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

Excessive Settlement in Buildings

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SYNOPSIS

The paper deals with three case studies where the foundations of buildings in the coastal areas of South India settled from 10 to 100 Cms resulting in excessive tilt or cracks in the superstructure. Details of soil exploration work carried out, description of the soil characteristics and the analysis of the causes of settlement are dealt with in this paper. The remedial measures suggested for the possible rectification of the damages are also presented.

INTRODUCTION

When the differential settlements in the foundations are over 6 Cms, often cracks develop in the superstructure. When the differential settlements are over 30 Cms, the tilt of the structure becomes visible. Excessive differential settlements could occur due to consolidation, shrinkage and creep failure. By such settlements the structures are not often rendered unserviceable. Identification of the causes of settlement therefore helps in implementing suitable remedial measures.

CASE - I

This particular case came up for investigation with the complaint filed by the owner of a five storeyed building in Cochin, Kerala stating that the neighbouring three storeyed building is falling on to his building. The complaint looked genuine as could be seen in Fig.1. The three storeyed building had a settlement of about 100 Cms on the side close to the five storeyed building. The investigation work was requested by the owner of the three storeyed building to defend the case.

Due to the limitation of space, the soil exploration could be undertaken only at two locations by the side of the three storeyed building. The soil profile, the soil properties and the loading details are given in Fig.2.

The three storeyed building was constructed on a strip raft foundation. The building settled by about 6 Cms within a period of three years. Since the differential settlements were within the allowable limits, no cracks developed in the structure. At this time, a single storeyed old building in the neighbouring compound was demolished and the five storeyed building was constructed on a full raft foundation. The clear gap between the foundations was only 1.5 M. Within an year after construction, excessive settlements were noted on the side of the three storeyed building close to the five storeyed building. The five storeyed building settled by 10 Cms on the side close to the three storeyed structure and by 3 Cms on the opposite side.

Fig.1 Settlement of the Building in Cochin

The soil exploration indicated that there is a marine silty clay layer present in the area from a depth of 2.5 to 18 M. Properties of this layer are given in Fig.2. The compression index C_c and natural moisture content W of the silty clay layer were seen to be of high order.

The settlement due to consolidation is worked out using the formula,

$$S = \frac{C_c}{1 + e_o} \times H \times 100 \times \log_{10} \left(\frac{p_o + \Delta p}{p_o}\right)$$

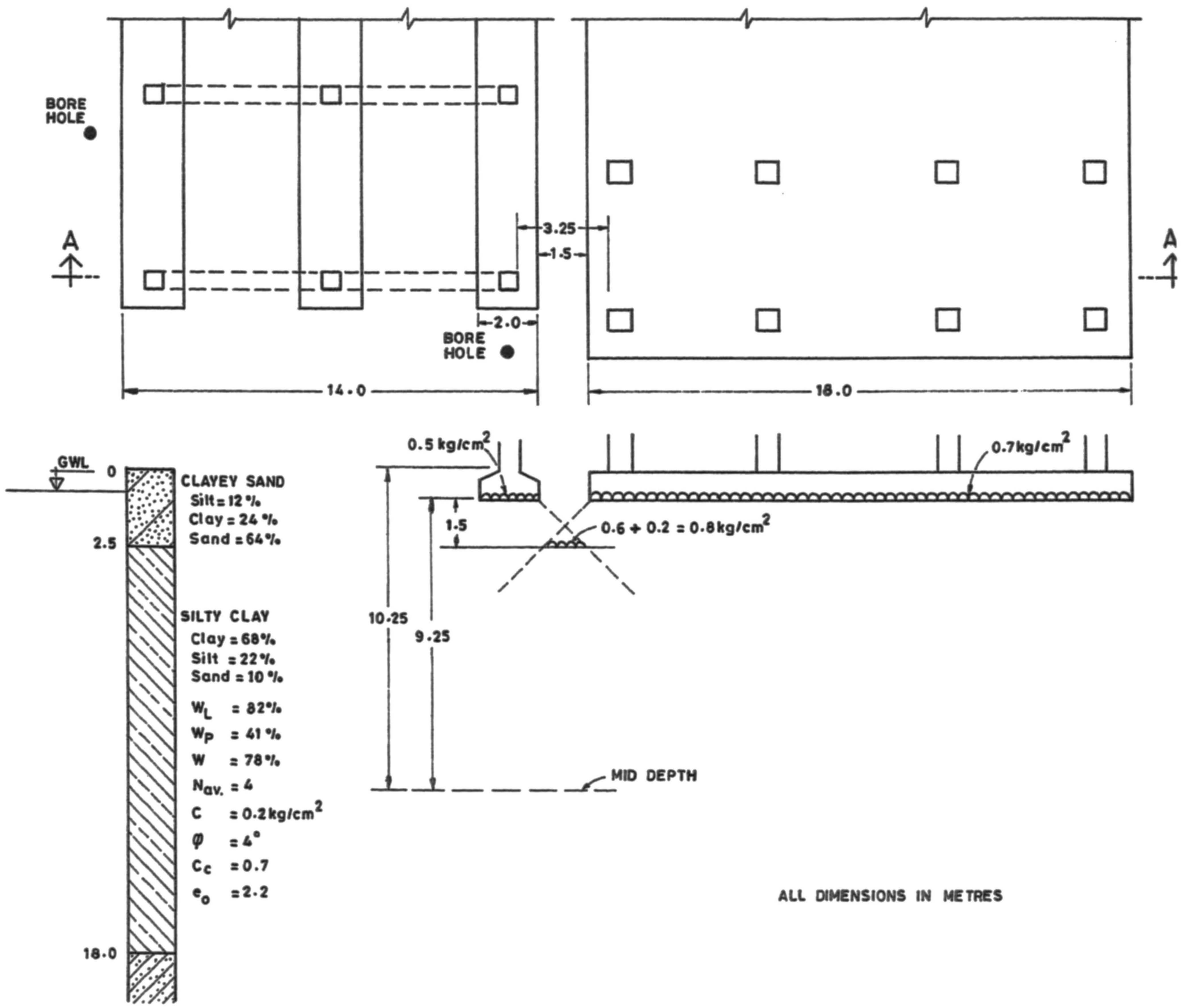

Fig. 2 Plan, Soil Profile and Section

where,

C_c - the compression index

e_o - the initial void ratio

H - the thickness of the layer undergoing consolidation

p_o - the existing load at mid-depth of the layer

Δp - the load increment at mid-depth of the layer

Submerged unit weight of soil of 1gm/cc is considered for computing the existing pressure p_o. The load increment at mid-depth of the layer is computed using Boussinesq equation (1). Accordingly, settlement of the strip raft foundation of 2 M width,

$$S_1 = \frac{0.7}{3.2} \times 15.5 \times 100 \times \log_{10} \left(\frac{1.025 + 0.05}{1.025}\right)$$

$$= 7 \text{ Cms}$$

Settlement of 18 M wide raft,

$$S_2 = \frac{0.7}{3.2} \times 15.5 \times 100 \times \log_{10} \left(\frac{1.025 + 0.42}{1.025}\right)$$

$$= 50.6 \text{ Cms}$$

Since the full raft is only 1.5 M away from the strip raft, the settlements of the former would induce further settlement in the latter.

It could be seen that nearly 90% of the settlement of the strip raft has already taken place. From the settlement time noted for the strip raft, it could be presumed that the settlement of about 45 Cms of the full raft would occur over a period of three years. The settlement that was induced in the strip raft being of the order of 100 Cms within an year of construction of the five storeyed building, the possibility of a creep failure was analysed.

Considering 45° load spread it could be seen from Fig.2 that the silty clay layer at a depth of 2.5 M in the gap between foundations is loaded upto 0.8 Kg/Cm^2; 0.2 Kg/Cm^2 from the strip raft and 0.6 Kg/Cm^2 from the full raft. The ultimate bearing capacity of the silty clay layer is computed using the formula,

$$Q_u = C \quad N_c$$

where,

C - Cohesion = 0.2 Kg/Cm^2

N_c - Bearing capacity factor = 5.7

Thus,

$$Q_u = 1.14 \ Kg/Cm^2$$

This indicates that, due to the construction of the five storeyed building the silty clay layer has been loaded to 70% of its ultimate capacity for a 1.5 M wide section. According to Peck, Hanson and Thornburn (3) creep in clays could occur at loads greater than half its ultimate strength. The full raft of 18 M width could absorb this settlement due to creep , while the 2 M wide raft tilted excessively to one side.

The analysis clearly indicates that the construction of the five storeyed building on the raft foundation violated the permissible limits of settlement and loading. The tilt of the three storeyed building was therefore caused by the wrong design of the foundation of the five storeyed building. With this data submitted the case was withdrawn by the owner of the five storeyed building.

The remedial measures for correcting the tilt was seen to be difficult due to the reason that the soil has been overloaded in one section. The possible solution was to induce a settlement in the three storeyed building on the opposite side. For this purpose loading on one side of the building and also the area opposite to the side were tilt has taken place were suggested. Sand drains to a depth of 18 M was also recommended to accelerate the settlement. Loading of 0.8 Kg/Cm^2 of the area close to the building for a width of 10 M which is vacant could induce a settlement of about 40 Cms. This would atleast prevent the leaning of the three storeyed structure on the neighbouring structure.

CASE - II

In this case three storeyed residential quarters constructed in Madras was seen to develop excessive settlement in the peripheral walls during the drought season. The drought occured nearly two years after the completion of the structure. No cracks or settlements were visible during the two year period. The magnitude of the damages in the structure due to settlement are indicated in Figs. 3 & 4. It could be seen that the ground floor wall has come out of plumb and the skirting has settled by nearly 20 Cms. Investigation conducted at a number of points in the area gave a generalised soil profile as indicated in Fig.5.

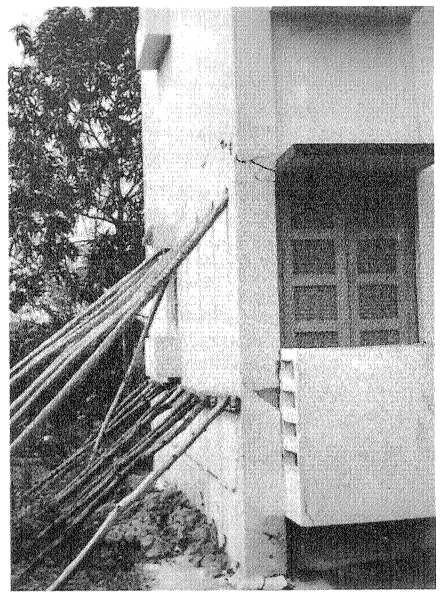

Fig. 3 Cracks in a three storeyed building in Madras

Fig.4 Settlement of skirting

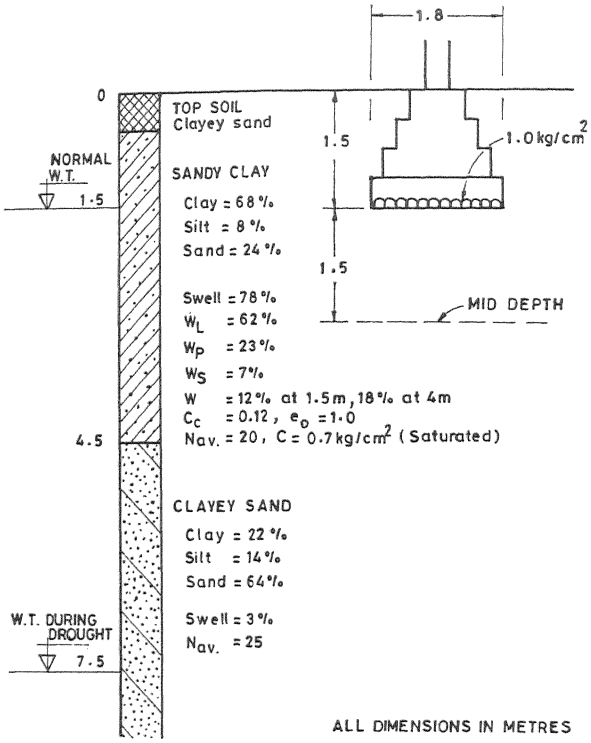

Fig. 5 Soil Profile and Loading Details

The consolidation settlement of the sandy clay layer computed as per the parameters given in Fig.5 is,

$$S_1 = \frac{0.12}{2.0} \times 3 \times 100 \times \log_{10} \left(\frac{0.45 + 0.4}{0.45}\right)$$

$$= 5.0 \text{ Cms}$$

This settlement which is within the allowable limits, indicates that the cracks have not developed due to consolidation. Observation of the shrinkage limit W_s of 7%, differential swell of 70% and the lowering of the water table from a normal depth of 1.5 M to 7 M below ground level during drought clearly indicates the cause of the settlement as that of the volume reduction due to the shrinkage of the sandy clay layer present upto 4.5 M. According to Holtz and Gibbs (4) when the shrinkage limit is less than 11% volume change of the order of 30% of the thickness of the layer could take place due to moisture variation. The settlement due to shrinkage of the sandy clay could thus be upto about 90 Cms. When the water table was lowered to 7.5 M, the moisture content became 12% at 1.5 M depth, 18% at 4 M. The moisture content at saturation was seen to be 38%. The water table normally being at 1.5 M the soil layer remained saturated. By lowering of the water table reduction in moisture content occured resulting in considerable volume reduction.

Treatment of the clay by lime has indicated an increase in the shrinkage limit and reduction in the swell pressure. Treatment by pressure grouting is seen to be ineffective due to the low permeability of the clay layer. Instead a mixture of 2:1 powdered unslaked lime and sand could be inserted into the soil by drilling boreholes of 100 mm dia at an interval of 1 M by the side of the foundation to the full depth of the expansive clay layer. Treatment of this nature undertaken for one of the structures was seen to be very effective (5). The treatment of the expansive sandy clay layer by lime in boreholes was recommended in this case. A layer of 15 Cms of lime and sand was also recommended to be placed below the skirting and flooring as the first layer above the expansive clay layer. Wherever the walls had become structurally weak, adequate strengthening was proposed. The R.C. beams and slabs were seen to have no damages.

CASE - III

In this case, the single storeyed portion of a residential building in Madras shown in Fig.6 settled and developed cracks during the drought season. A typical crack developed is shown in Fig.7. The foundation of the structure is on under-reamed piles. The single under-reamed piles were terminated on the clayey sand layer present at a depth of 4 M. Normal water table is at 1.5 M. During drought season the water table was lowered to 8 M below ground level.

Detailed investigation revealed the soil profile indicated in Fig.8. A layer of silty clay was seen to be present from a depth of 5 to 7 M only in the area where cracks developed. The settlement of the silty clay computed assuming that the entire load is transmitted at the bottom of the bulb of the pile is,

$$S = \frac{0.2}{2.4} \times 2 \times 100 \times \log_{10} \left(\frac{0.75 + 0.088}{0.75}\right)$$

$$= 0.8 \text{ Cms}$$

Fig. 6 Single storeyed portion of building which developed cracks

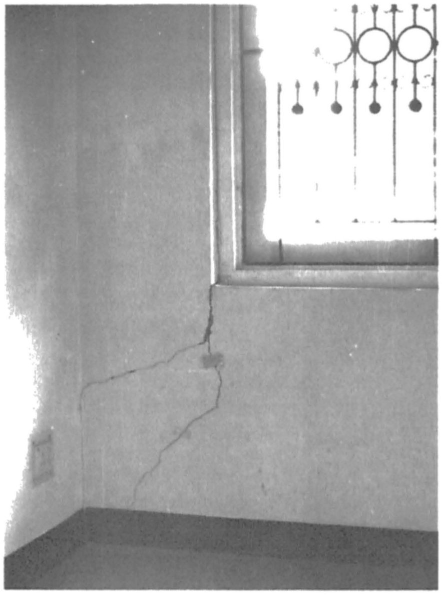

Fig. 7 A typical crack

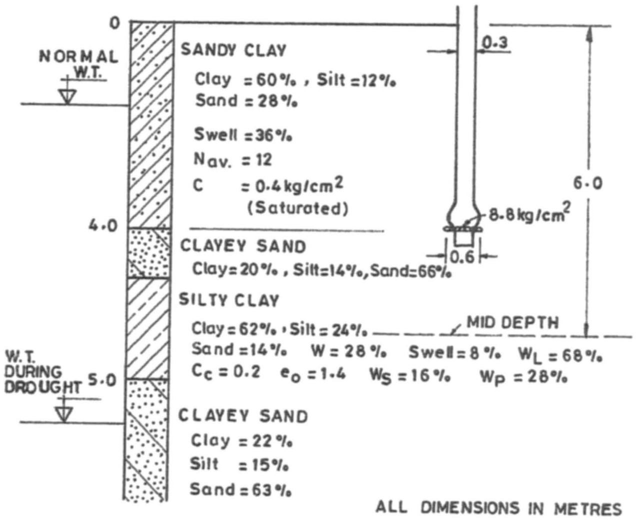

Fig. 8 Soil Profile and under-reamed pile

The settlement of the pile noted was of the order of 6 Cms. This indicated that the settlement occured not by the loading from the pile but by lowering of the water table beyond the depth to which the silty clay layer is present. The water content of the silty clay with the water table at 8 M was 28%. The water content at saturation was 42%. It could be concluded that the reduction in the moisture resulted in settlement of the layer causing the piles to settle. The settlement that occured could be considered to be the maximum that would occur since further reduction in the water content of the layer is not likely. The increase in volume of the layer on increase in moisture content would be small since the silty clay is not expansive as could be seen from the values of percentage swell of 8% and shrinkage limit of 16%. It was therefore recommended to undertake the repair of the building without any treatment of soil.

CONCLUSIONS

The three case studies presented give different reasons for excessive settlement in the buildings. The causes for the settlement are seen as consolidation, creep failure due to excessive loading, volume reduction of soil due to shrinkage and settlement due to reduction in water content. Remedial measures suggested in some of the cases are simple and others complicated.

REFERENCES

1. Bowels, E.J. (1977). Foundation Analysis and Design, 152 pp., Mc Graw-Hill Kogakusha Limited.
2. Brown, B.B., Boman, P. (1979). Lime Columns - A New Type of Vertical Drain. Proceedings of the Nineth International Conference on Soil Mechanics & Foundation Engineering Vol-1, 427 to 432.
3. Peck, R.B., Hanson, W.E., Thornburn, T.H. (1961). Foundation Engineering, 282 pp., Asia Publishing House.
4. Holtz, W.G., Gibbs, H.J.(1969). Engineering Properties of Expansive Clays, A.S.C.E. Transactions, Paper - 2814.
5. Verghese, A.C. (1977). Lime Treatment for the Gymnasium Building in Madras, Soil Exploration Report No.201.