

07 May 1984, 11:30 am - 6:00 pm

# Settlement of a Building Founded on Difficult Soil

Iqbal H. Khan
*University of Garyounis, Benghazi, Libya*

Fathi M. Layas
*University of Garyounis, Benghazi, Libya*

# Settlement of a Building Founded on Difficult Soil

**Iqbal H. Khan, Associate Professor and Fathi M. Layas, Lecturer**
**Department of Civil Engineering, University of Garyounis, Benghazi, Libya**

SYNOPSIS:- Many coastal areas in Benghazi have been reclaimed from lagoons. Quite often such areas are covered by debris, rubbish and other artificial fills over many years. The proximity of these deposits to the Mediterranian Sea coupled with the seasonal moisture variations has resulted in the formation of the so-called Sebkha soils having a high proportion of chemical content. Settlement records of a four storey building founded on Sabkha soil are prescuted for seven years. The building under went large settlement resulting in a tilt from the vertical. It is found that, for Sabkha soils, the measured settlement is larger than that predicted according to conventional theories. Based on this case study and constructions experience of many contractors in such areas, a number of useful suggestions are given for practicing engineers.

## INTRODUCTION

During the last decade a large number of buildings have been constructed in the city of Benghazi, Libya. Foundation conditions in the area are highly varying from place to place. A particularly difficult soil encountered in the coastal areas of Libya is called Sabkha soil. Damage due to excessive settlements is obvious in many buildings founded on Sabkha soils as evidenced by jammed doors, uneven floors, cracks and tilts in walls and dislocated service pipes. Settlement measurements of a building founded on Sabkha soils have been recorded for seven years. These are compared with those predicted according to conventional theories.

## THE BUILDING

The building selected for the present study is located in Salmani area of Benghazi (Fig.1). It is a four storey building constructed in 1976, (Fig.2) on a 20m x 20m mat foundation 50cm thick. The approximate weight of the building is 80,000KN exerting a gross bearing pressure of 200KN/m$^2$ at the foundation level. Borehole logs of the area have been obtained from the vicinity of this building (Fig.3). The range of particle size distribution of soil samples obtained from these boreholes is shown in (Fig.4)

The soil samples obtained were tested in the laboratory. The results are presented in Tables I and II. Some of these results have already been published (Khan and Hasnain, 1981).

## SETTLEMENT RECORD

Settlement observations were made on the four corners of the building with reference to an ordinance datum located in the area. Survey measurments were taken to an accuracy of 1.0 second in angular measurments and 0.5 m.m. in linear measurments. Measurments were taken at yearly intervals starting from March 1977. Unfortunately no record exists for the immediate, end of construction settlement. Table III gives the record of the settlement (maximum observed) of the corners of the building for each year.

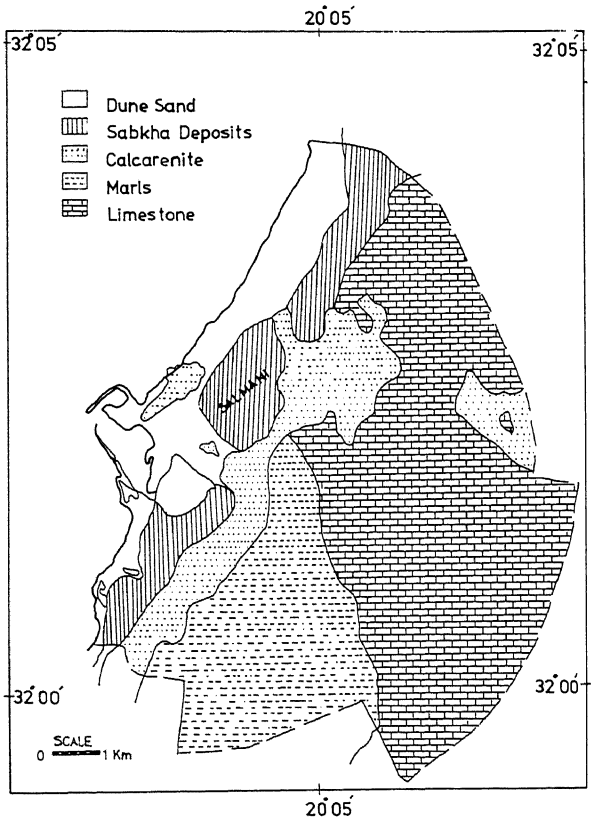


Fig.1 Location of building in Salmani Area.

Fig.2. Front view of the Building.

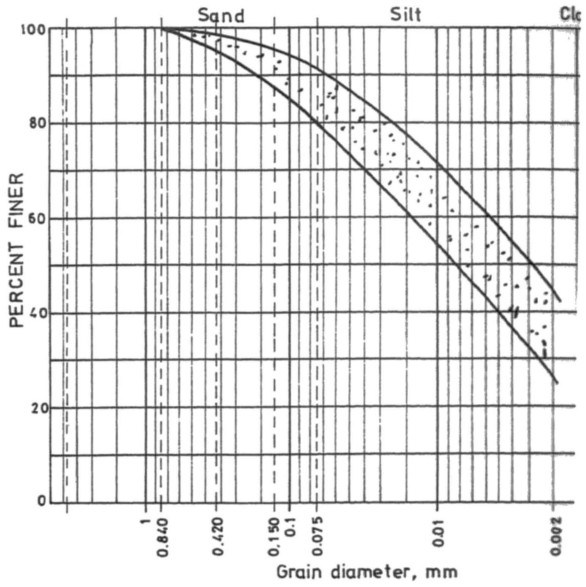


Fig. 4. Particle size of distribution of soil samples from site.

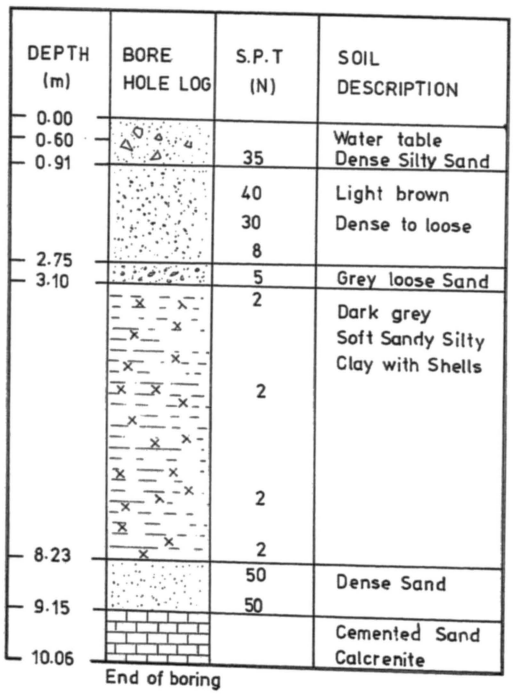


Fig. 3. Borehole log of the Site.

TABLE I Geotechnical Properties of Sabkha Soil

| Property | Range | Average |
|---|---|---|
| Liquid limit | 40-55 | 45 |
| Plasticity index | 10-30 | 15 |
| Soil classification | SM-SC, ML-CL | SM-SC |
| Cohesion(Undrained) $KN/m^2$ | 30-50 | 35 |
| Angle of internal friction (degrees) | 15-20 | 16 |
| Natural moisture content(%) | 24-56 | 40 |
| Natural dry density g/cc | 1.2-1.55 | 1.3 |
| Specific gravity of grains | 2.6-2.8 | 2.65 |
| $P_H$ | 7.8-7.4 | 7.2 |
| $m_v$ $(m^2/KN)$ x $10^{-5}$ | 40-13 | 21 |
| $C_v$ $(m^2/yr)$ | 0.427 | 0.427 |

1) Based on tests for at least 30 samples.

2) $m_v$ and $C_v$ values are for the particular pressure range at the centre of layer.

TABLE II. Chemical analysis of Soil and Water Samples

| Ions | | Soil p.p.m | Water p.p.m |
|---|---|---|---|
| 1. Calcium | Ca | 391 | 882 |
| 2. Magnesium | Mg | 359 | 1180 |
| 3. Sodium | Na | 3956 | 11500 |
| 4. Pottasium | K | 203 | 43 |
| 5. Carbonate | $CO_3$ | ---- | ----- |
| 6. Bicorbonate | $HCO_3$ | 92 | 366 |
| 7. Chlorides | Cl | 6702 | 20212 |
| 8. Sulphates | $So_4$ | 1441 | 3266 |
| 9. Nitrates | $NO_3$ | ---- | ------ |

p.p.m = parts per million

TABLE III. Settlement Record

| Time of observation (March) | Max.Consolidation settlement predicted(cm) | Measured (cm) | Angle of tilt measured (degrees) | Max. differential settlement calculated (cm) |
|---|---|---|---|---|
| 1976 | --- | --- | -------- | --- |
| 1977 | 4.2 | 7.0 | 1° 3' 30" | 36.9 |
| 1978 | 6.25 | 10.21 | 1° 5' | 37.8 |
| 1979 | 7.33 | 17.03 | 1° 7' 20" | 39.2 |
| 1980 | 8.7 | 19.21 | 1° 10' 8" | 40.8 |
| 1981 | 9.7 | 20.0 | 1° 12' | 41.9 |
| 1982 | 10.4 | 20.2 | 1° 13'10" | 42.6 |
| 1983 | 11.2 | 21.5 | 1° 14' | 43.1 |
| 1990 | 14.2 | ---- | --------- | --- |

Initial (elastic) settlement predicted is 37.5 cm.

Observations indicate that the two sides of the building have settled unevenly. In fact, one side of the building has settled into the ground well beyond its plinth level. The total vertical settlement of the building observed so far is 21.5 cm for the corner experiencing maximum settlement. The exterior walls of the building are out of plumb by about 29.0 cm (Fig.5). Presently the building is tilting at an angle of 1° 14' to the vertical.

SITE CONDITION

The foundation subsoil of the building is a typical Sabkha deposit. Such soils are incountered in many areas of the Middle East and North Africa (Fookes and Collie, 1977). Because of the trouble they give to engineers, such soils in U.A.E. are commonly called"Umm Samoom" - mother of poison (Glennie, 1970). Similar evaporite deposits have also been reported from and zones in U.S.A. and Australia, where the terms 'Playa' and 'Salinas' are more commonly used to describe these soils (Glennie,1970)

Sabkha soils in Salmani area of Benghazi consist of layers of very soft to soft grey silt and clay with organic matter and shells. This area was formerly a lagoon which was reclaimed by artificial fills over a long period. The ground water table undergoes large seasonal fluctuations. During the dry weather the water table recedes leaving salts and chemical deposits in the upper surface. Then salts are mostly varying quantities of carbonates, sulphates and chlorides of calcium, magnesium and sodium. In the subsurface environment of Sabkha several minerals are being continously formed (e.g. halite, dolomite, calcite). The crystal growth pressure exerted by the new minerals can be very large. Frequent moisture changes and presence of excessive salts in the soil is responsible for many kinds of foundation problems. (Newberry and Subramaniam, 1978)

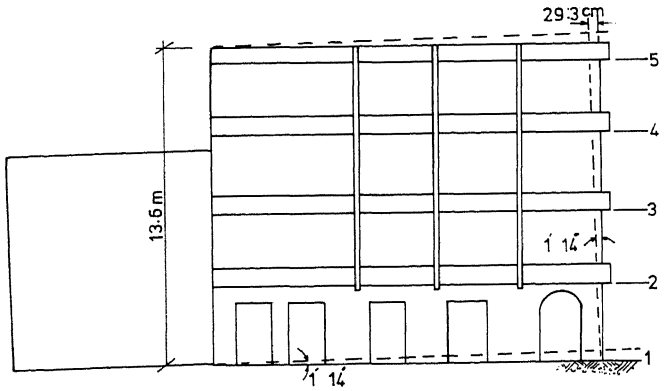


Fig. 5. Tilt of the Building

ANALYSIS

The total settlement of a foundation consists of two portions i.e. i) the elastic settlement ii) the consolidation settlement. The elastic settlement $S_i$, is obtained using the following expression (Janbu et al, 1956)

$$S_i = q \times B \times \frac{\mu_o \mu_1}{E}$$

where $q$ is the increase in stress due to building; B the width of the foundation; E the modulus of elasticity of soil; and $\mu_o$, $\mu_1$ are coefficients dependent on soil-foundation geometry. Difficulty arises in selecting a suitable value for E. Most workers however agree that E lies between 50 to 100 times undrained cohesion $C_u$. (Broms, 1972).

For the present case, $q$ = 200 KN/m$^2$, B = 20 m, $\mu_o$ = 1, $\mu_1$ = 0.3. For $C_u$ = 35 KN/m$^2$ (Table I) the elastic settlement $S_i$ obtained is within the range of 34.0 to 68.0 cm (assuming E to be between 50 and 100 $C_u$).

ii) The consolidation settlement $S_p$ is obtained from the following expression.

$$S_p = m_v . H_1 ( p_2 - p_1)$$

where $H_1$ is the thickness of consolidating layer, and $m_v$ is the compressibility of soil for the pressure range of $(p_2 - p_1)$; $p_1$ and $p_2$ being the initial and final

pressure respectively at the centre of the clay layer.

The soil profile assumed for the calculation of $s_p$ is shown in (Fig.6). The various parameters required are listed in Table I. $S_p$ thus obtained is about 15.6 cm, knowing $C_v$ the time-settlement curve (Fig.7) can be easilty drawn.

The calculated and observed settlement are fairly in agreement, the observed rate of settlement being faster. This may be due to the fabric of soil (Rowe, 1972) or due to the three-dimensional nature of field consolidation (Davis and Poulos, 1972). From the shape of settlement-log time curve (Fig.8) it is clear that the observed settlements are for primary consolidation (Simon,1974).

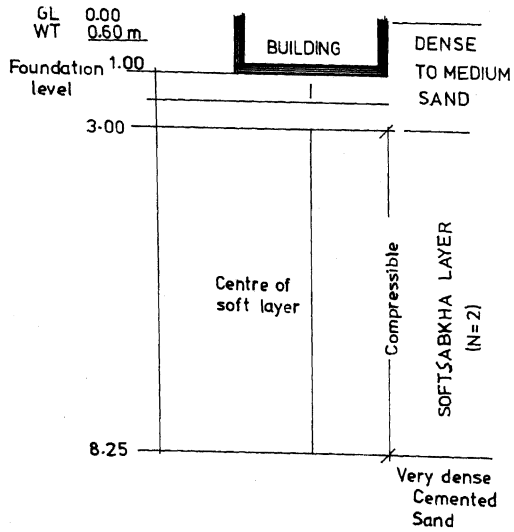


Fig. 6 Assumed Soil Profile

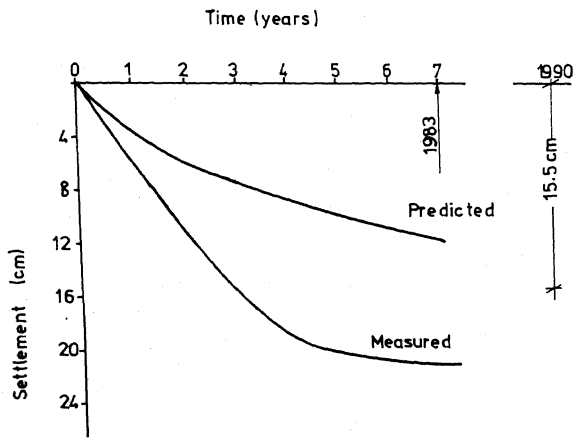


Fig. 7 Settlement Time Curve.

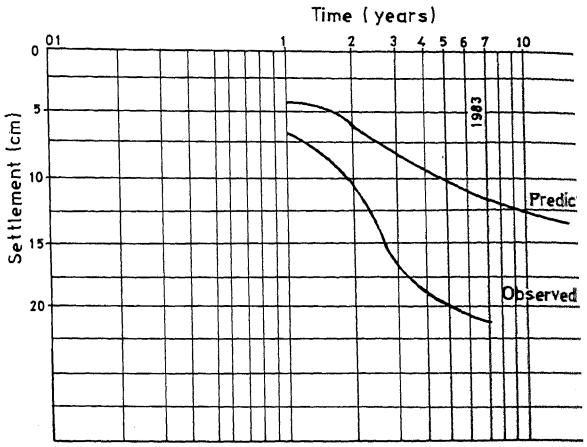


Fig. 8 Settlement Log Time Curve

Tilt measurements show that the differential settleme are large. The corresponding total maximum settlement (elastic plus consolidation settlement) would be abou twice the differential settlement (Skempton and Mcdon 1956). Since the observed settlements are relatively it is obvious that most of the settlement is the end-construction, (elastic) settlement. It appears that t the soft Sabkha soil, the value of E is probably of t order of 1750 KN/m$^2$ (50 times $C_u$) giving an immediate settlement of 68.6 cm; which accords fairly well with settlements computed from tilt measurements.

Some of the settlement may also be due to local yield (bearing capacity of failure) of the underlying Sabkh soil (Simon, 1974) which is very soft indeed (S.P.T. The ultimate bearing capacity as estimated from Terza theory is approximately 450 KN/m$^2$. The actual bearing pressure being 200 KN/m$^2$ the factor of safety is just above 2.0; which is inadequate, considering that the table is high from consideration of S.P.T values also bearing pressure should have been much less. Probably presence of the strong upper layer misled the designe to adopting a high bearing pressure. Very likely the investigation was inadequate.

CONSTRUCTION PRACTICES - LOCAL CONSIDERATIONS

The risk of foundation problems is appreciated by con tors operating in Sabkha areas. However there is no c dinated effort to share the experience and consequent uniform code of practice has evolved to tackle founda problems in Sabkha soils. From a detailed study of th special measures taken by various contractors operati Sabkha areas, the following results are summarised.

1. It is necessary to use sulphate resisting cement ( a minimum cement content of 370 kg/m$^3$) in the foun tion concrete. The aggregates used should be clean chemically inert; water used should be pure, not s Concrete should be dense so as to make it impermea A good cover should be provided for reinforcement preferably a few cms of sacrificial concrete. Sand grading for concrete should be carefully checked. ral sands are often poorly graded due to sorting b

wind or in the coastal areas by waves. Blending of sand from different areas or with other materials such as crushed rock fines may therefore be necessary.

2. For light structures upto 2 or 3 storeys generally shallow foundations are O.K. such foundations should be painted with hot bitumen to prevent chemical attack from soil and water. This practice is called 'tanking'. (Fookes and Collie, 1977). There is little danger of chemical attack if the ground water table is likely to remain more than 1.0 m below the base of the foundation.

3. Where rafts are provided the subsoil should be well-compated by heavy rollers usually at a moisture content 1 - 2% higher than optimum. Pre-loading can also improve this soil. For consturction of tanks founded on ground, a flexible foundation (not rigid) is more appropriate.

4. For heavy structures in Sabkha areas of Benghazi, use of piles is a common practice. Both cast-in-situ and driven piles have been successfully used. At many places limestone formation exists at depths not exceeding 7.0 m. In such areas bearing piles about 40 cm in diameter are commonly employed to bypass Sabkha layer altogether . Friction piles are used where Sabkha layers extend over great depths.

## CONCLUSIONS

Where Sabkha soils are likely to be encountered a very thorough site investigation work should be carried out. Actual settlements are likely to be more than those predicted on the basis of conventional theories. Also the initial settlement is likely to be a large fraction of the total ultimate settlement. Damage to the buildings can be avoided by designing for a lower bearing pressure or by improving the soil properties (compaction, preloading etc.) For heavy foundation loads, piles are adequate. The depth of water table and its seasonal fluctuations significatly affect the life of foundation concrete in Sabkha soils. Chemical attack, particularly due to sulphates should be prevented by taking suitable precautionary measures such as the use of sulphate resistant cement, achieving dense concrete, and providing a coating of hot bitumen allround the foundation concrete.

## ACKNOWLEDGEMENT

The authors would like to acknowledge the encouragement and facilities provided by Dr. Ahmed M. Shembesh, Dean, Faculty of Engineering, during the course of this study. Thanks are also due to Mr. Cz. Lipianin, lecturer in Surveying for his help in carrying out the Survey measurements.

## REFERENCES

1. Broms, B.B (1972). "Stability of flexible structures" General Report 5th European Conference Soil Mechanics and Foundation Engineering; Madrid, Vol.2, p.239-269.

2. Davis, E.H and Poulos, H.G (1972). "Rate of settlement under two and three-dimensional conditions", Geotechnique, London, Vol.22, No.1, p.95-114.

3. Fookes, P.G. and Collie, L. (1977). "Problems in the Middle East; Concrete in the Middle East". Concrete, Vol.9, p.1.

4. Fookes, P.G. and Higginbottom, I. (1975). "The classification and description of near shore carbonate sediments for engineering purposes". Geotechnique, Vol.25, No.2, p.406.

5. Glennie, K.W. (1970)."Developments in Sedimentology"; Elsevier, Amsterdam, 255pp.

6. Janbu, N; Bjerrum, L; and Kjaernsli B. (1956). Norwegian Geotechnical Institute Publication No.16, p.93.

7. Khan, I.H and Hasnain, S.I. (1981) "Engineering properties of Sabkha soils in the Benghazi plain and construction problems", Engineering Geology, Vol.17, p.175-183.

8. Newberry, J. and Subramaniam, A.S, (1978). "Middle East-sewerage projects for coastal towns of Libya" Quarterly Journal of Engineering Geology, Vol.11, p.101-112.

9. Rowe, P.W (1972), "The Relevance of soil fabric to site investigation practice", Geotechnique London, Vol.22, No.2, p.195-300.

10. Skempton, A.W and Mcdonald, D.H.(1956) "Allowable settlement of buildings", Proc.Inst.of Civil Engrs, pt.III, Vol.5, p.727-768.

11. Simon, N.E (1974) "Normally consolidated and lightly over consolidated cohesive materials", Review Paper in "settlement of structures", Wiley, 811pp.