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FORENSIC ANALYSIS OF AN UNCONTROLLED FILL

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ABSTRACT

This paper outlines the forensic analysis done in relation to a filling done to raise the general ground level in an area where a large housing complex is under construction near New Delhi, India. After the structures had been completed, trenches were dug to lay sewage and other service lines and the soil at the bottom had been observed to be in a slushy condition. A meticulous and detailed forensic diagnosis and analysis indicated uncontrolled filling. Measures were evolved to contain the slushy zone and compact the upper layers so that the service lines as well as roads could be laid. The paper presents the investigations conducted, analysis performed, and evaluation of the successful and satisfactory performance of the recommended remedial measures.

INTRODUCTION

A large housing complex is under construction near New Delhi, India. The complex consists of a number of blocks comprising structures having a ground floor and two upper floors. The construction consisted of reinforced cement concrete framework with in-filled brick walls.

The complex is situated in an area of land that had earlier been used for agricultural purposes. The whole area had been at a lower level than the surrounding area and also at a level lower than that of the service lines (roads, sewerage lines etc). Therefore, filling had been done throughout the area to raise the level of the ground. The thickness of the fill varied from 1m to 2.5m. The soil for the fill had been sourced from nearby areas.

After the construction of the structures when trenches were dug up to lay the sewerage and other service lines within the complex, slushy soil had been encountered at the bottom of these trenches. The thickness of this layer of slushy soil varied from about 0.5m to about 1m.

For laying the flooring in the ground floor of the structures, when compaction of the soil fill had been attempted, satisfactory levels of compaction could not be achieved as the surface layer of the soil fill appeared to float over a lower slushy layer of soil.

A meticulous and detailed forensic geotechnical investigation, analysis and diagnosis had been conducted to assess the causes for as also the nature and extent of the so termed slushy soil and remedial measures evolved to tackle the problem.

FORENSIC GEOTECHNICAL INVESTIGATION

The first step in the forensic geotechnical investigation involved collection of data from the initial soil investigation report and subsequently a comparison of these data with the soil conditions encountered presently at the site.
The initial soil investigation report indicated the subsoil profile consisted of Clayey Sandy Silt to Sandy Clayey Silt extending from initial ground level down to a depth of about 1.5m to 2m and beyond this depth the subsoil consisted of Silty Sand. The standard penetration test values (N-values) of the subsoil varied between 10 to 16. The relative densities of the subsoil varied between 40% to 55%. These indicate that the subsoil is in a medium dense state. The water table had been encountered at a depth of 2.5m below the initial ground level.

The present geotechnical investigations consisted of shallow depth boreholes at locations where slushy conditions had been encountered. These investigations showed that the filled-up soil consisted of Clayey Sandy Silt down to a depth of about 2m below the filled up ground level indicating that the soil for the fill had been obtained from the surrounding/nearby areas which was confirmed by the construction agency. The slushy conditions were invariably encountered between the depths of 0.5m to 2m below the filled up ground level indicating that such conditions were encountered only in the filled-up soil and not in the virgin soil.

During the borehole investigations, the bores were observed to collapse immediately on withdrawal of the auger on which basis the soil condition had been termed to be slushy. As is apparent, under such conditions, undisturbed soil samples could not be recovered and Standard Penetration Tests could also not be conducted.

FORENSIC DIAGNOSIS

The forensic geotechnical investigations indicated that the filled up soil is in a very loose to loose condition which can only be attributed to uncontrolled filling. This uncontrolled fill is underlain by a top virgin soil layer of soil having significant percentage of clay. Therefore, this top virgin soil would have low permeability.

A forensic diagnosis of the data available leads to the hypothesis that over a period of time, the water used for construction purposes as well as the water from rains would have penetrated into the filled up soil. Due to the low permeability of the underlying top virgin soil layer, the seeping water would have accumulated within the filled up soil leading to a condition of loose saturated soil fill.

This loose saturated soil fill would not have been noticeable as long as the top surface of the fill remained in a dry and intact condition as this created a confined condition. However, when and if the top dry surface were to be removed the underlying loose saturated soil fill would become unconfined and become slushy.

The so termed "slushy" conditions does not indicate slush as meant in the real sense of the term but in fact indicates loose filled up soil with a higher water content which tends to flow when changed from a confined state to an unconfined state such as during an excavation.

REMEDIAL MEASURES

Three different remedial measures were considered:

1. Removal of the so termed slushy soil and replacing with local soil or sand, well compacted in layers.
2. Consolidation of the soil fill to remove the trapped water by providing sand piles and applying surcharge loading.
3. Compaction of the soil fill, confinement of the soil fill and isolation of the soil fill from any future water seepage.

The first as well as the second options were considered to be not viable as these options would involve transportation of large quantities of soil or sand for the filling or for the surcharge loading respectively. Therefore, the third option had to be adopted as this was the most feasible option.

The objective of this remedial measure is to compact the soil fill and thereafter prevent any further seepage of water into the subsoil. The possibility of drying of the soil itself is quite remote and in any case would take many years to occur.

The compaction of the soil fill has to be done by dynamic compaction using heavy blocks falling through a height of at least 1m. This is needed to ensure that dynamic stresses of sufficient magnitude are generated in the soil to overcome the pore water pressures created within the soil. The larger height of drop is required to ensure that the effect of the dynamic blow reaches down to a depth of 2m (i.e. the bottom level of the slushy soil layer) below the filled-up ground level. .

The pore pressures created during the process of dynamic compaction have to be allowed to dissipate and for this purpose, sand piles have to be provided at regular intervals.

Finally, the soil needs to be isolated from any possible future water seepage. To ensure this, lean concrete cover has to be provided over the soil and the joints between the walls/beams and the concrete cover has to be sealed properly.
Even after the above remedial measure is adopted, the soil in the slushy zone will still have a high water content. Therefore, an analysis had been conducted to determine whether any significant settlement will occur under these conditions which also involved a few laboratory tests.

SETTLEMENT ANALYSIS

The settlement of the floor has been considered for analysis purposes as the floors will have the maximum live loads. The settlement of the floor can occur due to any of the sollowing:

a. drying of the so termed slushy soil
b. compression of the wet soil under the floor load
c. compression of the dried soil under the floor load

To determine the probable settlement of the floor on account of the drying of the so termed slushy soil, the so termed slushy soil had been filled into cylindrical moulds without any compaction and then kept in the oven for drying after which the change in height of the soil samples were determined. The change in height had been observed to be insignificant and therefore, it can be inferred that the probable settlement of the floor due to drying of the slushy layer will also be insignificant.

To determine the compression of the dried soil under the floor load, the stress strain behaviour of the dried soil has to be determined by considering the worst case scenario of no confinement of the soil. Therefore, Unconfined Compression tests had been conducted on oven dried samples to determine the stress-strain behaviour of the soil. These tests gave an average initial tangent modulus of the soil of 350 kg/cm^2.

Using this value of the deformation modulus of the soil, neglecting the effect of confinement of the soil, assuming the maximum floor load to be on the higher side at around 0.1 kg/cm^2 and considering the thickness of this so termed slushy soil layer of 2m, the settlement of the floor is determined to be about 0.66mm as shown below, which is insignificant.

$$s = \frac{q}{E} \cdot t = \frac{0.1}{300} \times 200 = 0.066\ cm = 0.66\ mm$$

Where q = loading pressure (kg/cm^2)
E = deformation modulus of the soil (kg/cm^2)
t = thickness of the soil layer (cm)

Similarly, to determine the compression of the wet soil under the floor load, the stress strain behaviour of the wet soil has to be determined. As mentioned earlier, the soil sample appears to be slushy as it has flowed out on account of loss of confinement, therefore, the same should not be used directly for conducting strength tests as otherwise the results will be erroneous. However, as the soil needs to be tested under fully saturated high water content conditions, the same has been achieved by soaking the oven dried sample as obtained by the earlier mentioned method, in water for sufficient period of time.

The Unconfined Compression tests on the so prepared wet soil samples gave an average initial deformation modulus of 60 kg/cm^2. Using the same procedure as before, the settlement of the floor is determined to be about 3.3mm. This magnitude of settlement is also insignificant.

Additionally, compaction of the soil fill will further ensure that the settlement due to consolidation of the soil fill will be negligible.
As the total probable settlement of the floor has been determined to be insignificant, even under the worst conditions, the proposed remedial measure may be safely adopted.

REMEDIAL PROCEDURE

The steps involved in the proposed remedial measure are given below:

i. Making 50 to 75mm diameter holes down to the natural ground in the form of a 1m x 1m grid and immediately backfilling with sand using light compaction.
ii. Dynamic compaction of the soil fill by giving blows using a 30cm x 30cm x 20cm (i.e. length x width x height) concrete block falling through a height of 1m. The dynamic compaction is continued until the settlement under a blow becomes imperceptible. Compaction near the walls may be done using heavy steel rammers.
iii. Filling up to the proposed finished ground level done using sand, well compacted in layers.
iv. Laying of the lean concrete slab which typically forms the base for the floor finish over the compacted sand fill. The joints between the lean concrete slab and the walls/plinth beams to be sealed with bitumen / tar.
v. Floor finish may then be laid above the lean concrete slab.

PERFORMANCE EVALUATION

To confirm the satisfactory performance of the proposed remedial measures, borehole investigations were conducted subsequent to the execution of the remedial measures at selected areas in the site, prior to lying of the lean concrete layer. These investigations showed that the relative densities of the soil varied from about 85% near the surface to about 60% at a depth of about 2m below filled-up ground level. Therefore, the satisfactory performance of the proposed remedial measure has been established.

CONCLUSION

A simple and feasible remedial measure has been successfully implemented to tackle the problem of slushy conditions of soil created by uncontrolled filling.