

Foundations for an Overhead Tank – Forensic Assessment

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ABSTRACT

Understanding the stratigraphy and nature of deposition is paramount for selection of appropriate foundation system for any structure. The paper presents case study of an overhead tank that was planned to be constructed at a site that had a fill of stone stones and boulders to about 7 m depth. A thorough geotechnical investigation with boreholes extending beyond the boulder filling helped generate adequate geotechnical data for a proper assessment of the foundation system required.

1 INTRODUCTION

A 18-m high overhead tank was planned to be constructed in Gwalior (Madhya Pradesh) in the vicinity of a heritage structure. At the site there was a heterogeneous fill of stones and boulders (probably discarded during the construction of the nearby fort) to more than 7 m depth.

The owners and designer had no clarity on the type of geotechnical investigation to be done. As a result, an unsafe foundation was designed.

2 ROUTINE GEOTECHNICAL INVESTIGATION

Routine geotechnical investigation conducted by the owner by drilling boreholes to a specified depth or refusal, whichever is earlier (standard soil investigation specifications) was a failure since the borehole met refusal to SPT at the ground surface.

On the advice of a structural engineer, a plate load test was performed on the stones fill using a 30 x 30 cm size plate which gave very low settlement.

The structural engineer thought he was conservative in designing the raft for a bearing pressure of 150 kN/m² at 4 m depth on the stones and boulders and recommended a 23 m diameter raft.

3 FOUNDATION EXCAVATION

Excavation was done to 4 m depth and it was noticed that the stone filling is loose, heterogeneous and non-uniform. Some of the stones seem to be part of an old stone masonry construction probably part of the fort construction during ancient days. Figure 1 presents a photograph of the excavation.

On seeing the nature of the fill, the contractor and the owner were concerned that the strata at 4 m depth may not be suitable bearing material.

The owner then requested the authors and them to propose a suitable and reliable foundation system for the overhead tank.



Figure 1. Excavation to 4 m depth showing loose heterogeneous boulders and stones in a soil matrix

4 SITE CONDITIONS

The site conditions as assessed by the authors are as follows:

- The fill encountered at site is loose, heterogeneous and non-uniform. It consists of stones mixed with soil. Some of the stones seem to be part of an old stone masonry construction. It could probably be part of the nearby ancient fort (See Figure 2).



Figure 2. Loose soil and boulders at base of excavation

- Several very-loose pockets are observed in the fill.
- Due to the presence of several buildings in the surrounding areas, the excavation has been carried out very close to these buildings. Foundations of these facilities are at shallow depth.
- Some of the foundations are exposed. Figure 3 illustrates the steep vertical cut adjoining the existing building.



Figure 3. Steep excavated slope of the boulder fill adjacent to nearby existing building

- In some areas, soil / fill material has been stacked up against the foundations of the existing buildings for lateral support to provide passive resistance. See Figure 4.



Figure 4. Boulder fill stacked up against wall of existing building

- Attempt had been made in one area to support the vertical cut by applying cement mortar on the exposed surface of fill.
- But the mortar was neither uniformly done nor was it of sufficient thickness as may be seen in Figure 5.
- Also, only part of the area has been stabilized when the contractor realized it shall not serve the desired purpose.

5 FORENSIC ASSESSMENT

5.1 What Went Wrong and Why

“What went wrong and why?” – known as the *4W's of forensics* is the key to understanding the problem in order to develop an appropriate engineering solution to the problem. It is the investigative part of forensic geotechnical engineering. Understanding the problem can provide insight to the type of foundation system that is required (Sanjay Gupta and Ravi Sundaram, 2005).

This involves a scientific approach to the problem, with clear understanding of sub-strata behavior in conjunction with the response of the structure, soil-structure interaction, and engineering judgment. The distress may not cause disaster / ultimate failure.



Figure 5. Attempt to stabilize excavation adjacent to nearby school building by applying cement mortar – it is evidently a poorly done job

5.2 Assessment of the Problem

The fill extends to 7-8 m depth below the road level. It is loose and heterogeneous in nature and is not a reliable foundation bearing material. Therefore, it is not suitable to support the heavy loads of the overhead tank.

The available geotechnical data which includes some limited borehole data that met refusal at shallow depth and plate load test on 30 x 30 cm size test plate is insufficient and incomplete.

No clear conclusion on the bearing capacity for 23 m diameter raft foundation can be drawn from these test results. Extrapolation of results of plate load test to a large 23-m size foundation can be misleading.

5.3 Action Plan

It was clear that the available geotechnical data was insufficient to make a conclusive assessment of the foundation system required for the overhead water tank.

In order to develop a sound engineering solution and to work out a suitable foundation system, the following steps as proposed by the authors were taken:

- A geotechnical investigation (4 boreholes) was carried out at site to assess the thickness of the fill across the site and to evaluate the engineering characteristics of the underlying soils to 20 m depth below the fill or refusal / rock strata, whichever is earlier.
- Standard Penetration Tests (SPT) was conducted in the boreholes at every 1.5-m depth interval. Undisturbed soil samples were collected at every 3 m depth interval. The samples were tested in the laboratory to determine various index and engineering properties.
- The data was analyzed to advise the owner on the suitable foundation system.



Figure 6. Borehole drilling in progress

6 GEOTECHNICAL INVESTIGATION

6.1 Borehole Drilling

Since boulder fill was encountered to about 3-4 depth below the excavated level, it was decided to excavate a pit to the top of the underlying natural soil and starting the borehole activity from the natural soils.

A temporary work platform of wooden sleepers and bamboos was set up over the pit excavated for ease of boring activity (See Figure 6).

6.2 Safety of Adjoining Buildings

The site is near a historical fort. It adjoins a school building. The excavation for the raft extends very close to the School and other buildings. Some of the building foundations have been partly exposed. The excavation through the boulders has been cut nearly vertically. The excavated face appear to be loose and may be unstable although there has been no failure reported during the past several months.

6.3 Soil Conditions

The soils in the area belong to the Older Alluvial plains. These soils are known to be underlain by the Gwalior System (Krishnan, 1986).

The investigation was done from the excavated level of 4 m below the road level which is at RL 100.5 m. The heterogeneous fill of gravel, boulders and building stones extends to 2-3 m depth below the excavated level (6-7 m depth below road level).

A pictorial summary of the borehole data is presented on Figure 7.

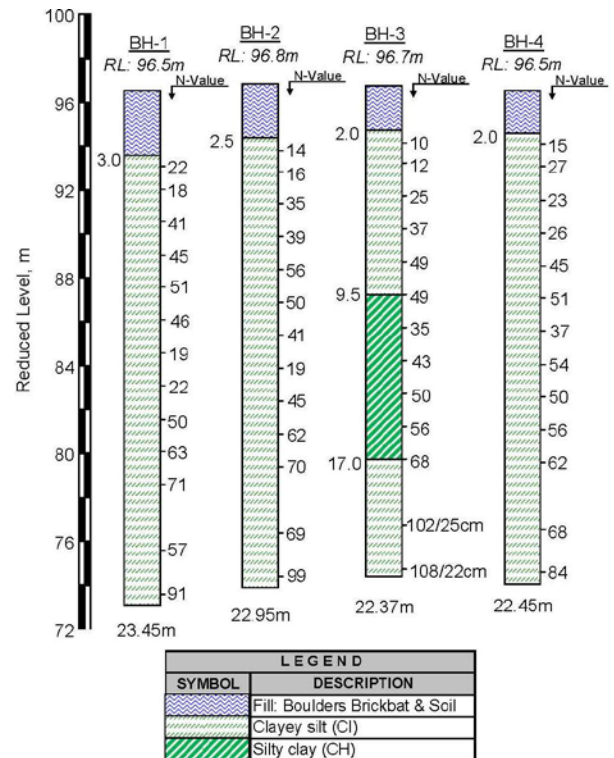


Figure 7. Summary of borehole profiles

The natural soil below the fill classify as clayey silt of medium plasticity to the maximum explored depth of 23.5 m below the excavated level. The field SPT values in the natural soil generally range from 10 to 15 to 5.0 m depth and gradually increase with depth.

Groundwater was not met to the maximum explored depth of 23 m below the excavated level.

Table 1 presents the soil properties based on laboratory test results.

Table 1: Soil Properties

Parameter	Typical range of values
Liquid Limit	35-46%
Plastic Limit	14-23%
Plasticity Index	11-29%
Free Swell index	7-13%
Gradation	
Gravel	3-8%
Sand	6-16%
Silt	50-72%
Clay	16-36%
Shear Strength Properties (undrained)	
4-10 m depth	c = 100-140 kN/m ² φ = 2-8 degrees
10-23 m depth	c = 200-250 kN/m ² φ = 7-15 degrees

7 ENGINEERING SOLUTION

7.1 Foundation for the Overhead Tank

The loose heterogeneous fill is not a suitable foundation bearing material. Construction of raft foundation on the boulder fill could result in differential settlement.

Therefore, the authors advised the owner to place the raft foundation on the natural soils at 7 m depth below the road level. This shall entail removal of the boulder fill and construction of foundation on the natural soils below the fill.

Restricting the total settlement of the raft foundation to 50 mm, the safe net allowable bearing pressure works out as 225 kN/m² on the natural soils.

Since the raft was earlier designed for SBC of 150 kN/m², the higher SBC shall mean the raft diameter may be decreased from 23 m to about 18.5 m. This shall not only result in cost-saving but also reduce the risk related to construction very close to the adjacent buildings.

7.2 Excavation

The site had already been excavated nearly vertical to about 4.0 m depth below the original ground level of RL 100.5 m. Further 3-3.5 m of excavation shall be required to cast the foundations on the natural soils.

This could cause risk to the foundations of the school and other surrounding buildings which are already in somewhat dilapidated state. Also, foundations of some of these buildings are also exposed.

The lateral support system required to excavate and construct depends upon the level of risk that the owner is prepared to take.

The excavation is marginally safe presently. It is likely that if excavation is done locally in different stretches carefully with proper monitoring, construction can be completed without affecting the nearby buildings. Since the adjoining dilapidated building is single-storeyed, the owner may take the risk and construct while offering to repair / reconstruct if any damage occurs.

Shotcreting the exposed excavated slope after placing a welded mesh over it could reduce the level of risk further.

However, for a safe and reliable excavation, contiguous piles or diaphragm walls may be an effective solution. But this could push up the cost of construction substantially and make the project financially unviable.

8 CONCLUDING REMARKS

Understanding what went wrong and why can help in developing an engineering solution to a geotechnical disaster-in-the-making. The overhead tank was planned to be constructed at a site that had a fill of stone stones and boulders to about 7 m depth.

After a thorough assessment of the problem, the owner was advised of the need for and a detailed geotechnical investigation with boreholes extending beyond the boulder filling.

Based on the geotechnical data, foundations on the natural soils below the fill was proposed to avoid possibility of differential settlement.

Adequate protection measures are required to protect the adjoining buildings to avoid any failures during excavation.

9 ACKNOWLEDGEMENTS

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10 REFERENCES

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