DYNAMIC OVERTURNING LOADS ON DRILLED SHAFT FOOTINGS USED FOR MINOR SERVICE STRUCTURES

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Design of Footings for Minor Service Structures

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SUMMARY

A theory which will predict the ultimate resistance of a drilled shaft footing to overturning loads was presented in Research Report 105-1 and was correlated with model tests as reported in Research Report 105-2. In Research Report 105-3, the results of full-scale tests on drilled shaft footings were presented and compared to a "Tentative Design Procedure" based on the previously published theory. Design curves which allow easy application of the theory were given as a part of the design procedure.

This paper gives the results of ten model tests of drilled shaft footings subjected to dynamic loads. These tests show that the footing rotations to be expected from dynamic loads are less than the rotations resulting from static loads of the same value. Footing rotations due to repeated dynamic loads did not exceed one degree for load intensities* of less than 50% of the maximum static pullover load for less than 10,000 repetitions of load.

* The ratio of the dynamic repeated load to the 5^{o} rotation static load, expressed as a percentage.

ABSTRACT

Ten model tests of drilled shaft footings subjected to dynamic overturning loads were performed. Compared to the average size footing used for minor service structures in Texas, the model footings were reduced by a factor of six. The footing reactions were investigated in a cohesionless sand, a laboratory sandy clay, and a laboratory clayey sand.

The results of the dynamic model footing tests were compared with the results obtained from the theory developed earlier in this study for determining static pullover loads. It was found that the footing resistance to single dynamic loads exceeded the static pullover resistance predicted by the theory. Footing rotations due to repeated dynamic loads did not exceed 1^{o} degree for 10,000 repetitions of dynamic load, with the further limitation that the repeated load was less than 50% of the static pullover load.

IMPLEMENTATION

An implementation statement for this research is included in Research Report 105-3, "Design Procedure Compared to Full-Scale Tests of Drilled Shaft Footings."

TABLE OF CONTENTS

INTRODUCTION

The objective of this study was to develop design procedures for the foundations of structures such as sign boards, strain poles, and lighting supports with factors of safety appropriate to the relative importance of the structure. A series of reports on individual phases of this study have already been published. The first report, 105-1[1*], "Theory, Resistance of a Drilled Shaft Footing to Overturning Loads," disclosed in detail the theoretical development of the new load prediction equations. Research Report 105-2[2], "Resistance of a Drilled Shaft Footing to Overturning Loads, Model Tests and Correlation with Theory," showed that the conventional methods of predicting ultimate overturning loads were conservative by as much as 500% for cohesionless sands to 20% for clays. The most recent publication, "Design Procedure Compared to Full-Scale Tests of Drilled Shaft Footings,"[3] gave the necessary design curves to apply the new design procedure.

Current design procedures for footings of minor service structures do not treat dynamic forces separately, thus implying that the effect of these forces is the same as the effect of static forces. Until this study, testing to support the above assumption had not been performed. The soils used in this dynamic testing phase are a cohesionless sand, a laboratory sandy clay, and a laboratory clayey sand. These tests on 4-inch diameter by 12-inch deep model footings show the footing

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* Superscript numbers refer to corresponding number in Selected References.

rotations that may be expected under repeated dynamic loads and that footing movements due to single dynamic loads are less than the movements under static loads of the same magnitude.

EQUIPMENT AND INSTRUMENTATION

General

Dynamic load testing of model footings required systems capable of (1) dynamic load application, (2) dynamic load measurement at desired intervals, and (3) measurement of rotations.

Loading System

The dynamic testing program was accomplished using a Gilmore servo-actuated testing machine. Placed in a horizontal position, the loading frame of the testing machine was positioned to apply a horizontal load to the model footings as shown in Figure 1. On one end of the Gilmore loading frame was a hydraulic actuator shaft extending to the inside of the frame. The shaft applied a cyclic loading which was set on the Gilmore controls. A Gilmore load transducer which controlled the load on the footing servomechanically was attached to the end of the shaft. A second independent load transducer (Instron CT) was attached to, and in series with, the Gilmore load transducer to measure the actual load. A cable was connected between the Instron load transducer and the steel pipe which projected from the top of the footing. The cable connected to the pipe at a point 24 inches above the surface of the soil.

The frequency of the load cycle was 0.1, 0.5, 1, and 2 Hertz* for the Ottawa sand tests and 1 Hertz under various load conditions for the laboratory sand-clay mixtures.

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*Cycles per second.

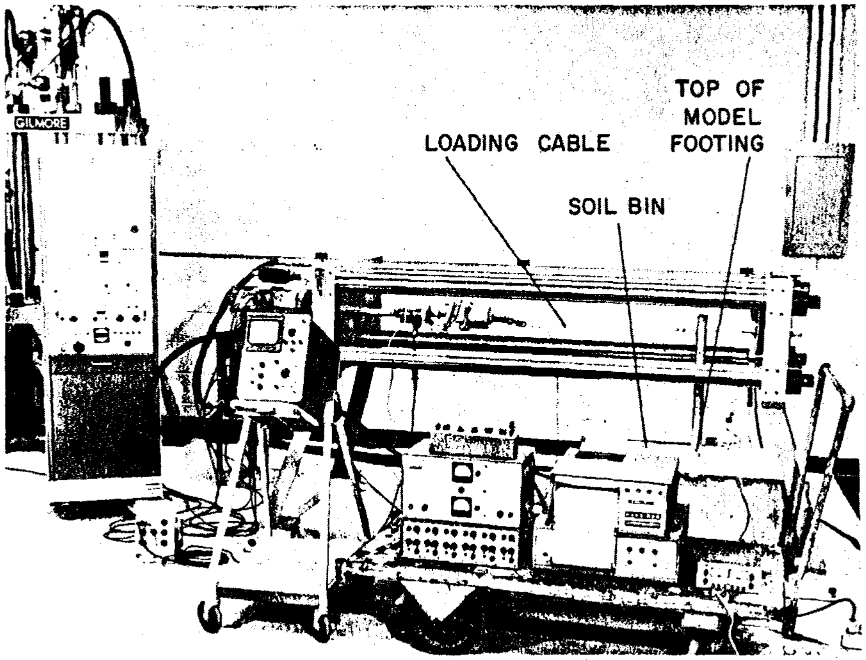


Figure 1. Dynamic Testing System.

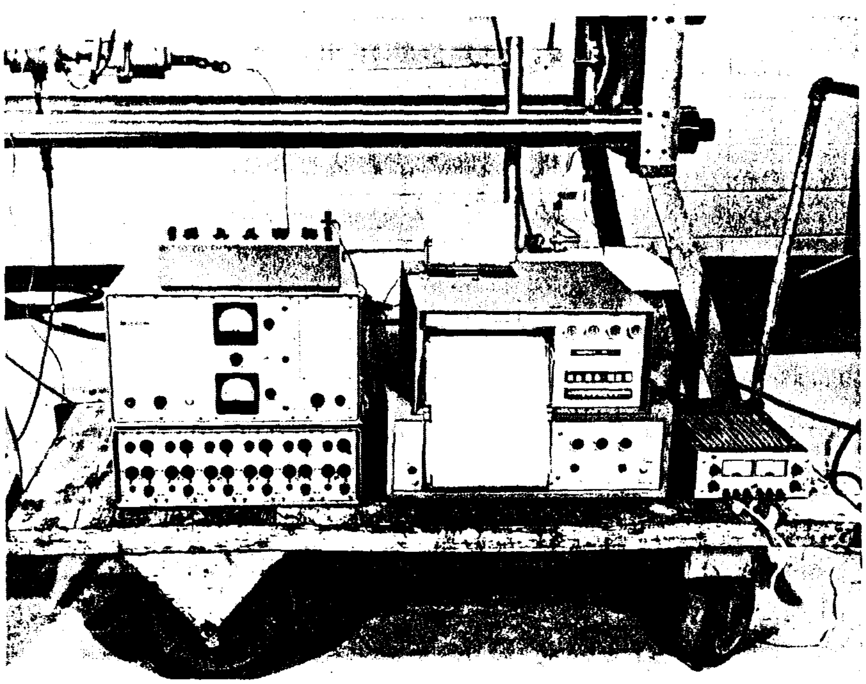


Figure 2. Dynamic Test Recording Equipment.

Dynamic Load Measurement

The Instron load transducer was calibrated for ranges from 0-100 lbs. and 0-200 lbs. tensile load, depending on the maximum load expected for a given test. The output voltage of the load transducer was amplified and recorded on a Honeywell Visicorder, giving a visual record of the load pattern that was applied to the model.

Rotation Measurement

The positions of the model footings during the dynamic load applications were measured by recording the displacement of the steel pipe attached to the top of each footing. The pipe was screwed onto a 3/4-inch diameter threaded rod extending from the top of the concrete footings. Linear displacement transducers were connected to the pipe 24 5/16 inches and 3 1/2 inches above the top of the footings, respectively. The output voltages from the linear displacement transducers were amplified and recorded on the Visicorder (see Figure 2).

PLACEMENT OF FOOTINGS AND SOIL CONDITIONS

Ottawa Sand

To conduct tests in a soil in which zero cohesion existed, 20-30 mesh Ottawa sand was used. The test apparatus included a reinforced concrete bin, 24 inches wide by 36 inches long, having an inside depth of 18 inches. This bin was placed inside the Gilmore loading frame and secured to the loading frame. The sand was then placed in the bin according to the procedure described in Research Report 105-2[2] and the dense condition (e = 0.51) obtained by use of a portable concrete vibrator. Sand parameters were taken from Research Report Number 105-2 as 37° for the angle of internal friction and 109 pcf unit weight.

Laboratory Sand-Clay Mixtures

To provide a basis for correlation with previous tests, laboratory sand-clay mixtures were constructed using the same procedures as described in Research Report 105-2. Trinity Clay in powdered form was mixed in a counter current mixer with a concrete sand. Water was added giving the soil properties shown in Table 1.

Four of the reinforced concrete bins were constructed. The insides were sprayed with an acrylic plastic to prevent loss of moisture through the concrete walls. The clay mixtures were placed in 4-inch-thick loose layers in the bins and a uniform compactive effort was applied to each layer by a pneumatic hammer as described in Research Report 105-2.

After each compacted bin was completed, the exposed soil surface was covered with a thin layer of grease and overlaid with a thin sheet of plastic to prevent loss of soil moisture. With the clay mixtures in place and airtight covers applied, the bins were allowed to stand for 14 days in a constant humidity environment at 72°F. During this time, the soil was expected to gain in strength due to thixotropy.[4-6] Thixotropy may be simply described as an aging process in remolded soil at a constant volume-water content, resulting in an increase in strength.

To install the footings, 4-inch diameter holes were drilled with a special flat-bottomed auger.[2] The cavities were right circular cylinders,

TABLE 1

COMPOSITION OF SAND CLAY MIXTURES

Test Number	% Sand by Weight	% Clay by Weight	Water Content (%)	In Place Unit Weight (pcf)
7	67	33	12.6	138.9
8	67	33	12.6	137.9
9	33	67	16.1	132.1
10	33	67	15.7	134.5

TABLE 2

ENGINEERING PROPERTIES OF SAND CLAY MIXTURES

Test Number	Cohesion (psf)	Angle of Internal Friction (degrees)
7	390	2.7
8	580	0
9	1600	0.75
10	1790	2.7

12 inches deep. Steel re-bar cages were attached to the 3/4-inch threaded bolt and placed in the holes. After filling the holes with cement mortar made from Type III cement and 20-30 Ottawa sand, the steel cages were vibrated with a portable vibrator to eliminate air bubbles and voids. An additional 14 days were allowed to elapse before the footings were tested, in order to provide sufficient time for the mortar to cure.

After the footings were tested, as described below, several soil samples were taken from each bin with a thin-walled core cutter. The core cutter was pushed into the soil by hand and then trimmed out with a knife, producing samples 1.425 inches in diameter and 3.0 inches long. After extruding the specimens from the cutter, unconsolidated, undrained triaxial compression tests were performed yielding the soil parameters shown in Table 2.

It should be noted at this point that while only one bin of each mixture was necessary for the testing program, replicate bin specimens were made in case of machine malfunction or other difficulties which might make a particular test questionable. Since no difficulties were encountered in the repetitive load tests, the two additional samples were used for rapid pullover tests. The results of these tests are included in this report.

TESTING PROGRAM

The model footing tests which were conducted in sand and sand-clay mixtures are summarized by Table 3. The duration of each load cycle was held constant for each individual test, but was varied from 1/2 to 10 seconds in the five test series. This was done to determine the

TABLE 3

SUMMARY OF TESTS

Soil Type	Test Number	Type of Loading	Duration of Each Load Cycle (seconds)	Range of Dynamic Loads (lbs.)	Static Load P for 5° Rotation From Theory[2] (lbs.)
Ottawa Sand	1	----	----	----*	32.5
"	2	Repetitive	1.0	6.8 - 29.7	32.5
"	3	Repetitive	2.0	8.9 - 37.3	32.5
"	4	Repetitive	10.0	6.9 - 38.7	32.5
"	5	Repetitive	0.5	12.2 - 35.9	32.5
"	6	Repetitive	10.0	6.3 - 33.2	32.5
Laboratory Clayey Sand	7	Rapid Pullover	----	102.2 max.	42.2
"	8	Repetitive	1.0	18.1 - 72.8	46.5
Laboratory Sandy Clay	9	Repetitive	1.0	7.5 - 196.0	144.0
"	10	Rapid Pullover	----	213.8 max.	196.7

* Machine malfunction (no data obtained).

effect, if any, of changes in the load cycle rate. In each test, the load was increased in increments until a footing rotation of over 5^{o} was observed. The progressive rotation of a model footing under repeated loads is shown in Figure 3.

Sand Tests

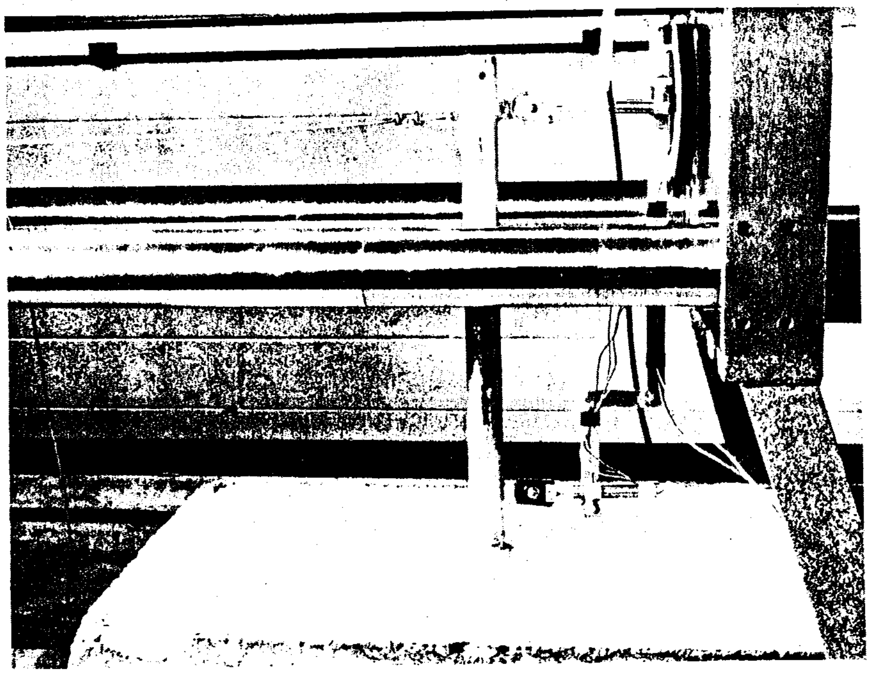
The shaft on the Gilmore load actuator was positioned to allow maximum footing movement before resetting. A cable from the Instron load transducer was attached to the pipe extending from the model footing to give a height of pull 24 inches above the footing. The slack in the load cable was then taken up with an initial horizontal load of 5 lbs. The Gilmore machine was set to provide a sinusoidal loading function and tests were conducted at frequencies of 0.1, 0.5, 1 and 2 Hertz. At each frequency, an initial nominal load of 5 lbs. was applied, and the load was increased incrementally after each 10 minutes of cyclic loading.

Sand-Clay Mixtures

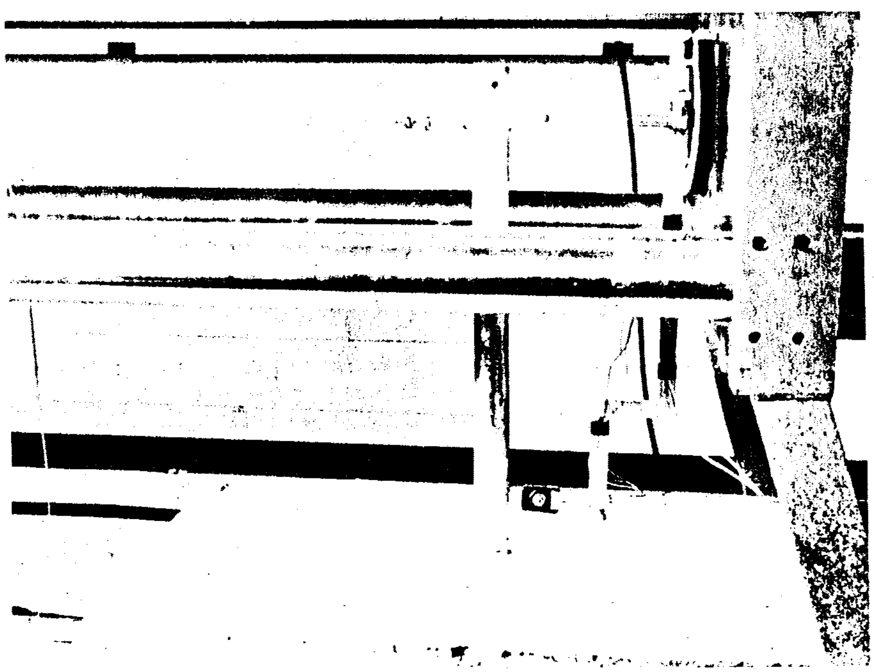
The preparation of the Gilmore testing machine was identical to that for the sand tests, as was the general testing procedure. The progressively increasing loads were applied at frequencies of 1 Hertz only (1 cycle per second), however, as in the sand tests, the load was increased in steps until 5^{o} of footing rotation was observed.

Sand-Clay Mixtures, Rapid Pullover Tests

Again, the preparation of the Gilmore testing machine was similar to that used for the sand tests. The only major difference was that

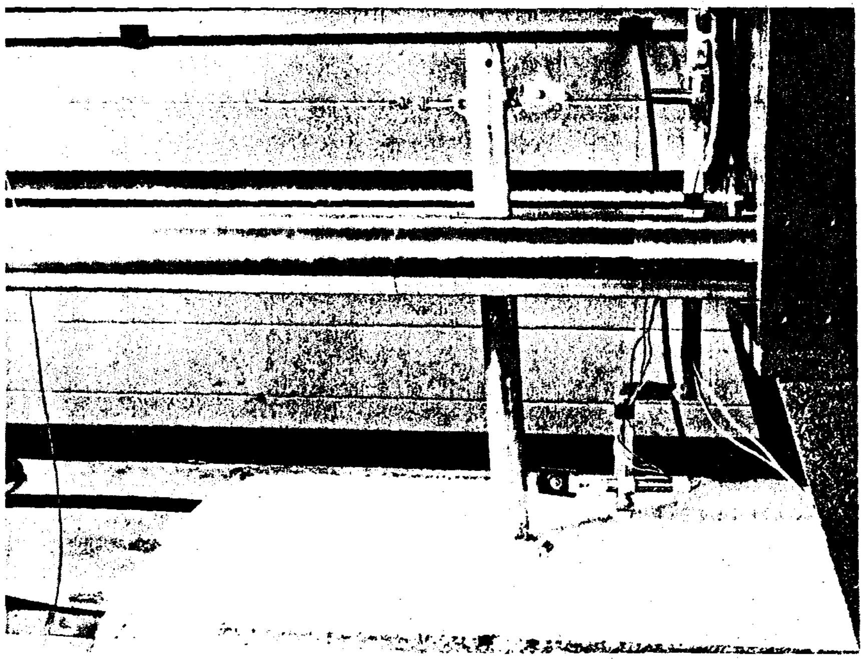


Test Footing Prior to Loading
t = 0 min

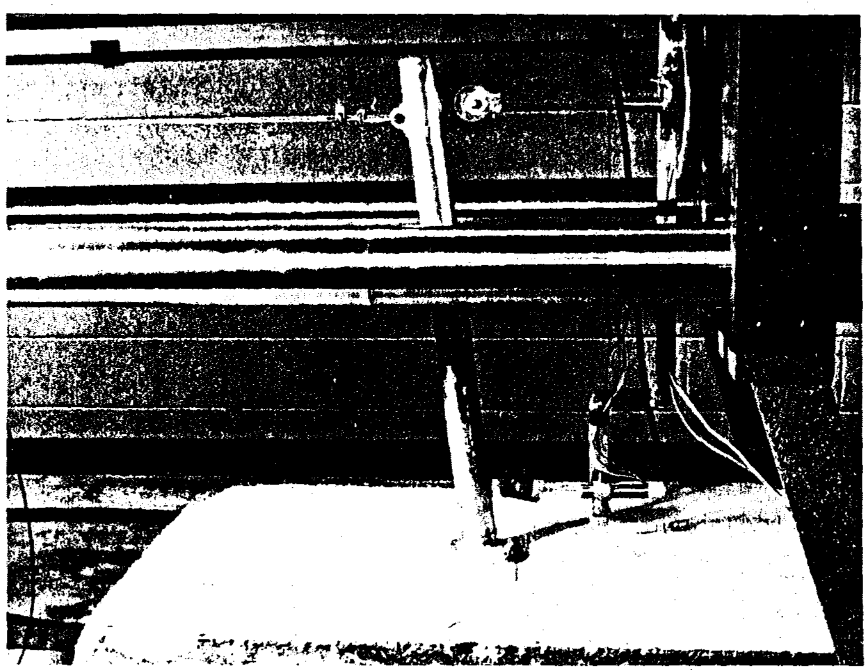


t = 30 min (1800 repetitions of load)

Figure 3. Typical Dynamic Model Test
Load Duration, One Second Per Cycle.



t = 47 min (2820 repetitions of load)



t = 60 min (3600 repetitions of load)

Figure 3 (continued).

the actuator shaft was initially positioned to limit its total travel to 5 inches to prevent damage to the top linear displacement transducer. The load was applied in a single 5-inch stroke which took place in approximately 1/2 second.

TESTING RESULTS AND DISCUSSION

The major results of this study are exemplified by Figures 4, 5, and 6, which are plots of footing rotation versus load repetitions for the Ottawa sand, the sandy clay, and the clayey sand, respectively.

In the Ottawa sand test, Figure 4 shows that, at load intensities up to at least 62% of the 5^{o} static pullover load*, the footing is stable. Stable is here defined to mean that at a particular load intensity the footing can sustain over 10,000 cycles of load before a rotation of one degree is reached. (This determination is based on the linear extrapolation of the test data on a semi-log plot.) This critical load intensity of 62% was obtained for a load cycling rate of one cycle per second, and it is reinforced by the stability determinations at the other cycling rates. (Test 5-59%, Test 4-54%, Test 6-59%, and Test 3-63%.)**

In the two tests of the sand-clay mixtures, shown in Figures 5 and 6, the sandy clay shows stability at 55% of the 5^{o} static pullover load, while the clayey sand (with a very low cohesion and no apparent angle of shear resistance) does not meet the stability criterion established above.

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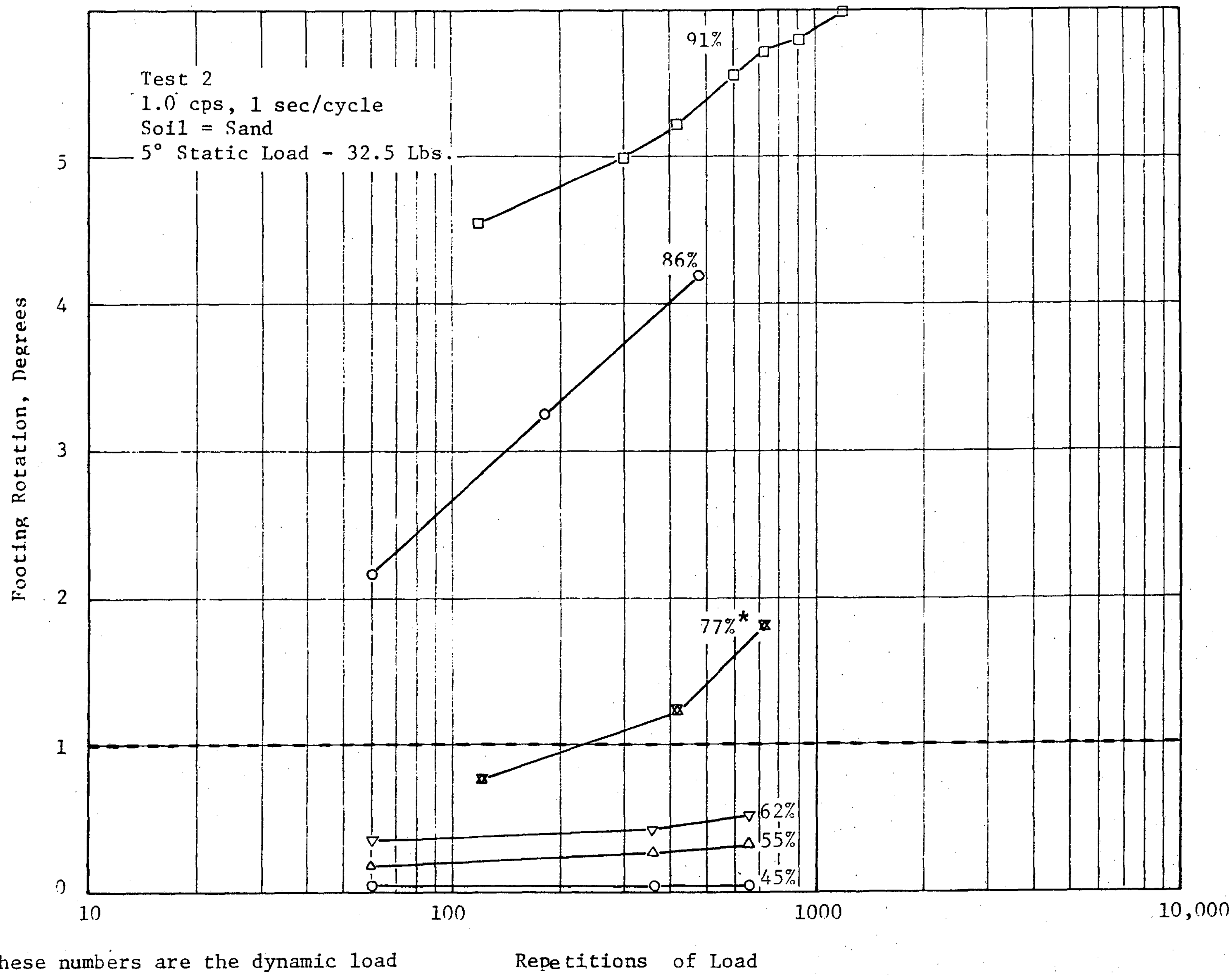
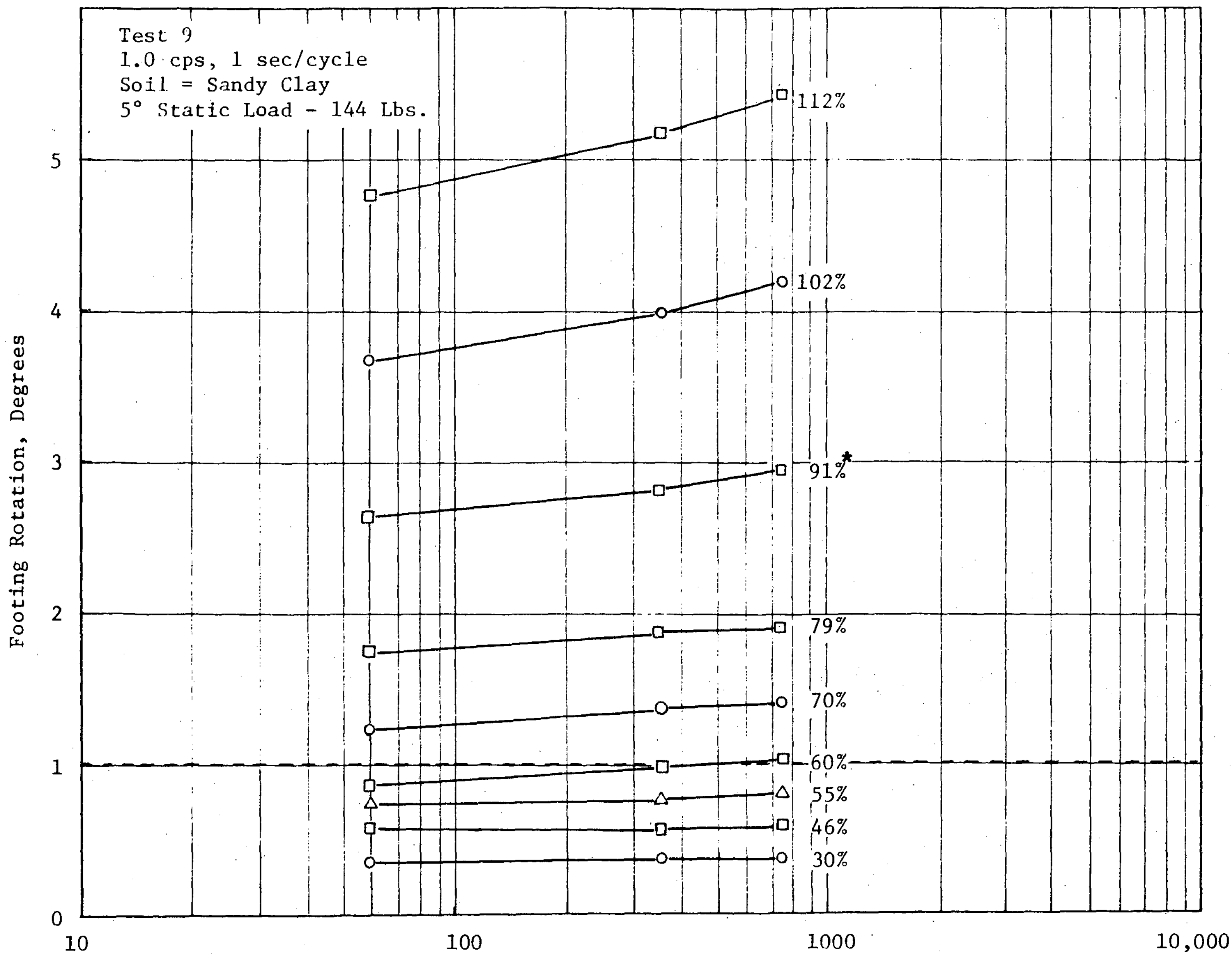
* The maximum load the footing would withstand under a gradually increasing static load was found to occur at a rotation of approximately 5^{o} in Research Report 105-2.

** Figures 9 through 12 in Appendix A.



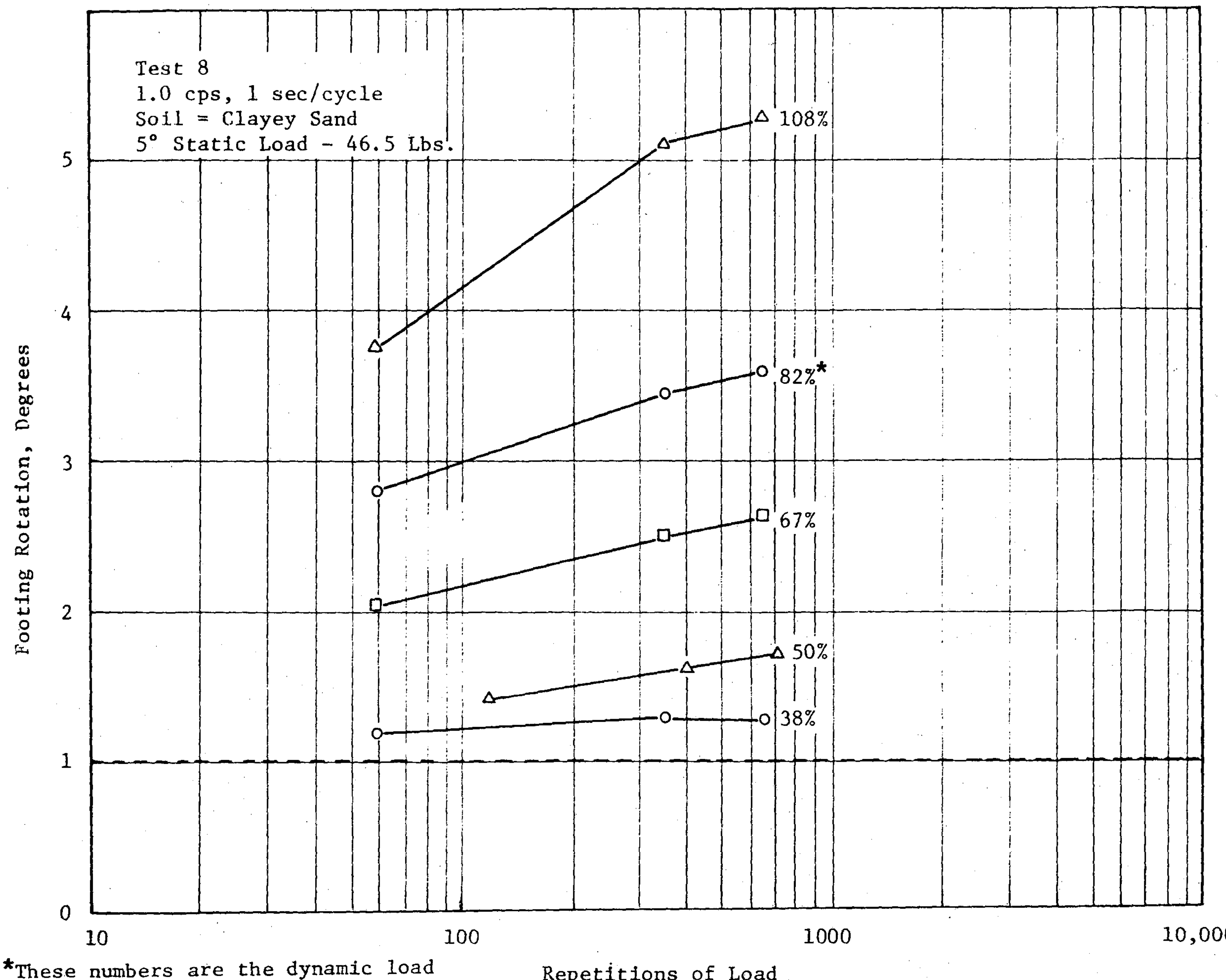
*These numbers are the dynamic load divided by the 5° static pullover load, expressed in percent.

Figure 4



*These numbers are the dynamic load divided by the 5° static pullover load, expressed in percent.

Figure 5



*These numbers are the dynamic load divided by the 5° static pullover load, expressed in percent.

Figure 6

It does appear to have reached a plateau of rotation at about 1.2^{o} for a loading intensity of 38%.

In summary, it appears that repetitive loads will not give rotations over approximately 1^{o} as long as the repetitive load intensity is equal or less than 50% of the 5^{o} static pullover load. An apparent exception, indicating the possible need for some design conservatism, is a footing in a very soft clay as evidenced by Figure 6.

Figures 7 and 8 show the rapid pullover test results. Shown--in order from top to bottom--are the Instron load transducer reading, the top linear displacement transducer reading, and the bottom linear displacement transducer reading. The tests show that more load is required to attain 5^{o} rotation than is predicted by the static load theory. However, the difference in soil characteristics seems to have a pronounced effect on the results. The clayey sand (Test No. 7) did not reach a peak load before the actuator shaft reached its maximum displacement of 5 inches. The sandy clay (Test No. 10), on the other hand, developed a maximum load in about 80 milliseconds--or approximately 0.7 inches of shaft displacement--and continued to maintain that load for the duration of the test. This elastic-plastic response was unexpected based on static test results and thus the results of this test are somewhat suspect.

Test data are presented in Appendix B. Tables 4 through 8 contain the results of the dynamic sand tests. Tables 9 and 10 present data for the laboratory clayey sand and sandy clay dynamic tests, respectively. The tabulated data include Machine Signal Conditioner and Machine Load Setting values. The actual load is given by the Instron load transducer and is listed under Load Cell Response. This column shows a maximum and minimum load corresponding to the extremes of the loading cycle. The Linear Displacement Transducer column shows displacement at the top and bottom of the metal pipe attached to the footing. When two values are given for a displacement, the first reflects displacement during the maximum load value of the cycle and the second is displacement at the minimum load value. Differences in these maximum and minimum values reflect soil elasticity. The last values listed are the rotations of the footings at the listed times.

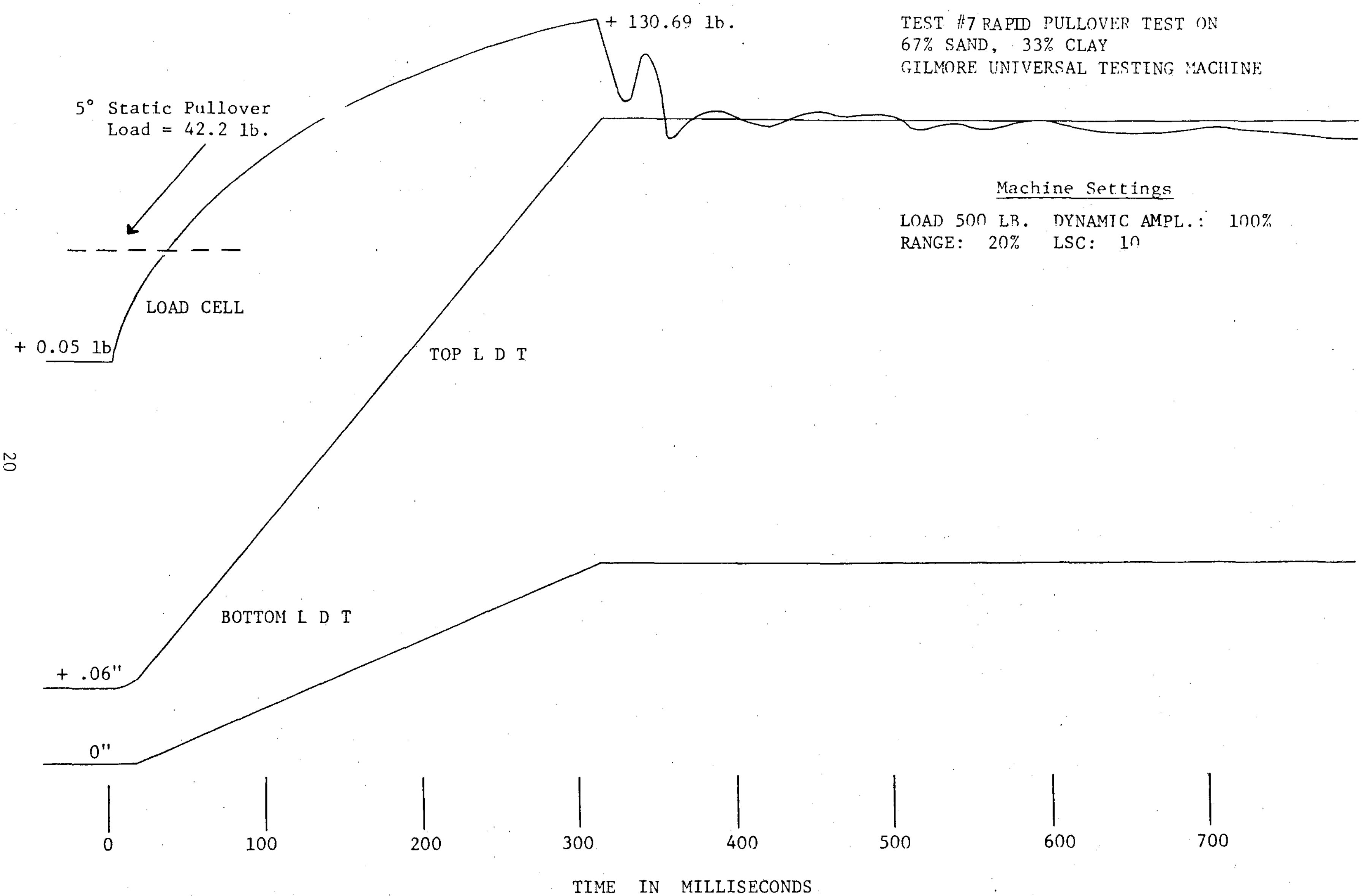


Figure 7. Rapid Pullover Test, Clayey Sand.

TEST #10 RAPID PULLOVER TEST ON 33% SAND, 67% CLAY
GILMORE UNIVERSAL TESTING MACHINE.

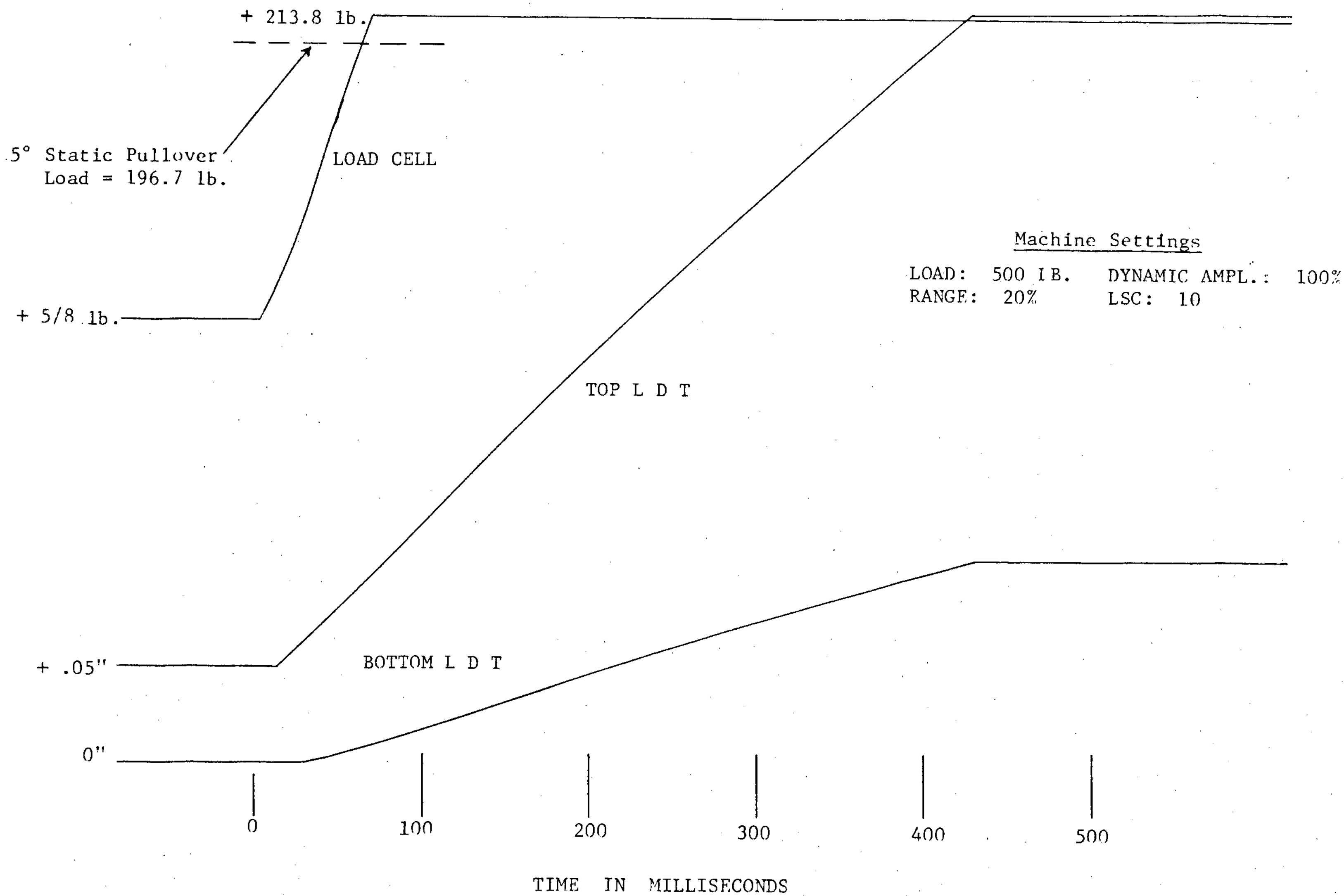


Figure 8. Rapid Pullover Test, Sandy Clay.

CONCLUSION

These tests indicate that the footing rotations due to single dynamic loads are significantly less than the rotations due to static loads of the same magnitude. Footing rotations due to repeated dynamic loads did not exceed one degree for load intensities* of less than 50% of the maximum static pullover load, and for less than 10,000 repetitions of load. This conclusion is based on extrapolated data and should, therefore, be used with care. An exception was the test of a very soft clay in which a footing rotation of 1.2° was observed at a load intensity of 38%.

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* The ratio of the dynamic repeated load to the 5° rotation static load, expressed as a percentage.

SELECTED REFERENCES

1. Ivey, Don L., "Theory, Resistance of a Drilled Shaft Footing to Overturning Loads," Research Report 105-1, Texas Transportation Institute, August 1967.

2. Ivey, Don L., Koch, Kenneth J., and Raba, Carl F., Jr., "Resistance of a Drilled Shaft Footing to Overturning Loads, Model Tests and Correlation with Theory," Research Report 105-2, Texas Transportation Institute, July 1968.

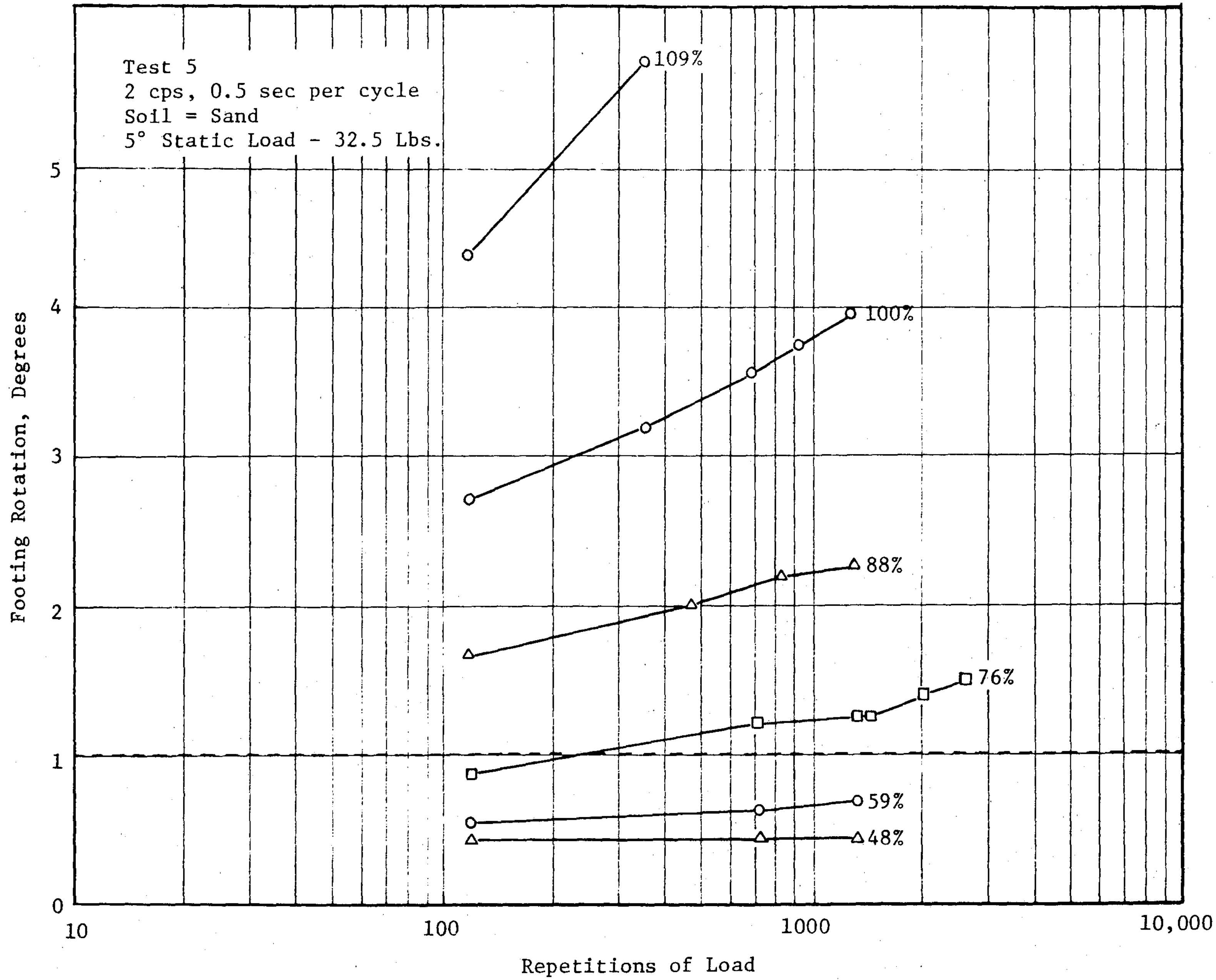
3. Ivey, Don L. and Dunlap, Wayne A., "Design Procedure Compared to Full-Scale Tests of Drilled Shaft Footings," Research Report 105-3, Texas Transportation Institute, May 1969.

4. Seed, H. B. and Chan, C. K., "Thixotropic Characteristics of Compacted Clay," *Proceedings*, ASCE, Vol. 83, S.M. 4, November 1957.

5. Mitchell, J. K., "Fundamental Aspects of Thixotropy in Soils," *Proceedings*, ASCE, Vol. 86, S.M. 3, June 1960.

6. Moretto, O., "Effects of Natural Hardening on the Unconfined Compression Strength of Remolded Clays," Second International Conference on Soil Mechanics and Foundation Engineering, Rotterdam, Vol. 1, 1948.

A P P E N D I X A



Test 5
2 cps, 0.5 sec per cycle
Soil = Sand
5° Static Load - 32.5 Lbs.
109%
100%
88%
76%
59%
48%
Footing Rotation, Degrees
0
1
2
3
4
5
10
100
1000
10,000
Repetitions of Load

Figure 9.

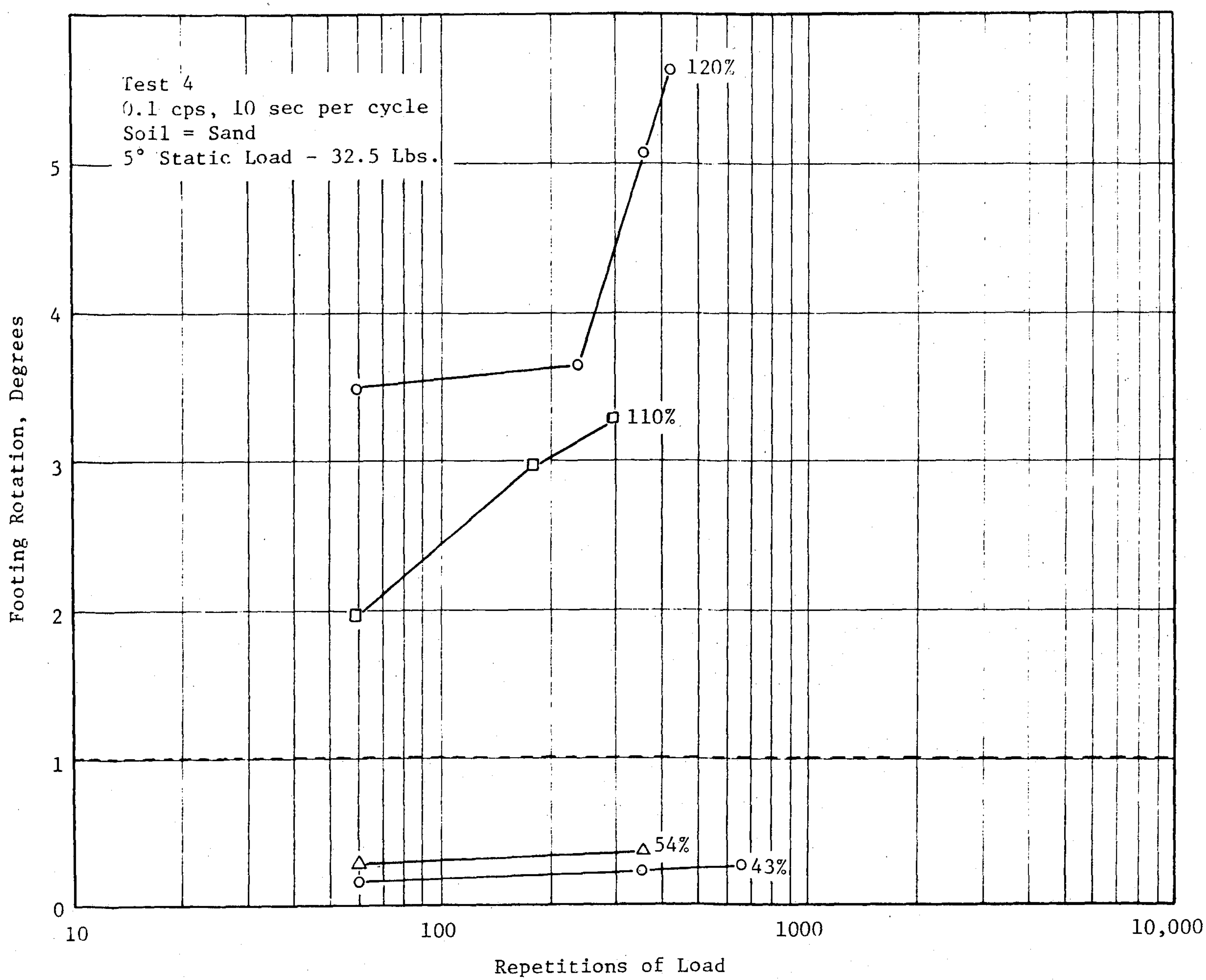

Test 4
0.1 cps, 10 sec per cycle
Soil = Sand
5° Static Load - 32.5 Lbs.
120%
110%
54%
43%
Footing Rotation, Degrees
0
1
2
3
4
5
10
100
1000
10,000
Repetitions of Load

Figure 10.

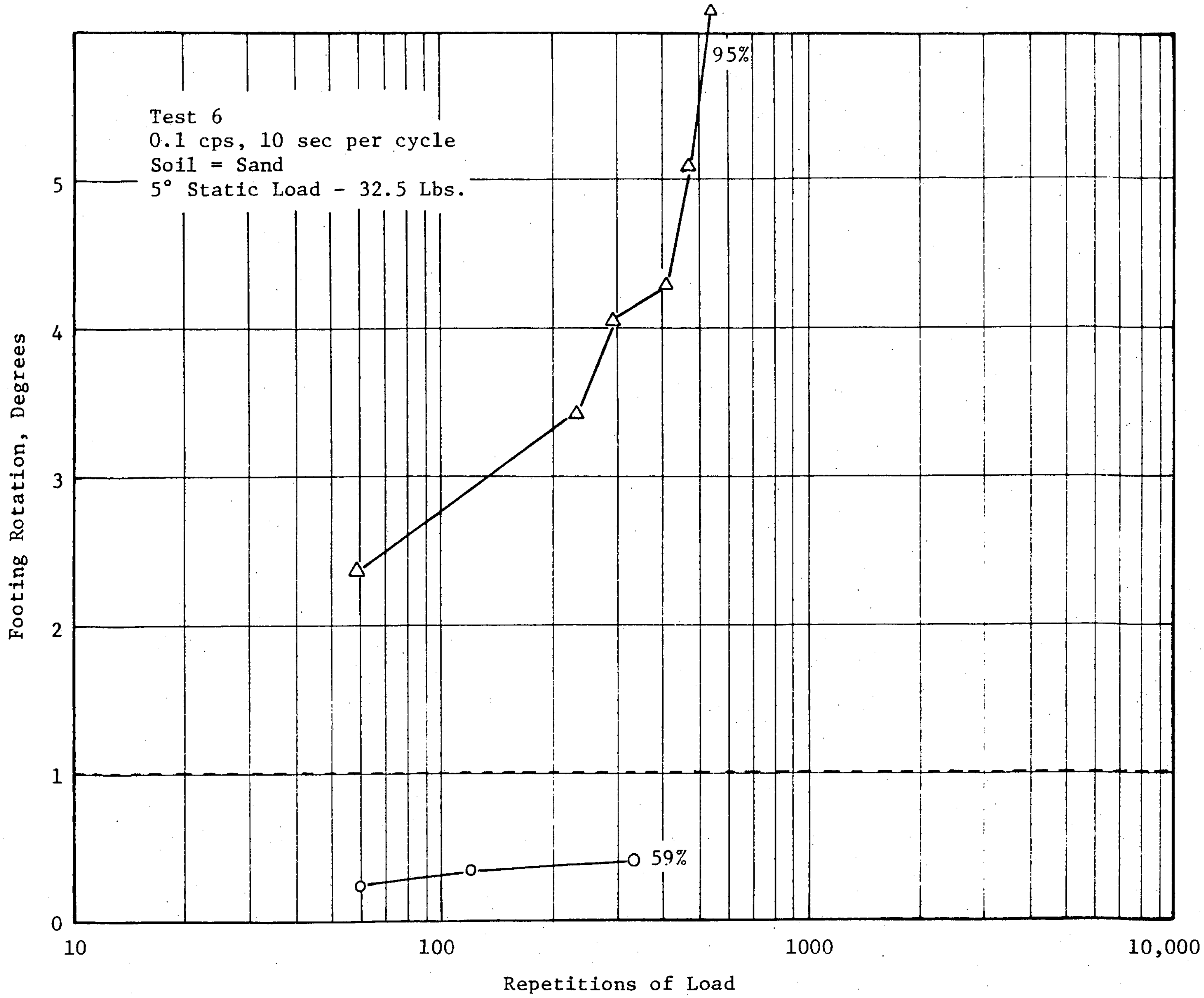

Test 6
0.1 cps, 10 sec per cycle
Soil = Sand
5° Static Load - 32.5 Lbs.
95%
59%
Footing Rotation, Degrees
0
1
2
3
4
5
10
100
1000
10,000
Repetitions of Load

Figure 11

Figure 11.

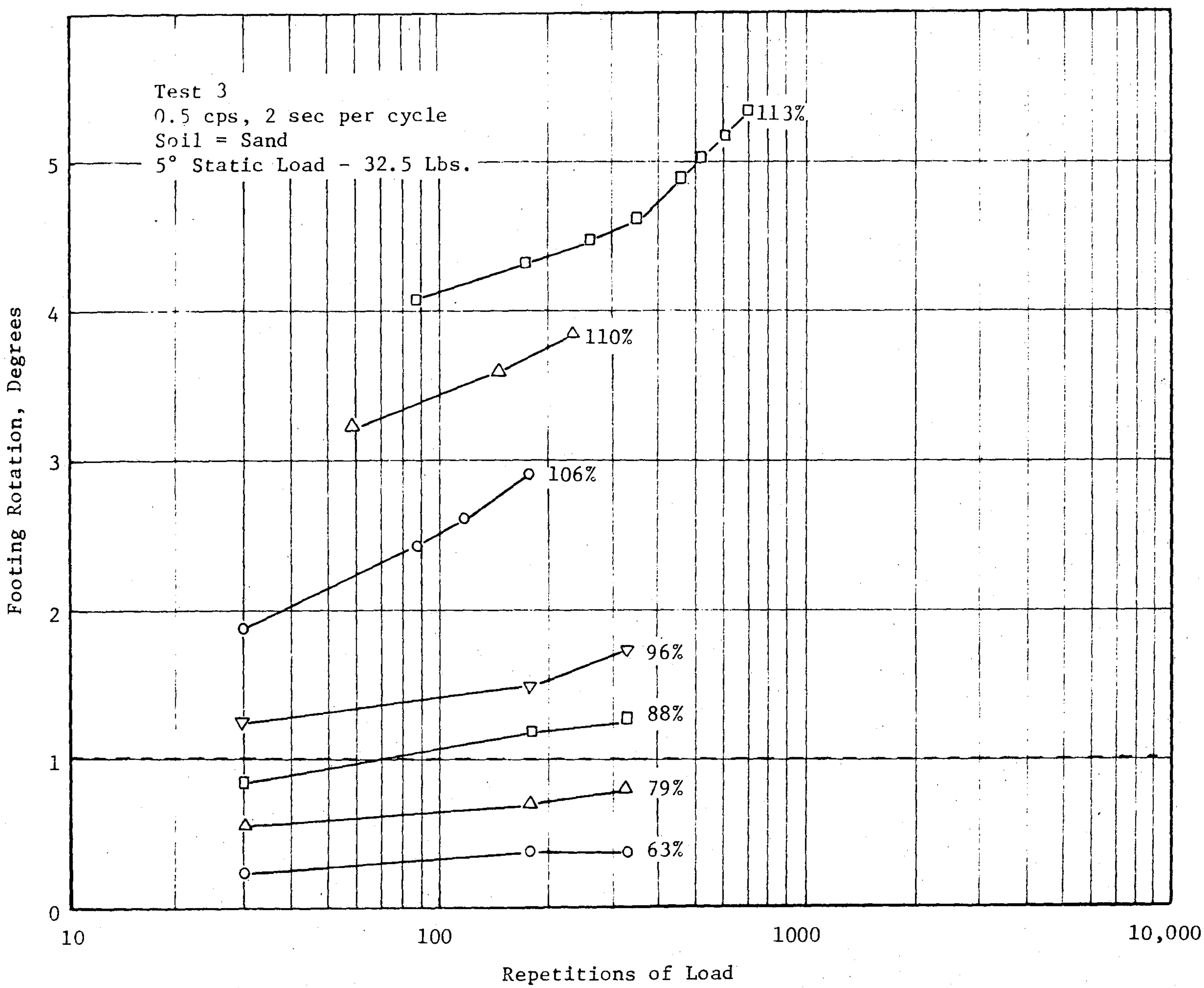


Figure 12.

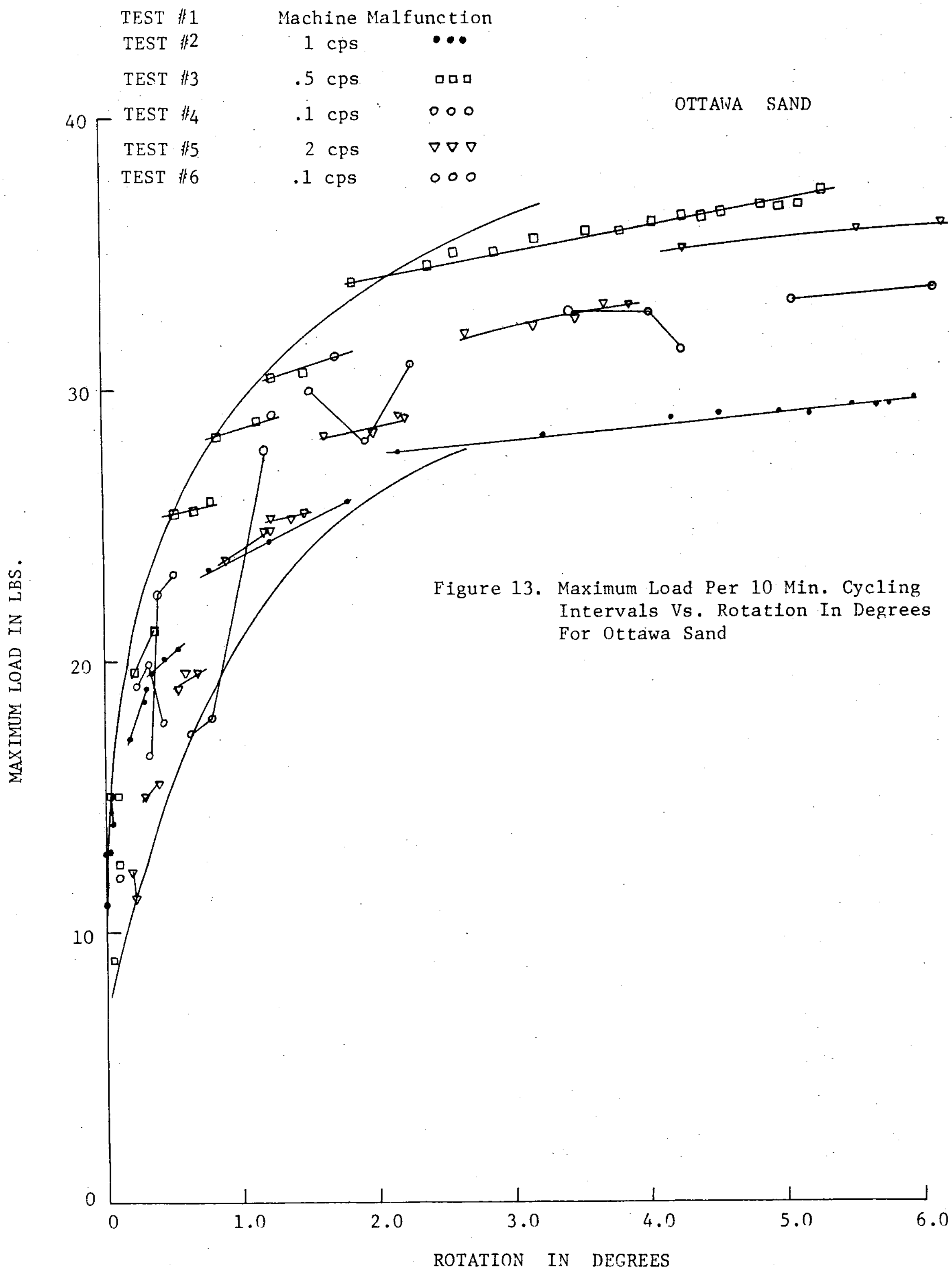


Figure 13. Maximum Load Per 10 Min. Cycling Intervals Vs. Rotation in Degrees for Ottawa Sand.

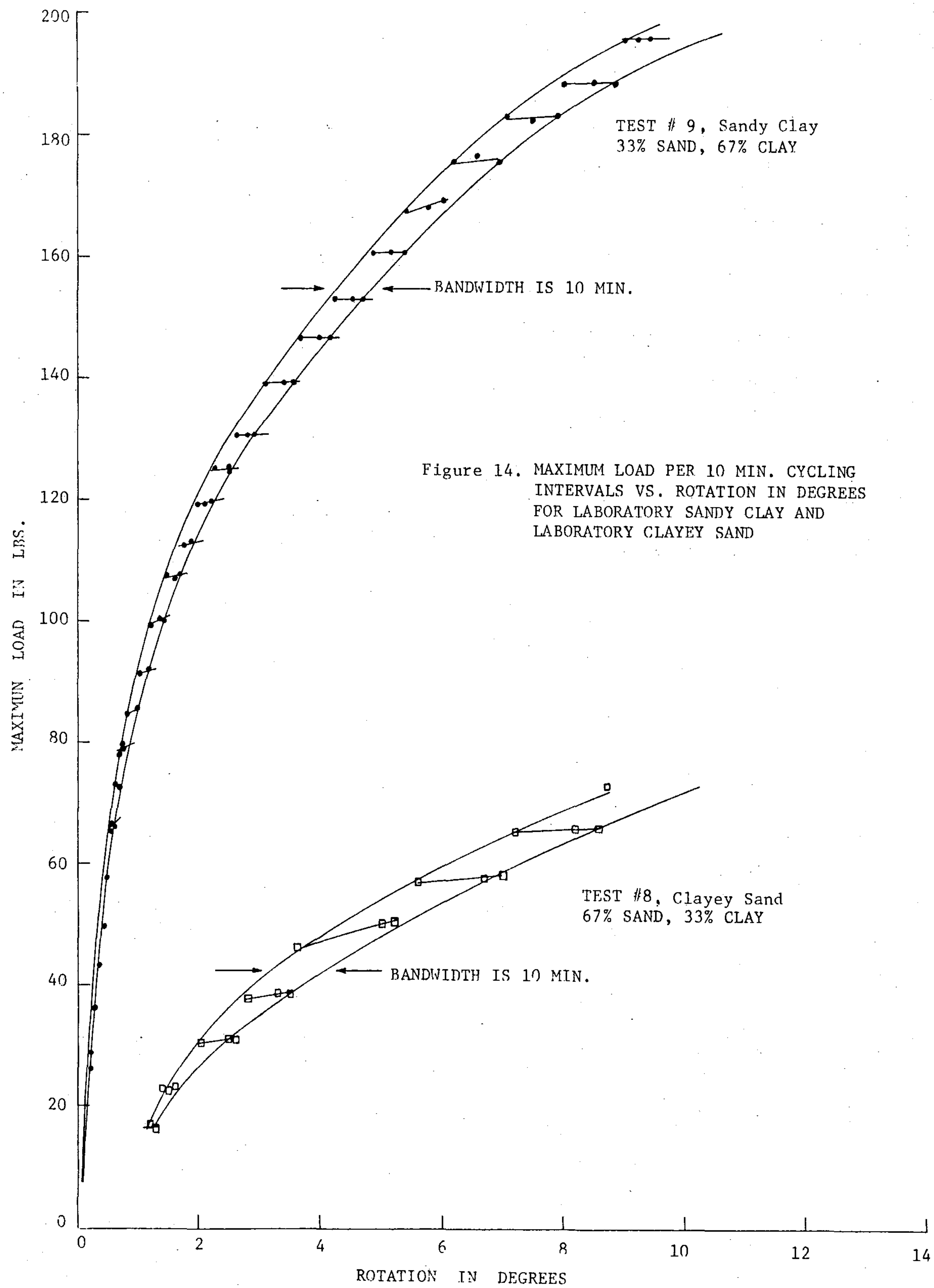


Figure 14. Maximum Load Per 10 Min. Cycling Intervals Vs. Rotation in Degrees for Laboratory Sandy Clay and Laboratory Clayey Sand.

APPENDIX B

TABLE 4

DYNAMIC TEST ON 20-30 MESH OTTAWA SAND

TEST #2

Loading Rate: 1 cps (1 Hertz)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ
			Max lb	Min lb	Top in	Bottom in	degrees
1056	6.40	2.5	6.8	5.5	0	0	0
1057	Machine Stopped Cycling						
1103	6.40	2.5	6.8	5.5	0	0	0
1106	Machine Stopped Cycling						
1107	6.40	2.5	6.8	5.5	0	0	0
1109	Machine Stopped Cycling						
1113	6.40	5.0	8.0	5.7	0	0	0
1118	Machine Stopped Cycling						
1119	6.41	5.0	11.2	8.5	0	0	0
1124	6.41	5.0	13.1	11.0	.01	0	.03
1125	6.41	10.0	14.1	8.5	.03	.01	.055
1130	6.41	10.0	14.7	8.7	.04	.02	.055
1135	6.41	10.0	14.7	8.7	.05	.03	.055
1136	6.42	12.5	17.2	10.3	.12	.05	.19
1141	6.42	12.5	18.6	10.3	.18/.17	.07	.29
1146	6.42	12.5	18.9	10.5	.20/.19	.08	.32
1147	6.42	15.0	19.7	9.8	.22/.20	.08	.36

TABLE 4

DYNAMIC TEST ON 20-30 MESH OTTAWA SAND

TEST #2 (Continued)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ degrees
			Max lb	Min lb	Top in	Bottom in	
1152	6.42	15.0	20.1	9.8	.28/.25	.10	.45
1157	6.42	15.0	20.5	9.8	.32/.29	.11	.54
1159	6.43	17.5	23.4	11.0	.47/.44	.17	.78
1204	6.43	17.5	24.3	11.1	.72/.70	.26	1.24
1209	6.43	17.5	26.2	12.5	1.04/1.02	.37	1.82
1210	6.44	20.0	27.7	13.7	1.27/1.24	.46	2.19
1212	6.44	20.0	28.3	13.6	1.91/1.88	.71	3.26
1215	6.44	20.0	28.7	13.3	2.44/2.39	.89	4.20
1217	6.44	20.0	29.1	13.3	2.68/2.65	.99	4.56
1220	6.44	20.0	29.1	13.0	2.92/2.89	1.09	5.00
1222	6.44	20.0	29.1	13.0	3.06/3.04	1.15	5.23
1225	6.44	20.0	29.4	13.3	3.25/3.22	1.21	5.58
1227	6.44	20.0	29.4	13.2	3.36/3.33	1.26	5.72
1230	6.44	20.0	29.4	13.2	3.46/3.44	1.32	5.80
1232	6.44	20.0	29.7	13.3	3.54/3.52	1.35	6.00

TABLE 5

DYNAMIC TEST ON 20-30 MESH OTTAWA SAND

TEST #3

Loading Rate: .5 cps (.5 Hertz)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ
			Max lb	Min lb	Top in	Bottom in	degrees
223	6.42	2.5	8.9	8.7	.03	.01	.055
224	Machine Stopped Cycling						
225	6.43	5.0	12.5	12.5	.05	.01	.110
226	Machine Stopped Cycling						
230	Established New Zeros						
231	6.40	2.5	10.1	8.3	.01	0	.03
234	Machine Stopped Cycling						
235	6.41	5.0	15.2	9.6	.02	0	.055
240	6.41	5.0	15.2	9.6	.03	0	.083
244	Machine Stopped Cycling						
245	6.42	10.0	19.7	10.4	.13/.11	.03	.230
250	6.42	10.0	21.2	11.0	.19	.05	.385
255	6.42	10.0	21.2	10.8	.21/.20	.07	.385
256	6.43	12.5	25.4	11.9	.30/.28	.10	.523
301	6.43	12.5	25.6	12.0	.40/.38	.14	.688
306	6.43	12.5	25.9	12.2	.46/.43	.16	.785
307	6.43	15.0	28.3	11.9	.49/.46	.17	.840
312	6.43	15.0	28.8	12.0	.65/.63	.22	1.16

TABLE 5

DYNAMIC TEST ON 20-30 MESH OTTAWA SAND

TEST #3 (Continued)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ degrees
			Max lb	Min lb	Top in	Bottom in	
317	6.43	15.0	29.1	11.9	.72/.69	.25	1.25
318	6.43	17.5	30.4	11.1	.74/.72	.26	1.24
323	6.43	17.5	30.6	11.1	.90/.86	.31	1.49
328	6.43	17.5	31.2	11.1	.99/.96	.35	1.72
329	6.44	20.0	33.9	11.7	1.07/1.03	.37	1.87
331	6.44	20.0	34.6	12.0	1.40/1.36	.50	2.42
332	6.44	20.0	34.9	11.9	1.50/1.45	.53	2.60
334	6.44	20.0	34.9	11.4	1.68/1.64	.60	2.92
336	6.44	20.0	35.4	11.9	1.84/1.80	.66	3.20
339	6.44	20.0	35.8	11.9	2.05/2.01	.74	3.58
342	6.44	20.0	35.8	11.9	2.21/2.17	.80	3.83
345	6.44	20.0	36.1	11.9	2.36/2.32	.86	4.08
348	6.44	20.0	36.3	12.2	2.48/2.44	.90	4.30
351	6.44	20.0	36.3	12.0	2.59/2.55	.95	4.46
354	6.44	20.0	36.4	12.0	2.70/2.66	.99	4.60
358	6.44	20.0	36.7	12.0	2.83/2.79	1.04	4.88
400	6.44	20.0	36.7	12.3	2.91/2.87	1.07	5.01
403	6.44	20.0	36.7	12.3	3.00/2.97	1.11	5.16
406	6.44	20.0	37.3	12.9	3.10/3.06	1.15	5.32

TABLE 6

DYNAMIC TEST ON 20-30 MESH OTTAWA SAND

TEST #4

Loading Rate: .1 cps (.1 Hertz)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ degrees
			Max lb	Min lb	Top in	Bottom in	
229	6.37	5.0	6.9	3.4	.02	0	.055
234	6.37	5.0	7.8	4.0	.03	0	.083
236	Stopped Cycling						
238	6.37	10.0	13.3	3.2	.07	.01	.165
243	6.37	10.0	14.4	3.4	.11	.03	.22
248	6.37	10.0	14.8	3.7	.13	.03	.275
249	6.37	12.5	16.4	3.5	.13	.03	.275
254	6.37	12.5	17.6	3.8	.16	.04	.33
259	Stopped Cycling						
302	6.38	15.0	21.7	8.9	.30/.26	.08	.55
	Stopped Cycling						
306	6.39	15.0	24.8	8.7	.39/.35	.11	.72
	Stopped Cycling						
316	6.42	17.5	35.6	9.2	1.27/1.22	.54	1.94
318	6.42	17.5	37.6	11.2	1.68/1.63	.58	2.96
320	6.42	17.5	36.2	12.7	1.85/1.81	.64	3.24
	Stopped Cycling						
322	6.43	20.0	38.4	14.4	1.97/1.92	.68	3.48
325	6.43	20.0	36.4	15.9	2.08/2.04	.73	3.62
327	6.43	20.0	39.1	11.3	2.88/2.84	1.03/.99	5.07
	Stopped Cycling						
		20.0	38.7	14.7	3.21/3.17	1.15	5.62

TABLE 7

DYNAMIC TEST ON 20-30 MESH OTTAWA SAND

TEST #5

Loading Rate: 2 cps

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ degrees
			Max lb	Min lb	Top in	Bottom in	
850	6.40	2.5	12.2	11.8	.10	.03	.19
852	Stopped Cycling						
853	6.40	2.5	11.3	10.7	.12	.04	.22
854	Stopped Cycling						
854	6.40	5.0	12.2	10.7	.13	.05	.22
858	Stopped Cycling						
859	6.41	5.0	15.0	13.5	.17	.06	.30
902	Stopped Cycling						
903	6.41	10.0	15.4	10.5	.22	.07	.41
908	6.41	10.0	15.4	11.3	.23	.08	.41
913	6.41	10.0	15.4	11.6	.23	.08	.41
914	6.42	12.5	19.0	13.5	.30	.10	.55
919	6.42	12.5	19.6	13.6	.36	.14	.61
924	6.42	12.5	19.6	13.9	.39	.14	.69
925	6.43	15.0	23.7	16.2	.52/.50	.19	.88
930	6.43	15.0	24.8	16.5	.69/.68	.25	1.20
935	6.43	15.0	24.8	16.5	.73/.71	.27	1.24
936	6.43	17.5	25.2	15.9	.73/.71	.27	1.24

TABLE 7

DYNAMIC TEST ON 20-30 MESH OTTAWA SAND

TEST #5 (Continued)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ degrees
			Max lb	Min lb	Top in	Bottom in	
941	6.43	17.5	25.2	16.1	.81/.78	.29	1.39
946	6.43	17.5	25.4	16.1	.85/.83	.30	1.49
946	6.44	20.0	28.3	17.4	.95/.93	.34	1.65
949	6.44	20.0	28.4	17.1	1.14/1.12	.41	1.98
952	6.44	20.0	29.0	17.3	1.22/1.20	.44	2.18
956	6.44	20.0	28.8	17.3	1.30/1.28	.48	2.23
957	6.45	22.5	32.0	19.0	1.56/1.54	.57	2.70
959	6.45	22.5	32.3	18.7	1.84/1.81	.67	3.18
1001	6.45	22.5	32.4	18.8	2.03/2.01	.74	3.52
1003	6.45	22.5	33.2	19.6	2.15/2.13	.79	3.72
1006	6.45	22.5	33.2	19.6	2.27/2.25	.84	3.91
1006	6.46	25.0	35.1	20.4	2.49/2.46	.91	4.31
1008	6.46	25.0	35.8	21.1	3.22/3.20	1.18	5.60
1009	6.46	25.0	35.9	20.6	3.61/3.59	1.32	6.28

TABLE 8

DYNAMIC TEST ON 20-30 MESH OTTAWA SAND

TEST #6

Loading Rate: .1 cps (.1 Hertz)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ degrees
			Max lb	Min lb	Top in	Bottom in	
1023	6.39	5.0	6.3	3.1	0	0	
1028	6.39	5.0	6.4	3.2	0	0	
1033	Stopped Cycling						
1034	6.40	7.5	13.0	4.9	.02	0	.055
1039	6.40	7.5	12.1	5.5	.04	0	.110
1043	Stopped Cycling						
1044	6.41	10.0	19.1	6.1	.13	.04	.230
1045	6.41	10.0	19.9	6.1	.19/.17	.05	.34
1049	6.41	10.0	17.7	6.9	.20/.18	.06	.40
1052	Stopped Cycling						
1054	6.41	10.0	16.5	8.3	.21/.19	.07	.34
1055	6.42	12.5	22.5	8.9	.26/.23	.09	.40
1055.5	6.42	12.5	23.2	8.4	.31/.28	.10	.52
1059	Stopped Cycling						
1104	6.43	12.5	27.8	11.6	.67/.64	.22	1.20
1108	Stopped Cycling						

TABLE 8

DYNAMIC TEST ON 20-30 MESH OTTAWA SAND

TEST #6 (Continued)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ degrees
			Max lb	Min lb	Top in	Bottom in	
1109	6.43	15.0	30.0	9.8	.87/.81	.28	1.54
1114	6.43	15.0	28.1	11.3	1.07/1.05	.36	1.95
1116	Stopped Cycling						
1117	6.44	15.0	30.9	12.2	1.32/1.29	.45	2.35
1120	6.44	17.5	32.9	10.9	1.95/1.91	.68	3.43
1121	6.44	17.5	32.9	13.2	2.32/2.25	.80	4.06
1123	6.44	17.5	31.5	14.7	2.42/2.39	.85	4.29
1124	Stopped Cycling						
1125	6.45	20.0	33.2	12.8	2.97/2.71	1.00	5.09
1126	6.45	20.0	32.4	14.2	3.53/3.50	1.26	6.19
1127	6.45	20.0	31.6	14.5	4.07/3.93	1.44	7.05

TABLE 9

DYNAMIC TEST ON 67% SAND, 33% CLAY

TEST #8

Loading Rate: 1 cps (1 Hertz)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ degrees
			Max lb	Min lb	Top in	Bottom in	
1043	6.22	5.0	18.1	15.1	.61/.60	.18	1.18
1048	6.22	5.0	17.6	14.1	.65/.64	.19	1.27
1053	6.22	5.0	17.1	14.6	.65/.64	.20	1.23
1055	6.24	7.5	22.6	19.1	.73/.72	.23	1.38
1100	6.24	7.5	22.6	18.6	.88/.87	.29	1.62
1105	6.24	7.5	23.1	18.6	.91/.90	.30	1.68
1106	6.26	10.0	30.6	22.6	1.10/1.08	.37	2.02
1111	6.26	10.0	31.2	22.6	1.40/1.38	.50	2.48
1116	6.26	10.0	31.2	24.1	1.47/1.45	.52	2.62
1117	6.28	12.5	37.7	27.6	1.56/1.53	.55	2.78
1122	6.28	12.5	38.7	27.6	1.92/1.89	.68	3.42
1127	6.28	12.5	38.7	27.1	2.03/2.00	.73	3.58
1128	6.30	15.0	46.2	32.7	2.10/2.07	.75	3.72
1133	6.30	15.0	51.2	36.7	2.91/2.88	1.06	5.08
1138	6.30	15.0	50.8	35.7	3.03/3.00	1.13	5.22
1139	6.32	17.5	57.3	39.2	3.20/3.16	1.16	5.60
1144	6.32	17.5	57.8	39.2	3.75/3.71	1.35	6.68

TABLE 9

DYNAMIC TEST ON 67% SAND, 33% CLAY

TEST #8 (Continued)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response Max lb	Load Cell Response Min lb	Linear Displacement Transducer Top in	Linear Displacement Transducer Bottom in	Rotation θ degrees
1149	6.32	17.5	58.3	39.2	3.99/3.94	1.43	7.02
1150	6.34	20.0	65.3	43.2	4.09/4.05	1.47	7.18
1155	6.34	20.0	65.8	43.2	4.67/4.62	1.68	8.18
1200	6.34	20.0	65.8	43.2	4.95/4.90	1.80	8.62
1201	6.36	22.5	72.8	47.7	5.00/4.95	1.82	8.70
1203			Exceeded limits of system				
1205			Full load sine wave is no longer obtained				
1206							

TABLE 10

DYNAMIC TEST ON 67% CLAY, 33% SAND

TEST #9

Loading Rate: 1 cps (1 Hertz)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation θ degrees
			Max lb	Min lb	Top in	Bottom in	
916	6.16	5.0	7.5		.03	0	.083
923	6.16	5.0	8.0		.04	0	.117
926	6.16	5.0	8.0		.04	0	.117
928	6.22	5.0	28.9	26.4	.08	0	.217
929	Stopped Cycling						
930	6.22	5.0	26.4	23.4	.08	0	.217
932	Stopped Cycling						
933	6.24	7.5	36.3	29.9	.10	0	.275
938	6.24	7.5	36.3	30.3	.12/.10	.01	.300
943	6.24	7.5	35.8	31.8	.11/.10	0	.300
944	6.26	10.0	43.3	36.3	.13/.12	0	.358
949	6.26	10.0	43.3	36.3	.14/.12	0	.383
954	6.26	10.0	43.3	36.3	.14/.13	0	.383
955	6.28	12.5	49.8	39.8	.16/.14	0	.450
1000	6.28	12.5	51.2	38.8	.16/.14	.01	.442
1005	6.28	12.5	50.3	37.8	.16/.14	.01	.442
1006	6.30	15.0	58.7	41.3	.19/.16	.01	.500
1011	6.30	15.0	58.7	41.3	.20/.17	.01	.517
1016	6.30	15.0	58.7	41.3	.20/.18	.01	.517

TABLE 10

DYNAMIC TEST ON 67% CLAY, 33% SAND

TEST #9 (Continued)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation Θ degrees
			Max lb	Min lb	Top in	Bottom in	
1017	6.32	17.5	65.2	45.3	.22/.19	.01	.575
1022	6.32	17.5	66.2	45.3	.23/.20	.02	.575
1027	6.32	17.5	65.7	45.8	.24/.20	.02	.600
1028	6.34	20.0	73.1	49.2	.26/.22	.03	.633
1033	6.34	20.0	73.1	49.2	.27/.24	.03	.667
1038	6.34	20.0	72.6	49.2	.28/.24	.03	.683
1039	6.36	22.5	78.1	50.7	.30/.26	.04	.717
1044	6.36	22.5	79.6	51.7	.32/.27	.04	.767
1049	6.36	22.5	79.1	52.3	.34/.29	.05	.800
1050	6.38	25.0	84.6	54.7	.36/.31	.05	.850
1055	6.38	25.0	85.6	54.7	.43/.38	.07	.992
1100	6.38	25.0	85.6	54.2	.45/.40	.08	1.02
1101	6.40	27.5	91.6	56.7	.47/.41	.09	1.05
1106	6.40	27.5	92.0	56.7	.52/.47	.10	1.16
1111	6.40	27.5	92.0	56.7	.55/.49	.11	1.22
1112	6.42	30.0	99.5	61.7	.58/.52	.13	1.23
1117	6.42	30.0	100.4	61.2	.66/.60	.16/.15	1.38
1122	6.42	30.0	100.4	61.2	.68/.62	.17/.16	1.40
1123	6.44	32.5	107.5	65.2	.72/.65	.18/.17	1.48
1128	6.44	32.5	107.0	64.7	.79/.72	.20/.20	1.63

TABLE 10

DYNAMIC TEST ON 67% CLAY, 33% SAND

TEST #9 (Continued)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation Θ degrees
			Max lb	Min lb	Top in	Bottom in	
1133	6.44	32.5	107.5	65.2	.83/.75	.22/.21	1.68
1134	6.46	35.0	112.5	68.6	.85/.78	.22/.21	1.73
1139	6.46	35.0	113.0	68.1	.93/.85	.25/.24	1.88
1144	6.46	35.0	113.0	68.1	.96/.88	.27/.26	1.90
1145	6.48	37.5	119.4	72.1	.99/.90	.27/.26	1.98
1150	6.48	37.5	119.4	72.1	1.08/1.00	.31/.30	2.12
1155	6.48	37.5	119.9	72.1	1.13/1.05	.33/.32	2.20
1156	6.50	40.0	125.3	75.1	1.15/1.07	.33/.32	2.26
1201	6.50	40.0	124.8	75.6	1.28/1.17	.36/.35	2.53
1206	6.50	40.0	125.3	75.1	1.30/1.21	.38/.37	2.53
1207	6.52	42.5	130.8	79.1	1.34/1.24	.39/.38	2.62
1212	6.52	42.5	130.8	79.1	1.45/1.35	.43/.42	2.80
1217	6.52	42.5	131.3	79.6	1.53/1.42	.46/.45	2.93
1218	6.54	45.0	136.3	83.6	1.58/1.48	.48/.47	3.03
1218	Gain cut in half		139.5	85.6	1.60/1.50	.49/.47	3.05
1223	6.54	45.0	139.5	85.6	1.79/1.70	.55/.53	3.42
1228	6.54	45.0	139.5	85.6	1.90/1.80	.59/.58	3.60
1229	6.56	47.5	147.0	89.6	1.94/1.84	.60/.59	3.68
1234	6.56	47.5	147.0	89.6	2.11/2.02	.66/.65	3.99
1239	6.56	47.5	147.0	89.6	2.21/2.10	.69/.68	4.20

TABLE 10

DYNAMIC TEST ON 67% CLAY, 33% SAND

TEST #9 (Continued)

Time	Machine Signal Conditioner	Machine Load Setting lbs	Load Cell Response		Linear Displacement Transducer		Rotation Θ degrees
			Max lb	Min lb	Top in	Bottom in	
1240	6.58	50.0	153.3	93.6	2.25/2.14	.71/.70	4.25
1245	6.58	50.0	153.3	93.6	2.43/2.33	.78/.77	4.53
1250	6.58	50.0	153.3	93.6	2.54/2.43	.82/.81	4.73
1251	6.60	52.5	161.0	98.5	2.57/2.46	.83/.82	4.78
1256	6.60	52.5	161.0	97.5	2.79/2.67	.91/.89	5.17
1301	6.60	52.5	161.0	97.5	2.91/2.79	.94/.93	5.41
1302	6.62	55.0	167.5	101.5	2.94/2.83	.96/.94	5.44
1307	6.62	55.0	168.4	101.5	3.15/3.03	1.03/1.02	5.82
1312	6.62	55.0	169.4	101.5	3.30/3.18	1.09/1.08	6.07
1313	6.64	57.5	175.8	105.4	3.36/3.23	1.10/1.09	6.20
1318	6.64	57.5	176.8	104.4	3.64/3.50	1.20/1.19	6.68
1323	6.64	57.5	175.8	105.4	3.80/3.66	1.26/1.24	6.97
1324	6.66	60.0	183.2	109.4	3.86/3.72	1.27/1.26	7.10
1329	6.66	60.0	182.3	108.4	4.13/3.99	1.36/1.35	7.58
1334	6.66	60.0	183.2	108.4	4.29/4.15	1.38/1.37	7.97
1334	6.68	62.5	188.7	111.4	4.32/4.18	1.39/1.37	8.03
1339	6.68	62.5	188.7	111.4	4.59/4.44	1.46/1.44	8.55
1344	6.68	62.5	188.7	111.4	4.79/4.64	1.53/1.53	8.92
1344	6.70	65.0	196.0	116.3	4.83/4.67	1.53/1.53	9.02
1347	67.0	65.0	196.0	115.3	5.02/4.86	1.60/1.58	9.28
1348.5	67.0	65.0	196.0	115.3	5.09/4.94	1.62/1.60	9.47