Behavior of Rectangular and T Shaped Diaphragm Wall Panels in Mixed Soil Conditions: A Case Study

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Abstract. In urban areas, properly designed deep excavation support systems are essential for any new underground construction adjacent to the existing buildings. Diaphragm walls are widely used in India as deep excavation support system to facilitate strut free excavation as well as to limit the soil movement of surrounding areas due to excavation. In this paper, a ten storey new commercial development required a three-level basement excavation of 12.5m (max.) from the Existing Ground Level (EGL). Project site consists of mixed soil condition with silty clay of varying consistency followed by dense sand underlain by a weathered rock layer. A 600mm thick rectangular D wall panel with temporary ground anchors was used to support deep excavation wherever sufficient setback is available. In the same site, one of the corners has a restricted setback which demanded 8m cantilever wall with high structural rigidity. Hence, T shaped diaphragm wall panels of 600mm thick were adopted as a permanent cantilever wall. Numerical modelling of the retention system was analysed using WALLAP and PLAXIS 2D software. The wall deflections were monitored through inclinometers. This paper reviews the performance of cantilever diaphragm wall and rectangular panel wall with single anchor for 8m excavation depth. Cantilever T shaped diaphragm wall proved to be effective and stable system, where tie back is not feasible.

Keywords: Diaphragm wall, T panel, PLAXIS 2D, WALLAP, Inclinometer, Deflection.

1 Introduction

Land has become scarce and expensive in the developing cities of India due to urbanization and this demands high-rise buildings with underground structures to meet the increasing space requirements. A ten storey commercial building requires a deep excavation of 12.5m for three level underground car parking in a busy area. The site has enough setback distance of about 10m to 12m in majority portion whereas very limited setback (less than 2m from boundary) is available in one of the corners. The subsoil consists of silty clay with varying consistency followed by silty sand underlain by weathered rock. The surrounding constraints of the sites are residential buildings, highway on one side and commercial multi-storied buildings on one side. Based on the site constraints and available setback distance diaphragm wall with 2 level inclined ground anchors has been adopted as a retention system to facilitate 12.5m deep excavation. Cantilever T shaped diaphragm wall was adopted for a small length having maximum excavation depth 8.0m and a limited setback distance of 2m. This paper reviews the performance of cantilever T panel in comparison with the rectangular diaphragm wall panels with single level anchor for 8m excavation.

2 Necessity of T Panel

The North-East corner of the site has limited setback of 2 m and anchors are not allowed to encroach into neighboring properties. Also, this part of the site is proposed with a utility tank wall of about 8m deep. So, in the permanent condition there will not be any structural slabs connection to the diaphragm wall as a prop. Also, there are issues of inadequate space between the diaphragm wall and permanent wall for facilitating de-stressing the anchors if provided in the retention system. Various options were reviewed during design stage and cantilever T shaped diaphragm wall was considered, which is structurally rigid to act as a permanent cantilever wall. Also, side friction will develop in the buttress portion of the T panel, that will provide additional passive resistance to the wall (Sheng et al., 2011). The proposed cantilever portion of the retention system is shown in **Fig. 1**.

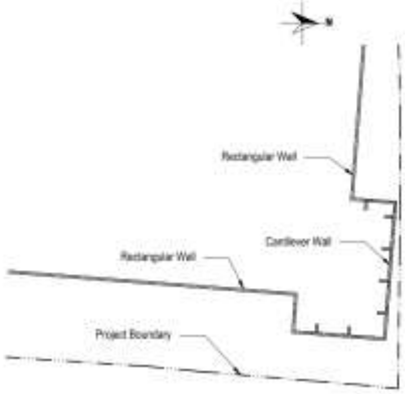

Fig. 1. Proposed cantilever portion of the wall

3 Soil Stratigraphy

The subsoil in cantilever wall location consists of silty clay with varying consistency followed by dense silty sand up to the depth of 18m to 19m underlain by weathered rock. The ground water table was at 3m to 4m below EGL during the time of soil investigation. The design soil parameters were arrived based on the confirmatory soil investigation. Ground water table at 2m below EGL was considered for the analysis.

4 Numerical Analysis of Retention System

The preliminary analyses were carried out using WALLAP which is fast and widely used software. Earth pressures are calculated using active and passive earth pressure co-efficient based on the wall and soil interface friction. In WALLAP analysis, the wall and soil interaction is modelled as a beam and spring analogy. The final design was carried out with plain strain model of 15 nodded elements using PLAXIS 2D. These two analyses were carried out for both rectangular and T panel cantilever wall.

4.1 Rectangular Wall Panels

A 600mm thick diaphragm wall of 19m deep with 2 level ground anchors was finalized to support 12.5m excavation for the majority of the project site where enough set back distance is available. The first level of ground anchor was proposed at 6.5m below EGL and second level was at 10m below EGL. The analysis model and predicted deflection profile for 8m excavation using WALLAP and PLAXIS 2D are presented in **Fig. 2**. Magnitude of the deflection of wall is almost same however WALLAP indicates at top whereas it is seen at middle of the wall excavation in PLAXIS 2D.

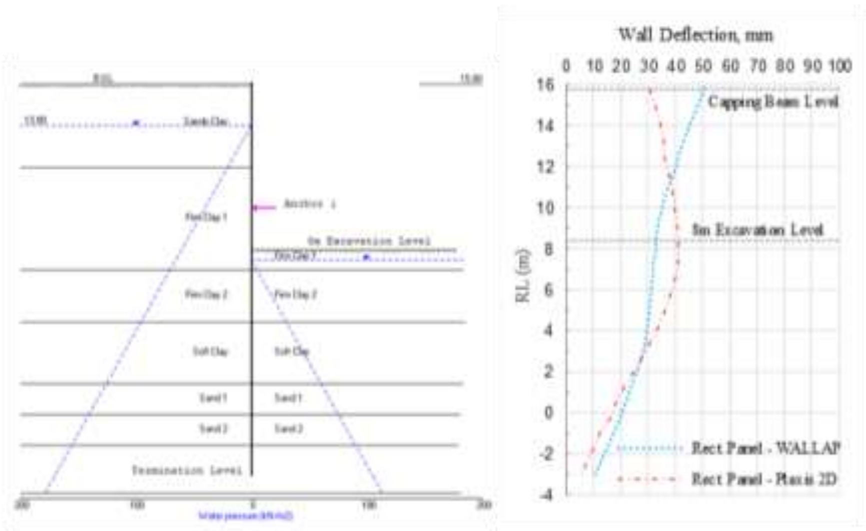

Fig. 2. Typical WALLAP model and predicted wall deflections of rectangular panels

4.2 T Shaped Panels

The behavior of T panel is three-dimensional problem which is having interaction between subsoil, buttress portion and rectangular panels. A 3D analysis being complex and expensive, 2D analysis was carried out using combination of different structural elements available in the program, at the same time providing a geometry close to 3D.

T shaped walls can be modelled in 2D software using two approaches. First approach is to estimate equivalent wall stiffness of rectangular and buttress portion of the wall. This approach will provide total bending moment and shear force of both rectangular and buttress wall. WALLAP uses this approach to design T panels.

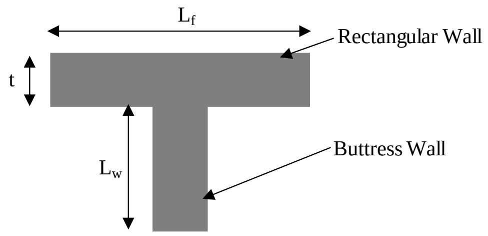

Fig. 3. Typical T panel

The second approach uses two different elements, plate elements to simulate the rectangular panel and embedded beam rows to simulate buttress wall. This approach can be used in PLAXIS 2D. Using this method, the bending moment and forces on the wall and buttress portion can be estimated separately. In PLAXIS 2D, T panel design was modelled using these two approaches. PLAXIS 2D model indicating these two approaches are illustrated in **Fig. 4**.

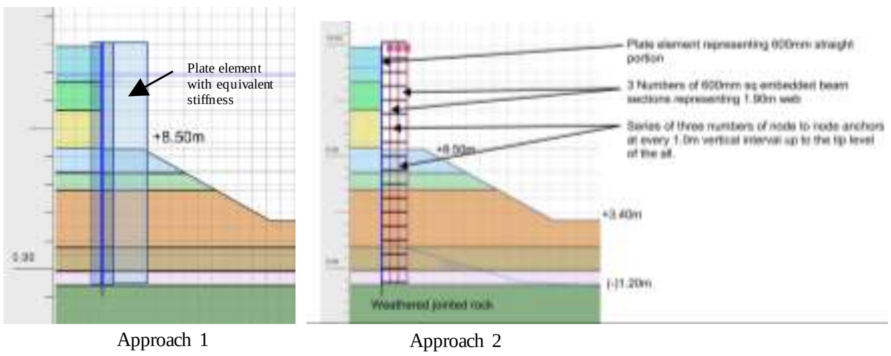

Fig. 4. Typical T panel model (PLAXIS 2D)

T panels design was carried out with different cross-sectional dimension and finalized with 1.9m web depth and 2.5m flange length of 0.6m thick as an optimized solution for the proposed cantilever wall portion. As per the design, the T panels are required to be installed between rectangular panels and are connected with the capping beam at top so that, it will act as monolithic element. The estimated deflection of T panels for 8m excavation using WALLAP and PLAXIS 2D is illustrated in **Fig. 5**. Similar trend is seen for the predicted deflection in both WALLAP and PLAXIS 2D. This confirms cantilever wall behavior and maximum deflection is around 50mm at top.

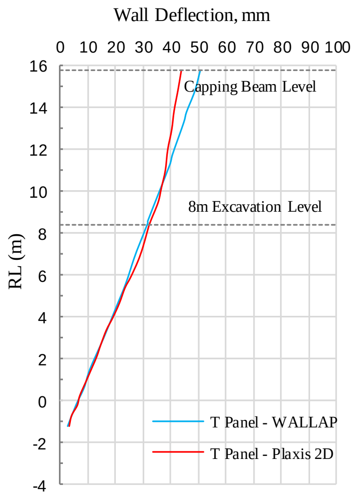

Fig. 5. Predicted deflection of cantilever T Panel wall (8m excavation)

T panels shall be constructed as a single panel to form an integral unit which will ensure the perfect structural rigidity between the buttress wall and rectangular panels (Ou et. al., 2008). Construction of monolithic T panel requires more care with special lifting hook and hangers. The T panel shall be restrained on stiff / dense soil to reduce the wall deflections (Ou et. al., 2008).

Fig. 6. Rectangular and cantilever wall

5 Performance of Executed Wall

Precise instruments like inclinometer, piezometers and deflection markers were installed at site to assess wall deflection and ground water table. This continuous monitoring system helped to assess the executed wall performance throughout the excavation and basement construction period. One inclinometer was installed in cantilever portion of the wall to observe T panel behavior during excavation. Also, another inclinometer was installed in rectangular panels which is close to the cantilever portion to compare the estimated results. The maximum deflection at T panel is observed as 50mm whereas in rectangular panel the maximum observed deflection is about 36mm. In T panel, the wall deflections are controlled by the combined stiffness of web and flange portion (Chang et al., 2017). The location of inclinometers and observed wall deflections are shown in **Fig. 7** and **Fig. 8** respectively.

Fig. 7. Location of inclinometers at T shaped cantilever and rectangular wall

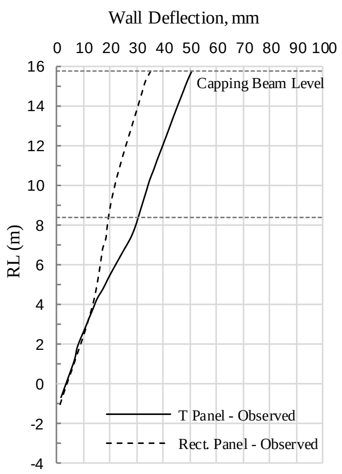

Fig. 8. Observed deflections of rectangular and T panels

6 Comparison of Wall Deflections

The estimated wall deflections of T panel with 8m cantilever wall and rectangular panel wall with one level anchor of 8m excavation are compared with respective actual field measurements. Deflection patterns are presented in **Fig. 9**.

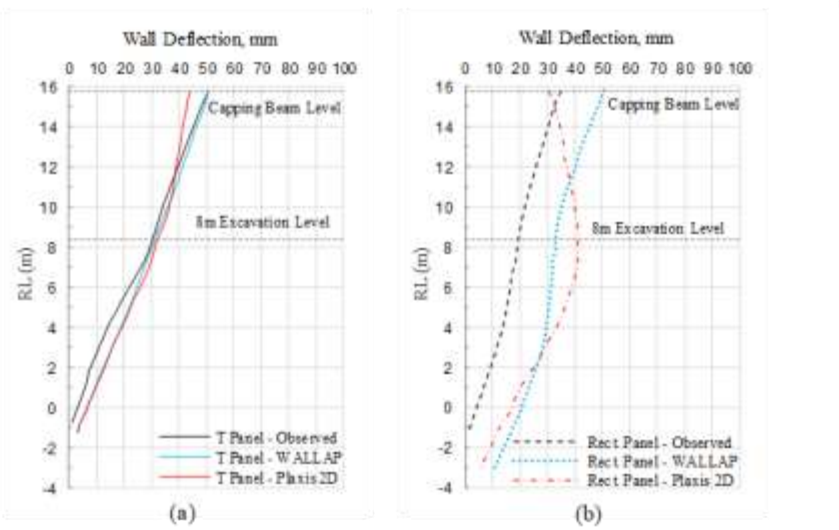

Fig. 9. Predicted and observed wall deflections of (a) T panel and (b) rectangular panel

The observed deflection of cantilever T panels is almost matching with the estimated deflections which indicates the design assumptions are reasonable and are accorded with actual site condition. In rectangular panels, the observed deflection and predicted WALLAP deflections are similar line and the magnitude of wall deflection is 36mm whereas the predicted values are in the range of 50mm (max.).

7 Conclusions

Various retention system proposals based on the available setback and site constraints are proposed and executed. T panel behavior can be modelled in 2D software with appropriate assumptions to simulate the 3D behavior. Different approaches of modelling of T panels are described and indicates the analysis results are comparable. The estimated and observed field behavior of cantilever T panel are matching. This proves that the design assumptions made for the simulation of 3D problem into 2D model and design soil parameters are reliable and reflects the actual site conditions. The actual performance of rectangular panels with one level anchor indicates that wall deflection is well within the predicted limits. Since the rectangular panel wall is designed for 12.5m deep excavation and provides more stiffness, resulted in less wall deflection.

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