


Different Methods of Excavation for Basement in Jakarta: Design, Reality and Associated Problems

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Abstract. Jakarta is a wide area covering different soils conditions and different surrounding. As metropolitan city, Jakarta has serious problems due to difficulties in the methods of excavation, geology, water table, and disturbance to neighbors. Of particular interest is there is no fixed standard of design and each designer has used different methods and references.

Many constructions have been successful, and some construction fail due to lack of understanding and knowledge on the soils condition. The soft soils condition is part of the cause of failures. These soft layers spread from south to north of the city owing the fact that old or ancient rivers were there and at present, they could not be identified after covered by sediments. Soil Investigation should be carefully planned to reveal the variety of ground condition. In most cases, the soft soils are still consolidating and hence some failures have been caused due to ignorance on the presence of excess pore pressures. On the other hand, in some areas strong lahar formation also exist and excavation lead the fact that they are stable upon deep excavation over 15 m even without protection or minor treatment. The area could change drastically within a distance of less than 50 m. In central Jakarta surrounding the National Monuments, loose to medium sands are found. The excavation dewatering has caused severe problems mainly settlement of neighborhood that subsequently sued the owner of the buildings. The City of Jakarta now prohibit dewatering by pumping during excavation.

The methods employed by designers and contractors vary depending on their experiences. Lessons learned from success and failures have been documented by the author. This paper discusses case histories of all common methods of excavation for the basement in Jakarta City from design perspectives and facts of recorded failures as well as successful measurements. A discussion on deep excavation for Jakarta MRT is also presented.

Keywords: Excavation · Safety factor · Deformation · Under-consolidation · Lahars

1 Introduction

Problems of deep excavations in urban areas like Jakarta and other big cities in Indonesia is critical due to the need of spaces for parking of high rise buildings. In the last 20 years, the design and construction of basement in Jakarta tend to be deeper say from 4 levels

to 6 levels of basement or even more. Other need for excavation is also on demand such as for MRT and underground storage.

The consequence of construction of a deep excavation can induce lateral movement as well as settlement of the ground which can have serious effects on adjacent buildings. The adjacent building may be damaged due to the excessive differential settlement caused by soil movement induced by the wall deflection and heave at the base of the excavation. This potential problem could be even amplified if the deep excavation is conducted in the congested urban area where existing structures are located in close proximity to the excavation.

Papers concerning these issues have been published every where and hundreds or even thousands of research on this topics are available, hence the main purpose of this paper is to present experience in specific location in the Jakarta area, mainly for the purpose of sharing “lessons learned from common practice to specific soil conditions”.

A number of the authors experience in handling deep excavation in Jakarta and advice to the local contractors or owners as they face difficulties or even failures will be addressed. Different methods have been proposed depending on soil condition.

2 Geological and Soil Condition

The soil condition in Jakarta varies between those relatively strong at the south part of the city and soft to very soft in the north coastal zone. Hence the main issue to be considered in design and construction of the basement depend primarily on the insitu site condition. Figure 1 shows the geology map of Jakarta metropolitan city and boundary of the soil conditions are clearly shown on the map. Location of Case Studies are also shown on the map.

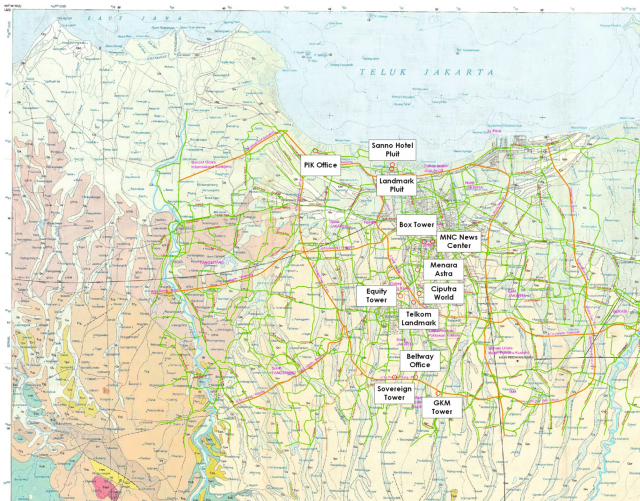


Fig. 1. Geology map of Jakarta and location of case studies

The south part of Jakarta is generally stronger sedimentary soils and volcanic soil. Lahar formation is generally found at a depth of 10–20 m which consist of lightly to strongly cemented sand. In contrast, the north parts of Jakarta is very soft so soft marine clay 15–17 m thick underlain by thin dilluvium clay with 2–6 m thick, then at a depth of 21–25 m sand lenses normally exist almost every where varying thickness of 2–15 m. Generally medium to stiff clay are located below these sand lenses to a depth of 40–50 m then becoming very stiff to hard to 100 m or even deeper. In some areas, the second sand lenses may be found at 30 m also with varying thickness.

3 Challenge for Design of Braced Excavation in Jakarta City

3.1 Problems of Dewatering

Despite of the challenge of uncertainty, the main issue for design is pro and con between cost and safety. Other important factors to be considered are soil condition, the proximity of the excavation from the neighbour buildings and how reliable is the soil information from the investigation report.

Some interesting problems due to the existence of loose sands and underconsolidating very soft soil layers might be of interest. These two soil conditions have been the cause of failures in excavation issue either due to lateral ground movement of unwanted effect of the excavation. Due to many problems caused by dewatering, it is presently prohibited to lower down water table by dewatering. Hence the designer shall apply other methods (Fig. 2).

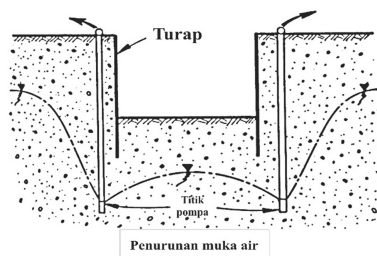


Fig. 2. Dewatering during excavation is not recommended or prohibited in practice for Jakarta City

When soils have high permeability, the practice in Jakarta always request the designer to avoid ground water flow into excavation area by closed system such as by use of cut-off wall or diaphragm wall (Fig. 3). This method is possible if the existence of clay layers are not quite deep from the base of excavation and the cut off system shall be constructed sufficiently deep into the impermeable layer. If impermeable layer is down below the base of excavation, then to reduce the ground water flow, sufficient thickness of grouting can be an alternative. However, this method does not guaranty full water tightness. *Cut off wall* can also be designed by use of bentonite cement. In practice, most design in Jakarta is by using either secant piles or diaphragm wall.

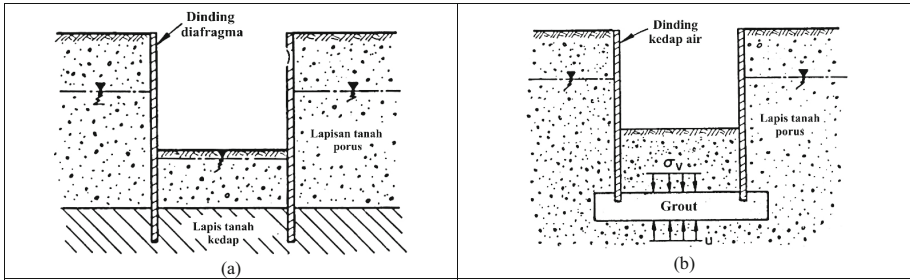


Fig. 3. (a) Reduce dewatering by cut off wall penetration through impermeable layer (b) or by grout at below excavation base layer when impermeable layer is too deep

Recently precast diaphragm wall is also used in practice. The excavation has to be conducted sufficiently deep into the impermeable layer, however the precast element can be positioned higher for economy reason. The precast panel method is desirable due to quality, however the present product is limited to 400 mm thick and limited length of 12 m. For larger size the difficulty is on the lifting and transporting the element (Fig. 4).

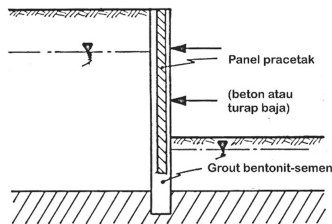


Fig. 4. Use of precast diaphragm wall

When the base of excavation find clay or silty soils relatively impermeable, then dewatering by pumping may not be relevant, then the popular way is by the method of passive dewatering. The water is collected in a pit and then pumping is allowed. This method must be carefully understood by the design engineer, because once the base concrete slab is poured, water will cause uplift and often contractors are not aware of this phenomena.

The best practice that we recommend is by constructing trenches and fill them by drain material or gravels to minimize the buoyancy effect. The unwanted effect of the dewatering was presented as an example in this paper.

3.2 Problems of Excavation in Consolidating Marine Clay Layer in Jakarta

Another challenge that most designers not aware of is the existence of underconsolidating soft marine clay in the north area of Jakarta. During testing in laboratory, the excess pore pressure of these soils disappeared due to stress release as the sample are opened. When designing the protection of excavation, designers only view water

pressure based on hydrostatic condition. The existing pore pressure is neglected. Some failures or excessive lateral movement have occurred. The author always use Cone Penetration Test to identify and quantify the excess pore pressure (Rahardjo 2015).

Research by Cox has shown that most alluvium in South East Asia are still consolidating. The degree of consolidation was found to depend on its sedimentation rate and type of soils. In most soil investigation report, the soils are described as normally consolidated (Fig. 5).

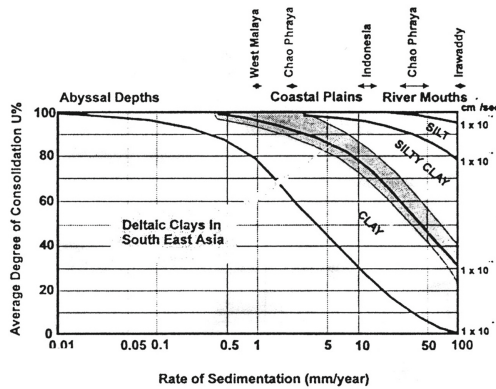


Fig. 5. Degree of consolidation of soft Deltaic Clays in South East Asia (Cox 1970)

4 Excavation at South Jakarta

Deep excavation South of Jakarta is in general in better soil condition where water table is normally low at 6–8 m below ground level. This condition is favorable to allow the excavation with minimum protection.

Favorable soil conditions mean:

- The subsoil has relatively medium to high shear strength, the upper layer are generally medium to stiff clay or cemented sands.
- Low ground water table so that pumping is not necessary or much less.
- There are not many building surrounding the excavation area.

Protection could be with only shotcrete and or soil nailing. Figure 6 show example of excavation with minimum protection in South Jakarta Area before covered by shortcrete. This type of excavation is about 9–10 m deep and the distance to the buildings on the order of 10–15 m. Usually inclinometers and pizometers are installed to monitor the behavior of the excavation. Notice that no water table of wet layers were detected in these excavation (Fig. 7).



Fig. 6. Example of excavation at south of Jakarta with minimum protection



Fig. 7. Another example of 9 m depth of excavation at south of Jakarta

In some cases, the first 3 m consists of soft soil or recent sediments of clay with a range of $SPT = 3-5$ and undrained shear strength of $S_u = 20-30$ kPa. This layer is normally protected by shotcrete cover and soil nailings. Figure 8 is an example of this case where a berm is provided at the boundary between soft clay layer and lower stiffer layer. The lower layer could be strong and stiff clay or cemented sands (lahar origin) and can be stable with very steep cuts of $H:V = 1:5$. The problems with the existence of sandy layer is water seepage. To avoid significant drawdown of the ground water, despite of dewatering by pumping, a passive way to dry the site is by horizontal drains as shown on Fig. 9.



Fig. 8. Excavation with combined soil nailing at upper slope and steep cut for excavation at south of Jakarta



Fig. 9. The use of horizontal drains to drain out ground water seepage for stable slope at South Jakarta

5 Use of Inclinometers Inside Soldier Pile to Measure Displacement and Estimate Forces in Piles

A simple method of pile behavior in stabilizing slope is measuring the pile top movement using theodolite. However this measurement is lack of accuracy due to the fact that it can not be used to observe movement below the ground. The use of inclinometers are common and usually they are installed in the soils behind the retaining system. The author has installed the inclinometers to measure the behavior of the soldier piles and to estimate shear forces and moment in the soldier piles. Pile behavior may be better measured using inclinometers embedded into the piles during pile installation. Basically it is assumed that the deflection of the piles will be automatically represented by the deviation of the inclinometers. The measurement can be done from time to time during construction or during the course of the slope movement (Fig. 10).



Fig. 10. Strong layers of soils alternating with the cemented sands are found at South Jakarta

The first step is to read the initial reading of the inclinometers. The initial reading means the position of the inclinometers prior to any changes or movement. The movement of the inclinometers then can be measured using inclinometers' probe inserted into the inclinometer. Based on the deflection of the inclinometers, the shear forces and bending moments can be estimated using simple formula based on finite difference method. Figure 11 shows how deflection is defined in a beam. Similarly this can also be used for piles (Figs. 12 and 13).

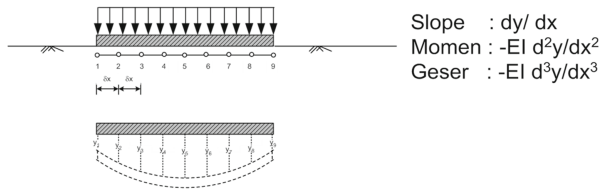


Fig. 11. Deformation of a beam and the magnitude of slope and forces in differential form



Fig. 12. Installation of inclinometers inside bored piles before excavation

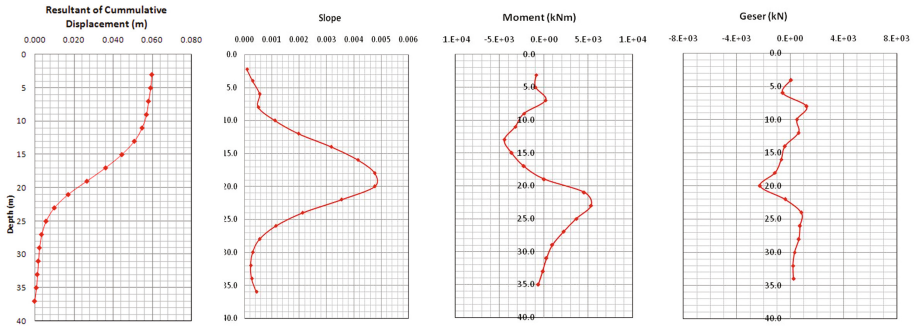


Fig. 13. Example of displacement measurement and calculation of forces in boredpiles

In most cases, the calculated movement is much higher than the measured displacement. This situation may be used to back calculate the soil parameters. Based on the author experience, the soil moduli in excavation (unloading condition) is much higher than the actual moduli although the value has been increased 2–3 times. An example of this experience is shown in Sovereign Tower Project. Free standing soldier piles of 800 mm diameters with c/c spacing of 1.6 m were used for protection of excavation of 12 m deep at south Jakarta (Figs. 14 and 15).



Fig. 14. Protection of excavation by soldier piles at South Jakarta

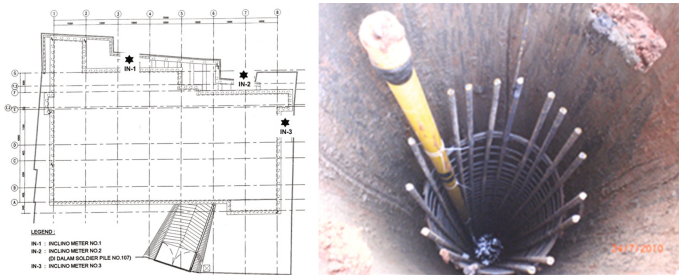


Fig. 15. Inclinometers were installed inside soldier piles at South Jakarta

The calculated movement of the soldier piles analysed by 2DPlaxis with free standing condition was 141 mm and with two level of struts was 70 mm. However until end of excavation, the actual movement of the soldier piles were in the range of 4.0–9.0 mm as shown on Fig. 16.

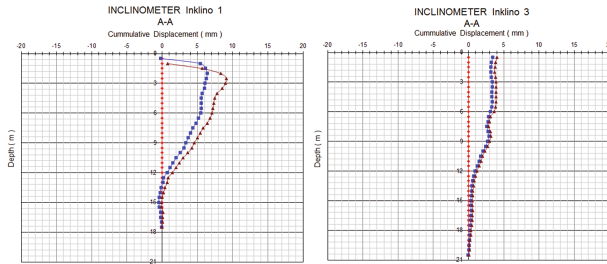


Fig. 16. Displacement measured by Inclinator inside soldier piles

Comparable soil condition near the area of Sovereign Tower is a project (GKM Tower) located east Jalan Simatupang where similar soil condition and the same dimension of bored piles with the same spacing were used as soldier piles except that soil nailings were installed 4 m below ground level. The soil condition is soft clay with $N = 2-4$ to 14 m depth but water table is low. Underlying this soft clay are stiff to hard clay ($N = 15-38$), dense sand or cemented sand. Soil parameters were derived from laboratory tests as well as insitu testing (pressuremeter test). Dilatometer test results and Pressuremeter Test data are shown on the following figures. The data have been used to estimate the insitu stress condition and the moduli for analysis. The results of analysis using the data is better than automatically generated data from the computer (Fig. 17). The soil moduli is normally assumed 3 times the results of insitu tests.

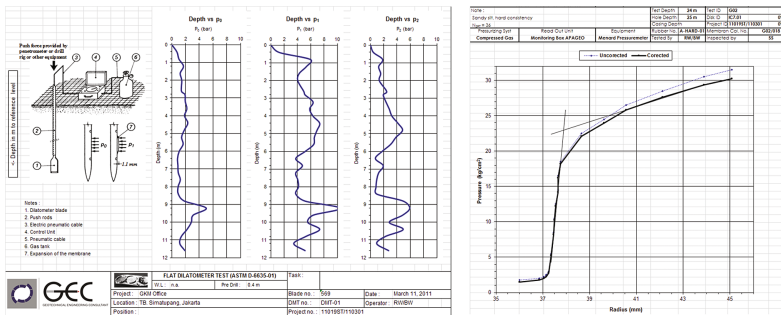


Fig. 17. Insitu test results for better estimate of the design parameter

The results of Pressuremeter Test is shown on Table 1. Po of pressuremeter test represent the insitu total horizontal stress which is more representative for the assumption as the initial pressure. Upon excavation this pressure will automatically drops together with development of the deformation along soldier piles. The moduli also

represent in situ moduli under insitu stress condition. However since excavation in under unloading condition, the moduli has been multiplied by 3 for input in the analysis. It is of interest that even though the N-SPT values of the upper soils layer is soft, the dilatometer and the pressuremeter tests confirm the soil is stiffer than expected. Figure 18 shows measured displacement (from inclinometers) and calculated shear force and moment compared to the results of analysis. The original design was protection by soldier piles and installation of struts, however due to difficulties in construction of struts and considering soil condition shows promising strength, the redesign has been changed using soil naillings.

Table 1. Result of Pressuremeter test and Dilatometer test for GKM tower

Borehole	Depth (m)	N _{SPT}	P ₀ (kg/cm ²)	P _Y (kg/cm ²)	P _L (kg/cm ²)	E _M (kg/cm ²)
BH-01	6.00–7.00	2	0.75	1.74	4.6	66.73
	12.00–13.00	4	1.83	5.69	10.5	181.07
BH-02	18.00–19.00	28	2.13	5.56	9.25	348.68
	24.00–25.00	36	4.25	18.2	39	1686.51

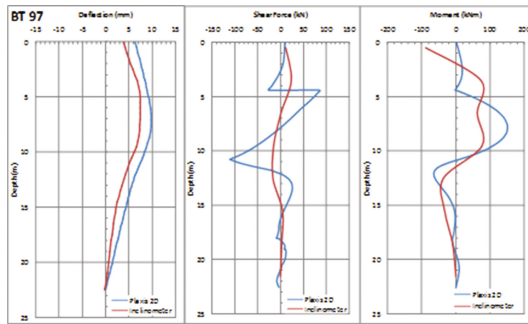


Fig. 18. Results of analysis and measured displacement, shear forces and moments for GKM Tower

The 2 D Plaxis analysis has been used to calculate the forces in the soldier piles, and is plotted on Fig. 18 with measured forces calculated from the inclinometer. The model was analysed with assumption that the position of struts or soil nailings was represented by fixed end anchor. This model results in the high and sharp shear forces, however the re-calculated forces based on the inclinometer shows smooth curves.

6 Excavation at Central Jakarta

In Central Jakarta, the soil condition is mixed depending on its location. Most locations have medium consistency clay but other might have soft layer at significant depth. Water table is high at 2–3 m below ground surface. At certain location in Jakarta specially in the Menteng Area, loose sands are found and these layers have caused difficulties for

causing significant effect due to the dewatering problem since the drawdown can reach sufficiently far distance as far as 150–200 m away (Fig. 19).

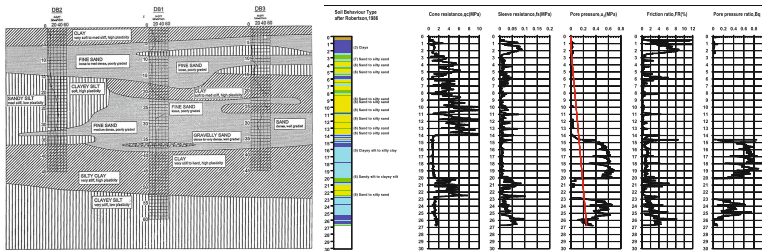


Fig. 19. Typical soil condition in Central Jakarta

Problems of dewatering in sandy soils during excavation are sometimes overlooked. More attention are being focused on stability and deformation problems, particularly of the earth retaining structures. However, the effect of dewatering might be disastrous depending on the reliability of the system and the soils condition. Despite of the necessity for draining an excavated area, method of selected dewatering system may cause serious failure due to lowering of the water table. There are two types of causes of failures, the first one being internal erosion due to piping and the second one due to settlement caused by the increase of effective stress related to ground water lowering. Measurement of water discharge is one factor that can be used to describe the severity of the dewatering problem and the second one is usually deals with the magnitude of settlement and the extent of the subsidence. To overcome the problems, an approach has been adopted.

This condition requires careful design and strict monitoring system to avoid the unwanted effect of dewatering. Rahardjo et al. (2016) reported a drop of water table in Central Jakarta causing damages to buildings surrounding the project site as shown on Figs. 20 and 21.

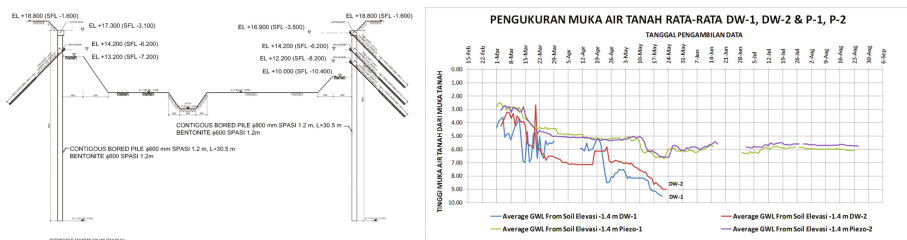


Fig. 20. Excavation system and monitoring of ground water table (Rahardjo 2016)



Fig. 21. Typical damages of buildings due to settlement caused by dewatering (Rahardjo 2016)

Solutions for this problems have been immediately carried out by terminating the pumping and rebackfill the excavation (at this point, the excavation was also terminated at 9 m depth out of the design elevation of 12 m depth) and finally reduction of the basements from 3 level basement to 2 level basement. The continuation of dewatering is by passive dewatering system where water freely flow and collected in sumpit for further disposal.

The excavation system in Central Jakarta can be done by braced excavation, anchored D-wall or anchored Secant Piles or by the top down construction method. To avoid dewatering problem, the drainage are conducted passively with sumpit and pumping on the ground surface. A case history of excavation in this area is represented by top down construction method as shown on Fig. 22. The openings were located in the middle part of the tower. In this method, struts were substituted by the floor slab supported in the periphery and at the location of the column. Care was to be given to watch the movement of column (Fig. 23).

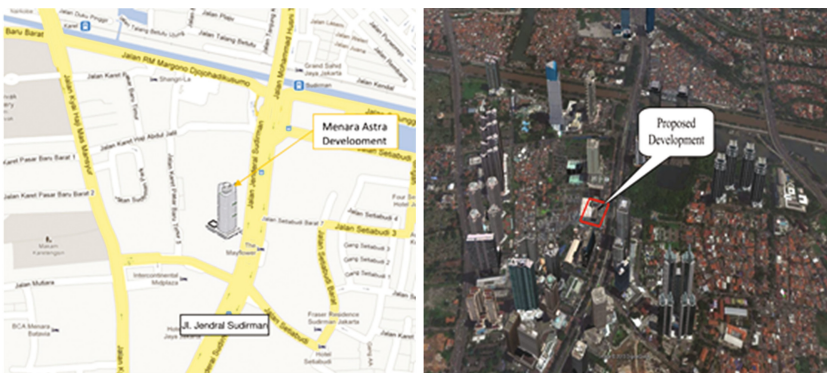


Fig. 22. Case history of excavation in central Jakarta



Fig. 23. Cross section and plan view of the project

This project consists of two buildings with estimated area of 7930 m² and 215 m in height, namely a 50-floors tower and 5-floors Annex. This building will have a 6-floors basement. Due to proximity of the construction to its neighbour, top down construction method was proposed with first floor and third floor concrete slabs were skipped. The soil condition is soft clay 6–8 m depth underlain by stiff clay. Lenses of dense sands were found continuously at depth of 17 m–22 m depth to 21 m–27 m. The bearing layer is very stiff to hard clay (Fig. 24).

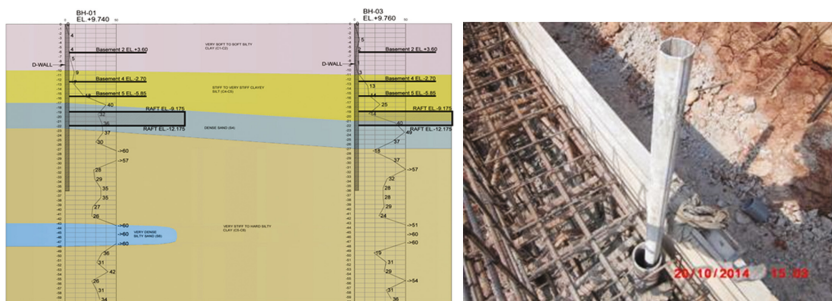


Fig. 24. Soil condition and scheme of excavation

Monitoring of the D-wall movement and water table by pizometers were carried out through out the excavation to warn any excessive displacement of the wall and the fluctuation of water table. The deformations were predicted using 3D Finite Element Method using conservative soil parameters. As high as 150 mm were obtained as shown on Fig. 25. However the actual deformation of the system is only 40 mm (Fig. 26).



Fig. 25. Stage 2 excavation to 4th level Basement and measurement of D-wall movement

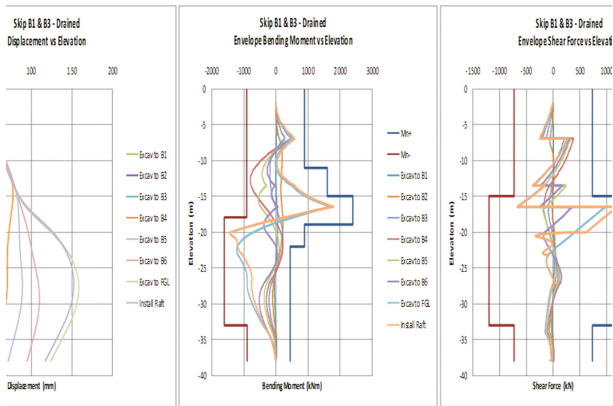


Fig. 26. Results of design analysis for wall movement and forces on the D-wall

7 Excavation at North Jakarta Area

Excavation at North Jakarta is the most challenging one. Due to the existence of soft soils specially because of the underconsolidating condition, many problems arise. Common problems are:

- Stability problems during excavation, because the soils are not only very soft, but also residual excess pore pressure may cause additional load on the retaining system and no passive resistance can be expected.
- Deformation problem may cause substantial movement of the wall and settlement of the neighbour.
- The piles that were driven prior to excavation may be tilted during the excavation period.

Important factors that influence the stability of excavation in soft soils include the low shear strength of the soils and stress level, creep and strain softening, effect of existing pore pressure due to underconsolidation and influence of excavation on nearby building and foundation (Wong 1985; Rahardjo 2005). A study by Rahardjo (2005) has shown that underconsolidation may affect safety factor even for shallow excavation of

3 m protected by sheetpile. Figure 27 shows the influence of the degree of consolidation (representing underconsolidation for $OCR < 1$) on the safety factor. Hence an excavation of 2.5–3.0 m is very critical in Jakarta depending on whether one can detect the existing pore pressure. Rahardjo et al. (2008), Setionegoro (2013) and Rahardjo (2015) developed a method to determine the Underconsolidation using CPTu which is very useful to in the assessment of soil condition for excavation in soft soils.

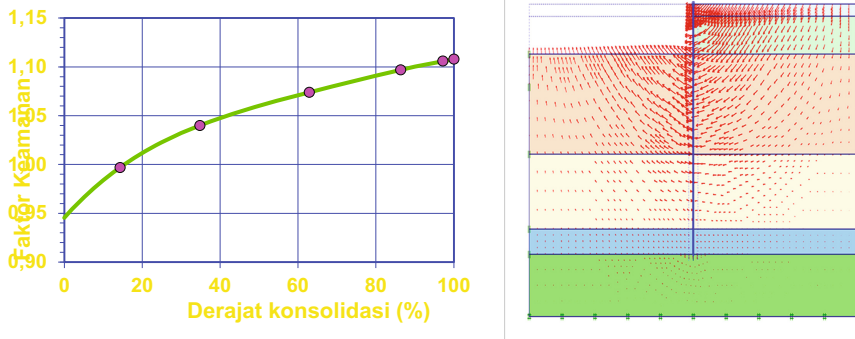


Fig. 27. Influence of the degree of consolidation of the safety factor of excavation in soft soils

Classical example of failures in excavation in North Jakarta area were discussed by Poulos (1991) and Zanusi (1991) where an excavation of unprotected excavation has caused excessive movement of 1 m and failure of building foundation at the project site. The following is chronology of the event:

- 25 August '89: Foundation of Hotel Completed
- 31 Oktober '89: Office Foundation completed
- August '90: Upper Structure of Hotel and Office Completed
- September ~ November '90: Foundation for mall completed
- 20 October '91: Excavation for *ground tank*
- Local failure (slide) during excavation, installation of bamboo piles and sheet piles. Excavation continued
- 30 October '90: Pile head of the mall moved 1 m. Excavation terminated
- 21 November '90: Excavation rebackfilled: No compaction on backfill, Backfill completed in 3 weeks
- 01 and 02 Januari '91: Cracking sound heard by witness (3 times)
- Early morning 02 Januari '90 the corner of office settled 140 mm
- Grouting was conducted but no effect

Zanusi (1991) reported that the reason for this failures were due to no design for safety of excavation, foundation installation induced excess pore water pressure, and failure of piles were due to induced moment exceeding the moment capacity of the pile. Poulos (1991) reported with more detail study on the behavior of the pile based on numerical calculation. Excessive movement of piles (about 1.0 m) caused overloading on piles under the office and hotel. Delay of soil movement (from the start of excavation

to the event of soil cracking) may be due to creep which is time dependent. Failure of beam and base slab caused building tilting. According to Poulos (1991), soil movement caused increasing lateral load and moment on piles. Analysis by computer program ERCAP explain that at pile movement of 20 cm, has caused the pile to reach its ultimate moment capacity (Figs. 28 and 29).

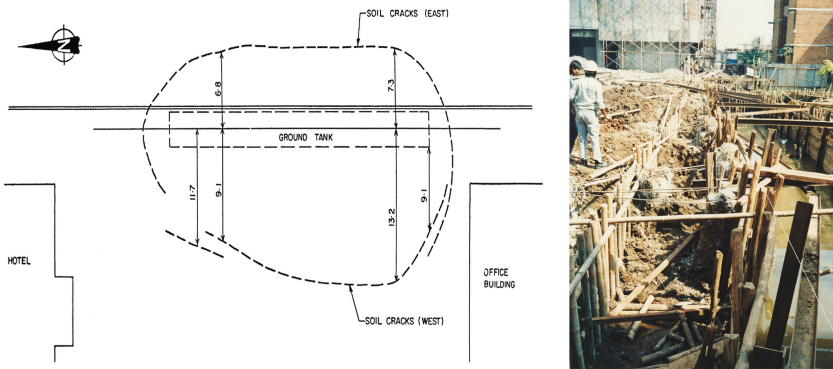


Fig. 28. Movement of boredpiles and cracks showing sliding (Poulos 1992; Zanusi 1992)

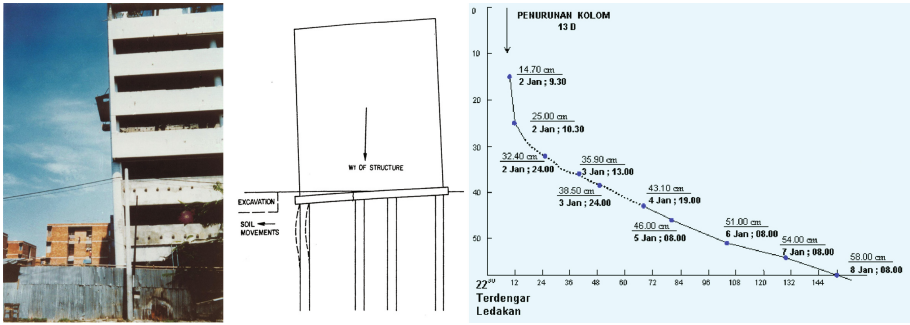
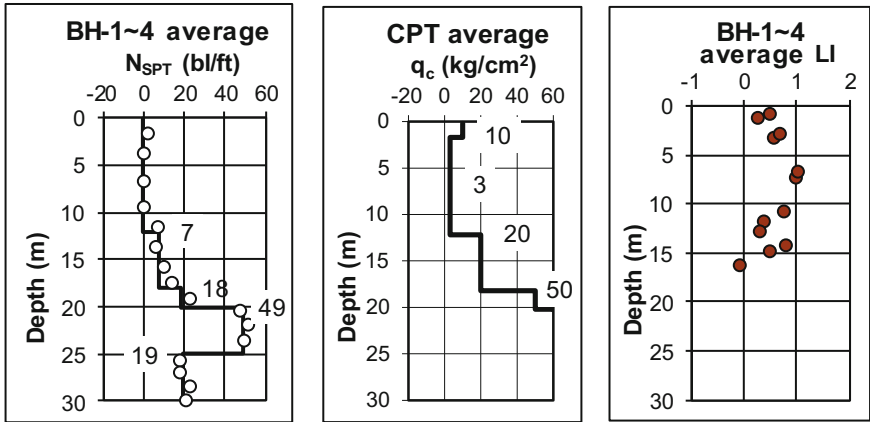
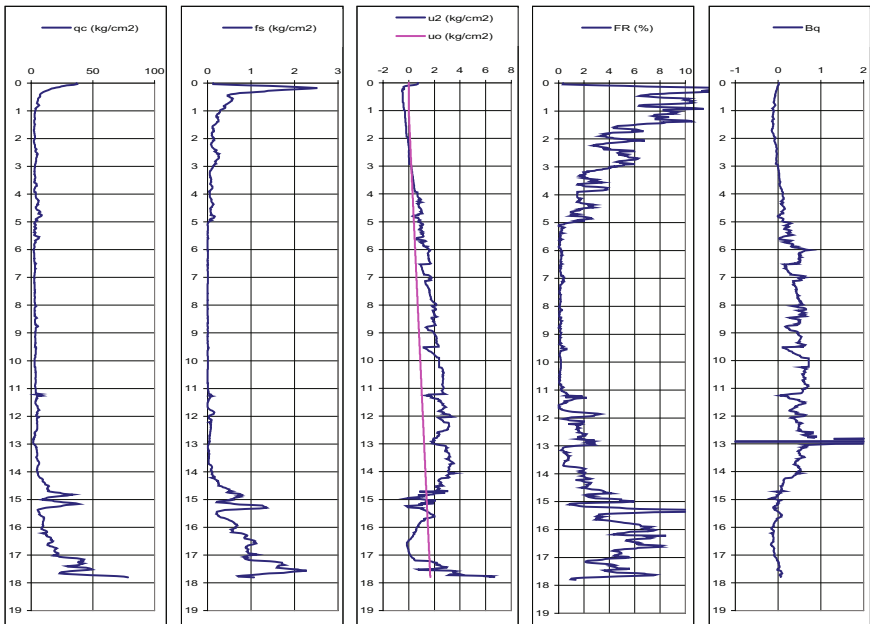


Fig. 29. Tilting of building and settlement of nearest column to excavation (Poulos 1992; Zanusi 1992)

Rahardjo (2005) revisited the problem with geotechnical review including: soil condition, phenomena of under consolidation, effect of excavation of Soft Soil on Pile Foundation, modeling by Finite Element Method and conducted study on the possibility of progressive failures/slides. By use of CPTu and supporting data, Rahardjo (2005) has shown that the soil at depth 5 m–11 m is underconsolidating as shown on Figs. 30 and 31.



(a)



(b)

Fig. 30. Soil condition at North Jakarta area showing underconsolidation (Rahardjo et al. 2015)



Fig. 31. Excavation in soft marine clays North Jakarta

Based on the study, Rahardjo (2005) reported that the soil is consolidating and residual excess pore pressure was found causing Safety Factor of the excavation calculated by Bjerrum and Eide (1956) = 0.26–0.69, hence causing problem of instability, deep sliding was detected at depth of 5–7 m, and due to lateral movement and restraint of pile foundation by the building, the pile failed. The excess pore pressure may be combined by the effect of pile installation.

Further study on excavation at North Jakarta was reflected from the excavation for basement with 12 m depth protected using diaphragm wall of 800 mm thick embedded 25 m and supported by struts or ground anchor at different end. The investigation show that the soft marine clay is consolidating. Movement was measured 120 mm at the end of the excavation or about 1% of the excavation depth.

Further north at the coastal area, an excavation of 5 m was protected by sheetpiles 12 m long, anchored by 600 mm boredpiles at the outer side with 600 mm diameter and 18 m depth. Inclinometers were installed behind the excavation. Large movement occurred to more than 150 mm as shown on Fig. 32.

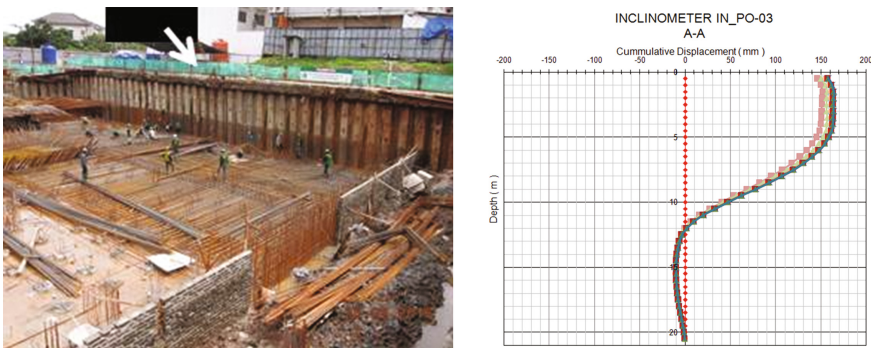


Fig. 32. Movement of retaining system in North Jakarta Excavation

8 Conclusions Summary

1. Excavation in South Jakarta is generally in good soils and may be conducted by open cut with minimum protection (soil nailing, anchor, shotcrete).
2. For excavation in soft soils at North Jakarta there are risks. Excavation in under-consolidating soils need attention on existing pore pressures and very low strength. Uncontrolled excavation of soft soil could result in significant movement of soil mass that could endanger nearby structures.
3. Monitoring of excavation is important part for safety, performance, and warning system (sometimes good for back analysis).
4. Determination of soil parameters are important input.

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