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Geotechnical and Geochemical Characteristics of Obhor Sub-Soil

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ABSTRACT. The geotechnical and geochemical characteristics of the sub-soil over an area of about 90 km^2 in and around Obhor are described. Five soil units and three rock units with differing characteristics have been identified in the area within a maximum depth of 15 m. These units are (1) the soft grey clay, (2) the stiff brown clay, (3) the very loose silty sand, (4) the very loose carbonate silty sand, (5) the medium carbonate gravelly sand, (6) the weak coralline limestone, (7) the Tertiary to Quaternary basalt and (8) the Tertiary sandstone and claystone. Based on the location of these units, the area has been divided into seven zones, three of which show the characteristics of coastal sabkha. Chemical composition suggests the units 1, 4 and 5 to be derived from coralline limestone whereas the units 2 and 3 to be of continental origin. Protective measures are found to be necessary for concrete and steel due to aggressive ground condition.

Introduction

Obhor is a township on the Red Sea coast of Saudi Arabia, about 30 km north of the port city of Jeddah with the King Abdulaziz International Airport between them (Fig. 1). The presence of a creek (Sharm Obhor) and its proximity to Jeddah is causing a great interest in rapid development of Obhor and its surrounding area into a residence-recreational zone with the construction of roads, villas, hotels ... etc. The ground surface in this area is partly underlain by coralline limestone and partly by a variety of soils, some of which form salt-encrusted surfaces generally known as sabkhas. Growing demand for land is going to utilize not only the areas with limestone which are considered to pose little or no geotechnical problem for ordinary structures but also those with soils, whose properties have little been studied so far. Geological reports such as those by Skipwith (1973) and Morris (1975) generally describe the surficial materials in the coastal plain (of which Obhor area is a part) as corals, sand, silt and clay and mentions casually about the presence of sabkhas along this coast without indicating their location or extent or geotechnical properties. Oweis and Bowman (1981) showed some borings from Jeddah (location not mentioned) which involved loose or soft soil (presumably from sabkha areas) and Sabtan and Shehata (1982) showed presence of sabkha at a location about 50 km south of Jeddah and two other locations near Rabigh and Yanbu (far north of Obhor). Thus, there is no published data on the nature and geotechnical or geochemical characteristics of the sub-soils in Obhor area which could help in understanding their formations

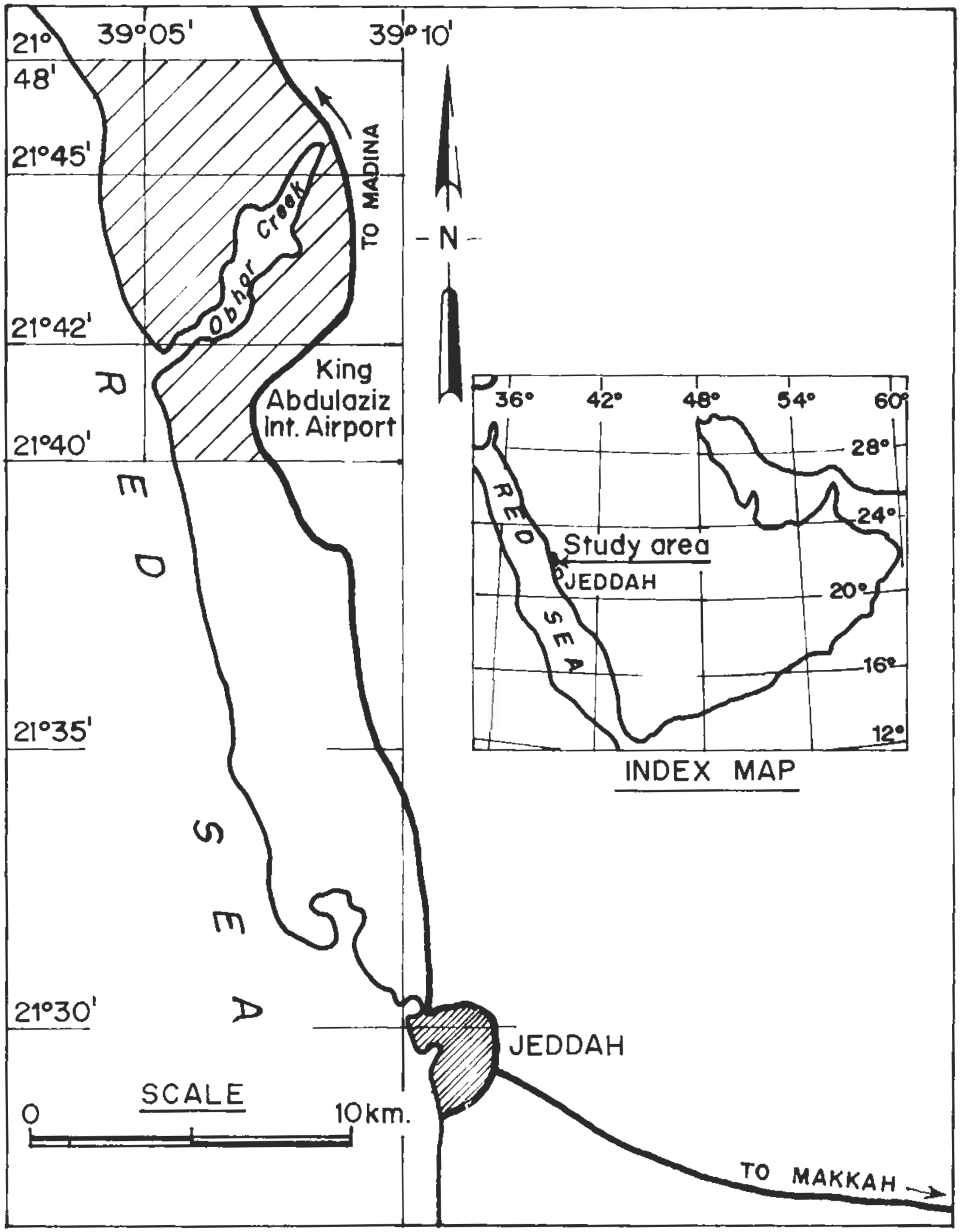

FIG. 1. Location of the study area.

or be used as a basis for geotechnical design and construction. Al-Hafith (1983) and Al-Safadi (1983) carried out small scale preliminary studies in this area and these were followed by a more detailed and large scale investigation undertaken by the authors.

The aim of the present paper is to provide a general view of the ground condition in and around Obhor along with important geotechnical properties and chemical composition of the soil and rock units identified by the authors' investigations.

Physiography and Geology

The studied area is located in the western and lower part of the Red Sea coastal plain of Saudi Arabia, known as Tihama. To the east of the studied area, lies the upper section of Tihama, which is a pediment cut on Tertiary and Precambrian rocks. Obhor creek divides the studied area into a northern and a southern part. This creek is a channel eroded in the coral reef and is believed by Skipwith (1973) to be a drowned estuary which must have been formed when there was greater rainfall and a lower sea-level than those of the present.

On the southern Obhor, the lower Tihama consists of a level or gently slopping flat surface of coralline limestone sometimes covered by a thin layer of coralline and shelly silty sand. In north Obhor, a coastal strip of raised reefal limestone about 0.5 km wide lies between the coast and relatively lower inland areas covered with soil. The soil area at the north-eastern part is the lowest in elevation. This area along with a slightly higher strip on its west has a salt encrusted surface and, together, they constitute a coastal sabkha, as defined by Kinsman (1969).

Basaltic lava flows ranging in age from Eocene to the present occur in abundance and cover sedimentary sequence to the east of the area. One flow extended unto the coastal plain, where it now caps a ridge of Tertiary sediments within the north-eastern part of the studied area. Skipwith (1973) believes this flow to be late Tertiary to early Quaternary in age. The above noted Tertiary sediments are the oldest ones exposed within the studied area. Behairy (1983) identified 3 major transgression of this coast between mid-Pleistocene and early Holocene on the basis of ages of limestone terraces between Jeddah and Yanbu and suggested a fourth transgression probably in mid-Holocene related to the formation of the coastal sabkhas. This needs further investigation.

The presence of the sabkha area inland of the raised coastal reefs in Obhor and the present-day existence of Al-Qasr Lagoon and Sulaimania Lagoon north of Obhor suggests that these sabkhas developed through filling of lagoons inland of the reefs followed by sea regression and evaporation under hot and arid climate. The present investigation sheds further light on this aspect.

Technique of Field Investigation

The technique of investigation for the sub-soil of Obhor had to be decided judiciously keeping in mind the possible variety of the deposits. Reconnaissance visits indicated that although most of the area was passable by a land-rover during the periods free of rain, it was unsafe to take a drilling rig into the sabkha areas except along some roads already made within the area. Hence, it was considered appropriate to conduct the investigation in three stages.

The first staged consisted of probing by a dynamic light cone penetrometer known as Makintosh (Chan and Chin 1972) at a large number of stations selected approximately on a grid pattern with a spacing between stations of about 0.5 km. The maximum depth penetrated by Makintosh was 3.3 m except at two stations near the landward end of the creek where it was possible to reach depths of 9.0 m and 13.8 m. This stage enabled the identification of areas with weak sub-soil and the thicknesses of these weak layers at different locations. This stage was followed by drilling in the soil areas by using a post-hole auger or a light portable power auger and sampling with shelby tubes 76 mm O.D. or piston sampler 57 mm O.D. and vane shear tests at stations showing cohesive soil. This stage indicated the presence of very stiff clayey layers or dense sandy layers or limestone at depth (mostly at 2-3 m) which could not be penetrated with the light equipment that were used up to that stage. A final stage consisted of performance of static cone penetration tests (CPT) at 5 stations using a 20-ton capacity Dutch Cone and drilling at 4 stations with a drilling rig. This stage included performance of standard penetration test (SPT) and collection of samples from SPT as well as by shelby tubes from soil layers and by a double tube core barrel from limestone layers. The maximum depth reached by Dutch cone was 10 m while drilling was made to a maximum depth of 15 m.

In some areas, where drilling was not undertaken, the sub-soil stratification was observed in excavations made for construction or for quarrying. The details of all the investigations are reported by Ali (1985).

Soil and Rock Units

From the present investigation, 5 soil units and 3 rock units have been identified within a maximum depth of 15 m. These are as follows:

1) grey to light-brown soft to medium sensitive sandy silty clay with gypsum crystals and shells (CL to CH),
2) stiff to very stiff brown sandy silty clay (CH),
3) grey very loose to loose silty sand to sandy silt (SM to ML),
4) light brown to grey very loose carbonate silty sand (SM),
5) grey medium carbonate gravelly sand (SP),
6) yellowish to creamy white coarse grained shelly coralline limestone, weak to moderately weak,
7) tertiary to quaternary basalt, and
8) tertiary sediments consisting of sandstone, siltstone or claystone.

The units 1-5 are soils and they have been classified as per unified soil classification system of ASTM (1975). The consistency of the clayey units were based on undrained shear strength either obtained from field vane shear tests or estimated from the N-values of the SPT (in case of very stiff to hard layers), while the relative density of the sandy units were determined either from the N-values as per correlation of Terzaghi and Peck (1967) or from equivalent M-values from Makintosh probing.

In the discussion that follows, the units 1, 2 and 6 will be referred to as "soft clay" and "stiff clay" and "limestone", respectively, for brevity.

Soil Profile

Based on the presence of the different soil and rock units at the surface, the whole area was divided into seven zones, marked I to VII as shown in Fig. 2. Using the method of Zaruba and Mencl (1976), the areas with top layer thickness greater than 1.2 m have been indicated either by closer hatching (in zone I) or by closer dotting (in zones II and VII) compared to that in the areas with thickness 1.2 m or less. Typical soil profiles for zones I, II and III are shown in Figs. 3, 4 and 5, while Table 1 summarises some particulars of the different zones.

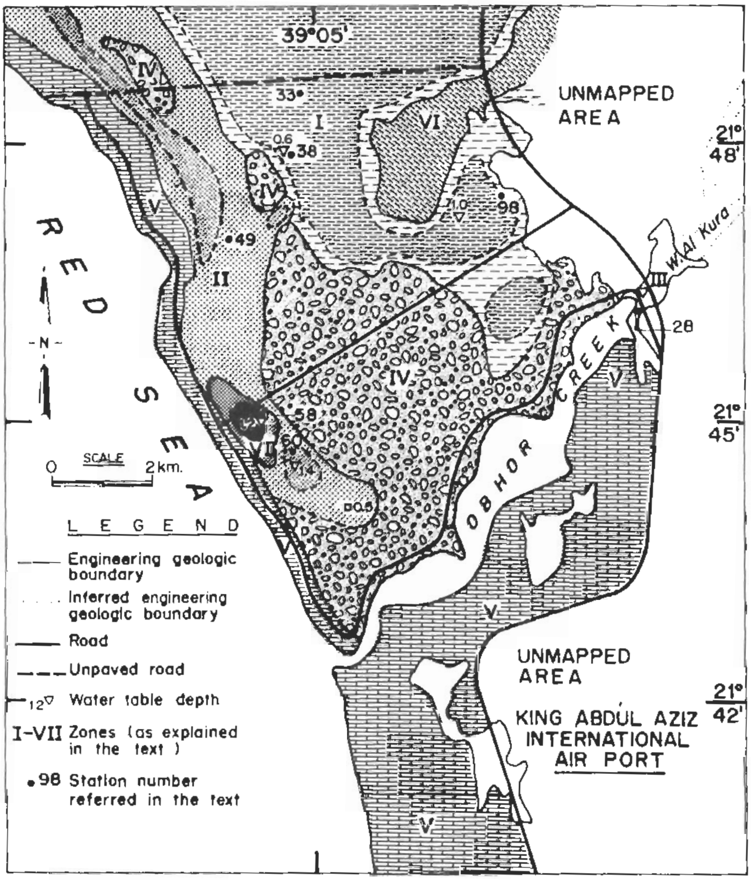

FIG. 2. Location of different zones.

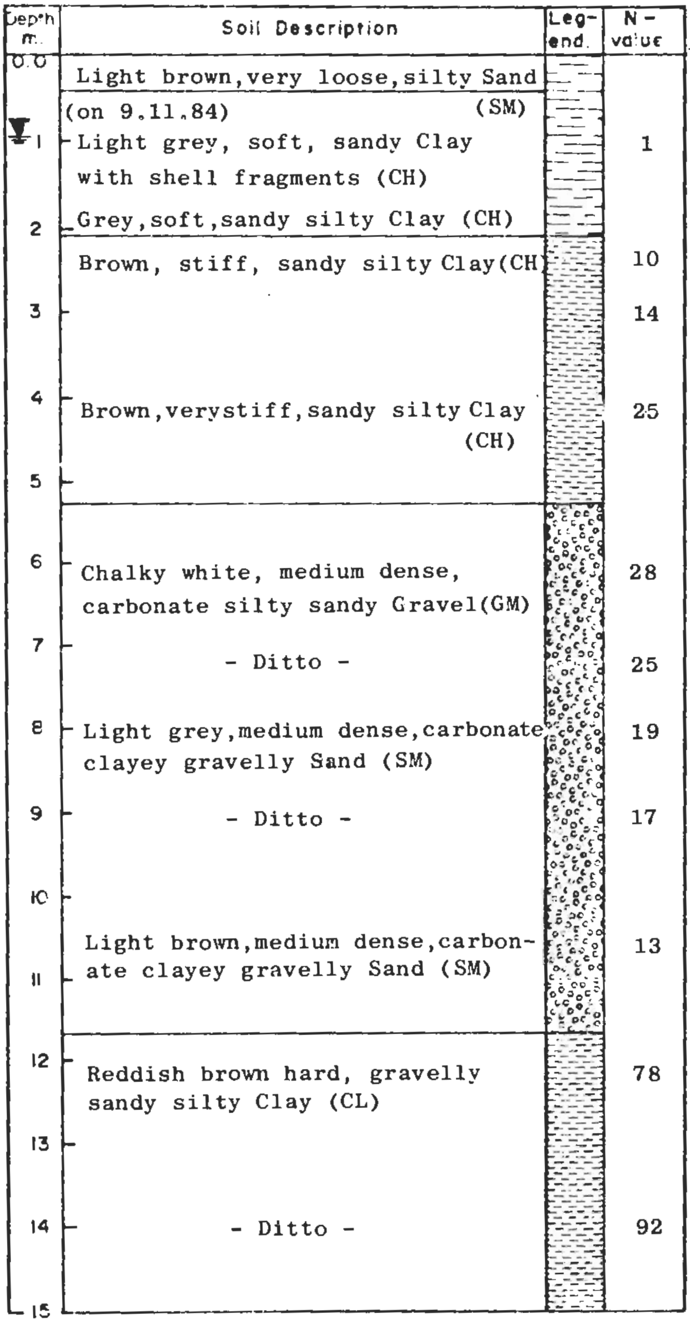

FIG. 3. Typical soil profile in Zone I (Station 38).

Depth m.	Material Description	Legend	N-value
0	Brown cemented sandy crust (SM)		
1	Chalky white, very loose, carbonate silty Sand with shell fragments (SM) (on 10.11.84)		3
2	Light grey, loose, carbonate gravelly silty Sand (SM)		8
3	Bluish grey, medium dense, carbon-ate silty gravelly Sand (SM)		22
4	Light grey, medium dense, carbon-ate silty gravelly Sand (SM)		23
5	- Ditto, but dense		31
6	Dark grey, very dense, carbonate silty sandy Gravel (GM)		80
7–9	Yellowish to creamy white, coarse grained shelly Coralline Limestone, moderately weak.		
	End of Boring		

FIG. 4. Typical soil profile in Zone II (Station 60).

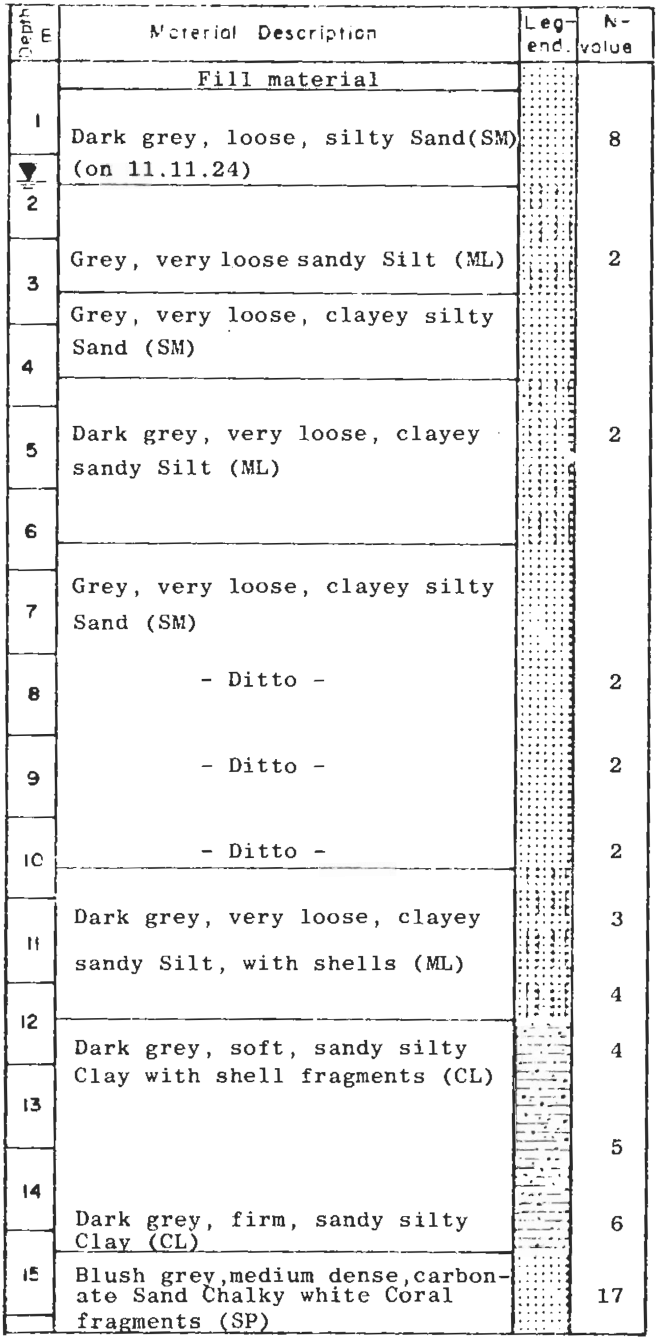

FIG. 5. Typical soil profile in Zone III (Station 28).

TABLE 1. Summary of particulars of different zones.

Zone		Succession of units starting from top	Area (km^2)	Depth to water level (m)
No.	Location			
I	North-east	1, 2, 5(or 8)	20	0.6-1.2
II	North-west	4, 5, 6	10	1.2
III	East	3, 1, 5	1	1.4
IV	North bank of creek	5, 6(?)	22	1.5-2.5
V	West margin of north Obhor and all of south Obhor	6	28	3.0
VI	North-east	7, 8	3	>3.0
VII	North-west	1, 5	1	1.2

Geotechnical Characteristics of Soil and Rock Units in Different Zones

Zone I

In this zone, soft clay (unit 1) overlies stiff clay (unit 2) which is underlain either by medium dense carbonate gravelly sand (unit 5) (*e.g.* station 38 as shown in Fig. 3) or by a hard clay or claystone (unit 8) (*e.g.* station 33, not shown). The ground level in this zone is fairly level with water table lying at a depth of 0.6-1.2 m. Figures 6 and 7 show detailed profiles of the top 3 m of the sub-soil at stations 38 and 98 consisting of

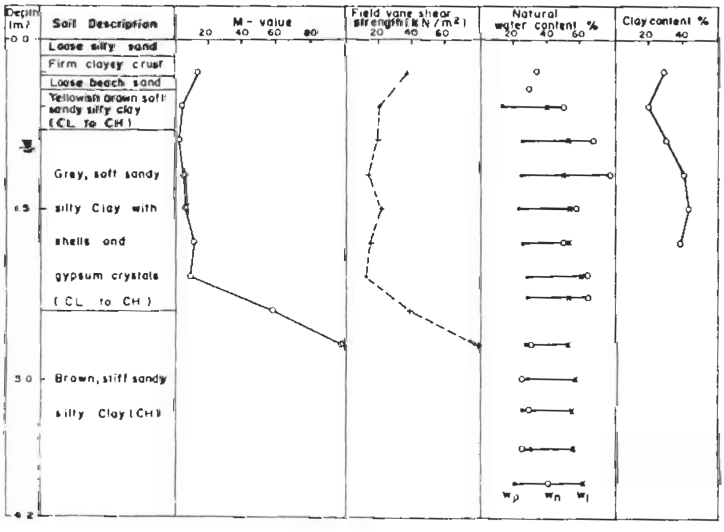

FIG. 6. Detailed Profile at Station 38 (Zone I).

soft clay and stiff clay. The difference in color and strength between the two layers is quite distinct. The thickness of the soft clay unit is in the range 2.0-2.6 m over most of the area of this zone and it feathers out at the zone boundaries (Fig. 2).

The soft clay unit could be subdivided into two sublayers, namely, the crustal sublayer of soft to medium consistency about 0.4-0.6 m thick and with some variation in texture, and the lower main body of the soft grey layer. The crustal sublayer generally has an upper part of very loose eolian sand 10-15 cm thick covering the medium stiff part of cemented sand or sandy silty clay. At some locations (e.g. station 98 shown in Fig. 7) the crustal sublayer consists of only a thin layer cemented by halite,

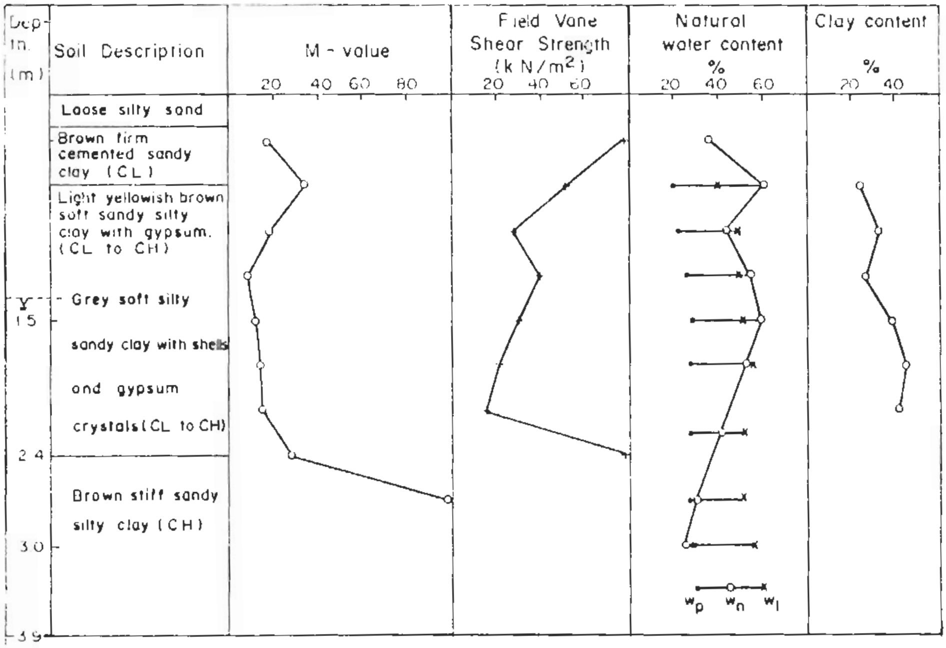

FIG. 7. Detailed profile at station 98 (Zone I).

whereas at some other locations, (e.g. station 38) a layer of white carbonate beach sand 10-15 cm thick was encountered between the crustal sublayer and the lower grey soft sublayer. The top part of the crustal layer is generally so puppy that it compresses by a few centimeters below a man's feet. Field density measurements indicated that the natural density in the top 20 cm is in the range 0.8-1.35 Mg/m^3 with a moisture content of 15-25 percent.

The soft clay (unit 1) is rich in shells and gypsum crystals with many small shells spread over the surface. The crystals are of varying shape and sizes and mostly either plate or flake shaped. The stiff clay (unit 2) appears to be free of shells and crystals. Figures 6 and 7 and Table 2 show that the natural water content of the soft clay (40-78) is nearer to its liquid limit (36-60) than to its plastic limit (18-30) and sometimes exceeds the liquid limit, except in the crustal part where it is relatively lower, suggesting major part of it to be normally consolidated. The natural water content of the stiff clay unit (25-31) is nearer to its plastic limit (25-33) than to its liquid limit, suggesting this to be overconsolidated. Figure 8 shows the range of grading curves of the soft clay and the stiff clay, the clay content of the latter being higher than that of the former. According to ASTM (1975) classification, the plasticity of the soft clay is to low to high (*i.e.* CL to CH group) and that of the stiff clay is high (*i.e.* CH group) as shown in Fig. 9.

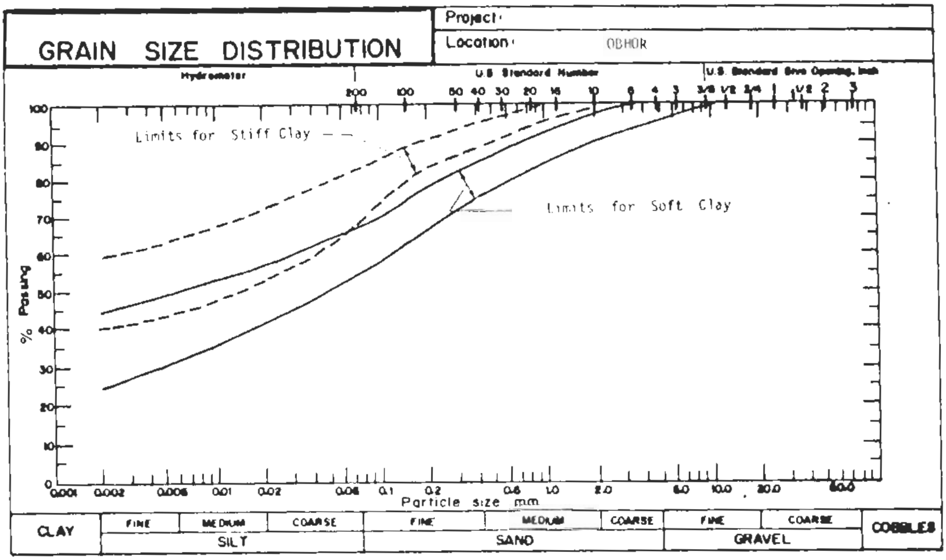

FIG. 8. Ranges of grading for soft clay and stiff clay.

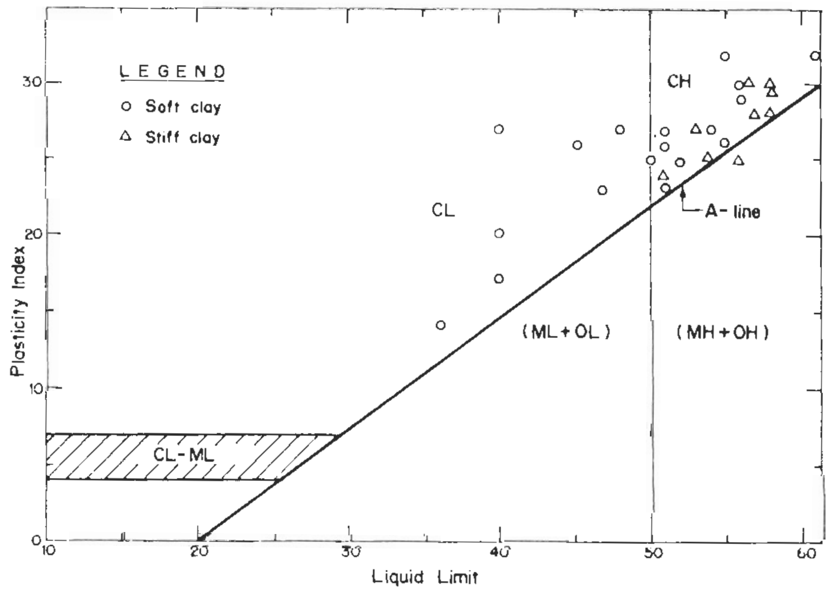

FIG. 9. Plasticity chart showing position of soft clay and stiff clay.

M-values from Makintosh probing within the crustal sublayer are in the range of 15-100 blows/30 cm and shear strength by field vane (S_{uv}) is in the range of 18-50 kN/m^2. The corresponding values for the lower sublayer are in the range of 3-40 blows/30 cm and 12-42 kN/m^2, respectively, and those for stiff clay are greater than 60 and 80 kN/m^2, respectively. The soft clay is found to be sensitive with sensitivity values in the range of 3-20 but the stiff clay is slightly sensitive with sensitivity less than 2.

The greater strength of the crustal sublayer (compared to the main body of soft clay) is considered to be partly due to greater cementation by the halite and other salts and partly due to desiccation.

One-dimensional consolidation tests indicate that the soft clay below the crustal part is normally consolidated to lightly overconsolidated with overconsolidation ratio in the range 1-2.7 confirming the indication from natural moisture content noted earlier. This unit is highly compressible as per Tomlinson's (1980) grouping with the co-efficient of volume compressibility, m_v in the range of 0.52-1.47 m^2/MN (Table 2). The stiff clay, on the other hand, is found to be overconsolidated with an overconsolidation ratio of 4.2-5.7 (higher than that of soft clay) and this unit possesses medium compressibility with m_v-values in the range of 0.17-0.22 m^2/MN. The values of co-efficient of consolidation, c_v for the soft clay determined by using Taylor's method (Taylor 1942) are mostly in the range of 1.2-15 m^2/year and those for the stiff clay are in the range of 1 2-20 m^2/year. Thus , there is not much difference between the two units in this respect.

TABLE 2. Summary of important geotechnical properties of soft clay and stiff clay.

Property	Ranges of values for	
	Soft clay	Stiff clay
Natural water content %	40-78	25-31
Liquid limit	36-60	50-56
Plastic limit	18-30	25-33
Plasticity index	20-32	24-30
Undrained shear strength by field vane shear test kN/m^2	12-42	>80
Coefficient of volume compressibility m^2/MN	0.52.1.47	0.17-0.22
Coefficient of consolidation m^2/year	1.2-15	1.2-20
Overconsolidation ratio	1-2.7	4.2-5.7

The carbonate gravelly sand unit found below stiff clay in this zone is similar to that found in Zone II and Zone IV discussed later.

Zone II

This zone covers an area of about 10 km^2 and extends parallel to the coast in north Obhor and is separated from the coast by a coralline strip (of Zone V).

Here a layer of very loose carbonate silty sand (unit 4) occurs over medium dense carbonate gravelly sand (unit 5, whose lowest 1 m is very dense), underlain by coralline limestone (unit 6) as shown in Fig. 4. The thickness of the top layer is generally less than 1.2 m except a narrow strip in the northern part and two small areas in the eastern and southern parts of the zone (shown by closer dotting in Fig. 2), where the thicknesses are in the range 1.5-2.5 m. The two upper units consist mainly of coral debris and shell fragments. Figure 10 shows typical grading curves for two depths.

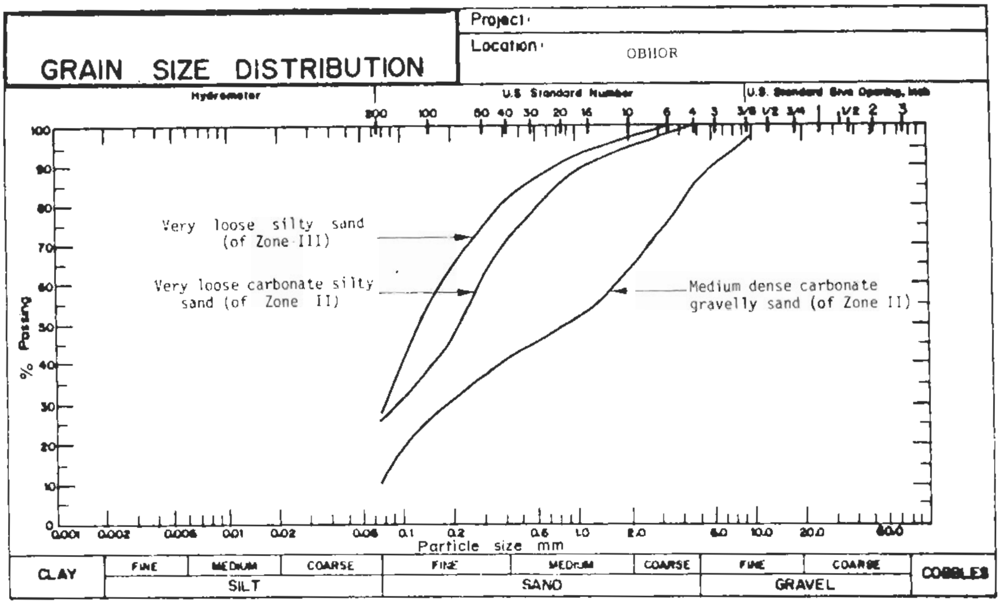

FIG. 10. Typical grading curves of sandy units.

Unit 4 in this zone has a crustal sublayer (similar to that of unit 1 in Zone 1) with M-values mostly in the range 20-50. The water table is at a depth of 1.2 m or more.

The Rock Quality Designation (RQD) of the limestone layer (unit 6) in this zone was 58% and core recovery was 70%. The limestone was found to be a yellowish white, coarse grained shelly type with open cavities and with uniaxial compressive strength in the range of 2400-8700 kN/m^2 and is, therefore, classed as weak to moderately weak as per BS (1981). The observed RQD may be smaller than that representative of the actual natural fractures due to some new fractures formed during drilling in this weak rock.

Zone III

This zone covers a small area (about 1 km^2 and is located at the upstream end of the Obhor creek. Here a layer of very loose silty sand (unit 3) about 11 m thick whose lower part is slightly clayey, overlies a layer of soft clay (unit 1) which is underlain by medium dense carbonate gravelly sand (Fig. 5).

This area is believed to be a part of Wadi Al-Kura (Fig. 2) which originates from the crystalline rocks eastward and was linked to the creek. The part of the wadi within the study area can hardly be recognised now because it has been filled almost up to the level of the coastal plane through which it passes. Figure 10 shows the grading curve of a sample of the sandy unit from a depth of 3.5 m at station 28, while Fig. 11 shows pattern of variation of N-value (from SPT), M-value (from Makintosh) and

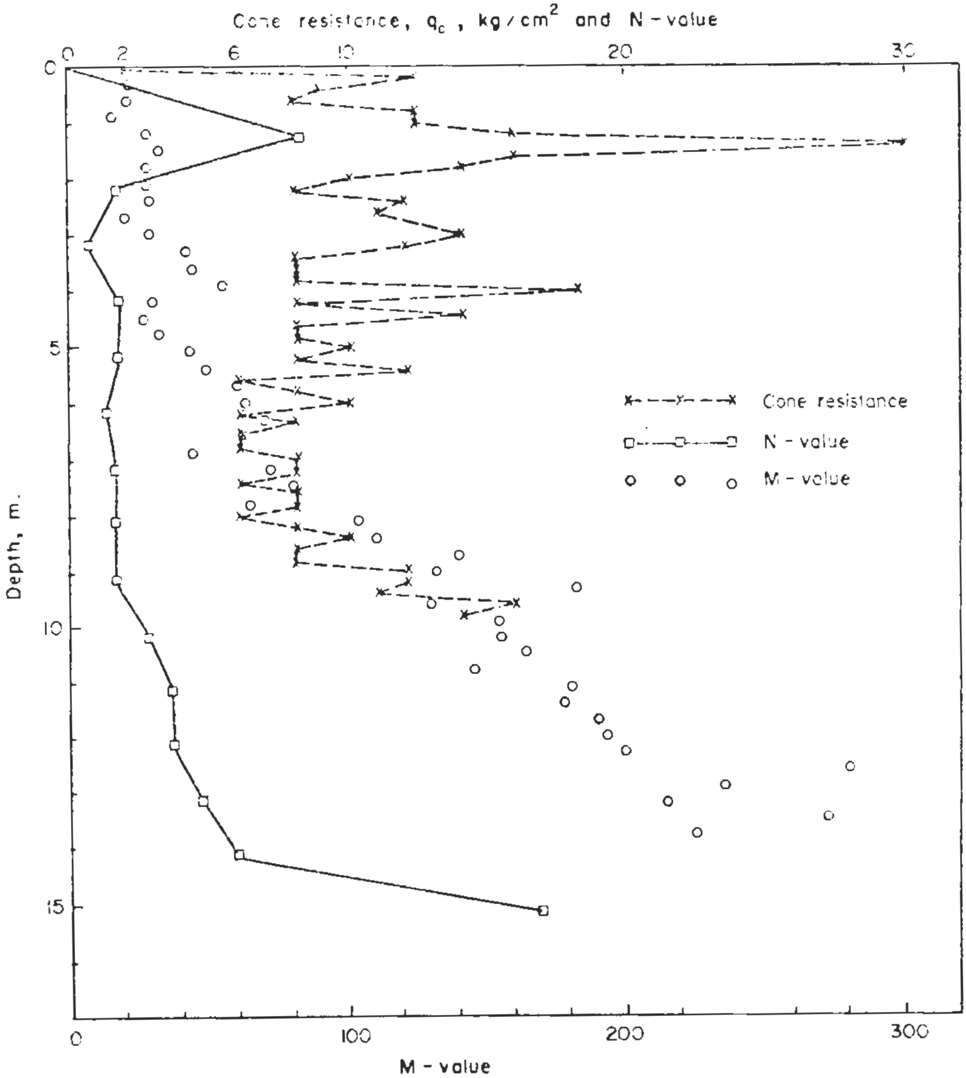

FIG. 11. Variations of cone resistance, q_c, N-values and M-values with depth for Stn. 28 (Zone III).

q_c-values (from CPT) at the same station. There is quite a good correspondence between the three methods.

Zone IV

This zone consists of a major terrace and two minor ones of medium dense carbonate gravelly sand (unit 5) covering an area of about 22 km^2 located at the north bank of Obhor creek. This zone is characterized by its relatively higher elevation with the depth of water table varying from about 1.5 m at the western edge to more than 2.5 m at the central and eastern parts. A thin layer (about 10 cm thick) consisting mostly of eolian sand covers this area. The gravel size fraction of this zone is made up of shells and coral fragments. The subsoil from parts of this zone is currently being used to fill some low lying areas around. The M-values from Makintosh probing are in the range of 40-150 at depths up to 2 m beyond which it increases and reaches up to refusal.

Zone V

This zone covers almost the whole of the area located to the south of the Obhor creek as well as a strip about 0.5 km wide along the coast in north Obhor. In south Obhor, the limestone is sometimes covered with a thin layer of carbonate gravelly sand 10-50 cm thick, the larger thicknesses being in the areas away from the coast. In some borehole logs within the King Abdulaziz International Airport reported by Morris (1975), the limestone was described as very compact based on N-values from SPT which were more than 50. The thickness of limestone layer was found to vary from about 2.5 m to about 10 m at different locations and it was found to be underlain by stiff brown clay with gravel. The water table was found at a depth of 3 m or more below the ground surface.

Zone VI

This is a small elevated zone within Zone I. It consists of a hill made up gravelly sand or sandy gravel layers underlain by layers of red or chalky hard clays or mudstone or friable sandstone (unit 8) and capped with basaltic lava (unit 7) as observed at the face of two quarries as shown in Fig. 12. This succession is referred to as

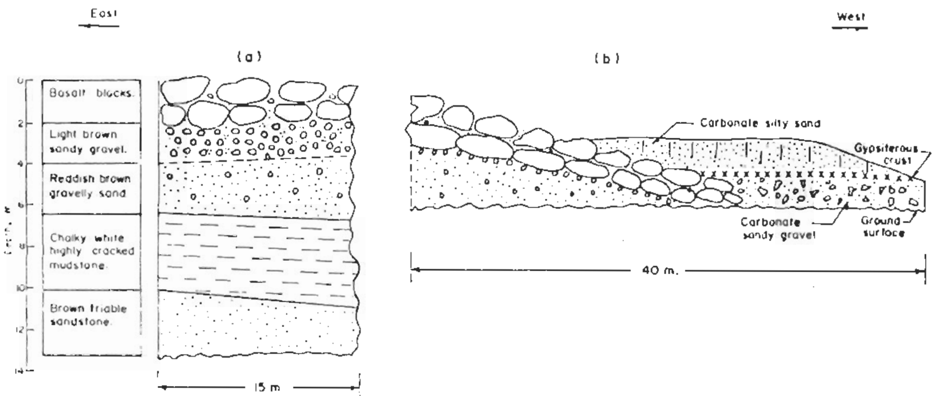

FIG. 12. Succession of Quaternary and Tertiary sediments observed on quarry faces.

Al-Kura succession in previous studies and is considered to be an extension of the Tertiary formations encountered within the Arabian Shield east of Jeddah.

Zone VII

This is a small area within Zone II, with a layer of soft clay about 2.5 m thick similar to the soft clay of Zone I overlying medium dense carbonate gravelly sand. At one location in this zone, large gypsum crystals (probably part of a gypsum layer) were found at a depth of 0.5-0.6 m and these raised the M-values to 260.

Chemical Characteristics of Soil and Rock Units and Groundwater

Table 3 shows the ranges of some chemical constituents of 5 subsoil units. It is observed that the units 1 and 4 generally have high calcium carbonate contents (35-67% and 40-75%, respectively) and relatively low silica contents (11.7-26.5% and 20-23%, respectively). The units 2, 3 and 8 show the opposite trend.

TABLE 3. Ranges of results of chemical analysis of soil and rock samples.

Soil Unit	Soil Type	Cl^- %	SO_3 %	Fe_2O_3 %	$CaCO_3$ %	SiO_2 %	Organic matter %	pH
1	Soft clay	1.6-4.8	0.7-5.2	1.7-4.6	35-67	5-27	3.6-7.4	7.8-84.
2	Stiff clay	2.4-2.6	0.3-0.6	8.7	11-13	48	4.3	7.5
3	Silty sand	1.02	0.76	5.7	9.3	59	1.4	7.8
4	Carbonate silty sand	0.8-3.1	0.5-1.0	1.4-2.4	40-75	20-23	5.7	7.8
8	Tertiary rocks	–	0.1-0.12	5-8.2	0-3	55-72	–	–

Table 3 also shows that the sulphate contents of the various soil units are generally more than 0.5% (and values up to 34% have been observed in some surface samples). Thus as per BS (1972), the aggressiveness of attack by sulphate on concrete in contact with soil varies from class 2 to class 4.

Table 4 shows that salinity of groundwater at stations 38 and 98 (of Zone I) are 85‰ and 155%, respectively. Salinity at stations 60 (Zone II) and 28 (Zone III) are 55‰ and 150‰, respectively. Al-Hafith (1983) and Al-Safadi (1983) showed salinities of 58‰ and 128‰ in groundwater from two boreholes within the present study area. These salinity values are greater than the salinity of water in southern Red Sea which is 37‰ (as per Siedler, 1969 quoted by Skipwith, 1973). High salinity of groundwater is a characteristic of sabkha environment. For example, salinity values in the range of 107-170‰ were reported by Butler (1969) for Abu Dhabi sabkha.

TABLE 4. Results of water chemical analysis.

BH	pH	Cl^- ppm	$SO_4^{=}$ ppm	HCO_3 ppm	Na^+ ppm	K^+ ppm	Ca^{++} ppm	Mg^{++} ppm	Mg^{++}/Ca^{++}	Salinity ‰
98	7.15	49600	3210	244	95000	1900	1803.4	3307.6	3.0	155
60	7.60	27500	3710	213.5	20000	900	436.6	1829.0	6.9	54.6
38	7.05	45908	4350	213.5	30000	500	1489.0	2296.0	2.5	84.8
28	7.55	24346	2820	212.0	20000	850	412.0	1714.0	6.9	50.4

For the present study area, it appears that higher salinities in Zone I is due to the longer distance from and poor communication with the sea and lower salinities in Zone II and III are due to proximity with the sea or the creek.

The sulphate contents of the groundwater in Obhor (in terms of SO_4) shown in Table 4 are in the range of about 2800-4400 ppm. This indicates a condition of severe attack by sulphate on concrete according to U.S.B.R. (1956).

Discussion on Environment of Formation of Different Units

The physiography of the area and the geotechnical properties and the chemical composition of the various units described above suggests the following points with respect to the nature and the mode of formation of the soil and rock units.

(i) There was an active coral growth along the coast in this region as in evidenced by the presence of coralline limestone over large part of the studied area and the carbonate sand and gravels.

(ii) The soft clay (unit 1) and the carbonate silty sand (unit 4) which are rich in $CaCO_3$ and poor in silica are believed to have been derived mostly from the corals or coralline limestone. On the other hand, stiff brown clay (unit 2), very loose silty sand (unit 3) and the tertiary sediments (unit 8) which are rich in silica and poor in $CaCO_3$ are continental derived materials.

(iii) The soft clay in Zones I and VII and the very loose carbonate silty sand in Zone II were deposited in lagoons which formed inland of coral reefs (Zones IV and V) during the last transgression of the coast in mid-Holocene as suggested by Behairy (1983). The filling of the lagoons was followed by a regression of the sea with the emergence of the surface in Zones I, II and VII. These developed into coastal sabkhas due to the deposition of halite, gypsum and other diagenetic materials caused by intense evaporation under hot and arid climate and the presence of groundwater table at shallow depth. Accepting the suggestion of Behairy (1983), the time of formation of the present sabkha corresponds to that of Abu Dhabi sabkha whose formation, according to Bush (1973), started 7000 years before present through the transgression of the Trucial coast. The contribution of eolian sands in the formation of

Obhor sabkha appears to be minimum because wind direction here is fairly constant throughout the year (Schyfsma 1978) and is from NNW-N which is parallel to the coast in the studied area. In this respect, this sabkha is different from those of eastern Saudi Arabia and of eastern Qatar whose formation is strongly influenced by the north-westerly "shamal wind" passing obliquely towards the Arabian Gulf. Thus, whereas the sabkha sediments of eastern Saudi Arabia are mostly sandy in nature (Akili and Ahmad 1983), the major portion of Obhor sabkha is underlain by soft clay (Zones I and VII) and a small part (Zone II) between the raised reef and terraces is underlain by carbonate sand.

(iv) The very loose silty sand in Zone III represents a recent alluvium transported through Wadi Al-Kura during the periods of heavy rain as suggested by Skipwith (1973) and deposited within its lower region.

Geotechnical Implications

The observed variation of near surface deposits in terms of their composition and strength in different zones in Obhor will influence the selection of appropriate foundation for a structure and its construction as explained by Hossain and Ali (1986). It is found that for light structures (say a two-storied villa), usual footings at a depth of 1 m or so are suitable in most of Zone II and in Zone IV, but such foundations need soil improvement in Zones I, II (part), III and VII. Otherwise, rafts at small depths or footings with bases below the upper weak layers or deep foundations are necessary in these later zones. Among the ground improvement techniques, normal or partial preloading or vibro-replacement (stone column) is considered appropriate in Zones I and VII but vibro-compaction or dynamic consolidation may be suitable in Zones II and III. However, the relative cost of an improvement method with respect to the total cost of a project and the necessity of a permanent raising of the ground level should be considered while selecting a method. The situation with respect to sulphate attack on concrete or corrosion of reinforcement by chloride is more or less alike in all the zones. The degree of sulphate attack noted earlier requires the use of sulphate resistant portland cement with a minimum cement content of 390 kg/m^3 and maximum water cement/ratio of 0.45 in all concrete in contact with soil or groundwater as per BS (1972). In addition, protective coating along with dense concrete and a minimum cover of 50 mm for reinforcement will be required.

Conclusions

Five soil units and three rock units have been identified within a maximum depth of 15 m within Obhor. These units vary from soft clay or very loose silty sand to weak coralline limestone. The undrained shear strength of the soft clay (below top crust) is in the range 12-42 kN/m^2 and that of the stiff clay is more than 80 kN/m^2. The soft clay (below top crust) is normally consolidated to lightly over consolidated and is highly compressible. The very loose silty sand and carbonate silty sand units show N-values (from SPT) as low as 2-3. On the basis of location of the various units, the area can be divided into seven zones, of which Zones I, II and VII have the characteristics of coastal sabkhas. Chemical composition suggests the soft clay, δ and the carbonate silty sand to be derived from coralline limestone, whereas stiff brown clay and very loose silty sand to be derived from continental materials. Large differences in geotechnical characteristics between the different units suggest the need for different solutions for foundations of structures in different zones. Appropriate measures are necessary for protection of concrete and steel against attack by sulphate and chloride, respectively.

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الخواص الجيوتكنيكية والجيوكيميائية للتربة تحت السطحية في منطقة أبحر

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تم وصف الخواص الجيوتكنيكية والجيوكيميائية للتربة التحتانية في وحول منطقة أبحر وذلك لمساحة قدرها حوالي ٩٠ كم٢ ، وقد تم التعرف على خمس وحدات من التربة ، وثلاث وحدات من الصخور تبعا لصفاتها وخواصها في المنطقة وذلك بعمق أقصى خمسة عشر متراً للدراسة وتشتمل هذه الوحدات على التالي :

١) الطين الرمادي الرخو .
٢) الطين البني القاسي .
٣) الرمل الغريني شديد التفكك .
٤) الرمل الغريني الجيري شديد التفكك .
٥) الرمل الحصباوي الجيري متوسط الكثافة .
٦) الحجر الجيري المرجاني الضعيف .
٧) بازلت العصرين الثلاثي والرباعي .
٨) حجر الرمل وحجر الطين الثلاثي .

واستناداً على مواقع وجود هذه الوحدات قسمت المنطقة إلى سبعة نطاقات ، ثلاثة منها تتصف بخواص السبخات الساحلية . وبعمل التحليلات الكيميائية تم الاستدلال على أن الوحدات الأولى والرابعة والخامسة قد تكون ذات أصل من الحجر الجيري المرجاني ، بينما الوحدات الثانية والثالثة قد تكون ذات المنشأ القاري . ويُستدل من الدراسة على أن هناك ضرورة لحماية الخرسانة والحديد من تأثير العوامل والمؤثرات الأرضية .