Double diaphragm wall – Design and construction experience

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Keywords: diaphragm wall, numerical analysis, Plaxis, construction

ABSTRACT: The project finished the construction of diaphragm wall ten years ago. Due to change of the Owner, the scale of building was increased, higher and deeper. Therefore, an additional diaphragm wall, beside the existing one, was considered as a solution for basements structure. This paper aims at giving a case study on calculation method of two parallel diaphragms walls system, which be called double diaphragm wall, based on inhouse software with finite difference method and Plaxis software with finite element method. The deflections, bending moments and shear forces came from two methods were relatively similar and reasonable. This paper also presents some challenges on the construction experience during constructing the additional diaphragm wall on site. Some conclusions will be drawn for design and construction, as a referential case for future projects.

1. INTRODUCTION

As the previous design, the building included 20 floors with 4 levels of basement. The max excavation depth to bottom level of pile cap was 14.5 m. Diaphragm wall, at that time, was a final choice for both temporary and permanent supporting structure, with thickness of 0.8 m and depth of 22.0 m.

The new design of building has increased to 27 floors and the max excavation depth to 16.7 m, with similar number of basement level.

The calculation showed that, with the same number of basements, bending moment increased proportionally with the lowering max excavation depth. It made the diaphragm wall structure out of its capacity. Then the need of reinforcing for constructed diaphragm wall has to be considered. As the result, a new diaphragm wall, parallel with the old one, formed a system as double diaphragm wall was the most efficiency solution.

The diaphragm wall calculation was based on two software, for comparison and for the purpose of double checking as well.

2. CALCULATION

2.1 *Input data*

The stratigraphy of soil layers was inspected as below:

- Layer 1: Backfill, average thickness of 2 m.
- Layer 2: Sandy clay, soft to medium dense, SPT N_{30} = 5 with average thickness of 2.92 m.
- Layer 3: Clayey sand, stiff, SPT N_{30} = 6 with average thickness of 3 m.
- Layer 4: Fine sand, medium, SPT N_{30} = 16 with average thickness of 9.51 m.
- Layer 6: Sandy clay, stiff to very stiff, N_{30} = 13 with average thickness of 4.36m.
- Layer 7: Clay Sand, stiff, N_{30} = 21 with average thickness of 4.15 m.

P. Duc Long and N. T. Dung (eds.) et al., *Geotechnics for Sustainable Infrastructure Development*, Lecture Notes in Civil Engineering 62,
https://doi.org/10.1007/978-981-15-2184-3_57

- Layer 8: Fine to coarse sand, medium to dense, N_{30} = 30 with average thickness of 6.74 m.
- Layer 9: Gravel with fine sand, very dense, N_{30} > 50 with average thickness of 4.20 m.
- Layer 10: Fine to coarse sand, medium to dense, N_{30} = 36 with average thickness of 6.28 m.
- Layer 11: Gravel, very dense, N_{30} = 50 with average thickness of 6.11 m. The observed static water level around 5 m deep underground.

In the layout of figure 1, the old wall was in hatch and the new one was inside. The diaphragm wall was divided into panels. The joint connection between two continuous panels was water stop joint type. Distance of the two walls was preferred as closed as possible. In theory, two walls were in contact with each other.

Ground water level was 5.0 m below ground level. The soil profile and soil characteristic were presented in figure 2 and table 1. The basement construction sequences (Fig. 3):

- Step 1. Construction Diaphragm wall and capping beam.
- Step 2. Excavating to -3.60 m.
- Step 3. Installing B1, then excavating to -8.30 m, dewatering to -9.30 m.
- Step 4. Casting B2, then excavating to -11.50 m, dewatering to -12.50 m.
- Step 5. Casting B3, then excavating to -16.70 m, dewatering to -17.70 m
- Step 6. Casting B4.

The horizontal subgrade reaction K_h is proposed by Chadeisson (1961) in experimental correlation with soil characteristics *c*, *phi* (see Fig. 4).

2.2 Case study

2.2.1 Existing diaphragm wall capacity

The construction sequences of new structure applied on the existing d-wall for reinforcement capacity checking. As the result, the material line was going out of bending moment envelop, on excavation side, from -6 m to -10 m and from -13 m to -19 m in depth. While on the soil side, from ground floor to the depth of 11 m, the wall was enough reinforcing. That means the thickness of the existing d-wall was not enough for a higher internal force. Bending moment increased progressively 1.5 times as max excavation depth deepened from 14.5 m to 16.7 m, as shown in figure 5.

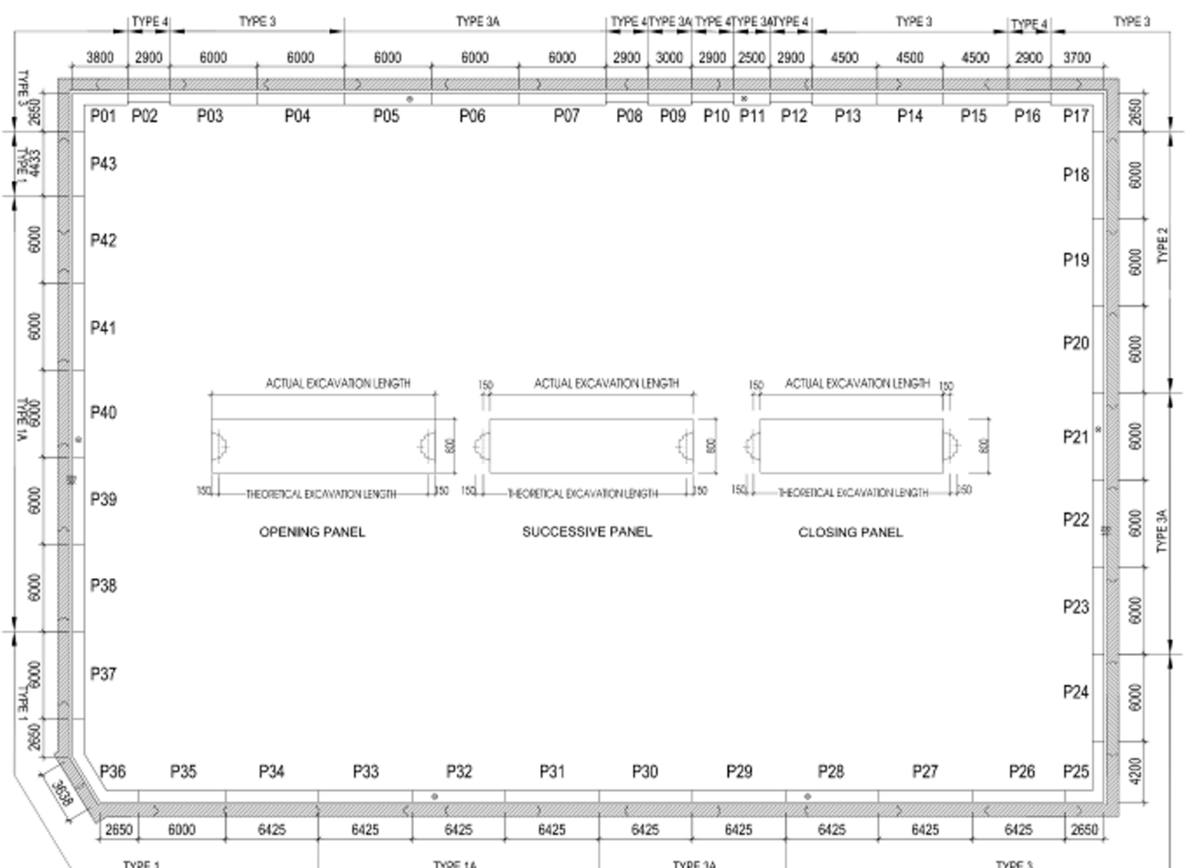


Figure 1. Diaphragm wall layout

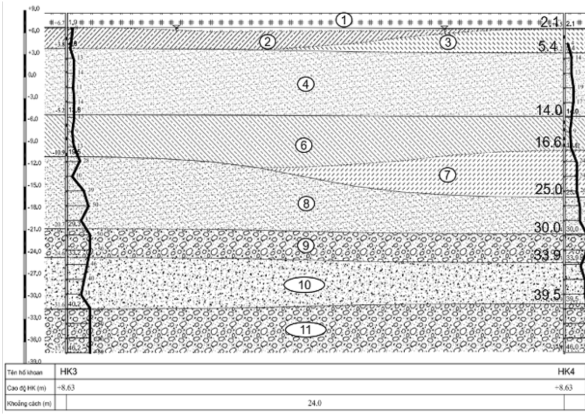


Figure 2. Soil profile

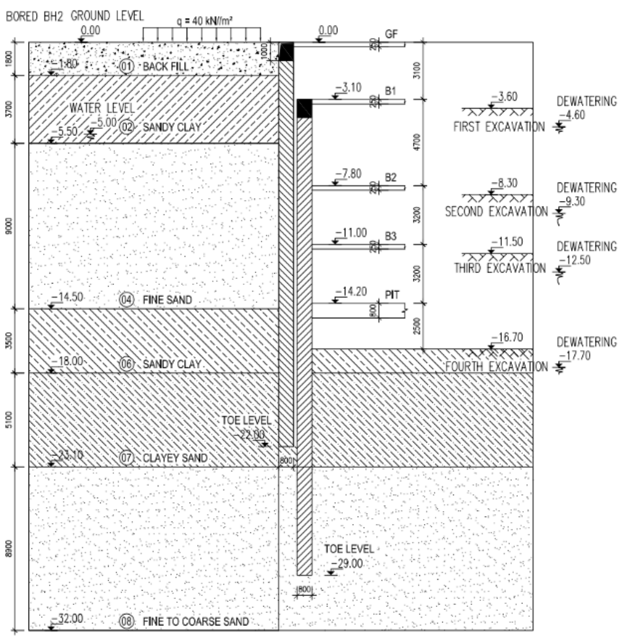


Figure 3. Construction sequences

Table 1. Soil characteristics

Item	Unit weight (kN/m³)	Friction angle (degree)	Cohesion (kN/m²)	Soil stiffness (kN/m³)
1. Backfill	18	30	0	27286
2. Sandy Clay	19.4	2	60	13320
4. Fine Sand	18	24	0	17726
6. Sandy Clay	20.1	3	60	13900
7. Clayey Sand	19.7	21	14	17614
8. Fine to coarse Sand	18	30	0	28658
9. Gravel with fine sand	18	32	0	31664
10. Fine to coarse Sand	18	31	0	27286
11. Gravel	18	32	0	31664

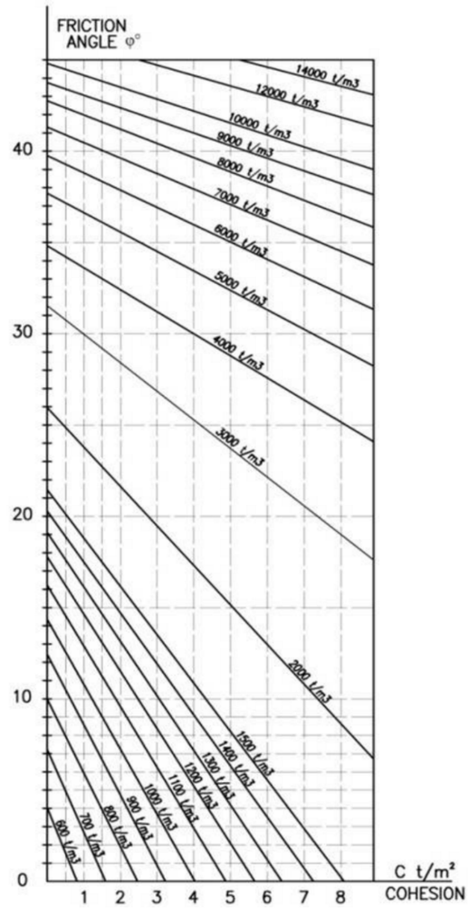
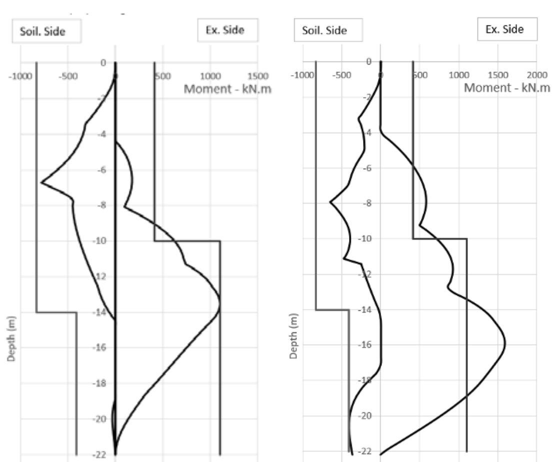


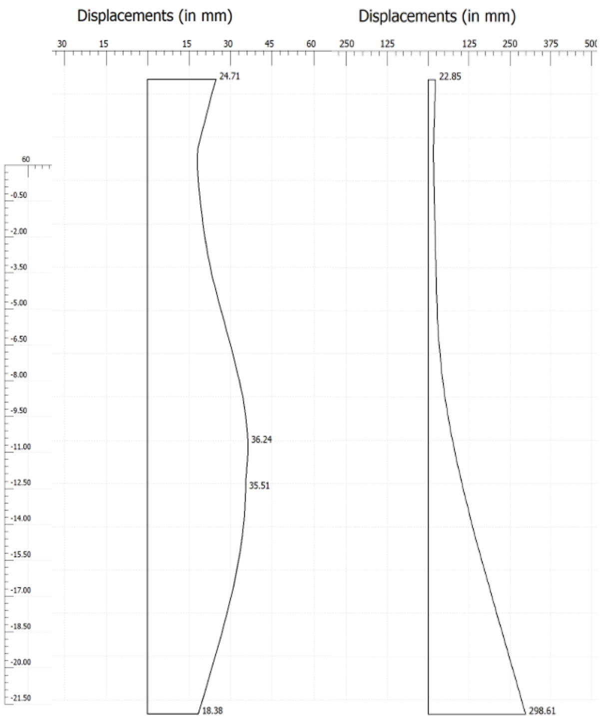
Figure 4. Correlation between K_h & c, *phi*



(a) (b)

Figure 5. Bending moment of existing d-wall with (a) old basement sequences & (b) new basement sequences

With deeper excavation level, displacement of the wall also increased to failure at its toe, as shown in figure 6. Then, the D-wall need to embed into the lower soil layer.



(a) (b)

Figure 6. Displacement of existing d-wall with (a) old basement sequences & (b) new basement sequences

Therefore, an effective technical solution has to solve 2 problems, firstly, about the thickness and secondly, the depth of existing d-wall. Soil improvement should respond for the second problem, by reinforcing the soil below the old wall, but a new D-wall, parallel with the existing one should be a better answer.

2.2.2 Double diaphragm wall calculation

Calculation procedure using Paris – finite difference method was presented as below and in figure 7.

- Run one D-wall model to obtain the required depth.
- Run two D-walls model to obtain the required bending moment and shear force.
- Reinforcement calculation

Considering that each single D-wall takes half of the internal loads for the upper part and the new d-wall will support for the lower part. The result as shown in figure 8 and figure 9.

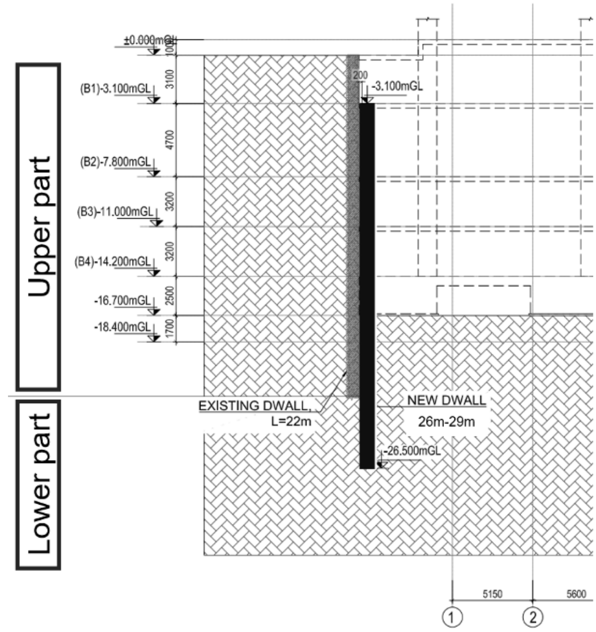


Figure 7. Section of two D-walls

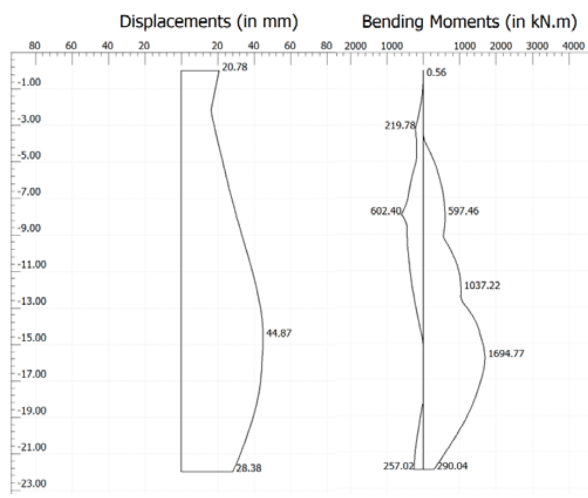


Figure 8. Displacement & Bending moment of two d-wall models – the upper part.

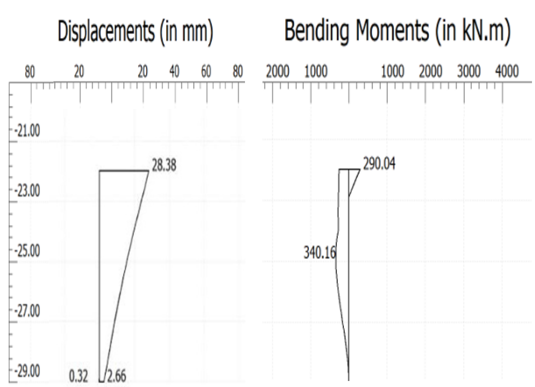


Figure 9. Displacement & Bending moment of two d-wall models – the lower part.

In the model of two D-walls, the inertia moment was the sum of each 0.8 m d-wall's inertia moment. The result showed that, displacement of two d-wall in the upper part was 45 mm, and the maximum bending moment was 1,695 kNm. The lower part get displacement of 24mm and maximum bending moment of 340 kNm. Applying haft of the internal load into the old d-wall for checking its capacity, whether the old one should be strong enough for co-working with the new one. In other hand, if the old one is not strong enough, checking how many percentages of the internal force that the old D-wall has taken, the remain be supported by the new one, in proportion with its stiffness. Then, thickness of the new d-wall was determined.

The grade of concrete of new D-wall was similar with the old one, in order to create a favourable condition for two D-wall system in construction and permanent stage.

Calculation procedure using Plaxis - finite element method was that running two parallel and independent d-walls with different depth, at the same time, by iteration method to determine the dimension of new one.

The result from Plaxis showed as similar with one from Paris program as shown in figure 11.

The result from two different methods, calculated by two different softwares used for double check and otained an objective solution. Based on that, double diaphram wall had co-working in sharing internal load.

3. CONSTRUCTION

In theory, the double diaphragm walls need a good contact between each other. It has to takes into account in construction method statement. On the top of the new D-wall, the clearance was 200 mm, in order to have place for guide wall. When the excavation was carried out, firstly the grab made a trench of 0.8 m thickness, then, it enlarged the trench toward the old wall, brush on that side in order to make as good contact as well.

Distance between two d-walls was 200mm, required the Contractor to follow a serious and well-prepared construction sequences. Although all the as-built and inspection of old d-wall had collected sufficiently, the construction still had major risk. From the risk of verticality and the concrete bulge of the old d-wall could cause bad contacted on the shaft. To the risk of existing bored piles, which were close to the old d-wall 800 mm at some locations, just enough room for the grab to go by. Therefore, firstly, the inspection for the concrete bulge of the old d-wall, by a system of observation bored hole, had been carried out. Bored holes were 1.5 m spacing and 22 m depth.

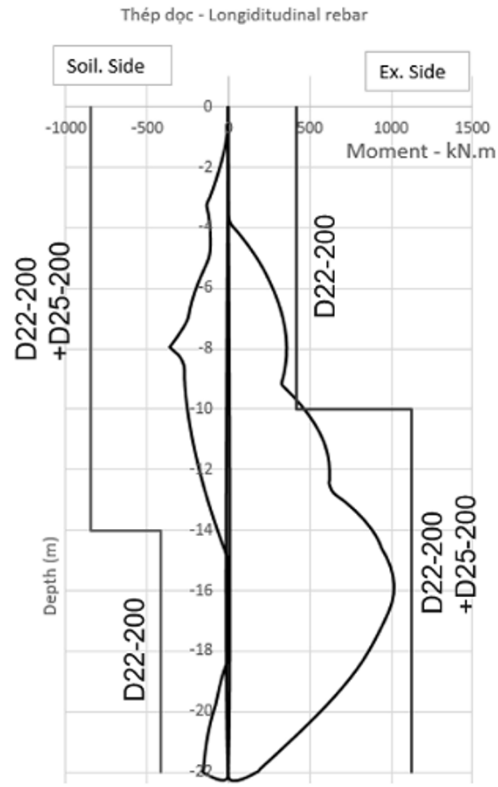


Figure 10. Reinforcement of the old d-wall & the new d-wall for haft of bending moment from Paris result

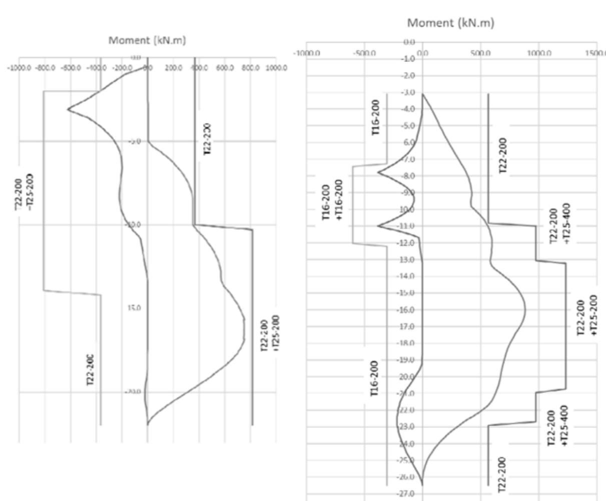


Figure 11. Reinforcement of the old d-wall & the new d-wall from Plaxis result.

Based on the inspection, some locations had found concrete bulge from the old D-wall. The method using chisel to break concrete bulge as much as possible. The lower required spacing at some location, caused by the existing bored piles was found also. Solution of decreasing thickness of D-wall was applied on one bite panel for several panels in the middle of D-wall and bored pile.

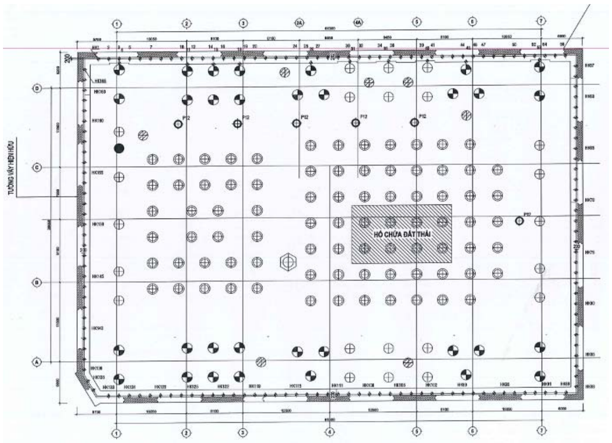


Figure 12. Observation bored holes system

Figure 13. Observation bored hole constructed on site

4. CONCLUSION

Double diaphragm wall, which was a well – combined of theory calculation and real construction method statement, to be an effective and an economic solution for Client in this project. The calculation and the comparison result from two software by two different methods to be a high objective and referent procedure.

The study was to be continued as the bulk excavation and basement construction stage was carrying out. A back analysis of displacement of d-wall from monitoring should be an additional item to make the study more efficient and referential for other future projects.

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