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**Analysis of lateral wall movement for deep excavation in
Bangkok subsoils**

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ANALYSIS OF LATERAL WALL MOVEMENT FOR DEEP BRACED EXCAVATION IN BANGKOK SUBSOILS

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ABSTRACT

This paper presents the case histories and back analysis of diaphragm walls for deep-based excavations in Bangkok subsoils. Three case studies with different boundary conditions are detailed as under unbalanced loading, underpass project under very narrow clearance under the first stage expressway, and short embedded wall for modified deeper excavation. The back-figured values for the soil stiffness in terms of Young's modulus are calculated as $E_u/S_u = 500$ and 2000 for the soft Bangkok clay and stiff clay, respectively. The results have later on been confirmed with the first self-boring pressuremeter tests in Bangkok subsoils.

INTRODUCTION

Deep excavations in Bangkok City are still necessary even the country has faced severe economic crisis. There are still required the necessary civil works to serve the demands and also to solve the environmental problems such as the first underground subway project, and the wastewater treatment schemes. Subsoils condition in Bangkok is generally consists of a very soft dark gray of about 12-14 m thick layer underlain by stiff and very stiff clay to about 23-25 m depth then followed by the first dense silty sand layer. Excavation in such soft dark gray clay requires efficient retaining structures such as temporary sheet pile for shallow excavation, and cast in-situ reinforced concrete (RC) diaphragm wall as permanent structures for deep excavation. There are a lot of diaphragm wall activities under construction and under excavation stages for the first blue line subway project, Metropolitan Rapid Transit (MRT). This subway project consists of 18 underground stations, about 20 km long twin tunnels running from North of Bangkok at Bangsue station and turn around the business area, bus terminal and ended at the main state railway station namely Hua Lumpong station (Teparaksa, 1999). Excavation depth for the underground stations is between 22-33 m.

This paper aims to evaluate the soil stiffness parameters of the soft and stiff Bangkok clay for RC diaphragm wall based on back analysis of three case studies with different construction boundaries.

SOIL PARAMETERS FOR DIAPHRAGM WALL DESIGN

The RC diaphragm wall can be designed by various methods such as Finite Difference Method, Beam on Elastic Foundation Method, and also the Finite Element Method (FEM). The most well known and commonly used method is the two dimensional (2D) FEM method or plain strain method. The 3D FEM analysis is rarely used. The FEM analytical method can simulate the soil-structure interaction, and can predict the lateral wall movement as well as the

ground surface settlement. The appropriate soil modelings as well as the input soil parameters are the key issues to simulate the system. The most important soil parameter is the stiffness of each soil layer, which is normally specified in terms of Young's modulus (E). The E value is very important especially for the soft clay layer that lead to induce the lateral wall movement and ground settlement during excavation works. Normally, E is assumed to be linear and determined from the conventional triaxial compression test and is very low as compared to the values obtained from the empirical correlation. This is because of the high strain levels at which the E is measured in the conventional triaxial test. The E value is recently known to be dependent on the order of shear strain level. Mair (1993) compared the soil stiffness at various shear strain levels for different structural systems as well as various kinds of laboratory tests as shown in Figure 1. In case of concrete diaphragm walls, the shear strain is of the order of 0.01% to 0.10% only.

The research works on the soil behaviors at the low strain level in soft Bangkok clay was presented by Shibuya et al (1997) based on laboratory tests as well the in-situ field vane shear tests. Authors presented the soil stiffness in terms of Maximum Shear Modulus (Gmax). Gmax is about 300*Su (300 times of Undrained Shear Strength) to 500*Su and if converted to the Undrained Young's modulus (Eu) will be equal to 900*Su to 1500*Su for Poisson ratio (v) of 0.5. Teramast (1998) also presented the soil stiffness at low strain levels based on the Bender Element Test as $G_{max} = 400 * S_u$ to $570 * S_u$ or $E_u = 1200 * S_u$ to $1710 * S_u$. As shown in Figure 1, Mair (1993) mentioned that the Bender Element Test is suitable for very low strain levels such as applied to the dynamics or earthquake problems. Most practical value of Eu for Bangkok subsoils is based on the empirical correlation proposed by Duncan & Buchigani (1976) as shown in Figure 2. The Eu values were presented relative to the undrained shear strength, which is dependent on the order of Over Consolidation Ratio (OCR). For Bangkok soft clay where OCR is about 1.6, $E_u/S_u = 300-600$.

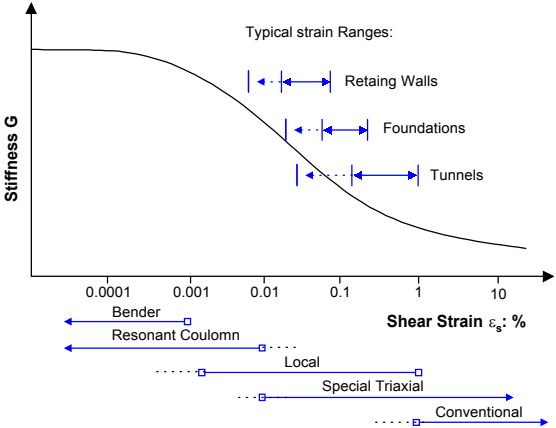


Figure 1 : Typical Strain Range (Mair, 1993)

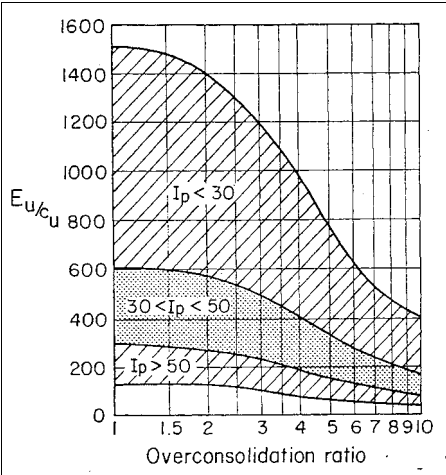


Figure 2: Empirical Young's modulus Values, Duncan & Buchigani, 1976.

BACK ANALYSIS CASE STUDIES

As mentioned above that the soil stiffness varies and depends on the shear modulus. However, the values from laboratory tests give a high variation with the empirical correlation. Therefore, the back analysis from case histories of diaphragm wall construction is really

necessary to verify the appropriate soil stiffness. The back analysis was carried out for three case studies at the Thammasat University project, Dindang underpass project and Sathorn Complex project. Using the 2D-FEM program namely “PLAXIS” (Brinkgreve & Brand, 1996) back analysis for the said projects have been carried out. The analytical plain strain concept and the Mohr-Coulomb soil model or bi-linear modeling was used.

Thamasart University Project

The building site is located nearby the Chao Phaya River and surrounded by a historical building seated on shallow raft foundation as shown in Figure 3. The diaphragm wall along the river was constructed about 3-4 m away from the existing old and shallow river wall as shown in the building section in Figure 4. The river bed near the river wall is about 3 m in depth and sloping towards the mid-stream to a depth of about 10-12 m (Thasananipan et al, 1998). This riverbank lead to induce the unbalanced lateral earth pressure on the diaphragm wall system between land side and riverside. A 800 mm thick diaphragm wall was designed for excavation down to 12.7 m below the ground with two levels of temporary bracing at -1.5 m and -6.5 m depth. The diaphragm wall toe was embedded down to 28 m to achieve the overall stability of the excavation which is right on the river bank (Fig. 4). A site investigation was carried out by two boreholes and four field vane shear tests, the subsoil properties are summarized in Table 1.

Table 1. Summary of subsoil properties

Soil Type	Depth (m)	Wn (%)	Unit Weight, γ_s (kN/m ³)	Cu (kPa)	SPT-N (Blows/ft)
Crust	0.0-2.5	50	19	30	-
Soft Clay	2.5-12.7	70-85	26	15-30	-
Medium Clay	12.7-14.0	50-55	17	30-45	-
Siff Clay	14.0-25.0	20-25	20	130-250	14-40
Dense Sand	>25.0	-	20	-	>39

Instrumentation

Due to the locality and particular conditions of the site, more instrumentation than those used by other projects in Bangkok were installed and monitored. Three types of instrumentation - Eight inclinometer tubes are installed in diaphragm wall panels to monitor displacement of wall, ten settlement plates of 1.0m and 5.0m in depth around excavation zone, and ten tiltmeters and four vertical beam sensors on surrounding buildings were installed to monitor tilting. Layout of instrumentation is presented in Fig. 3. Since the excavation work is located adjacent to the river and surrounded by old buildings, the diaphragm walls are subject to the unbalanced lateral load The model analysis indicated relatively less movement of Wall D1 towards excavation in the land side and move less in the river side as well as induce forward movement of river wall to the river (Fig. 5). This analysis led the engineer to solve the damages of the river wall due to unbalance loading by using the following construction methods.

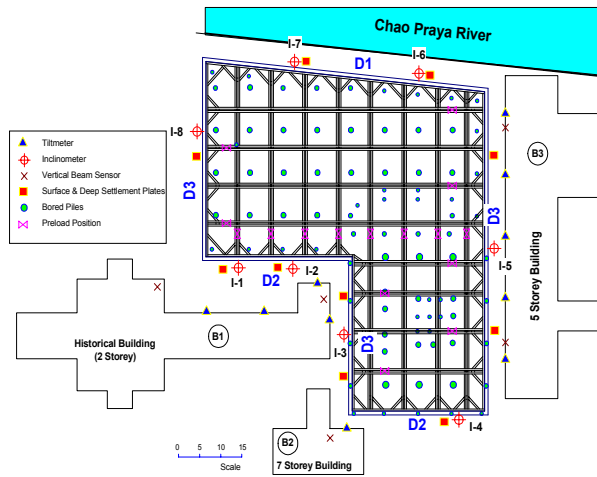


Figure 3: Project Layout

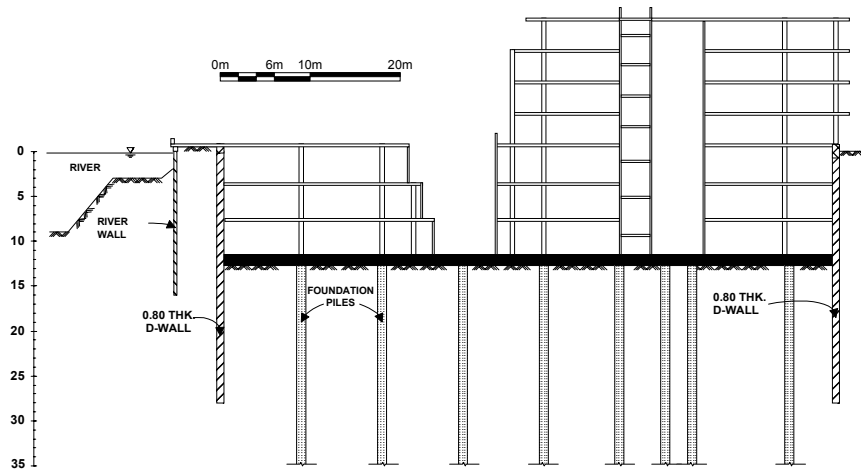


Figure 4: Section perpendicular to the river

1. Arrange the strut as a simple straight grid line
2. Pre-loading of the struts (200kN/m and 400kN/m for first and second levels respectively) on the one end of the strut on the land side wall.
3. Excavating the soil in front of Wall river side first at any excavation stage

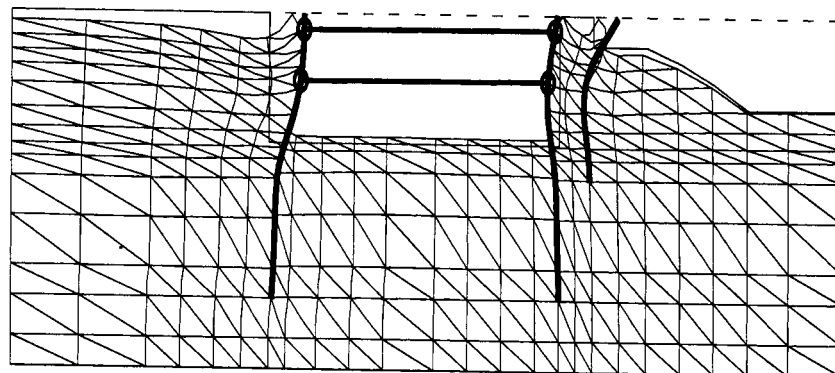


Figure 5 : Deformed Mesh of Two-Dimensional model

Analytical Results

The analysis was trial by changing the soil stiffness and compares the results with the field performance. Figure 6 shows the results of FEM analysis compared with inclinometer measurements based on soil stiffness of $E_u/S_u = 500$ and 2000 for soft Bangkok clay and stiff clay, respectively. . Movements of Wall D1 close to the river are found to be cantilever shape indicated by I-7 while movements of Walls D2 and D3 have inward bulging shape indicated by I-1 to I-5. Generally the predicted and measured lateral wall movements are in a good agreement, except for the top portion of wall in which the measured wall movements exceed the predicted movements. The differences in wall movement were found to be caused by the following;

- Advancement of excavation in front of Wall D1 further than other walls, allowing Wall D1 to stand longer prior to strut installation than the others.
- Wall D1 was in cantilever condition for about 3 months after initial excavation for first level bracing.

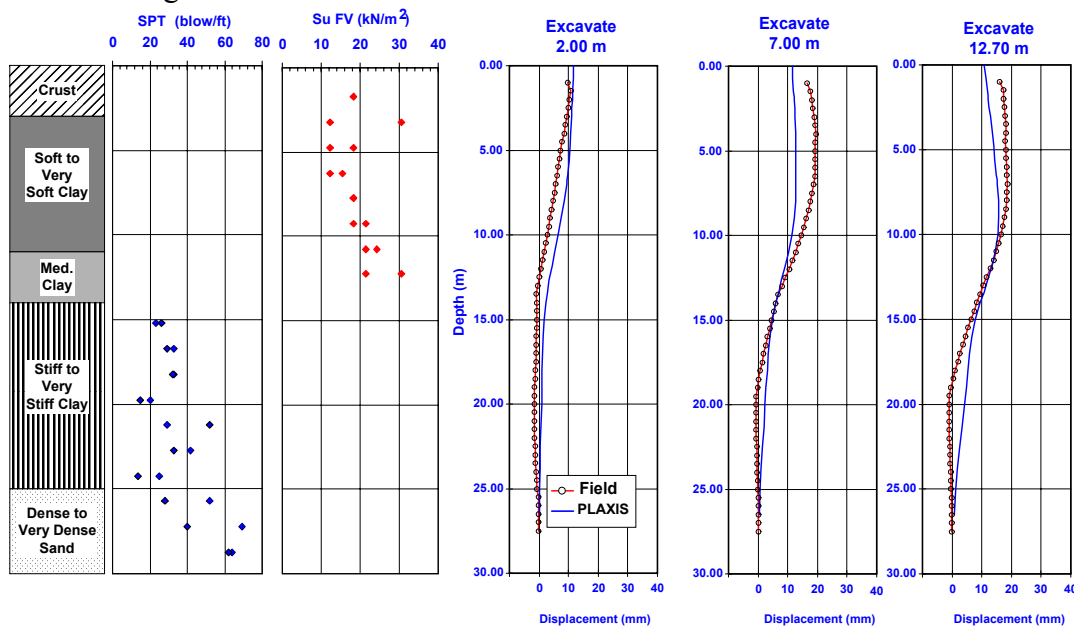


Figure 6 : Comparison between calculations and observation (Thammasat University Project)

Dindang Underpass Project

The Dindang underpass was the first Bangkok underpass project at Dindang intersection. Underpass the main road beneath the main foundations of the expressway. This project is also very interesting, specially designed equipment for D-wall construction was employed under very narrow clearance under the first stage expressway (Thasananipan et al. 1996). There was one temporary bracing layer at 2 m. depth and excavation to 4.9 m. depth. Figure 7 shows the results of FEM analysis compared with inclinometer measurements based on soil stiffness of $E_u/S_u = 500$ and 2000 for soft Bangkok clay and stiff clay, respectively. The predicted and measured lateral wall movements are in a good agreement.

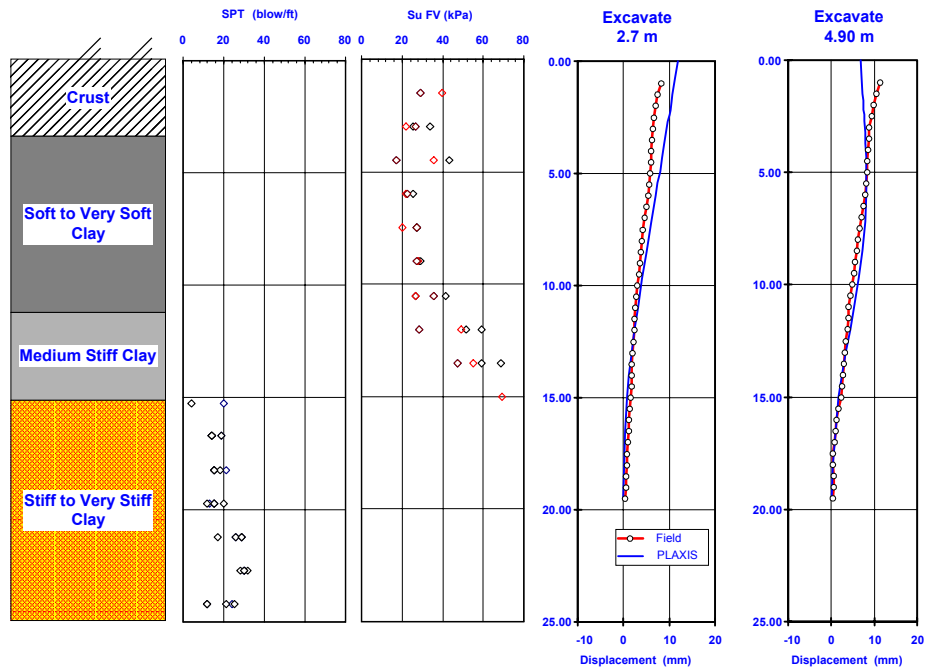


Figure 7 : Comparison between prediction and observation (Dindang Underpass Project)

Sathorn Complex project

The project site is located in the vicinity of central business area of Bangkok. The structure is a multi-storied building for a business complex. The load of the structure would be carried by bored cast-in-situ bored piles and barrette piles with toe depth of 60m below the ground level, embedded into the second sand layer of the Bangkok subsoil. The constructed cast in-situ diaphragm wall is 0.8m thick and the toe is embedded into stiff clay at a depth 18m below the ground level. Initially the wall was designed for construction of four basements including mat foundation of 3.5m thick. The maximum excavation depth was set to be 14m and a three level of temporary bracing system was considered to construct the basements with conventional bottom up construction method. Embedded depth below the final excavation for the mat foundation was designed to be 4m. Figure 8 shows the layout plan of the building

After construction of the wall it was decided to increase the number of basements to be five for part of the building area (tower area) and excavation depth needed to be increased by 1.8m from the originally designed depth, leaving the wall embedment depth of 2.2m only. The first author was invited to solve such a short embedded diaphragm wall (Teparaksa et al, 1998). The temporary bracing was changed from three layers to be four layers with using the soil berm of 12 m. wide to prevent the excessive wall movement as shown in Figure 9.

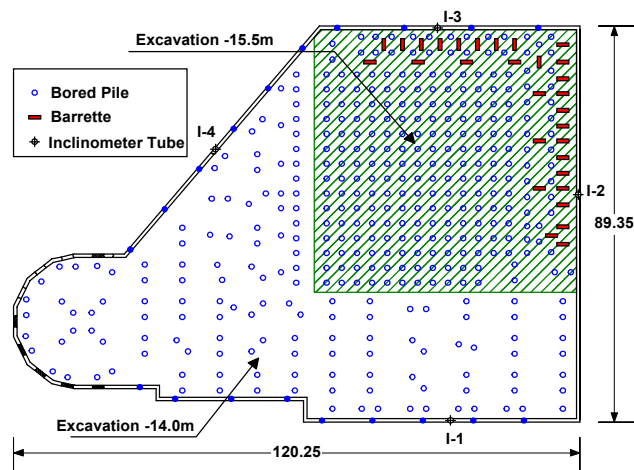


Figure 8: Layout of Project

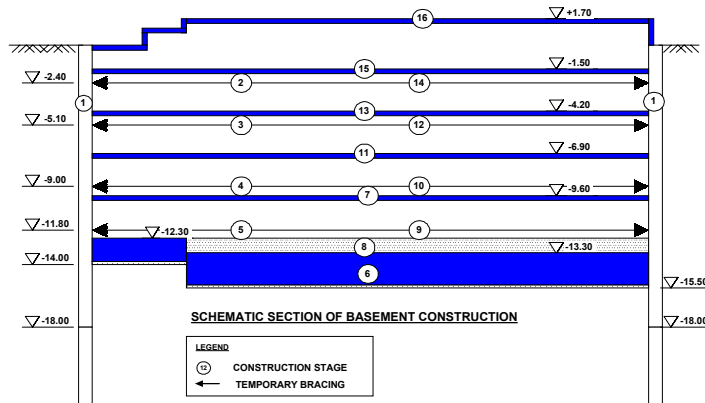


Figure 9: Schematic Section

Subsoil Conditions

The sub soil conditions at the project site is not uncommon to usual conditions observed in Bangkok comprising a 15m thick soft to medium clay layer on the top underlain by stiff clay to a depth of about 22m. Below the stiff clay is a series of alternating layers of hard silty clay, sandy clay and dense sand. The soil properties used for Diaphragm wall design are summarized in the table 2 belows:

Table 2 Soil Properties used for D-Wall Design

Soil Type	Unit Weight γ_s (kN/m ³)	Undrained Shear Strength, S_u (kPa)
Soft Clay, CH	16	10-29
Medium Clay, CH	18	35
Stiff Clay, CH	20	137-180

Analytical Results

The wall constructed was designed for initial excavation of -2.5m to install the first bracing layer. However the excavation has been done to about -3.0m to -3.2m at once and a movement of 40mm was observed. Time delay during construction of capping beam and over excavation deeper than the critical height ($H_{cr} = 2C/\gamma$) was unsupported around three months resulted an increase in wall movements to 55mm -70mm. Tension cracks were developed in the soil of active side about 2-3m away from the wall. After installation of struts and pre-loading them, the lateral movements of the wall ceased off. Struts from first to fourth levels were pre-loaded 40 t/m, 75 t/m, 75 t/m and 40 t/m respectively, 20%-25% of design load of bracing system, prior to further excavation. The pre-loading of the strut was very effective to reduce lateral movement of the wall and ensuring good intact between wall and bracing system. Figure 10 shows the comparison of the results of FEM analysis compared with inclinometer measurements based on soil stiffness of $E_u/S_u = 500$ and 2000 for soft Bangkok clay and stiff clay, respectively. The measuring data was neglect the first movement due to the delay of the first cantilever diaphragm wall around three months. The predicted and measured lateral wall movements are in a good agreement.

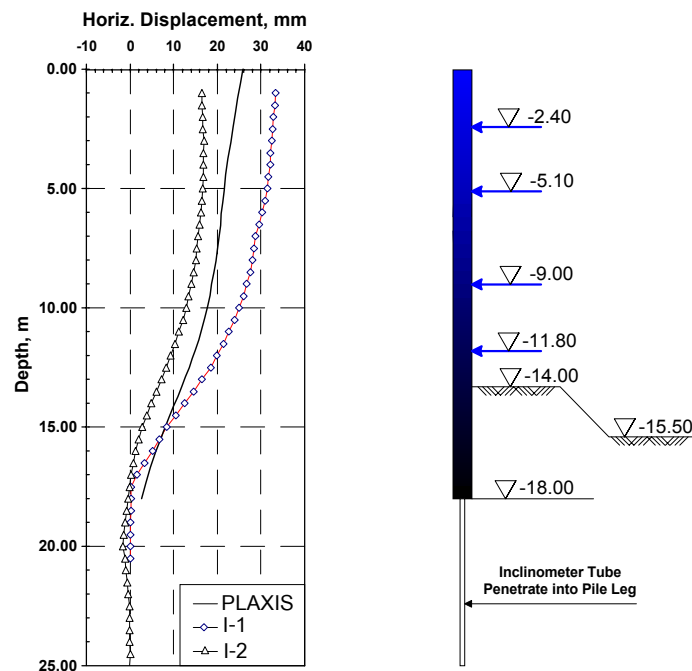


Figure 10 : Comparison of wall movement from FEM analysis and inclinometer results

COMPARISONS OF ANALYSIS WITH PRESSUREMETER TEST

The trial soil stiffness based on the back analysis shows that the Young modulus of soft Bangkok clay and stiff clay are $E_u/S_u = 500$ and 2000 , respectively. Recently, six self-boring pressuremeter tests were performed along the route of Metropolitan Rapid Transit (MRT) northern contract by the Cambridge In-situ of Little Eversden (1997). The self-boring pressuremeter tests were carried out by reload/loading cycles in order to determine the soil stiffness at various shear strain levels. Figure 11 shows the results of pressuremeter test and

shows the variation of shear modulus with shear strain, Figure 11.1 is for soft clay while Figure 11.2 is for first stiff clay. For normal practice of diaphragm wall construction for deep basements in Bangkok soft clay, the shear strain is in the order of 0.1-0.2%, where the G/S_u is about 160 or $E_u/S_u = 480$. In case of the first stiff silty clay layer where shear strain is in the order of 0.05-0.1%, the G/S_u is about 340 or $E_u/S_u = 1020$. The soil stiffness of the soft clay from pressuremeter test results is very close to the results of back analysis, however, the values of stiff clay from pressuremeter test results is lower than the results of back analysis, this is might due to the effect of bored pile stiffness inside of the excavation area. The correlation from the self-boring pressuremeter was the non-linear soil model that will be used to carry out the future back analysis.

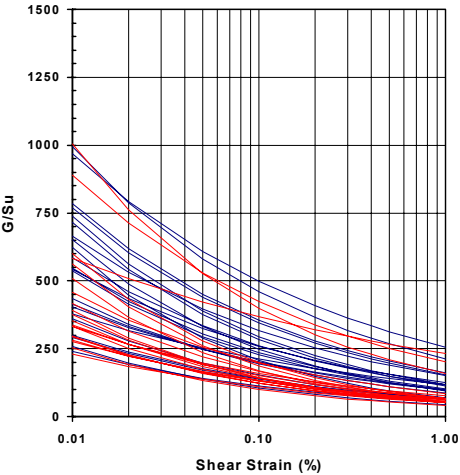


Figure 11.1: Self-boring Pressuremeter Test Result of Bangkok Soft Clay

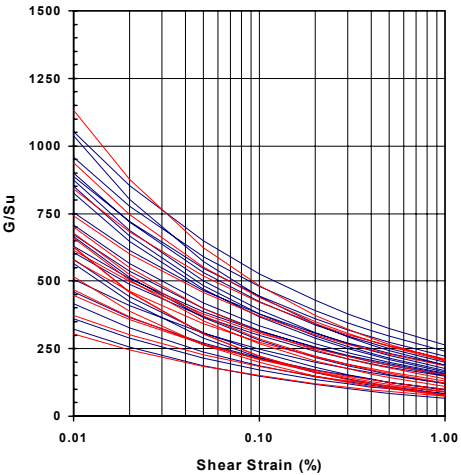


Figure 11.2: Self-boring Pressuremeter Test Result of Bangkok Stiff Clay

CONCLUSIONS

The analysis and the design of the diaphragm wall are normally based on the assumption of soil stiffness. Back analysis to verified the soil stiffness based on three different cases as under unbalanced loading, underpass project under very close to the foundations of the first stage expressway, and short embedded wall. The results shows that the soil stiffness in terms of Young modulus is $E_u/S_u = 500$ and 2000 for soft Bangkok clay and stiff clay, respectively. These values were also corresponding to the results of self-boring pressuremeter tests of the first blue-line subway project in Bangkok.

REFERENCES

Brinkgreve, R. and Brand, P.A.(1996): Application of PLAXIS for soil and rock plasticity, Short Course on Numerical Analysis in Geotechnical Engineering, AIT.

Cambridge In-situ (1997): Self-boring pressuremeter MRTA initial system project, North Contract.

Duncan, J.M. and Buchigani, A.L.(1976): An engineering manual for settlement studies, Geotechnical Report of Civil engineering Department, university of California at Berkeley.

- Mair, R.J. (1993): Development in geotechnical engineering research, application to tunnels and deep excavations, Proceedings of the Institution of Civil Engineers and Civil engineering.
- Shibuya, S., Hanh, L.T., Wilailak K., Lohani T.N., and Tanaka H. (1997): Characterizing stiffness and strength of soft Bangkok clay from in-situ and laboratory tests, First Int. Conf. on Site Characteristics.
- Thasananipan N., Muang A. Singtokaew K. (1996): Experiences in construction of diaphragm wall for underpass project, Seminar on Underground Construction'96, Engineering Institute of Thailand.
- Thasananipan N., Teparaksa W, Muang A. and Baskaran G., (1998): Design, construction and behavior of bored cast in-situ concrete pile in Bangkok subsoils, Proc. 4th Int. Conf. on Case Histories in Geotechnical Engineering, St. Louis, Missouri, USA.
- Thasananipan N., Muang A., Tanseng P. and Wei S. H., (1998): Performance of a braced excavation in Bangkok Clay, diaphragm wall subject to unbalanced loading conditions, 13th Southeast Asian Geotechnical Conference, Taipei, Taiwan ROC.
- Teparaksa W., Thasananipan N., Muang A., and Wei S. (1998): Prediction and performances of short embeded cast in-situ diaphragm wall for deep excavation in Bangkok subsoils, Proc. 4th Int. Conf. on Case Histories in Geotechnical Engineering, St. Louis, Missouri, USA.
- Teparaksa W. (1999): Geotechnical aspects of the Bangkok subway design and construction, guest speaker for the Society of Professional Engineers Thailand (S.P.E.T.) member meeting at British Club, 18 February. .
- Theramast N. (1998): Characterization of pseudo-elastic shear modulus and shear strength of Bangkok clay, M. Eng. Thesis, AIT.