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DEADMAN ANCHORAGES IN VARIOUS SOIL MEDIUMS

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U.S.Naval Civil Engineering Laboratory
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BUREAU OF YARDS AND DOCKS

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DEADMAN ANCHORAGES IN VARIOUS SOIL MEDIUMS

Technical Report R-434

Y-F015-15-01-010

by

J. E. Smith and J. V. Stalcup

ABSTRACT

A test program was conducted to investigate deadman anchorage holding capacities under applied horizontal loads. Deadmen fabricated of concrete and ranging in face area from 5 to 72 square feet were tested in depths of embedment from ground level to 7 feet. The deadmen were pulled both singly and in groups of three, in sand and in two soils with cohesive characteristics. The test program also included tests on a model scale.

The applied load versus horizontal displacement relationship exhibited a basic recognizable form for all conditions of tests. By graphic analysis, a series of reaction-pattern curves was developed relating deadman holding power in each cohesive soil to three factors: deadman face area, depth of embedment, and whether the deadmen were embedded singly or in a group. The results of the sand tests which were described in a previous report were converted from the previous analysis to a compatible form and presented with the cohesive soil test results. These curves provide an empirical means for determining deadman holding capacities at different amounts of displacement within the range of conditions tested.

The investigation disclosed that multiple anchors develop a higher holding capacity per net area than a single deadman with the same total face area. The increase in holding capacity ranging from 5 to 20% depends upon such factors as depth of embedment, the type of soil, and the spacing between deadmen. Under most test conditions, up to a 30% increase in holding capacities was attained in cohesive soils as compared to sand, but 2 to 3 times the horizontal displacement was required to achieve the maximum holding capacity.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

CONTENTS

INTRODUCTION

The use of deadman anchorages to provide lateral support for structures such as quay walls is an accepted engineering practice. High quay walls must remain vertical for ship-docking purposes while containing and supporting large quantities of fill material behind them on the dockside. Theoretical computations for the holding power of deadmen generally are based on equivalent fluid pressure or on an assumed failure of a soil mass along a shear plane. But the theories do not readily account for the load-displacement characteristics of deadmen.

The U. S. Naval Bureau of Yards and Docks sponsored an investigation, Task No. Y-F015-15-01-010, conducted by the U. S. Naval Civil Engineering Laboratory at Port Hueneme, California, to determine deadman reactions under applied horizontal loads. The investigation has encompassed three separate phases of testing. In Phases 1 and 2, full-scale tests were conducted in sand in which deadmen were pulled singly and in rectilinear groups of three; the results were previously reported.[1,2] In Phase 3, full-scale tests were conducted in two cohesive soils with test conditions similar to those in sand; model tests were included. This report describes the overall investigation; the results obtained from the cohesive soil tests are presented along with the results previously obtained in the sand tests.

TEST PROGRAM

History

The three separate test phases of deadman anchorages were conducted at intermittent times over a period of years. Phase 1 included tests of two sizes of deadmen in sand and in depths to 3 feet. Subsequently, Phase 2 included tests of deadmen of seven sizes in various depths to 7 feet. The results of the Phase 2 tests were combined with those of Phase 1. By means of computer programming, a regression analysis of the data was performed and an empirical equation was developed relating holding power at specific horizontal displacements to three variables: depth, face area, and whether the deadmen were single or in a group of three. By means of a nomograph based on this equation, it was possible to rapidly determine deadman holding capacities for different amounts of horizontal deadman displacements in sand.[2]

The encouraging results obtained from the deadman tests in sand prompted Phase 3 of the program in which deadmen were tested in soils with cohesive characteristics. The intent was to combine and analyze the results of all three phases in a manner that would enable the accurate determination of deadman holding powers at various displacements, while considering such variables as soil characteristics in addition to the variables which were accounted for in the prior programs. To this end, Phase 3 was designed so that a minimum number of tests could be integrated with the previous tests to give a maximum amount of information. In addition, model tests were incorporated into the third phase for two purposes: first, to investigate the variables affecting deadman performance over a wider range of conditions than was practical to investigate on a full scale; and second, to investigate the effect of additional variables not practical to investigate on a full scale.

Framework of Tests

Full-Scale Tests. Fifty-seven full-scale tests were included in the program covered by this report. Each test represented a separate set of conditions relating to such factors as soil type, depth of embedment, face area of deadman, and whether the deadmen were pulled singly or in multiples of three. An outline of the full-scale tests in a classified order is presented in Table I. The test numbers represent a logical order for classifying the tests. The sequence of the tests as actually conducted was different and extended over a considerable period of time.

Thirty-three of the full-scale tests were conducted in sand, 12 in sandy silt, and 12 in silty sand (Table I). An irregular variety of deadman sizes, depths of embedment, and spacings was used to envelop the range of conditions investigated in sand (Phases 1 and 2). This irregularity resulted because Phases 1 and 2 initially were independent programs whose results were subsequently combined when computer analysis was undertaken. The cohesive soil testing (Phase 3) was planned with results of the sand tests considered as a base and with computer programming in mind. Consequently, a more efficient coverage of the variables was possible. In Phase 3, deadmen of three sizes were pulled singly at depths of 0, 3, and 6 feet, and deadmen of one size were pulled in multiples of three at these same depths in the two cohesive soils.

Model Tests. The model tests were comprised of two parts. First, all 57 full-scale tests were duplicated on a scale of 1 to 18. The intent was to obtain a comparability factor that would permit a reliable determination of deadman anchorage performance from model tests. Second, 37 additional tests (termed extra-variable tests) were conducted for the purpose of studying the variables of the full-scale tests over a wider range and for investigating additional variables not included in the full-scale tests. Table II lists the 37 extra-variable model tests that followed the first 57 tests. The purpose of each of these tests is indicated in the Shape and Spacing columns of Table II. In general, the effect of and limits for spacing multiple deadmen, the effect of shape and perimeter of deadmen, and the effect of additional moisture in the cohesive soils were the additional variables included in the extra variable model tests.

Table 1. Outline of Full-Scale Tests

Single Deadman			Multiple Deadmen			
Test No.	Face Area (sq ft)	Depth[1] (ft)	Test No.	Face Area[2] (sq ft)	Depth[1] (ft)	Spacing[3] (ft)
Sand: Phases 1 and 2[4]						
1-6	5	GL,1,2,3,5,7	27	33	4	6.5
7	9	6	28-30	54	GL,2,4	3.5
8-11	10	GL,1,2,3	31-33	60	GL,2,4	2.0
12,13	11	4,6				
14	17	6				
15-21	20	GL,1,2,2,3,4,6				
22,23	45	GL,2				
24-26	72	GL,2,4				
Sandy Silt: Phase 3						
34-36	13.5	GL,3,6	43-45	27	GL,3,6	4.5
37-39	27	GL,3,6				
40-42	54	GL,3,6				
Silty Sand: Phase 3						
46-48	13.5	GL,3,6	55-57	27	GL,3,6	4.5
49-51	27	GL,3,6				
52-54	54	GL,3,6				

1/ GL = ground level

2/ The face area includes the total face area of three single deadmen; e.g., 33 indicates three deadmen, each with a face area of 11 square feet.

3/ Distance between deadmen in multiple-deadman grouping.

4/ Tests 8-11, 15-17, and 19 are Phase 1; all others are Phase 2.

Table II. Outline of Model-Scale Extra-Variable Tests[1]

Single Deadman				Multiple Deadmen			
Test No.	Face Area (sq ft)	Depth[2] (ft)	Shape[3]	Test No.	Face Area (sq ft)	Depth[2] (ft)	Spacing (ft)
Sand							
58-60	17	GL,2,4	▯,▯,▯	67,68	33	4,4	3.75,5.25
61-64	20	GL,GL,2,2	○,△,○,△				
65,66	27	2,2	○,△				
Sandy Silt							
69-71	13.5	GL,3,6	▯,▯,▯	76-78	27	GL,3,6	3.00
72-75	27	GL,3,GL,3	○,○,△,△	79,80	27	GL,3	6.00
Silty Sand							
81-83	13.5	GL,3,6	▯,▯,▯	88-90	27	GL,3,6	3.00
84-87	27	GL,3,GL,3	○,○,△,△	91,92	27	GL,3	6.00
Sandy Silt With Extra Moisture							
93	27	3	▭				
Silty Sand With Extra Moisture							
94	27	3	▭				

1/ All full-scale tests outlined in Table I were duplicated on a model scale in addition to the model-scale extra-variable tests outlined in Table II.

2/ GL = ground level

3/ Shape symbols are as follows:
Rectangle on end
Rectangle on side
Round
Triangle

Description of Deadmen

Full-Scale Specimens. All of the full-scale specimens were constructed of reinforced concrete. Table III summarizes their dimensions, weights, and face areas; most of them were 3 feet high. With two exceptions, the deadmen were designed so that a steel coupling pad could be attached with four bolts. The pad was designed so that a coupling elevation of 0.3 h or 0.4 h could be achieved depending upon the orientation of the pad, where h is the specimen height and the coupling elevation is the location of applied force on a vertical axis of deadmen measured from the bottom. Figure 1 shows representative deadmen used in the tests; the coupling pad may be noted. The 10- and 20-square-foot deadmen tested in Phase 1 were designed with a vertical slot in their faces (Figure 2) so their behavior with various coupling elevations could be studied. It was determined in Phase 1 that maximum holding power could be attained with the coupling elevation at 0.3 h for ground-level tests and 0.4 h for all tests at greater depths.[1] This criterion was used for all subsequent tests.

The deadmen which were 20 square feet in face area and smaller had one coupling; larger specimens had two or three couplings (Figure 1).

Model Specimens. The model specimens were shaped from blocks of redwood and were sanded to a smooth but not fine finish. Their dimensions corresponded to the full-scale specimens on a scale of 1 to 18. Round and triangular models were also included.

Soil Summary

The full-scale and model tests were conducted in three soils: sand, sandy silt, and silty sand (Figure 3). The identifications are based on the U. S. Army Corps of Engineers system for describing soils.[3] Table IV lists the characteristics of the soils used in the test programs.

The sand was natural beach sand found at the NCEL beach test location. The sandy silt was imported in the dry season from the bottom of a small inland reservoir basin. One-thousand cubic yards of material was transported to the test site and utilized as explained under Equipment and Procedures. The silty sand was obtained by blending the sand and the sandy silt. The characteristics of the soils in the full-scale and model tests were maintained as nearly identical as possible. However, because of necessarily different methods of handling and compaction, slight differences in characteristics did result as indicated in Table III.

Table III. Deadman Anchorage Sizes

Face Area (sq ft)	Dimensions			Approximate Weight[3] (lb)
	Width (ft)	Height (ft)	Thickness (in.)	
Prototype and Model[1]				
5	2.50	2.00	12	730
9	3.00	3.00	12	1,320
10	3.54	2.83	10	1,225
11[2]	3.75	3.00	12	1,470
13.5	4.50	3.00	12	2,310
17[2]	5.63	3.00	12	2,900
20	6.67	3.00	12	3,430
20	5.00	4.00	10	2,860
27	9.00	3.00	12	4,600
45	15.00	3.00	12	8,400
54	18.00	3.00	12	10,000
72	24.00	3.00	12	13,200
Model Only				
20	Round, D = 5.05		12	not applicable
20	Triangle, W = 682 H = 5.90		12	not applicable
27	Round, O = 5.86		12	not applicable
27	Triangle, W = 7.90		12	not applicable

1/ Models were 1-to-18 scale.
2/ Nominal face area.
3/ Weights do not apply to models.

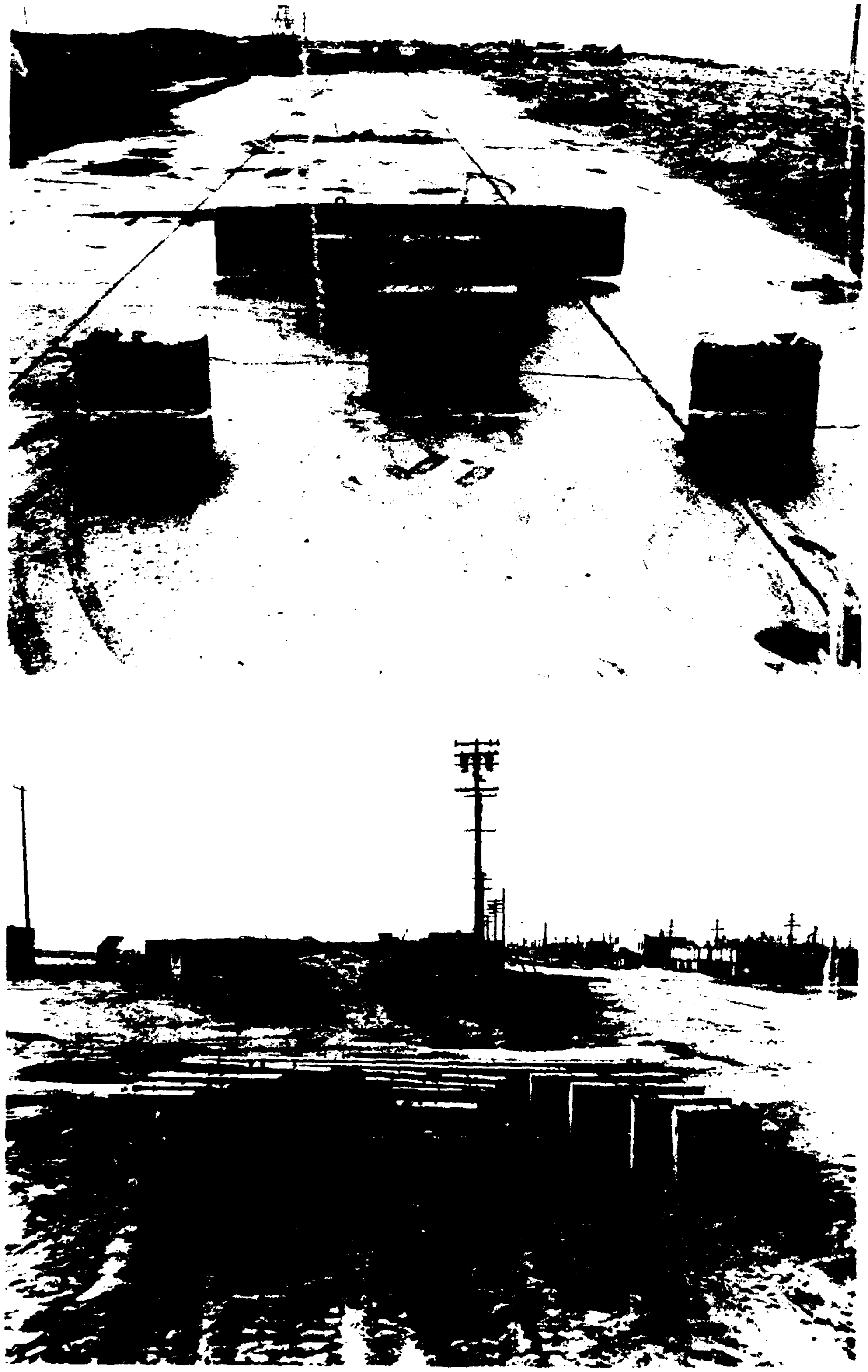


Figure 1. Representative deadmen after use in test programs.

Figure 2. Deadman anchorage with adjustable coupling.

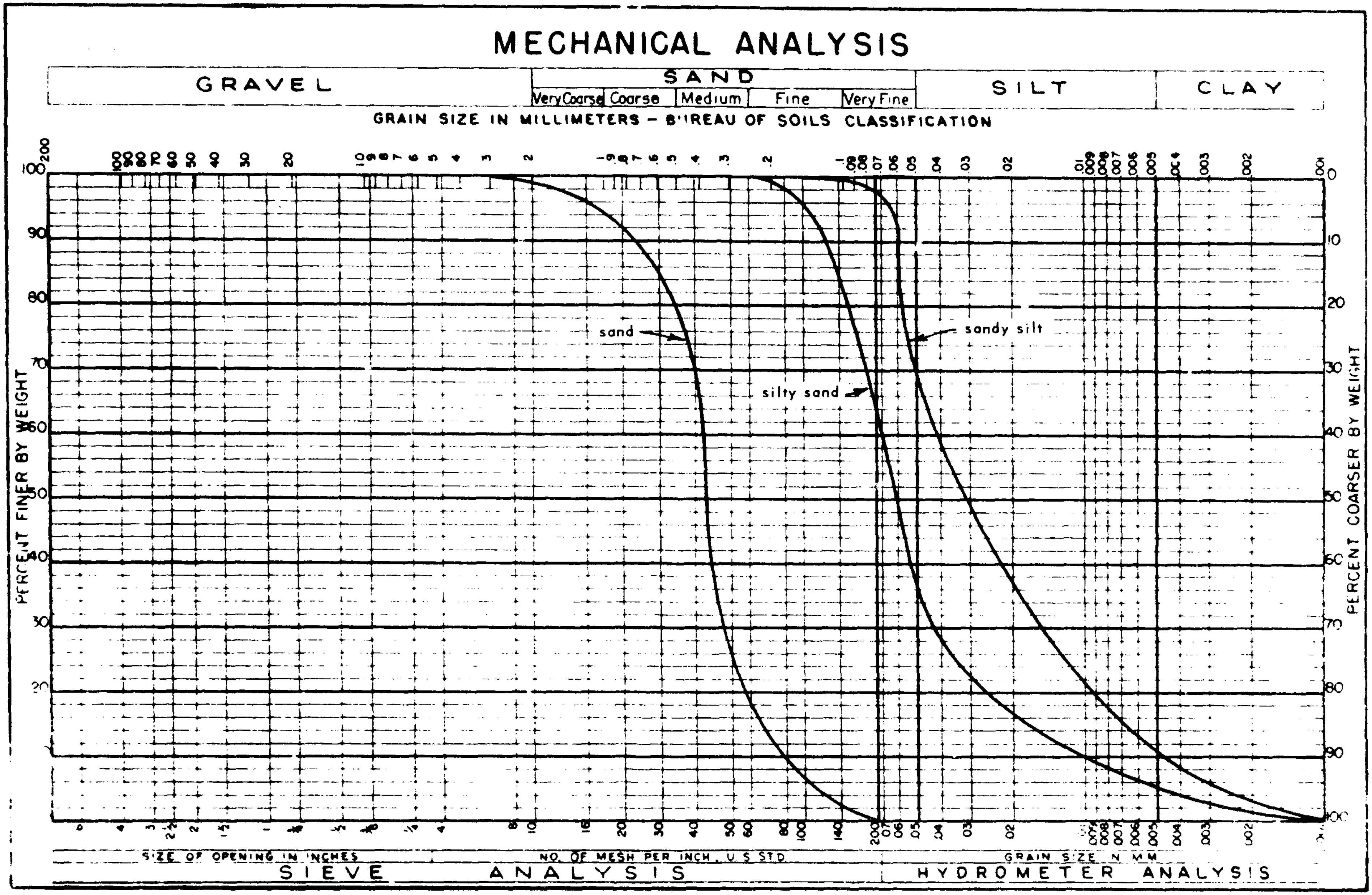


Figure 3. Mechanical analysis of soils.

Table IV. Soil Summary

Soil Properties 1/	Sand		Sandy Silt		Silty Sand		Sandy Silt (Excess Moisture)	Silty Sand (Excess Moisture)
	Prototype Tests (1-33) 2/	Model Tests (1-33, 58-68)	Prototype Tests (34-45)	Model Tests (34-45, 69-80)	Prototype Tests (46-57)	Model Tests (46-57, 81-92)	Model Test (93)	Model Test (94)
c	1.0	1.0	4.0	4.0	2.2	2.2	0.9	0.4
ϕ	32	32	22	22	23	23	20	28
γ	100	100	128	123	129	125	120	121
MC	9	4	18	18	19	19	21	21
PI	-	-	15.5	15.5	5.5	5.5	15.5	5.5

1/ c Cohesion
ϕ Angle of internal friction (degrees)
γ Wet density (lb/ft^3)
MC Moisture content (percent)
PI Plasticity index

2/ Numbers placed in parentheses are Test Numbers.

EQUIPMENT AND PROCEDURES

Full-Scale Test Apparatus

The general layout of the apparatus used is shown in Figure 4. Essentially, the test facility consisted of a 20-foot-gage railway about 250 feet long. A rail cart and a BU-140 Type M two-drum winch were anchored securely at one end of the railway, and the site of embedment, an area about 75 feet wide by 100 feet deep, was at the other end. For tests in sandy silt and silty sand, a U-shaped enclosure 54 feet wide by 72 feet long was constructed to contain the imported soil (Figure 5). The winch applied the load to the rail cart through a six-part line, and the rail cart in turn was connected to the deadmen; for some of the very high-capacity pulls, it was necessary to two-part the dead end of the six-part line. A wire-rope attachment was used in the tests of the single smaller deadmen. Multiple wire-rope attachments were used with a spreader-bar arrangement (Figure 5) in tests of multiple deadmen and in tests of single deadmen 9 feet wide or wider. Chains up to 2-3/4-inch size were incorporated in the apparatus in lieu of wire ropes when especially high loads were anticipated. A horizontal pull was maintained on the deadmen by passing the loading wire rope through a looped bar attached to a 20,000-pound concrete weight (Figure 6). The weight was buried in the sand more than 120 feet from the deadmen so that the vertical component at the weight would be relatively minor and not raise the weight.

Applied loads were measured by means of a dynamometer placed in the line between the rail cart and the deadmen at a point where friction would not affect the reading (Figure 7). For some high-capacity pulls it was necessary to place two instruments in parallel to obtain the maximum readings. A 100,000-pound-capacity Baldwin Type D SR-4 load cell and two specially fabricated 400,000-pound-capacity dynamometers were used interchangeably as appropriate according to anticipated loads.

Full-Scale Test Procedures

Phases 1 and 2: Tests in Sand. The procedures for some of the 33 tests in sand reported here varied somewhat because two separate phases of testing were involved; however, the basic principles of the tests were maintained, and an examination of the data indicated that the effects on the net results were negligible. The test numbers that apply to each phase are identified in Table I.

Preparation for each test consisted of excavating sand within the embedment area, positioning the anchorage(s), and backfilling the sand to a prescribed depth (Figures 8 and 9). In the tests involving multiple deadmen, three deadmen were aligned in rectilinear groups of three perpendicular to the direction of pull (Figure 10). Depth was controlled by altering the overall elevation of the ground surface. The backfill was compacted by applying fresh water for a prescribed length of time once during and once again upon completion of backfilling.

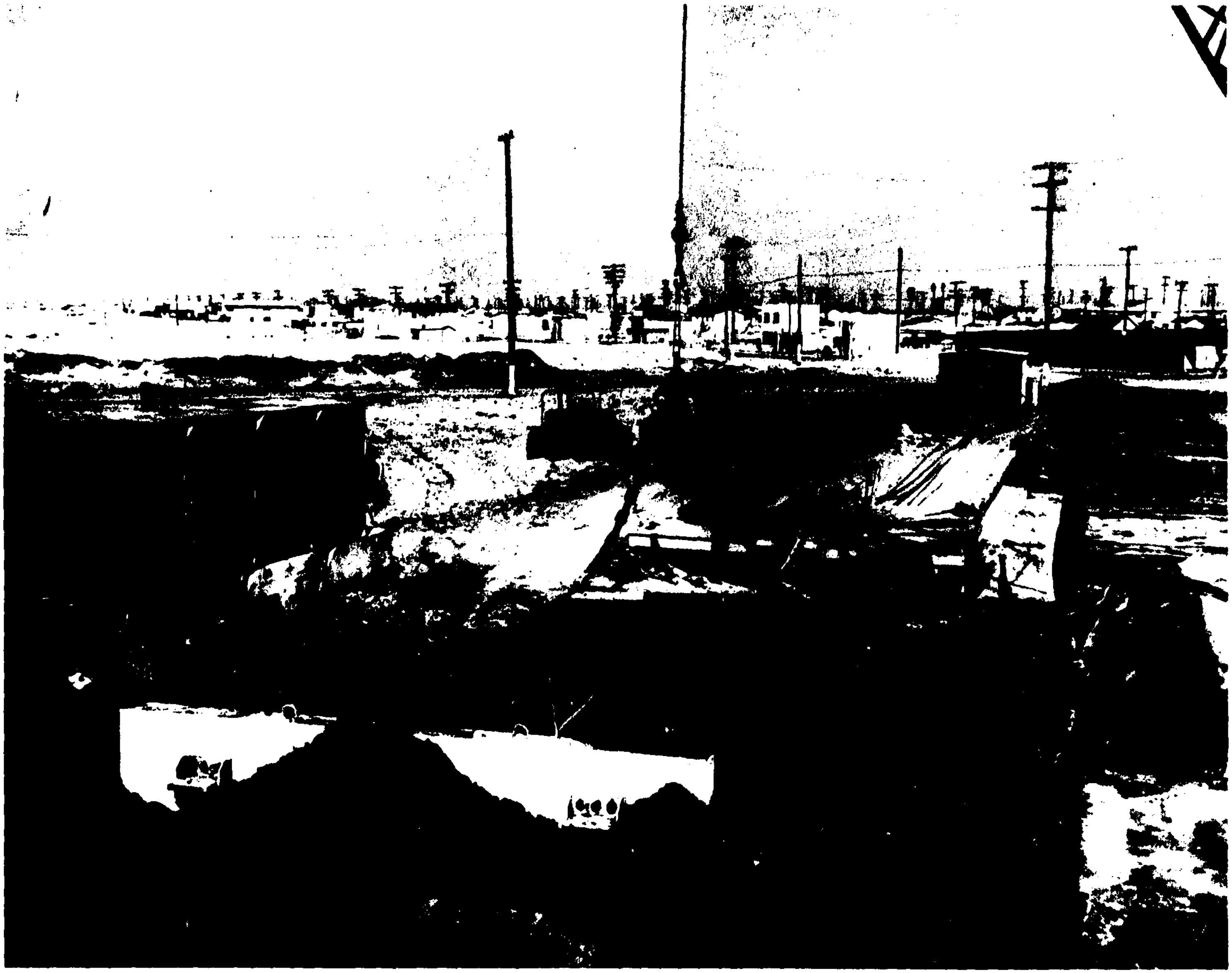


Figure 4. Full-scale test apparatus.

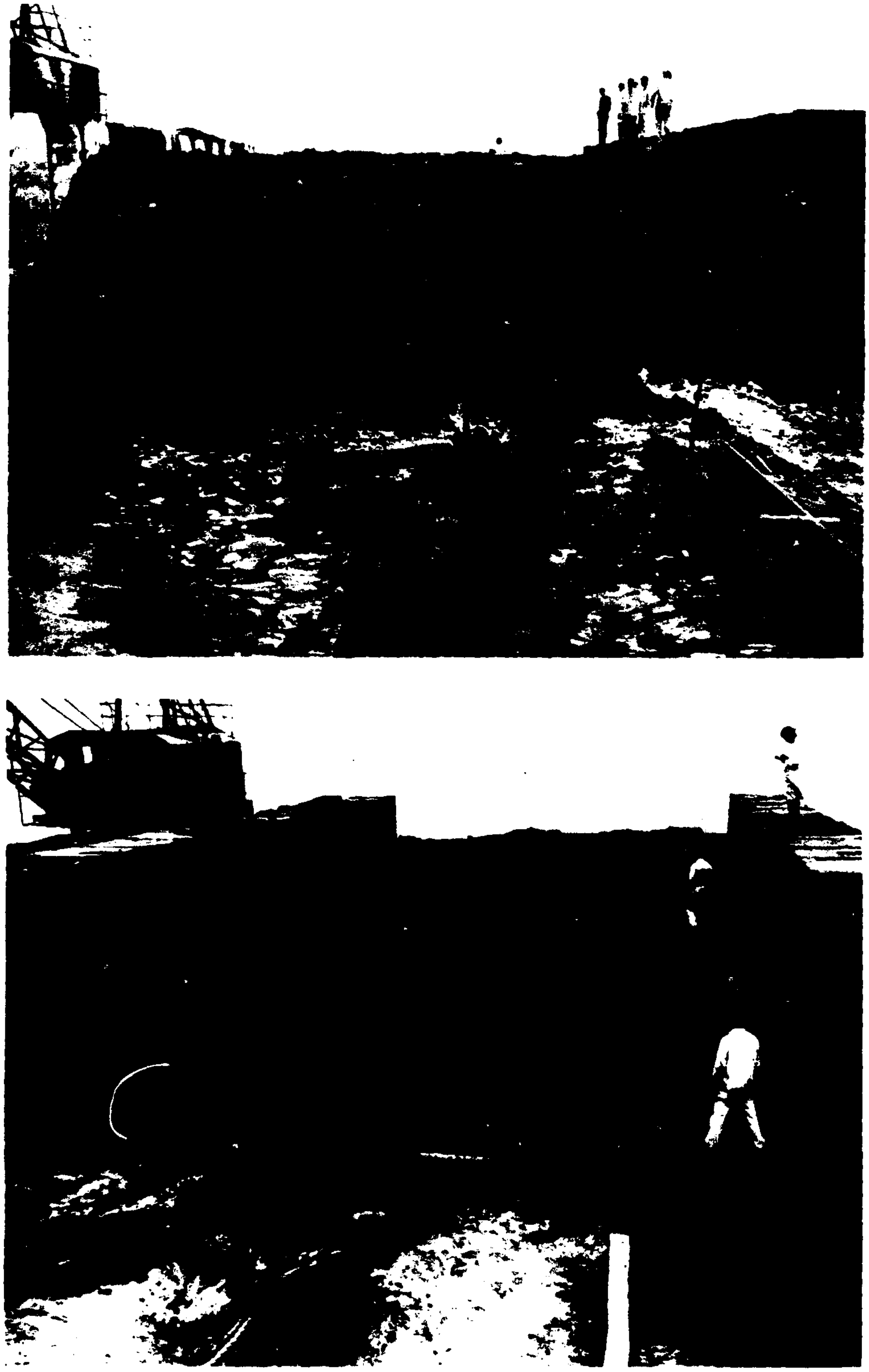


Figure 5. Cohesive soil containment area.

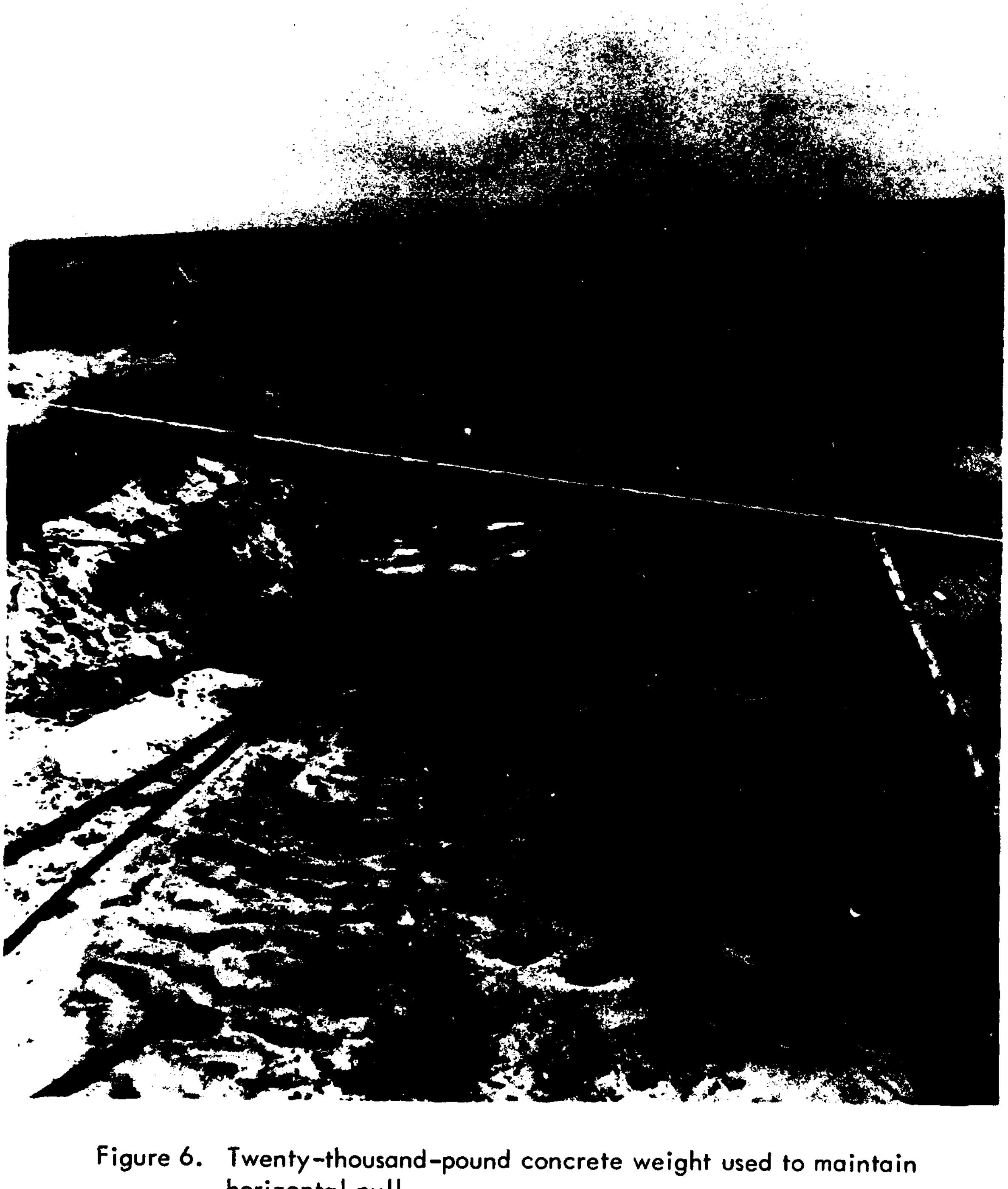


Figure 6. Twenty-thousand-pound concrete weight used to maintain horizontal pull.

Figure 7. Dynamometer used for measuring applied loads.

Figure 8. Positioning deadman anchorage.

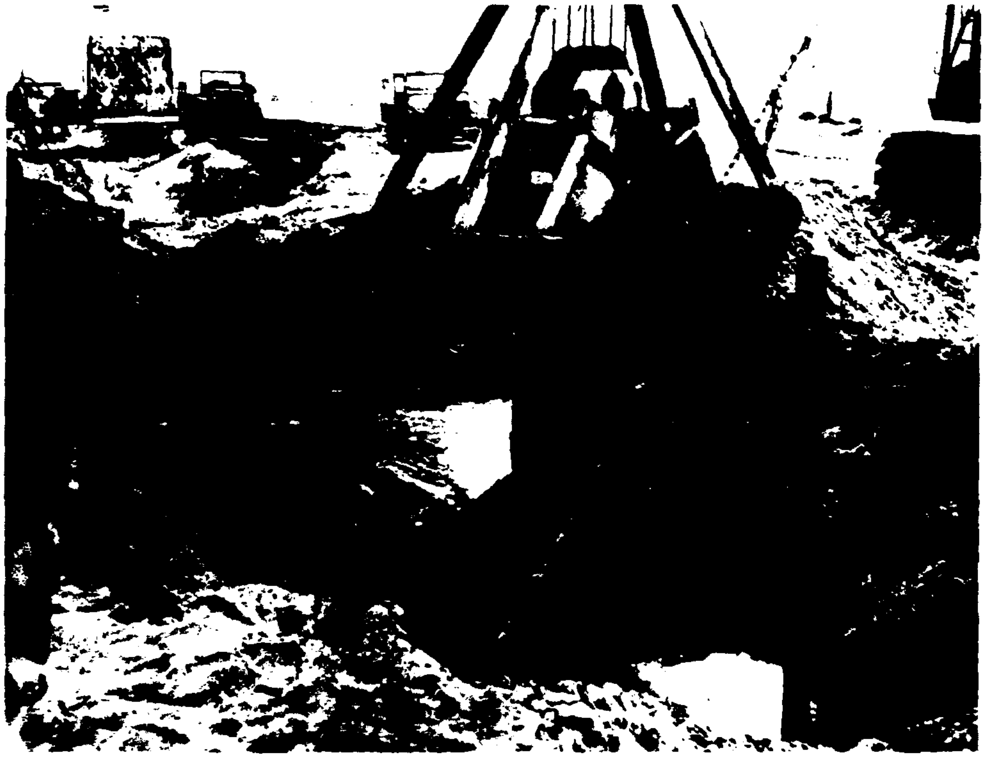


Figure 9. Backfilling around deadman anchorage.

Figure 10. Multiple deadman anchorages positioned for test.

Figure 11. Protractor device for determining deadman anchorage displacement.

Upon completion of preparations for the Phase 1 tests in sand, loads were applied in increments of about 3,000 pounds. Horizontal, vertical, and rotational movements were recorded between each load increment. These measurements were obtained by means of a pencil and a protractor device suspended from a steel bar fixed to the back of the deadmen (Figure 11). Field measurements of the horizontal and vertical movements were later adjusted to apply to the center of the face of the deadmen. No consistent pattern of load versus vertical-movement was determined from the Phase 1 tests, and therefore, only total vertical movement was recorded in later tests.

The procedure for the preparation of the Phase 2 tests in sand was similar to that of Phase 1; however, the method of applying loads and measuring displacements differed. Loads were applied continuously to the deadmen in a manner that resulted in a rate of horizontal movement of 2 to 5 inches per minute. Because of limitations of the control mechanism of the winch, this rate of movement increased to about 13 inches per minute as ultimate holding power was approached. Load magnitudes were recorded on the continuous chart of a Consolidated Electrodynamics Corporation oscillograph in conjunction with a Model 1-113 carrier amplifier. Corresponding horizontal displacements were also recorded on the chart. These measurements were obtained by means of a flexible rod extending to a helipot 10,000 ohms potentiometer secured in open ground 10 to 15 feet back of the deadmen (Figure 12). At the conclusion of each test pull, the total vertical displacements were measured. On the occasions when the deadmen were exposed sufficiently, total rotational movements were also obtained.

Soil samples were obtained periodically throughout both sand-test phases to establish and define the standard sand condition and to verify acceptable uniformity of sand conditions. The samples were obtained at different locations and depths in the areas affected by displacement of the deadmen. Moisture content and wet and dry densities were determined. The mechanical analysis was unnecessary after the initial samples because variations in sand gradient were negligible.

Phase 3: Tests in Sandy Silt and Silty Sand. Procedures for applying loads and obtaining measurements in the Phase 3 tests were the same as described for the Phase 2 tests. Also, preparations were similar through backfilling and compacting the soil. For each test, the cohesive soil within the entire area affected by the movement of the anchorage(s) was excavated. The deadmen were then carefully positioned so their face areas were perpendicular to the direction of pull, and so the coupling elevation was at the necessary height to allow a horizontal pull. Backfilling to the prescribed depth was done in 18-inch layers. The desired moisture content and compaction required for uniformity was achieved by sprinkling the area with fresh water a prescribed length of time for each layer and then making four passes with a 6-ton caterpillar tractor (Figure 13). For the cohesive soils, samples were obtained for each test at 1-, 3-, and 5-foot depths at random locations in the soil area affected by deadman displacements. Moisture content and wet and dry densities were measured. The procedure followed for preparing the soils resulted in reasonably uniform conditions with regard to all tests. Average values obtained are listed in Table IV. Three triaxial shear tests for each of the two cohesive soils were conducted on the samples taken at random times throughout the testing. The results of the three tests agreed within 10% and the average cohesion values determined for each soil (Table IV) were considered to be valid.

Model Test Apparatus

The model apparatus (Figure 14) was designed and constructed to duplicate the full-scale facility as closely as practicable. A scale of 1 to 18 was selected to reduce the model tests to laboratory dimensions.

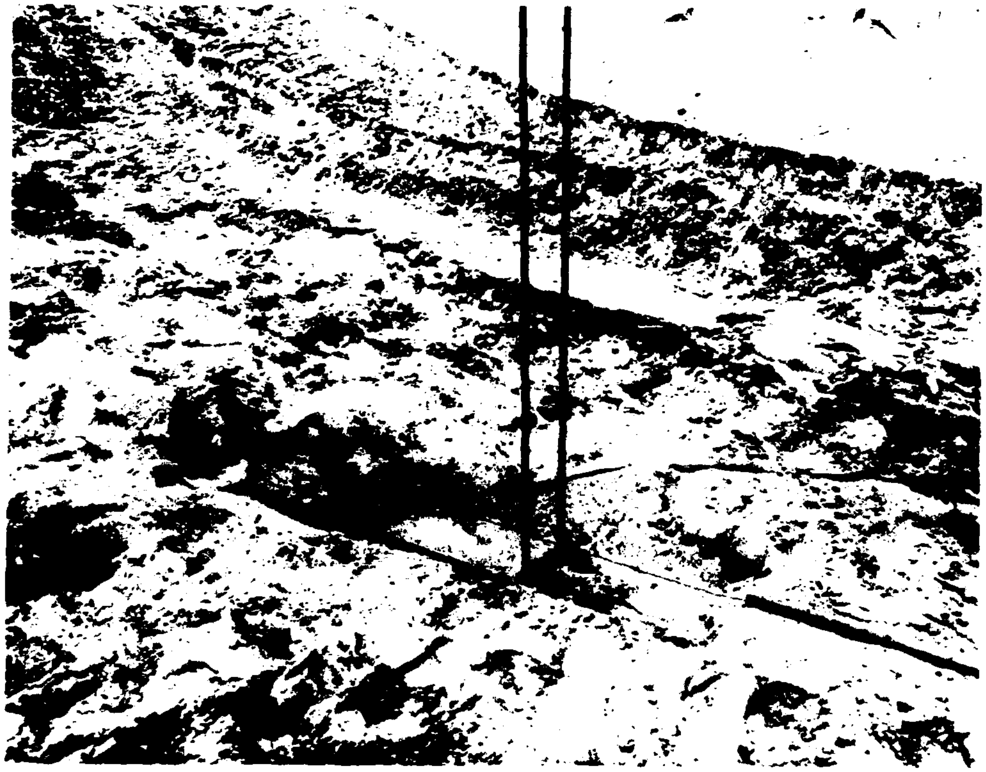


Figure 12. Potentiometer on open ground behind deadman anchorage.

Figure 13. Compacting cohesive soil.

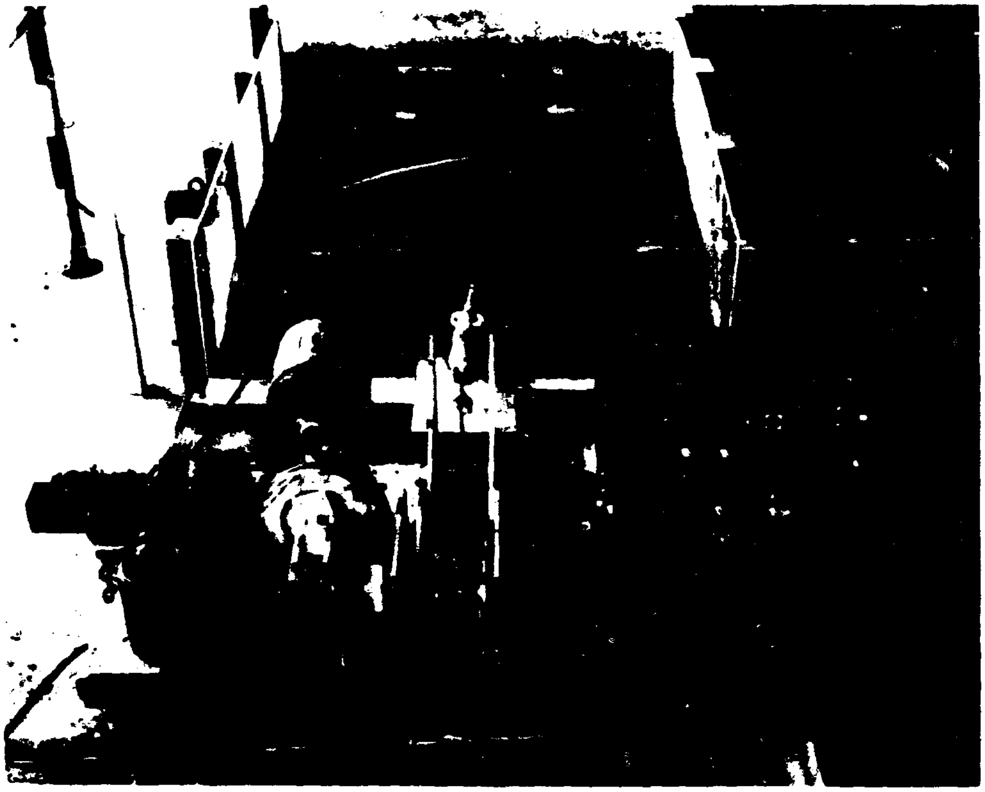


Figure 14. Model test apparatus.

The model was assembled on a 3-foot 8-inch by 8-foot table. A small winch powered by a 1/4-horsepower electric motor was mounted on one end of the table. At the opposite end, the soil was contained in a 3- by 3-foot area with a 1-foot-high buttress constructed of 1/2-inch-thick plywood at the back and 1/2-inch-thick plastic glass at the sides. The area was open on the side toward the center of the table. To avoid the possibility of the soil mass sliding on the bottom, 1/4-inch strips of wood were tacked onto the bottom of the containment area crosswise to the direction of pull. Behind the soil-containment area, a platform was constructed for the support of three potentiometers used to measure the horizontal displacements of the model deadmen.

Model Test Procedures

The procedures for the model tests were essentially the same for all three types of soil and corresponded to the procedures used for Phases 2 and 3 of the full-scale tests. The model deadmen were embedded in the soil in the containment area and positioned relative to the winch so that the applied loads would be perpendicular to deadman face areas and level with coupling elevations. The soil then was backfilled and compacted in a carefully prescribed manner. A hand-operated vibrator compactor was used to compact the soil as each 1-inch layer of soil was added to the soil mass. The 6-pound vibrator was constructed of a 1/6-horsepower motor, bolted to a 3/4- by 12- by 16-inch plyboard with a stainless steel bottom. A 3- by 1-1/4-inch round metal plate was attached to the shaft of the electric motor, 1/4-inch offset for vibration (Figure 15). The vibrator was used for precisely the same length of time at each level.

Controls were exercised to maintain a uniform moisture content. The procedure for sand differed slightly from that used for the cohesive soils. It was learned by experiment that the maximum practicable moisture content attainable for the sand was 4%. Consequently, water was not applied after moistening the sand at the commencement of backfilling. This procedure resulted in a relatively uniform 4% moisture content at the time of each test pull. Between tests, a plastic cover was placed over the soil containment area. An amount of water equal to that removed with the plastic sheet was applied to the soil prior to the next text. Soil-sampling tests confirmed the validity of this procedure.

Once preparations were completed, the winch applied loads directly by a single cable to single deadmen less than 9 feet wide (scale dimension). For single 9-foot-wide deadmen and greater and for multiple deadmen, a spreader-bar arrangement similar to that of the full-scale tests was used. Loads were applied continuously to the specimens in a manner to cause horizontal displacement at a rate of 5 inches per minute in the model. The loads were measured by a 2,000-pound-capacity electric dynamometer placed in the line between the winch and the soil mass and on the single-part line side of the spreader bar when it was used. Corresponding horizontal displacements were measured by three 10,000-ohm, 4-inch lineal Bourns potentiometers mounted on the instrument platform behind the deadmen. The measured loads and displacements were recorded on the continuous chart of a Sandborn 4-channel oscillograph DC amplifier Model 67-3000.

Soil sampling procedures for tests in sand differed from those in the two cohesive soils. In sand, it was established early that the density and moisture content remained reasonably constant by following the preparation procedure previously described. Consequently, it was not considered necessary to obtain samples for each test thereafter.

For the two cohesive soils, samples were obtained prior to each model test from outside the soil mass area affected by displacement of the test specimens. Since all of the soil in the containment area was treated the same, the samples were considered to be valid representatives of the conditions within the soil-mass-resisting movement of the deadmen. The samples were obtained by means of a 1-1/2-inch cube-shaped box (Figure 16). The box was so constructed that the sample could be sliced to form a near-perfect 1-inch cube. The correct density per cubic foot was calculated and a correctional factor which was determined by comparison with results from larger samples tested by normal procedures. The moisture content was also determined from each sample. The cohesions were determined in the same manner as for the prototype tests.

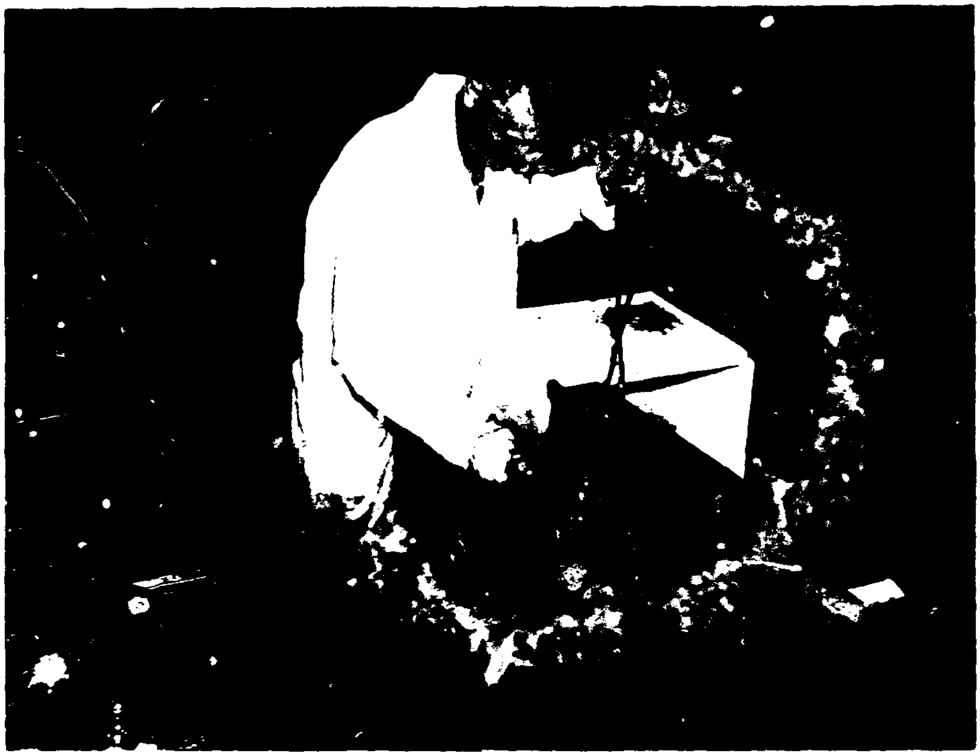


Figure 15. Compacting soil for model test.

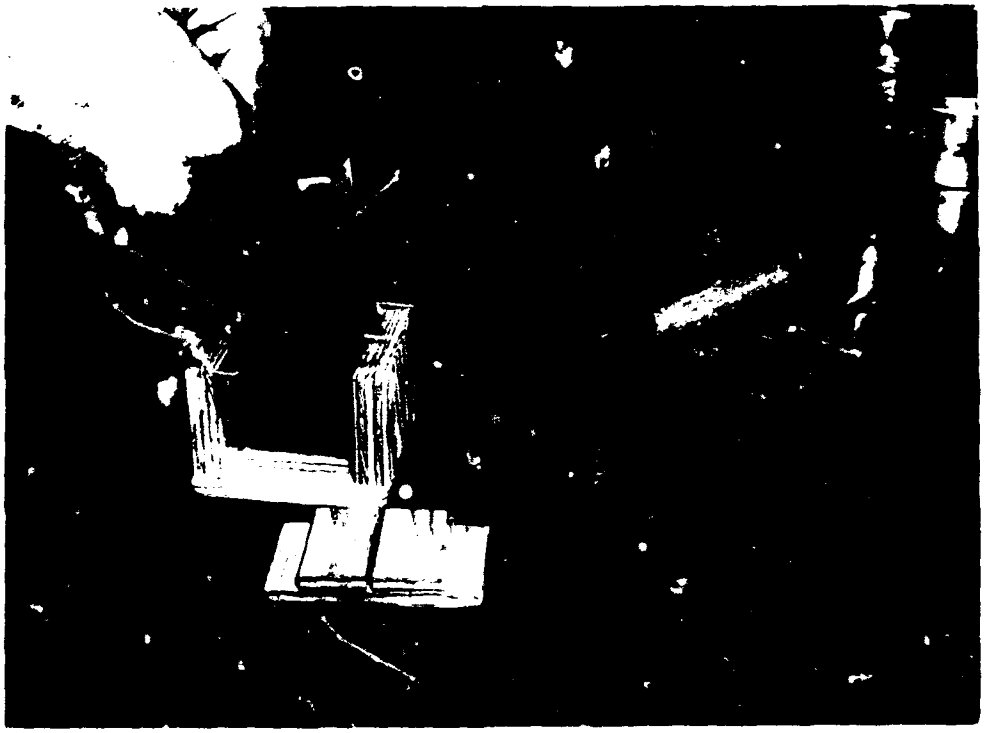


Figure 16. Model test facility soil-sampling tools.

RESULTS

General

The applied load versus horizontal displacement relationship, herein referred to as the deadman anchorage reaction pattern, represents the primary data desired from the tests on which this report is based. The reaction patterns observed for all full-scale and model tests exhibited a basic recognizable form, but with a considerable range of variation. Typical configurations of the basic form are shown in Figure 17. As load was applied to single or multiple deadman anchorages, they first would adjust to a condition of equilibrium before finite motion occurred. Then the deadmen would move in the direction of pull in a creeping uneven fashion. The net result of this uneven motion, however, was a smooth even record of displacement for the deadmen as a whole. Initial movements were so small that they could not be accurately measured and can reasonably be assumed to be negligible. Consequently, the deadmen essentially remained immobile until a breakaway load was reached (k_o, Figure 17). At this load, measurable anchorage movement occurred at an ever-increasing rate as the load increased until the maximum attainable load was reached. Here the load record would begin to undulate and gradually drop off. Tests were terminated before deadmen were pulled out of the ground, but it was believed that this would be the eventual result with continued pull.

Vertical and rotational movements in sandy silt and silty sand are comparable to those in sand. Their effect on and relation to deadman holding capacities appeared to be negligible. The total vertical movement at the termination of each pull ranged from 0 to 5 inches regardless of the depth and size of the deadman. The rotational movement, when obtained, also showed a random variation between rotation forwards and backwards. Total rotation was always less than 4 degrees.

The extent of the soil mass affected by displacement of deadmen in both cohesive soils in the full scale was indicated by a slight to pronounced bulging at the surface depending on the depth of embedment (Figure 18). As nearly as could be determined, the extent of the soil mass forward of the deadman that was mobilized due to deadman movement was equal to about 1-1/2 times the depth to the bottom of the deadman (Figure 19). Similarly, the extent of the mobilized soil mass to each side of the deadman due to its movement was approximately equal to half the depth to the bottom of the deadman. On the model scale the definitions of affected soil mass were more clear. The same criterion for the extent of affected soil mass applied on the model scale as on the full scale.

Analysis

Computer Approach. A computer programming approach to analysis was attempted first. The development and present status of the computer program is described in Appendix B. It was believed that the influence of some or all of the following variables on deadman performance and their interdependence might be defined in equation form: (1) depth of embedment, (2) height of deadman, (3) width of deadman, (4) multiple versus single deadmen, (5) height to width ratio of deadman, (6) perimeter of deadman, (7) cohesion of the soil, and (8) density of the soil. Further, it was believed that by testing on a model scale, the same variables might be investigated over a greater range and that the influence of the following additional variables might be determined: (1) the most effective spacing of deadmen at various depths for multiple pull effect, (2) the limits for spacing deadmen at various depths for multiple pull effect, (3) the most effective shape for single deadmen, and (4) the effect of excess moisture content on cohesive soils.

Two steps toward successful computer program analysis were accomplished. A basic equation was developed that accurately fits a smooth curve through observed data points defining the deadman reaction pattern for each individual test in all three soils. Also, it was determined that a good comparability factor exists between the full-scale and model test results. However, the nature of a computer program analysis effort encompassing the numerous variables mentioned is that of successive trials and adjustments. Satisfactory determination of deadman anchorage performance and definition of the effects of the variables by computer analysis were not achieved. Thus, it was not possible to obtain meaningful computer results for this report nor to utilize the model test results. It is important to emphasize that the computer program analysis previously reported[2] for tests conducted only in sand remains valid, and in fact, is used to supplement the graphic procedure that is described next. Computer programming for the sand phases was more successful because fewer variables were involved, and also the reaction patterns proved more compatible throughout the range of test conditions.

Graphic Procedure. When it became evident that the computer program analysis combining results of tests in all three soil types was not promising, test results were examined separately by soil type. A graphic analysis of the full-scale test results in cohesive soils was undertaken. It was not necessary to include the sand tests in the graphic procedure. These were the same tests encompassed by the earlier test phases previously reported.[2] The prior sand-test computer analysis is valid and can be used. For this report, the sand-test results analyzed earlier were reconstructed to a form compatible with the cohesive soil results so that direct comparisons could be made.

For practical reasons, the graphic analysis of the cohesive soil tests cannot account for the influences of all of the variables that were meant to be analyzed by computer. Instead, it defines the deadman reaction patterns for the tests in cohesive soils correlating three variables: (1) depth of embedment, (2) face area, and (3) whether the deadmen were pulled singly or in multiples of three.

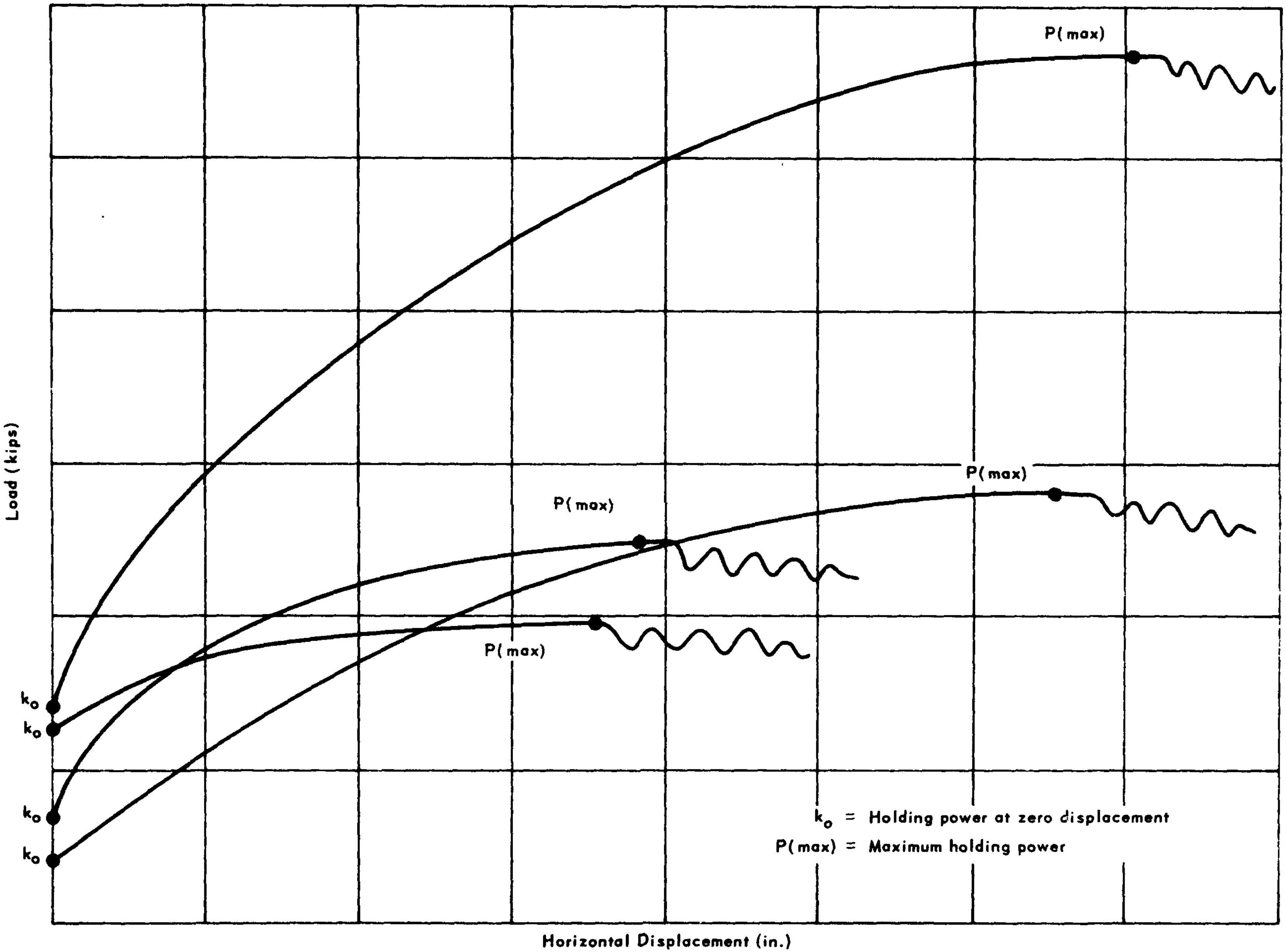


Figure 17. Typical deadman reaction patterns.

Figure 18. Deadman anchorage failure in cohesive soil.

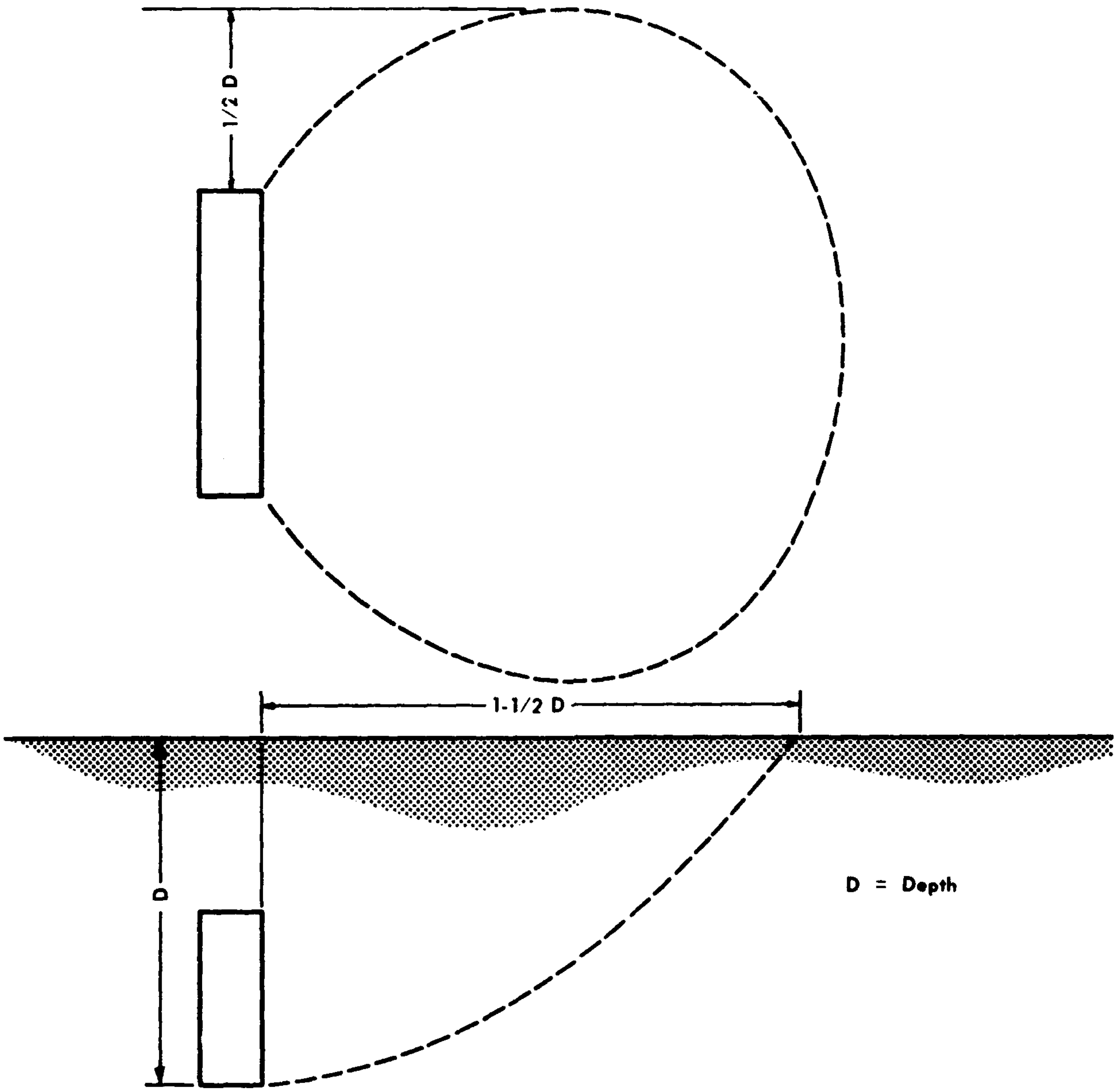


Figure 19. Approximate extent of soil mass mobilized by horizontal displacement of deadman.

The observed data points recorded for all of the full-scale tests in the cohesive soils and the curves graphically determined to fit them are shown in Figures A-1 to A-14 of Appendix A. Figure A-15 presents an example of the observed data points recorded for three of the tests conducted in sand together with the curves calculated to fit them by means of the equation previously developed from the sand tests. Comprehensive data for the model and full-scale tests are presented in Table B-1 of Appendix B.

In large measure, the results of the first step in the graphic analysis are shown in Appendix A. Three important factors were taken into account in achieving the empirical curves shown for the deadman anchorages in the cohesive soils. First, because of the difficulty in measuring initial small increments of movement of the deadmen, it was known that the maximum holding powers, P(max), measured (Figure 17) were the most accurate and reliable data points. Consequently, the P(max)'s were used as the starting points for graphing each curve. Second, the basic deadman reaction pattern was known from the overall results. In some tests, load readings at small increments of movement were erratic and lower than they reasonably should be. Therefore, the basic reaction pattern proceeding from the P(max)'s was permitted to override the lower observed load readings for small increments of movement. Third, for multiple deadmen, reaction patterns were compared with those single deadmen having similar total face areas, and the increased holding-power effect of the multiple pull as determined for sand[2] was taken into account.

Once the initial curve fits for each individual test were achieved on the basis described, groups of tests of deadmen with identical face areas were plotted, and proportional adjustments were made on the basis of depth. Likewise, groups of tests of deadmen embedded at the same depth were plotted, and proportional adjustments were made on the basis of face areas. By several successive adjustments, the graphs as presented in Appendix A were completed. Figures A-1 to A-3 illustrate the empirical curves arrived at for deadmen with identical face areas at different depths in sandy silt. Figures A-4 to A-6 illustrate the empirical curves for deadmen with different face areas at the same depth in sandy silt.

Upon completion of the curves shown in Appendix A, further analysis was necessary to convert the information into "design graphs." The development of design graphs was achieved by a process similar to that described for the development of the curves in Appendix A. However, this time it was possible to use a more direct plotting method because the irregularities and inconsistencies in portions of the reaction patterns for all the tests had been corrected in the earlier process used for the curves in Appendix A. The first step was to plot the maximum holding power, P(max), versus face area for the different depths in each type of soil. These "analysis" graphs are shown in Figures 20, 21, 22, and 23. Smooth curves were drawn giving weight to the data points primarily according to depth and face area with secondary considerations given to soil type. Then new data points on the curves coinciding with the face areas desired for the design graphs were determined. From these data points the design graphs for the cohesive soils were developed (Figures 24 through 27). Again because the maximum holding power is the most reliable reference point, P(max) was used as the starting point for each curve. From here the curve could be drawn accurately to the k_o point by comparison with previous curves in the same soil type that exhibited a P(max) close to the same value.

To complete the comparisons of deadman holding powers in the three soil types covered by this report, corresponding design graphs were drawn for the sand condition (Figures 28 and 29). These were obtained by plotting the reaction patterns of deadman anchorages using the graph of average holding power of deadmen in sand previously developed and reported.[2] Figure 28 shows the reaction patterns for single deadmen of four face areas (10, 20, 40, and 60 square feet) embedded at three depths in sand: ground level (GL), 3 feet, and 6 feet. Figures 24 and 25 give the reaction patterns for the same four sizes of single deadmen at the same three depths in sandy silt and silty sand. These sizes and depths were selected because they are practicable for design application and they offer a reasonable range for interpolation.

Figures 26, 27, and 29 show the reaction patterns for multiple deadmen of two face areas (40 and 60 square feet) embedded at three depths (ground level, 3 feet, and 6 feet) in sandy silt, silty sand, and sand respectively. The two face-area sizes used in developing these graphs are considered to encompass the practicable design ranges covered in the test programs.

Use of the design graphs for single deadman design is self-evident. The holding powers per particular displacements for a particular size of deadman can be interpolated from the graph representing the type of soil of interest. Use of the design graphs pertinent to multiple deadmen is similar, but it must be kept in mind that the face areas listed represent the aggregate total for the number of deadmen used; for example, if three deadmen of 20 square feet each are used, the face area to use in referring to the graph is 60 square feet.

DISCUSSION

Application of Results

The test results may be considered valid for those conditions encompassed by the test program. These conditions are (1) the types of soils described, (2) depths of embedment from ground level to 6 feet, (3) deadman face areas from 5 to 72 square feet, and (4) spacing distance of multiple deadmen within the range of 0.6 h and 1.7 h. Interpolation within the range of conditions represented by the graphs can give characteristic deadman reaction patterns under applied loads not readily determined by analytical means.

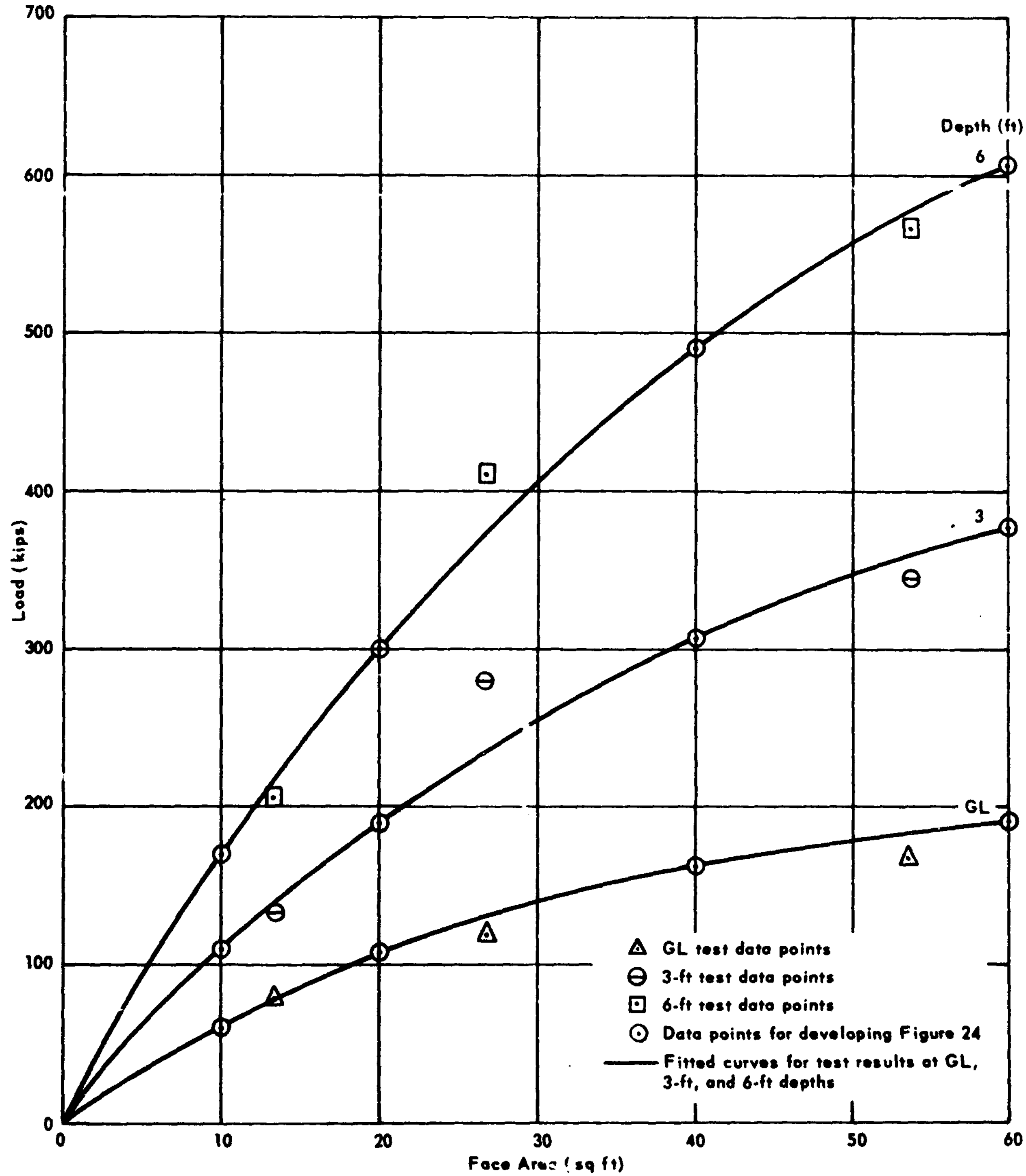


Figure 20. Analysis graph: maximum load versus face area for single deadmen in sandy silt.

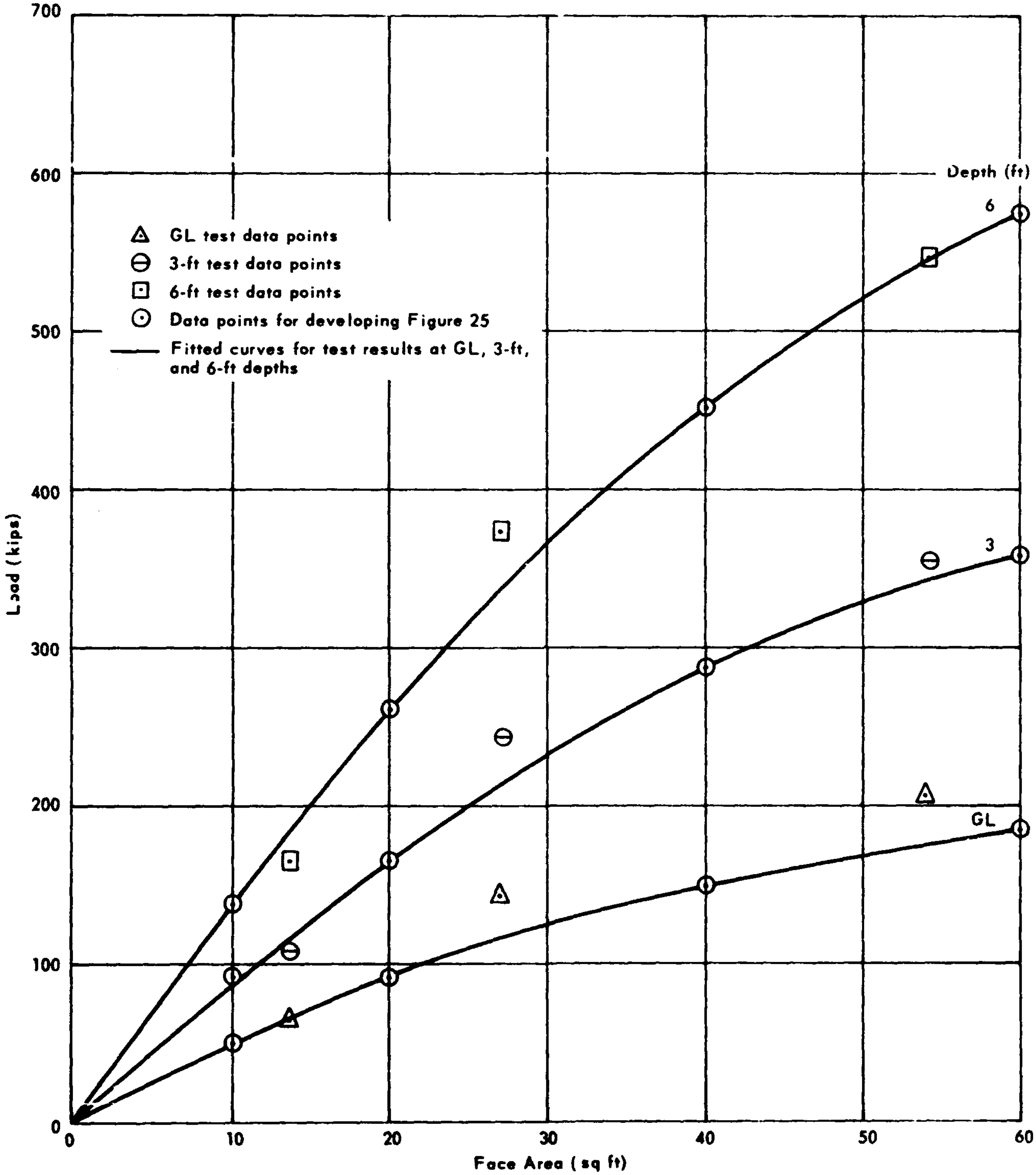


Figure 21. Analysis graph: maximum load versus face area for single deadmen in silty sand.

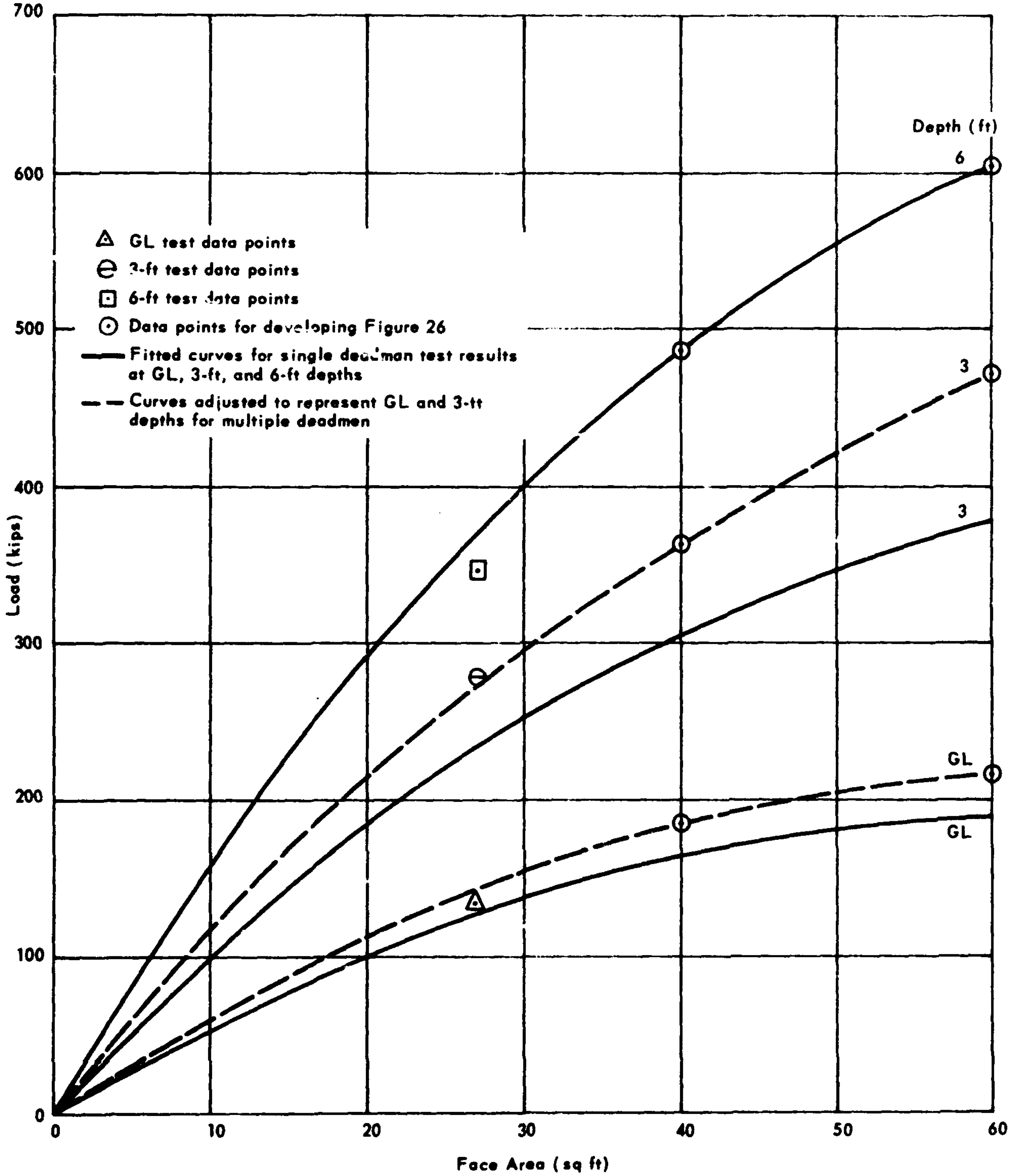


Figure 22. Analysis graph: maximum load versus face area for multiple deadmen in sandy silt.

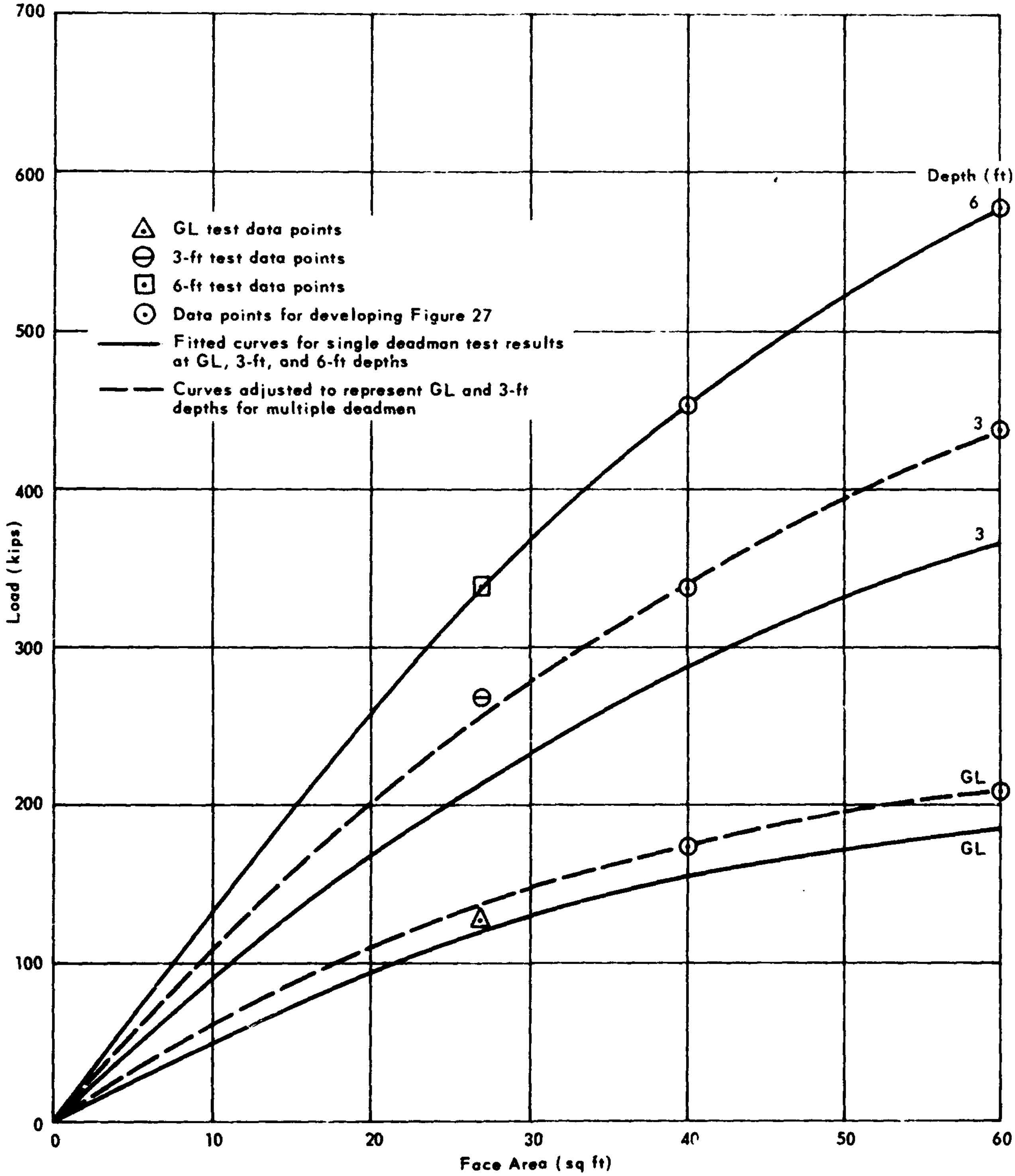


Figure 23. Analysis graph: maximum load versus face area for multiple deadmen in silty sand.

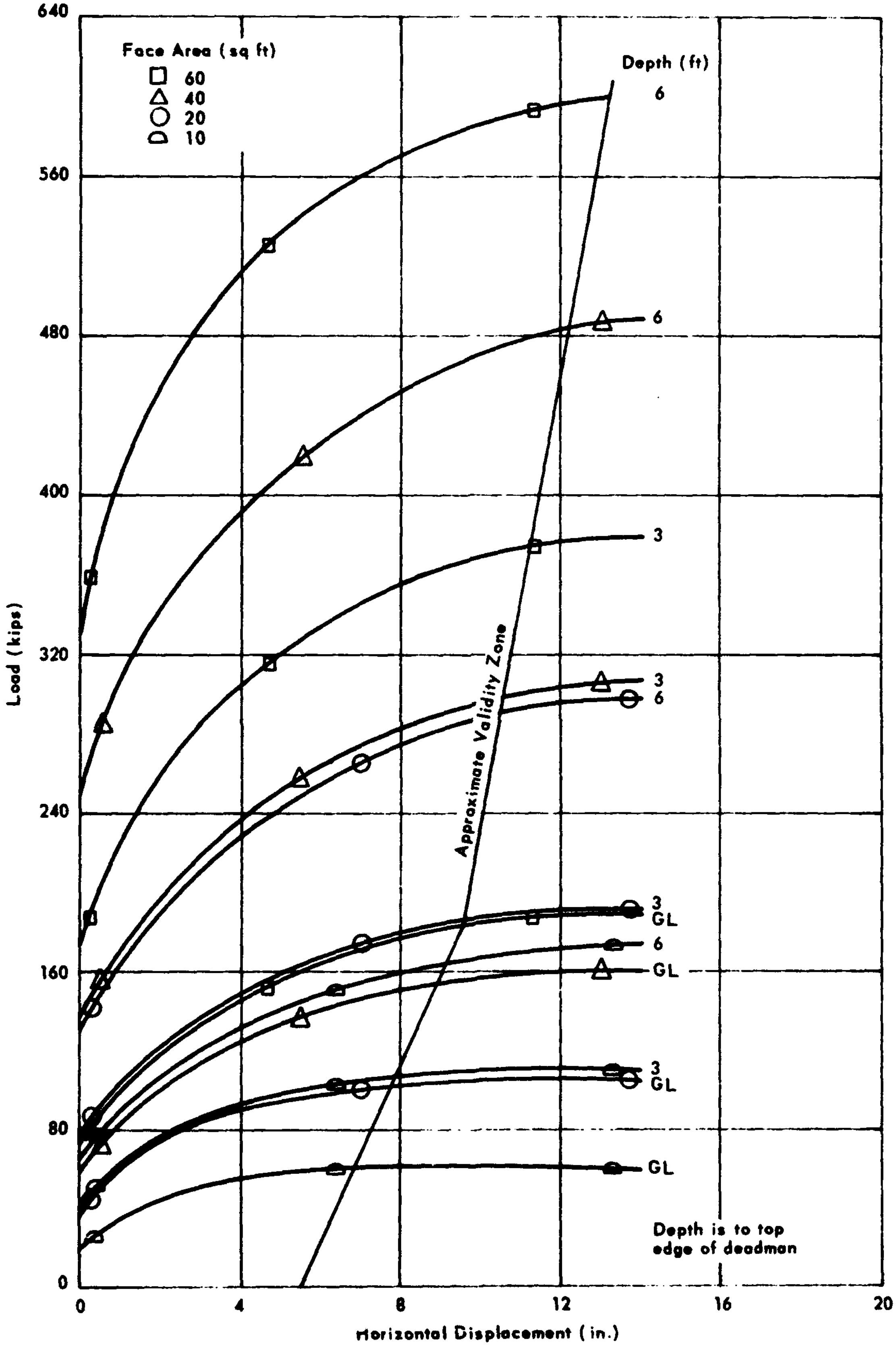


Figure 24. Design graph: load versus horizontal displacement for single deadmen in sandy silt.

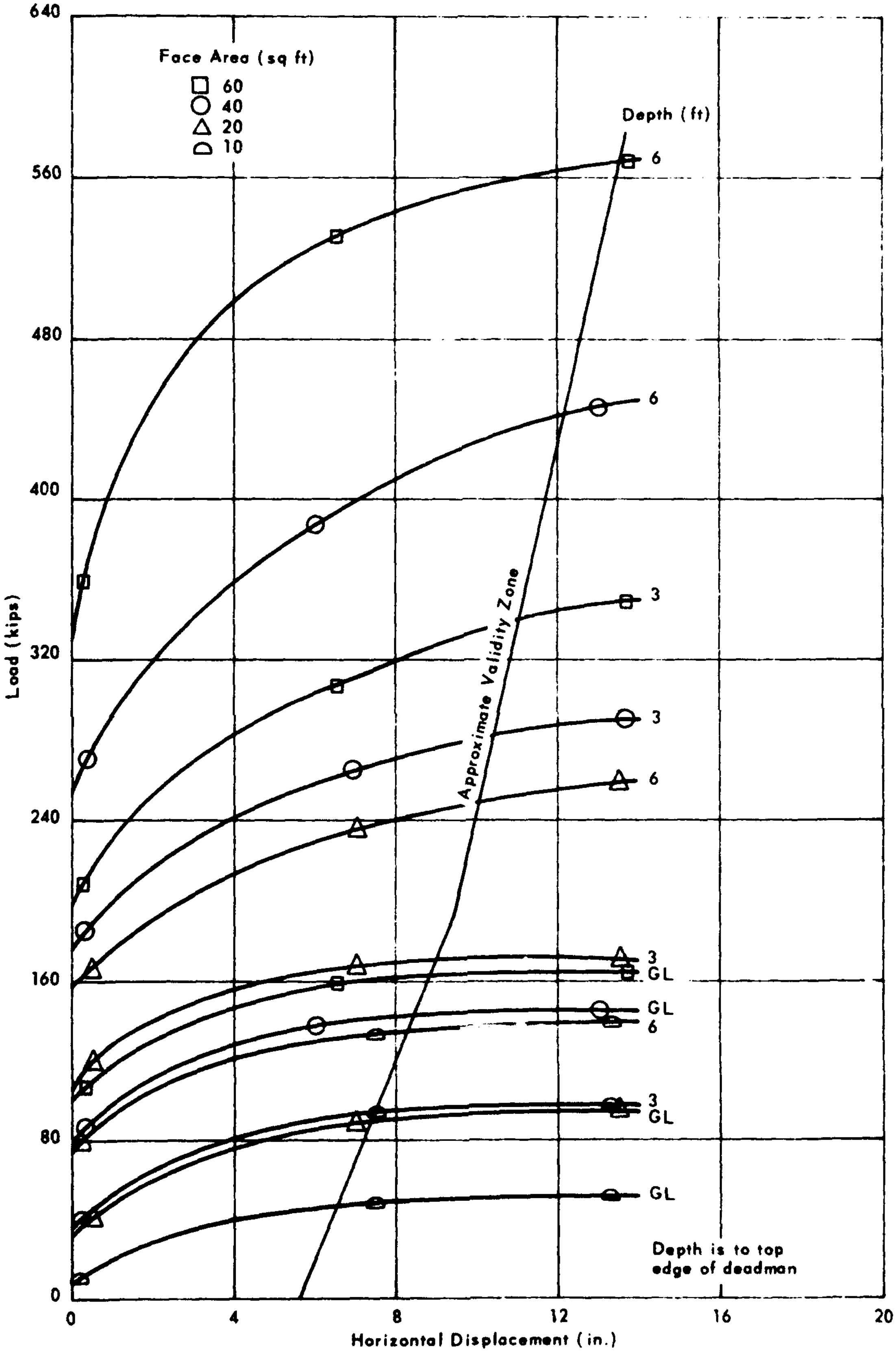


Figure 25. Design graph: load versus horizontal displacement for single deadmen in silty sand.

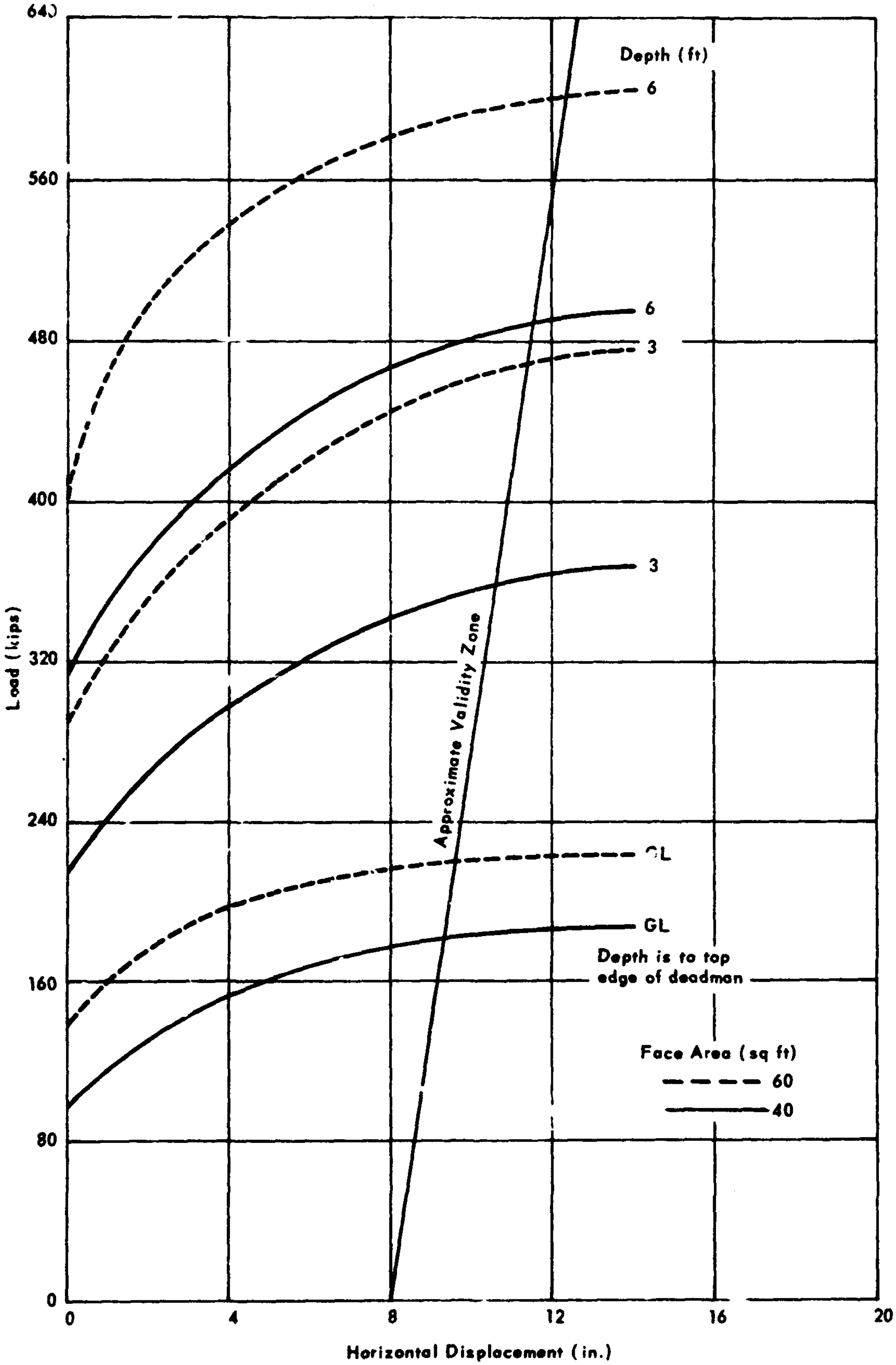


Figure 26. Design graph: load versus horizontal displacement for multiple deadmen in sandy silt.

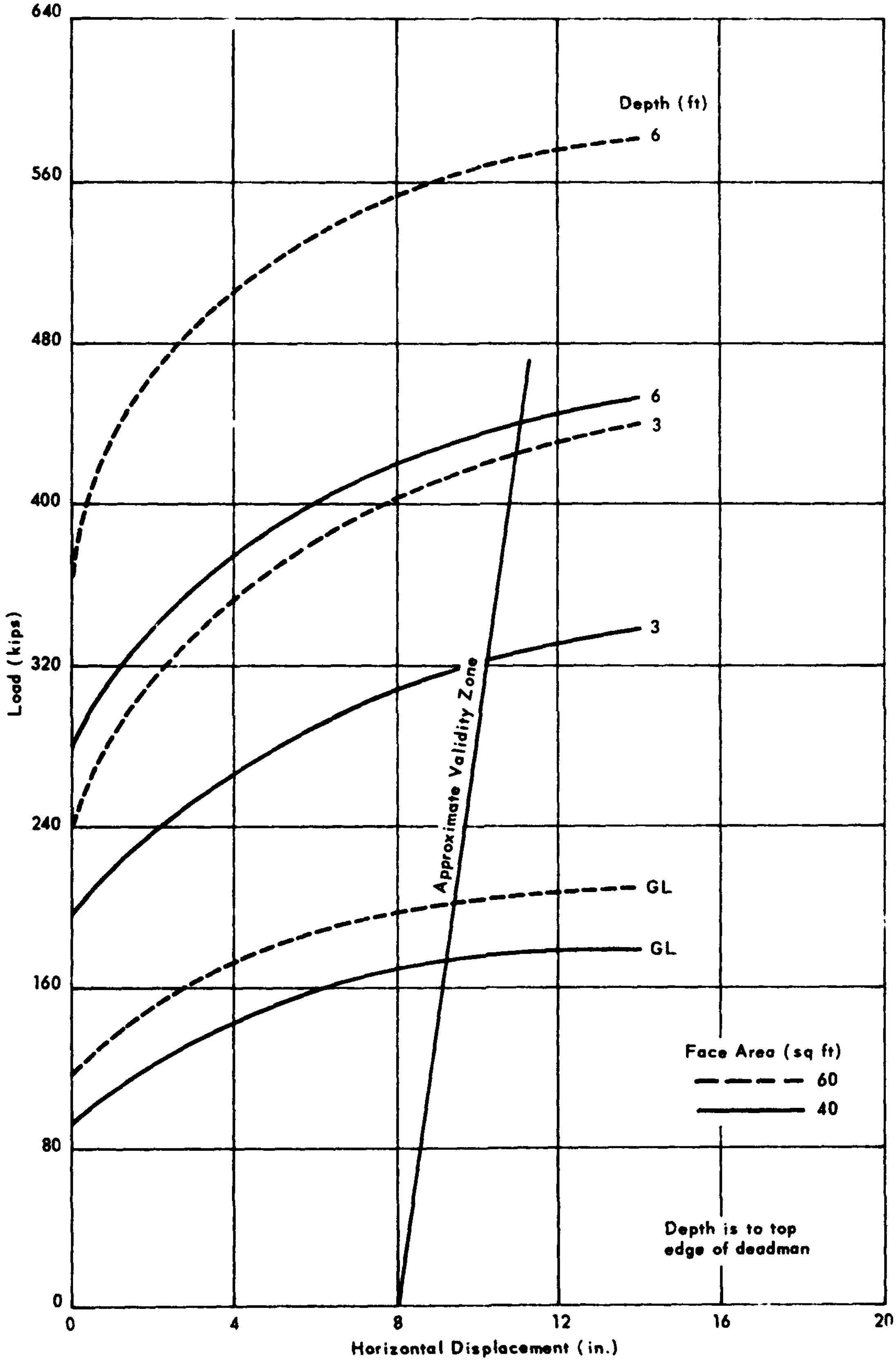


Figure 27. Design graph: load versus horizontal displacement for multiple deadmen in silty sand.

The amount of displacement corresponding to maximum holding power generally increased with the depth of embedment, size of the deadman, and cohesiveness of the soil. After the maximum load was attained the load would decrease. For uniformity and practicability in presentation, all design graphs showing the reaction patterns were extended to 14 inches of displacement. The pattern to failure occurred within this distance for almost all test conditions. Deadmen in sand exhibited a pattern that rises more abruptly with continued displacement than did deadmen in the cohesive soils. The ultimate holding capacity and failure occurred at much less displacement than that indicated by the graphs extended to 14 inches of displacement. Also, in all three soil types the ultimate holding powers of the smaller deadmen and the deadmen at shallower depths occurred before 14 inches of displacement was attained. The validity zone shown on each design graph (Figures 24 through 29) defines the approximate limits within which the curve is a valid representative of the reaction pattern for the conditions specified.

Establishment of a level of confidence pertaining to deadman anchorage performance is important in an application of empirical data for design purposes. The basis for determining a lower confidence limit curve and its significance is described in Reference 2. The immense number of calculations involved makes impractical the precise mathematical determination of confidence limits by any means other than computer. Therefore, until such time as a computer program analysis of the deadman anchorage test data is achieved, firm lower confidence limits cannot be established. However, examination of the plotted curves and observed raw data points given in Appendix A shows that if the ordinates of the curves are reduced by 35%, over 95% of the observed data points will fall on or above the new curves. Thus, use of the empirical curves reduced by 35% would appear to give values with a confidence level of 95%. Also, reducing the ordinates of the curves for the sand condition (Figures 28 and 29) gives a close approximation of the lower-limit values having a 95% confidence level as discussed in the previous report.[2]

Computer Program Potential

The difficulties experienced in the computer program analysis stem from several important conditions. These include (1) the problem of accurately measuring initial small amounts of displacement and correlating them to specific holding powers, (2) the wide range of variations in the form of the reaction patterns obtained between the sand and the cohesive soils, (3) the limited range of and the lack of replication and randomization in the experiment design, and (4) the large number of variables not practicable or possible to record. The cohesive soil phase of testing was undertaken with recognition of these limiting conditions, but in the belief that computer program analysis could account for, or otherwise overcome, the problems presented.

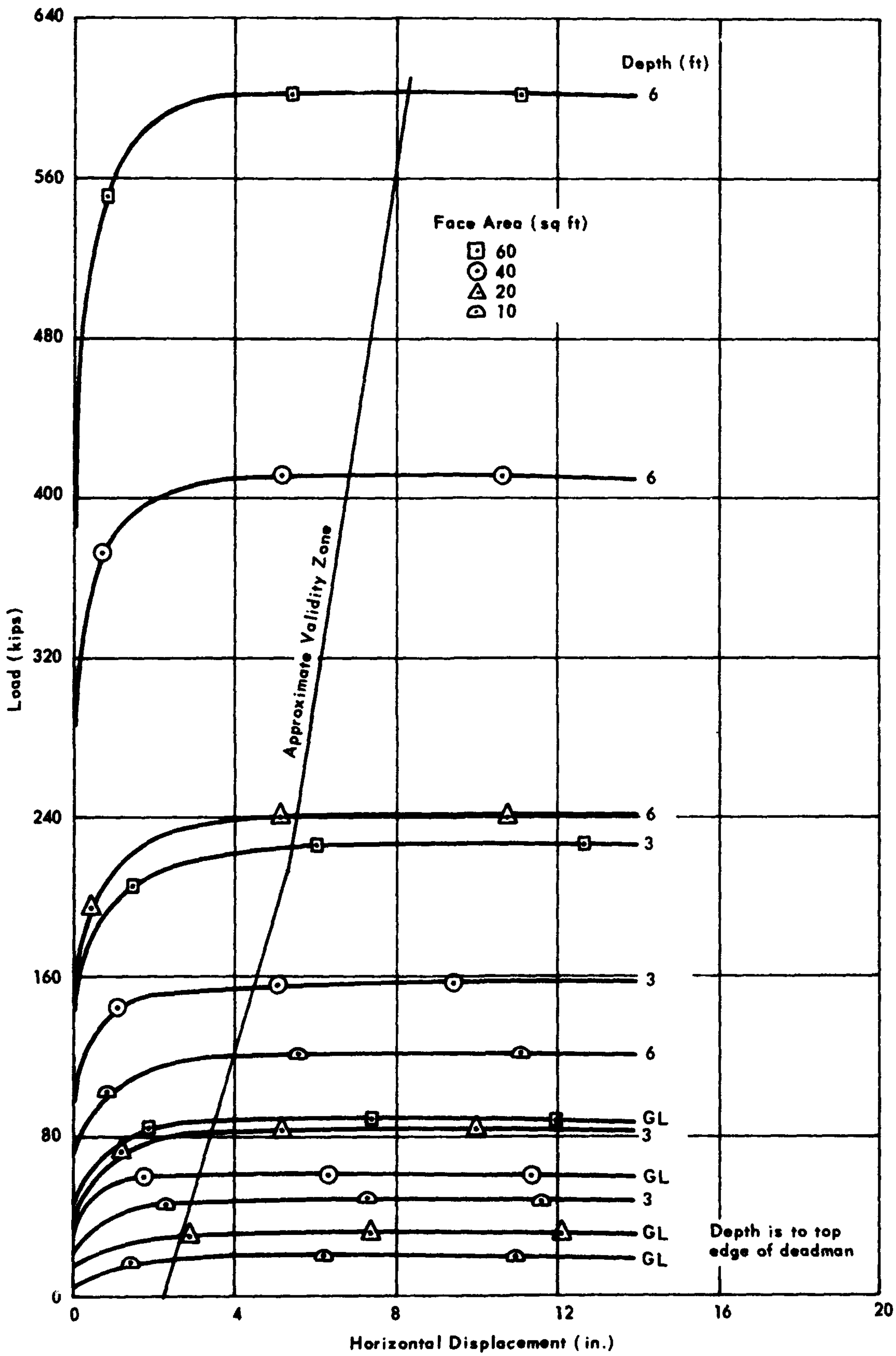
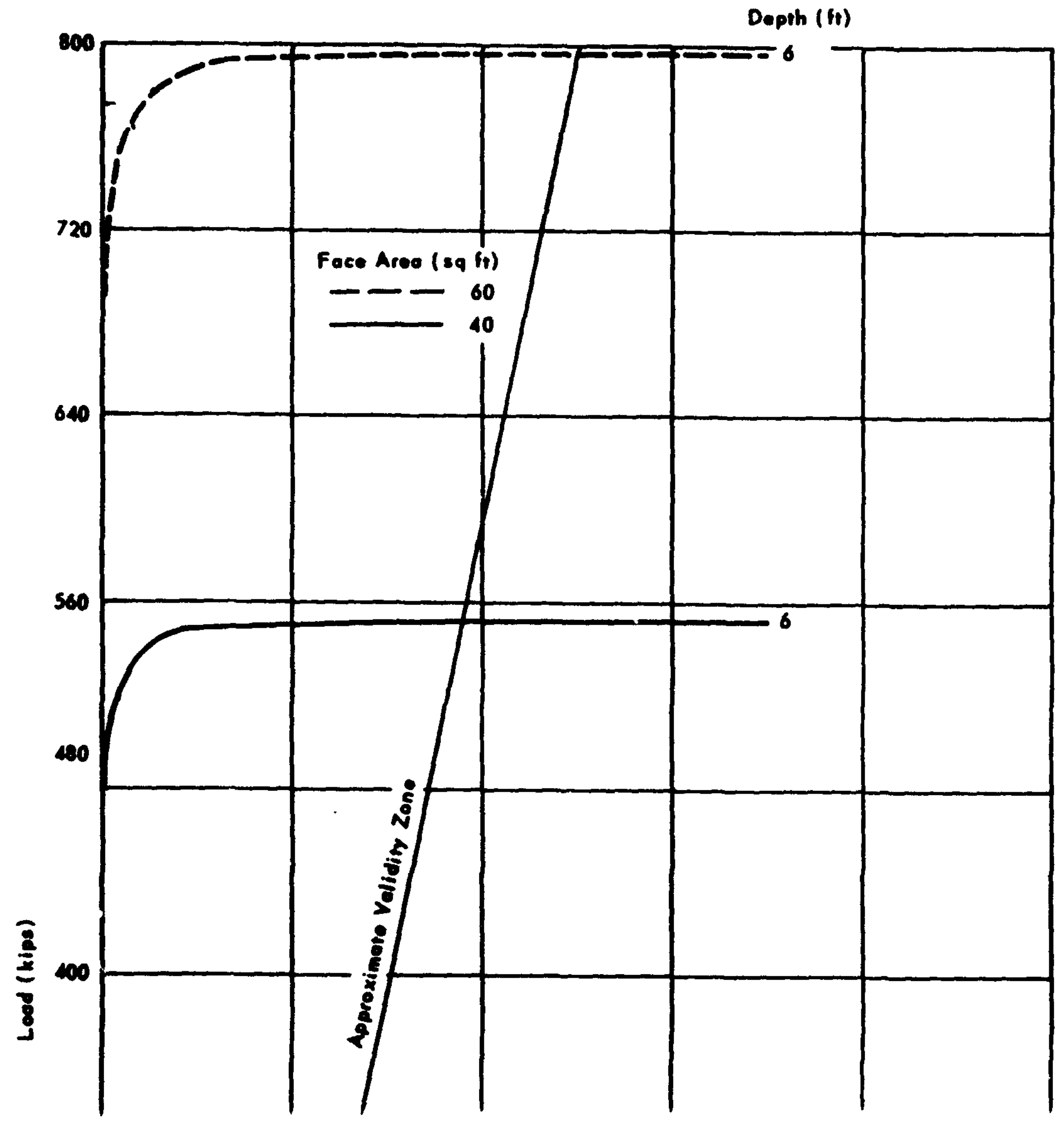


Figure 28. Design graph: load versus horizontal displacement for single deadmen in sand.



Depth (ft)
Load (kips)
800
720
640
560
480
400
6
6
Face Area (sq ft)
60
40
Approximate Validity Zone

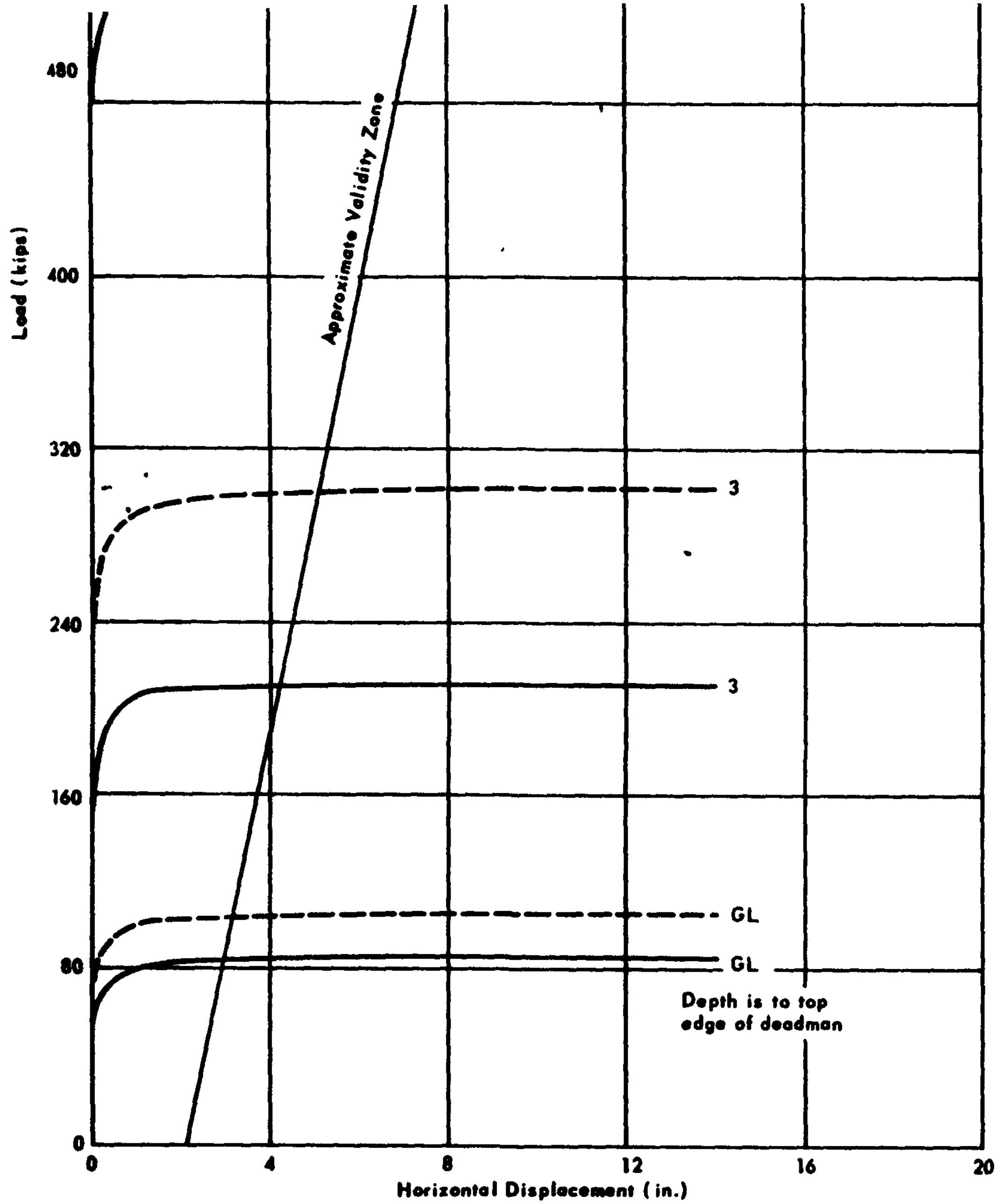


Figure 29. Design graph: load versus horizontal displacement for multiple deadmen in sand.

CONCLUSIONS

1. The design graphs provide a practicable means for determining deadman anchorage holding capacities at various displacements in soils with characteristics within the range tested in this report.

2. Deadman anchorage performance in a particular soil is largely influenced by two variables, the depth of embedment and the face area.

3. Multiple anchors placed in rectilinear formation perpendicular to the direction of applied force and within a spacing distance of 0.6 h to 1.7 h will develop a higher holding capacity per net face area than a single deadman with the same total face area. The percent increase varies with the depth of embedment, ranging from about 15% at ground level to 25% at 6 feet.

4. Soils with cohesive characteristics enable deadman anchorages to develop higher maximum holding capacities than in sand, but 2 to 3 times the horizontal displacement is required to attain the maximum holding capacity.

ACKNOWLEDGMENT

Mr. I. W. Anders provided valuable assistance on mathematical and statistical procedures used in analysing, checking, and presenting the test data.

Appendix A

OBSERVED DATA POINTS AND EMPIRICAL CURVES FOR THE FULL-SCALE TESTS

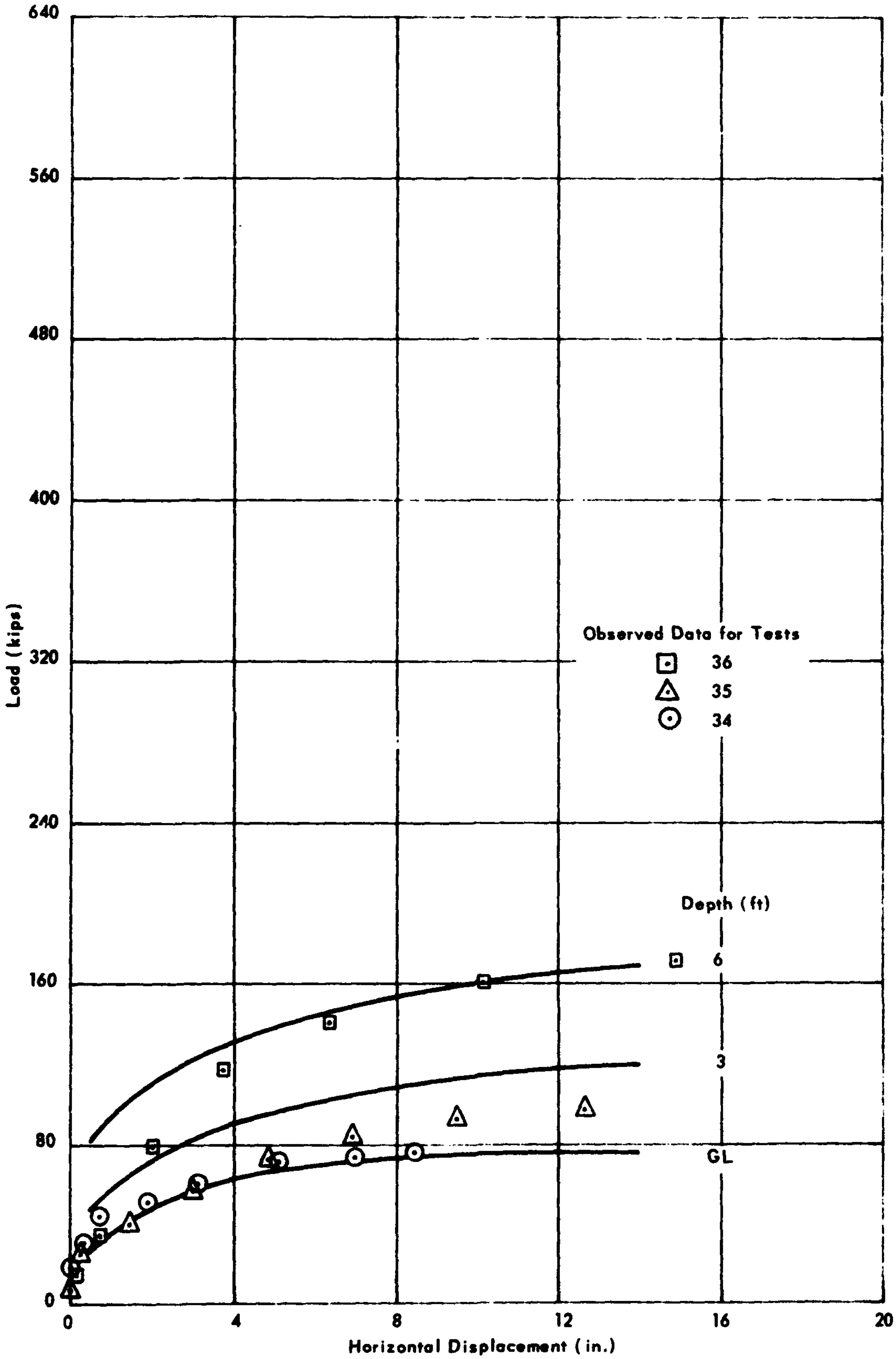


Figure A-1. Load versus horizontal displacement for single deadmen in sandy silt — face area, 13.5 sq ft.

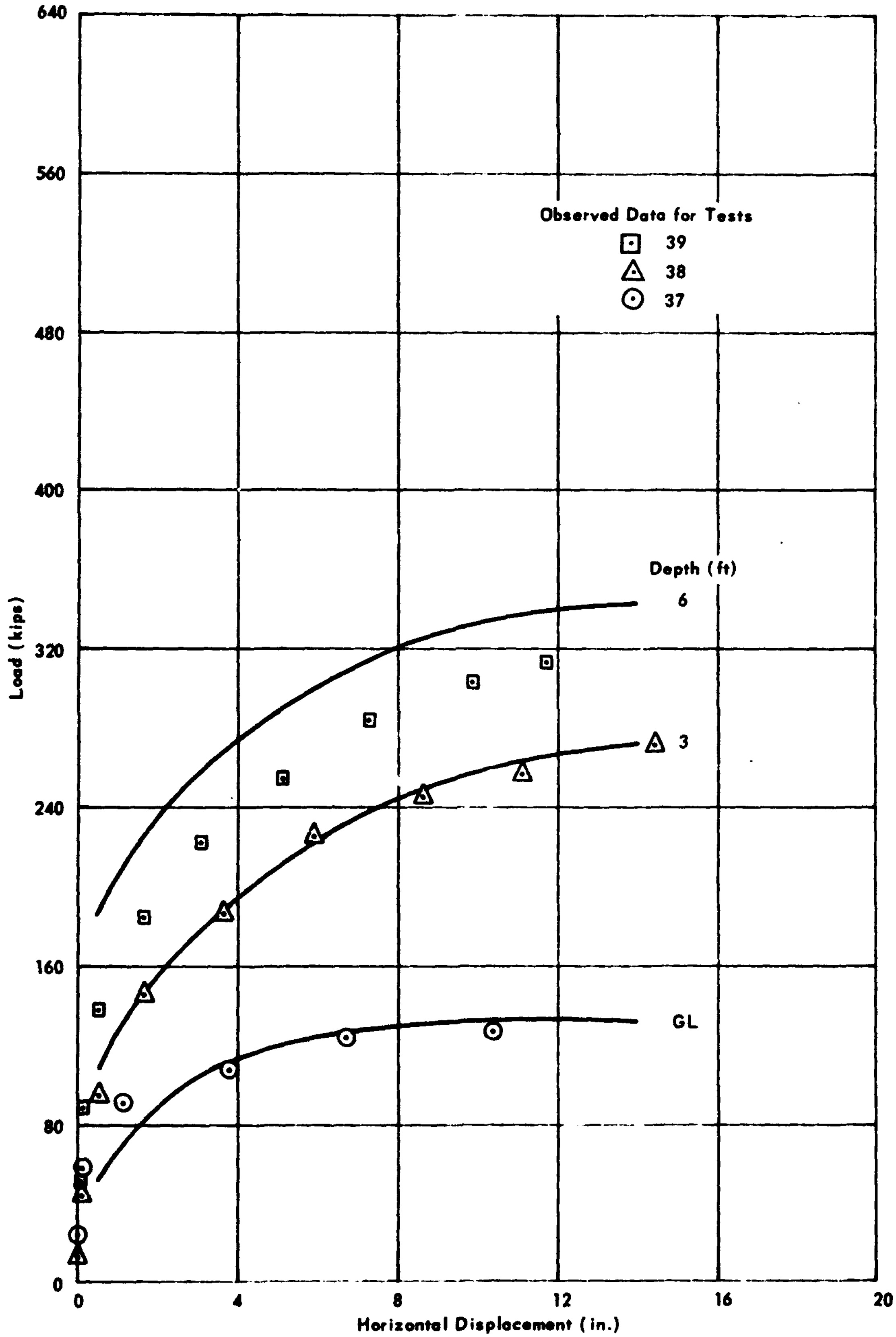


Figure A-2. Load versus horizontal displacement for single deadmen in sandy silt — face area, 27 sq ft.

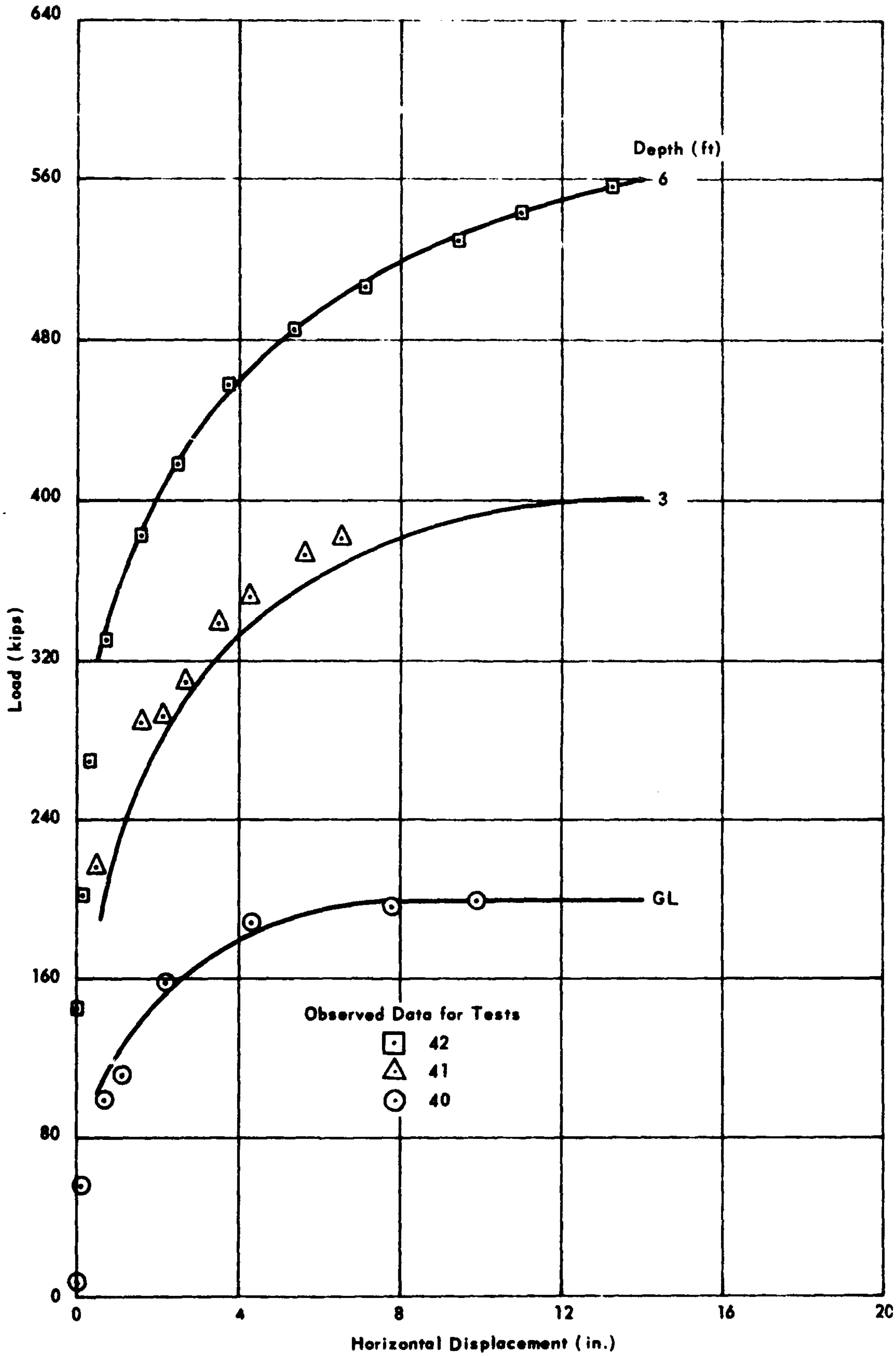


Figure A-3. Load versus horizontal displacement for single deadmen in sandy silt — face area, 54 sq ft.

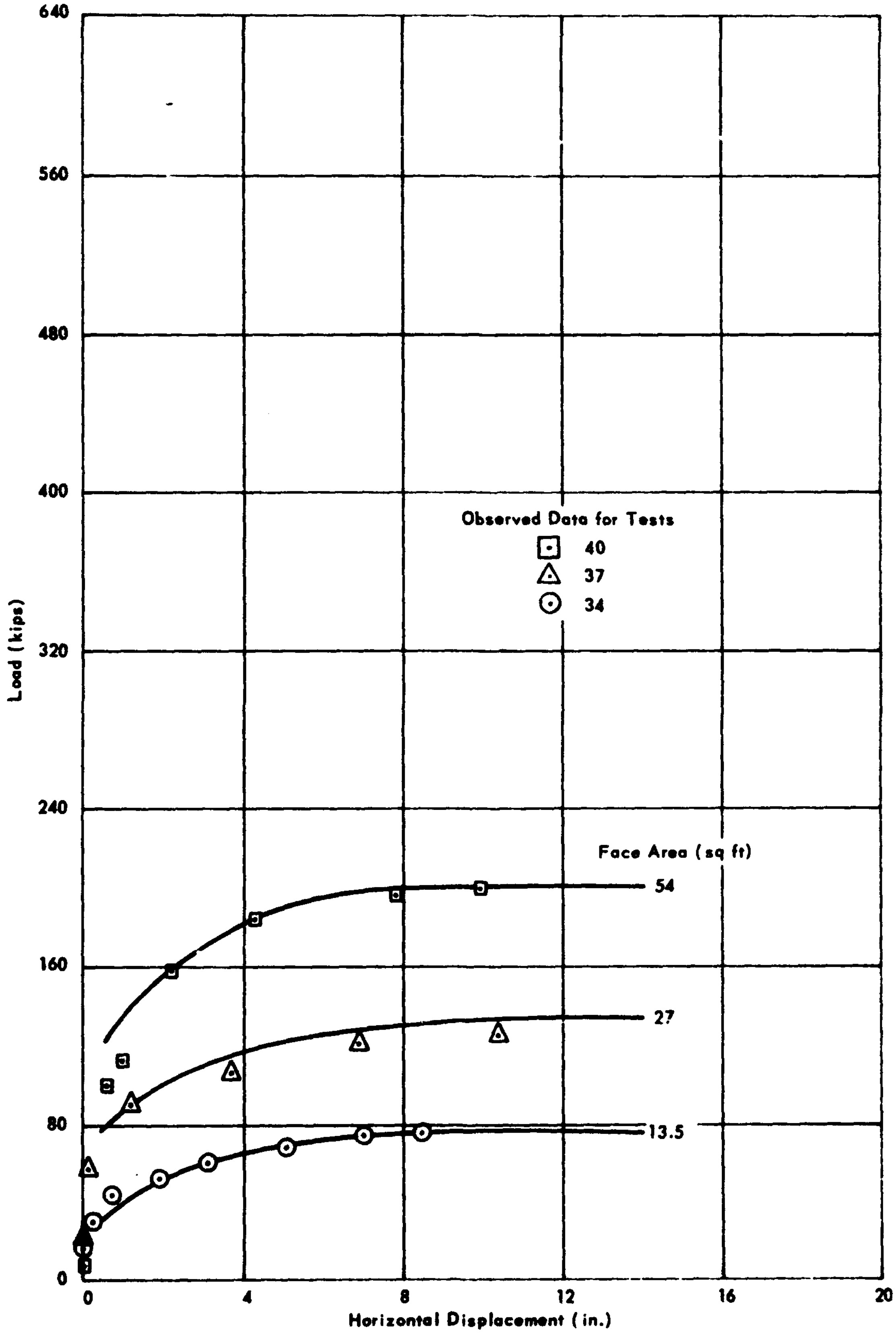


Figure A-4. Load versus horizontal displacement for single deadmen in sandy silt — depth, GL.

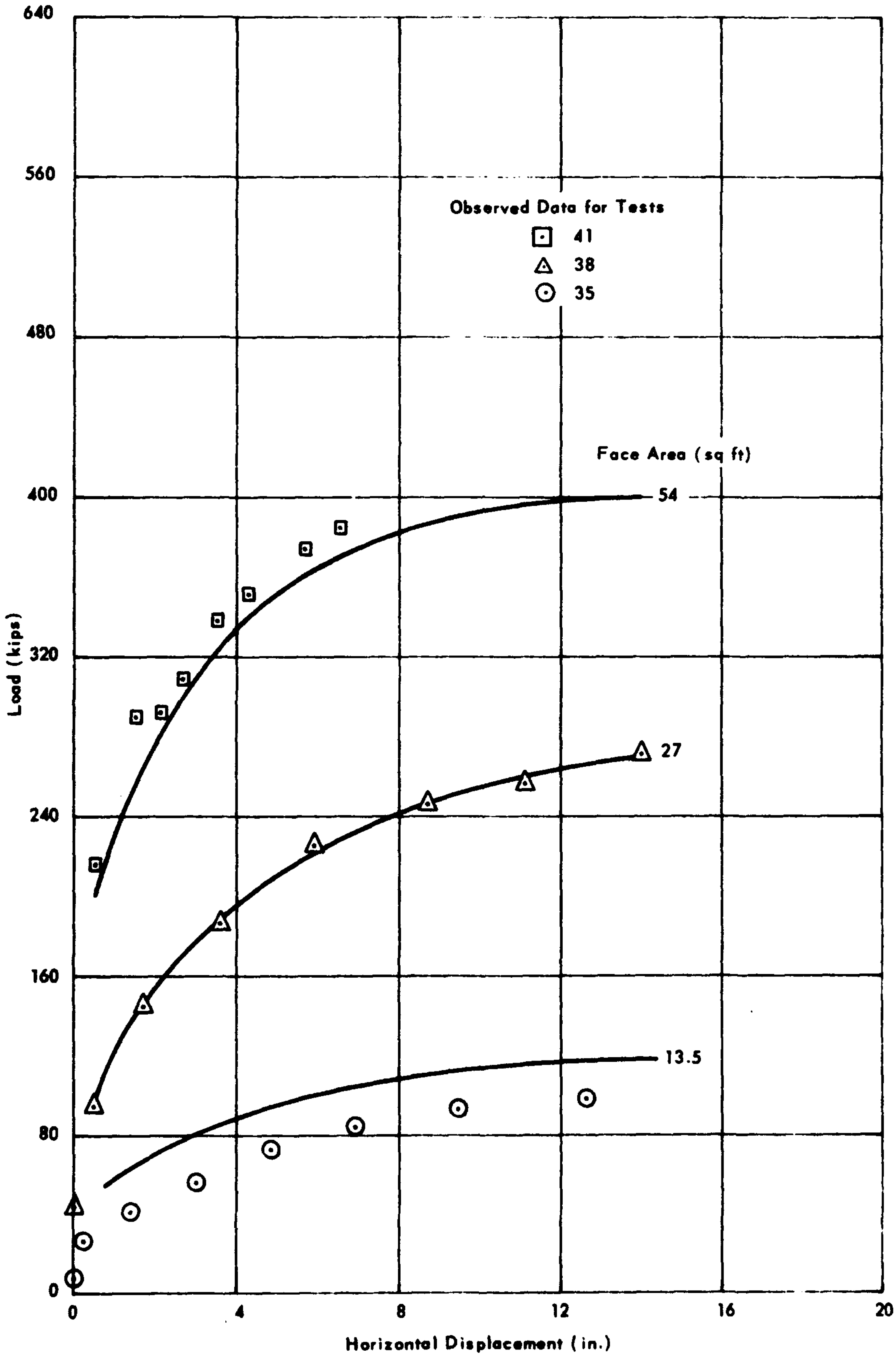


Figure A-5. Load versus horizontal displacement for single deadmen in sandy silt — depth, 3 ft.

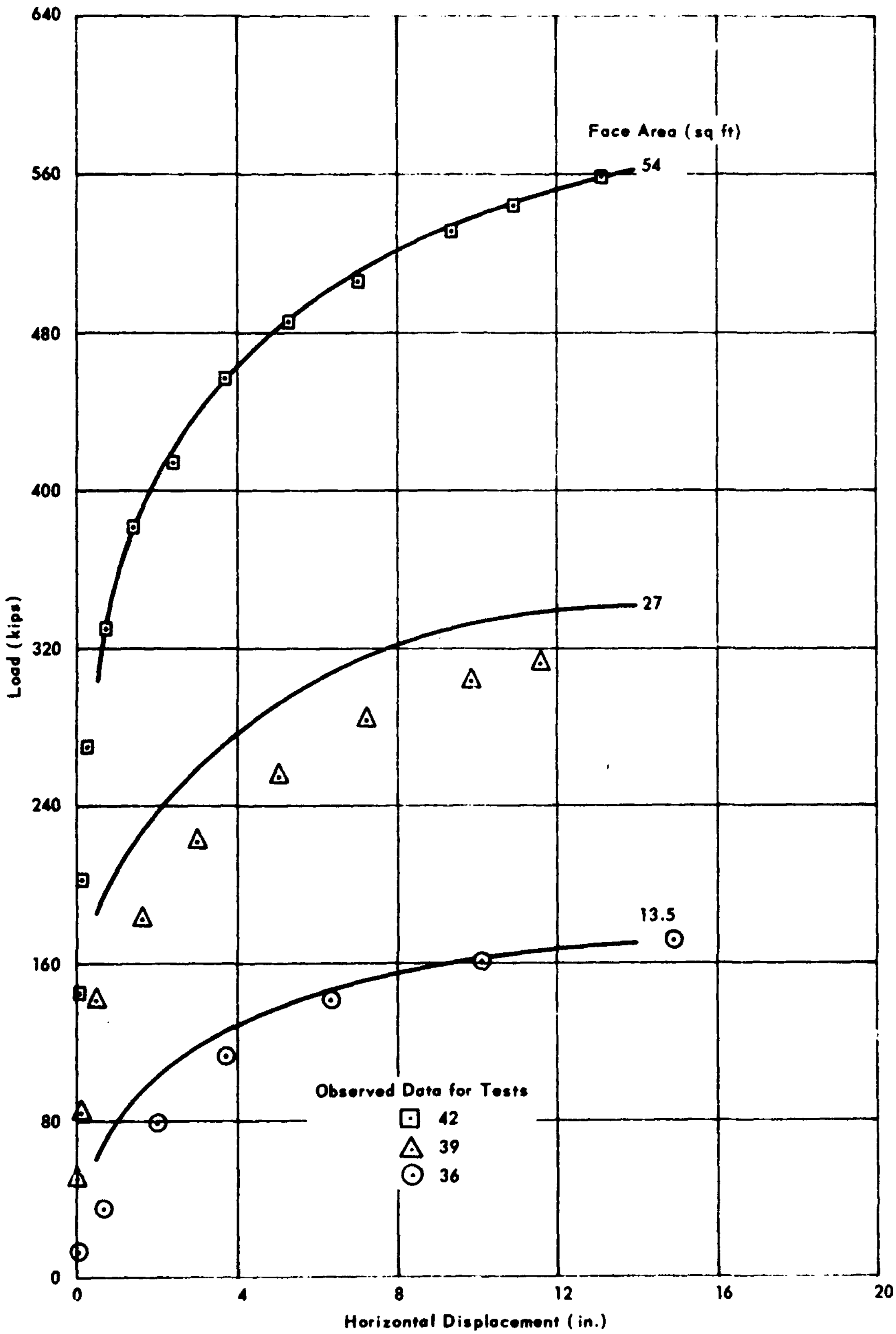


Figure A-6. Load versus horizontal displacement for single deadmen in sandy silt — depth, 6 ft.

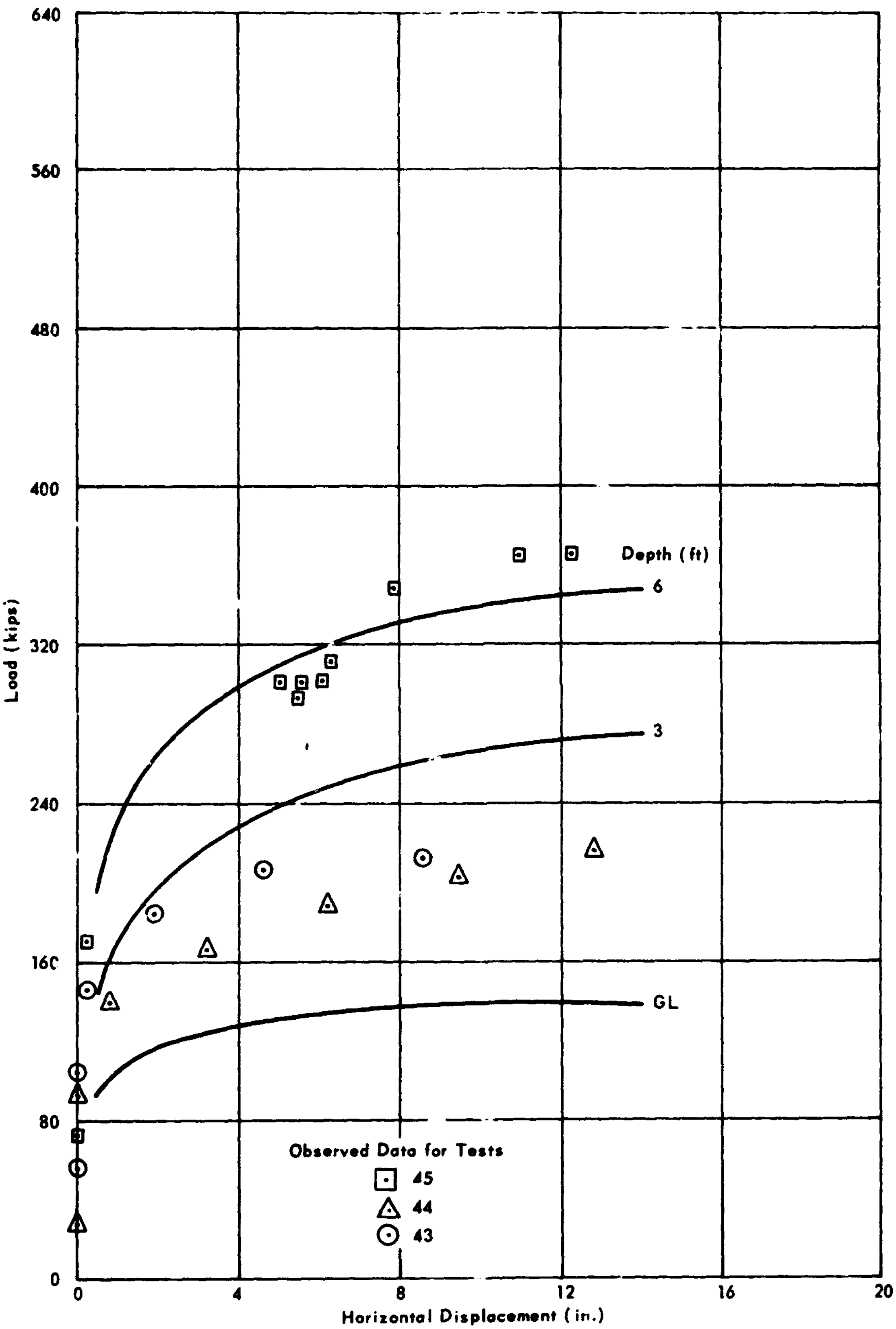


Figure A-7. Load versus horizontal displacement for multiple deadmen (3) in sandy silt — total face area, 27 sq ft.

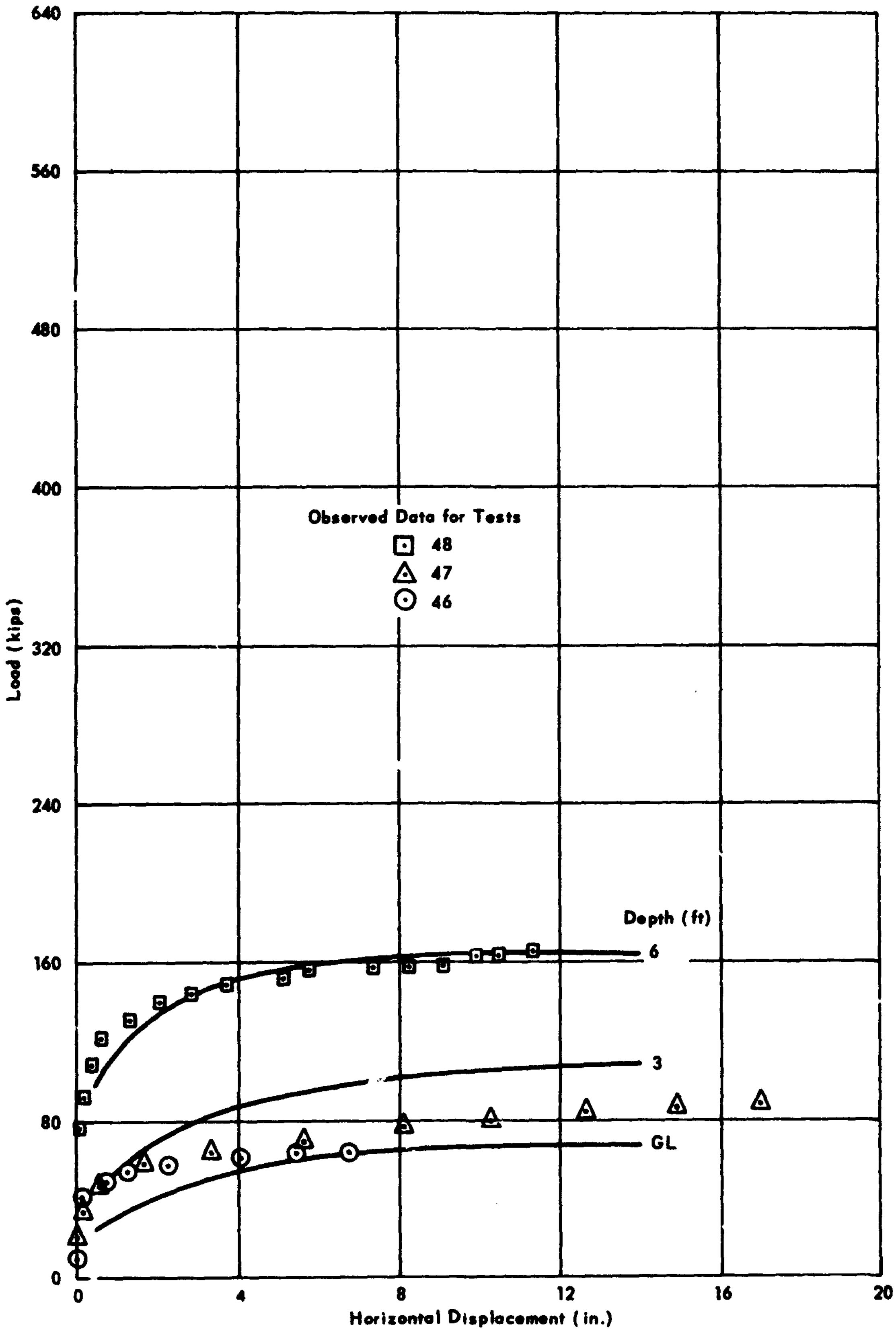


Figure A-8. Load versus horizontal displacement for single deadmen in silty sand — face area, 13.5 sq ft.

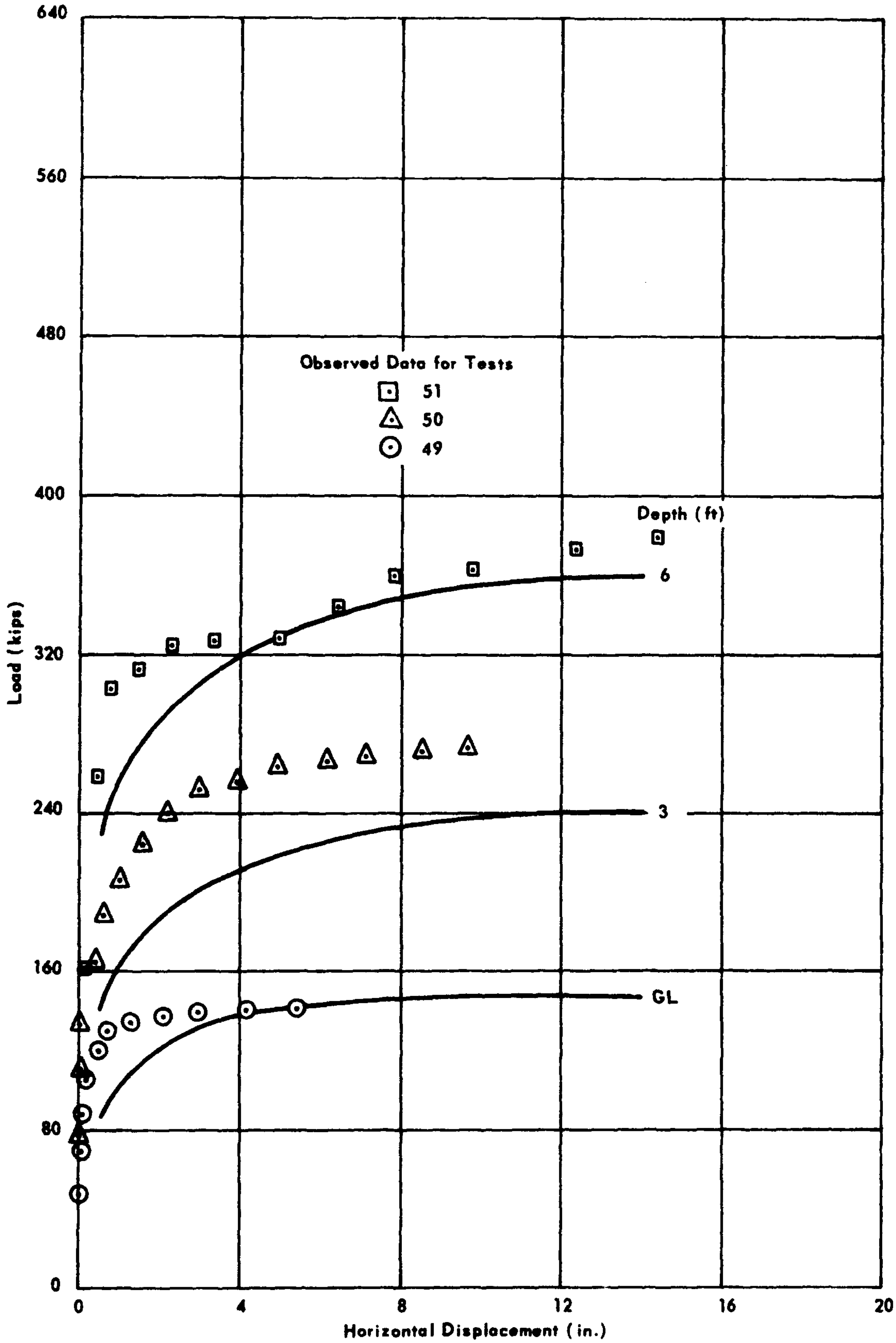


Figure A-9. Load versus horizontal displacement for single deadmen in silty sand — face area, 27 sq ft.

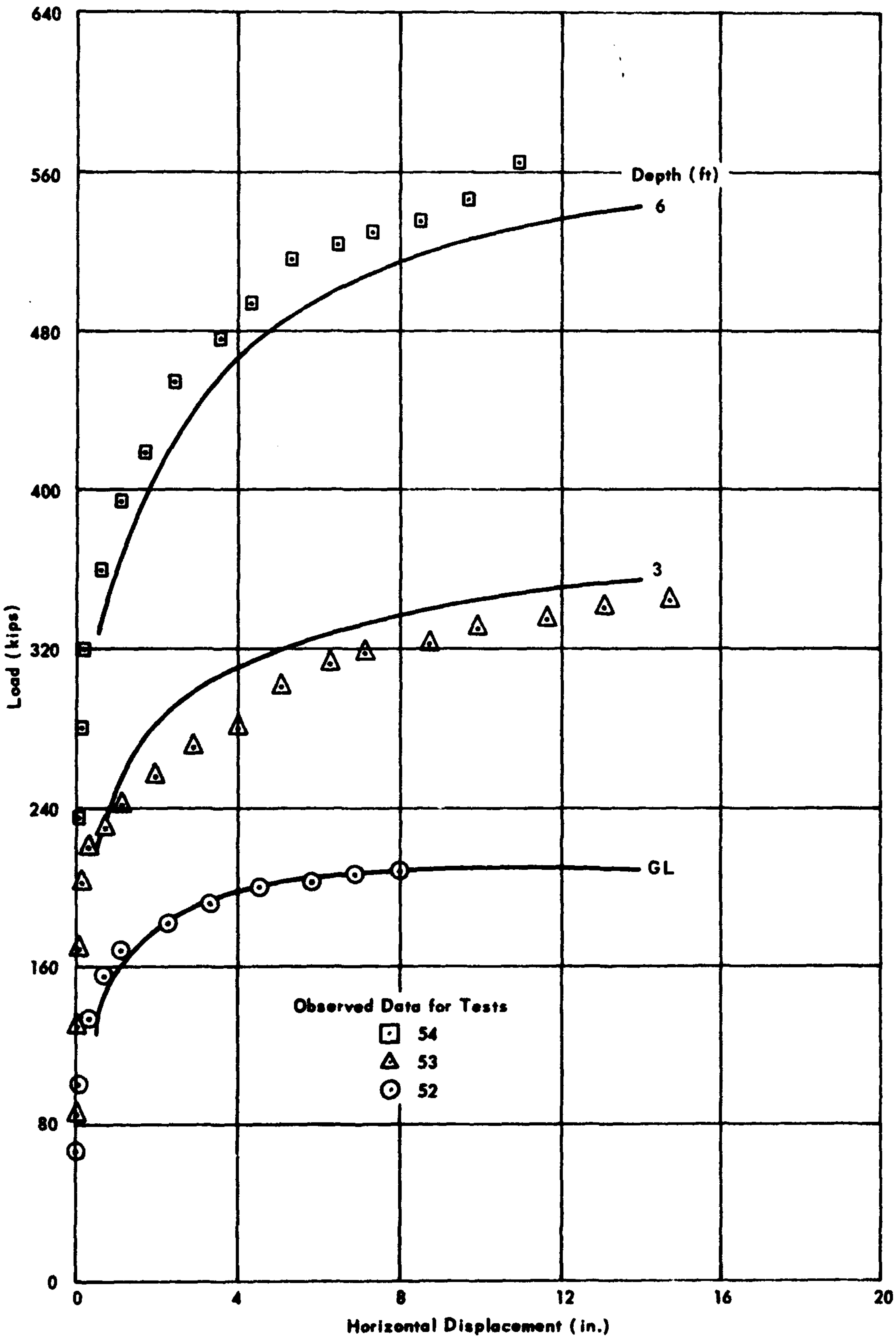


Figure A-10. Load versus horizontal displacement for single deadmen in silty sand — face area, 54 sq ft.

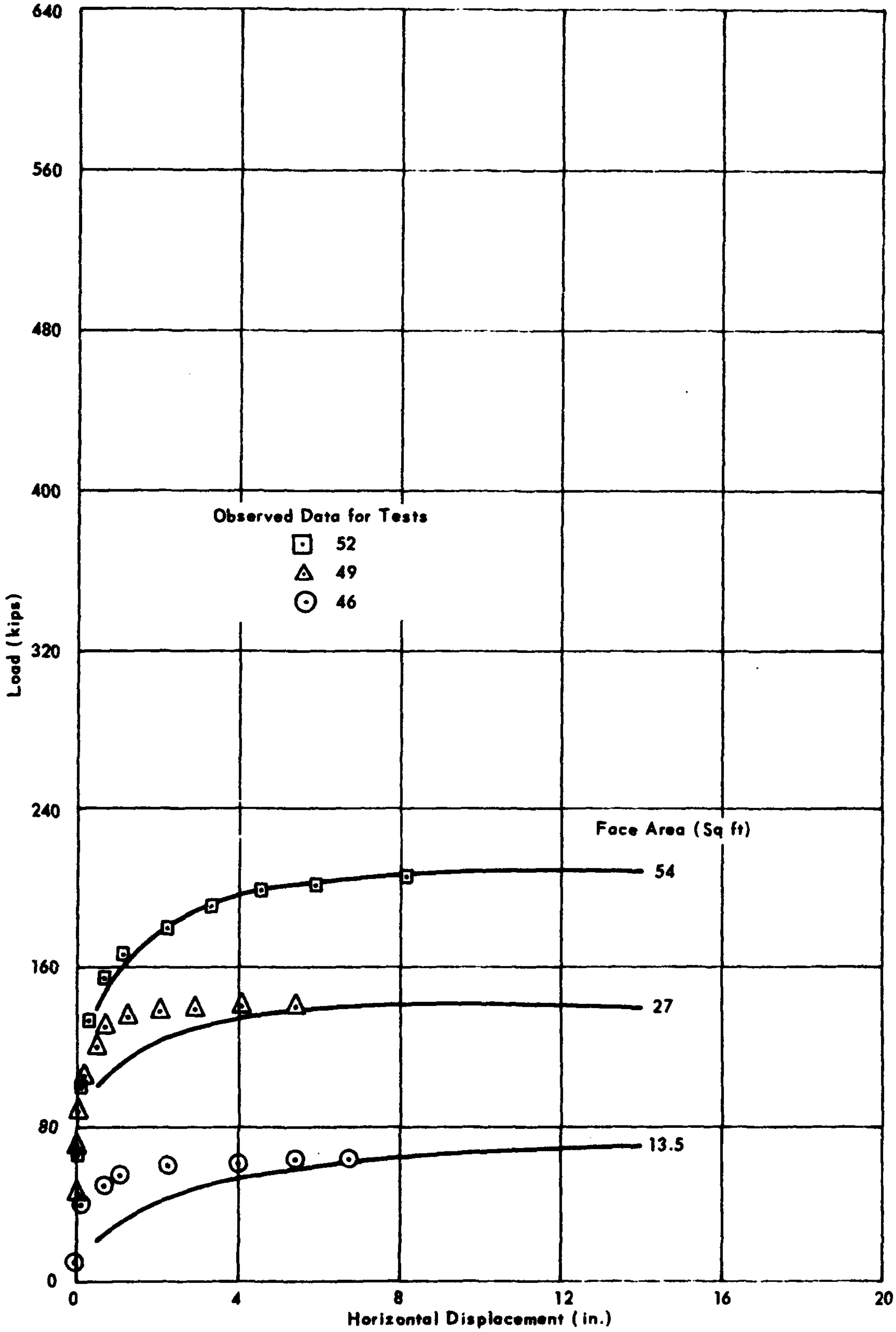


Figure A-11. Load versus horizontal displacement for single deadmen in silty sand — depth, GL.

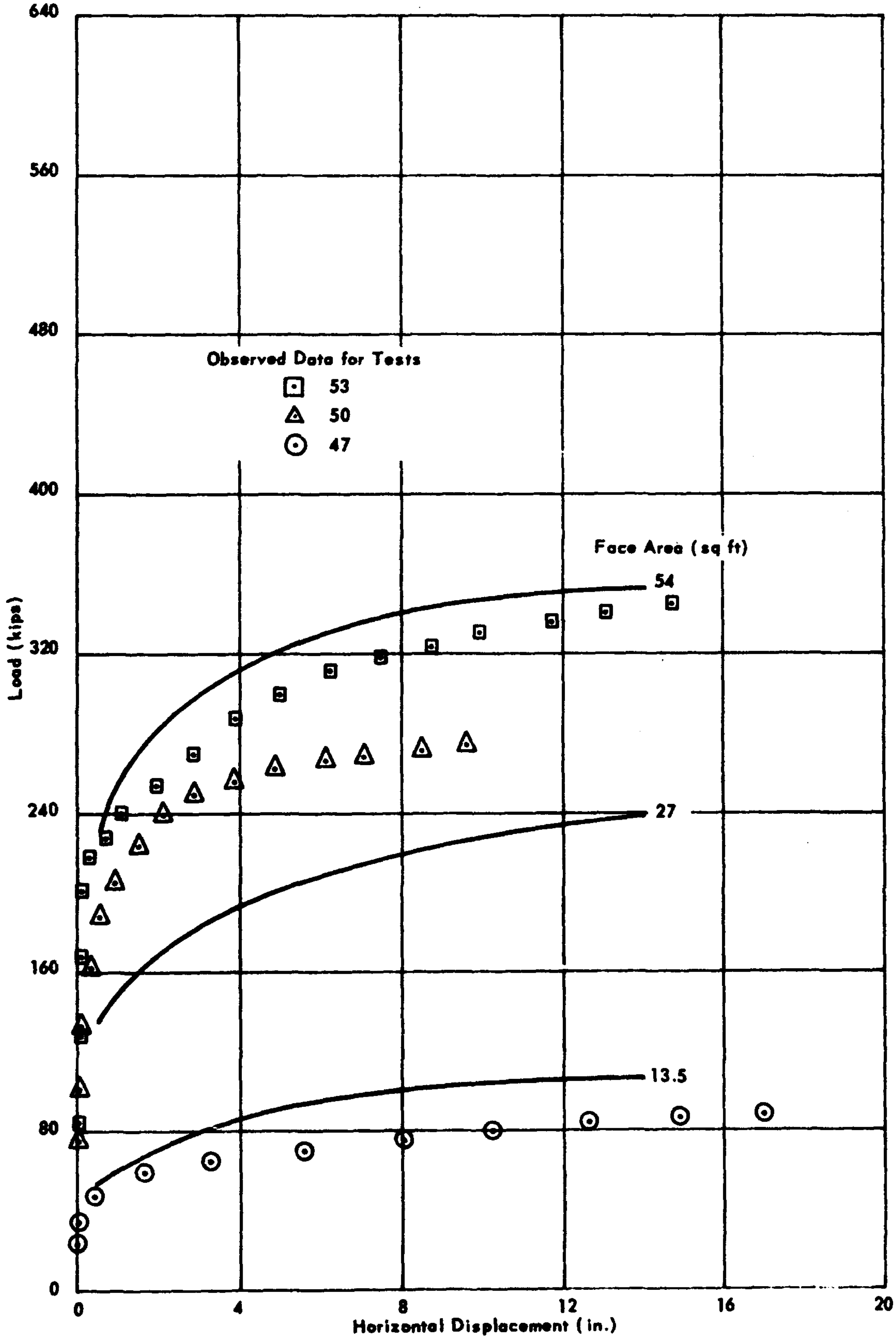


Figure A-12. Load versus horizontal displacement for single deadmen in silty sand — depth, 3 ft.

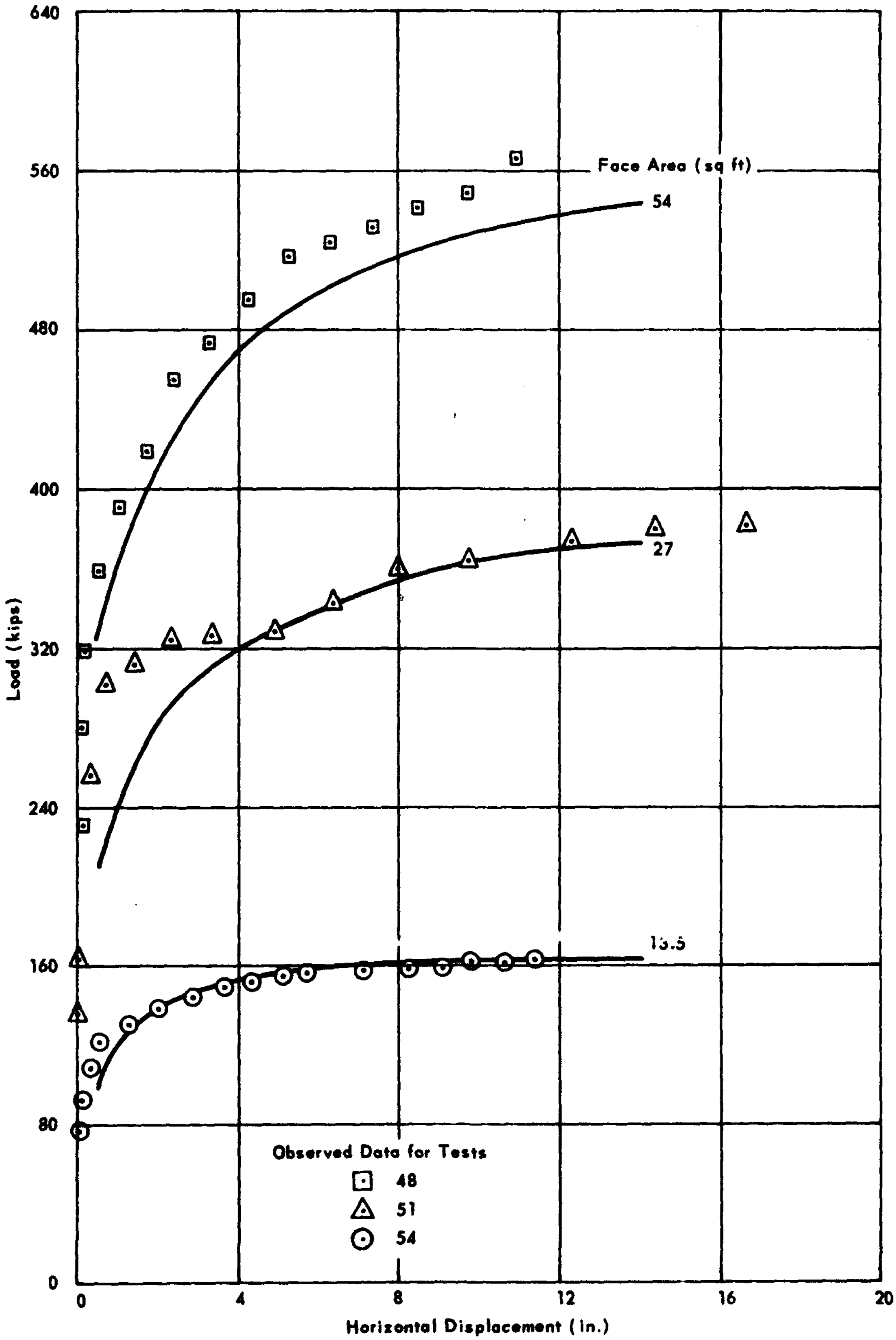


Figure A-13. Load versus horizontal displacement for single deadmen in silty sand — depth, 6 ft.

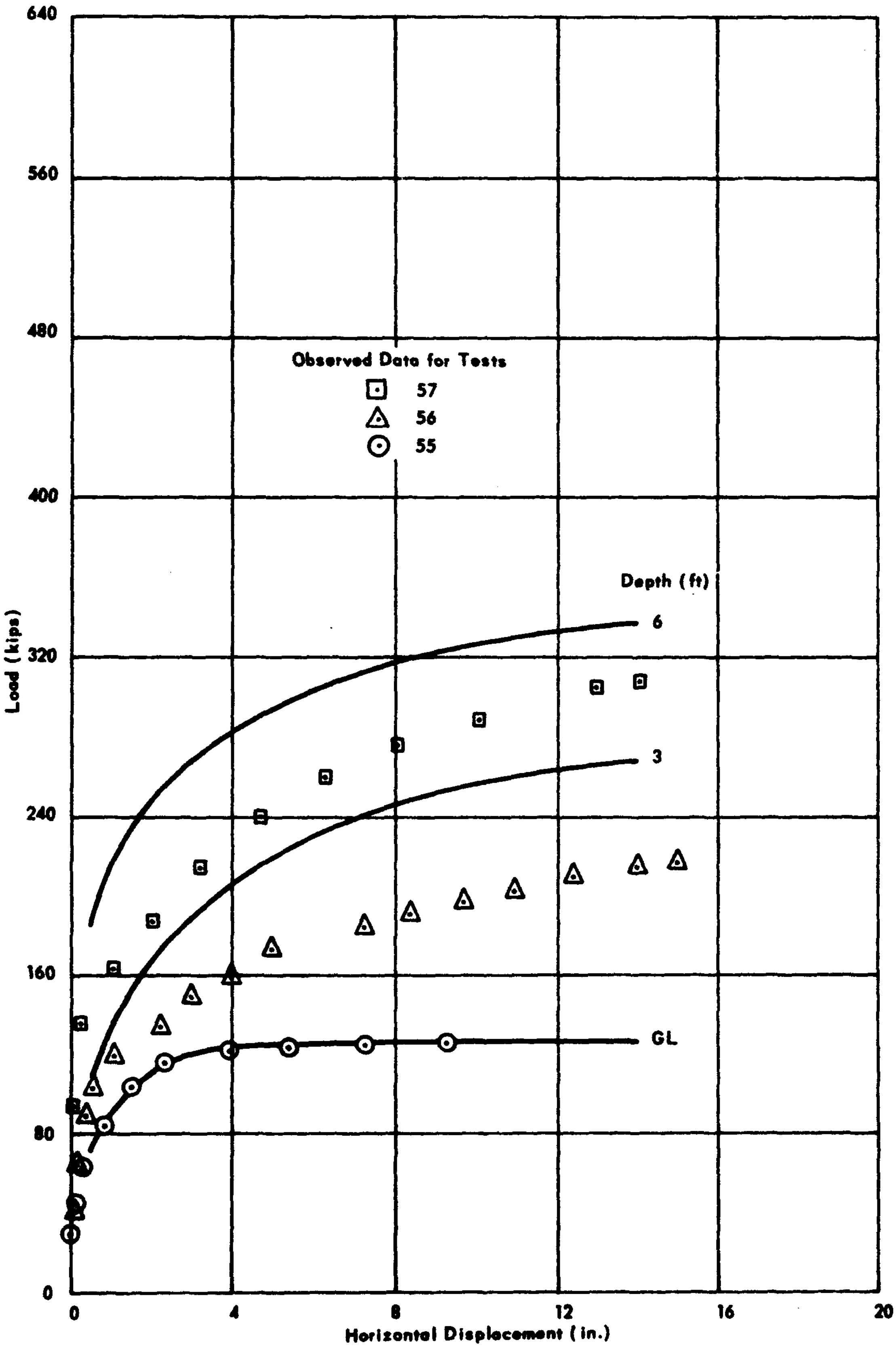


Figure A-14. Load versus horizontal displacement for multiple deadmen (3) in silty sand — total face area, 27 sq ft.

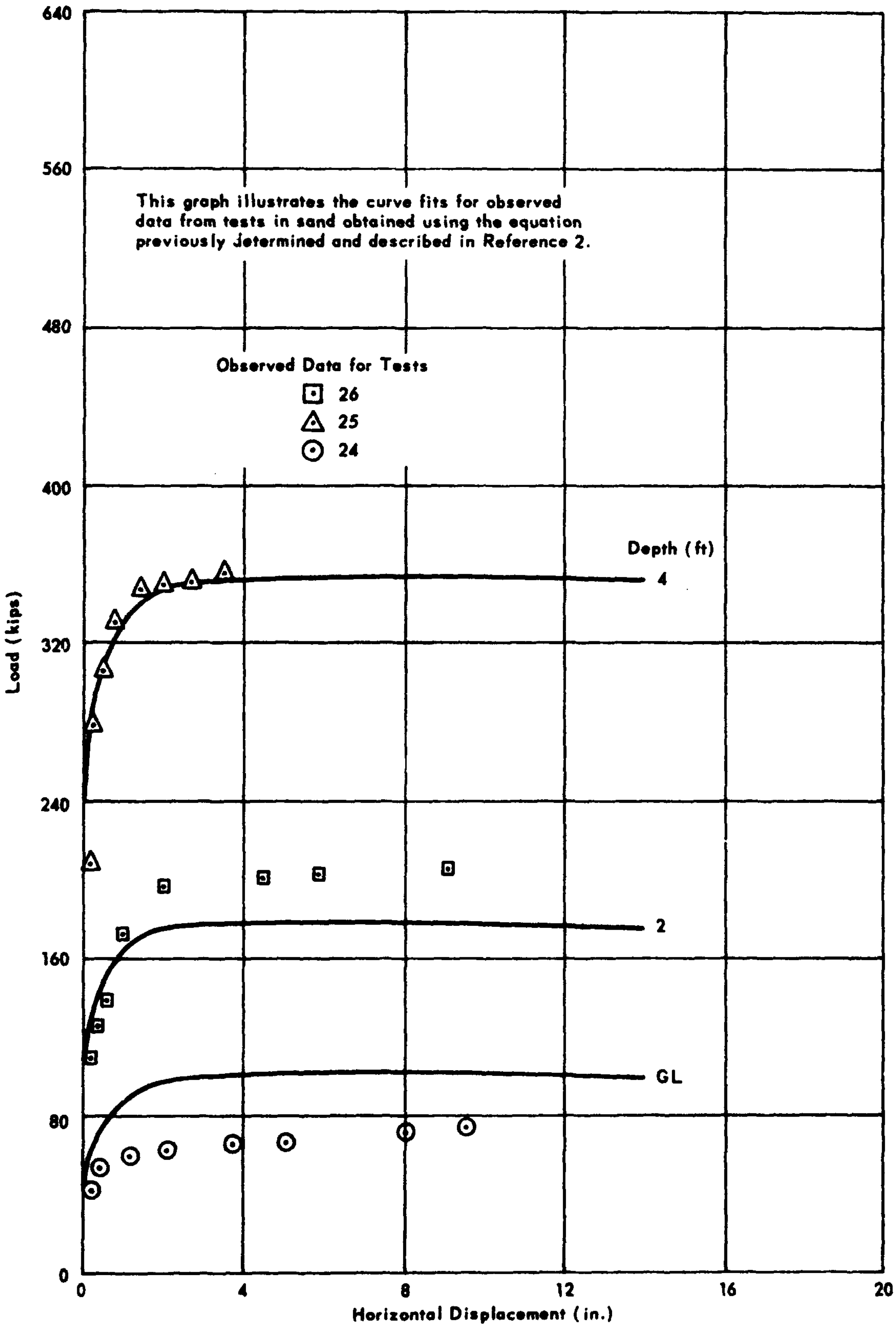


Figure A-15. Load versus horizontal displacement for single deadmen in sand — face area, 72 sq ft.

Appendix B

MATHEMATICAL ANALYSIS

S. H. Brooks, Sc. D., CEIR, I. W. Anders and W. L. Wiscoxson, NCEL

The data from the 57 tests of prototype anchors and 94 tests of model anchors were analyzed. The data consisted of sets of ordered pairs of numbers (P, d) representing the holding power of each anchor at given displacements. In general, the following properties appear to exist between the holding power and the displacement:

1. At small values of the holding power, the holding power is linearly related to the anchor displacement.
2. As the holding power is increased, less additional holding power is associated with a given further displacement.
3. There is a maximum holding power.

A simple relation consistent with these properties is

$$\Delta P = R(m - P)\Delta d \tag{B-1}$$

where d = horizontal displacement of deadman

Δd = an increment of displacement

P = force, or deadman holding capacity, required to achieve that displacement

ΔP = an increment of deadman holding capacity

m = maximum holding capacity which a deadman can attain without continuous displacement

R = rate constant which indicates how a change in holding capacity (ΔP) is related to a small change in displacement (Δd)

When the force P is small, the above formula becomes $P = R(m)\Delta d$ so that property 1 above is satisfied. Properties 2 and 3 can be confirmed by noting that as P increases, $(m - P)$ and therefore ΔP decreases for fixed Δd, and that when $P = m$, ΔP is zero. This relation expressed as a differential equation is

$$P'(d) = R(m - P) \tag{B-2}$$

A solution to this equation is

$$P = m[1 - e^{-R(d - b)}] \tag{B-3}$$

where b is the displacement at which the force required is zero. This may also be expressed as

$$P = m(1 - e^{-Rd}) + ke^{-Rd} \tag{B-4}$$

where k is the force at the zero point on the displacement scale. A representation of this equation is shown in Figure B-1.

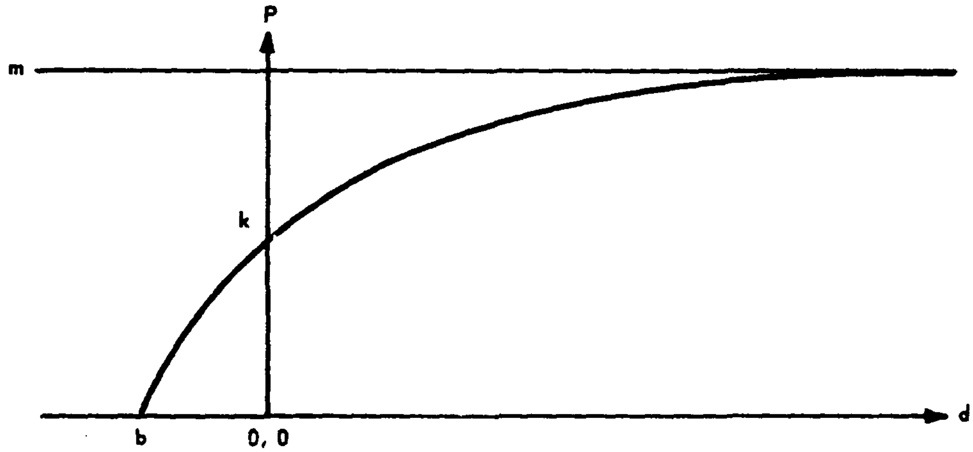


Figure B-1. Graph of Equation B-4.

Fitting the Curve to Equation B-4:

Let Δm, Δk, and ΔR be identically equal to their differentials. An increment of force may then be approximated by a function of m, k, and R as

$$\Delta P \doteq \frac{\partial P}{\partial m}\Delta m + \frac{\partial P}{\partial k}\Delta k + \frac{\partial P}{\partial R}\Delta R \tag{B-5}$$

Assume the parameters are some arbitrary value, say m_0, k_0, R_0. From Equations B-4 and B-5,

$$P \doteq P_0 + (m - m_0)\frac{\partial P}{\partial m}\bigg|_{m_0,\, k_0,\, R_0} + (k - k_0)\frac{\partial P}{\partial k}\bigg|_{m_0,\, k_0,\, R_0}$$

$$+ (R - R_0)\frac{\partial P}{\partial R}\bigg|_{m_0,\, k_0,\, R_0}$$

$$\doteq m_0(1 - e^{-R_0 d}) + k_0 e^{-R_0 d} + (m - m_0)(1 - e^{-R_0 d})$$

$$+ (k - k_0)e^{-R_0 d} + (m_0 - k_0)(R - R_0)de^{-R_0 d} \qquad \text{(B-6)}$$

Equation B-6 reduces to

$$P \doteq m(1 - e^{-R_0 d}) + ke^{-R_0 d} + (m_0 - k_0)(R - R_0)de^{-R_0 d} \qquad \text{(B-7)}$$

Letting

$$\left.\begin{aligned} U &= 1 - e^{-R_0 d} \\ V &= e^{-R_0 d} \\ W &= de^{-R_0 d} \\ Q &= (m_0 - k_0)(R - R_0) \end{aligned}\right\} \qquad \text{(B-8)}$$

there results

$$P \doteq mU + kV + QW$$

The statistical model to be fitted is then

$$P_i = U_i m + V_i k + W_i Q + \epsilon_i \qquad \text{(B-9)}$$

where $U_i = 1 - e^{-R_0 d_i}$, $V_i = e^{-R_0 d_i}$, $W_i = d_i V_i$, P_i and d_i are the set of observations, and ϵ_i is the deviation of the i^{th} observation from the fitted curve. Rearranging, squaring, then summing over the n observations in Equation B-9 results in

$$\sum_{i=1}^{n} \epsilon_i^2 = \sum_{i=1}^{n} (P_i - U_i m - V_i k - W_i Q)^2 \qquad \text{(B-10)}$$

To minimize the sum of squares of the errors, differentiate partially with respect to each parameter and equate each of the results to zero. This leads to the three simultaneous equations:

$$\left.\begin{aligned} m\sum U_i^2 + k\sum U_iV_i + Q\sum U_iW_i &= \sum U_iP_i \\ m\sum U_iV_i + k\sum V_i^2 + Q\sum V_iW_i &= \sum V_iP_i \\ m\sum U_iW_i + k\sum V_iW_i + Q\sum W_i^2 &= \sum W_iP_i \end{aligned}\right\} \qquad \text{(B-11)}$$

Let

$$\left.\begin{aligned} C_{11} = \sum U_i^2,\ C_{12} = \sum U_iV_i,\ C_{13} &= \sum U_iW_i,\ C_{1j} = \sum U_iP_i \\ C_{22} = \sum V_i^2,\ C_{23} &= \sum V_iW_i,\ C_{2j} = \sum V_iP_i \\ C_{33} &= \sum W_i^2,\ C_{3j} = \sum W_iP_i \\ C_{jj} &= \sum P_i^2 \end{aligned}\right\} \qquad \text{(B-12)}$$

Also let

$$\left.\begin{aligned} A &= C_{11}C_{33} - C_{13}^2 \\ B &= C_{12}C_{33} - C_{13}C_{23} \\ C &= C_{22}C_{33} - C_{23}^2 \\ E &= C_{1j}C_{33} - C_{3j}C_{13} \\ F &= C_{2j}C_{33} - C_{3j}C_{23} \end{aligned}\right\} \qquad \text{(B-13)}$$

Using the symbols of Equations B-12 and B-13, it can be shown that the solutions to Equation B-10 for m, k, and Q are

$$m = \frac{EC - FB}{AC - B^2} \tag{B-14}$$

$$k = \frac{F - mB}{C} \tag{B-15}$$

$$Q = \frac{C_{3i} - mC_{13} - kC_{23}}{C_{33}} \tag{B-16}$$

The analytical expression for the variance of the deviations of the observations from the fitted curve is

$$S^2 = \frac{C_{ii} - mC_{1i} - kC_{2i} - QC_{3i}}{n - 3} \tag{B-17}$$

which should, upon convergence, be nearly the same as

$$\frac{1}{n-3}\sum_{i=1}^{n}[P_{i(obs)} - P_{i(fit)}]^2 = \frac{1}{n-3}\sum_{i=1}^{n}[P_{i(obs)} - m(1 - e^{-Rd_i}) - ke^{-Rd_i}]^2 \tag{B-18}$$

From Equation B-8,

$$R = R_0 + \frac{Q}{m_0 - k_0} \tag{B-19}$$

Iterate, letting $R_0 = R$, $k_0 = k$, and $m_0 = m$, until

$$\left|1 - \frac{m}{m_0}\right| < \delta, \left|1 - \frac{k}{k_0}\right| < \delta, \left|1 - \frac{R}{R_0}\right| < \delta \tag{B-20}$$

where δ is some predetermined small number. (The minimum value for δ was determined as 1.0×10^{-5} for the IBM 1620 floating point subroutines. Smaller values caused endless wandering or resulted in oscillatory values for the parameters.)

Compared to k and R, m was found to be relatively stable; i.e., the value obtained for m on the first iteration was nearly the same as the final value. Therefore, let $m = m_0$ in Equation B-19. This changes Equation B-6 to

$$P \doteq P_0 + (k - k_0) \left.\frac{\partial P}{\partial k}\right|_{k_0, R_0} + (R - R_0) \left.\frac{\partial P}{\partial R}\right|_{k_0, R_0}$$

$$\doteq m\left(1 - e^{-R_0 d}\right) + ke^{-R_0 d} + (m - k_0)(R - R_0)de^{-R_0 d} \qquad \text{(B-21)}$$

Since the data is in an ascending order, let

$$k_0 = P_1 \qquad \text{(B-22)}$$

A procedure to construct the initial guess of R_0 is

(a) Assume

$$m = P_n \qquad \text{(B-23)}$$

(b) Choose some value P_i such that

$$P_i > \frac{1}{2}(P_1 + P_n) \qquad \text{(B-24)}$$

(c) From Equation B-4,

$$\frac{1}{2}(P_1 + P_n) < P_n - (P_n - P_1)e^{-R_0 d_i} \qquad \text{(B-25)}$$

or

$$R_0 > \frac{1}{d_i} \ln 2 \qquad \text{(B-26)}$$

(d) Therefore, choose

$$R_0 = \frac{1}{d_i} \qquad \text{(B-27)}$$

Example:

Using the multiple deadmen at a depth of 4 feet (Test No. 27), with the following observations:

i	d_i	P_i	i	d_i	P_i
1	0.00	57	9	1.26	287
2	0.07	95	10	1.63	290
3	0.11	137	11	2.15	296
4(J)	0.16	183	12	2.56	298
5	0.31	225	13	3.20	300
6	0.36	243	14	3.88	300
7	0.40	250	15	4.52	300
8	0.86	277	16(N)	5.20	302

Let $k_0 = 57$ and assume $m = 302$, then $P_i > 179.5$. From the observations, $P_i = 183$ $d_i = 0.16$. Equation B-27 then gives $R_0 = 1/0.16 = 6.25$. Next, perform the transformations indicated in Equation B-8 and fit the model of Equation B-9 using Equations B-12 through B-19. Repeat this procedure until Equation B-20 is satisfied. For this example, six iterations were required for $\delta = 1 \times 10^{-5}$.

Results:

b	m	k	R	S^2	Sum of Differences
-0.456	295.96	50.46	4.098	66.96	-0.0001

$$P = 295.96(1 - e^{-4.098d}) + 50.46e^{-4.098d}$$

Figure B-2 shows the observations and the corresponding fitted curve.

The procedure of the foregoing example was followed using all the test data. Table B-1 lists the values of m, k, R, and S^2 respectively for all anchor tests along with the completed holding power at displacements of 0.5, 1.0, 2.0, 4.0, 8.0, and 14.0 inches for the full scale and 0.01, 0.02, 0.04, 0.08, 0.016 and 0.28 inches for the model.

In an attempt to determine the relationship of the experiment variables to the parameters of Equation B-4, numerous combinations of experiment variables were investigated. The best results of the investigation arrived at within a reasonable time is a set of relationships of five experiment variables to the parameters (m, k, and R) of Equation B-4 for the model and prototype anchors which was determined by the least-squares method of curve fitting.

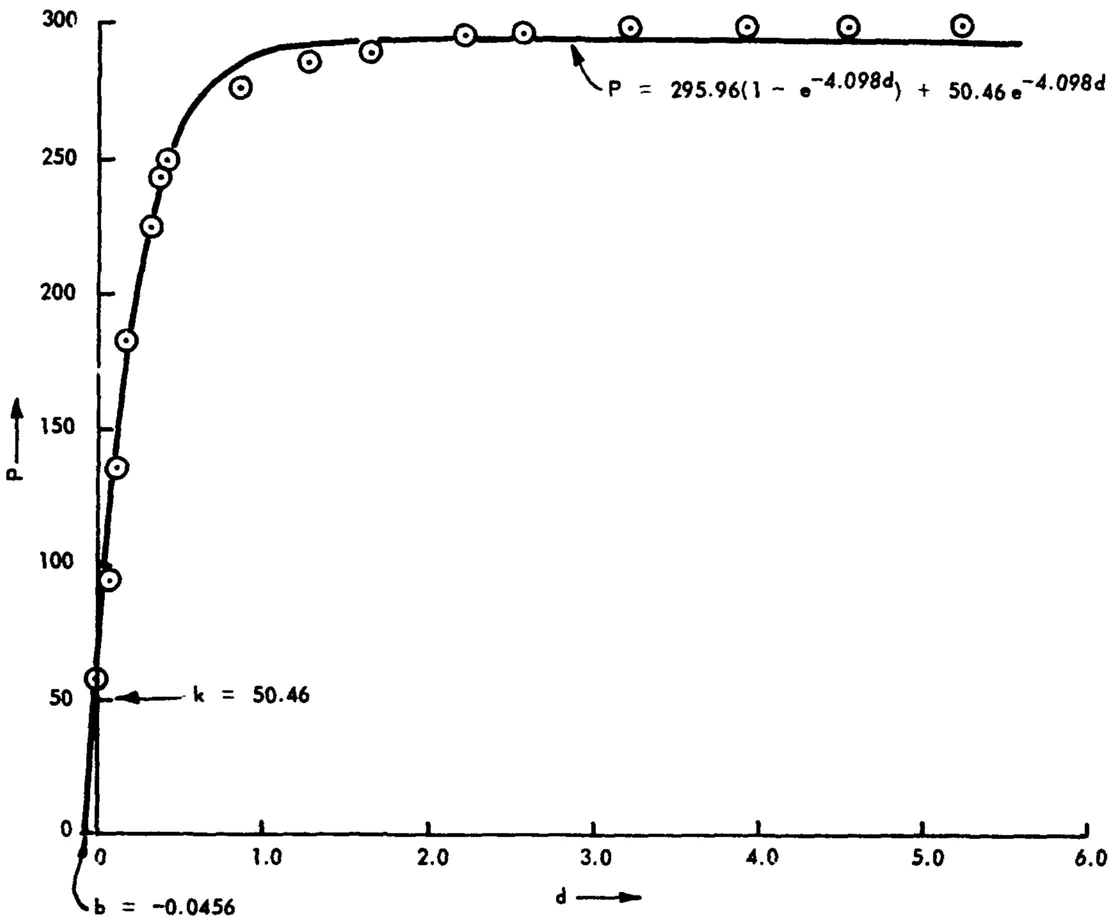


Figure B-2. Graph of example for the multiple deadmen at a depth of 4 ft (Test No. 27).

These relationships are as follows:

$$m = A_1X_1X_2 + A_2X_3 + A_3X_1X_2X_4 + A_4X_1 + A_5(X_4 + X_5) + A_6$$

$$k = B_1X_1X_2 + B_2X_3 + B_3X_1X_2X_4 + B_4X_1 + B_5(X_4 + X_5) + B_6$$

$$R = C_1X_1X_2 + C_2X_3 + C_3X_1X_2X_4 + C_4X_1 + C_5(X_4 + X_5) + C_6$$

where X_1 = number of anchors

X_2 = area of the anchors

X_3 = cohesion of the soil

X_4 = Depth to the top of the anchor

X_5 = Height of the anchor

For the prototype:

A Values	B Values	C Values
$A_1 = 1.444$	$B_1 = 0.882$	$C_1 = -0.006$
$A_2 = 32.628$	$B_2 = -0.920$	$C_2 = -0.119$
$A_3 = 1.077$	$B_3 = 0.717$	$C_3 = 0.001$
$A_4 = 12.306$	$B_4 = 18.419$	$C_4 = 0.012$
$A_5 = 5.926$	$B_5 = 4.216$	$C_5 = 0.082$
$A_6 = 59.564$	$B_6 = -29.418$	$C_6 = 1.367$

and for the model:

A Values	B Values	C Values
$A_1 = 0.152$	$B_1 = 0.044$	$C_1 = 0.391$
$A_2 = 40.515$	$B_2 = 11.337$	$C_2 = 4.213$
$A_3 = 0.516$	$B_3 = 0.197$	$C_3 = 0.043$
$A_4 = 3.033$	$B_4 = 0.033$	$C_4 = 0.729$
$A_5 = 3.510$	$B_5 = 2.566$	$C_5 = 3.060$
$A_6 = 55.883$	$B_6 = 20.728$	$C_6 = 56.321$

Statistically, there is a high correlation between observed data and calculated results using the derived relationships in Equation B-4. However, for certain combinations of the variables, inexplicable inconsistencies occur. Thus for engineering design purposes, application of Equation B-4 with the listed coefficients would be hazardous and impractical.

Table B-I. Values of m, R, k, and S^2, and Holding Powers at Different Displacements for all Tests

Full-Scale Test	Factors				P(kips) for Displacement (in.) of					
	m	R	k	S^2	0.5	1.0	2.0	4.0	8.0	14.0
1	8.20	1.09	5.30	0.0041	6.52	7.23	7.87	8.16	8.20	8.20
2	12.21	0.96	9.14	0.0036	10.32	11.04	11.76	12.14	12.21	12.21
3	24.22	1.46	15.32	0.0351	19.94	22.16	23.74	24.19	24.22	24.22
4	32.00	0.65	18.49	0.1560	22.25	24.96	28.34	31.00	31.92	31.99
5	46.15	0.59	20.35	0.0431	26.99	31.92	38.31	43.77	45.93	46.15
6	75.07	0.62	39.41	0.0242	49.00	56.02	64.89	72.16	74.83	75.07
7	150.23	0.33	103.34	0.6475	110.54	116.63	126.16	137.87	146.97	149.79
8	19.48	0.95	8.25	0.0014	12.51	15.16	17.82	19.23	19.47	19.48
9	27.00	0.67	12.55	0.0776	16.67	19.62	23.23	26.02	26.93	27.00
10	35.94	0.76	21.31	0.0493	25.96	29.13	32.77	35.26	35.91	35.94
11	41.87	1.05	22.12	0.1908	30.20	34.98	39.47	41.58	41.87	41.87
12	79.25	0.49	54.39	0.0534	59.87	64.14	70.07	75.86	78.79	79.23
13	154.62	0.32	111.97	0.6348	118.35	123.77	132.31	142.95	151.43	154.17
14	173.11	0.33	113.09	0.8130	122.35	130.19	142.42	157.42	169.01	172.56
15	32.07	1.14	15.99	0.0442	23.01	26.97	30.45	31.90	32.07	32.07
16	40.49	1.09	25.78	0.1554	31.98	35.56	38.84	40.31	40.49	40.49
17	73.26	1.02	49.53	0.0429	59.08	64.78	70.23	72.87	73.25	73.26
18	73.26	1.02	49.53	0.0429	59.08	64.78	70.23	72.87	73.25	73.26
19	81.81	0.78	58.88	0.4669	66.34	71.37	77.06	80.82	81.76	81.81
20	148.44	0.57	103.90	1.6965	115.00	123.33	134.28	143.94	147.99	148.43
21	259.40	0.43	182.77	4.2583	197.74	209.78	227.27	245.93	257.03	259.23
22	63.50	0.66	30.85	0.1697	40.14	46.78	54.94	61.26	63.35	63.50
23	167.95	0.38	85.59	0.4609	100.16	112.16	130.15	150.60	164.30	167.60
24	84.65	0.63	48.41	0.3183	58.25	65.42	74.45	81.78	84.42	84.64
25	222.54	0.46	124.11	3.4268	144.42	160.54	183.48	207.04	220.10	222.39
26	373.46	0.46	272.62	3.2026	293.47	310.01	333.54	357.66	370.99	373.31
27	304.93	0.73	255.23	1.0971	270.48	281.05	293.45	302.28	304.79	304.93
28	93.36	0.82	63.27	0.5960	73.40	80.12	87.54	92.23	93.32	93.36
29	232.61	0.67	183.19	4.2390	197.37	207.47	219.83	229.30	232.39	232.61
30	322.09	0.66	277.84	0.7653	290.34	299.31	310.36	318.98	321.88	322.09
31	108.63	0.63	83.41	0.4673	90.30	95.31	101.59	106.67	108.48	108.63
32	242.48	0.52	200.23	1.7820	210.01	217.54	227.75	237.35	241.86	242.46
33	328.09	0.57	267.69	1.1791	282.70	293.98	308.82	321.94	327.46	328.07
34	74.72	0.44	13.93	0.5620	26.11	35.84	49.86	64.55	73.02	74.60
35	122.62	0.23	39.61	0.9711	48.95	57.24	71.12	90.67	110.32	119.68
36	171.99	0.22	73.36	5.8523	83.89	93.29	109.19	132.01	155.78	167.81
37	131.35	0.42	32.44	1.5193	51.29	66.55	88.90	113.14	128.00	131.09
38	283.02	0.19	91.11	3.5559	109.17	125.53	153.78	195.98	243.54	270.96
39	347.76	0.22	166.67	1.3753	186.28	203.77	233.27	275.38	318.83	340.45
40	201.38	0.45	77.77	2.8938	102.75	122.66	151.27	181.07	198.04	201.16
41	399.44	0.33	157.57	32.937	194.96	226.57	275.89	336.33	382.98	397.25
42	568.08	0.23	300.71	39.681	329.81	355.74	399.45	461.73	525.78	557.47
43	135.48	0.55	79.61	2.0553	93.09	103.32	116.97	129.34	134.80	135.45
44	273.43	0.29	127.96	27.358	147.87	165.06	192.70	228.63	259.63	271.07
45	345.50	0.34	174.66	43.155	201.68	224.43	259.70	302.41	334.63	344.12
46	67.09	0.34	16.28	1.0350	24.34	31.12	41.62	54.33	63.88	66.68
47	103.71	0.33	40.21	1.9878	49.99	58.27	71.19	87.05	99.34	103.13
48	164.35	0.47	82.82	0.1373	100.14	113.77	132.98	152.28	162.56	164.25
49	147.24	0.58	65.83	0.8009	86.58	102.04	122.14	139.50	146.50	147.21
50	239.30	0.39	121.63	10.978	142.48	159.64	185.37	214.58	234.10	238.80
51	359.62	0.35	207.02	8.9149	231.94	252.80	284.84	322.98	350.82	358.59
52	207.06	0.75	89.67	17.397	126.40	151.63	180.89	201.23	206.77	207.06
53	349.77	0.37	197.99	56.362	224.11	245.74	278.46	316.27	342.38	349.01
54	543.44	0.29	299.21	21.899	332.54	361.33	407.64	467.93	520.10	539.43
55	127.05	0.82	41.42	0.8247	70.26	89.39	110.49	123.85	126.93	127.05
56	270.29	0.26	86.82	11.283	109.31	129.04	161.55	205.84	247.65	265.58
57	334.48	0.30	164.92	21.571	189.20	210.01	243.10	285.24	320.18	332.24

Table B-1. Values of m, R, k, and S^2, and Holding Powers at Different Displacements for all Tests (Contd)

Model Test	Factors				P(lb) for Displacement (in.) of					
	m	R	k	S^2	0.01	0.02	0.04	0.08	0.16	0.28
1	9.51	33.22	3.09	0.0351	4.90	6.21	7.81	9.06	9.48	9.51
2	12.77	66.81	3.27	0.0849	7.90	10.28	12.12	12.73	12.77	12.77
3	17.20	48.61	6.91	0.0648	10.87	13.30	15.72	16.99	17.19	17.20
4	19.56	50.78	8.88	0.1587	13.13	15.69	18.16	19.38	19.56	19.56
5	25.02	42.26	13.80	0.2524	17.67	20.20	22.95	24.63	25.00	25.02
6	41.74	18.92	18.25	0.2627	22.30	25.65	30.72	36.57	40.60	41.62
7	42.80	10.68	26.27	0.9514	27.95	29.45	32.02	35.77	39.81	41.97
8	15.51	31.22	4.68	0.1392	7.58	9.71	12.41	14.62	15.44	15.51
9	19.36	26.39	7.32	0.0551	10.11	12.26	15.17	17.90	19.18	19.35
10	23.14	34.50	12.22	0.0206	15.41	17.67	20.40	22.45	23.10	23.14
11	26.04	50.78	14.45	0.0918	19.07	21.85	24.52	25.85	26.04	26.04
12	31.35	25.73	20.60	0.0210	23.04	24.93	27.51	29.98	31.17	31.34
13	44.85	10.21	29.85	0.1027	31.31	32.63	34.88	38.23	41.93	43.99
14	41.82	20.07	24.41	0.4019	27.57	30.17	34.02	38.33	41.12	41.76
15	18.06	24.65	7.98	0.2551	10.18	11.91	14.30	16.66	17.87	18.05
16	24.26	26.68	8.63	0.1651	12.29	15.09	18.88	22.41	24.04	24.25
17	31.38	27.65	10.78	0.1938	15.76	19.53	24.56	29.12	31.13	31.37
18	31.38	27.65	10.78	0.1938	15.76	19.53	24.56	29.12	31.13	31.37
19	35.54	25.78	14.92	0.1817	19.61	23.23	28.19	32.92	35.20	35.52
20	41.60	18.50	22.31	0.3542	25.57	28.28	32.40	37.21	40.60	41.49
21	54.65	26.81	32.48	0.1325	37.69	41.68	47.06	52.05	54.35	54.64
22	25.06	18.47	6.56	0.0480	9.68	12.28	16.22	20.84	24.10	24.95
23	43.40	19.53	14.90	0.7277	19.95	24.11	30.35	37.43	42.15	43.28
24	40.37	23.04	13.85	0.4115	19.31	23.64	29.82	36.17	39.70	40.33
25	57.17	12.93	20.27	0.2661	24.75	28.68	35.18	44.06	52.51	56.18
26	66.84	15.18	27.77	0.3220	33.28	38.01	45.56	55.25	63.40	66.29
27	58.48	15.74	29.83	0.1103	34.01	37.57	43.22	50.36	56.18	58.14
28	35.88	21.58	13.95	0.0852	18.21	21.64	26.63	31.98	35.19	35.83
29	51.43	17.70	23.39	0.2302	27.94	31.76	37.62	44.63	49.78	51.23
30	76.89	15.05	38.35	0.2672	43.74	48.37	55.79	65.33	73.42	76.32
31	36.52	31.11	14.34	0.2422	20.27	24.61	30.13	34.68	36.36	36.51
32	61.22	20.37	27.98	0.1747	34.11	39.10	46.51	54.71	59.94	61.11
33	76.33	19.41	38.53	0.1361	45.20	50.70	58.94	68.33	74.64	76.16
34	49.17	27.82	12.60	0.7338	21.48	28.21	37.15	45.22	48.75	49.16
35	96.30	13.71	33.60	4.7741	41.63	48.64	60.07	75.36	89.31	94.95
36	142.51	18.19	44.89	0.1233	61.13	74.66	95.35	119.73	137.19	141.91
37	77.19	17.42	28.41	0.0624	36.21	42.76	52.90	65.09	74.19	76.82
38	158.11	9.43	51.78	1.5069	61.36	70.07	85.22	108.14	134.63	150.55
39	235.33	9.96	95.81	4.0145	109.04	121.02	141.68	172.46	207.00	226.76
40	118.76	12.62	31.74	1.4984	42.06	51.16	66.24	87.07	107.22	116.22
41	218.85	9.24	76.90	0.7904	89.44	100.87	120.80	151.12	186.53	208.20
42	369.31	9.13	147.43	3.5054	166.80	184.47	215.32	262.44	317.84	352.10
43	107.73	14.02	20.66	1.7544	32.05	41.96	58.05	79.39	98.50	106.02
44	201.65	9.90	47.43	10.212	61.98	75.16	97.90	131.85	170.06	192.03
45	246.29	13.30	90.33	2.1528	109.76	126.77	154.69	192.49	227.73	242.53
46	43.88	31.48	7.57	1.0444	17.38	24.54	33.58	40.96	43.65	43.88
47	76.25	19.09	22.98	0.3109	32.24	39.89	51.43	64.68	73.74	75.99
48	120.03	19.87	48.78	0.4833	61.63	72.16	87.86	105.50	117.07	119.76
49	70.59	14.49	16.57	0.8299	23.86	30.17	40.34	53.65	65.28	69.66
50	129.67	14.01	36.73	1.6614	48.88	59.45	76.61	99.38	119.80	127.84
51	195.57	18.18	63.54	22.652	85.50	103.80	131.78	164.75	188.38	194.76
52	105.79	11.40	17.71	0.1764	27.20	35.66	49.96	70.41	91.57	102.17
53	200.62	8.61	72.94	5.3403	83.48	93.15	110.16	136.53	168.45	189.18
54	356.22	6.81	113.51	2.8686	129.51	144.46	171.46	215.57	274.71	320.26
55	86.58	16.17	19.25	0.7973	29.30	37.85	51.32	68.12	81.52	85.86
56	153.72	14.35	46.91	1.4730	61.20	73.57	93.57	119.85	142.98	151.80
57	237.08	13.14	72.28	0.3631	92.58	110.37	139.66	179.49	216.95	232.92

Table B-1. Values of m, R, k, and S^2, and Holding Powers at Different Displacements for all Tests (Contd)

Model Test	Factors				P(lb) for Displacement (in.) of					
	m	R	k	S^2	0.01	0.02	0.04	0.08	0.16	0.28
58	34.56	19.72	9.86	0.4285	14.28	17.91	23.34	29.46	33.51	34.46
59	47.94	19.31	24.31	0.5988	28.46	31.88	37.03	42.90	46.86	47.83
60	60.22	15.97	33.60	0.0380	37.53	40.88	46.17	52.81	58.16	59.92
61	39.39	11.10	10.90	0.3773	13.90	16.58	21.12	27.68	34.58	38.12
62	34.03	11.59	8.13	0.6107	10.96	13.49	17.74	23.78	29.98	33.02
63	45.83	12.34	13.54	0.1510	17.29	20.60	26.12	33.80	41.35	44.81
64	51.93	13.41	15.31	1.4431	19.91	23.93	30.51	39.40	47.64	51.07
65	61.59	19.75	27.93	0.0845	33.96	38.91	46.31	54.66	60.16	61.46
66	58.38	15.40	20.79	0.0488	26.16	30.76	38.08	47.42	55.18	57.88
67	86.12	17.17	25.30	0.9314	34.90	42.98	55.52	70.73	82.22	85.62
68	110.77	27.13	29.42	1.7164	48.75	63.49	83.29	101.49	109.71	110.73
69	87.75	5.24	12.47	7.3392	16.32	19.97	26.73	38.28	55.24	70.43
70	121.51	4.84	25.80	0.2212	30.33	34.64	42.66	56.55	77.42	96.86
71	131.50	5.57	26.86	1.2134	32.54	37.91	47.79	64.53	88.64	109.56
72	139.62	4.87	23.71	6.3090	29.22	34.47	44.23	61.12	86.45	109.98
73	187.93	4.72	40.70	1.6325	47.49	53.97	66.04	87.02	118.77	148.68
74	118.86	7.27	32.60	0.6620	38.65	44.28	54.37	70.65	91.92	107.60
75	173.56	7.31	62.70	0.5019	70.53	77.80	90.84	111.83	139.19	159.28
76	122.67	9.73	40.56	0.1432	48.18	55.09	67.05	84.99	105.38	117.29
77	211.37	8.44	67.65	0.2058	79.30	90.00	108.87	138.26	174.18	197.87
78	304.08	9.21	122.31	8.6656	138.31	152.90	178.35	217.11	262.47	290.31
79	143.26	12.04	59.93	0.7214	69.39	77.77	91.79	111.47	131.13	140.40
80	208.65	9.87	87.01	0.6949	98.45	108.81	126.70	153.44	183.59	200.98
81	79.02	9.45	12.38	0.9275	18.39	23.86	33.36	47.73	64.33	74.29
82	93.43	8.22	22.30	12.076	27.91	33.08	42.23	56.58	74.34	86.31
83	128.51	7.69	34.01	1.0820	41.01	47.49	59.05	77.45	[illegible]	117.55
84	116.53	8.11	27.20	0.5915	34.16	40.57	51.95	69.84	92.13	107.31
85	175.61	6.20	59.06	5.0768	66.06	72.65	84.66	104.64	132.39	155.07
86	82.87	10.98	8.21	0.6684	15.98	22.94	34.76	51.87	70.00	79.43
87	164.22	8.28	43.60	3.4327	53.19	62.02	77.63	102.06	132.19	152.37
88	100.54	13.00	29.48	0.3493	38.14	45.75	58.30	75.43	91.67	98.67
89	167.01	10.74	58.59	0.4506	69.63	79.55	96.46	121.10	147.57	161.65
90	287.87	8.01	108.80	0.2889	122.59	135.32	157.91	193.56	238.20	268.88
91	123.22	13.62	46.54	0.7890	56.31	64.84	78.77	97.45	114.56	121.54
92	183.24	10.59	73.74	0.7469	84.74	94.64	111.55	136.31	163.13	177.60
93	146.22	11.01	27.38	7.7127	39.78	50.88	69.73	96.98	125.82	140.78
94	119.35	8.02	12.38	0.4729	20.63	28.24	41.75	63.06	89.73	108.05

REFERENCES

1. U. S. Naval Civil Engineering Laboratory. Technical Memorandum M-121: Tests of concrete deadman anchorages in sand, by J. E. Smith. Port Hueneme, Calif., Feb. 1957.

2.———. Technical Report R-199: Deadman anchorages in sand, by J. E. Smith. Port Hueneme, Calif., July 1962.

3. G. P. Tschetobarioff. Soil mechanics, foundations, and earth structures. New York, McGraw-Hill, 1951.

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A test program was conducted to investigate deadman anchorage holding capacities under applied horizontal loads. Deadmen fabricated of concrete and ranging in face area from 5 to 72 square feet were tested in depths of embedment from ground level to 7 feet. The deadmen were pulled both singly and in groups of three, in sand and in two soils with cohesive characteristics. The test program also included tests on a model scale.

The investigation disclosed that multiple anchors develop a higher holding capacity per net area than a single deadman with the same total face area. The increase in holding capacity ranging from 5 to 20% depends upon such factors as depth of embedment, the type of soil, and the spacing between deadmen. Under most test conditions, up to a 30% increase in holding capacities was attained in cohesive soils as compared to sand, but 2 to 3 times the horizontal displacement was required to achieve the maximum holding capacity.

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Deadman						
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