02 Jun 1993, 9:00 am - 12:00 pm

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Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 1.20

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SYNOPSIS Jizan city is located on a salt dome surrounded by low-lying flat terrain consisting of silty-sandy soils. Being on the sea-shore, water immigrates to the surface leaving a salt crust on the top surface, which is known as 'Sabkha' soil. This salt bearing (saline) soil and the salt dome affected the foundation performance in the area. Buildings are experiencing foundation problems as a result of the low bearing capacity of the 'Sabkha' soil and the dissolution of the salt rock underneath the footings of the low-rise buildings, causing tilting of such structures. This paper would present the geotechnical aspects of the area concentrating on the foundation design and construction practice. Remedial aspects would be discussed to improve the performance of foundations.

SITE DESCRIPTION

Jizan city is located at the south side of the western coast of Saudi Arabia (Fig.1) at the foot of the Asir mountains in the Red sea graben. A great part of the city is built over a salt dome which forms a distinct physiographic feature in the area (Fig.2). The other part is located on a low laying flat area bordering the Red sea shore. The coastal plain is alternatively filled with sand and limestone deposits which belong to the Jurassic period. These deposits are overlaid by deposits of the Tertiary period which consist of continental series of salt deposits and marine calcareous rocks causing puffy surface called "Sabkha" .

The salt dome is elevated at about 10-50 m above the surrounding area forming rolling hilly terrain at the city old center. It has a highly disturbed material. At the bottom is a thick evaporite succession consisting of rock salt and gypsum. The dome core is made up of halite which is flanked by other members of the evaporite series. The salt rock is coarse grained white to light gray in color with average density of about 20 kN/M^3 and average compressive strength of about 10 MPa. Diapiric movements of salt in forming the dome have folded, faulted and contorted the overlying layers. These layers which are 6-15 m thick consist of gray, red and green siliceous and tuffaceous shale, sandstone and limestone with variation within short distance. The overlying shales are highly weathered and have converted into brecciated gypsferous hard to very stiff fissured clays. The broad depressions between the hill tops were filled with loose sands of aeolian origin. Most of the buildings, which consist of two to three storeys, are built on these sand deposits. Collapsibility of the soil was reported when soil gets wet [Ghazali et al 1986] as the result of both domestic drainage from leaks of water supply system, septic tanks and/or from the high intensity infrequent rain.

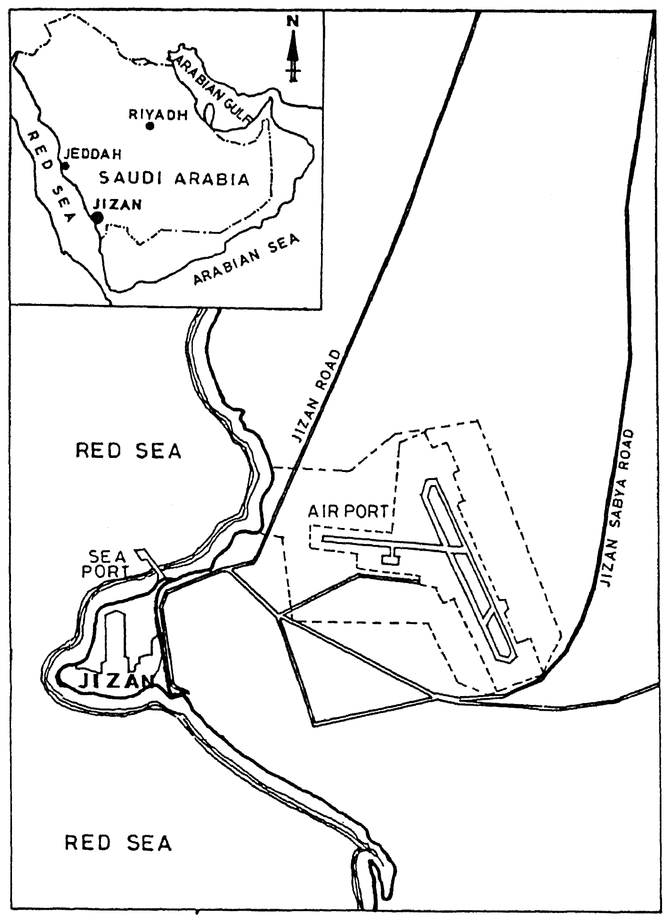

Fig 1 :Location map of Jizan

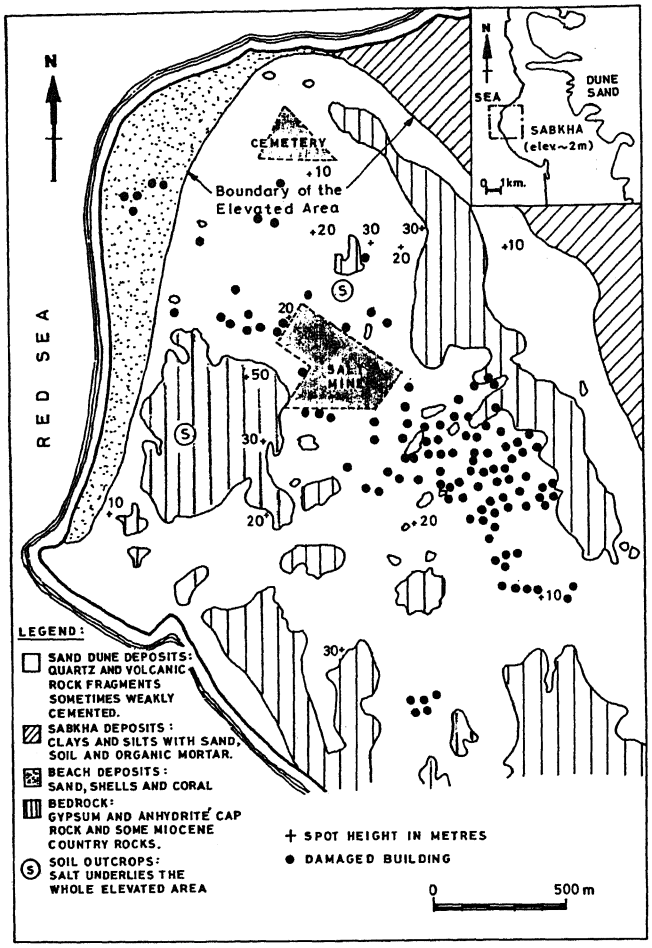

Fig 2 : Physiographic features of Jizan area and location of damaged buildings

The gypsiferous material is generally utilized as fill material to level up local depressions or to elevate the site for different constructional activities within the city. The geotechnical properties of these highly desiccated clays indicate that they are of high swelling potential. Such information is supported by the fact that buildings built on this clay fill material have developed cracks . Farther more, the evaporite series is susceptible to dissolution. This is evidenced by the wide spread occurrence of linear depressions which extend over considerable area. Sink holes were observed in some places which may be resulting from the manifestations of subsidence caused by the collapsing of top layers into underground cavities.

The Sabkha flats, on the other hand, are restricted to the supra- tidal part of the coastal plain . These flats are salt encroached plain underlain by deposits of loose and soft sandy silt and sand silt clayey mixture which are embedded with lenses of salt formation, anhydrite and gypsum.. Water table in this area is very close to the ground surface and of high salinity levels reaching higher levels than the sea water. As water immigrates to the surface by capillary action and evaporates, it leaves the salts on the ground surface. This process would form a low density fluffy loose structured soil characterized by low bearing capacity and possessing high settlement. The sabkha contain organic matter of appreciable amount adding to the complexity of the geotechnical problem [Erol and Dhowiyan , 1987].

The sabkha flat can be devided into three distingushed layers,[Hodgson et al,1989 and Erol, 1989] : *a)* top fluffy hard loose mixture of non plastic fine sand and silt crust of high halite content of a depth about 1.5 m, *b)* compressible soft or loose non plastic sandy silty and clay layer of an average thickness of 8.5m. This layer is variable in geometry,and *c)* a relatively firm layer of medium dense to dense fine sand. Typical average boring logs from several boreholes in the sabkha area are presented in Fig 3. The SPT blow counts lie in the range between 1-20 in the top two layers and are greatly affected by the low relative density of fine textured material with high moisture content. The loose submerged fine sands with traces of silt or clay, and clayey silt to silty-clay deposits in the area ,are typical of the problematic soils in the Jizan flat terrain .

EXISTING FOUNDATION PRACTICE

Jizan city is considered a small town with population not exceeding 100,000 people. Fishery and local commerce is the practice of the Jizanees .Buildings in Jizan city are mainly of two to three storeys in height. Old buildings are built with adobe bricks and wooden roofing. Recently constructed buildings are built with steel reinforced Portland cement concrete as structural frame and sand cement bricks as dividing walls. Water supplied to each dwelling is stored in waterproof under ground water tanks. Water is pumped to a distributing water tank placed at the highest point in the building. Water falls by gravity to the different units within the building. Overflow of the top water tank is common. All domestic water usage will flow to under ground septic tank usually placed on the other side of the building far away from the fresh water under ground water tank.

Strip footing, to support structural walls, is the main foundation of old buildings. The foundation is usually built by granite or basaltic stones. The relatively new buildings are built supported on reinforced concrete spread footings. Engineering practice is considered poor to fair for the old buildings while is considered fair to good for the new units.

THE PROBLEM

There are several geotechnical problems in the area causing several structural failures (see Fig.2). The failures ranged from minor cracks to complete collapse. Tilting of buildings up to 12° was reported. Several buildings were abandoned due to failure expectation from the tenants as a result of structural tilting. This foundation caused problem was investigated by several committees and engineering houses. One of the recommendations was to abandon the site by relocating the city in near area where less geotechni-cal problems exist. This decision was neither economically nor politically feasible.

The complex geotechnical problems in the area could be summarized as follows:

a) A dissolvable salt dome material made up of halite as the main mineral, of high bearing capacity when dry, once come in contact with water, from domestic water or natural water it dissolves leaving cavities of variable sizes. Water leakage from septic tanks is the main source of such water.

b) The water percolating through the salt formation would dissolve the salt causing cavities and under ground gullies . Depending where the location of the septic tank is , the tilt of the building direction could be expected.

c) A collapsible aeolian sandy soil between the depression on the salt dome area. Soil structure is intact due to salt, silt, and clay particles presence. Water would break such contact causing collapse of the soil structure, thus sudden large settlement take place followed by immediate failure.

d) A sabkha soil [salt encrusted flats] of low densities having very low bearing capacity causing excessive settlements. Crack of different patterns and sizes are found in the collapsible and sabkha areas.

e) Seismicity of the area around Jizan is expected to reach lateral ground acceleration of 0.15 g for 50 years return period of earthquake [Ali, 1983]. The 100 year period expectation is 0.20 g The non-cohesive character-istic of some soil layers and the saturated environment, make the area highly vulnerable to liquefaction [Hodgson et al 1989].

f) Vulnerable environment of high cholride and sulphate content which attack concrete foundation material and reinforcement steel bars.

FOUNDATION FAILURE

The unusual and poor soil conditions of Jizan city [Soil Testing Services, 1984] have led to foundation failures and associated structural damages to dwellings and buildings (Fig. 2). The pavements have also been subjected to deformation and failure. These foundation failures are attributed to the susceptibility of the salts to dissolve, the soils to exhibit large volume changes upon wetting, and presence of cavities, which are generally missed during routine subsurface explorations or developed after construction as a result of domestic water effect. The structures built on these deposits have suffered extensive damage ranging from tilting, minor to major cracking and even complete collapsing. The pavements have also been deteriorated and broken up. Such collapses are combination of tilting and multiple cracking initiated by excessive non-uniform settlement of the foundations. The main reasons for such failures are the poor soil conditions having extremely low bearing capacity, movement of subsoil water, salt attack, and excessive non uniform settlement. Normal or routine foundation practice shall not warrant safety of the foundations and superstructures. A specialized foundation design and construction practice involving soil treatment is essentially needed for Jizan area.

RECOMMENDATIONS

The sabkha deposits in Jizan area are such that they are generally difficult to improve [Ghazali et al,1986]. The main difficulties are high percentage of salt contents (13.4%), fine gradations (ML, CL) with loose state of relative density, high water table and high moisture content (Fig 3). It is recommended to replace the very weak sabkha deposits in the shallow depth 1-2 m range (sabkha crust), before laying structural foundation. This depth is considered to be critical for commonly used footings without undergoing excessive settlements.

There may be locations in the sabkha area where the soil thickness is large and the deeper layer may also be weaker and compressible. In such cases, it will not be sufficient to replace the upper 2 m layer and it will also be uneconomical to replace the entire weak deposit which may be as much as 10 m thick. When the foundations are required to be laid at such soil, in situ improvement of the scond layers (compressible sabkha) will have to be carried out. Rein Ruhr [1973] have suggested various soil improvement methods for use in Jizan area so that the foundations can be designed and constructed safely.

Five major factors should be considered during foundation design to overcome the geotechnical problem: *(1)* fluctua-tions of the high ground water table that vary with tides. *(2)* highly saline water which is quite aggressive against concrete. material *(3)* thickness of the loose upper layer is large (2m -10m thick) *(4)* presence of compressable layer below upper loose layer and above sabkha base layer, and *(5)* rock or rock-salt deposit below transition layer which is likely to creep and flow with time.

Considering various possible site conditions, the following soil improvement techniques are suggested for better foundation performance.

(A) To use vibroflotation technique for improving the low density sabkha crust layer. Addition of water and surcharge may enhance efficiency of vibroflotation (Fig. 4 A).

(B) The upper layer may be completely replaced by selected well compacted material and the use of shallow foundations (Fig. 4 B).

(C) In case of cohesive soil found in the upper layer, soil improvement may be done by preconsolidation method (Fig. 4 B).

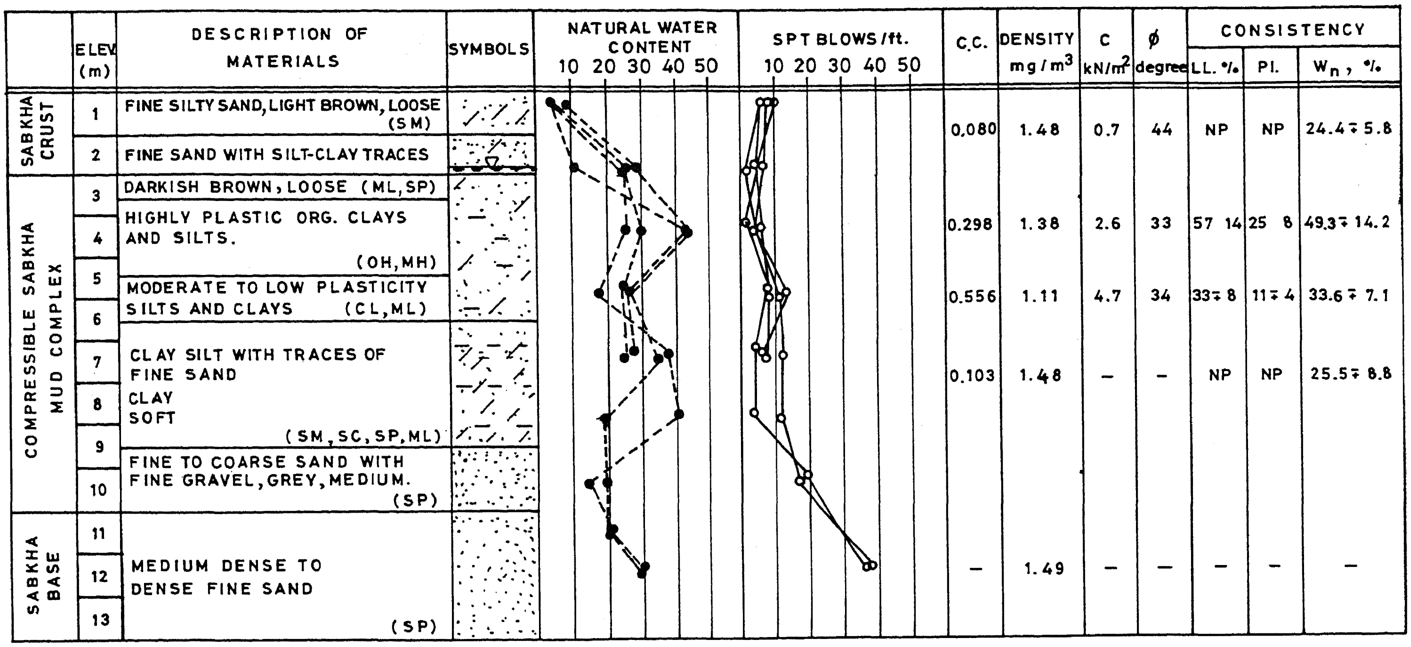

Fig.3 : Description of Sabkha layers and typical bore log results

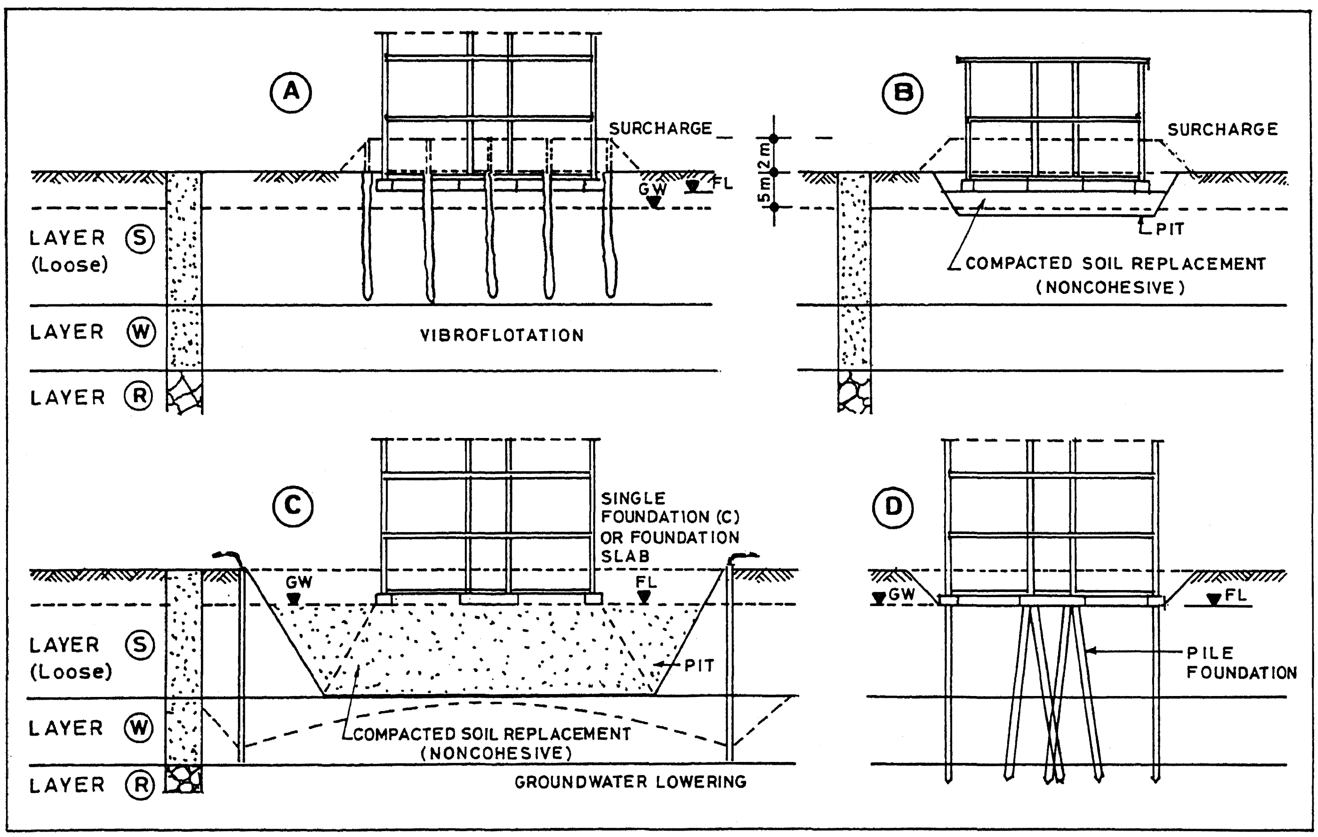

Fig 4 : Improvement techniques for foundation practice

(D) For high-rise buildings, pile foundations should be used with the consideration that piles are placed on rock and not on salt dome(Fig.4 D).

(E) If piles are not applicable, complete replacement of loose sabkh crust is used in conjunction with mat foundation. The slab of the mat foundation could safely undergo a total settlement of about 10 cm (Fig4 C).

(F) For all cases salt resistance portland cement concrete should be used for all underground structure elements with high quality water proofing techniques

(G) Construction should follow high standard practice with tight and close supervission.

(H) Water seepage from domestic useage should be prevented.

(I) Complete geotechnical investigation should be carried out for each construction project. An engineering judgement will be of vital importance.

The choice of an appropriate method will depend on particular site condition, especially the type and thickness of soil strata, and structural loads involved.

ACKNOWLEDGMENTS

The authors are grateful to the geotechnical companies for supply of data utilized in the paper. Thanks are also expressed to all those who assisted in the preparation of the manuscript.

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