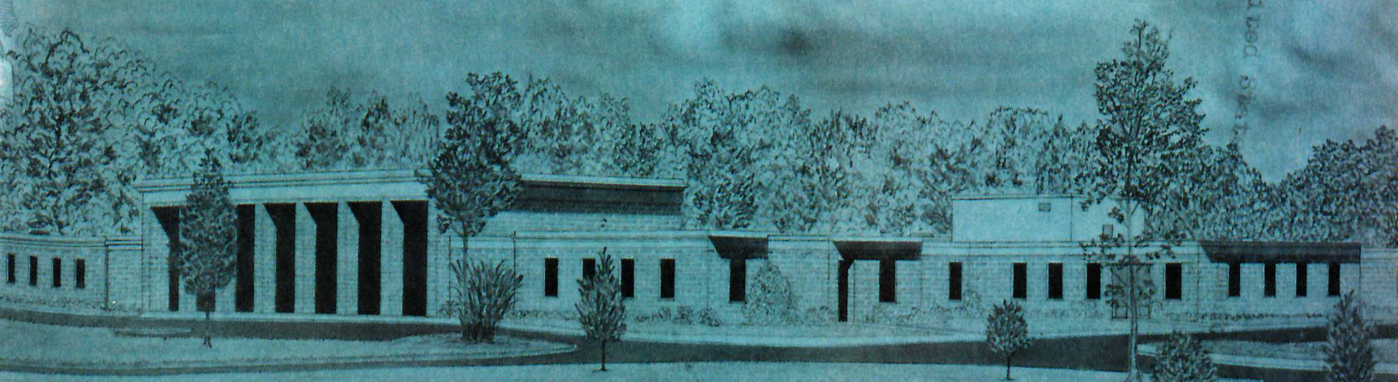
TECHNICAL REPORT S-70-3

EFFECT OF SATURATION ON DYNAMIC RESPONSE OF FOOTINGS IN SAND

by

J. K. Poplin



May 1970

Sponsored by Office, Chief of Engineers, U. S. Army

Conducted by U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

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ARMY-MRC VICKSBURG, MISS.

FOREWORD

The investigation reported herein was conducted in the Soils Division of the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the Office, Chief of Engineers, U. S. Army (Effects of Nuclear Weapons Project No. 1T02261A09102, Development of Design Criteria for Foundations of Army Protective Structures) during May and June 1969. The tests were planned by Mr. P. F. Hadala and conducted in the Soil Dynamics laboratory under the supervision of Mr. R. C. Sloan assisted by Messrs. B. F. Wright, L. F. Steen, and A. G. Reno. General supervision was exercised by Messrs. A. A. Maxwell, R. W. Cunny, and J. G. Jackson, Jr. This report was prepared by Dr. J. K. Poplin of Louisiana State University during summer employment at WES.

COL Levi A. Brown, CE, was the Director of WES during the period of this investigation and preparation of the report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
mils	25.4	micrometers
inches	25.4	millimeters
feet	0.3048	meters
kips	4.448222	kilonewtons
tons per square foot	9.7649	metric tons per square meter
pounds per cubic foot	16.0185	kilograms per cubic meter
inches per second	25.4	millimeters per second
feet per second	0.3048	meters per second

SUMMARY

This investigation was undertaken to determine the effect of saturation of dense sand on the response of square footings to nuclear blast-type loading. Tests were conducted with footings on the surface and at a depth of burial equal to the footing width with a water table coincident with the plane of the footing. The results of these tests were compared with data from similar tests on dry sand from a preceding study.

Saturation of dense sand had the effect of reducing maximum displacement. The displacements of surface footings were only about 30 percent of the displacement of footings on dry sand with equivalent soil density and loading condition, and the displacement of shallow buried footings was reduced by 50 percent. Empirical load-displacement curves developed from previous studies on dry sand were shown to be conservative when used to predict the response of footings on saturated dense sand.

The primary difference in response occurred after peak reaction. The footings on saturated dense sand came to rest immediately, while footings on dry sand continued to displace for some short distance. This behavior was attributed to the development of transient negative pore pressures resulting from dilation of the sand.

A similar laboratory investigation on a medium-density sand is recommended in order to determine whether or not any tendency toward liquefaction may occur at the lower end of the range of densities of interest for protective structure foundations.

EFFECT OF SATURATION ON DYNAMIC RESPONSE OF FOOTINGS IN SAND

PART I: INTRODUCTION

BACKGROUND

1. Underground protective structures must be located near or below the water table in many cases. The quantitative effects of groundwater on foundation response under a high-intensity, short-duration load pulse have not been fully established for foundations supported by sand.

Previous Studies

2. Considerable insight into foundation behavior under dynamic loading has been gained through the use of small-scale experimental models. The feasibility of using experimental models to study the response of footings to load pulses characteristic of nuclear detonation airblasts was established using small plates on prepared specimens of remolded clays, which showed that footing response could be related to load, footing, and soil parameters.[1] A similar study showed that the response of footings on dry sand could also be predicted in terms of comparable parameters.[2] This study and succeeding parametric extensions established the effects of load intensity, pulse duration, footing shape, depth of burial, and relative density on footing displacements for dry sand,[3,4] but the influence of water in sand was not investigated.

Need for This Study

3. When the void spaces of a granular soil are filled with water, the behavior of the soil under loading is considerably different from that of a dry soil, particularly if the loading is transient. When loaded rapidly, essentially undrained conditions prevail, and the shear strength of a saturated sand is dependent on the stress state of the pore water, which is related to volume change characteristics. Experimental studies at the Massachusetts Institute of Technology (MIT) on the effect of loading rate on shear strength of saturated sands indicate a definite trend toward increase in strength with increasing strain rate, although strain rate was found to have only a nominal effect on frictional resistance.[5]

4. In a saturated soil, stresses are transmitted through the pore fluid as well as through the mineral skeleton of the soil. The effect of saturation can be assessed qualitatively based on assumed deformation mechanisms for the soil, but several deformation mechanisms may develop simultaneously within the zone beneath a footing under dynamic loading. For example, dense sands are known to tend to dilate when undergoing shear deformation, which results in increased undrained shear strength through increased effective stress. Loose sands tend to contract on shearing, thereby reducing effective stress and leading to possible liquefaction conditions under which the soil will have essentially no shear strength, which could result in a catastrophic situation. However, if significant compression of the mineral skeleton of the soil occurs under the stress applied by the footing, an excess pore pressure can develop, leading to a momentary liquefaction. Thus, the effect of saturation on footing response depends on the relative influence of shear and compression deformations.

5. Small-scale tests offered the most logical approach to determine the relative effect of saturation by comparing the results of tests on saturated sand with those from tests on dry sand. If it could be shown that, when pore water is present, a response occurred identical to that observed in dry sand, then the effect of pore water could be considered negligible and the extensive empirical relations developed using dry sand would also be valid whenever water is present in the pores. If a smaller response occurred (indicating a greater stiffness), then the empirical relations would constitute a conservative upper bound for displacement prediction purposes. However, if much larger responses occurred, then a more extensive study to evaluate these effects and to develop extended relations for the saturated case would be justified.

PURPOSE AND SCOPE

6. The study reported here was undertaken to observe the effect of saturation on the response of footings on sand within the range of relative densities of interest to foundation designers for protective structures. For this study, a relative density of 90 percent was selected. Surface footings and footings buried at a depth equal to one footing width were used, and the water table was maintained at the footing level for all tests. The results of four dynamic tests were compared with counterpart tests on dry sand and with prediction equations developed from the results of the tests on dry sand to determine if the empirical relations represent at least conservative bounds for all cases.

PART II: DESCRIPTION OF TESTS

PLAN OF TESTS

7. The individual tests in this study were designed to match specific tests on dry sands so that any observed differences in response for the two conditions could be attributed to the influence of the water table. The detailed plan of tests is given in table 1. Following precedent, the specimen was serially designated cart 64.

CONDUCT OF TESTS

8. The procedures and test equipment used in this study duplicated as nearly as possible those used in the preceding model study of footings on dry sand with minor modifications to permit testing of saturated sands. The test equipment and procedural details are fully described in Appendix B, reference 2,* and only essential details are presented and significant variations are noted in this report. Basically, the test system consisted of uniform fine sand (SP) specimens prepared in mobile metal carts, a dynamic loading device, and square aluminum footing plates.

9. Before preparing the 90 percent relative density specimen, the cart was lined with a 6-mil-**thick polyethylene sheet to prevent water leakage through the end gate joints, and four hoses for introducing water into the specimen were placed along one side extending from the top to the bottom of the cart. The bottom of the cart was filled 1 ft deep with pea gravel to further facilitate saturation. The system for sealing the cart was less than satisfactory because the polyethylene liner was damaged by placement operations and leaks developed when water was introduced into the specimen. Also, the water hoses hampered placement of the specimen and affected density control.

10. The remaining 2 ft of the cart was filled by sprinkling dry sand with a spreader specially designed for preparing large uniform specimens of sand. By varying the flow rate of sand while maintaining a constant height of fall and spreading rate, relative densities from 70 to 90 percent could be obtained with this device.[3]

11. After the sand was placed in a dry state, water was introduced into the specimen from the bottom and the water table was raised very slowly to drive out air in the voids as the wetted front proceeded upward. The water level was raised to 7.5 in. below the surface and maintained for tests 64-1 and 64-2 on footings buried at this level. Capillary action caused the wetted front to extend above the water table, reaching to the surface in many places, so the zone above the footing was nearly saturated. After conducting these two tests, the water level was raised to the surface and tests 64-3 and 64-4 were conducted on footings on the surface.

12. Loading of the footing plates was produced by a dynamic loader installed since the completion of the foregoing model study. This device is capable of applying load pulses up to 100 kips, although only a loading range of 0.5 to 5 kips was required for this study. Load

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* The appendixes for reference 2 were published as a separate volume in a limited edition. Loan copies are available from Research Center Library, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

** A table of factors for converting British units of measurement to metric units is presented on page vii.

pulses as short as 30 msec with rise times of 3 msec could be programmed with this device, but longer times were used in this study.

13. During the tests, the following parameters were measured and recorded:

a. Displacements were measured with a slide-wire potentiometer attached to three corners of the footing plate and a reference cross arm.

b. Load applied to the footing was measured by a load cell located between the loader and footing.

c. Acceleration of the load column, hence, acceleration of the footing, was measured by an accelerometer located in the load column assembly.

d. Pressure causing the load was monitored by transducers within the loader.

The signal outputs from all of the sensors were suitably conditioned and recorded as functions of time by a light-beam oscillograph operating at 160 ips.

14. An understanding of the effect of saturation on the shear strength as measured with a cone penetrometer was highly desirable but not essential for this study. When the tests were conducted, the mechanized cone penetrometer was not available, but some data were obtained with a hand penetrometer.

PART III: TEST RESULTS AND ANALYSIS

EVALUATION OF TEST DATA

15. Since the purpose of these tests was to examine the validity of empirical relations developed for dry sands when applied to saturated sands, detailed evaluation and analysis were not required. It was only necessary to examine the procedures and results to ascertain that extraneous factors did not influence the response. When it was established that no uncontrolled variables were involved, the difference in response could be directly attributed to the presence or absence of pore water.

Specimen Data

16. Careful control of the placement by sprinkling technique has repeatedly proven to yield uniformly consistent specimens of dry sand. Therefore, for this study, detailed documentation of the specimen properties was not essential. The average dry unit weight of the sand specimen based on total weight before saturation and original cart volume was 101 pcf, which corresponds to a relative density of 84 percent. However, it is known that the original volume of the cart was somewhat larger than the specimen volume after the liner and hose were installed. Thus, the relative density for cart 64, targeted at 90 percent, may have been slightly lower, but was definitely not less than 85 percent. Shear strength-relative density relations for the sand based on cone penetration resistance[2] have shown that the shear strength may decrease by as much as 15 percent when relative density changes from 90 to 85 percent, so the net effect could result in larger displacements. However, no such trend was observed in the test results to be presented. The limited cone penetration resistance data taken with a hand penetrometer were inadequate to make an assessment of the effect of saturation on cone penetration resistance measurement.

Load Test Data

17. The only significant deviation in the conduct of the loading tests was the use of a different loading device. However, for this study the time-history records of load, displacement, and acceleration appeared typical of those recorded during the preceding studies using the other loader, and no serious departures were detected. For the purposes of this study, analysis of the effect of saturation was based on the following parameters:

P_{max} = peak dynamic load determined as peak pressure applied to load column piston times loaded area, F*

R_{max} = maximum footing reaction measured by load cell, F

z_{max} = maximum footing displacement measured by potentiometer, L

These data are presented in table 2. In addition, continuous footing reaction-footing displacement (i.e. R versus z) curves were examined and compared. Minor variations in variables such as preload, load rise time, etc., were shown to have negligible effects, so these variables were excluded from the analysis.

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* Units in this report are given as follows: F = force, L = length, T = time, D = dimensionless.

ANALYSIS OF DATA

18. The test data were compared with data from specific counterpart tests and empirical relations from the model study on dry sand. The effect of saturation was assessed by comparison of peak dynamic load-maximum displacement and reaction-displacement relations. Test data for the counterpart tests are also listed in table 2.

Peak Dynamic Load-Maximum Displacement

19. The nondimensional load-displacement curves fitted to the model study data incorporated a shear strength parameter based on measured cone penetration resistance. Since the quantitative effect of pore water on cone penetration resistance was not established for the sand used, the empirical relations were reverted to dimensional form for direct comparison with dimensional data from this study.

20. In fig. 1, the peak dynamic load-maximum footing displacement data from cart 64 are compared with counterpart test data from carts 41 and 44 of the model study and with prediction curves based on all the model study data. The displacement curves predicted from the model study are in very close agreement with the counterpart tests on dry sand, but the response of footings on saturated sand is grossly overpredicted by these curves. For footings on the surface, predicted displacements are about 3.5 times greater than the actual displacement, while for the buried footings the predictions were larger by a factor of about 2. Based on this alone, a definite trend toward lesser response for equal loading is evident for saturated dense sand.

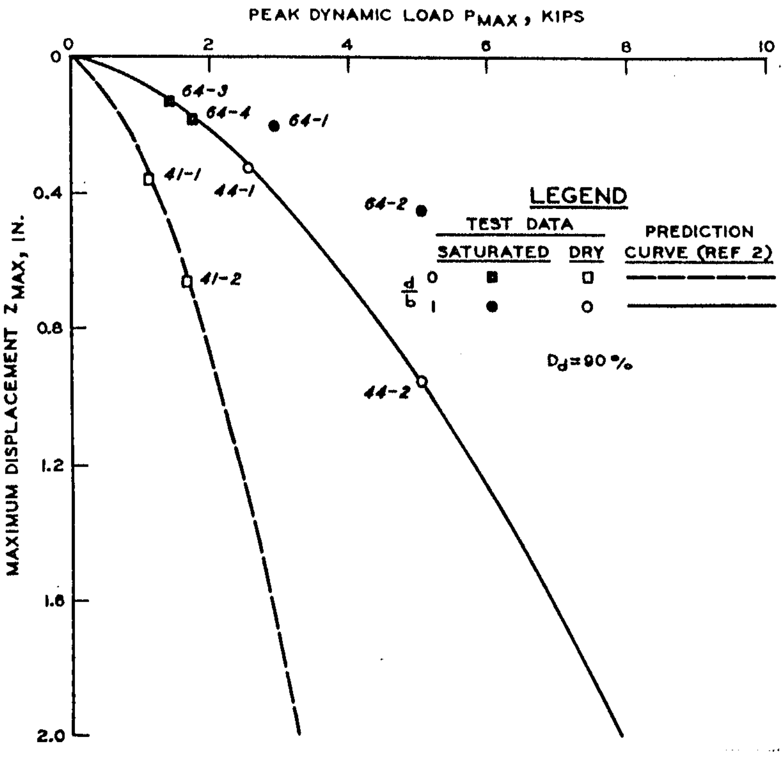

Fig. 1. Load-displacement relations compared with model study data

Reaction-Displacement Curves

21. Continuous reaction-displacement curves for the tests in this study are shown in fig. 2 for buried footings and in fig. 3 for surface footings, along with the curves from counterpart dynamic tests and static tests on dry sand. The curves for saturated sand exhibit a relatively high initial stiffness when compared with the static test curves. After the initial portion of the loading,

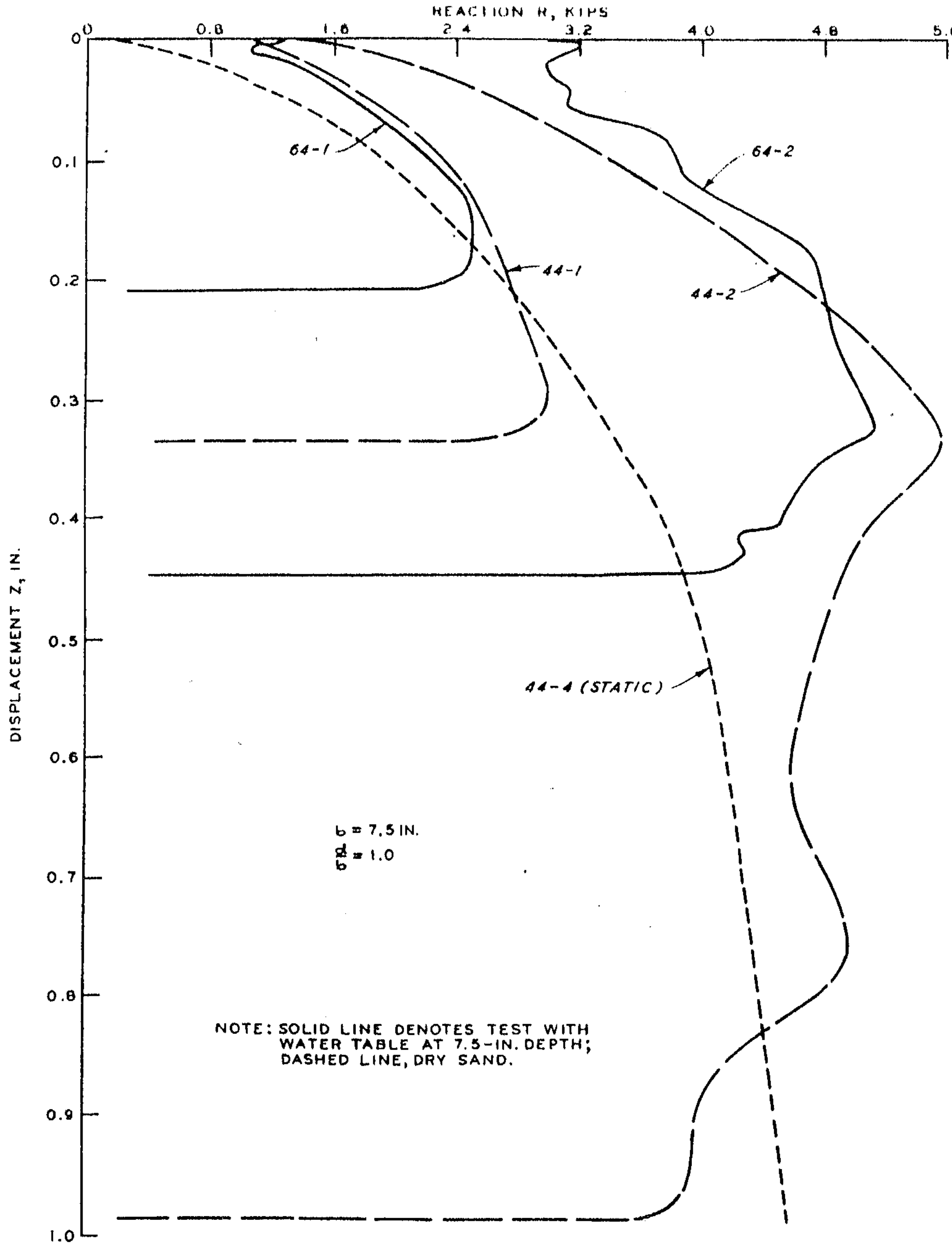

Fig. 2. Reaction-displacement curves for buried footings

the curves tend to move toward the dry sand curves up to peak reaction. Beyond peak reaction, very little additional displacement occurred, accounting for the major difference in displacements for the two cases.

22. Dynamic loading on dry sand was observed to have the effect of significantly increasing the initial stiffness over that for static load and this study shows that further stiffening occurred when pore water was present. Whenever this initial resistance was overcome, the footing began to

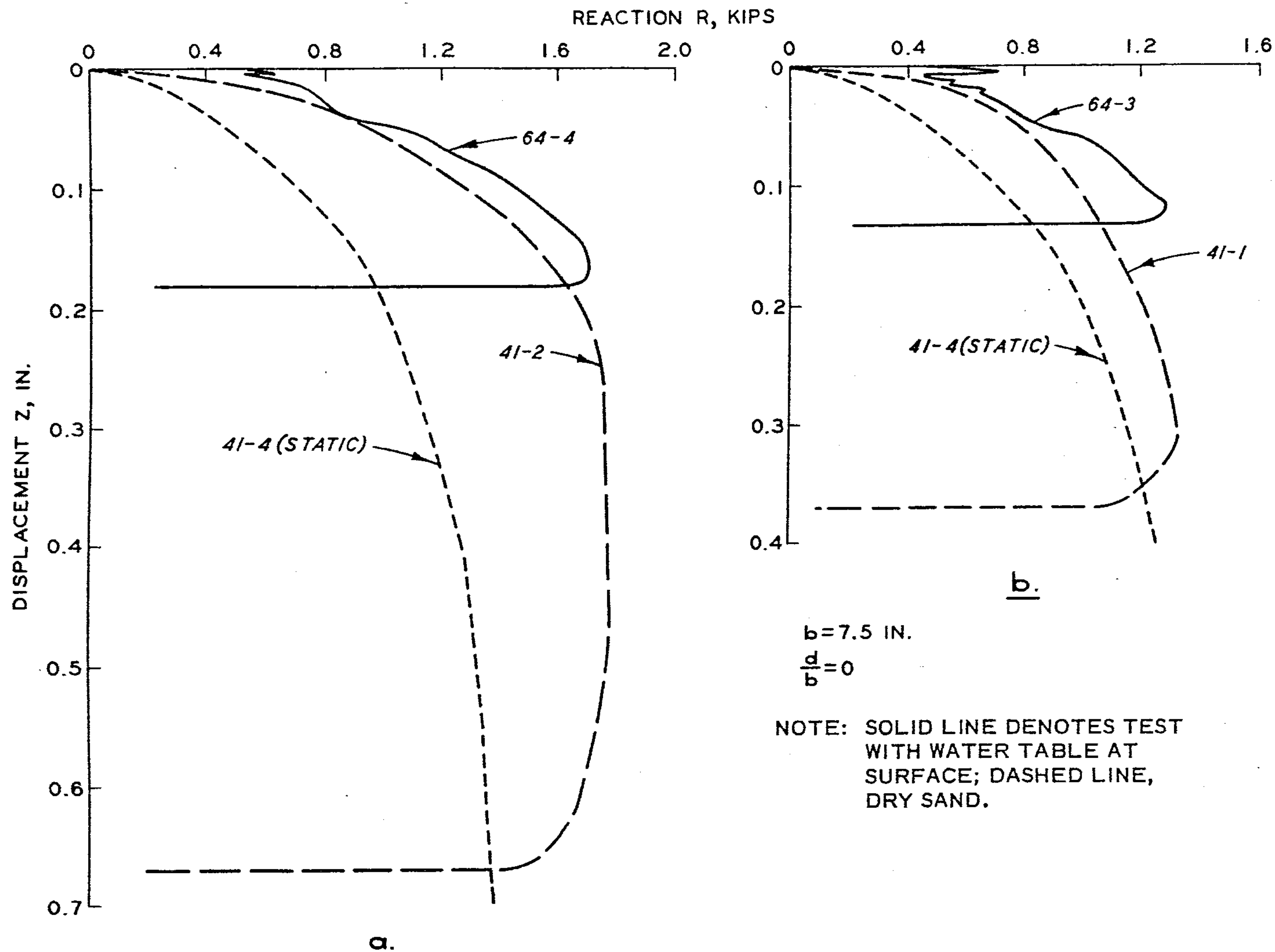

Fig. 3. Reaction-displacement curves for surface footings

move with a slight reduction in reaction,* then reaction increased with displacement up to peak reaction at nearly the same rate for buried footings and at a slightly greater rate for surface footings than for a footing in dry sand. The footing on saturated sand came to rest shortly after reaching peak reaction, whereas in the dry sand test, considerable postpeak reaction displacement occurred. The net effect of the pore water in a 90 percent relative density sand is to increase the stiffness with consequential reduction in final displacement of about 50 percent for buried footings and nearly 70 percent for surface footings.

23. In the model study, the increase in stiffness due to dynamic loading was found to be greatest for surface footings, i.e., when the shear strength of the sand was least. As the shear strength increased with depth of overburden, the dynamic resistance was also greater than the static resistance, but the percentage increase at $d/b = 1$ was much less than at $d/b = 0$. A similar phenomenon is indicated in the results reported herein; the beneficial increases in resistance due to pore water are much greater for the surface footings than for the buried ones.

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* This reduction in reaction is believed to be at least partially a characteristic of the loading machine used. Similar oscillations have been observed with many different types of test specimens under the machine.

PART IV: DISCUSSION OF TEST RESULTS

COMPARISON WITH BEARING CAPACITY THEORY

24. Although bearing capacity theory is of little value for predicting limiting dynamic loads on foundations, it was found that the response of footings on dry sand to dynamic loads could be rationally related to static bearing capacity parameters.[2] Thus, an evaluation of the effect of saturation on bearing capacity should indicate at least qualitatively the effects on load-displacement relations.

25. The bearing capacity equation for cohesionless soils as given by Terzaghi[6] is:

$$q = \gamma d N_q + \frac{1}{2} \gamma b N_\gamma \tag{1}$$

where

q = unit bearing capacity at failure, FT^{-2}

γ = effective unit weight, FL^{-3}

d = depth of burial of footing, L

b = width of footing, L

N_q, N_γ = bearing capacity factors, a function of the angle of friction of the soil, D

This relation is for continuous footings and requires an empirical shape factor to be applicable to square footings, but for demonstration purposes this modification is not necessary. Using equation 1, nondimensional bearing capacity relations in terms of $q/\gamma_d b$ versus ϕ were developed as shown in fig. 4, where γ_d is the dry unit weight and ϕ is the angle of internal friction. Considering the two limiting cases of completely dry and completely saturated, the bearing capacity would change as shown in fig. 4 for various depths of burial and depths of water table. This figure shows the effect of some of the parameters in equation 1 on static bearing capacity. Comparing Case A with Case C when ϕ is 35 deg, the bearing capacity of a footing with the water table at the surface is reduced to 62 percent of the bearing capacity of dry sand due to the buoyancy effect below the water table. A similar reduction occurs for buried footings as shown by comparing Case B and Case D. When the water table is lowered to the level of the footing (Case E) with saturation maintained above the water table, the bearing capacity is about equal to that in Case B. The weight of the water in the overburden increases the effective overburden and compensates for the buoyancy reduction below the footing. If the water is lowered to a greater depth (Case F), the maximum percentage increase in bearing capacity over the dry condition (Case B) is equal to the water content.

26. If the dynamic response is directly related to static bearing capacity, then the displacements for the buried footing should have been about equal for each case, and, for the footings on the surface, much larger displacements would occur when the sand is saturated. Since no such trends were observed, it is reasonable to assume that other factors, such as transient pore pressures and inertial resistance, are more relevant in response of footings on saturated sand at 90 percent relative density.

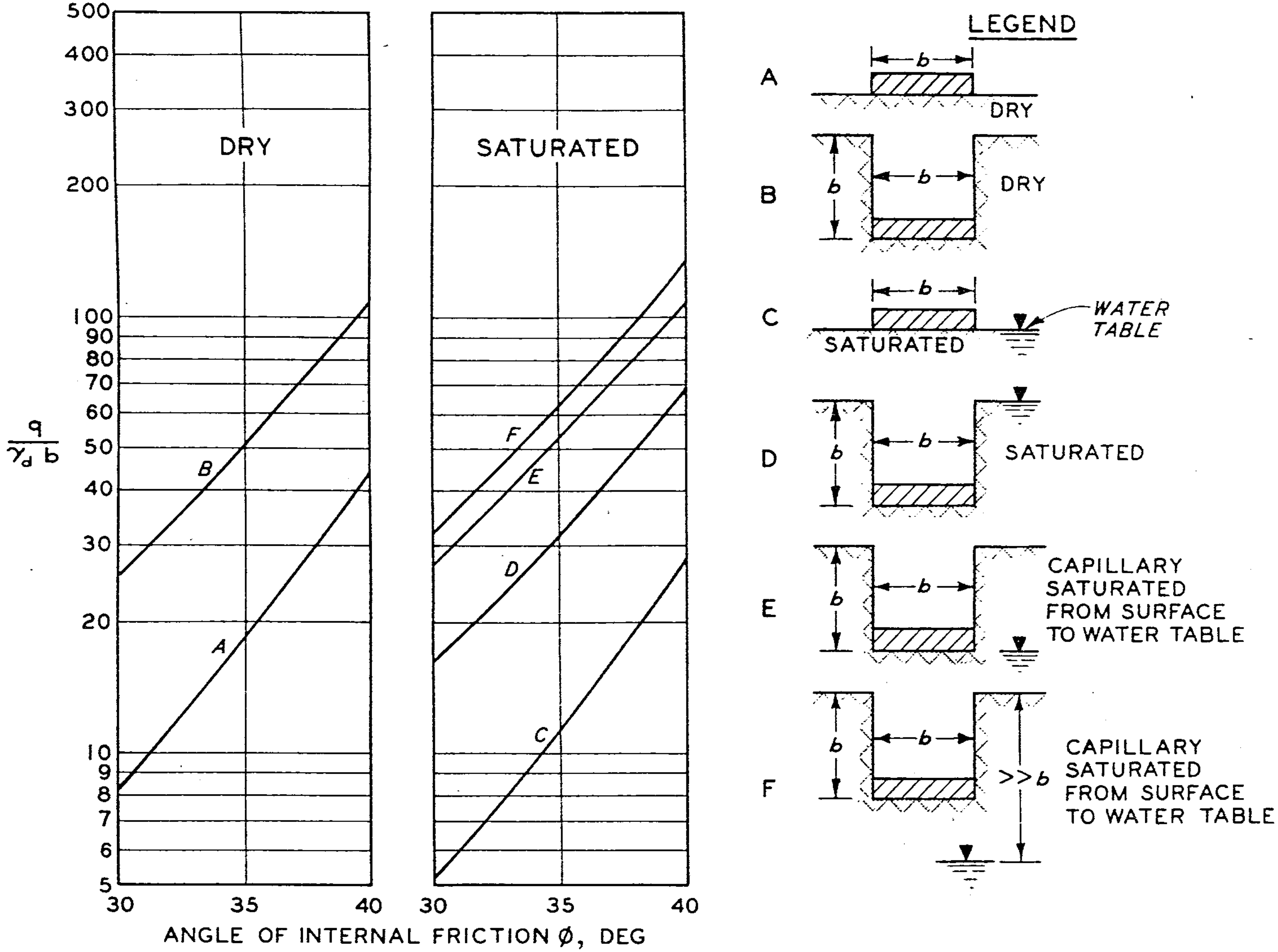

Fig. 4. Effect of groundwater table on bearing capacity

EFFECT OF INERTIAL RESISTANCE

27. At the same void ratio, the following relation holds:

$$\rho_{saturated} = (1+w)\ \rho_{dry} \qquad (2)$$

where

ρ = mass density, FT^2L^{-4}

w = water content, D

For the sand used in this study, the saturated water content was about 23 percent; so under the same loading, the inertial resistance should be about 23 percent greater for the saturated case and should have the effect of reducing displacement.

28. Based on stress-wave propagation, Carroll[7] proposed that the influence of inertia could be neglected if:

$$\frac{ct_o}{b} > 3.5 \qquad (3)$$

where

c = stress-wave velocity in soil, LT^{-1}

t_o = load rise time on footing, T

b = footing width, L

Using the following representative values: c = 500 fps, t_o = 20 msec, and b = 7.5 in. then

$$\frac{ct_o}{b} = 16 \text{ (i.e. } > 3.5)$$

The value of c used is conservatively low, since it was determined for dry sand; the actual velocity in saturated sand is probably 2 to 3 times greater, further reducing the relative influence of inertia. Thus, the influence of inertia would be greatest during the initial period of loading but would have a minor effect on the total response. Therefore, the large difference in maximum displacement response must be attributed to factors which affect the resultant stiffness of the soil mass.

EFFECT OF VOLUME CHANGE

29. Since the mechanisms of footing resistance are primarily related to shear deformations, the effect of volume changes on shear resistance should be examined. Volume change characteristics of granular soils are adequately documented in most elementary soil mechanics textbooks, and the qualitative influence on undrained shear strength is generally understood. At 90 percent relative density, a tendency to dilate upon shearing is expected, and if a constant volume is maintained as in an undrained triaxial test, shear strength is considerably increased over the drained shear strength due to increases in effective stress. At low relative densities, sands contract on shearing and strength reductions occur. The granular arrangement that denotes the transition

between dilation and contraction is designated as the critical void ratio.[8] For a uniform, fine sand similar to the one used in this study, the critical void ratio was found to correspond to relative densities from 25 to 30 percent for initial effective confining stresses up to 0.1 tsf and increased to 50 percent relative density as confining stresses increased to 10 tsf.[9] Further experimental work at MIT indicated that strain rate can influence the volume change behavior such that, under rapid loading, the critical void ratio may occur at relative densities considerably less than 25 percent.[10]

EVALUATION OF DIFFERENCES IN RESPONSE

30. Based on the preceding considerations, the differences in reaction-displacement behavior for saturated and dry sand were evaluated. For this purpose, the reaction-displacement curves in figs. 2 and 3 were examined in three distinct stages.

Initial Stage

31. The initial stage of the curve extends from initial reaction up to about one-half of the peak reaction. During this stage, the footings on saturated sand encountered stronger resistance and very little displacement occurred. This increase in initial resistance is primarily attributed to inertia of the saturated soil, since ct_0/b is somewhat less than 3.5 at this time and deformations necessary to produce negative pore pressures did not develop in this stage.

Intermediate Stage

32. The intermediate stage begins at the point where the inertial resistance was overcome and continues up to peak reaction. During this stage, the relation between reaction and displacement is not significantly different for either the dry or saturated case, so the effects attributable to saturation are assumed to be minimal.

Final Stage

33. In the final stage, covering response after peak reaction, the most significant difference was observed. The footings on dry sand continued to displace after peak reaction, whereas the footings on saturated sand stopped abruptly. This behavior is adequately explained by the development of transient negative pore pressure within the saturated soil brought about by dilation, which in turn produced a momentary increase in effective stress. The effective-stress increase caused a greater stiffness of the mass to prevail, retarding further displacement after peak reaction.

34. The apparent beneficial effect of saturation on response is limited by the capacity of pore water to accept negative pressure. As the water pressure approaches the vapor pressure (approximately one atmosphere reduction), cavitation occurs and no further increase in effective stress can occur. Also, the development of negative pore pressures creates a hydraulic gradient between the zone under the footing and the surrounding soil and the high permeability of sands allows rapid equalization of pressures, so the undrained conditions are valid only momentarily.

EFFECT OF SATURATION AT OTHER RELATIVE DENSITIES

35. The results of this study show conclusively that empirical relations developed for dry

sand conservatively predict the response of footings on saturated sand at 90 percent relative density. However, the degree of conservatism must diminish with decreasing relative density, as this built-in factor of safety is dependent on the dilation capacity of the sand. Eventually, at low relative densities, i.e., those less than critical, the empirical relation should become strongly unconservative as the dilation tendency changes to contraction, which could lead to severe losses of strength.[8]

36. The theoretical considerations and experimental evidence appear to indicate that the empirical relations are conservative for all ranges of relative density that are of interest in practical application to protective construction. A deposit of sand, either natural or artificial, with a relative density of 25 percent would undoubtedly be compacted to a denser state before attempting construction in a protective structures project. The primary concern is with design related to medium and high relative density sand. However, under rapid loading, some deformation patterns may develop in the medium range of relative density that were not present in dense sand. For example, the more compressible mineral skeleton may allow a liquefaction condition to develop immediately under the footing prior to activation of dilation in the exterior region. The development of a similar condition was deemed possible even at 90 percent relative density under rapid loading before this study was conducted, so that testing was approached with caution in the event of excessive settlements. Any concern could be alleviated by an additional study of a similar nature using a lower relative density. Since the data for dry sand have been obtained for 70 percent relative density, tests on saturated sand at this density would be a logical choice. If the empirical relations from dry sand are proven to be conservative at 70 percent relative density, they may be used in complete confidence over the practical range of relative density.

PART V: CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

37. As a result of this study, the following conclusions were drawn:

a. The presence of groundwater in dense sand has the effect of significantly reducing the displacements of foundations under dynamic loading.

b. The empirical relations for predicting the response of footings developed in the model study using dry sand represent a conservative bound for predicting response of footings on dense saturated sand.

c. The reduction of displacement due to saturation of dense sand was primarily due to increases in strength of the soil attributable to the development of transient negative pore pressures; increases in inertial resistance had only minor effects.

RECOMMENDATIONS

38. Based on the findings of this study, the following research efforts are recommended:

a. An additional study quite similar to this study should be conducted using saturated sand at a 70 percent relative density to determine if the empirical relations from dry sand tests are still conservative at medium densities.

b. The effect of saturation on the shear strength measurement with a cone penetrometer should be investigated. This information is needed to aid in the interpretation of field cone penetration data for use in the empirical prediction curves.

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Table 1

Plan of Tests

Test No.	Location sta	Footing Width b, in.	Depth of Burial d, in.	Depth to Water Table in.	Peak Dynamic Load P_{max} kips	Pulse Duration t_o, msec	Dry Unit Weight γ_d, pcf	Relative Density D_n, pct
64-1	9+50	7.5	7.5	7.5	2.60	400	102.2	90
64-2	7+00	7.5	7.5	7.5	5.00	330	102.2	90
64-3	4+50	7.5	0	0	1.10	640	102.2	90
64-4	2+00	7.5	0	0	1.70	570	102.2	90

Table 2

Test Results

Test No.	Depth of Burial Ratio d/b	Peak Dynamic Load P_{max} kips	Max Footing Reaction R_{max} kips	Max Footing Displacement z_{max} in.
		Saturated Sand*		
64-1	1	2.95	2.50	0.209
64-2	1	5.06	5.16	0.446
64-3	0	1.39	1.29	0.131
64-4	0	1.75	1.70	0.182
		Dry sand		
44-1	1	2.56	2.85	0.332
44-2	1	5.06	5.48	0.956
41-1	0	1.14	1.33	0.369
41-2	0	1.67	1.79	0.663

Note: All tests on 7.5-in.-square footings.
* Water table at footing level.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

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EFFECT OF SATURATION ON DYNAMIC RESPONSE OF FOOTINGS IN SAND

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13. ABSTRACT

This investigation was undertaken to determine the effect of saturation of dense sand on the response of square footings to nuclear blast-type loading. Tests were conducted with footings on the surface and at a depth of burial equal to the footing width with a water table coincident with the plane of the footing. The results of these tests were compared with data from similar tests on dry sand from a preceding study. Saturation of dense sand had the effect of reducing maximum displacement. The displacements of surface footings were only about 30 percent of the displacement of footings on dry sand with equivalent soil density and loading condition, and the displacement of shallow buried footings was reduced by 50 percent. Empirical load-displacement curves developed from previous studies on dry sand were shown to be conservative when used to predict the response of footings on saturated dense sand. The primary difference in response occurred after peak reaction. The footings on saturated dense sand came to rest immediately, while footings on dry sand continued to displace for some short distance. This behavior was attributed to the development of transient negative pore pressures resulting from dilation of the sand. A similar laboratory investigation on a medium-density sand is recommended in order to determine whether or not any tendency toward liquefaction may occur at the lower end of the range of densities of interest for protective structure foundations.

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