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Embedded Retention Wall Design Practices Consequences and Measures

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Abstract. Embedded retention walls generally comprise of vertical structural members namely diaphragm walls, secant or contiguous walls, sheet piles or berlin walls. These structural members are sufficiently embedded into ground to make excavation pits stable. The stability of embedded walls significantly depends on the passive resistance of the soil. Inappropriate choice and misinterpretation of design soil parameters make the retention system design more complex. Even though a normal retention system falls under "no exceptional risk category" [3], usage of improper method of analysis make wall unstable. Majority of deep excavations are installed in densely populated areas and consequences of failures are immeasurable. Hence, practicing engineer must have commendable knowledge on usage of design parameters and method of analysis to prevent failures. This paper illustrates parametric study on performance of wall focusing on method of analysis, effect of water table, over dig, surcharge, soil stiffness, wall flexibility and drained & undrained behavior of soil.

Keywords: Embedded retention walls; limit state; subgrade reaction; drained/undrained.

1 Introduction

The embedded retention walls systems offer constructive solutions for underground structures in crowded areas. The retaining wall analysis is influenced by the method of analysis used and parameters like drained/undrained analysis, wall flexibility, effects of ground water table, over excavation and effects of surcharge.

Common analysis methods used for the design of the embedded retaining structures are limit equilibrium method, subgrade reaction method and finite element method. The purpose of the study is to identify the wall behavior by using these 3 approaches.

In addition to this, comprehensive parametric study has been carried out to show the influence of various parameters as indicated above to understand behavior of the retaining walls.

2 Method of Analysis and its Influence

2.1 Method of analysis

Common analysis methods used for the design of the embedded retaining structures are limit equilibrium method, subgrade reaction method and finite element method.

2.1.1 Limit Equilibrium method

Limit state equilibrium analysis is used to describe an analysis where equilibrium of the wall is assessed under the action of linear, simple distributions of soil lateral pressures, usually calculated based on limiting (active and/or passive) lateral earth pressure coefficients. Cantilever/unpropped walls are assumed to rotate about a pivot at some depth below excavation level whereas strutted/anchored walls rotate about the position of support. Cantilever walls rely on the support of ground to maintain horizontal and moment equilibrium whereas strutted/anchored wall relies on the support of ground and prop to maintain the equilibrium.

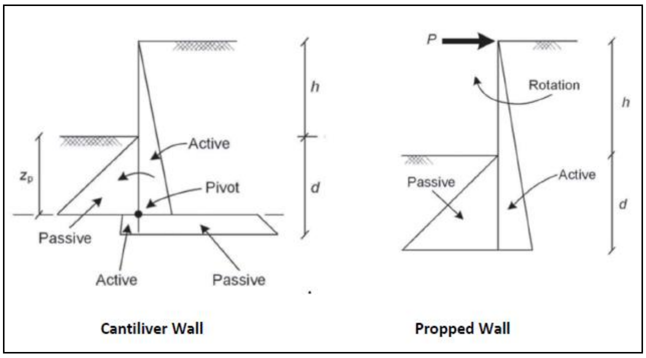

Fig. 1. Limit equilibrium analysis theories

2.1.2 Subgrade Modulus method

Second approach is the subgrade reaction method in which wall is modelled as a beam and the ground as a series of horizontal springs. This method considers the interaction between soil and structure which was ignored in the limit equilibrium approach. Wall displacements can be calculated by using this method.

2.1.3 Numerical Modeling method (FEM)

The third approach is the analysis using finite elements. It involves splitting the computational domain into smaller elements and finding solutions. It needs a good knowledge of soil behavior.

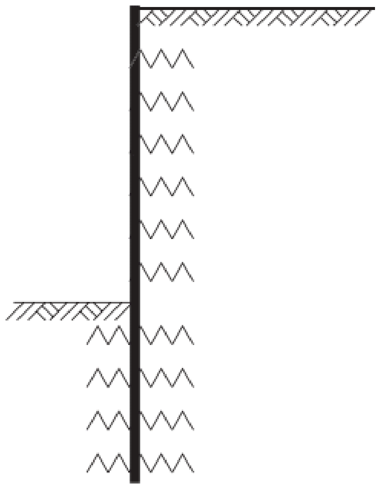

Fig. 2. Subgrade reaction methods

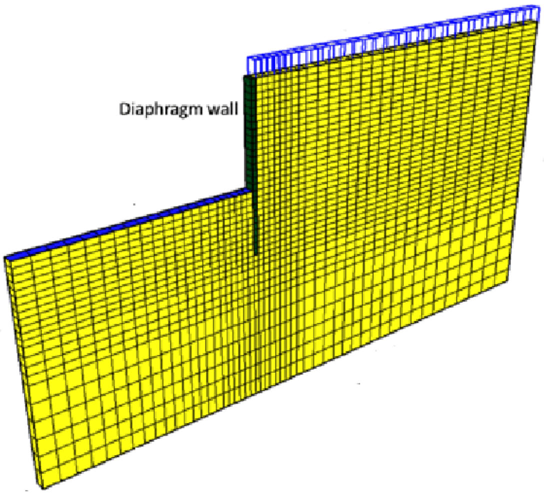

Fig. 3. Finite Element Method

2.2 Case studies

Two examples are considered in this study to compare results of three methods of analysis. First case is a cantilever problem whereas the second case is a strutted wall. Wall forces, deflections and embedment are calculated and the results are discussed. Bending moments are computed based on ULS combination of Eurocode 7 (DA1C2) [2] and at service conditions whereas the deflections are checked at service conditions only. Wall friction of 0.67tan Ø and effective stress approach is used.

Case 1-Cantiliver Example. Cantilever wall for 7m excavation is considered for Case 1.

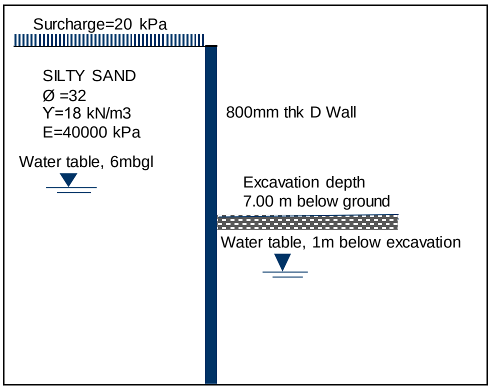

Fig. 4. Cantilever problem considered for the analysis

Table 1. Comparison of results for a Cantilever Wall

Item	Equilibrium Method	Subgrade Reaction Method	Finite Element Method	% Variation in Results
ULS Bending Moment (DA1C2), kNm/m	1618	1545	1529	6%
Deflection at Service Condition (mm)	-	59	62	-

Case 2-Strutted Wall Example. Strutted walls for 7m and 11m excavation are considered for Case 2.

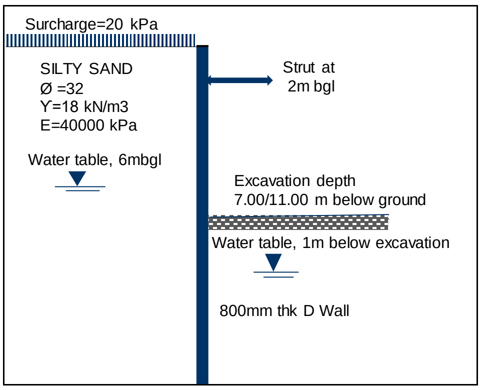

Fig. 5. Strutted wall considered for the analysis

2.3 Observations

The results suggest that the bending moment in the ULS Condition are comparable in all the methods for a cantilever case. However, there can be considerable difference between the methods in the case of a strutted/ anchored wall. This is due to the consideration of soil structure interaction in the Subgrade and Finite Element analysis whereas Limit Equilibrium Methods ignore soil structure interaction.

Table 2. Comparison of results for a Strutted Wall (7.00m and 11.00m excavations)

Item	7m excavation depth with strut (2mbgl)				11m excavation depth with strut (2mbgl)			
	Equilibrium Method	Subgrade Reaction Method	Finite Element Methods	% Variation Method	Equilibrium Method	Subgrade Reaction Method	Finite Element Methods	% Variation Method
Staged Construction	No	Yes	Yes	-	No	Yes	Yes	-
ULS Bending Moment (kNm/m)	303	285	271	14%	1739	1637	1507	15%
ULS Prop Load (kN/m)	162	186	228	41%	393	530	508	35%
ULS Shear Force (kN/m)	134	137	144	8%	365	369	378	4%
Deflection at service condition (mm)	-	9	10	-	-	24	29	

It is found that for heavy loading cases, the difference in prop loads can be quite significant between the equilibrium method and Subgrade/Finite element approaches in case of a strutted/ anchored wall. The use of limit equilibrium methods can underestimate the prop loads in such a case whereas FEM/Subgrade reaction methods yield comparable results.

3 Parametric Study

Ground water table variations, over excavation, surcharge, wall flexibility, stiffness of the soil affect the behaviour of the retaining walls. The cantilever example shown in Section 2 is used to assess influence of parameters on the retention wall design. The bending moments and factor of safety of embedment are computed based on the working conditions (SLS). Excavation depth of 7m with a surcharge of 20 kPa for a 20m deep wall is considered for the parametric study and Burlands Potts method is used to assess the factor of safety in embedment. GWT assumed at 6m below EGL.

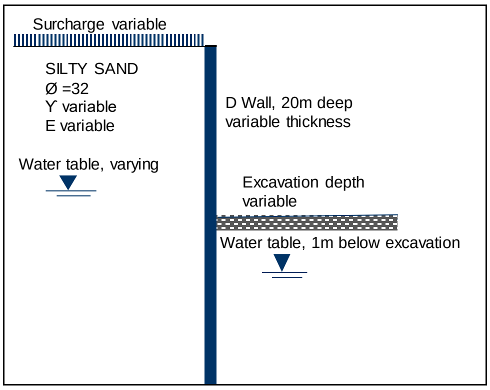

Fig. 6. Cantilever problem considered for the parametric studies

3.1 Effect of water table

First parametric study is carried out by varying water table levels. It is found that water table levels are having a major impact on the behavior of the retention walls. The major reduction in the factor of safety and the sharp rise in the bending moment with the increase in water table explain the importance of consideration of water table variations for retention system.

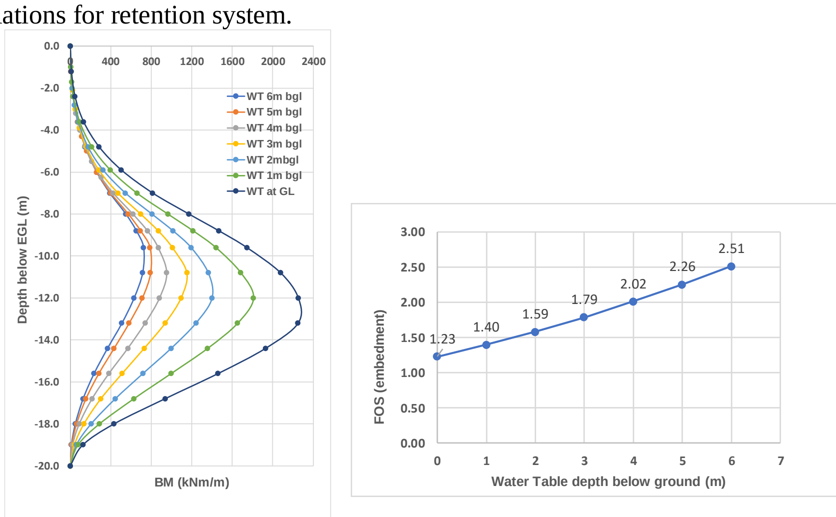

Fig. 7. Effect of water table variations on retaining walls

3.2 Effect of over excavations

Second parametric study is carried out by varying overexcavation that can happen due to improper construction practices. Graphs below indicate the importance of consideration of over excavations in a retention wall design. Any increase in excavation depths are accompanied by sharp increase in bending moments and steep decline in the available factor of safety for embedment.

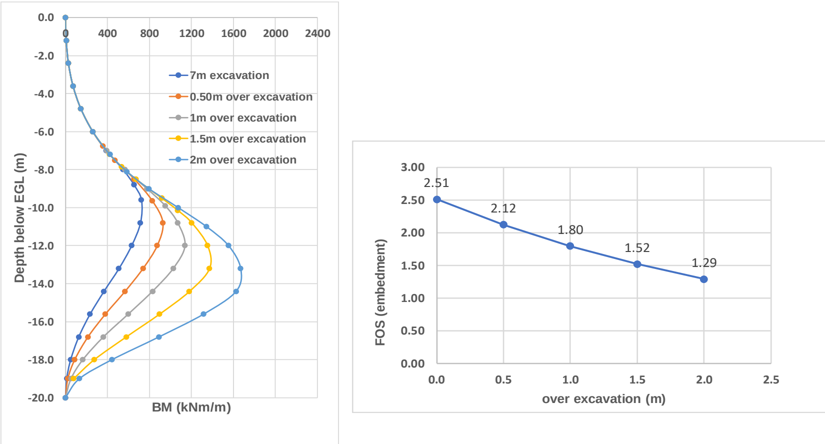

Fig. 8. Effect of over excavations on retaining walls

3.3 Effect of surcharge

Third parametric study is carried out by varying surcharge. The bending moment is increased and available factor of safety for embedment is reduced with increase in surcharge. Even though the variation is considerable, it is comparatively less as compared to variation in water table and excavation depths.

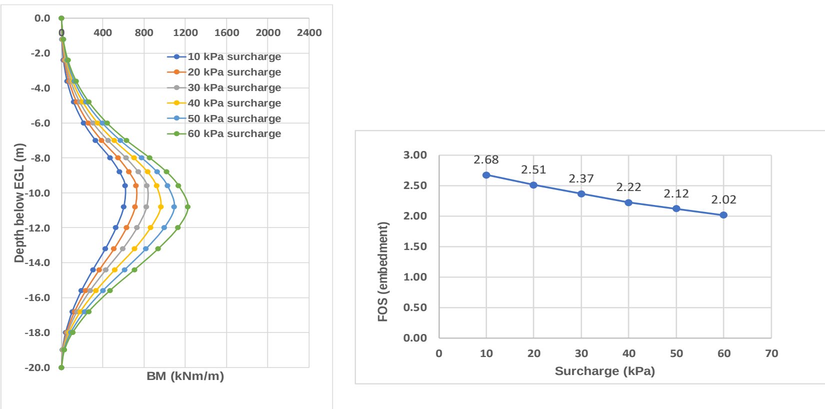

Fig. 9. Effect of surcharge on retaining walls

3.4 Effect of Moment of Inertia of wall

Fourth parametric study is carried out by varying wall flexibility. The bending moments are increased, and deflections are reduced with increase in Diaphragm Wall thickness. However, the influence of wall flexibility on the factor of safety of embedment is negligible.

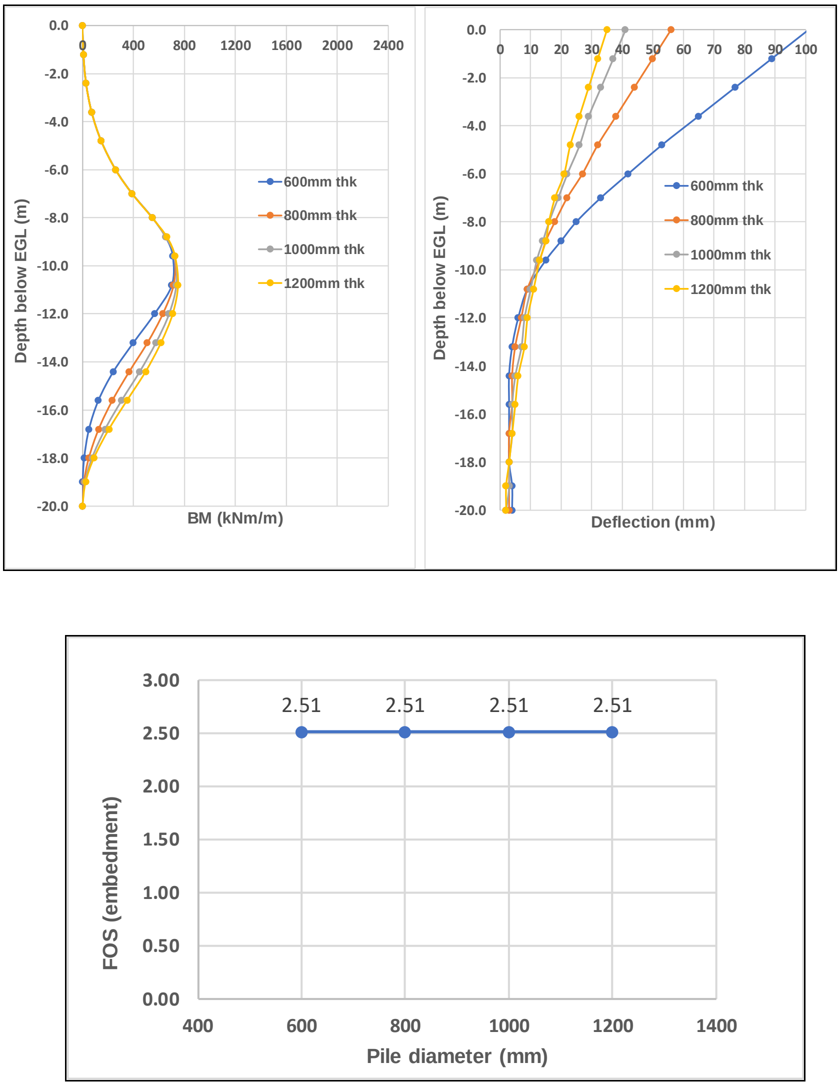

Fig. 10. Effect of wall flexibility on retaining wall performance

3.5 Effect of soil stiffness

Fifth parametric study is carried out by varying soil stiffness. There is a considerable impact on the wall deflections due to varying soil stiffness. However, the influence of soil stiffness on the factor of safety of embedment is negligible.

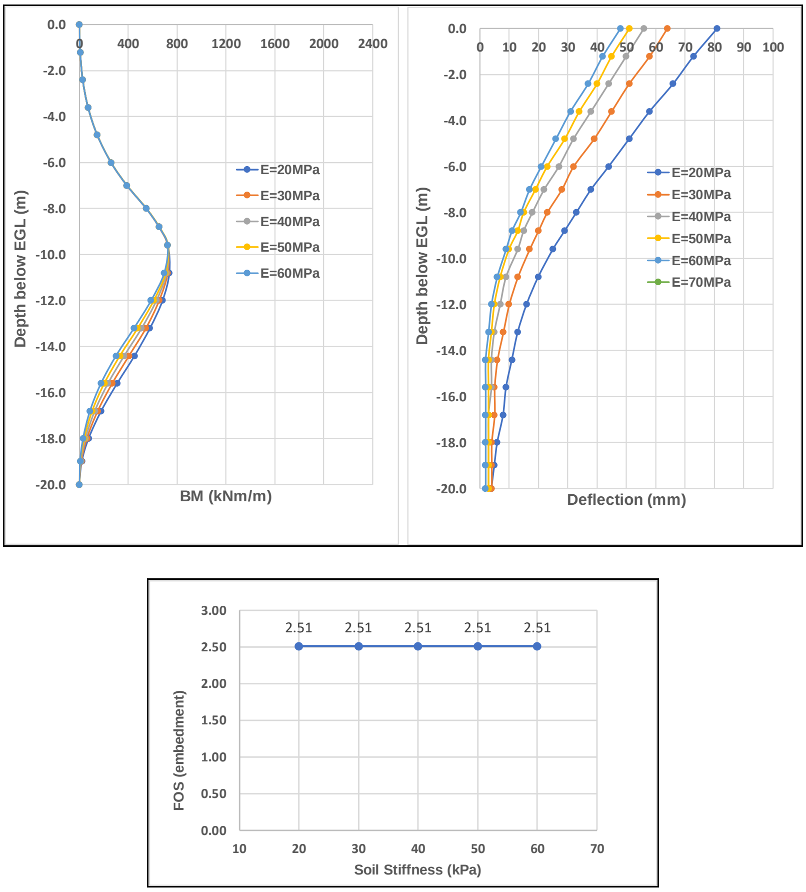

Fig. 11. Effect of soil stiffness on retaining walls

4 Influence of Drained/Undrained Behavior of Soil

The distinction between drained (long term) /undrained (short term) analysis is very important in a retaining wall design. Any long-term exposure of the pit will eventually lead to the failure of the wall if it is designed only for the undrained cases. The assessment of which condition prevail depends on the in-situ permeability of the soil. The following can be used as a guide to identify which behavior prevail. Cantilever shown in **Fig. 2** is used to find the influence of long term and short-term effects. The bending moments and wall depths for factor of safety of embedment (2.0) are computed based on the working conditions (SLS). The difference between the approaches can be found below.

Table 3. Drained Vs Undrained -Applicability

	Undrained Analysis (short term)	Drained Analysis (Long term)
Soft / Very soft	Critical	--
Stiff / Very Stiff	--	Critical

Table 4. Drained Analysis Vs Undrained Analysis-Results of Case Study

Item	Drained Analysis	Undrained Analysis
Required Wall Depth (m)	18.00	17.50
SLS Bending Moment (kNm/m)	735	415
Deflection at Service Condition (mm)	71	59

5 Discussions and Conclusion

This paper covers study on behavior of wall addressing method of analysis i.e. limit equilibrium method, subgrade and finite element approaches. Further, parametric study carried out with effect of water table, over dig, surcharge, soil stiffness, wall flexibility and drained & undrained to understand behavior of wall.

This study suggests that behavior of cantilever walls show similar trend for all three methods of analysis. In contrary, significant difference in behavior is seen for anchored/strutted walls (esp. for heavily loaded cases), due to redistribution of stresses. Significant variation is observed especially for prop loads and bending moments among all three methods. The results of the study also confirm subgrade reaction or finite element methods are appropriate for analysis of deeper/anchored/strutted walls.

Retention system analysis using undrained parameters can create unfavorable environment in excavation pits. Hence, it is suggested to check analysis for drained conditions addressing long-term stability of wall. Water table variations and over excavations have considerable influence on the retaining wall. Influence of surcharge has a moderate impact. Soil stiffness and wall flexibility have less impact on the embedment depth but significant influence in wall movements.

References

1. BS EN 1997- Part 1 (2004), Eurocode 7. Geotechnical design.
2. BS 8002 (1994), Code of Practice for earth retaining structures.
3. CIRIA C760 (2017), Guidance on Embedded Retaining Wall Design