UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

DETERMINATION AND ANALYSIS OF BEARING CAPACITY OF CALCARENITES OFF THE FLORIDA KEYS

by

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Contents

Illustrations

Table

ABSTRACT

A specially designed instrument was used to determine the *in situ* bearing capacity at 12 sites in the carbonate sand seaward of the Florida Keys. The resulting data set not only represents unique information in such an environment, but also provided an opportunity to determine whether bearing capacity is controlled by any specific property of the calcarenites, or, conversely, whether the bearing-capacity value could be used as an index of a particular substrate characteristic.

The *in situ* measurements were made in several subenvironments in order to bracket the variability of sediment properties throughout the area. Samples were collected at each bearing-capacity test site and were analyzed for selected geological and geotechnical properties, including texture, grain shapes, and biological constituents.

No relationship was found between bearing capacity and any of the analyzed properties of the sediment. Although many salient characteristics of calcarenites exist, at the stress levels used in this study their influence is either masked owing to the complex interaction of properties that leads to a specific bearing-capacity value or, at least in these sediments, is absent.

INTRODUCTION

Studies of the geotechnical properties of marine sediment have become increasingly important as petroleum exploration and production have been extended into offshore areas and as coastal and nearshore areas have been further developed. Calcarenites, as a major type of marine sediment, should thus be included as a target for geotechnical research. Yet, despite the abundance of studies in other disciplines on the properties of carbonate sands (see, for example, Milliman, 1974), which contribute information indirectly for foundation analysis, geotechnology, which should be at the core of any such analysis, has received little emphasis. The geotechnical properties of calcarenites are, therefore, largely unknown. The purpose of our research was to focus on one such property--bearing capacity--and to investigate its relationship to the geological properties of this type of sediment.

Ultimate bearing capacity (q_{ult}) is the maximum load per unit area that a foundation can support without undergoing immediate and rapid settlement. Aside from its obvious role in foundation design, measurement of bearing capacity also has the potential to be used as a geologic research tool, as it reflects a combination of sediment properties.

With consideration for both the geotechnical importance and the geologic potential, two specific objectives were defined for the investigation. First, as *in situ* measurements of bearing capacity have been rare in the marine environment and heretofore have been confined to noncarbonate sediment (e.g., Harrison and Richardson, 1967; Kretschner and Lee, 1970), our foremost goal was to take such measurements successfully and thus provide a data set from a "frontier" environment. The second objective was to determine whether bearing capacity could serve as an index to describe substrates or whether a specific sediment property could be used to characterize bearing capacity.

The carbonate platform seaward of the eastern Florida Keys was selected as the general area of study (fig. 1). It is blanketed by generally sand-sized carbonate rubble and skeletal debris consisting of various types of coral, foraminifers, mollusks, coralline algae, halimeda, and other typical carbonate environment flora and fauna. This calcarenite veneer is locally absent in some areas adjacent to the keys, but typically is more than 2 m thick and reaches a thickness of about 15 m near the outer edge of the platform (Enos and Perkins, 1977). Reefs are also present on the outer edge of the platform and serve as a natural seaward boundary for the study. The inner boundary is the keys themselves, which consist of indurated Pleistocene bedrock. Multer (1977) has summarized much of the research done in the area.

In order to test a spectrum of bottom conditions the works of Ginsberg (1956) and Swinchatt (1965) were used in planning station locations. Their research provided information on changes in constituent percentages and textural variations in the study area. In addition, the presumed variation in wave and current energy applied to the several provinces within the area (e.g., tidal channels, outer reefs) could affect the densities, and hence the bearing capacities, of the calcarenites at the different test sites. Accordingly, the area was divided into five subenvironments: (1) reef flat (RF); (2) reef edge (RE) or outer reefs; (3) intrareef (IR), including zones within patch reefs on reef flat; (4) nearshore (S), the shoal areas near keys; and (5) tidal channels (TC), which incise the keys. Figure 1 shows the test sites.

METHODS

Field

Collecting *in situ* bearing-capacity data was essentially an instrumentation problem. A device was needed that (1) was capable of delivering appropriate and controlled levels of stress to the sediment, (2) was capable of extruding the bearing-plate piston far enough to accommodate large amounts of settlement, (3) could operate underwater, (4) could be easily transported and handled, (5) could be operated by SCUBA divers, and (6) was inexpensive. An instrument was designed and fabricated to meet these criteria (fig. 2). Briefly, a bearing plate is attached to a piston that is powered by a diver's compressed air tank. A valve controls the load that is transmitted to the piston, and the exact force is recorded on the gauge. Extension (settlement) for each load increment is read off calipers that are fastened to the piston and frame. Lead weights were added to the tripod feet in order to supply an adequate reaction force. A bubble level on top of the instrument assured a proper orientation on the sea floor.

The device was lowered from a boom on the support ship and was guided to the bottom by two SCUBA divers. A bearing plate was then selected, on the basis of apparent bottom firmness, and attached to the piston rod. The device was leveled, the lead weights were added, and the tether was released. Stress was then applied to the underlying sediment in increments of approximately 15 kPa. A 1- or 2-minute waiting period allowed for essentially full settlement under the existing stress before the stress level was increased. The test was terminated after the ultimate bearing had apparently been exceeded or, in several tests, when the reaction force (i.e., the total weight of the instrument and the lead on the tripod feet) was exceeded and the instrument was raised off the bottom. This "lift-off" problem was most common where bedrock underlying a very thin sediment cover inadvertently became the test material rather than the sediment.

Laboratory

The texture, biological constituents, and grain shapes were determined for the samples collected at each test site. A rapid sediment analyzer was used to analyze texture. The percentage of sediment that was not sand sized was separated by wet-sieving and screening. The fines and gravel generally constituted less than 10% of the samples by weight. The method of moments was used to calculate the various textural parameters from the weight-percent data.

The biological constituents were identified under a binocular microscope. The samples were split, and only the fraction greater than 0.5 mm was used in the determinations. Three hundred grains were counted. Shape analysis of the grains was done without size bias using a modified Zingg classification system; 300 grains were counted in this procedure as well.

RESULTS AND DISCUSSION

The bearing-capacity test results are shown in figure 3. The variety of shapes of the stress vs. settlement plots reflects differences in bottom firmness, sand bulk density, angle of internal friction, and sizes of the bearing plates used for the tests. In the preponderance of plots, however, the slopes are fairly gentle until shear failure. These plots indicate that in much of the area, the sand is dense or firm. In some tests--for example, that at site RF8 (fig. 3b)--no actual failure point could be defined, and the ultimate bearing capacity had to be taken as the stress level corresponding to the steepest part of the plot. This was the only apparent case of local or perhaps punching failure observed, however, and, in general, identifying the point on the "curve" that corresponded to q_{ult} was straightforward.

The q_{ult} values taken from these plots are governed by a combination of sediment properties. The hierarchical relationship is that bearing capacity in this type of sediment is largely a function of bulk density and shear strength--as represented by the angle of internal friction. These factors, in turn, are influenced by various textural characteristics: grain shape and roundness, composition, and properties associated with the overall depositional history, such as degree of compaction and cementation. Perhaps an individual property is dominant in controlling bearing capacity in the carbonate environment, or, alternatively, perhaps bearing capacity values may be used as indices of certain sediment properties. These possibilities were examined by analyzing the data as summarized in table 1. At the bottom of each column is the correlation coefficient (r) of that particular variable vs. the normalized bearing-capacity values. Normalization was necessary because different-sized bearing plates were used in the tests and influenced the measured bearing capacities. Thus, for a valid comparison, the values were adjusted to an arbitrarily selected 0.05-m-radius standard.

The correlations between bearing capacity and the other variables are weak to nonexistent. This suggests that the interaction among the sediment properties that leads to a specific bearing capacity is essentially masked, at least at the stress levels used in this study, and that the relationships that do exist can be revealed only under controlled conditions.

However, an apparent relationship exists among the bearing-capacity values and the subenvironments. Specifically, the values shown in table 1 suggest a rather simple relationship of bearing capacity being greatest in highest energy environments; that is, the shallow or shoal areas (S) tend to have the highest values, followed by (in general) the reef-flat areas. The lowest values are associated with the reef edge (RE) and the apparently quiescent tidal channel (TC). We believe, however, that to conclude that the relationship is real is premature. First, no current or wave data were collected in the field, and, thus, quantitative statements cannot be made. Second, observations in the field clearly indicated a high local variability of the sediment. Underscoring this variability is the value that was determined on sand within the tidal channel which is adjacent to the hard, indurated carbonate bedrock of the channel walls. We conclude, therefore, that the apparent relationship of subenvironment to bearing capacity is fortuitous.

CONCLUSION

Given the constraints of this study, the ultimate bearing capacities estimated from in situ measurements off the Florida Keys show no apparent relationship to texture, shape, or composition of the sediments. Thus, no one property can be used to characterize bearing capacity; conversely, a bearing-capacity value cannot be used as an index of a particular sediment property.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1. Bearing-capacity test sites. Prefixes refer to sub-environments: RF is reef flat, RE is reef edge (outer reefs), IR is intrareef (includes zones within patch reefs), S is nearshore (shoal areas), and TC is tidal channels.

Figure 2. Bearing-capacity test instrument.

Figure 3. Stress vs. settlement plots of bearing-capacity tests. Dashed line that intercepts stress axis indicates the value of general bearing capacity (q_{ult}). r refers to the radius of the bearing plate used in the test.

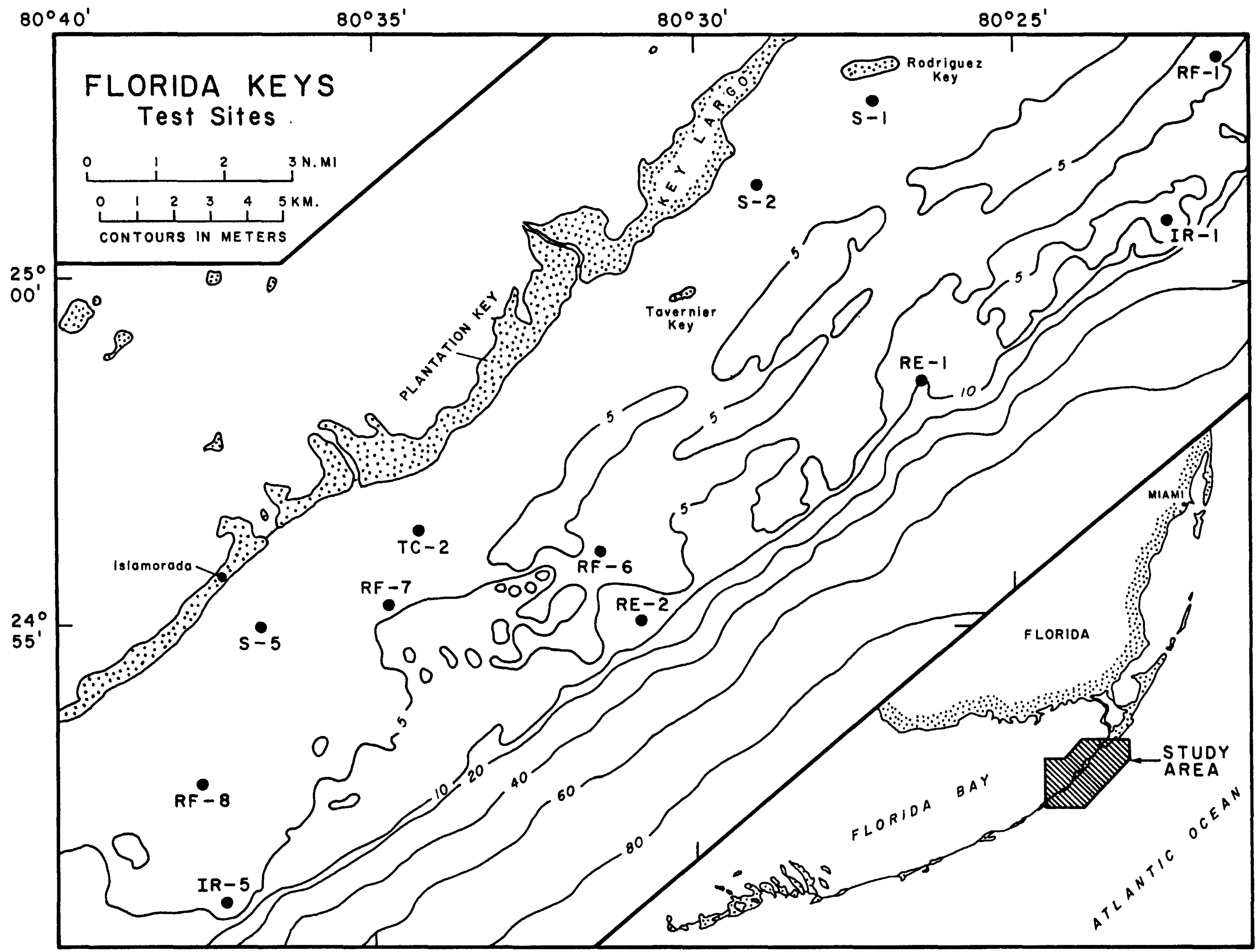
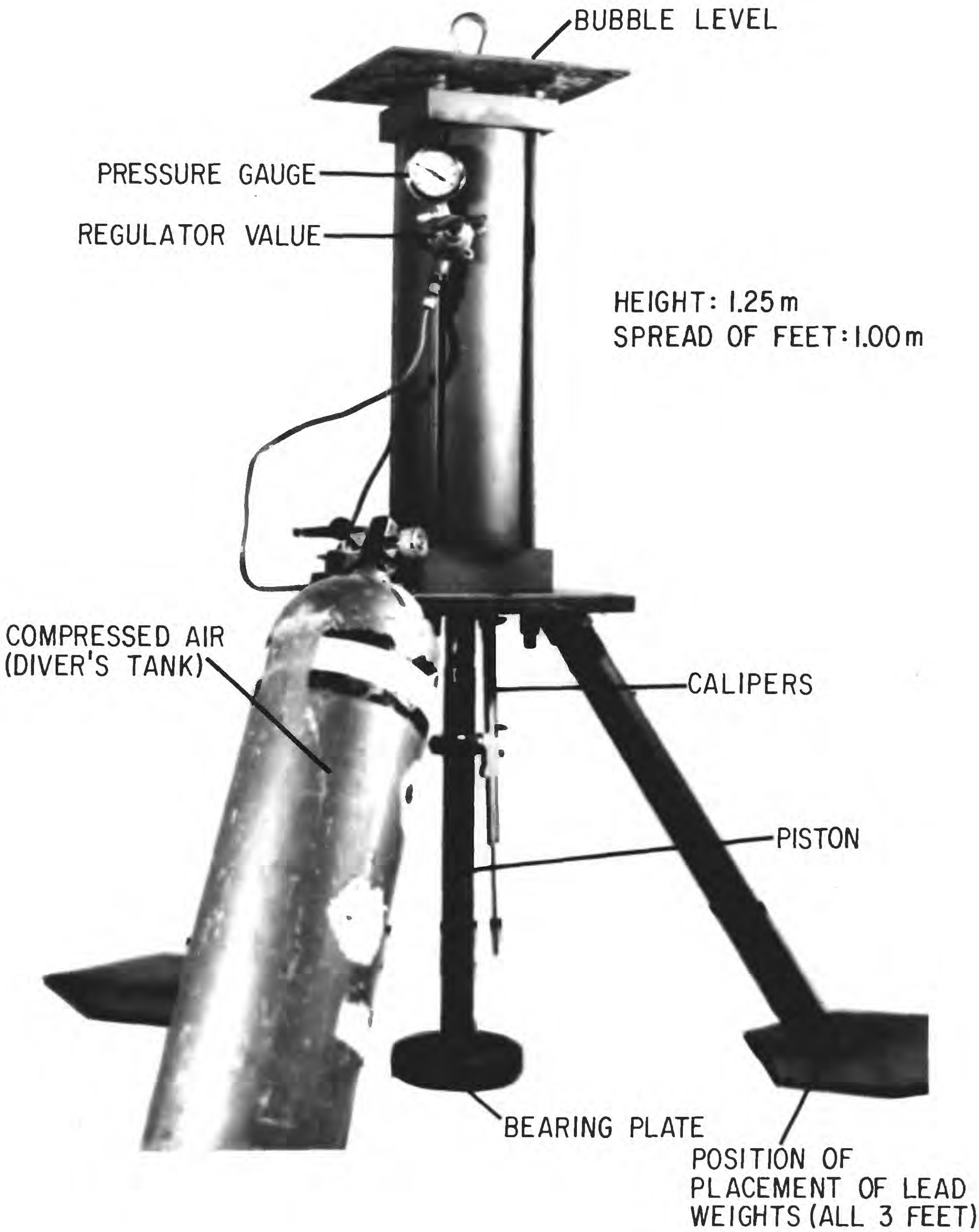
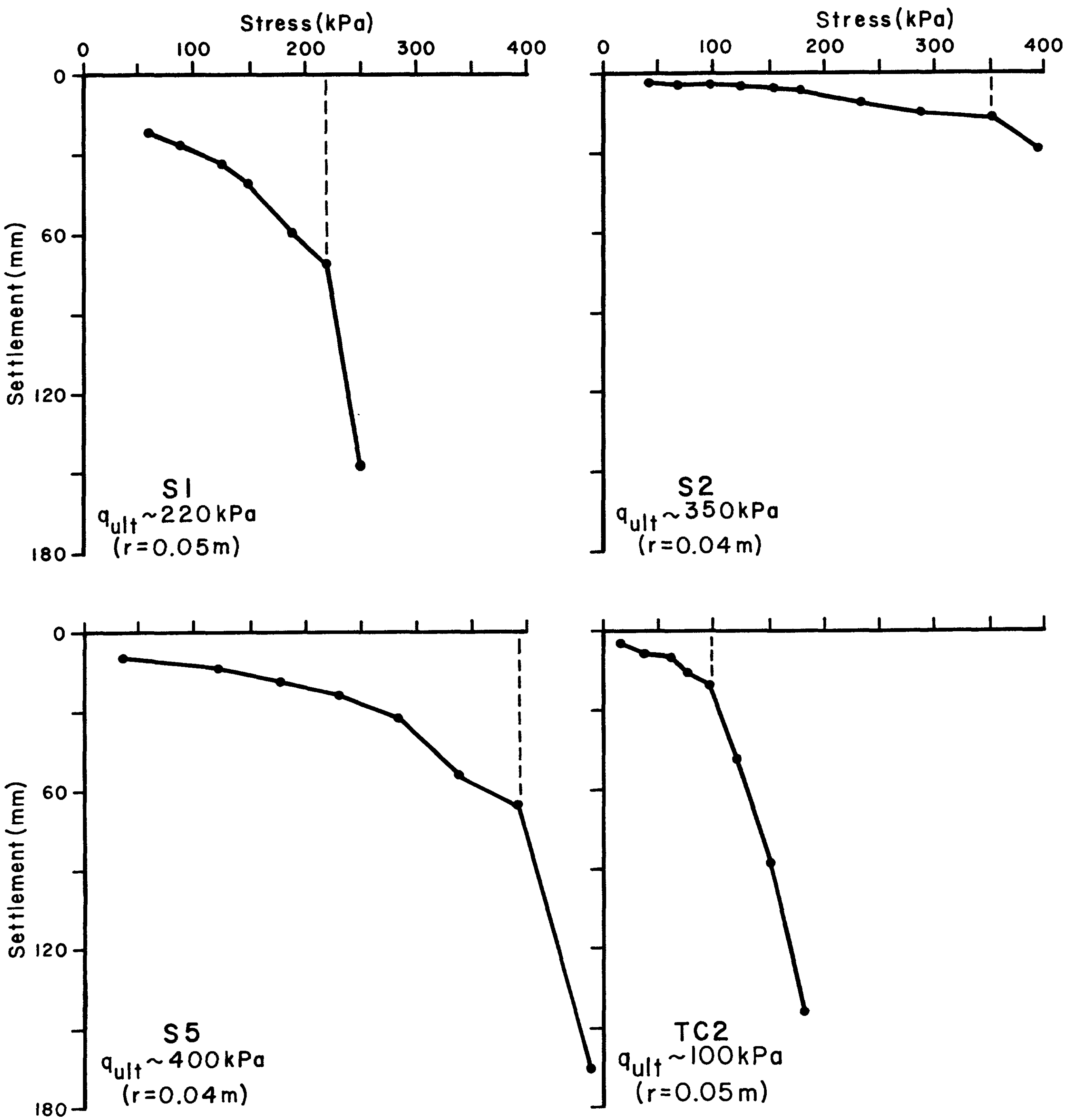

80°40'
80°35'
80°30'
80°25'
25° 00'
24° 55'
FLORIDA KEYS
Test Sites
0 1 2 3 N.MI
0 1 2 3 4 5 KM.
CONTOURS IN METERS
KEY LARGO
PLANTATION KEY
Islamorada
Rodriguez Key
Tavernier Key
RF-1
S-1
S-2
IR-1
RE-1
TC-2
RF-6
RF-7
RE-2
S-5
RF-8
IR-5
5
10
20
40
60
80
MIAMI
FLORIDA
FLORIDA BAY
ATLANTIC OCEAN
STUDY AREA

Figure 1

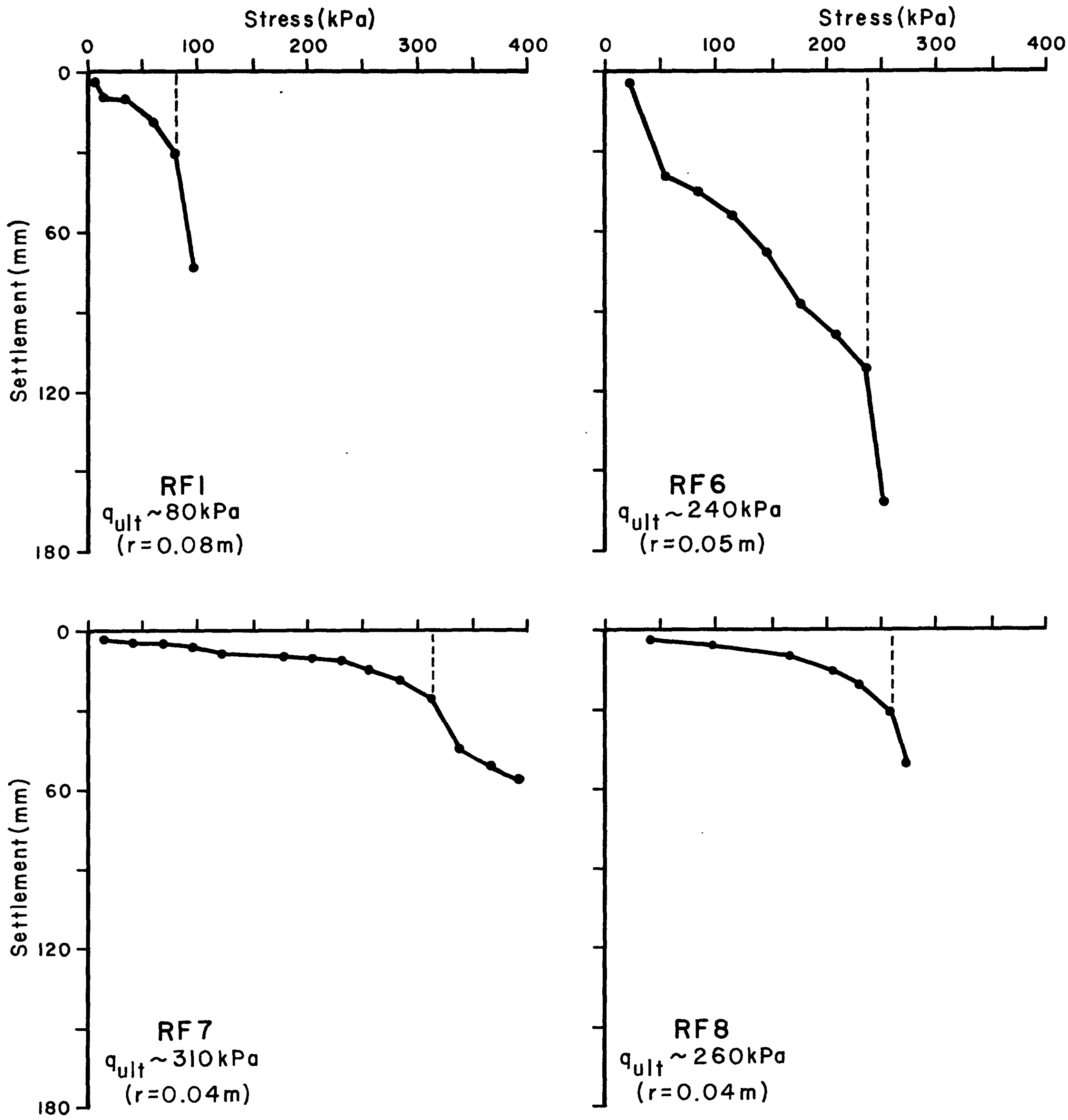
Figure 2


BUBBLE LEVEL
PRESSURE GAUGE
REGULATOR VALUE
HEIGHT: 1.25 m
SPREAD OF FEET: 1.00 m
COMPRESSED AIR
(DIVER'S TANK)
CALIPERS
PISTON
BEARING PLATE
POSITION OF
PLACEMENT OF LEAD
WEIGHTS (ALL 3 FEET)



Stress (kPa)
0
100
200
300
400
0
60
120
180
Settlement (mm)
S1
q_{ult} ~ 220 kPa
(r = 0.05 m)
Stress (kPa)
0
100
200
300
400
S2
q_{ult} ~ 350 kPa
(r = 0.04 m)
0
60
120
180
Settlement (mm)
S5
q_{ult} ~ 400 kPa
(r = 0.04 m)
TC2
q_{ult} ~ 100 kPa
(r = 0.05 m)

Figure 3b



Stress (kPa)
0
100
200
300
400
Settlement (mm)
0
60
120
180
RF1
q_{ult} ~ 80 kPa
(r=0.08m)
RF6
q_{ult} ~ 240 kPa
(r=0.05m)
RF7
q_{ult} ~ 310 kPa
(r=0.04m)
RF8
q_{ult} ~ 260 kPa
(r=0.04m)

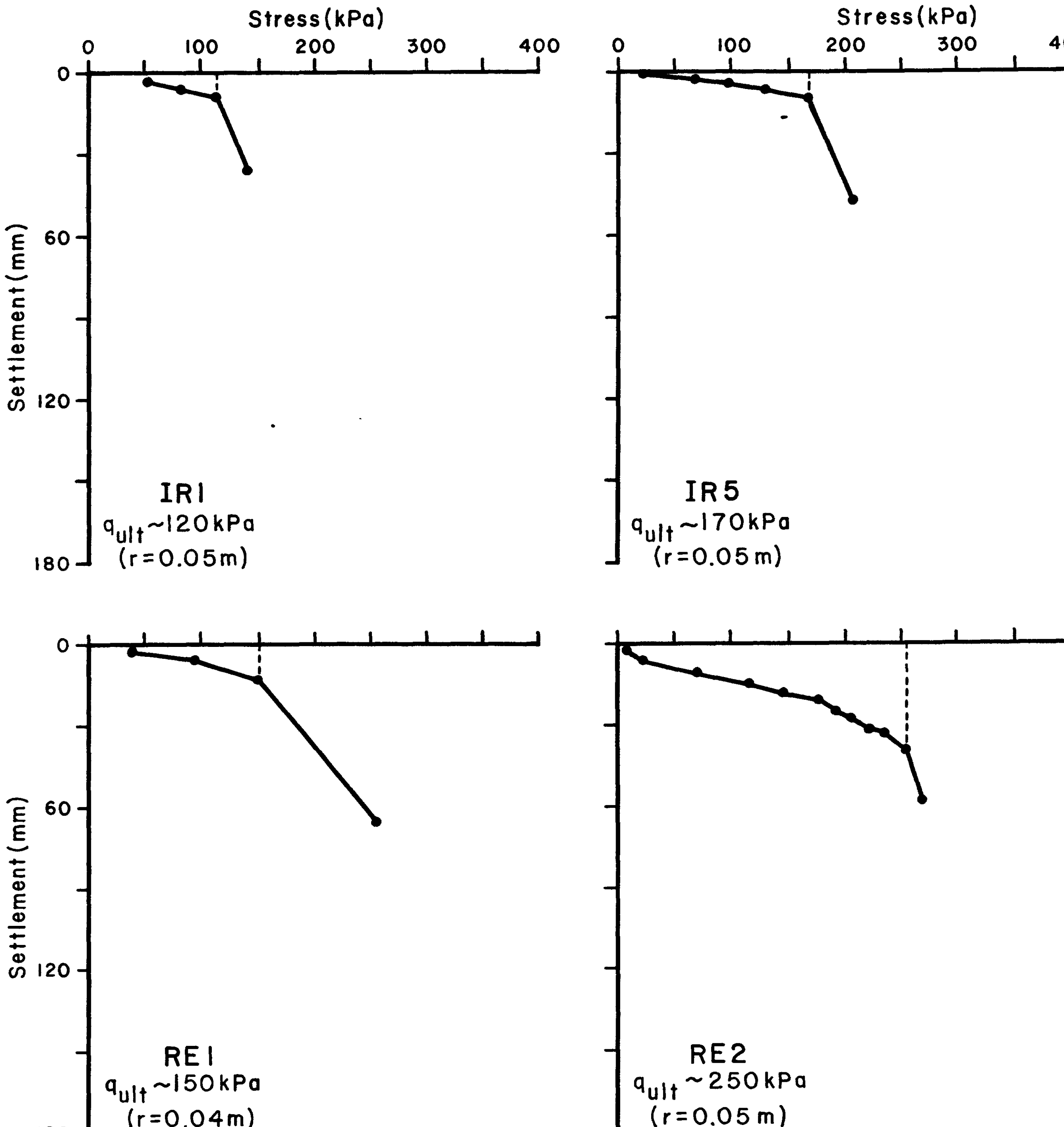

Stress(kPa)
0
100
200
300
400
Settlement (mm)
0
60
120
180
IR1
q_{ult} ~120 kPa
(r=0.05m)
IR5
q_{ult} ~170 kPa
(r=0.05 m)
RE1
q_{ult} ~150 kPa
(r=0.04m)
RE2
q_{ult} ~250 kPa
(r=0.05 m)

Table 1. Data summary and correlation coefficients, r, of variables vs. normalized bearing-capacity values.

SITE	BEARING-PLATE RADIUS (m)	BEARING CAPACITY (kPa)	NORMALIZED BEARING CAPACITY (Std. radius=.05m)	TEXTURAL PARAMETERS* $\bar{X}$ (ϕ)	S (ϕ)	SK (ϕ)	Sand:Mud	MAJOR GRAIN SHAPES % Roller	% Blade	% Sphere	% Tetrahedron	MAJOR CONSTITUENTS %Mollusc	% Halimeda
S-1	0.05	220	220	3.43	2.19	0.40	2	2.45	41.46	11.27	52.45	23	74
S-2	0.04	350	440	2.83	1.41	0.40	7	2.10	38.49	9.60	51.09	52	41
S-5	0.04	400	500	3.31	1.30	1.02	6	3.00	34.10	5.48	54.87	33	62
TC-2	0.05	100	100	2.34	0.63	1.70	109	1.16	43.20	9.30	43.85	47	45
RF-1	0.08	80	50	2.25	0.92	2.06	49	6.87	36.25	15.00	39.37	27	57
RF-6	0.05	240	240	1.70	0.82	0.70	134	31.89	17.92	16.12	32.97	59	15
RF-7	0.04	310	390	2.22	1.17	1.08	14	7.20	50.00	11.00	31.20	68	26
RF-8	0.04	260	320	2.86	1.31	1.11	9	6.57	41.44	9.86	39.47	60	24
IR-1	0.05	120	120	0.62	1.16	1.57	84	2.60	33.30	3.64	59.37	19	57
IR-5	0.05	170	170	1.71	0.83	3.15	81	2.60	41.93	11.82	40.86	24	70
RE-1	0.04	150	190	0.66	1.18	2.21	51	9.0	41.46	11.27	46.52	54	39
RE-2	0.05	250	250	0.72	1.38	1.93	41	8.9	44.58	5.00	38.20	13	80
				r=0.47	r=0.36	r=-0.56	r=-0.62	r=-0.03	r=0.00	r=-0.25	r=0.06	r=0.38	r=-0.21

*$\bar{X}$, mean grain size; S, standard deviation; SK, skewness; Sand:Mud, ratio of % sand to % silt and clay.