CONSTRUCTION PRACTICES OF DEEP BASEMENTS

ANIL JOSEPH¹, A MURALIKRISHNA²

ABSTRACT

With increasing cost of land in urban areas, vertical growth has become essential in city centers. With the requirement of service facilities like car parking and the restriction for height of buildings, construction of deep basement has become a necessity. Structures in the immediate vicinity of excavations, dense traffic scenario, presence of underground obstructions and utilities have made excavations a difficult task to execute. In this context, proper analysis and design of deep excavations and their supporting systems are essential. Even in complicated urban settings, deep retaining systems have been deployed successfully by overcoming construction challenges. For several infrastructure projects like metro rail, parking lots in commercial area, shopping malls etc underground structures are preferred to preserve the landscaping in the area. The basic steps which should be carried out by design engineer for deep excavations are: site characterization; selecting dimensions of excavation; surveying adjacent structures; establishing permissible movements; selecting earth retaining system; selecting supporting and construction scheme; predicting movements; compare predicted with permissible movements; alter supporting (bracing) and construction scheme if needed; monitor instrumentation, alter as needed; compare monitored results with predicted and permissible values; alter bracing and construction scheme, if needed. Since deep excavation is a total technique, proper coordination and integration of design and construction are of utmost important. Various earth retention techniques like dumpling method, sheet piling, cofferdams, diaphragm walling, contiguous and secant piling, soil nailing, active and passive pre-stressed ground anchors etc., could be adopted. Further ground water control and dewatering strategies are very crucial in deep basement construction. Efficient project management and planning is required to adopt best possible combination of various methods for successful completion of basement construction. This paper presents various aspects and challenges of deep basement constructions with reference to a case study. The case study is of a residential apartment building in Chennai which consists of three basement floors and G+19 apartment floors. Pile foundation with raft was used for the tower structure. The depth of excavation including that for the raft was of 14 m deep. The retaining was made possible by touch piles extending up to a depth of 24 m. Optimization of the retaining system was made possible by employing the cross strutting system supported on soldier piles at an intermediate level of 5m from the top. The 3 dimensional modeling was done using STADD software. Various possibilities were examined in detail before zeroing in on the adopted method. The problems encountered during the execution and the remedial measures adopted is also covered. The actual effectiveness of work is highly dependent on the as constructed site environments, quality of the management and executing parties as well as the problem solving ability of the frontline personnel. Dynamic layout arrangement is usually required for the removal of the excavated soil from the basement, this may involve forming of temporary ramp, provision of special equipments or taking part of the completed building as temporary access. The use of instrumentation and the reporting of the results are important to benefit the overall knowledge base of each region where deep basements are a popular choice for building owners and developers. Design techniques that involve sophisticated soil structure interaction models combined with local data and experience give a high level of confidence for predicting wall performance on projects surrounded by other structures, where control of building

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movement and damage are paramount to a successful project delivery. These models need to be calibrated to empirical predictions and other case histories of successful excavation support projects in similar ground conditions.

Keywords: deep excavation, basement construction, construction practices, earth retention systems
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ABSTRACT: This paper presents various aspects and challenges of deep basement constructions with reference to a case study. The case study is of a residential apartment building in Chennai which consists of three basement floors and G+19 apartment floors. Pile foundation with raft was used for the tower structure. The depth of excavation including that required for the raft was 14 m deep. The retaining was made possible by contiguous piles extending up to a depth of 24 m. Optimization of the retaining system was made possible by employing the cross strutting system supported on soldier piles at an intermediate level of 5 m from the top. Various possibilities were examined in detail before zeroing in on the adopted method. The problems encountered during the execution and the remedial measures adopted is also covered. Design techniques that involve sophisticated soil structure interaction models combined with local data and experience give a high level of confidence for predicting wall performance on projects surrounded by other structures, where control of building movement and damage are paramount to a successful project delivery. These models need to be calibrated to empirical predictions and other case histories of successful excavation support projects in similar ground conditions.

INTRODUCTION
With increasing cost of land in urban areas, vertical growth has become essential in city centers. With the requirement of service facilities like car parking and the restriction for height of buildings, construction of deep basement has become a necessity. Structures in the immediate vicinity of excavations, dense traffic scenario, presence of underground obstructions and utilities have made excavations a difficult task to execute. In this context, analysis and design of deep excavations and their supporting systems are essential. Even in complicated urban settings, deep retaining systems have been deployed successfully by overcoming construction challenges. The process of an excavation may encounter different kinds of soils underneath the same excavation site—from soft clay to hard rocks. During excavation, some soil types pose greater problems than others. Sandy soil is always considered dangerous for deep excavations. Vibrations from blasting, traffic and heavy machinery movements, and material loads near the cut can also cause earth to collapse in sandy soil. The instability can be caused by moisture changes in the surrounding air or changes in the water table. Clayey soils in general, present less risk than sand; however, soft clay can prove to be very treacherous. Silty soils are also unreliable and require the same precautions and support provision as sand. For several infrastructure projects like metro-rail, parking lots in commercial area, shopping malls etc., underground structures are preferred to preserve the landscaping in the area (Gandhi, 2011). The basic steps which should be carried out by design engineer for deep excavations are: site characterization; selecting dimensions of excavation; surveying adjacent structures; establishing permissible movements; selecting earth retaining system; selecting supporting and construction scheme; predicting movements; compare predicted with permissible movements; alter supporting (bracing) and construction scheme if needed; monitor instrumentation, alter as needed; compare monitored results with predicted and permissible values; alter bracing and construction scheme, if needed(Puller 2003, Moh and Chin 1991, Pearlman et al 2004). Since deep excavation is a total technique, proper coordination and integration of design and construction are of utmost important (Chang-Yu-On, 2006). Deep basement can be constructed using some traditional ways such as cut and fill or bottom up methods. These methods are relatively economical and effective when
dealing with certain jobs which are simple in nature. On the other hand where basement is going deeper and the surrounding environment getting more complex and sensitive, top down or combined method may be a more appropriate option (Wong, 2000, Gibson, and MacArthur, 1999, Godavarthi et al 2011). Various earth retention techniques like dumpling method, sheet piling, cofferdams, diaphragm walling, contiguous and secant piling, soil nailing, active and passive prestressed ground anchor etc., could be adopted. Further ground water control and dewatering strategies are very crucial in deep basement construction.

This paper presents various aspects and challenges of deep basement constructions with reference to a case study of a residential apartment building which consists of three basement floors and G+19 apartment floors. The depth of excavation including for the raft was of 14 m deep. The retaining was made possible by touch piles extending up to a depth of 24 m. Optimization of the retaining system was made possible by employing cross strutting system supported on soldier piles.

SITE DETAILS
The project is located at the heart of Chennai city with roads on northern and southern sides and a 15 storied high rise residential apartment on the western side and an 8 storied hospital building on the eastern side. The aerial view of the project site and section with set-back to the adjacent buildings are shown in Figs. 1 and 2 respectively. Typical soil profile of the site is as shown in Table 1.

<table>
<thead>
<tr>
<th>Borehole No/Water Table</th>
<th>Description of Soil</th>
<th>Thickness of Layer (m)</th>
<th>N-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH-1 (G.W.L-1.00m)</td>
<td>Soft to Medium Stiff Silty Clay</td>
<td>13.00</td>
<td>4 to 14</td>
</tr>
<tr>
<td></td>
<td>Dense to Very Dense cemented Silt/Sand</td>
<td>27.00</td>
<td>24 to &gt;50</td>
</tr>
<tr>
<td>BH-2 (G.W.L-1.00m)</td>
<td>Soft to Medium Stiff Silty Clay</td>
<td>10.00</td>
<td>3 to 12</td>
</tr>
<tr>
<td></td>
<td>Dense to Very Dense cemented Silt/Sand</td>
<td>24.00</td>
<td>18 to &gt;50</td>
</tr>
<tr>
<td>BH-3 (G.W.L-1.00m)</td>
<td>Soft to Medium Stiff Silty Clay</td>
<td>10.00</td>
<td>3 to 29</td>
</tr>
<tr>
<td></td>
<td>Dense to Very Dense cemented Silt/Sand</td>
<td>24.00</td>
<td>30 to &gt;50</td>
</tr>
<tr>
<td>BH-4 (G.W.L-1.70m)</td>
<td>Soft to Medium Stiff Silty Clay</td>
<td>11.00</td>
<td>4 to 18</td>
</tr>
<tr>
<td></td>
<td>Dense to Very Dense cemented Silt/Sand</td>
<td>24.00</td>
<td>22 to &gt;50</td>
</tr>
</tbody>
</table>

OPTION EVALUATION OF RETAINING SYSTEM
Evaluation of the 4 bore holes shows a soil profile of similar nature in the entire plot area with the top soil comprise of soft to medium stiff silty clay extending up to a depth of 10 to 13 m. This was followed by dense to very dense cemented silt/sand. All the bore holes were terminated in the very dense cemented sand strata at a depth of 34 to 40 m.
The project requires 14m depth of excavation in an area of 2000m$^2$ to accommodate for three floors of basement and the raft foundation for the structures. Since the set-backs were low and depth of excavation required was high, open cut arrangement was not feasible. Due to the limitation of site and the time required for the execution, top down construction system was not adopted. Hence it was decided to go for bottom up method.

Considering the soil profile, level of water table, practical difficulty and the safety required for the adjacent buildings dumping method, soil nailing, sheet piling etc were ruled out. It was decided to go for either diaphragm wall or secant/contiguous pile. Preliminary designs were carried out for the various systems and the comparison of cost was worked out. Figure 3 shows the comparison of cost required for the different systems. From the preliminary studies and considering the practical feasibilities it was decided to adopt contiguous pile.

![Figure 3: Cost comparison for the different options of retaining system](image)

**Fig.3** Cost comparison for the different options of retaining system

**OPTIMISATION OF THE SELECTED SYSTEM**

In order to optimise the cost of the contiguous pile, the options of pre-stressed ground anchors, strutting with Island Method, Installation of dead man for back anchorage and cross strutting with lattice beams were evaluated. Since the set-backs were less and the top soil comprise of soft clay the option of cross strutting with lattice beam was found to be most viable. Analysis was carried out using STADD Pro software. From studying the variation of bending moment, shear force and deflections of the retaining wall due to location of cross strutting at different depths, it was noted that the most optimum position of cross strutting was at a depth of 5 m from the top. Since the span between the two retaining walls was of 25 m, in order to optimise the cost of cross strutting lattice it was decided to go in for a supporting system at the centre using a soldier pile. The soldier piles provided to hold the lattice were eventually converted to a structural member and a part of the pile raft foundation system. The STADD model along with the bending moment and shear force diagram and the deflection diagrams are given in Figs. 4, 5 and 6.

![Figure 4: STADD Model with loading](image)

**Fig.4** STADD Model with loading
Fig. 5 Bending Moment and Shear Force Variation from the STADD Model for the adopted system

Fig. 6 Deflection of the adopted system as per STADD Model

SEQUENTIAL PROGRESS OF THE PROJECT

The sequence of operations planned and carried out for the project is given below followed by the layout of cross bracings and photograph of progress of work (Fig 7).

I. Executing the shore piles and the building piles

II. Installation of instruments for monitoring the movements of shore piles and retained mass.

III. Excavation and dewatering up to 5.5m depth. Dewatering was done by adopting well point system.

IV. Erection of prefabricated box girders for back strutting systems at 5m depth.
Suitable jacking system to effect the side thrust on the box girders to be provided as required.

V. Excavation up to the bottom level of foundation.

VI. Construction of piled raft foundation and skin retaining wall with raft beams to support shore piles at base.

VII. Casting of 2nd basement slabs and beams. Extension of beams and slabs to provide support to the retaining wall and shore piles.

VIII. Removal of back strutting system.

IX. Casting of 1st basement slabs and beams to provide support to retaining wall and shore piles.

X. Casting of ground floor slab.

XI. Construction of super structure.

**INSTRUMENTATION ADOPTED FOR MONITORING THE PERFORMANCE OF THE RETAINING SYSTEM**

It is required to instrument and monitor the horizontal and vertical movements of the excavated face, so as to give an advance alarm to any impending failure and necessary protective measures can be taken well in advance. It was done by adopting a combination of survey techniques and geotechnical techniques. Survey techniques involve installation of Bi-Reflex targets in a grid pattern and the change in the location of these were monitored by using a Total Station, the frequency of monitoring was twice in a week initially and was decreased/increased based on the analysis of monitoring records. Settlement gauges, and tiltmeters were deployed in sufficient numbers to monitor the performance of the system.

**MAJOR PROBLEMS ENCOUNTERED DURING THE EXECUTION:**

The problems faced during the execution process were the gap formation between the shore pile and the wailer beams, alignment variation, clay lumps in pile, and exposed reinforcement of the pile. By providing suitable packing systems, pressure grouting and additional strengthening with self compacting concrete these problems were solved. During the rainy seasons the dewatering and excavation works were stopped and the excavated area was filled with water to counter the pressure due to soil movements. Major problem encountered during the work was the failure of anchor bolts on pile supporting the wailer beam, leading to deflection of wailer beams and movement of the retaining wall system (Figure 8). The cross strutting system area was strengthened by an additional lattice on the top (Figure 9) and the soil was strengthened with cement grouting.

**Fig 7** Layout of the strutting system and photograph during the progress of work
CONCLUSIONS
Construction of deep basement is a challenging task which requires proper coordination and integration of design and construction. A case study of 14 m deep basement construction is presented. Considering the site restrictions few methods of basement construction were ruled out. Contiguous pile method with cross bracing with lattice supported on soldier pile, was adopted based on cost analysis. The problems encountered in the execution of the basement excavation and the remedial measures adopted are presented. The paper highlights the following points.

Every project, though look relatively similar from certain indicating factors, is in fact unique in itself. A great number of random and uncontrollable variances are likely to arise during the course of work, this makes planning and scheduling difficult. The actual effectiveness of work is highly dependent on the as constructed site environments, quality of the management and executing parties as well as the problem solving ability of the frontline personnel. Dynamic layout arrangement is usually required for the removal of the excavated soil from the basement, this may involve forming of temporary ramp, provision of special equipments or taking part of the completed building as temporary access. The use of instrumentation and the reporting of the results are important to benefit the overall knowledge base of each region where deep basements are a popular choice for building owners and developers. Design techniques that involve sophisticated soil structure interaction models combined with local data and experience give a high level of confidence for predicting wall performance on projects surrounded by other structures, where control of building movement and damage are paramount to a successful project delivery. These models need to be calibrated to empirical predictions and other case histories of successful excavation support projects in similar ground conditions.

REFERENCES