Comparison of Conventional Method with Finite Element Analysis Using Plaxis 2D for Cantilever and Anchored Sheet Pile Walls

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Abstract. Excavation support system is essential component of modern time, where buildings with multiple basements are essential for parking and other purpose in large cities, where adjoining buildings are already functional. The purpose of this work is to present the comparison of the behavior of sheet pile wall at critical depth obtained from conventional method and finite element analysis. The conventional methods used in the structural design of sheet pile walls are based on the limit equilibrium approach. Program in MATLAB software is developed for this purpose. This program is evolved from simplified method for design of flexible retaining structure, which is introduced by the Herman Blum (1951). It is noted that conventional design method for retaining structures is unable to determine deformation of structure which is important for serviceability consideration. Hence finite element method was used to perform numerical modelling and analyses to evaluate the structural response and the behavior of wall. PLAXIS 2D software is used for this purpose. Present work is an attempt to study the behavior of cantilever and anchored sheet pile wall penetrating in homogeneous cohesionless and cohesive soil, c-φ soil and layered soil for the excavation depth of 3m and 6m.

Keywords: Excavation support system; sheet pile wall; Limit equilibrium approach; finite element method; MATLAB; Plaxis 2D

1 Introduction

Deep excavation is becoming increasingly common for the construction of tall structures, road tunnels, mass rapid transit systems and other facilities in densely built-up areas within the city and suburban areas. Thus, deep excavations are supported by retaining structures like conventional retaining walls, sheet piles wall, braced walls, diaphragm walls and pile walls etc.

Sheet pile walls are one of the oldest earth retention systems utilized in civil engineering projects. It is most common as the installation is relatively cheap and can be performed in many ways depending on the surroundings. The sheet pile walls can be either cantilever or anchored.

The selection of the wall type is based on the function of the wall, the characteristics of the foundation soils, and the proximity of the wall to existing structures. While the cantilever walls are usually used for wall heights less than 5 m, anchored walls are required for higher walls or when the lateral wall deformations are needed to be restricted. Typically, the anchors are installed when the wall height exceeds 6m or the wall supports heavy loads from a structure

The conventional methods used in the design of sheet pile walls are based on force and moment equilibrium using active and passive earth pressures that are concerned with the failure condition. These design methods do not specifically consider wall displacements.

2 Problem Formulation

Cantilever sheet pile design

Hermann Blum (1951) introduced simplified method for analysis sheet pile wall that in formulation of the equivalent beam method. As shown in Fig.1 and Fig.2, the earth pressure below the rotation point can be replaced by an equivalent concentrated force acting on point O, represented as the resultant force. The value for the depth d has been found to be considerably lower than compared to the value calculated by the full method. Thus, the simplified method is slightly more conservative than the full method, although it leads to appreciable results

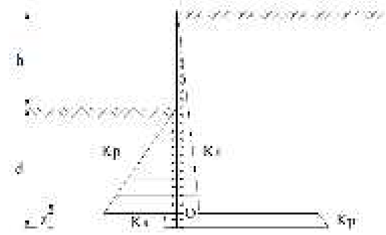

Fig.1 Conventional design method of Cantilever Sheet Pill Wall in granular Soils

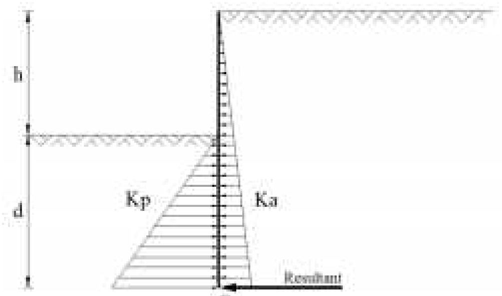

Fig.2 Conventional design method of Cantilever Sheet Pill Wall in granular Soils

Anchored sheet pile design

Anchoring the sheet pile wall requires less penetration depth and less moment to the sheet pile because it will drive additional support by the passive pressure on the front of the wall and the anchor tie rod. Anchored sheet pile walls are typically constructed in cut situations, and may be used for fill situations with special design considerations to protect the anchor from construction damage from fill placement or fill settlement. Although the excavation depth may be increased thanks to the existence of the anchor, it should not be forgotten, that until the anchor is placed, the structure behaves as a cantilever sheet pile wall.

Free earth support method for anchored sheet pile wall:

In this method, as shown in Fig.3, the movement on the embedded zone of the wall has been assumed enough to mobilize both the active and passive pressures behind and in front of the wall, respectively. Thus, the method assumes to satisfy stability of the sheet pile against lateral displacement by means of driving the sheet pile only deep enough to withstand such pressures. The entire depth of embedment mobilizes the shear strength of the soil.

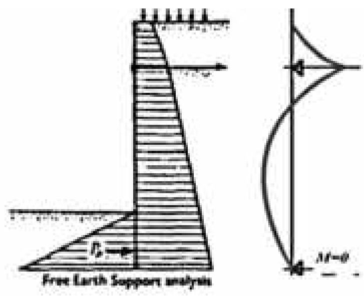

Fig.3 Free Earth Support Method

Fixed earth support method for anchored sheet pile wall:

The fixed-earth support method, as shown in Fig.4, assumes that the wall is sufficiently embedded so that the toe of the wall is prevented from rotation. For propped retaining walls the simplified force system is statically indeterminate and consequently the solution procedure to obtain the embedment depth, do, is not trivial. The problem is solved by iteration or by assuming the location of the point of zero bending moment. A common assumption is that the point of contraflexure (zero bending moment) coincides with the point of zero net pressure.

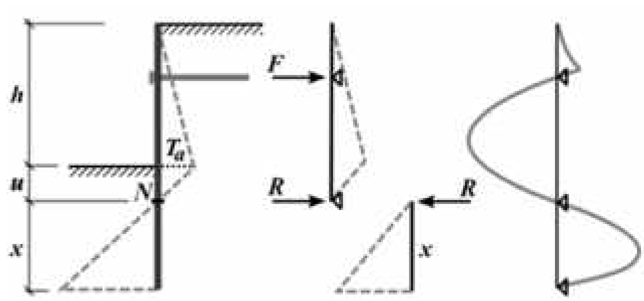

Fig.4 Fixed in heel Support Method

Anchor design:

Several types of anchors can be used with sheet pile walls, such as dead-man and grouted tiebacks. Temporary support can also be provided for the walls by making use of struts, braces and rakes. The selection of the most suitable type of anchor generally depends on the soil type, presence of groundwater and cost considerations. For situations in which one or more levels of anchor are required, it is most suitable to make use of grouted tiebacks, whereas the suitability of tie dead-man anchors is typically limited to situations requiring a single level of anchor.

Horizontal struts need to be used when the width of excavation is small and when their usage does not affect the construction of permanent elements; inclined rake's are used for wide excavation. According to Gulhati and Datta (2008), grouted tiebacks and dead-man anchors are used when there is available underground space beyond the excavated area. This space should be free from the foundations and the underground utilities of adjacent structures. Anchor design is based on FHWA Anchor design Manual and Helmut Ostermayer & Tony Barley.

3. Comparative Study

Design and analysis of sheet pile for 3m and 6m excavation depth for following homogeneous soil conditions using conventional method and Plaxis 2D:

For Cantilever sheet pile wall-

- In cohesionless soil analysis for 26˚ to 36˚ internal friction value.
- In cohesive soil analysis for 10kN/m^2 to 45kN/m^2 Cohesion value.
- In c-φ soil analysis for 26˚ to 36˚ internal friction value and 5kN/m^2 to 25kN/m^2 Cohesion value.

For Anchored sheet pile wall analysis from free earth support-

- In cohesionless soil analysis for 26˚ to 36˚ internal friction value.
- In cohesive soil analysis for 10 kN/m^2 to 45 kN/m^2 Cohesion value.

- In C-φ soil analysis for 26˚ to 36˚ internal friction value and 5kN/m^2 to 25kN/m^2 Cohesion value.

For Anchored sheet pile wall analysis from fixed at heel-
- In cohesionless soil analysis for 26˚ to 36˚ internal friction value.
- In cohesive soil analysis for 10kN/m^2 to 45kN/m^2 Cohesion value.
- In C-φ soil analysis for 26˚ to 36˚ internal friction value and 5kN/m^2 to 25kN/m^2 Cohesion value.

Design and analysis is also carried out for cantilever and anchored sheet pile wall in layered soil condition.

4 Conclusion

For Cantilever sheet pile wall penetrating in:

[A] Granular and Cohesive soil
- Depth of penetration obtained from conventional solution is higher than the FEA solution.
- The maximum bending moment obtained from the conventional solution is higher than that of the FEA.
- Displacement at FEA critical depth is higher than the displacement at conventional depth of penetration.
- With the increase in Ø or c value, the depth of penetration, maximum bending moment & displacement values decreases.
- With increase in depth of penetration from FEA by 20% & 30%, the maximum bending moment increases and displacement decreases as compared to critical depth obtained from the FEA.

[B] C-φ soil
- Depth of penetration obtained from conventional method is higher than the depth of penetration obtained from FEA.
- For the same c value, with the increase in Ø, the maximum bending moment decreases. The maximum bending moment obtained from the conventional solution is higher than that of the FEA. The change in value of maximum bending moment is negligible for the increasing Ø.
- For the same Ø, with increase in cohesion value, the maximum bending moment decreases. The maximum bending moment obtained from the conventional solution is higher than that of the FEA.
- For the same c value, with the increase in the Ø, displacement decreases. Displacement obtained from the conventional solution is higher than that of the FEA. The change in value of displacement is negligible for the increasing Ø.
- For the same Ø, with increase in c value, displacement decreases. The displacement obtained from the conventional solution is higher than that of the FEA.

[C] Layered soil condition

- Depth of penetration obtained from conventional method is higher than that of FEA critical depth.
- Maximum bending moment obtained from conventional method is higher than that of FEA.
- Displacement obtained from conventional method is higher than that of FEA.
- With increase in Ø, depth of penetration decreases slightly, change in bending moment is negligible and displacement decreases.

For Anchored sheet pile wall (Free & Fixed) penetrating in:

[A] Granular and cohesive Soil

- Depth of penetration obtained from conventional method is higher than that of FEA critical depth.
- Max bending moment obtained from the conventional solution is higher than the FEA. The maximum bending moment is higher in free earth support system as compared to fixed earth support system.
- Displacement obtained from the conventional solution is higher than the FEA. Displacement is higher in free earth support system as compared to fixed earth support system.
- With increase in Ø or c, the depth of penetration, maximum bending moment and displacement decreases.
- With increase in depth of penetration from FEA by 20% & 30%, the maximum bending moment and displacement decreases as compared to critical depth obtained from the FEA

[B] C-φ soil

- Depth of penetration obtained from conventional method is higher than that of FEA critical depth.
- For the same c value, with increase in Ø, the maximum bending moment decreases. The maximum bending moment obtained from free earth support method is higher than fixed earth support method.
- For the same Ø value, with increase in cohesion, the maximum bending moment decreases. The maximum bending moment obtained from free earth support method is higher than fixed earth support method.
- For the same c value, with increase in the Ø, the displacement decreases. Displacement obtained from free earth support method is higher than fixed earth support method.
- For the same Ø value, with increase in cohesion, displacement decreases. Displacement obtained from free earth support method is higher than fixed earth support method.
- With increase in depth of penetration from FEA by 20% & 30%, the maximum bending moment and displacement decreases as compared to critical depth obtained from the FEA.

[C] Layered soil condition

- Depth of penetration obtained from conventional method is higher than that of FEA critical depth.
- Maximum bending moment obtained from conventional method is higher than that of FEA.
- Displacement obtained from conventional method is higher than that of FEA.
- With increase in Ø, depth of penetration decreases slightly, change in bending moment is negligible and displacement decreases.

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