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ENGINEERING PROPERTIES OF SOIL LAYERS OF KARACHI

S.I. Mohsin, Gulraiz Hamid, Ehtesham Siddiqui and Arif Zubair
Department of Geology, University of Karachi, Karachi-75270, Pakistan

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Karachi has been a fast growing city by any standards and planning could never keep the pace of construction. Engineering properties of the soils in various parts of the city have been studied to evaluate the foundation conditions. It is found that the soils of Karachi, in the northern part, are coarse grained, medium to coarse sand and sandy gravel, well graded and unimodel. The moisture content, bulk density and specific gravity are in the range where shallow foundations can safely be placed for medium sized civil projects. Shear strength of the soil has been tested in the field by an improvised penetration test and by pocket penetrometer at three feet depth. The results provide a useful guideline and it is believed that the standard test for penetration will corporate with the obtained results. The foundations in the southern part of the city, particularly in Defence Housing Society, require caution. The soil is finer in size, very poorly graded and recently deposited in tidal flats, creeks and swamps. Drainage conditions are poor and the problem of salinity and water logging is encountered in the area. More high-rise buildings are being built in this part of the city and each site deserves to be carefully examined for the foundation conditions including the seismic risk.

Key words: Engineering properties, Foundation conditions, Soil, Seismic risk.

Introduction

Karachi is a megametropolis, grown to a giant city in only half a century. It had a natural harbour, and two seasonal rivers, Malir and Lyari which provided a plain for establishment of a cantonment. Creation of a new state and inflow of emigrants from across the borders as well as from upcountry totally changed the character of the city. The neat and quiet port city in forty years swelled to an unplanned mega-city with all kinds of problems owing to overpopulation, lack of civic amenities and exposure to various environmental hazards.

The geological foundations of the city. The city of Karachi is situated on young folded Tertiary strata (Fig. 1). The western flank striking NE-SW is of a narrow monoclinal nature dipping around 20 degrees west. The Hub River flows parallel to this flank and makes the western boundary of the city. The eastern flank is very broad and gently folded on which at least three anticlinal crests and three synclinal troughs can be discerned. The dips are very low, ranging between 2 to 5 degrees. Anticlines have eroded crests while the synclinal troughs have been filled by river alluvium. It is this terrain on which the city is founded.

The Karachi area is a tectonic embayment. However, it is a trough in a geomorphological sense. An embayment is a down warped area containing stratified rocks that extends into a terrain of other rocks [1]. Trough is a narrow depression in the earth surface such as between hills: in a regional tectonic framework the Karachi embayment is a part of Kirther fold belt. It is flanked by Khude range on the west which becomes extremely narrow (Jhill Range) jutting into the sea. Cape Monze, Pab range forms the northern limb of the embayment. The eastern flank is not expressed by a distinct ridge, rather by uplifted areas such as Sunbak and Lakhra uplift. The embayment is open to the south where rocky and sandy beaches and tidal flats form the limits.

The rocks deposited in the Karachi embayment belong to Tertiary and Quaternary systems. Paleogene rocks are not exposed within the trough although exposures of Eocene Kirthar Formation in immediate vicinity across Hub River can be seen on a prominent peak known as Gandbo Hill. It is mainly Neogene rocks, i.e., Nari Formation (Oligocene), Gaj Formation (Miocene) and Manchar Formation (Pliopleistocene) which constitute the bedrock for the most part of the urban and sub-urban areas. Of these three, Nari Formation is exposed only at the eroded Manghopir anticlinal structure and continues at Jhill ranges at Cape Monze. Manchar Formation forms a plateau-like feature at Korangi Landhi-Pipri. For the rest of the city it is the Gaj Formation which is either a bed rock or is exposed as bare rock. It is covered by thin veneer of aeolian soil in anticlinal crests and by moderately thick alluvium in synclinal troughs.

The quaternary cover. The urbanization and the industrialization is more influenced by the Quaternary cover than the underlying older geological formations. However, in case of Karachi both appear to be of equal importance. Densely built-up society area, Drigh Road and part of Gulshane-Iqbal directly sit on bare rock strata or on only thinly covered Gaj Formation. The thickly populated North Karachi and Orangi townships are similarly situated. But the river valleys and coastal belt have moderately thick Quaternary deposits.

The Lyari River cuts its course through Gaj rocks while Malir drains through the Gaj/Manchhar Formation. The two rivers have brought gravel, coarse sand and silt from these formations. The alluvial plain is not built entirely out of river load but has received materials from highlands as sheet wash and as wind-blown deposits. The thickness of the alluvium is about 50 to 60 feet. The maximum thickness is upto 200 feet. Most bore holes drilled for water or for foundation close to the river course or even within the channel, strike bed-rocks at depths ranging 40 to 60 feet. The thickness of the alluvium, understandably reduces as one moves away from the river course in either direction.

The beach sand, the coastal sand dunes and the tidal mudflats are the main Quaternary deposits along the coastline. They have assumed significance as the building activity has shifted to the coast. The thickness of this Quaternary cover needs to be determined carefully as much as its geotechnical behaviour. The coastal belt is deemed highly unfavourable from environmental geology point of view.

The colluvial deposits which form the cover on the pediment at the foot hills of Pir Mangho or Jhil range consist of loose boulders, cobbles and gravelly sand. A similar blanket is found in the zone of ridge and valley such as those of Orangi township. This Quaternary deposit is variable in thickness but overall is a thin cover overlying the older strata.

The bed rocks and the Quaternary cover should be studied together for the various environmental parameters, essential in urban planning. Zaidi *et al.* [2] have identified several parameters such as relief, water table elevation, slope, geological hazards and foundation conditions. In this report soil layers have been evaluated for the foundation point of view.

The formation of soil. The formation of soil depends on several factors such as nature of rocks, climate, topography and time. In an arid region where young geological structures are being denuded forming bold relief, only coarse, granular, transported soils are expected. Water has been main transporting agent, followed by wind, both as channel flow and as sheet wash, and is responsible for the formation of the alluvial plain. Gravity movement of talus, scree, pseudo-fans aided by sheet wash has resulted in colluvial soil in pediment zone. Wind blown silt or fine sand form patches in many valleys, particularly in ridge and valley terrain and also in the coastal belt. The source rock for the soil layers are Nari, Gaj and Manchar Formations consisting of light brown coloured sandstone, shale and limestone. One can easily identify pebbles of Nari and Gaj limestone or sandstone in a gravelly soil, so common in the Karachi alluvial plain.

The surficial deposits in the Karachi embayment have not developed true soil layers which are the results of chemical weathering and formation of humus. The arid climate with scanty rainfall did not permit any significant vegetation except shrubs and xerophytic plants to grow. The weathering of rocks has largely been mechanical and bold relief allowed rapid transportation. This has resulted in gravelly and stoney soil. In a sandy loam the silt and clay-size material is derived from shale strata. All soils are generally calcareous because of the abundance of thick bedded limestone in both Nari and Gaj Formation which are the parent material of the soil layers.

The soils of Karachi embayment are characteristically poor in organic carbon, less than 1%. This is not surprising in an arid climate with desolate landscape and where soils have low clay content. The finer fraction, i.e., silt and clay together in Karachi soil rarely exceed 20% and is quite often below 10%. In the 50 or so samples analyzed during this work, the fine fraction does not exceed than 2%.

The various soils of Karachi can be classified in three groups. The soils of river plain of Malir and Lyari are fluvisols. The soils related to pediments of the hills and ridges are skeletal soil and can be called lithosol or regosol. The third group includes the sandy/silty cover which blankets the fluvisols of the plain area and at the toe slopes at the lower parts of the scarp and dip slopes and some times found as a valley fill covering the entire surface between the low ridges. These aeolian deposits can be called aerosols.

Materials and Methods

To study the geotechnical characters of the soils, three methods are available, namely, field methods, laboratory techniques and acquisition of the subsurface data from the available reports. Intensive subsurface investigation is expensive and need not be duplicated. It is always advisable to explore the availability of the subsurface data. When interprated with field testings and laboratory analyses, most satisfactory results are obtained.

A previous study of bearing capacity of soil layers of Karachi [3] was based on the SPT results from boreholes available with foundation companies. From borehole data the layers as much as 30 feet depth were studied. The present work is based on the three-feet deep pits made by the investigators for this purpose and wherein samples were collected for laboratory test.

Sampling techniques. Samples in this study have been obtained from various sites from a depth of approximately three feet. A pit is made of about two foot by two foot (60 cm x 60 cm) size and is dug upto three feet. Sometimes when the soil layer is very hard, a depth of 2.5 feet has been considered sufficient. Most foundations of single or double storey houses are placed at three feet depth. For a 4 to 5 storey apartment the foundations may be deeper. But the geotechnical properties of soil from three feet depth will, in any case, be a fair guide.

Generally a one-kilogram sample of soil is sufficient for most testing. However, a larger sample may be required for some tests. Sample of one kilogram was adequate as most of our tests such as moisture content, bulk density, specific gravity, grain size analysis etc. require 50 to 100 gm of sample for each test. The sample was collected in double packing of polythene bags so that natural water content is not lost during transportation.

Improvised penetration test. In foundation investigation practices, in Karachi, the penetration test is most significant. It is a standard test when a two feet long and one inch diameter sampler is penetrated in the soil. A 140-lb (65 kg) hammer is allowed to fall freely from a height of 30 inches. The first six inches of the sampler penetrating in the soil is ignored. For the next 12-inches penetration, blows of hammer are counted. The number of blows are directly proportional to the shear strength of the soil [4].

It was not possible to carry out this standard penetration test for us. It requires a boring rig and a truck for mobilizing the SPT outfit from one site to the other. Therefore, we improvised a smaller equipment which can easily be carried and can be used without a rig.

A one-inch diameter galvanized iron pipe is chosen for penetration. The hammer weights 5 kg and slides on the pipe to strike a socket at the lower end.

Penetration of the first two inches of the pipe is ignored. The blows required to penetrate the next four inches are counted. This crude penetration test does not replace the standard penetration test. However, it gives a fair idea of the strength of the soil layer.

Pocket penetrometer. A pocket penetrometer has an iron needle to be penetrated in the soil. A spring is attached to it which is pressed during penetration. It is so calibrated that it gives a direct reading in kg/cm^2. This is the force required to penetrate a given length of the iron needle. The use of pocket penetrometer requires a careful handling. The bottom of the pit where a soil is to be tested should be level and be a representative one. Test may be performed twice or three times and an average is taken. We have attempted to use the results of our improvised penetration test and the pocket penetrometer together. In this way the reliability of the test results has been somewhat enhanced.

Grain size analysis. A soil is a heterogenous mixture of solid particles. The sizes may range from several millimeters down to a few microns. To separate various fractions of soil by their sizes is the most effective means to classify a soil. Grain-size analysis has been carried out by a set of sieves of standard mesh. Shaking of sieves is done on electric shaker. Each fraction is carefully weighed and is calculated as percentage of the whole sample.

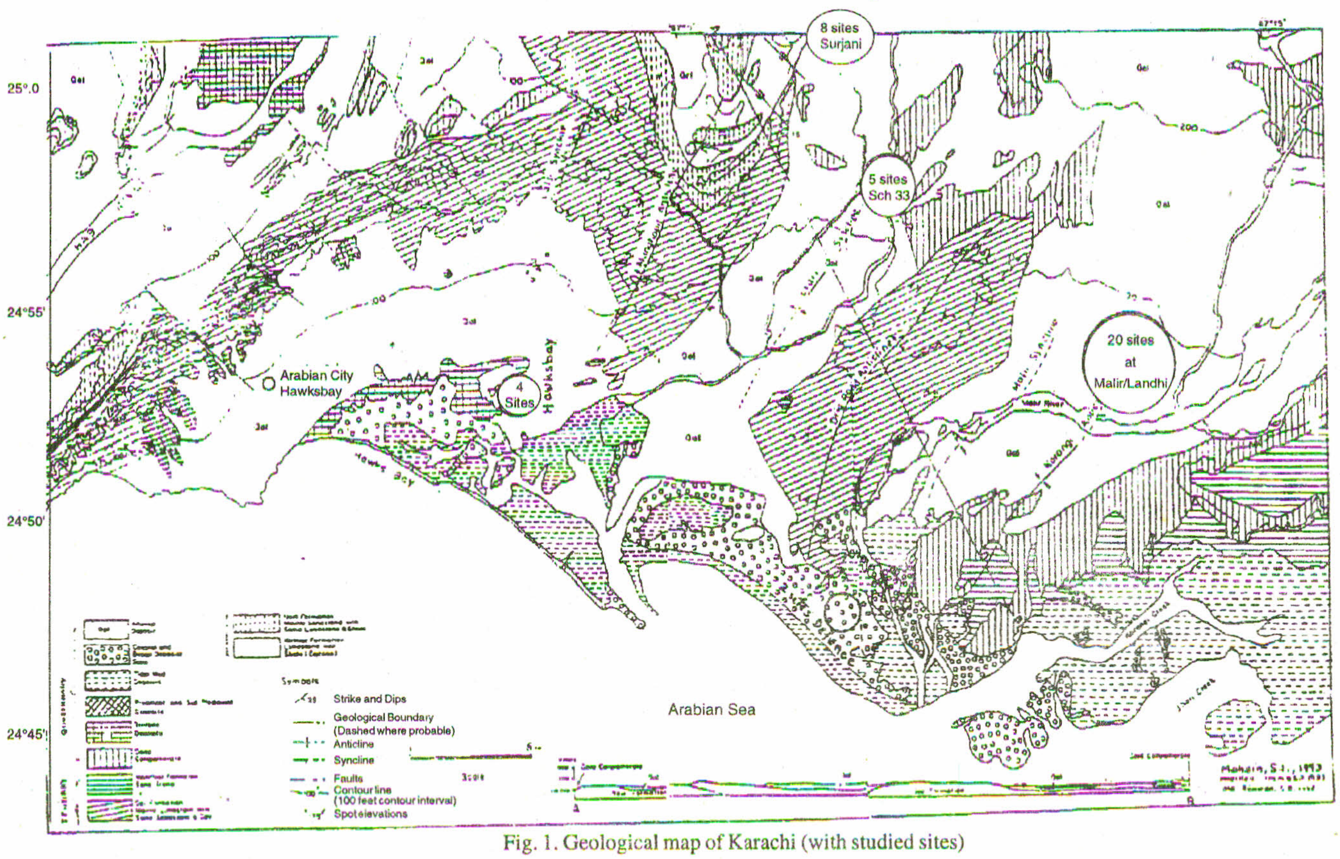

Fig. 1. Geological map of Karachi (with studied sites)

The grain size is represented as histograms or as cumulative curves. Both methods have their own advantages and many parameters helpful in understanding the engineering behaviour of the soil can be determined.

Results and Discussion

Malir and Landhi. Soil samples were collected from twenty different sites in Malir-Landhi area. The moisture content of the soils vary from 4.1 to 13.6% and the average moisture content is 9.1%.

Grain size of the 20 samples showed that all are well graded sand. All histograms (Fig. 2) show that the sands are mostly unimodal and only few are bimodal. All cumulative curves (Fig. 3) of the size analyses are S-shaped. The grains between 3 and 4 ϕ (approx. 0.12 to 0.06 mm) are around or less than 10% in each soil. The clay content, therefore, not be more than a few percent in any case.

Thus the upper three feet of Malir and Landhi soil show fairly good engineering characteristics. A well graded sand with an average moisture content of 9% will provide an overall satisfactory foundation.

In-situ strength test has been performed by a pocket penetrometer and an improvised crude penetration of a one-inch diameter pipe with the help of a 5 kg hammer falling freely from 30" height. The blows required to penetrate 4 inches of the pipe ranged from 5 to 17 blows and the average was 9 blows. The soil will sustain a load of 0.75 kg/cm to 1.75 kg/cm^2 as is found by the pocket penetrometer. The average of the tests performed at 20 sites comes out to be 1.33 kg/cm^2.

Both the tests, i.e. pocket penetrometer as well as our improvised penetration have their limitations. However, when plotted on a graph, the two methods correlate with one another (Fig. 4a & Table 1). Thus the field tests indicate a fairly good shear strength of the soils of Malir and Landhi areas.

A relationship has been investigated between the moisture content and the blows for penetration. A linear inverse relationship is found between the two parameters (Fig. 4b).

A soil profile of 120 cm thickness, 3 kilometers from Malir town, is studied by the Soil Survey of Pakistan. Their grain size analyses are in Table 2.

They also studied a few other properties significant for agriculture purposes Table 3.

TABLE 1.

	Penetrometer	Hammer blows
Arithmetical average of 20 tests	1.33 kg/cm	9
Average of same 20 tests from the graph	1.25 kg/cm	10

TABLE 2.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Classification
00-10	50	37	13	Dark yellow Brown loam
10-45	53	36	11	Dark yellow Brown loam
45-55	60	33	7	Yellow brown Fine sandy loam
55-120	10	64	26	Yellow brown Silty loam

TABLE 3.

Depth (cm)	$CaCO_3$ (%)	Organic matter (%)	pH
00-10	22.5	1.51	7.6
10-45	20.5	0.20	7.1
45-55	18.5	0.13	8.0
55-120	21.5	0.41	8.0

Surjani town. Eight sites have been visited in various sectors of Surjani town. Samples were collected from pits of 2 to 3 feet depth.

Moisture content:

Maximum	13.6%
Minimum	6.7%
Average of 8 samples	11.3%

Bulk density:

Maximum	2.14 gm/cm^3
Minimum	2.00 gm/cm^3
Average of 8 samples	2.08 gm/cm^3

Average of 8 samples. The grain size analyses of all the eight samples show that the soil is a well graded sand. There is invariably a small fraction of gravel present in the soil which is less than 10%. There is hardly any silt or clay content. The finest fraction of each sample between 3 to 4 ϕ is less than 10% of the soil. Particles less than 4 ϕ are clay and silt particles and are sieved in the pan. This fraction is less than one percent. The histograms indicate four samples to be completely unimodal. The other four samples are also almost unimodal.

To test the soil strength for bearing load, the pocket penetrometer was used. At the same time the improvised penetration test was also employed.

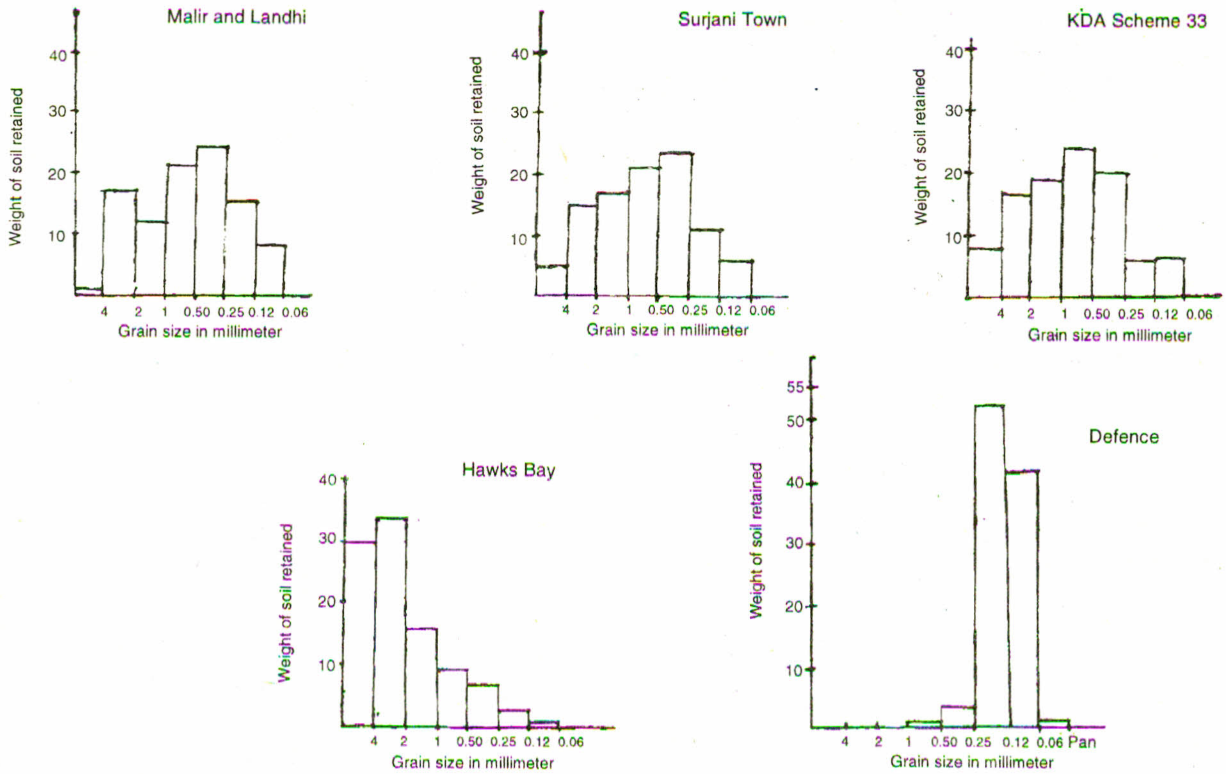

Fig. 2. Histograms of representative soil samples of Karachi region.

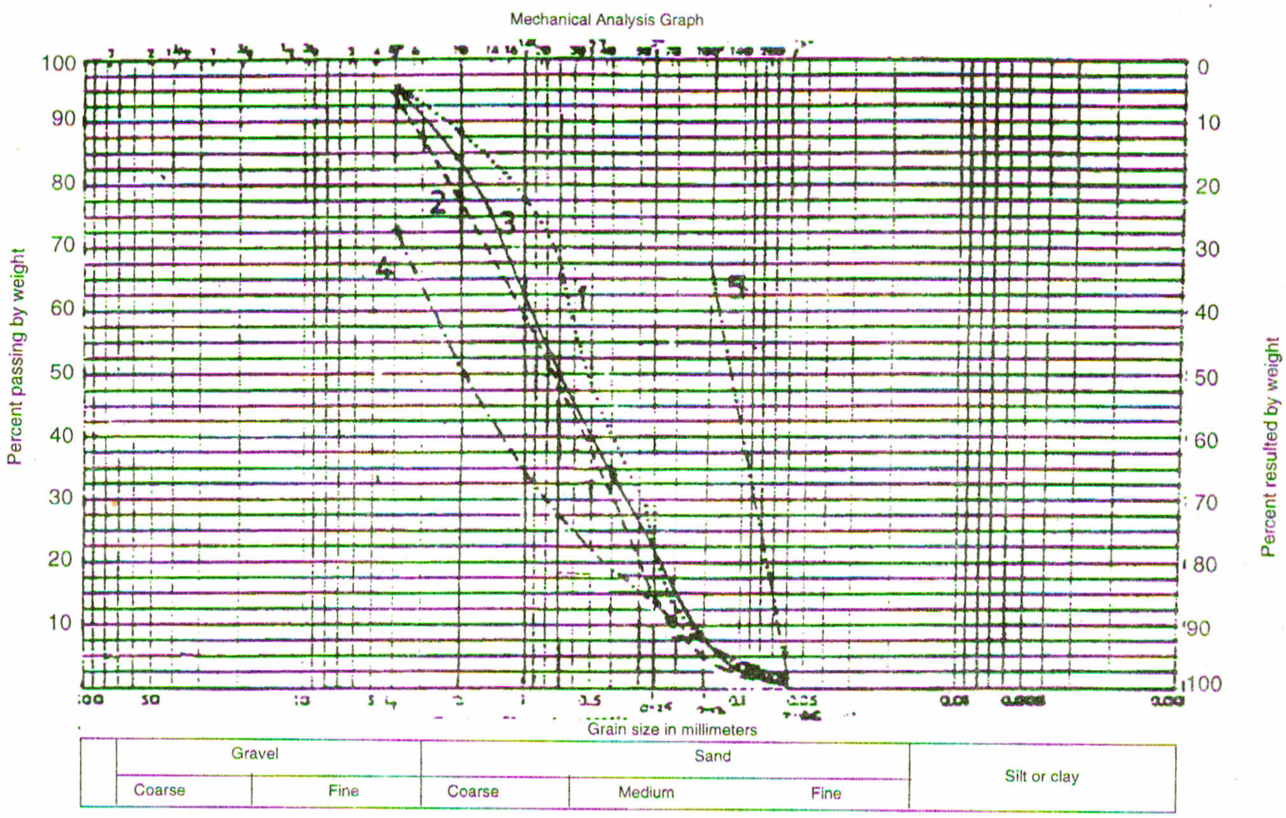

Fig. 3. (ii) Malir & Landhi .... Cu = 4.28, Cc = 0.75, Poorly graded sand. (ii) Surjani Town ------- Cu = 7.05, Cc = 0.80, well graded sand with gravel. (iii) KDA Scheme 33 ________ Cu = 7.14, Cc = 0.85, well graded sand with gravel. (iv) Hawks Bay-.-.-.-.- Cu=16.1, Cc=1.36 well graded sand with gravel. (v) Defence -...-...- Cu = 10.5, Cc = 1.50, poorly graded sand.

Following are the results of the eight sites (Table 4).

TABLE 4.

	Penetrometer	Hammer blows
Maximum value	1.44 kg/cm²	16
Minimum value	1.25 kg/cm²	9
Average of 8 samples	1.44 kg/cm²	12

When the results of the two tests are plotted against one another on a graph, the same average value is obtained, (Table 5).

TABLE 5.

	Penetrometer	Hammer blows
Average of 8 tests	1.44 kg/cm²	12
Average from graph	1.50 kg/cm²	12

It can be summarized that the top three-foot soil layer of Surjani area is a well graded sand with 11% moisture content and 2.08 gm/cm³ bulk density. It can bear a strength of 1.50 kg/cm², a fairly good soil for any kind of foundation.

KDA Scheme 33. Sampling was done at five sites in KDA Scheme 33 on either side of the Super Highway. The moisture content varies from 3.7 to 9.7% with an average of 5.3%.

The grain size analysis show the soil to be a coarse grained one. There is 5 to 10% of gravel in a well-graded sand. There is no silt-size or finer material in them. The sands are unimodal and show a smooth S-shaped cumulative curves.

To test the shear strength of the soil, blows of 5 kg hammer to penetrate 4 inches of the pipe were counted. The blows range from 15 to 40 with an average of 24 blows. The penetrometer test was not carried out. From the experience of the other areas where both tests have been performed, it can be said that these soils can bear a load of 2.5 kg/cm².

Hawks Bay. KDA is now developing Hawks Bay residential scheme. The area is a gentle plain inclined towards the sea and is composed of coarse-grained soil which is dominantly gravel. The gravel may be even more than 60% in some samples while 30% in others. The sand present in these soil is well graded. Thus the soil is classified as well graded gravel with sand.

The moisture content varies with 4.71% as the minimum value to 11.11% as the maximum. The average moisture content of these soils is about 6.8%.

The penetration test for shear strength was truly difficult to perform. To achieve a 4-inch penetration as many as 83 blows were needed while the minimum blows required at any site were 37. Thus, on average 67 blows were needed. It was obvious that the soil was too dense for the pocket penetrometer. The bearing strength of the soil is more than what penetrometer could measure. It is concluded that these soil can bear a load of over 4 kg/cm².

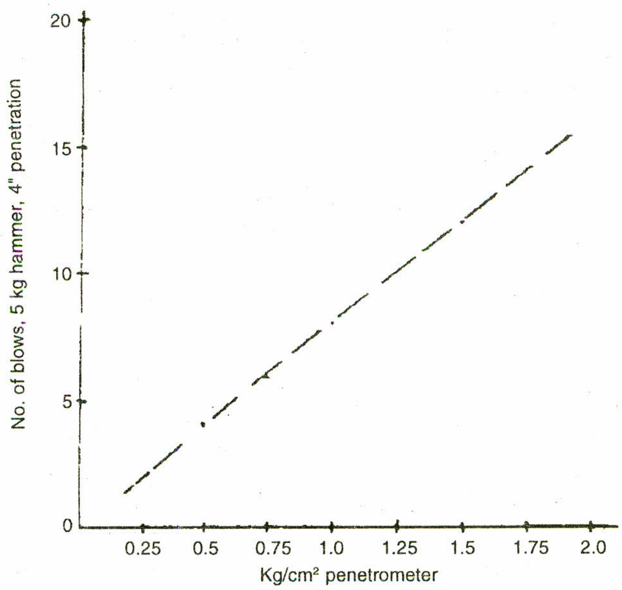

Fig. 4a. Correlation of results obtained from improvised penetration test and from penetrometer at 20 sites in Malir and Landhi.

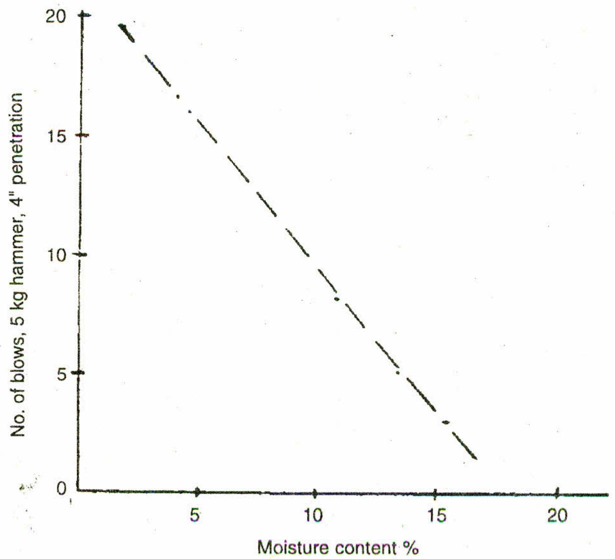

Fig. 4b. Penetration versus moisture content at 20 sites in Malir and Landhi.

Defence Housing Society. Three samples from Phase V and VI and two samples from Phase VII and VIII were analyzed. All the 5 samples are very fine sands. The sands are poorly graded and few may have silt. The moisture content in the two samples of Phase VII/VIII is 25-32% while those of Phase V/VI is 7%.

Penetration test in the Phase VII/VIII which are rather close to the shore indicated a very poor strength. Two blows of the 5 kg hammer were sufficient to penetrate the 4-inch mark of one-inch diameter pipe. The pocket penetrometer also plunged into the soil with ease and a bearing strength of less than 0.5 kg/cm^2 is estimated at three feet depth.

Conclusions

The soils of Karachi are coarse-grained ranging from sandy gravel, sand with gravel to fine sand. The silt and clay content is minor and in many cases negligible. The soils are non-cohesive with very few exceptions.

Soils are generally well graded; those which are classified as poorly graded are often on the margin of being well graded. The histograms are unimodal showing a uniform mode of soil formation.

The moisture content, bulk density and specific gravity of the studied soils are in the range considered satisfactory for foundation purposes (except for Defence)

The improvised penetration test alongwith pocket penetration proved a useful guide for the shear strength of the soils. The soils of Hawks Bay, Surjani and Scheme 33 have a good bearing strength, often more than 2 kg/cm^2. Soils of Malir and Landhi at three feet depth will bear a load only between 1 and 1.5 kg/cm^2 . Fine sand with high moisture content at Defence are weak, not able to bear even 0.5 kg/cm load at three-foot depth.

Foundations at Defence must be laid down at deeper levels, even for ordinary houses. For multistoried buildings and high-rise plaza, detailed investigations and extreme cautions are required.

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