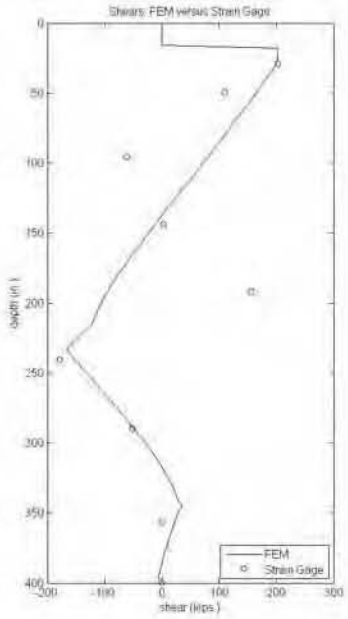




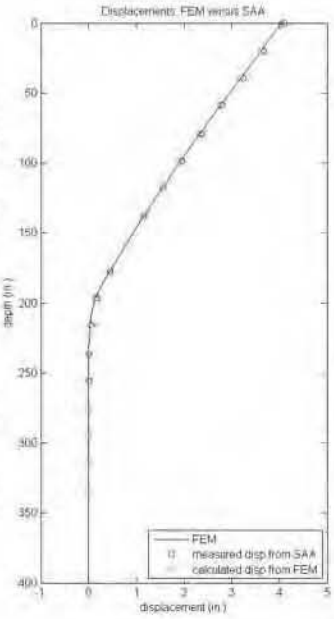
W15 Soil Removed 202.3 kips

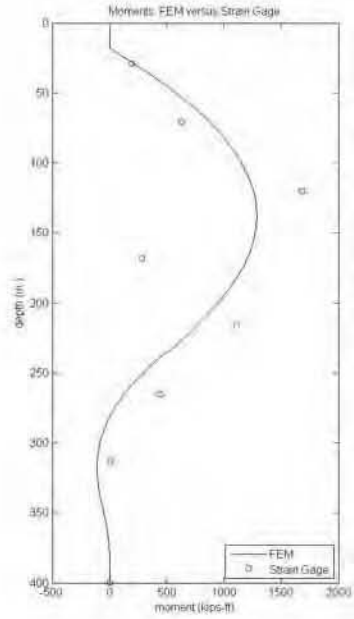


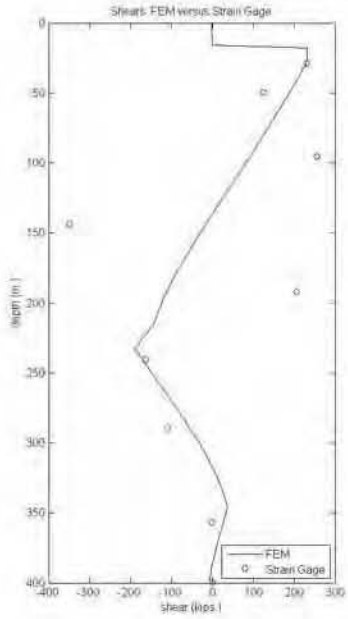
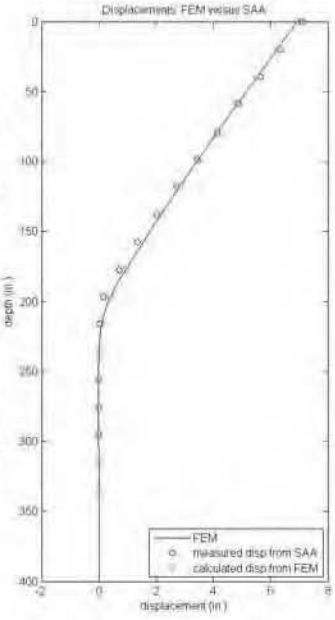
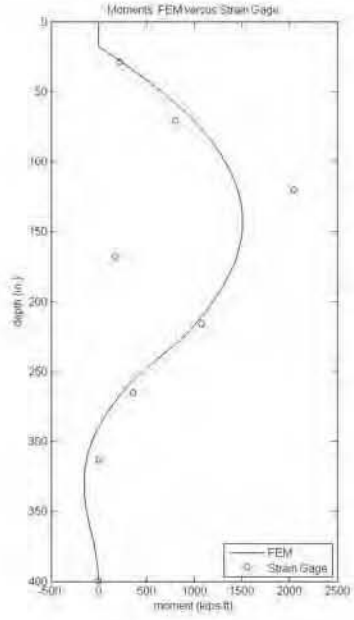
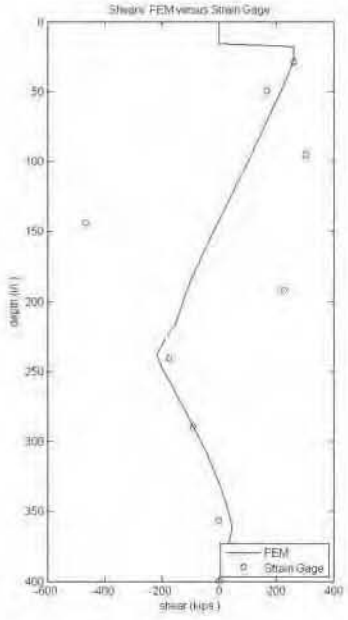




W15 Soil Removed 231.5 kips







W15 Soil Removed 260.7 kips