Settlement of A Six-Story Building on A Soft Organic Clay Deposit in Kathmandu, Nepal

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ABSTRACT

This paper presents the result of the settlement observations of a six-story building built on raft footing on a compressible organic clay deposit known as Kalomato in Kathmandu, Nepal. Settlement was recorded through elevation readings on markers on several reinforced concrete columns spread along the periphery of the building. Readings, taken weekly by means of a leveling instrument, commenced on February 21, 2006, or 136 days after the construction started, and ended on day 441, more than two months after the final application of the construction load.

The records suggest that the building settled in a non-uniform fashion, and that the settlement pattern changed gradually over the monitoring period. The building dipped initially towards the northwest then towards the west direction at the end of the monitoring program, with the highest settlement at one part of the building being 121 mm while the lowest being 48 mm. Finite difference analysis used to provide settlement estimation at the initial, unrecorded stage of the construction, resulted in estimated 144 mm maximum settlement at the end of the monitoring program, well beyond the conventional standards set for maximum allowable settlement for mat foundation on clay.

Key words: Raft footing, soft organic clay deposit, settlement

1 INTRODUCTION

The widely spread lacustrine organic soil deposit locally named Kalomato (meaning 'black soil' in Nepali) in Kathmandu Valley often posed construction limitations due to its low shear strength and high compressibility. Soil investigations conducted at different locations of the Valley revealed that the allowable bearing capacity for isolated footings on Kalomato could be as low as 20 KN/m^2, with settlement criterion to be the governing factor. Though in many areas in the Valley suitable bearing layers in the forms of sand, silt or low plastic clay layers could be found, there are areas where Kalomato virtually exists from the surface to large depths, forcing foundations in these areas to rest right above it.

In recent years Kathmandu has seen a steep increase in the number of highrise apartment buildings reaching well beyond ten stories. These buildings were generally built on mat footings underlain by deep piles. When this study was conducted in 2006, however, the buildings in Kathmandu rarely exceeded six floors. Most buildings were built on isolated footings, or to a much lesser extent, mat footings, even in areas where thick Kalomato deposit was found near the ground surface. Except for the very old buildings, the buildings in Kathmandu rarely showed excessive damage associated with large settlement, even on those constructed above thick Kalomato deposit. The absence of problems normally associated with excessive settlements was intriguing and forced one to wonder whether the large settlements predicted from the results of soil tests on Kalomato samples would actually translate to building settlements at the same degree of severity. In the pursuit to find the answer to this question, a plan was envisaged to carry out a settlement monitoring program on a building on Kalomato deposit that was in its early stage of construction. The existence of a building settlement record would provide valuable information for the design of foundations on Kalomato, especially since to the authors' knowledge, no such information was available prior to this study.

Permission was obtained to carry out a settlement monitoring program on a six-story building which was being constructed to be the Civil Saving and Credit Co-operative Limited Head Office building. The building was located in Kalimati area where Kalomato deposit existed from the ground surface to deep depths. The building was made of reinforced concrete and has a basement on raft footing placed at 2.5 m depth. The raft was supported by 102 bored piles, each 5.4 m long. Measurements of settlement started soon after the casting of the basement's columns, early enough for the intended purpose. Final measurements were taken more than 100 days after the roof slab was cast.

2 BUILDING AND FOUNDATION LAYOUT

The floor plan of the building can be seen in Fig. 1.

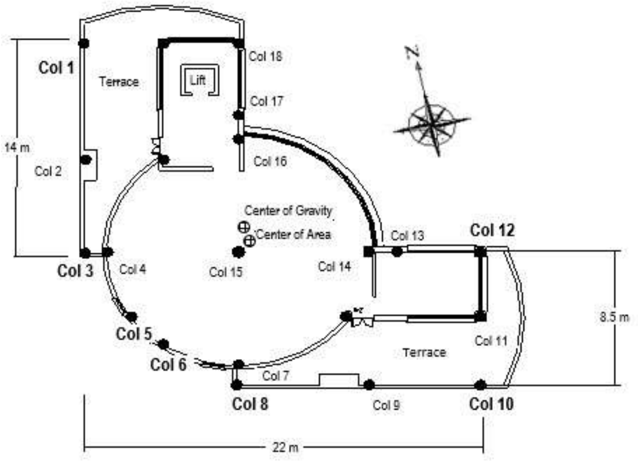

Fig. 1 Floor Plan of the Building.

The total area of each floor was 310 m^2. The building has 21 columns of circular section, each having a diameter of 0.6 m, except for the column at the center of the building which had a diameter of 0.7 m. The length of the columns were 3.2 m, except for those in the basement where they were 3.65 m long. The center of area and center of gravity of the building are indicated in the figure, the latter being determined from the dead weight of the building. The center of gravity was found to be 1 m north of the center of area, due to the presence of the shear walls around the lift shaft and the staircase on the northern side.

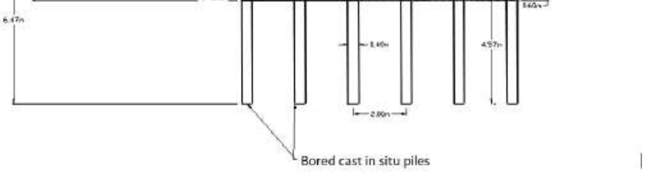

Fig. 2 Longitudinal Cross-section of the Foundation.

The longitudinal section of the foundation can be seen in Fig. 2. The RC slab of the raft footing was 450 mm thick. The bored piles under the raft were 5.4 m long and 0.4 m in diameter, placed at a distance of 2 m from each other. The purpose of the piles were mainly to provide anchoring against potential seismic load and not to increase the allowable bearing capacity of the foundation, since at 7.9 m depth the pile tips rested entirely on deep and soft Kalomato. The rigidity of the footing was enhanced with the provision of 1.2 m thick tie beams above it. Basement floor of 150 mm thick was cast over the tie beams, creating a void of 1.2 m high between the raft and the basement floor.

3 NATURE OF SUBSOIL

Information on the subsoil was obtained from soil investigation work conducted for the design of the particular building. Three boreholes were drilled to 30 m depth. The disturbed and undisturbed samples from the boreholes were utilized to determine the soil properties, deformation and strength characteristics. The organic content was determined by Loss in Ignitation Method according to ASTM D 2974-87. The soil investigation of one of the boreholes near the center of the building was performed in more detail for the thesis work of Upadhyay (2005) and the summary of results are shown in Fig. 3 and Fig. 4.

Except for the organic soil of low plasticity (OL) found from the ground surface to about 2 m depth, the subsoil consisted of slightly overconsolidated organic soil of High Plasticity (OH according to USCS) up to the end of the borehole. Thin laminated structures were observed at depths of 12 m, 15 m and 18 m, however based on the soil colour and properties the subsoil could be simplified into just three layers, namely the upper layer from the ground surface to 6 m depth, the middle layer from 6 m to 15 m depth and the bottom layer from 15 m to 30 m depth. The organic content of the soil had been found to increase with depth, with the upper, middle and bottom layers having organic contents in the range of 5% and 6%, 7% and 8%, 10% and 13%, respectively. The soil properties were strongly affected by the presence of the organic matter, i.e., water content, liquid limit, plasticity index, void ratio and compression index increased with increasing organic content (hence they increased with depth), while the specific gravity, bulk density and dry density decreased with increasing organic content, and hence they decreased with depth.

4 LOADING HISTORY OF THE BUILDING

The time history of the construction load applied on the base of the excavation is presented in Fig. 5.

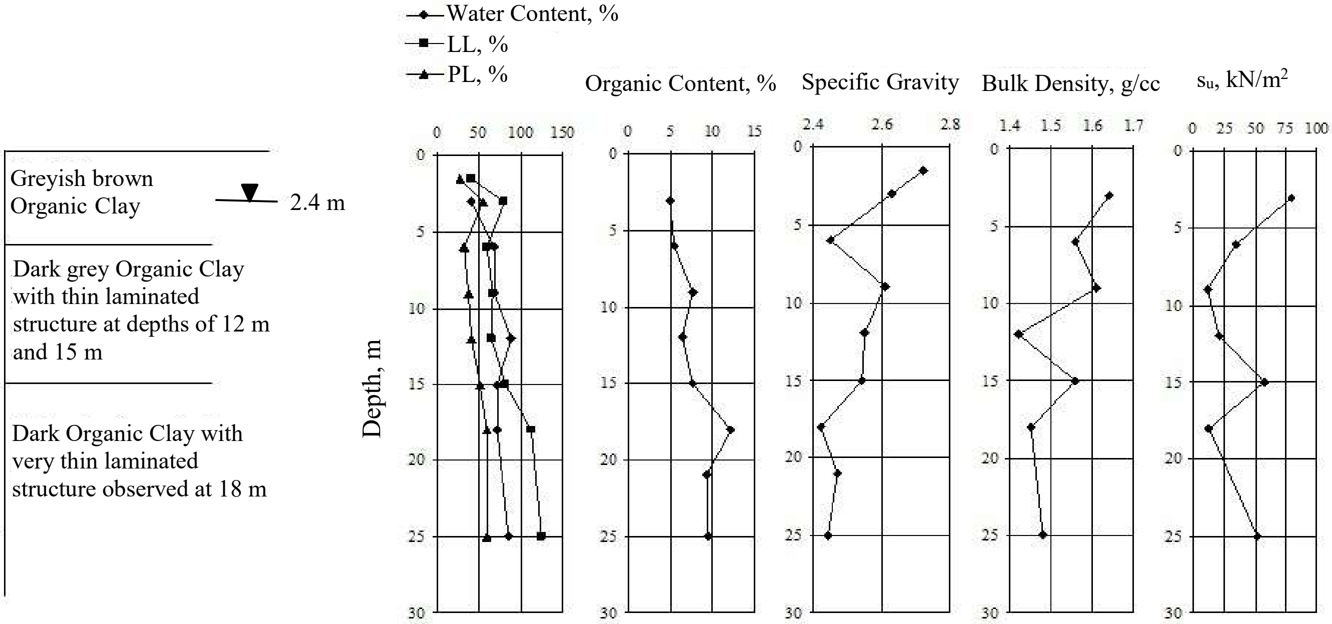

Fig. 3 Soil Profile at the Center of the Building. ((Upadhyay, 2005)

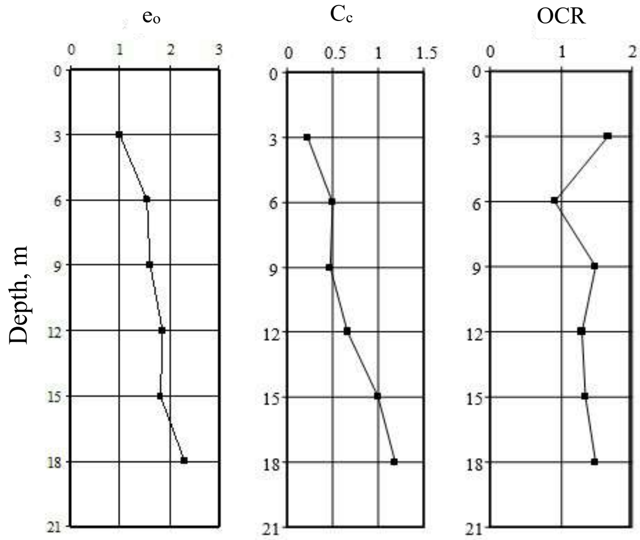

Fig. 4 Variations of Consolidation Parameters with Depth at the Center of Building (Upadhyay, 2005)

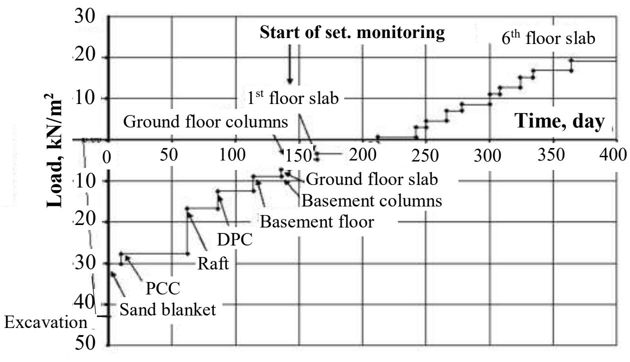

Fig. 5 Load vs. Time During Construction Period.

The graph commenced with unloading equal to 42.9 kN/m^2 due to the removal of 2.5 m thick overburden. Loading began with the application of 100 mm sand blanket at the base of excavation followed by the construction of 100 mm PCC slab. The elapsed time for each stage of construction in Fig. 5 was marked with reference to the date when the sand blanket was placed, which was September 9, 2005. Time delays observed in the graph were caused by non-technical reasons. Walls were constructed on each floor right after the particular floor was ready. The load imposed on the base of the excavation was 62.4 kN/m^2.

5 MEASUREMENT OF SETTLEMENT

Measurement of the settlement started on February 21, 2006, after the basement columns have been casted, or 136 days after the sand blanket has been placed on the base of excavation. Settlement readings were done by measuring the elevations of markers placed on seven of the columns in the basement, namely Columns 1, 3, 5, 6, 8, 10 and 12 (see Fig. 1). The columns for settlement reading were located at the periphery of the building to facilitate the observation of the settlement pattern of the building as a whole. The initial plan to include other columns, particularly Column 15 near the center of area of the building, and Columns 13 and 17 (on the eastern periphery) had to be abandoned since none of those columns were visible from the locations where the leveling equipment could be placed. Four permanent objects outside of the building were chosen to serve as reference points for the leveling work. These were permanent, existing features (such as ellectric poles)

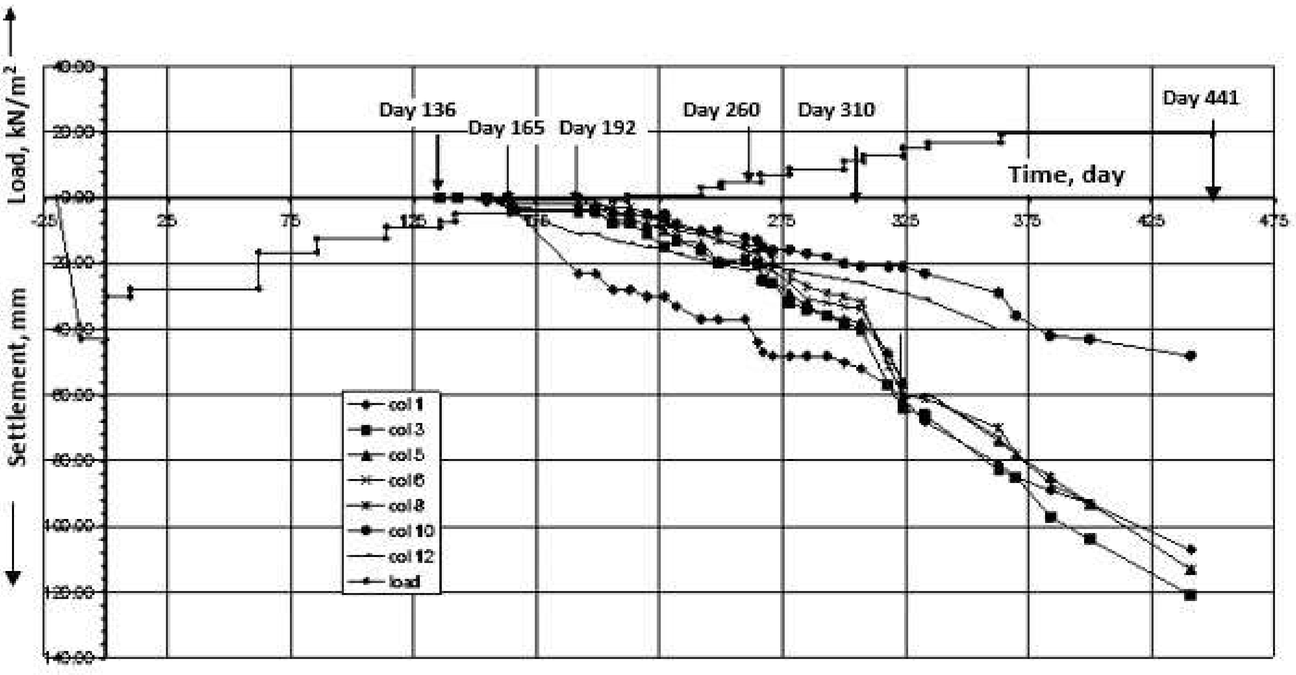

Fig. 6 Settlement and Load vs. Time Reccords.

that were positioned at sufficient distances from the building to assure that their integrity as reference points would not be compromised by the construction or other types of disturbances. Settlement readings were taken weekly or after a major load has been applied on the structure. Some longer than usual gaps in the readings were caused by non-tecnical situations.

6 SETTLEMENT OBSERVATIONS

6.2 Progress of Settlement

Figure 6 shows the settlement records of the columns with respect to time, along with the time history of the construction loading. Settlements were initially negligible prior to Day 165, ranging between 1 mm and 4 mm. On Day 192, however, the settlement of Column 1 had increased substantially compared to those of the other columns, increasing as much as 20 mm within less than a month. The settlement of Column 12 increased by 7 mm while the other columns experienced no additional settlement. Between Day 192 and Day 310 the rate of change in the settlements were similar in Columns 1, 3, 5, 6 and 8 but between Day 310 and Day 325 the settlements of Columns 3, 5, 6 and 8 accelerated relative to Column 1, adding between 18 mm and 28 mm within 15 days, causing the settlements of those columns to catch up with that of Column 1. From Day 325 until Day 441 (the end of monitoring program), the settlements of Columns 1, 3, 5, 6 and 8 grew more or less at the same rate. Settlement of these columns ranged between 107 mm and 121 mm on Day 441, while Columns 10 and 12 continued to experience relatively lower settlements below 50 mm at the end of the monitoring program.

6.3 Magnitude of Settlement

The guideline used for the calculation of allowable settlement based on settlement criterion in Nepal was the Indian Code of Practice IS:1904-1978, which permitted a maximum settlement of 100 mm for raft foundation on plastic clay, in accord with the widely accepted recommendation of Skempton and MacDonald (1956). As mentioned earlier, the highest settlement measured on the building at the end of the monitoring program was 121 mm, already beyond the permissible mark of 100 mm. The steep slopes of the end section of the settlement curves indicate that the consolidation of the soil on Day 441 was long from over, hence significantly higher settlement than the 100 mm mark would be expected. It should also be remembered that the settlement records did not include settlements during the first 136 days of construction.

A 1-D consolidation analysis was conducted to estimate the settlement at the center of the building, using the soil data in Figs. 3 and 4. The parameters for the regions in the stress bulb beyond 30 m deep were assumed to be the same as those of the lower organic layer. The analysis revealed that the ultimate settlement of the building would be 254 mm. Based on this value, Terzaghi's 1-D consolidation analysis was carried out to estimate the amount of settlement that had occured before the monitoring program started. The analysis was also used to calculate the average degree of consolidation that the soil had undergone at the final day of the monitoring program. Settlement-time relationship was created with the help of a Finite Difference Analysis, taking into account the construction loading history (see Maharjan, 2006). The result of the analysis revealed that the soil had undergone 23 mm settlement prior to the start of the monitoring program. This value was then added to the highest recorded settlement on Day 441, which was 121 mm, resulting in a 144 mm settlement. The result of the analysis also showed that the soil on Day 441 had just reached an average degree of consolidation of 42%, which means that the 100 mm mark had been well exceeded even before the soil has reached half of the consolidation process.

6.4 Differential Settlement

The above settlement records also suggest that the building settled in a non-uniform fashion, and that the settlement patterns changed with time. The following figures show the direction of the tilt that the building experienced during the monitoring period. Each of the figure in Figs. 8, 9 and 10 shows the difference in settlement between a pair of columns located at opposite ends of the building to highlight the direction of the tilt. The pair of columns and their locations are highlighted in Fig. 7.

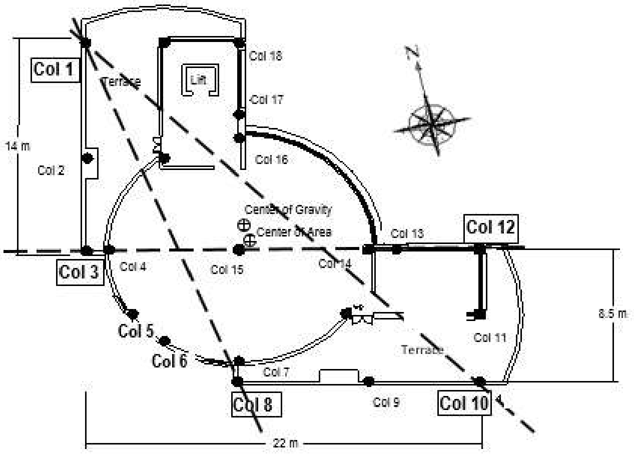

Fig. 7 Pairs of Columns Selected for the Observation of Tilt

From Fig. 8 it can be seen that the settlement of Column 1 (at the northeast boundary of building) was constantly higher than that of Column 10 (southeast boundary of the building), and that the difference in settlement between those columns grew with time. This observation leads to the conclusion that tilting with increasing magnitude towards Column 1. At the end of Day 441 the difference in settlement between the two columns was nearly 60 mm, already exceeded the 44 mm limit suggested by Skempton and MacDonald (1956) for raft foundation in clays. The angular distortion between the two columns was 0.002, exactly on the maximum limit specified by IS 1904-1978.

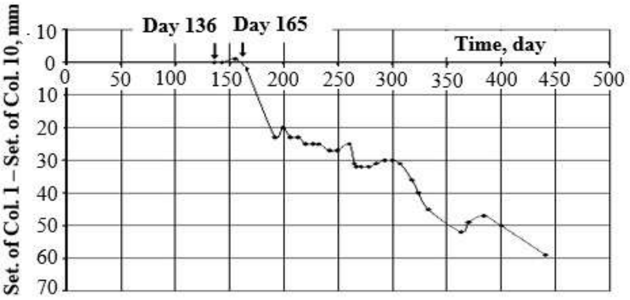

Fig. 8 Differential Settlement between Columns 1 and 10

The difference in settlement between Columns 3 (roughly west of the center of the building) and Column 12 (east-southeast of the center) in Fig. 9 showed an initial minor tilt in the direction of Column 12 followed by a reversal of tilt onto the direction of Column 3 at Day 265. The settlement difference between the two columns then continued to grow and was calculated to be 43 mm at the end of monitoring program.

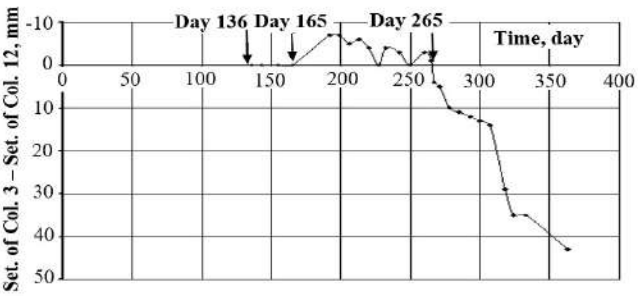

Fig. 9 Differential Settlement between Columns 3 and 12

The tilt along the straight line connecting Columns 1 and Column 8 in Fig. 10 showed a significant change in the direction of the tilt of the building. It can be seen in Fig. 10 that the building initially tilted in the direction of Column 1 with increasing magnitude, but then on Day 271 tilting gradually reversed towards Column 8. At Day 441 the building was slightly tilted in the direction of Columns 8. The reason for the tilt revearsal during the relatively short time span was unclear, though it was speculated that the highly commpressible nature of the soil has caused it to respond almost immediately to the change in the loading pattern of the building during construction.

Evaluation of the overall settlement patterns lead to the conclussion that at the end of the monitoring program the building was tilting in the direction of the area where Columns 1, 3, 5, 6 and 8 were located (roughly the western part of the building), with the deepest dip being at Column 3 and the shallowest part being in the eastern part where Columns 10 and 12 were located.

As the center of gravity of the building was located about 1 m north of the center of area of the building, it would be reasonable to suspect that the building would tilt slightly towards the north. There was therefore no particular reason why the building tilted to the west except for the possibility that soil in the western part of the building was slightly more compressible than that in the other parts of the building.

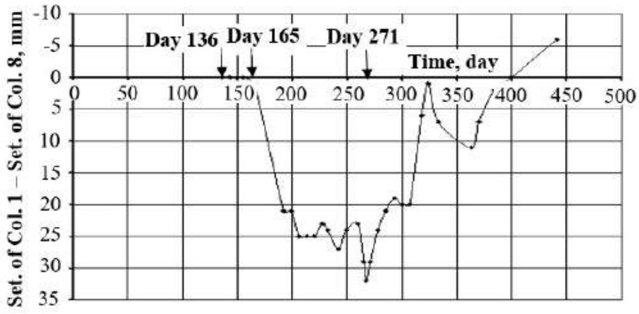

Fig. 10 Differential Settlement between Columns 1 and 8

7 CONCLUSIONS AND RECOMMENDATIONS

The settlement monitoring program clearly showed that the building in this study experienced large settlement, well beyond the 100 mm maximum limit of the IS:1904-1978. It was noticeable also that the building settled in a non-uniform pattern accross the building area and that the direction of tilt changed during the relatively short span of the construction period.

Based on the findings of this study the following recommendations are proposed for the construction of buildings on deep deposit of Kalomato:

a) The excessive settlement recorded in the building clearly showed that buildings on Kalomato should be planned to have lower mass. This could be achieved by curtailing the number of stories and the utilization of leaner and lighter building materials. The thick brick walls commonly used as partitions for the buildings in Kathmandu should be replaced by leaner walls with lighter material.
b) A mat foundation with an underground basement placed at a deeeper level in the ground would help reduce the settlement.
c) Uniform load distribution accross the building would help reduce potential differential settlement, with special care to be taken to maintain equal distribution of load during construction to reduce tilt during construction.
d) An equally important observation is the fact that despite the alarming magnitudes of the absolute and the differential settlement, the building chosen for this study has been functioning well until recently with no noticeable damages associated with excessive settlement. In the authors' opinion, provided that the building is rigid, the 100 mm permissible settlement for mat footings on Kalomato could be relaxed to allow higher flexibility and cost efficiency in the design of buildings. The suggestion of Sowers (1962) of a permissible settlement between 75 mm and 300 mm would be worth considering for mats on Kalomato.

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