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Ground Condition in Jeddah and its Influence on Selection and Design of Foundation

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ABSTRACT. A general assessment is made of the sub-soil and groundwater conditions in the 12 km long central part of Jeddah and of their influence on the selection and design of foundations. This is based on a review of 44 site investigation reports, testing of soil samples from 55 locations and water samples from 12 locations and design calculations made by the authors. The soil and rock units identified within a maximum depth of 60 m are: (i) light brown silty gravelly sand, (ii) white loose uniformly graded sand, (iii) greyish brown loose to dense clayey silty sand, (iv) white loose to dense coralline silty sand, (v) fill material, (vi) white coralline conglomerate (rock) and (vii) light brown massive coralline limestone (rock).

The studied area has been divided into four main zones nearly parallel to the coast and with soil units (i), (ii), (iii) and (v) at the surface. In Zone I, footings are found to be adequate for buildings upto 6 stories high and rafts for taller buildings. In the other zones, deep foundations are more often necessary and bored piles are more commonly used. Protective measures against sulphate attack on foundation concrete and against corrosion of steel by chloride is found necessary.

Introduction

Jeddah, the largest city of the Kingdom of Saudi Arabia stands on the eastern shore of the Red Sea. In the recent past, Jeddah has been growing fast both vertically and horizontally to provide housing, business and other facilities to the ever increasing population which is projected to reach 1.5 million in 1990 (Ministry of Agriculture and Water, 1984).

Figure 1 shows the urban growth in Jeddah between 1971 and 1983 during which the city expanded by more than 5 times it's area in 1971. This expanded city with its tall buildings like the 26-storied National Commercial Bank building (tallest in Jed-

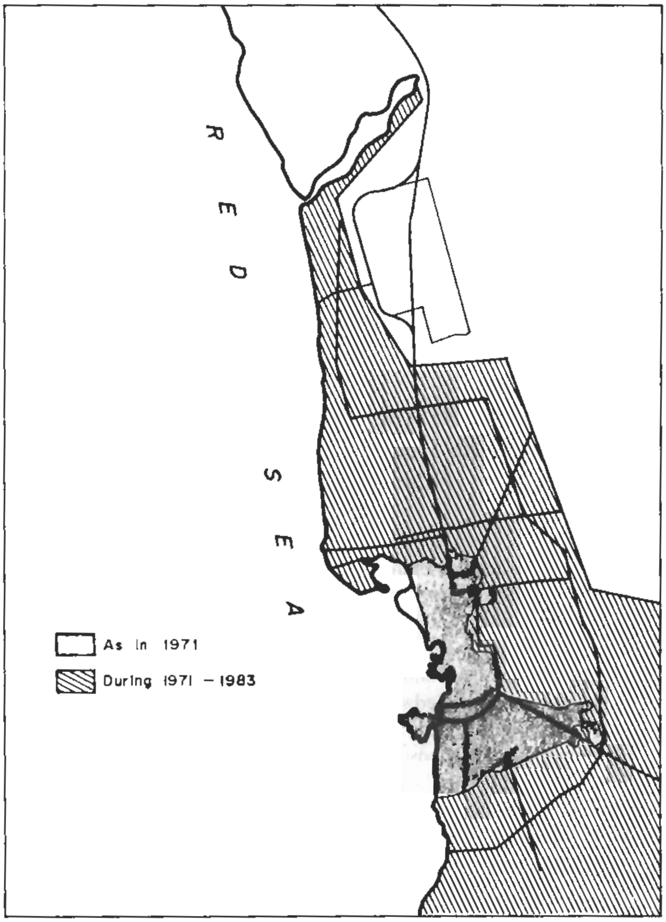

FIG. 1. Urban growth in Jeddah during 1971-1983. (modified after Sert-Jackson Int. 1979).

dah), large mosques, elevated water towers, overpasses etc., is built on the area available on the existing land as well as on those reclaimed from the shallow coastal region. Being restricted on the east by the hills and on the west by the Red Sea, Jeddah has been extending along the north-south axis and has already reached Obhor, about 35 km north of Jeddah (city centre). The buildings and other structures in Jeddah are supported by shallow foundations like footings and rafts as well as deep foundations like piles and diaphragm walls. The aim of the present paper is to present an up-to-date pricture of the ground conditions in Jeddah and its influence on the selection and design of foundation in this city.

Basis of the Present Study

The present study is based on a review of earlier works (*e.g.* Laurent *et al.* 1973, Morris 1975) as well as a study of 44 site investigation reports, listed in Table A.1 in

Appendix and testing of soil samples from 55 excavation sites and water samples from 12 locations and design calculations made by the authors, as described in detail by Abu-Hajar (1985). Fig. 2 shows the locations of these projects and sampling

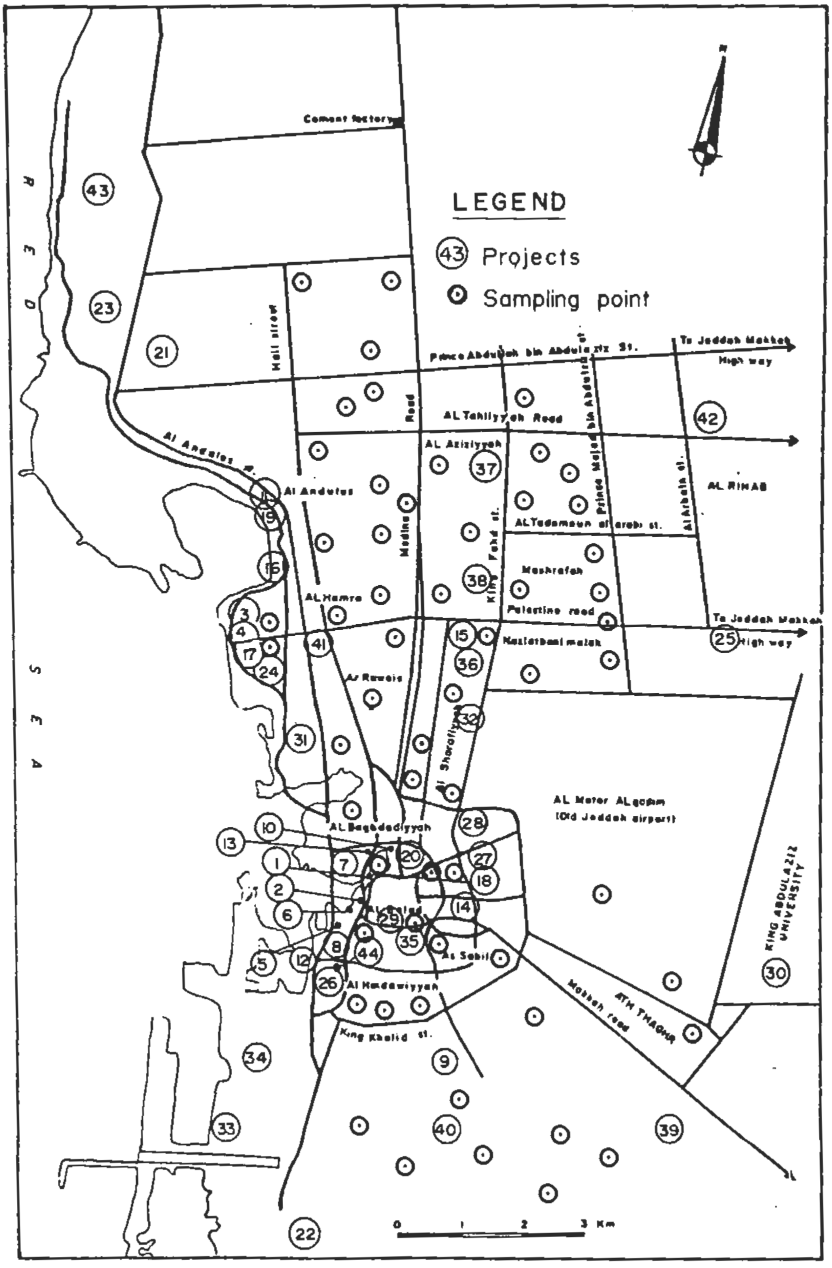

FIG. 2. Locations of projects and sampling points.

points. They are located within an area, about 12 km long (north-south) and 10 km wide extending from Qurayat and Al-Thulba areas at the south to Al-Faisalia and Al-Rawda at the north. Fifty percent of the projects had the maximum bore hole depths greater than 20 m and some had upto 60 m.

Geological Setting

Jeddah is built on the Red Sea coastal plain, known as Tihama. The latitude and longitude of the city centre are about 21° 29′N and 39° 11′E respectively. Tihama is backed by a prominent escarpment on the east. According to Skipwith (1973), the escarpment marks the uplift of the margin of the Arabian Shield. Morris (1975) divided Jeddah into two parts, of which, the western part is chiefly a depositional plain with materials such as coral, silt, clay and sand and accumulations of coral and shell fragments. The eastern part is covered by poorly sorted silt, sand and gravels derived from the crystalline rocks by mechanical weathering and redistributed as sheets of sediments during the periods of flooding.

The elevation of ground surface in the western part of Jeddah is around 0.5-3 m above mean sea level while it increases to 12-15 m in the eastern parts. Laurent *et al.* (1973) showed the route of four wadis – Wadi Ashir, Wadi Qwaz, Wadi Mashwab and Wadi Bani malik – all running across Jeddah. But now they have been covered by the city building process and cannot be identified. Wadi Fatima is a major wadi flowing south of Jeddah. All these must have influenced the deposition of continental sediments in the area as well the growth of coral, its disintegration and subsequent redeposition.

Soil and Rock Types

Nature of the units

On a map of the 6 km long (north-south) central part of Jeddah, Laurent *et al.* (1973) showed 3 natural soil units, one fill unit, one rock unit and one soil-rock unit. This map was based on the data of the top 6 m of sub-soil. Al-Qahtani (1979) collected data for an average depth of 20 m from a number of locations within the area studied by Laurent *et al.* (1973) and a little additional area on the south and north. The present study includes geotechnical data for depths upto 60 m and covers not only the area of the above investigators but also that within an additional distance of about 5 km on the north and about 1 km on the south. Compilation of the data of the previous studies with those of the present shows 4 natural soil units, one fill unit and two rock units which are listed in Table 1 with the environment of their deposition, their important geotechnical characteristics and their classification as per ASTM (1975).

Figures 3 and 4 show the comparison of the overall ranges of the grading for the different soil units. It is observed that the soil units vary in colour from brown through greyish brown to white and in grouping from silty gravelly sand (SW to SW-SM) through uniformly graded fine sand (SP), clayey silty sand (SM) to coralline silty sand (SM). The brown silty gravelly sand (soil unit 1) contains 10-30% gravels

TABLE 1. Soil and rock units in Jeddah.

Material type	Unit No.	Description	Environment of Deposition	ASTM (1975) class	Range of $N_{(SPT)}$	Maximum Observed Thickness
Soil	1	Light brown medium to dense silty gravelly sand	Continental	SW to SW-SM	11- over 100	10m (or more) in east Jeddah
	2	White loose uniformly graded sand	Marine	SP	5-8	8m in Al-Balad
	3	Greyish brown loose to dense clayey silty sand	Continental	SM	2-28	14m in Al-Kandara
	4	White loose to dense coralline silty sand	Marine	SM	2- over 100	17m in Al-Balad
	5	Fill material (Gravelly sand with some silt)	man-made	SM	15-40 (after preloading)	40m in Islamic Port
Rock	1	White coralline conglomerate	Marine	–	RQD, 20-40%	11m or more in Al-Khalidia
	2	Light brown massive coralline limestone	Marine	–	RQD, 40-60%	50m or more in Al-Hamra

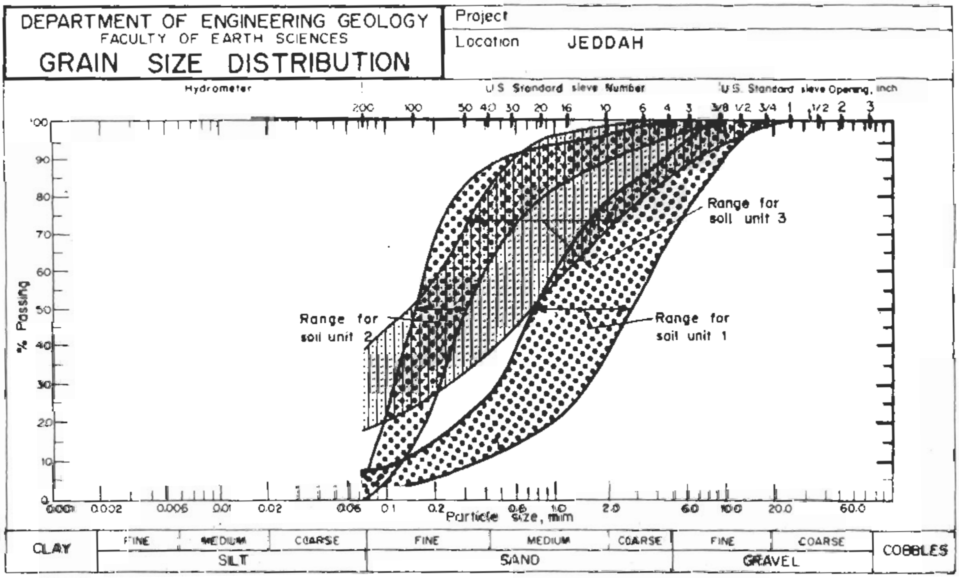

FIG. 3. Grading limits of soil units 1, 2 and 3.

(>4.76 mm) and 1-6% silt and is medium dense to very dense with N-values from standard penetration test (SPT) in the range of 11 to over 100. The coarse sand and gravel fraction of this unit consists of angular to subangular particles. This unit represents the sheet wash deposits noted by Morris (1975). The white loose uniformly graded sand (soil unit 2) contains small amounts of shells, and broken calcareous materials and consists mainly of reworked and rounded granitic and dioritic fine sand

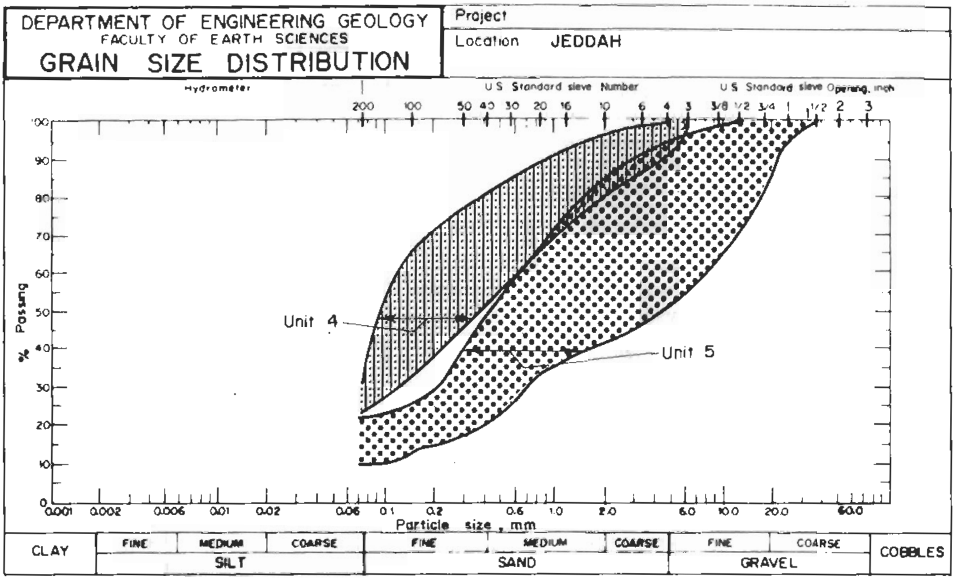

FIG. 4. Grading limits of soil units 4 and 5.

(presumably derived from the eastern hills) with D_{50} within a narrow range of 0.15-0.30 mm. The grading of this unit appears to be that of a dune sand and resembles that of a sand found in United Arab Emirates by Epps (1980). In respect of relative density, this unit (with N-values in the range 5 to 8) is more or less similar to soil unit 3 (*i.e.* clayey silty sand with N-values in the range of 2 to 10), but it has a lower fines content (0 to 5%) than the unit 3 (fines content 17 to 38%).

The white coralline silty sand unit varies in relative density from very loose to very dense with N-values in the range 2 to over 100 and has fines content in the range 20-35% which is similar to soil unit 3. The fill (soil unit 5) is the most variable in composition and contains appreciable proportion of gravels (5 to 45%) and/or fines (6 to 22%). No SPT data for the fill is available except at the Jeddah Islamic Port site where N-values from 15 to 40 were observed after improvement by preloading.

The above description shows that all the soil units in Jeddah are coarse grained in nature as per ASTM (1975) but some parts of unit 3 with fines content >35% might be classified as fine grained as per BSI (1981). Moreover, the coarse grains vary from granitic to coralline in nature.

The rock quality designation (RQD) of the white coralline conglomerate and the light brown massive coralline limestone are in the range 20 to 40% and 40 to 60% respectively. Sample recovery of 50-70% in SPT has been reported in some reports for the coralline conglomerate. Uniaxial compressive strength of 1500-2900 kN/m^2 with an average of 2000 kN/m^2 has been reported for coralline limestone in project no. 17 (Ref. Table A.1) in Al-Hamra area. Also N-value from SPT for this unit varies from 37 in project 13 to 100 in project 21.

Occurrence of the soil and rock units at ground surface

Figure 5 shows the areal distribution of the various soil and rock units at ground surface. It is observed that the soil units 1, 2, 3 and 5 appear at the ground surface in successive strips nearly parallel to the coast starting with the unit 1 at the east, while the soil unit 4 and the rock units appear at surface only at a few small isolated areas. It is seen in the X-sections in Figs. 6, 7 and 8 (discussed later) that these later units occur mostly below other units. Soil unit 1 has the largest surfacial coverage within the study area. Unit 2 disappears at the northern and southern parts of the studied area and its place appears to have been taken by soil unit 3 north of Andalus and by rock unit 1 south of Hindawiyyah. The width of fill unit varies from about 100 m in some areas to 2 km in the Islamic Port area.

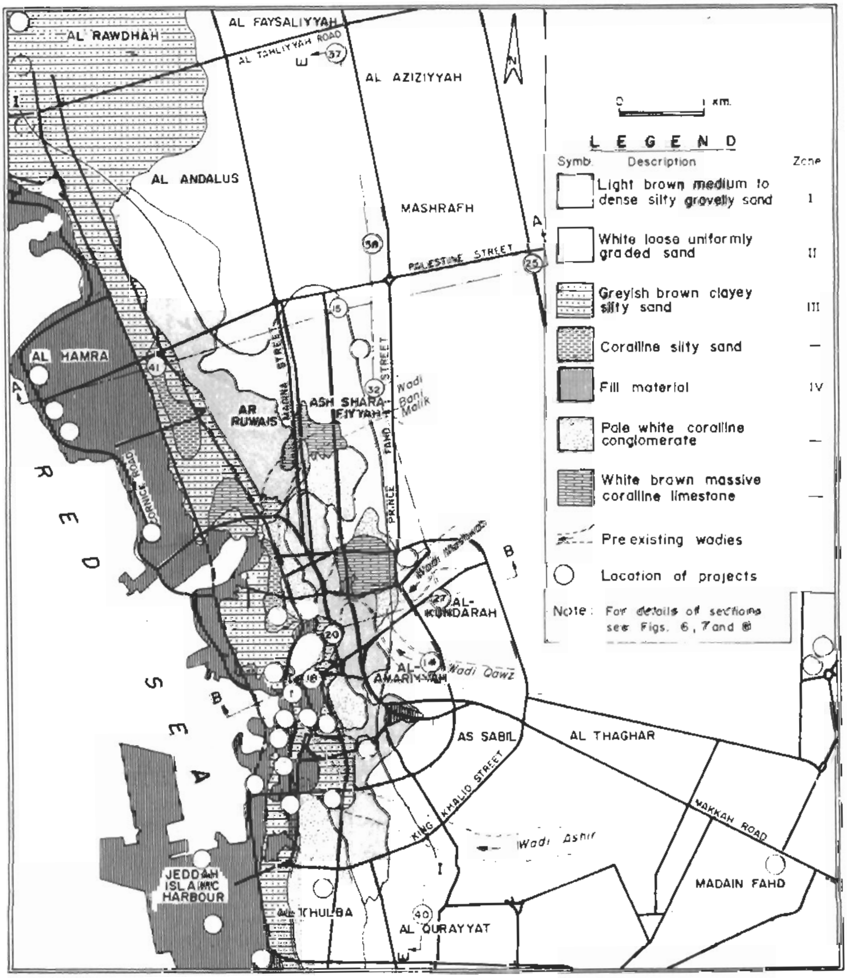

FIG. 5. Soil distribution map of Jeddah.

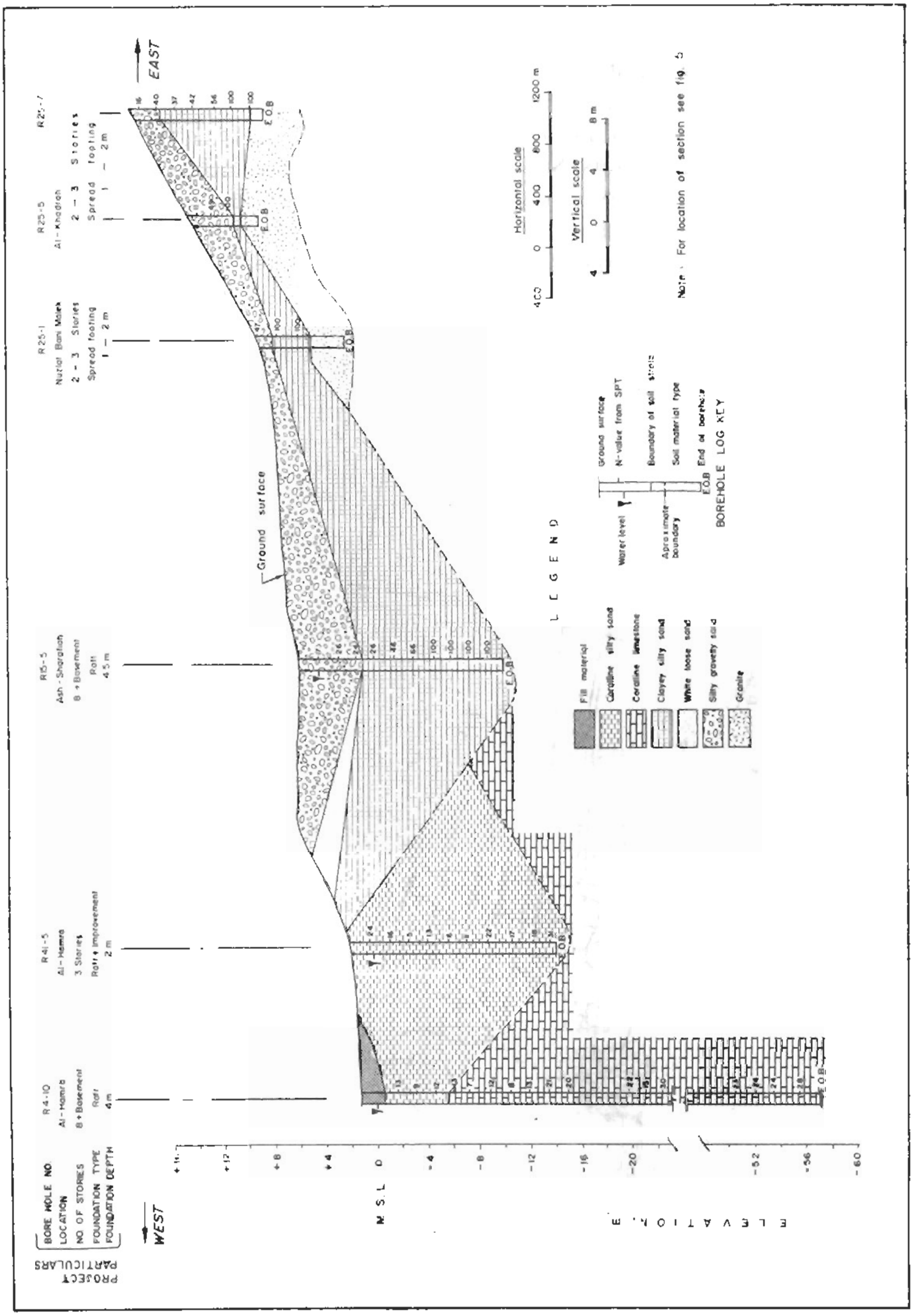

FIG. 6. Soil profile along an east-west section A-A (with project particulars).

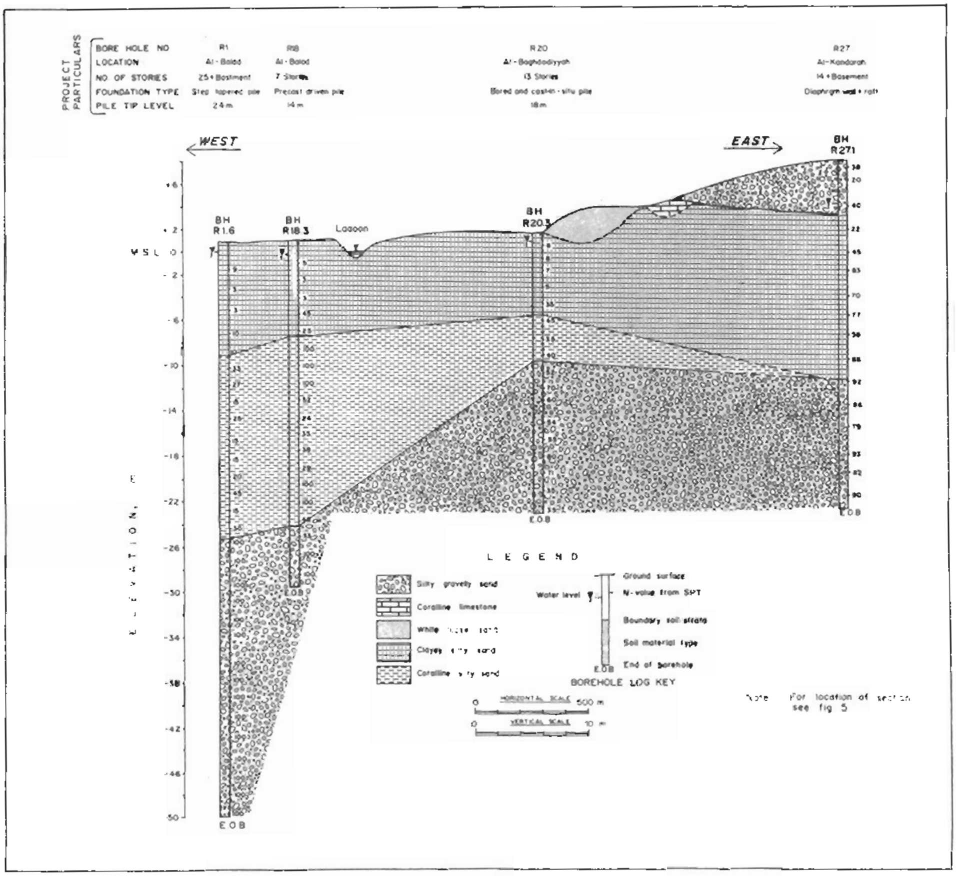

FIG. 7. Soil profile along an east-west section B-B (with project particulars).

Thickness of the soil and rock units

The variation of the thickness of the various soil and rock units as well as the N-values from SPT in representative boreholes from a number of project's are shown in two east-west cross sections, marked A-A and B-B, in Figs. 6 and 7 and one north-south cross section, marked E-E, in Fig. 8. Among them Fig. 6 shows the maximum number of soil units. Although these x-sections are self explanatory, a few general comments are made herein. Although Fig. 6 shows soil unit 1 to occur as top layer over most of the x-section and to have a maximum thickness of about 6 m, Fig. 7 shows it also below soil unit 3 in the central and southern areas.

In the eastern and northern areas the maximum thickness of soil unit 1 has not yet been determined but in the University area this has been drilled upto a depth of 20 m.

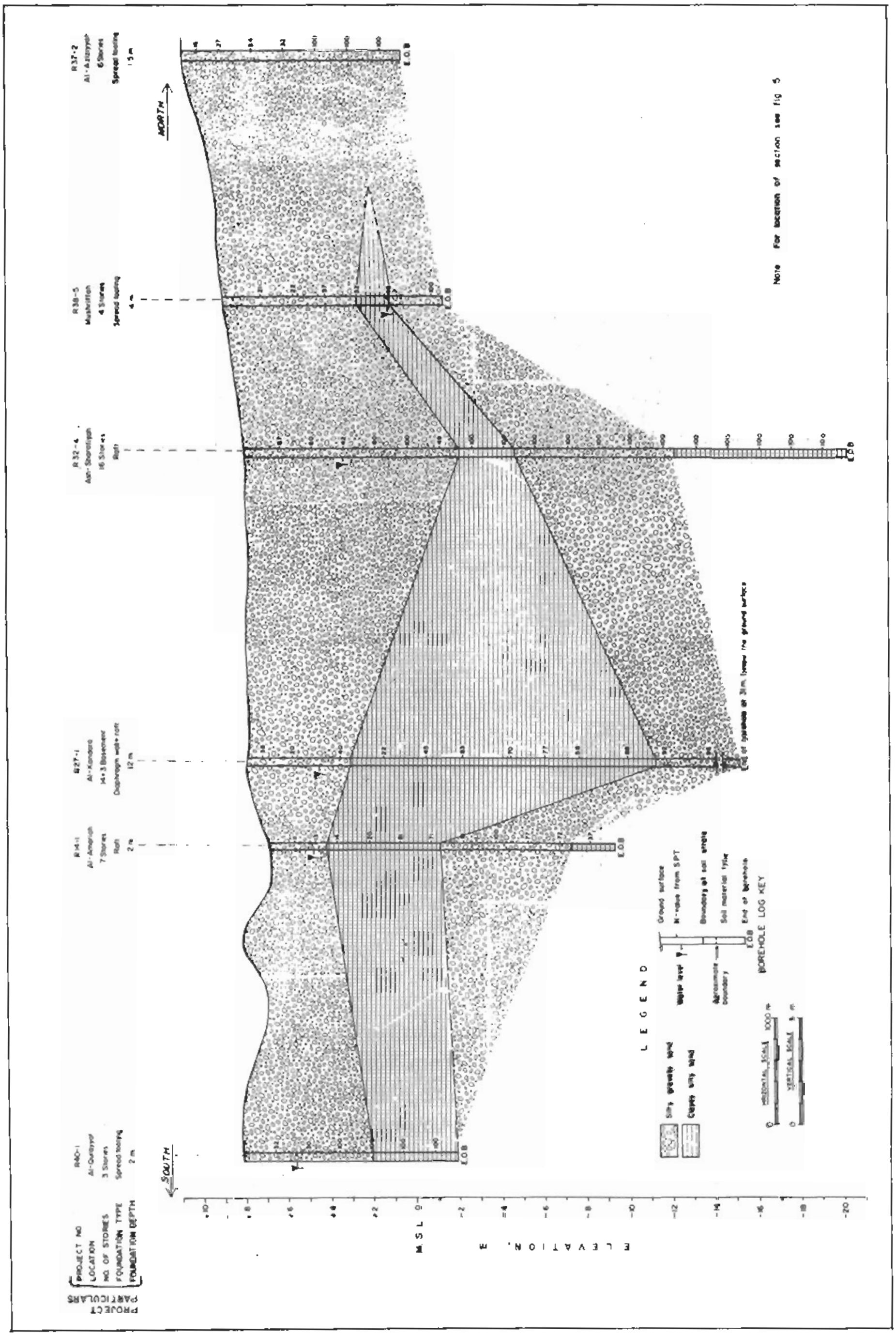

FIG. 8. Soil profile along a north-south section E-E (with project particulars).

Soil units, 2, 3 and 4 have their maximum thicknesses in the Al-Balad–Al-Kandra area of central Jeddah and these areas are beside the courses of Wadi Mashwab, and Wadi Qwaz and beside the lagoon in front of the Foreign Ministry Office. Fig. 9(a) shows an excavation within the soil unit 2 at a site in Al-Balad area whereas Fig. 9(b) shows brown fill (soil unit 5) over coralline silty sand at the site of Project No. 17 in Al-Hamra area.

The low N-values (in the range 2-10) of the soil unit 3 occur in the western areas where it forms the top layer (Ref. BH 1.6 in Fig. 7). In the eastern part this unit appears below soil unit 1 where its N-value is larger, (e.g. N > 22 in BH 27.1 shown in Fig. 7).

Sulphate and Chloride Contents and pH of Ground Water

Analysis of 12 samples of ground water from different sites by the authors showed that sulphate content of these samples varies from 25 ppm to about 4100 ppm. This indicates an aggressiveness of class 1-4 to concrete as per BSI (1972). The chloride contents in the same water samples are in the range 66-28400 ppm. Among the cations present in ground water, sodium is found to be the most abundant (43-13600 ppm) followed by calcium (4-1410 ppm). The pH values are in the range 7.5-8.7 indicating an alkaline environment. This might suggest the possibility of using normal portland cement in foundation concrete, but this cannot be used due to high sulphate contents noted above.

Results of Chemical Analysis of Soil

Table 2 shows the ranges of the contents of chloride, sulphate, sodium, potassium and calcium found by the authors' analysis of 38 soil samples from soil units 1, 2, 3 and 5 identified earlier. It is observed that no distinction in terms of the above ions could be made between the different soil units. Similarly no distinction was found in respect of these ions between different depths. The sulphate contents of all these samples are in the range 0.003-0.6 percent and chloride contents are in the range 0.01-4.27 percent. These ranges were found to be similar to those found from a combination of results available in 9 of the site investigation reports. The sulphate contents indicate aggressiveness of class 1 to 3 as per BSI (1972). This aggressiveness appears to be less than that suggested by results of water analysis mentioned earlier.

Figure 10 shows the variation of sulphate contents of soil at different locations in an east-west sequence for a depth of 0.5 m. Similarly Fig. 11 shows the variation of chloride contents. From these and another pair of figures for a depth of 2.5 m (not shown) it is observed that Jeddah can be divided by a line I-I, shown in Fig. 5, into two zones – one eastern zone with sulphate contents less than about 0.2 percent and chloride contents less than about 1 percent, and the other western zone with higher sulphate and chloride contents. These sulphate contents suggest that as per BSI (1972), protective measures against sulphate attack are necessary for foundations in areas to the west of line I-I only. But the sulphate contents in water noted earlier suggest the need for it in all the areas of Jeddah.

(a)

(b)

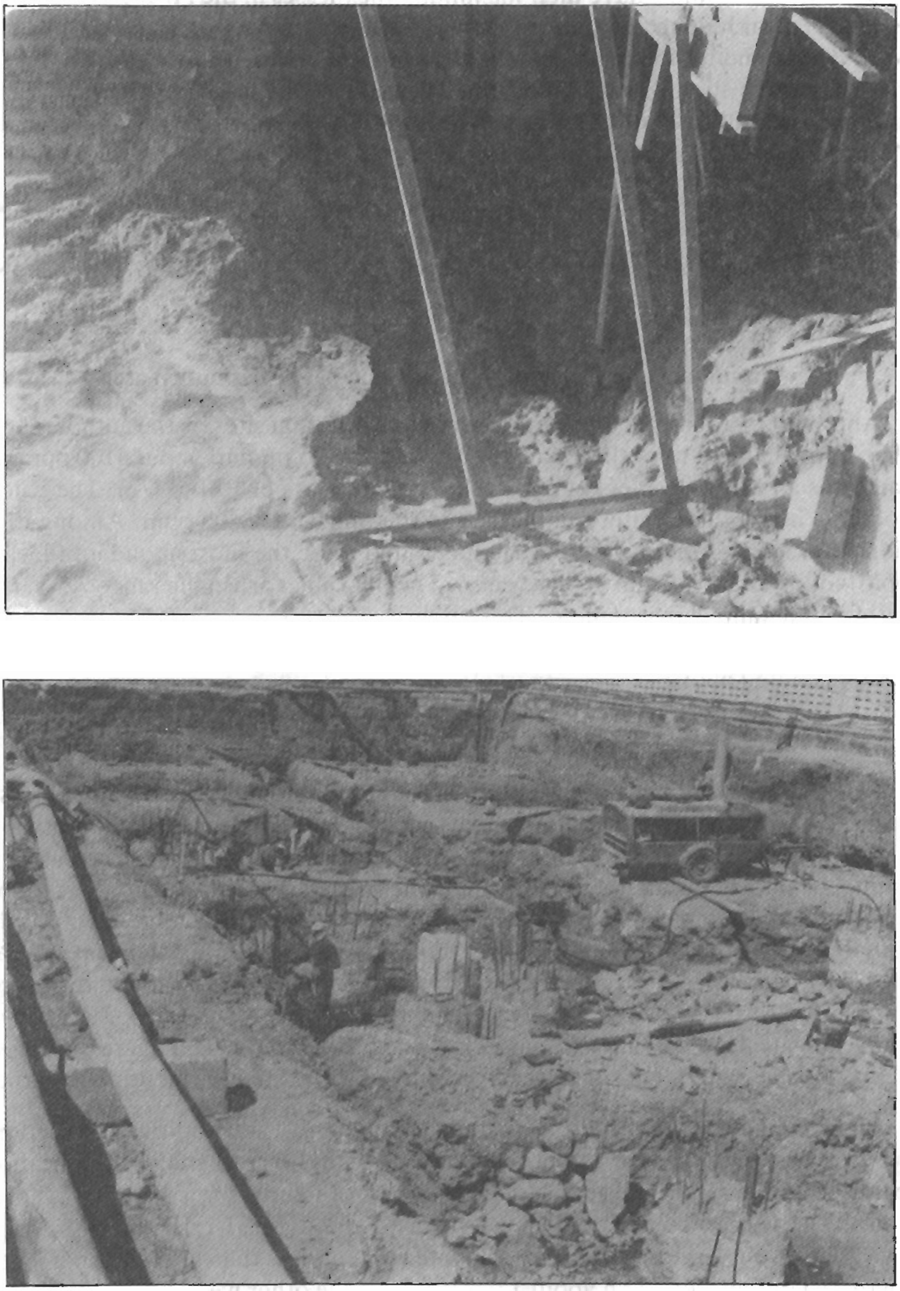

FIG. 9. Excavations showing soil units 2, 4 and 5.
(a) White loose uniformly graded sand (soil unit 2) at a site in Al-Balad area.
(b) Brown dense till (soil unit 5) overlying coralline silty sand (soil unit 4) at Atallah shoping centre site in Al-Hamra area.

TABLE 2. The chemical analyses of soil units* carried out by the authors.

Soil Unit	Description	Number of Sample	Range of				
			Cl^- (%)	SO_3^{--} (%)	Na^+ (%)	K^+ (%)	Ca^{++} (%)
1	Silty gravelly sand	20	0.01-0.65	0.003-0.49	0.01-0.45	0.009-0.23	0.1-4.16
2	White loose sand	3	0.25-0.68	0.013-0.29	0.04-0.25	0.01-0.042	0.19-0.6
3	Clayey silty sand	7	0.06-1.7	0.01-0.38	0.12-0.22	0.01-0.05	0.7-1.4
4	Fill Material	8	0.09-4.27	0.02-0.6	0.15-0.2	0.02-0.05	0.25-0.8

* Note : Soil unit 4 was not tested.

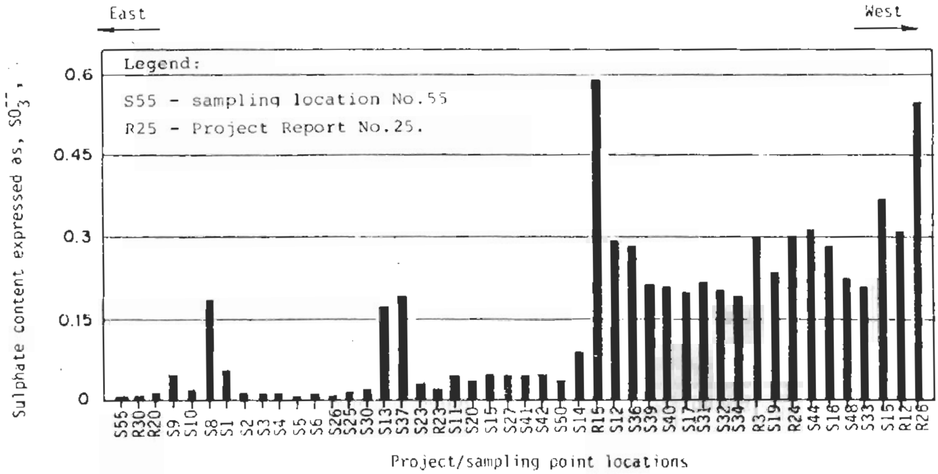

FIG. 10. Variation of sulphate content of soil at a depth of 0.5 m at different locations in an east-west sequence.

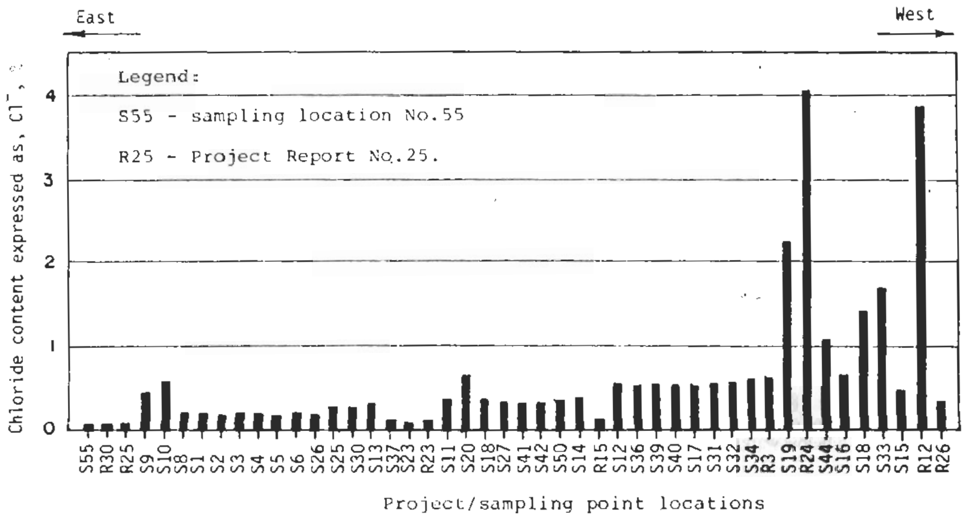

FIG. 11. Variation of chloride contents of soil at a depth of 0.5 m at different locations in an east-west sequence.

Shallow Foundations

Sub-soil zones

Based on the pattern of occurrence of the various soil and rock units at the surface, the studied area can be divided into 4 main zones as follows:

i) Zone I, having the soil unit 1 underlain by soil unit 3,

ii) Zone II, covered by soil unit 2 which is underlain by soil unit 1,

iii) Zone III, covered by soil unit 3 resting on soil unit 4 which is underlain by soil unit 1,

iv) Zone IV, covered by soil unit 5 (fill) underlain by soil unit 4 which rests on limestone.

These zones are shown in Fig. 5 as successive strips nearly parallel to the coast. The areas showing soil unit 4 and the rock units at surface are generally small or lacks sufficient data and hence are not discussed further.

Projects using shallow foundation

Tables 3, 4 and 5 lists 28 projects (out of 44 studied projects) for which shallow foundations were adequate. These foundations include (i) spread footings, (ii) strip footings, (iii) spread footing below basement, (iv) ordinary rafts and (v) compensated rafts. All these projects with footings and rafts are located in zones I, III and IV identified earlier (Ref. Fig. 5).

TABLE 3. Allowable soil pressures of spread and strip footings.

Zone No.	Project No.	Building's part	Foundation depth (m)	Foundation size m × m (square) or m (strip)	Depth• of water table (m)	Net allowable soil press. (kN/m^2) From soil report	Estimated with $C_W = 1$	Estimated with Actual C_W	No. of storeys
I	25	A	1	1 × 1	3.5	200	220	220	2
I	25	B	1	0.45	3.5	200	220	220	3
I	30	A	2	3 × 3	9	320	320	320	4
I	30	B	1.5	1	9	320	320	320	4
I	37	A	1.5	0.5×0.5-2.5×2.5	3.5	220-270	220-300	220-250	6
I	38	A	4	3 × 3	7.1	150	290	290	4
I	39	A	2	1.6 × 1.6	2.5	150	300	240	4
I	40	A	2⁺	1.6 × 1.6	2	120	190	140	3
I	42	A	3.5	2 × 2	6	200	220	220	4
IV	21	A	0.6	3 × 3	2.4	250	250	210	4
IV	23	A	1.5⁺	2 × 2	0.5	190	200	114	2
IV	23	B	3⁺	2 × 2	0.5	230	210	116	2 + B
IV	24	A	1⁺	1.5 × 1.5	0.5	48*-300**	40*	280**	5
IV	24	B	1⁺	1.5 × 1.5	0.5	48*-300**	40*	280**	5
IV	43	A	1.5⁺	1 × 1	1.2	100	240	178	4
IV	43	B	1.5⁺	1	1.2	200	300	210	4

⁺ Foundation below water table; * Before improvement; ** After Improvement.
B = Basement. • Below natural ground surface.

The depth of foundation, D_f for spread and strip footings are generally in the range 1-2 m except in project No. 21 where it is 0.6 m and in project No. 38 and 42 where the

D_f-values are 4 m and 3.5 m respectively. Footings are recommended at these unusually large depths due to low N-values at smaller depths. The D_f-values of the footings in zone I are generally less than the depths of water table, (which is generally large) but in zone IV, foundations are placed even below water table which generally occurs at small depths.

The depths of ordinary rafts are in the range 1-6 m and those of rafts with basements are in the range 3.75-12 m. The studied projects with rafts foundation are located in zone I, III and IV (no report was available for any project with shallow foundation located in zone II). In zone I, rafts were found necessary for buildings, 7 to 16 stories high. In zone III, a raft has been used even for a 3-storied building and in zone IV even for a 1-storied mosque.

TABLE 4. Allowable soil pressures of rafts with D_f less than 3 m.

Zone No.	Project No.	Building's part	Foundation depth (m)	Depth• of water table (m)	Net allowable soil press. q_n (kN/m²)		No. of storeys	Estimated	
					From soil report	Estimated with C_W=0.5, s=2.5 cm		Thickness (m)	Net app. load (kN/m²)
I	14	A	2	7.1	100	120	7	0.5	92
I	30	C	1	9	300	180	3	0.4	41
I	32	A	2	4.5	200	150	16	1.6	212
I	38	B	2	7.1	75	150	4	0.5	54
III	18	B	1$^+$	0.7	100	100	3	0.4	41
III	26	A	1$^+$	0.3	100	115	5	0.6	67
III	41	A	1$^+$	0.7	50* , 90**	20* , 60**	3	0.4	41
III	44	A	1.2	1.4	30* , 80**	30* , 55**	4	0.5	54
IV	16	A	2.5$^+$	1	50	65	1	–	–
IV	24	C	2$^+$	0.5	48* , 140	48* , 150**	5	0.6	67
IV	43	C	2.5$^+$	1.2	200	160	6 + B	0.7	70

$^+$ Foundation below water table; * Before improvement; ** After improvement.
B = Basement. s = Allowable settlement. • Below natural ground surface.

TABLE 5. Allowable soil pressures of rafts with D_f more than 3 m.

Zone No.	Project No.	Building's part	Foundation depth (m)	Depth• of water table (m)	Net allowable soil press. (kN/m²)		No. of storeys	Estimated	
					From soil report	Estimated with C_W=0.5, s=5 cm		Thickness (m)	Net app. load (kN/m²)
I	15	A	6$^+$	1.6	190	250	8 + B	0.85	34
I	27	A	12	17	200	160	14+3B	1.6	64
I	28	A	6.4$^+$	2.4	190	360	12+2B	1.4	111
I	36	A	4.5$^+$	3.4	142	340	7 + B	0.7	93
III	13	A	3.5$^+$	1.3	100	330	10	0.9	140
IV	4	A	4$^+$	0.5	120	230	8 + B	0.8	73
IV	9	A	3.7	3.75	100	220	4 + B	0.5	20
IV	11	SW	6$^+$	2.8	100	100	–	–	–
IV	19	SW	4.5$^+$	2.5	140	140	–	–	–

$^+$ Foundation below water table; SW = Storm water culvert. B = Basement. • Below natural ground surface.

Allowable soil pressure and settlement

a. General

The method of determining allowable soil pressures and settlements depends on the type of sub-soil. As listed earlier, Jeddah is mostly covered by cohesionless soil layers.

b. Method used in site investigation reports

Some of the studied site investigation reports mention the method of calculating the net allowable soil pressure, q_{na} and in majority of them, it is calculated from N-values of SPT by using Meyerhof's (1956) formulas. Some reports having pressuremeter test results base their calculation on the method suggested by Menard (1965).

c. Method of calculations made in this study

In order to make an assessment of the soil pressures recommended in the studied reports, independent estimates have been made by the authors for each project by using the method of Peck *et al.* (1974) for the footings with correction factor of unity for the effect of over burden pressure on N-value from SPT and by using the chart of Terzaghi and Peck (1967) for the rafts. Considering the presence of gravels or pieces of corals which may raise the N-value when SPT is made with the usual shoe, the maximum average N-value was considered to be 40. The appropriate value of water table correction factor, C_W as per Peck *et al.* (1974) has been used for footings.

For ordinary rafts with depth less than about 3 m, C_W was taken as 0.5. For these rafts and footings allowable settlement was assumed to be 2.5 cm. For rafts with depth more than 3 m, q_{na} was taken directly from the charts thus presuming C_W of 0.5 and allowable settlement of 5 cm as recommended by Terzaghi and Peck (1967).

d. Results of present calculation

The q_{na} values calculated according to the above procedure are presented in Table 3 for footings and in Table 4 and 5 for rafts and these Tables also show the values from the reports. It is observed that in zone I, with footing sizes and depths in the ranges 0.45-3 m and 1-3.5 m respectively, the estimated q_{na} values are in the range 140-320 kN/m^2. In zone IV with footing sizes and depths in the ranges 1.0-3 m and 0.6-3 m respectively, the estimated q_{na} values are in the range 114-300 kN/m^2. These ranges are more or less similar to those recommended in the reports but there are some differences in individual cases.

For rafts with D_f smaller than 3 m, the values of estimated net allowable soil pressure, q_{na} are in the range 55-180 kN/m^2 and those for rafts with D_f greater than 3 m are in the range 100-360 kN/m^2. Again there is a reasonable agreement between the estimates of the reports and those of the present study except in some individual cases. However, a crude estimate based on Tomlinson's (1980) thumb rule on actual building load of 12.5 kN/m^2/floor indicates that the actual net applied pressure of the structures (shown in Tables 4 and 5) are generally less than the q_{na} from the reports and from the present study.

Deep Foundations

Review of Projects with Deep Foundations

Among the 44 studied projects, 15 used pile foundation and one used diaphragm walls. Table 6 summarizes the relevant data for the piles. These projects are located along the coastal belt of Jeddah which includes zones II, III and IV. In these zones, the weak sub-soil combined with water table at shallow depth more often necessitates the use of deep foundations particularly for high rise buildings. Table 6 shows that piles were necessary in some projects even for 3-storeyed buildings. Driven and cast-in-situ pile (Raymond step-taper type) has been used in the 26 storeyed National Commercial Bank building (tallest in Jeddah) in Al-Balad area. The wide variations in the lengths of piles (10 to 30m) reflect the variations in depth at which a dependable soil or rock layer is available.

TABLE 6. Range of important parameters of piles.

Zone No.	Pile Type	Project No. (No. of Projects)	Range of			
			Size (cm)	Length (m)	Working load of single pile, kN	No. of storeys
II	Driven pile	35 (1)	30	10	450	3
III	Driven pile	5, 7, 18 (3)	30, 45	14, 25	300, 600	3, 8 + B**
	Driven and Cast-in-situ pile	1 (1)	20-35*	24	1200	26 + B
	Bored pile	2, 6, 10, 12, 20 (5)	48-125	11-30	300-4300	4-12
IV	Bored pile	3, 16, 17, 29 (5)	60-120	18-23	1200-4000	4-16

* Step-taper pile. ** B stands for a basement.

Choice of Pile Type

Table 6 indicates that driven piles have been used for low working loads whereas bored piles have been used for a wide range of loads. However, possible driving difficulty due to the presence of limestone lenses or boulders in the fill layer or the effect of vibration on nearby buildings probably discouraged the use of driven piles or driven-and-cast-in-situ piles even for low working loads in some projects. Moreover, the required large working load was a dominant factor in selecting bored piles for some other projects (e.g. Project 17).

Working Loads on Single Piles

In the studied reports the working loads for single piles have been estimated by using various methods based on N-values of SPT or cone resistance, q_c of static cone penetration test (CPT) or angle of internal friction, of the soil. Independent calculations have been made in this study by using:

(i) The method of Tomlinson (1980) with the Table of Broms (1966) and the Chart of Berezantsev (1961) for driven piles.

(ii) The method of Nordlund (1963) for driven and cast-in-situ step-taper piles.

(iii) The method of Touma and Reese (1974) for bored piles.

The working loads obtained from the above calculations are found to be in reasonable agreement with those in the reports except for some bored piles for which the values in the reports are somewhat higher than those of present calculations. However, the working load calculations for piles are always considered to be tentative subject to verification by pile load tests and it is assumed that in the actual execution of the studied projects, pile load tests have been made not only to check the estimated working loads but also the settlements.

Discussion

The present study brings to light the variety of soil and rock types in Jeddah, and the chemical nature of the environment and indicates the manner in which they affect foundation selection. It is limited by the number of studied site investigation reports and the accuracy therein, and the number of tests made by the authors and hence the findings should be used as a preliminary guide to plan detailed investigation for any specific project.

Conclusion

Five soil units with varying composition and relative density and two rock units have been identified within a maximum depth of 60 m within the 12 km long central part of Jeddah. Based on the occurrence of these units at surface, the studied area has been divided into 4 main zones. These zones are: zone I with light brown dense to very dense silty gravelly sand (soil unit 1), zone II with white loose uniformly graded sand (soil unit 2), zone III with greyish brown clayey silty sand (soil unit 3), and zone IV containing fill material (soil unit 5).

In the eastern part of Jeddah, the chloride and sulphate contents of soil were found lower than those on the western part. But no such distinction could be made for sulphate and chloride contents of ground water. So protective measures against sulphate attack on foundation concrete and against corrosion of reinforcement by chloride are necessary.

Estimates made by the authors show that in zone I, footings are adequate for low to medium rise buildings (say upto 6 storeys) and rafts for taller ones. Deep foundations or shallow ones with soil improvement are often necessary in other zones due to week sub-soil at shallow depths.

Review of 44 site investigation reports has shown reasonable agreement with the results of autors' analyses. Bored piles appear to be more common partly due to the heavy loading and partly due to the difficulties associated with driving in case of other piles.

Appendix

TABLE A1. Summary of projects and their characteristics.

Project No.	Project Name	Project Location	Building type	No. of stories	No. of Basement	Type of Foundation
1	National Commercial Bank	Al-Balad	O	26	1	Step-taper pile
2	Al-Mansour Building	Al-Balad	R	8	1	Bored pile
3	High rise office	Al-Hamra	R+O	16	Nil	Bored pile
4	Intercontinental Hotel	Al-Hamra	H	8	1	Raft
5	Electric power building	Al-Balad	O	8	Nil	Bored pile
6	Jeddah Commercial Center	Al-Balad	O	8	Nil	Bored pile
7	Hilton Hotel	Al-Baghdadiyah Al-Gharb	H	7	Nil	Bored pile
8	Postal Center Building	Al-Balad	O	6	Nil	Raft
9	Obaid-Bawbed Building	Al-Qurrayyat	B	4	1	Raft
10	Hassan Kutbi Building	Al-Baghdadiyah Al-Gharb	CC	12	1	Bored pile
11	Storm water	Al-Hamra	Outlet	–	Nil	Raft
12	Corniche bridge	Al-Hindawiyyah	Br	–	Nil	Footing + Pier
13	Salem Batarfy	Al-Baghdadiayh	B	10	Nil	Raft
14	Mohammed Al-Amoudi	Al-Ammariyyah	B	7	2	Raft
15	Omar Sedik	Ash-Sharafiyyah	B	8	1	Raft
16	Enani Mosque	Al-Hamra	Mosque + 2 minarets	15 m high	1	Bored pile + Raft
17	Atallah Shopping Center	Al-Hamra	R + O	16	1	Bored pile
18	Red Sea Palace Hotel	Al-Balad	H	3-6	1	Raft + Precast pile
19	Storm water	Al-Hamra	Outlet	–	Nil	Raft
20	Al-Nenieb Center	Al-Baghdadiyah	B	16	1	Bored pile
21	Abdul-Karim building	Al-Khalediyyah	R	4	–	Spread footing
22	Oil Refinnery	Petromin Area	–	–	–	Raft + treatment
23	Abdul-Maqssaud	Al-Khalediyyah	V	2	1	Spread footing
24	Ramada Hotel	Al-Hamra	H	5	1	Spread footing + treatment + Raft
25	National Guard Housing	Bani-Malek	Hsg.	2-3	Nil	Spread footing
26	Ibrahim Abdul Ghani Bldg.	Al-Hindawiyyah	R	5	Nil	Raft
27	Khoja building	Al-Kandarah	R	14	1	Raft + Dia-phragm wall
28	Sultan building	Al-Kandarah	R	12	1	Raft
29	Bughshan building	Al-Balad	R	4	Nil	Bored pile
30	King Abdulaziz Univ.	University area	Univ.	3-4	Nil	Footing
31	Dar-Al Phenoun building	Al-Hamra	R	16	Nil	Bored pile
32	Jeddah Tower building	Ash-Sharafiyyah	R	16	Nil	Raft
33	Jeddah Silo	Seaport area				Raft + treatment
34	Jeddah Islamic Harbour	Seaport area				Treatment
35	Abdul-Wahab Dayeh Bldg.	Al-Balad	R	3	Nil	Driven pile
36	Private building	Ash-Sharafiyyah	B	7	1	Raft
37	Private building	Al-Aziziyyah Dist.	B	6	Nil	Footing

TABLE A1. (continued).

Project No.	Project Name	Project Location	Building type	No. of stories	No. of Basement	Type of Foundation
38	Abdul Malik Bin Marwan School	Mushriffah	S	4	Nil	Footing
39	Sulaiman Bin Abdul Malik School	Madain Al-Fahad	S	4	Nil	Footing
40	Saad Bin Abi Waqqas Sch.	Al-Qurrayyat	S	3	Nil	Footing
41	Al-Hamra School	Al-Hamra	S	3	Nil	Raft foundation +improvement
42	Secondary School	Al-Sourah	S	4	Nil	Footing
43	Atallah Hotel	Okaz area	H	6	Nil	Footing + Raft
44	Al Hindawiyyah School	Al-Hindawiyyah	S	4	Nil	Raft + improvement

O = Office; R = Residence; R+O = Residence and Office; H = Hotel; B = Building;
CC = Commercial Center: Br = Bridge; V = Villah; Hsg = Housing; S = School.

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العوامـــل الأرضيـــة وتأثـــيرها في اختيار الأساسات وتصميمها في مدينـــة جـــــدة

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المستخلص . تشمل الدراسة التقييم العام لظروف التربة التحت سطحية والمياه الجوفية في مسافة ١٢ كم على طول الجزء الأوسط من مدينة جـدة وتأثيرها على اختيار وتصميم الأسـاسـات معتمدة على مراجعة دقيقة لـ ٤٤ تقريرا للفحص الموقعي وعمل اختبارات معملية لعينات من ٥٥ موقعا مختلفا وعمل تحاليل كيميائية لعينات مياه من ١٢ موقعًا ، وحسابات التصميم المعمولة بواسطة المؤلفين .

ولقد عُرفت التربة والصخور حتى عمق يصل إلى ٦٠ مترًا كمايلي :

(أ) رمـل حصـوى غريني بني فاتـح ، (ب) رمل متوافق التدريج فتوت أبيض ، (جـ) رمـل غروي طيني متماسك إلى فتوت بني رمادي اللون ، (د) رمل غريني مرجاني متماسك إلى فتوت أبيض ، (هـ) مواد ردم مالئة . أما الصخور فكانت عبارة عن (و) دُملوك مَرجاني أبيض و (ز) حجر جيري مَرجاني بني فاتح اللون .

وقـد قسمت المنطقة المدروسة سطحيا إلى أربعة نطاقات رئيسة موازية لشاطئ البحر ويحتـوى على أنواع التربة الأول والثاني والثالث والخامس المذكورة سابقا . فقد وجد أن الأسـاسـات المناسبة للنطاق الأول هى من نوع القواعد الخرسانية للمباني ذات الأدوار الستة ، والأساسات المسماة الفرشة الحصيدة الخرسانية بالنسبة للمباني العالية الارتفاع . أمـا في النـطاقـات الأخـرى فإنها تحتاج غالبا إلى أساسات عميقة وأكثرها استعمالا هى الدعامات (الأعمدة العميقة) المحفورة والمصبوبة في الموقع .

ولقد وجد أنه من الضروري اتباع معايير وقائية خاصة لحماية الأساسات الأسمنتية من تأثير الكبريتات عليها وحماية حديد التسليح من تأثير الكلوريدات .