International Conference on Case Histories in Geotechnical Engineering

(1993) - Third International Conference on Case Histories in Geotechnical Engineering

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

Remedial Measures to a Building Settlement Problem

A. Sridharan
Indian Institute of Science, Bangalore, India

B. R. Srinivasa Murthy
Indian Institute of Science, Bangalore, India

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 1.49

Remedial Measures to a Building Settlement Problem

A. Sridharan and B. R. Srinivasa Murthy
Department of Civil Engineering, Indian Institute of Science, Bangalore, India

SYNOPSIS A ten storeyed building, built on a subsoil of an onshore marine soil, was observed to be tilting away from the vertical. Extensive field and laboratory investigations were carried out to establish the reasons for the differential settlement causing the tilting. Though, nearly uniform pressure has been achieved at the foundation level, presence of a soft marine clay layer with varied thickness and location has caused the differential settlement. To arrest further increase in differential settlement, micropiling in the zone of higher settlement and additional loading and lowering of water table in the zone of lower settlement have been carried out as remedial measures. Controlled removal of the silty soil from below the foundation in the low settlement zone has reduced the differential settlement. The performance of the remedial measures has been monitored for more than two years.

INTRODUCTION

Recently, a ten storeyed (35 m high) building rectangular in plan of size 35 m X 20 m was constructed on an onshore marine clay soil in Madras, India. The construction of the building started in June 1985 and completed in December 1989. In March 1990, a plumb-line was established in the elevator lift well wall at the centre of the building to install elevators. With time, it was observed that the building was tilting. In four months between March and July 1990, the marked line on the wall was out of plumb by about 60 mm over a height of 30 m. At this stage, the problem was posed to the authors. A detailed field and laboratory investigations were carried out to arrive at the reasons for the tilt and to suggest suitable remedial measures to ensure the safety of the building. This paper presents the details of the field and laboratory investigations carried out, the remedial measures undertaken and their performance over the last two years.

DETAILS OF THE PROBLEM

As a first step, the structural design details of the building and the original soil investigation report were reviewed. The building has a 3 m basement construction below the general ground level. The foundation level has been at 2.4 m below the basement level i.e., 5.4 m below the general ground level. The ground water level has been at the foundation level during the month of July and fluctuates ±1 m over the year. The types of foundation adapted has been combined raft for about 60% of the area, combined footings and independent footings for the rest of the area. Fig. 1 shows a schematic plan and details of the foundations.

The original soil investigation report (not prepared by the authors) indicated that the depth of soil exploration was restricted to 6 m below the general ground level, which was grossly inadequate. The report recommended an allowable soil pressure of 14 T/m² at a depth of 2 m below the general ground level. The structural and foundation designer had extrapolated this value to get 20 T/m² at a depth of 5.4 m below the general ground level. However, the actual foundation pressure on soil varied between 16.5 and 18 T/m².

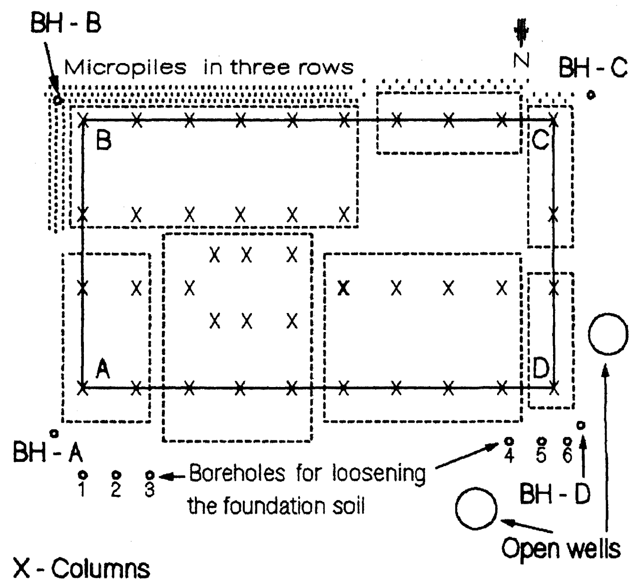

Fig. 1 Layout plan of the building at foundation level.

A review of structural designs of the various components revealed that the stresses in some of the components would exceed the permissible stresses for a tilt of about 230 mm in 30 m. Since no measurements were made prior to March 1990 it was not possible to assess the magnitude of settlement that has occurred at various points from the beginning of construction. So the problem was to assess the total settlements at various locations from the laboratory test results and loading pattern, the maximum tilt, the present level of tilt and to suggest the remedial measures to arrest further tilting of the building.

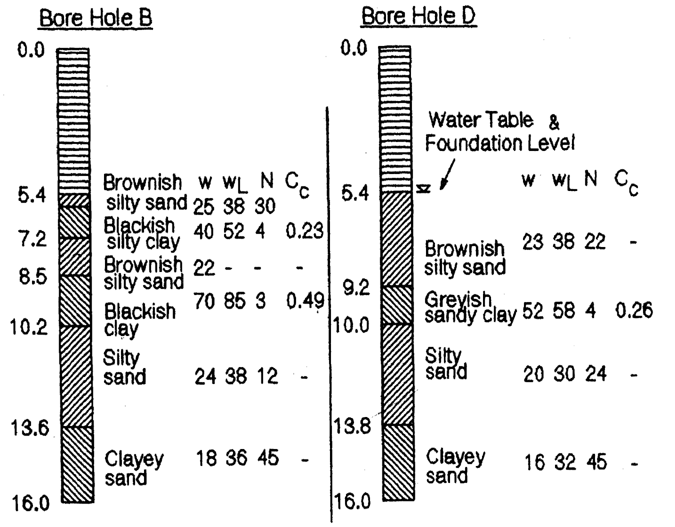

Fig. 2 Soil profile from bore holes at B and D corners

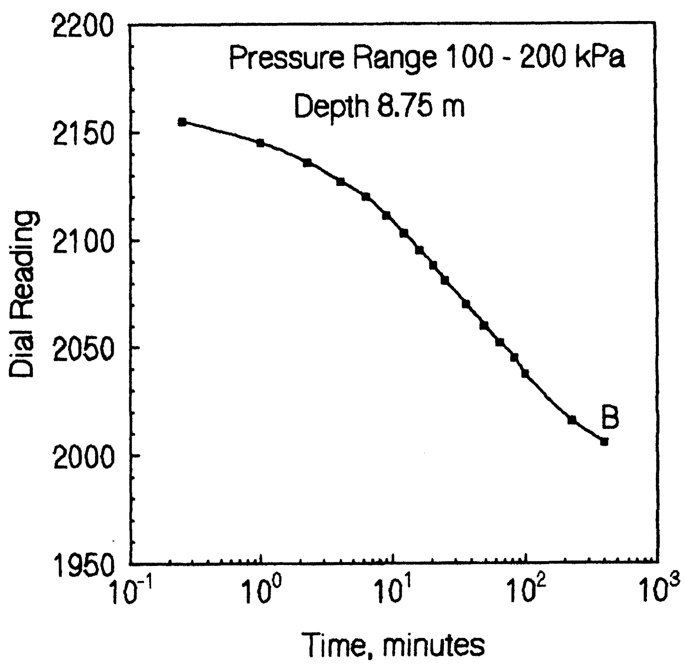

Fig. 3a Typical time versus dial reading plot of soft clay from location B

FIELD AND LABORATORY INVESTIGATIONS

Fresh soil investigations were carried out to a depth of about 20 m below the foundation level at four corner locations (A, B, C and D in Fig. 1) around the building. The soil profile indicated layers of silty clay, silty sand, soft clay, clayey sand and silty sand with varying thickness of each layer in the four locations. Fig. 2 shows the bore log details with N values, water content, liquid limit and C_c for the locations B and D forming the extreme conditions. The other two bore logs were also similar except for the variations in the thickness of different layers. Laboratory oedometer tests were conducted on the undisturbed samples from these locations. Fig. 3(a) shows the typical time-compression curve while Fig. 3(b) shows the typical e - log σ_v' curves.

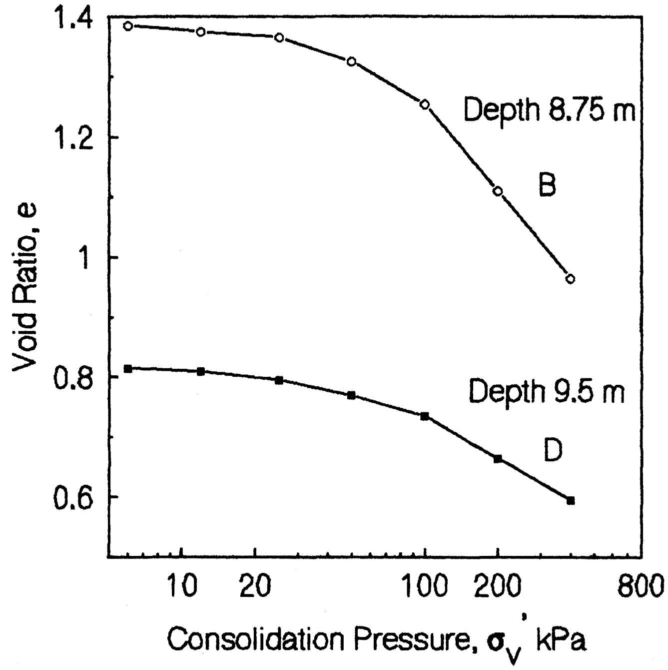

Fig. 3b Typical e - log σ_v' plots of the soft clay from locations B and D

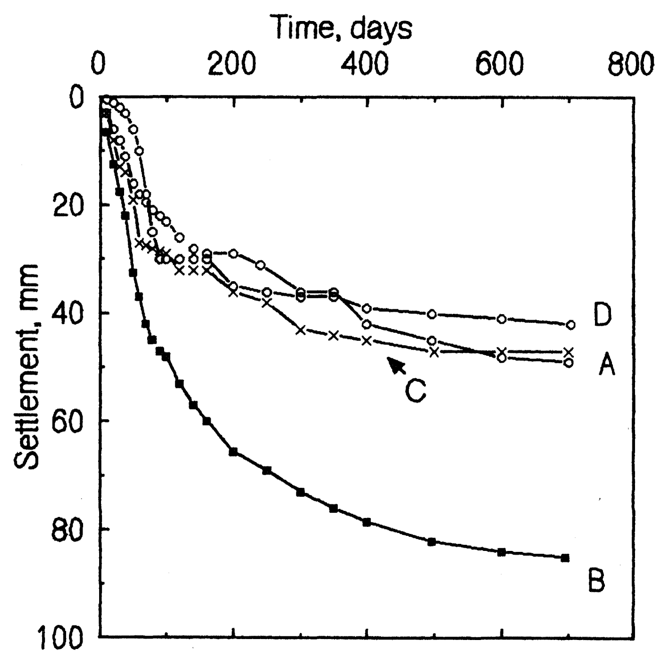

Fig. 4 Time versus settlement plot of the four corners of the building

Settlement measurements were started simultaneously in July 1990 at the four corners of the building. The settlements were monitored using mercury filled flexible nylon tubes in relation to an established permanent bench mark outside the building area. This method enabled recording of the settlement to an accuracy of ±0.5 mm. The initial part of the curve in Fig. 4 shows the thus observed settlements at all the four locations. During the first 38 days of observation, the corner B had a settlement of 22 mm against a settlement of 3 mm in corner D. The corners A and C had settlements of 11 mm and 14 mm during the same period. This resulted in a greater rotation in the North-South direction (about 11 mm in 20 m) than that in West-East direction (8 mm in 35 m). This was comparable with the rotation of the plumb-line which was about 20 mm in 30 m, during the same period.

From the laboratory test results and the known loading patterns the consolidation and compressibility behaviour of the soft clay layers were estimated for all the four locations. This included the time for primary consolidation, the maximum settlement and the relative differential settlement. It was concluded that the differential settlement between various points is primarily due to variation in thickness of the compressible layers and their relative location with respect to the foundation level. Since, the silty sand layers have undergone immediate settlement and their compression index values were very low, their contribution to the overall behaviour of the building were ignored. The estimated maximum differential settlement was about 240 mm in 20 m (North-South direction) over a period of 5 to 8 years. This would result in a maximum tilt of about 360 mm in 30 m which was more than the structural limit of 230 mm for some critical components. It is possible that substantial amount of settlement would have occurred during the time of construction itself. Since it was not possible to precisely estimate this, it was decided to undertake immediate remedial measures together with further monitoring of field settlements.

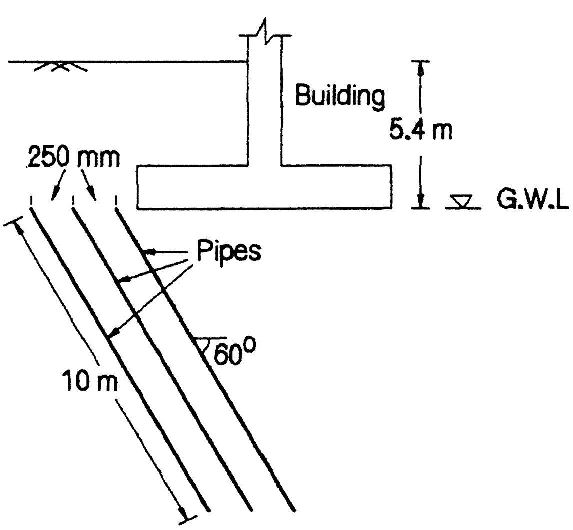

Fig. 5 Schematic orientation of micropiles.

REMEDIAL MEASURES

Since the four corners of the building were settling at different rates, it was decided to attempt for achieving a near uniform rate of settlement for all the corners. For this, the subsoil near the corner B had to be stabilised while the settlement rate in the corner D had to be increased. Based on engineering feasibility and considering various options the following remedial measures were adapted:

1. Driving micropiles in zone B and C: Three rows of micropiles inclined at an angle of 60° with the horizontal (Fig. 5), at a spacing of 250 mm c/c in both the directions were driven below the foundation level in the South-East quadrant of the building (Fig. 1). These piles were of 100 mm dia. and 10 m long galvanised steel pipes with bottom end closed with a shoe. While driving the piles outer row was driven first and the piles in the second and third row were staggered. Around the corner C the piles were driven along CB in two rows at a spacing of 250 mm c/c.
2. Additional loading in zone D: The North-West quadrant of the basement floor was loaded with sand bags for a height of 2.4 m and to an area of about 200 sq. m. This was to induce additional settlement in corner D.
3. Lowering of ground water table in zone D: As mentioned earlier the general ground water level was at foundation level during the months of July - August. Two open wells of dia 2.5 m were sunk to a depth of 15 m from the ground level. The locations are shown in Fig. 1. Using continuous pumping the ground water level was lowered and maintained at 10.4 m below the ground level. This gave an additional uniform loading of about 3-5 T/m^2 in the corner D and its surrounding area.

The above remedial measures were implemented with in the first 100 days. The subsequent settlement measurement (Fig. 4) indicated a substantial decrease in rate of settlement of the corner B and an increase in rate of settlement of the corner D. There was a slight increase in the rate of settlement of corners A and C, may be due to overall lowering of the water table, which reduced with time. Fig. 4 shows clearly the variations of differential settlement with time. However, the following additional remedial measure was adapted which induced increased settlements of corners D and A to maintain a near constancy of differential settlement between A and B.

ADDITIONAL REMEDIAL MEASURE

The additional remedial measure carried out was a totally innovative and new idea. Since there was a layer of silty sand of substantial thickness below the foundation level in the northern side i.e., along DA, controlled loosening and removal of soil was attempted from November 1990 onwards. For this, six bore holes of diameter 225 mm to a depth of 15 m below the ground level were advanced with specially made casing pipes. The casing pipes were perforated (25 mm dia. holes at 150 mm c/c) on one half of their face to a length of about 9.5 m from the bottom. This facilitated installation of casing pipe which had perforation only below the foundation level and facing the foundation. With pumping of water from the bore holes, the inflow in to the bore holes carried the silty sand from the region below the foundation. Initially, the collected silty soil in the bore holes was removed once a week. The average removal was about 45 kg per bore hole. Removal of 45 kg of silty sand from each of the three bore holes close to the column D could induce about 1 to 1.5 mm of settlement. Depending on the requirement from the field monitoring (i.e., how much settlement has to be induced in which corner of the building) periodic removal of soil was resorted to and was carried out till the stabilization of the corners B and C.

Fig. 4 indicates the monitored settlement for about 700 days which includes the effect of rectification measures. Had the rectification measures were not taken up immediately, the corner B would have settled much more and the corner D would have practically no settlement at all. During the implementation of remedial measures including the removal of the soil a close monitoring of all the structural components of the building was carried out. No structural distress was noticed. It may be mentioned here that because of very stiff structural elements like stiff foundations, beams and columns, short spans, etc., the whole building behaved like a rigid body. The measurement of tilt at opposite points and at different locations using plumb-lines confirmed the rigid body rotation. The building was commissioned for its slated purpose during May 1991.

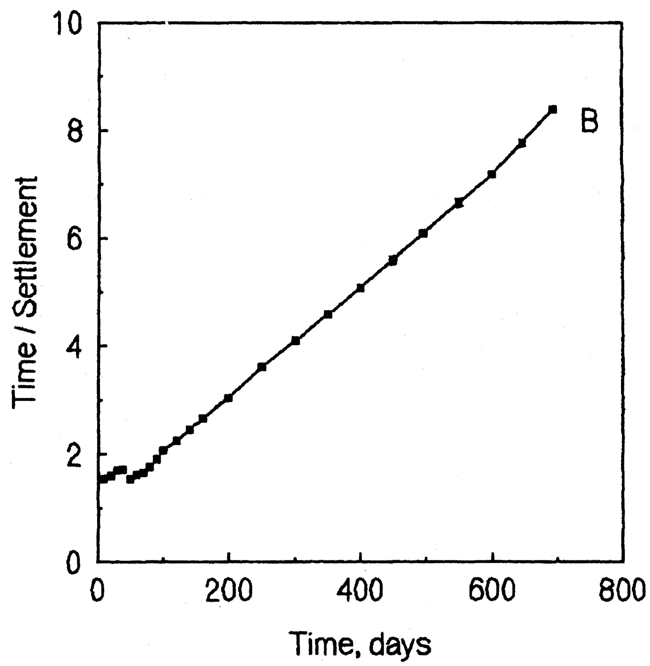

Fig. 6 Time versus Time/Settlement plot for the location B

ULTIMATE SETTLEMENT

The prediction of ultimate settlement was attempted for the corner B, using the field measurements. Sridharan and Sripada Rao (1981), Sridharan and Prakash (1985) and Sridharan et al (1987) have shown that the time - settlement behaviour can be represented by a rectangular hyperbola. Fig. 6 shows the time vs settlement of corner B, replotted in the form of time versus time/settlement. In this plot, the reciprocal of the slope at the latter part of the curve gives the ultimate settlement. From the Fig. 6 it can be observed that the initial part of the curve has a flatter slope (before treatment i.e., first 38 days) indicating a much higher settlement. After treatment the slope (after 100 days) has gradually increased to become a constant. From this, an ultimate settlement of about 110 mm is predicted. This compares against a possible settlement of about 300 mm based on initial slope which was much flatter before treatment.

CONCLUDING REMARKS

The differential settlement causing tilting of the building was due to variation in the thickness and their location in relation to the foundation level of the soft marine clay. The observed rate of tilting warranted immediate action and also control of the differential settlement to within certain limits. From the engineering feasibility, three immediate remedial measures were implemented. This brought down the rate of differential settlement. A new innovative technique of controlled loosening and removal of silty soil from the zone below the foundation was adapted to induce higher settlement in certain areas which controlled the differential settlement.

REFERENCES

Sridharan, A. and Prakash, K (1985), "Improved rectangular hyperbola method for the determination of coefficient of consolidation", Geotechnical Testing Journal, Vol. 8, No. 1, pp.37-40.

Sridharan, A. and Sripada Rao, A. (1981), "Rectangular hyperbola fitting method for one dimensional consolidation", Geotechnical Testing Journal, Vol. 4, No. 4, pp.161-168

Sridharan, A., Murthy, N. S. and Prakash, K. (1987), "Rectangular hyperbola method of consolidation analysis", Geotechnique, Vol. 37, No.3, pp.355-368.