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Influence of the soil/rock conditions at wall toe on the behavior of the diaphragm wall

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Abstract. Diaphragm walls are commonly used for supporting deep excavation when there are restricted setback conditions. The behavior of wall is influenced by variation of ground water table, surcharges, type and stiffness of supports and encountered soil types. In this paper, diaphragm wall with two level of anchors supporting a 12.5m deep basement excavation in mixed soil conditions has been discussed. There is considerable variation in the level of weathered rock within the project site, i.e., between 15m and 21m. Panels of varying depth are identified based on the soil/rock conditions at wall toe. The performance of wall for different soil/rock conditions at wall toe has been analyzed by subgrade reaction approach. Design assumptions and results of the subgrade reaction analysis is validated by examining “no rock condition at wall toe” using Finite Element Approach. This paper compares theoretical deflections calculated with subgrade reaction approach with recorded wall deflections and discussed about the performance of retention system for various toe termination levels.

Keywords: Toe conditions, finite element, subgrade modulus method, monitoring of deflections through inclinometers.

1 Introduction

As buildings go taller and taller, number of basements and associated excavation goes deeper and deeper. Rapid urbanization has necessitated taller buildings and deeper basements. Diaphragm walls are the most used retaining wall for basement excavation. Proper design of the retaining walls is the key to ensure safety of basement excavation and adjacent structures. Wall deflections and associated ground movements behind the wall are the major source of damage to surrounding structures. Estimation of wall deflection using reliable methods under working conditions are essential for safety of the system and surroundings of excavation pit.

Diaphragm wall with two levels of supports was used to retain 12.5m deep basement excavation for a commercial project in Chennai. The sub-soil profile comprised of firm to stiff clay layers and sand layers followed by weathered rock. The depth of weathered rock showed a considerable variation within the site. The rock level varies between 15m and 24m below existing ground level (EGL). It posed a question of execution feasibility with grab, socketing into rock (wall toe embedment into rock) and associated design challenges.

This paper illustrates performance of the wall termination for various soil/rock conditions at wall toe. Five embedment conditions are discussed in the paper. Wall movements area estimated by using subgrade reaction method. Design assumptions and the results of the subgrade reaction method are validated for “no rock condition at wall toe” (19m wall depth case) using finite element approach. Results of the subgrade reaction methods are compared with field measurements.

2 Site and Subsoil Conditions

The subsoil profile comprises layers of medium-stiff to stiff clay of medium plasticity to a depth of about 12.0m below EGL followed by relatively weak clayey sand and sandy clay up to about 15m. Very stiff sandy clay/ dense clayey sand/weathered layers are observed below this layer. The level of the weathered rock showed considerable variation within the project site, it varied between 15m to 24m below ground. Rock mapping based on the soil investigation is shown below:

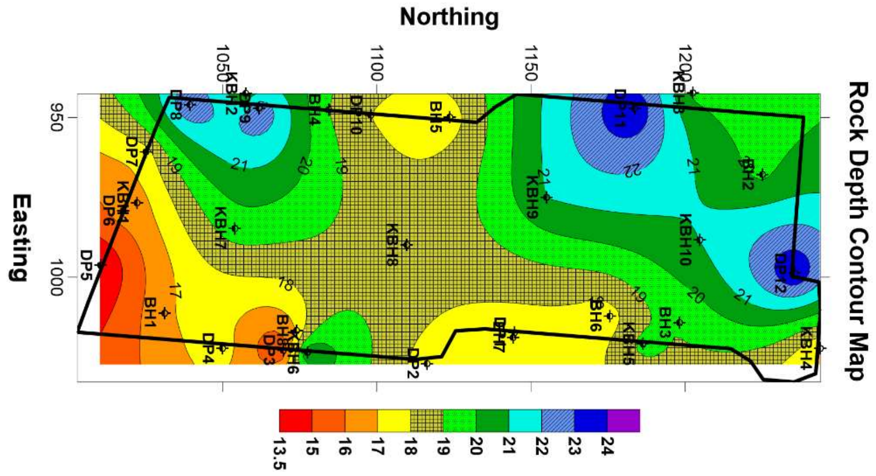


Fig. 1. Variation of weathered rock within the site boundary

The ground water table was encountered between 3m and 4m below existing ground level at the time of investigation. A design ground water table of 2m below EGL has been considered for analysis.

3 Numerical Analysis

600mm thick diaphragm wall with two levels of anchors is considered as the retaining wall system. The first anchor level is considered at 6m below ground and the second at 10m below EGL. The anchors are spaced at 2.0m c/c and are inclined at 45 degrees.

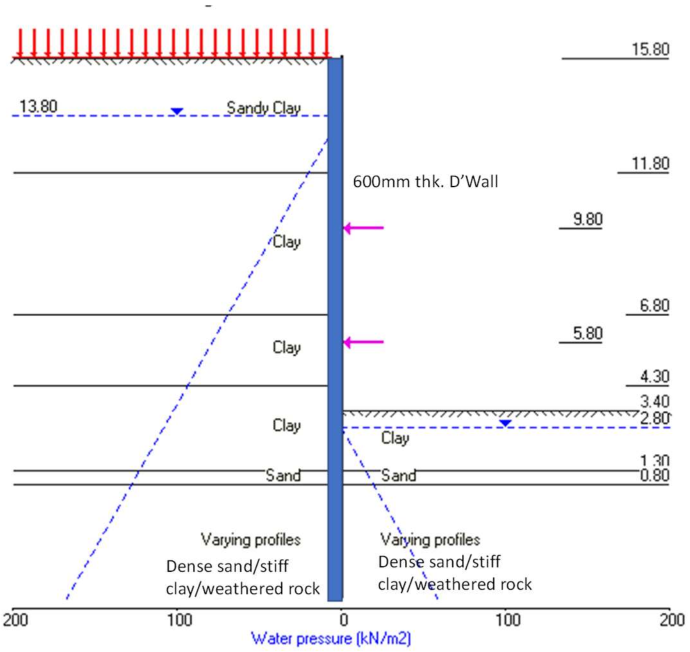


Figure 2: Proposed retaining wall system

Numerical analysis is made considering the varying rock levels. The following load cases are analyzed based on the embedment in rock:

Case 1	19m D-wall panels with no penetration into weathered rock.
Case 2	18m D-Wall panels with no penetration into weathered rock, but weathered rock just touching the toe
Case 3	17m D-wall panels with 300mm penetration into weathered rock.
Case 4	16m D-wall panels with 300mm penetration into weathered rock.
Case 5	15m D-wall panels with 300mm penetration into weathered rock.

Calculations are made using subgrade reaction method. The design assumptions and results are validated by examining Case 1 using finite element method. The construction stages of retention system are considered in the analysis which include installation of 600mm thick diaphragm wall, dewatering and excavation to a level below anchor levels, constriction and pre-stressing of respective anchors and so on, and final excavation to the bottom of piled raft. The results of the analysis are discussed in Section 5.

4 Field Monitoring

Deflection monitoring was carried out through eight inclinometers which are installed in the middle of diaphragm wall panels. Results of inclinometers 1,2 ,4,5 & 8 are considered as part of the current study (covering all 5 cases). Other inclinometers are not considered in the present study as they belong to different design conditions. Inclinometers positions are illustrated in **Figure 3**.

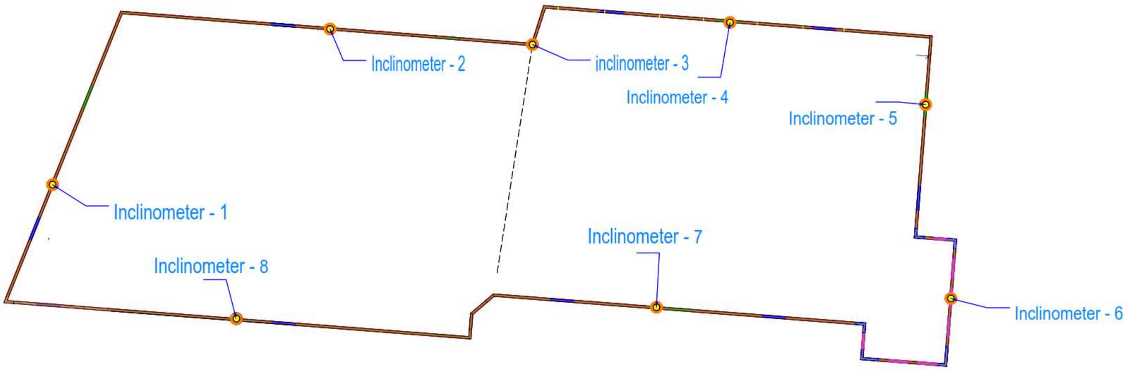


Figure 3: Position of Inclinometers

Description of inclinometers are explained in Table 3.

Analysis Cases	Inclinometer	Description
Case 1	4&5	19m D-wall panels with no penetration into weathered rock.
Case 2	-	18m D-Wall panels with no penetration into weathered rock, but weathered rock just touching the toe
Case 3	2&8	17m D-wall panels with 300mm penetration into weathered rock
Case 4	1	16m D-wall panels with 300mm penetration into weathered rock
Case 5	1	15m D-wall panels with 300mm penetration into weathered rock

Table 1. Details of Analysis Cases and the Inclinometer installed

The inclinometer readings together with the results of the numerical analysis are discussed in Section 5. Inclinometer 6 is not relevant to the present study as depth of excavation was less than 8.5m.

5 Discussion of results

5.1 Validation of the results (Subgrade Reaction Method)

The results of subgrade reaction method for Case 1 are compared with the finite element results. The summary is highlighted below:

Case	Results	Subgrade Reaction Method	Finite Element Method	Field Monitoring
Case 1: 19m wall with no penetration into rock	BM (kNm/m)	441	469	
	SF (kN/m)	255	204	
	Deflection (mm)	47	46	>50mm *

Table 2. Subgrade reaction method Vs Finite element method

The results of the subgrade reaction method are well in agreement with the finite element modelling for Case 1.

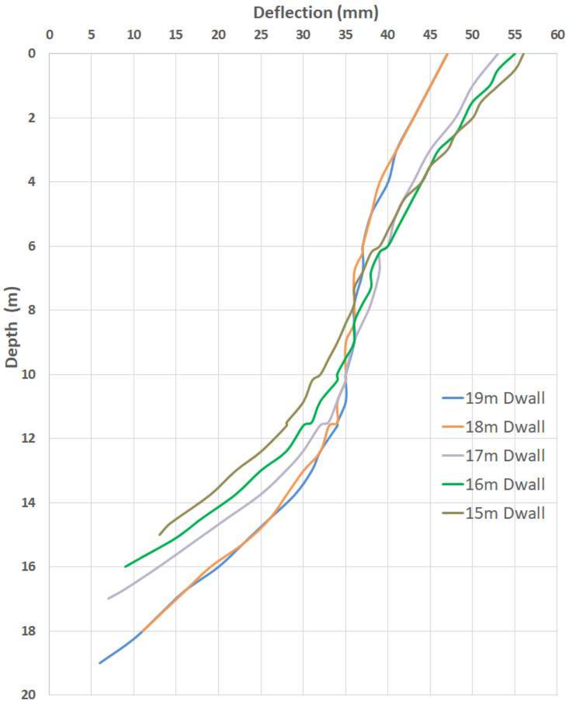
* Observed deflection was more than the predicated. This is due to change in construction sequence (Reference 5).

5.2 Numerical analysis (Effect of varying toe/wall depth)

The influence of varying wall depths on the deflection envelope patterns are calculated by subgrade reaction method. Deflection with respect to depth of wall is illustrated in the 3following graphs.

There is a good comparison between the estimated and measured deflection of the wall top for 16m deep diaphragm wall. Figure 5 represents the comparison between the estimated and measured deflection profiles of this wall section. However, some variation in values is found to be for the 17m deep diaphragm wall.

It is observed that deflection patterns follow a similar trend with the embedment. The wall deflection and toe movements increase with reduction in embedment.



`**Fig.** 4. Variations in deflections for different wall depths

5.3 Comparison with Inclinometer readings

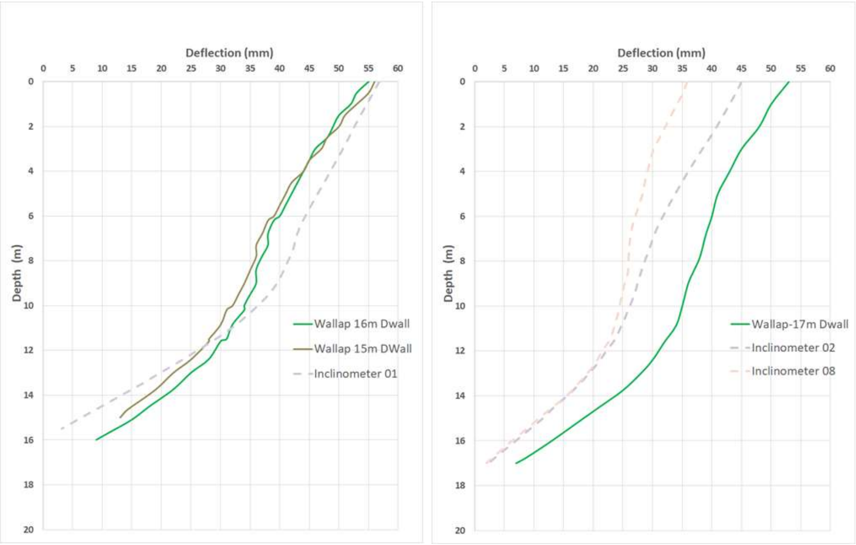


Fig. 5. Variations in deflections for different wall depths

6 Conclusion

This paper demonstrated the behavior of diaphragm wall of varying embedment / wall depth with complex soil conditions. Wall deflections are calculated by subgrade reaction method and the results are validated by examining a case study using finite element method. It is observed that the wall deflection and toe movements increase with reduction in embedment, especially while socketing into rock.

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