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AN INNOVATIVE GROUND ANCHOR FOR DEEP EXCAVATIONS IN VIETNAM

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ABSTRACT: Large excavation-induced deformation of the anchored wall due to the limitation of anchor rod capacity in thick soft soil strata remains a problem in a deep excavation. In this paper, the performance of an innovative anchor type, so-called Hotdog anchor, invented by Korean engineers is investigated using the numerical and field test methods for excavation in Southern Vietnam. For comparison, both hotdog and pack anchor types are introduced in the case study. Proof tests of anchors were also conducted to provide data for the simulation. Four layers of hotdog anchors with 12m-bond length and 40 cm-diameter are adopted to compare with 4 layers of 18m-bond length and 20cm-diameter pack anchors in a soft to medium clay layers (NSPT = 1 ~ 13). In numerical analysis, the soil behavior was simulated using the Mohr-Coulomb model. The plate and node-to-node anchor elements were adopted to model the diaphragm wall and the anchors, respectively. Results show that the hotdog anchors could provide the larger bearing capacity and so that decrease the required bond length as compared with the pack ones. Based on that a guideline for the adoption of hotdog anchor to deep excavations in thick soft soil deposit in Southern Vietnam was proposed.

Keywords: Hotdog anchor, Pack anchor, Finite element analysis, Deep excavation, Tie-back wall.

1. INTRODUCTION

Deep excavation for the basement in the metropolis nowadays become an indispensable part as a way of space exploitation for underground parking or refuge in special circumstances. The application of anchored retaining walls has been adopted in urban construction for recent several decades (Finno and Roboski 2005; Orazalin et al. 2015; Dai et al. 2016; Rouainia et al. 2017; Murugamoorthy). A large number of researchers and engineers have contributed to the development of both design and construction methods for tie-back anchored walls in order to increase anchor bearing capacity in the last three decades (e.g., Briaud and Lim, Lambe and Hansen). However, there are still required the necessary attempt to solve the problem, especially under soft soil conditions.

In recent years, an innovative anchor method developed for soft grounds named Hotdog anchor has been proposed and widely accepted in Korea. The anchor overcomes the limitation of conventional ground anchors since it works effectively in either soft ground, fill deposit, gravel layer or a ground layer where groundwater exists. The Hotdog anchor works by creating a large anchorage bulb in the bond length with a compressive pack expanded through pressurized grouting in order to increase skin friction resistance and to create bearing stress on the soil around the anchorage bulb. This paper focuses on the design and construction method of the Hotdog anchor. In addition, a numerical analysis was conducted to compare the performance of Hotdog anchor and pack anchor for deep excavation in the Southern of Vietnam.

2. A HOTDOG ANCHOR

2.1 Installation Method

The construction sequences of the hotdog anchor installation (Figure 1) are performed as follow: Firstly, the casing is injected to the required depth of anchor. Then, the bonding part is filled with cement grout. At the same time, casing at the bonding part has been slowly removed. Next, the inner rod is inserted inside the casing and since it approaches the expansion length, the agitation has

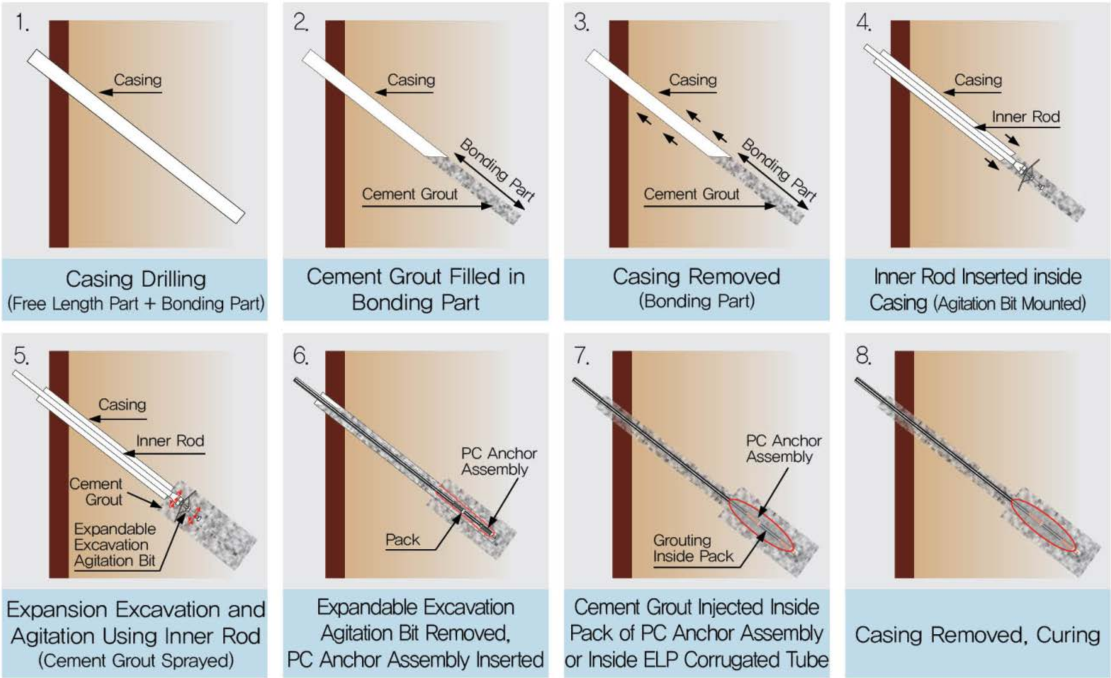

Fig.1 Construction procedures of hotdog anchor installation (after Dean, 2018)

been activated and also cement grout sprayed simultaneously from the inner rod. When a soil-cement bulb has been formed with the right shape (normally 0.4~0.5 m in diameter), the PC anchor assembly is inserted between the soil-cement bulb and the rod. Finally, cement once again is injected inside the pack in order to increase resistance between strands and the bulbs before casing is removed and curing work is carried out accordingly.

2.2 Advantages

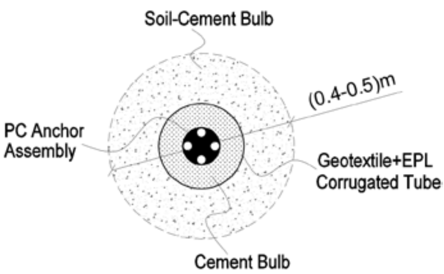

Fig.2 Cross-section of the bonding part (modified from Dean, 2018)

The structures of the 0.5m-diameter grout body could divide into three parts (Figure 2). The outer part is the soil-cement bulb created by agitation and cement grouting at the same time. The middle part is a cement bulb made from cement and the inner part is a PC anchor assembly that strengthens the connection between the rod and the grout body. The strength of the soil-cement bulb for pack anchor and hotdog anchor is 300 kPa and 500 kPa, respectively.

The hotdog anchor method uses the expansion of the bonding part to provide high tensile resistance. It could be used in the soft ground by increasing bearing capacity through an area of friction resistance and bearing effect. There are several reasons that advance the design load of hotdog anchor in soft ground as shown in Figure 3. Firstly, 2.5 ~ 3 times larger in diameter of the bond length of the hotdog anchor compared to the pack anchor increase the area of friction resistance at the perimeter. Secondly, anchoring strength could double or more as the passive region expands. Thirdly, the bearing effect provided by ground at a connection between expanded bonding part and free length part enables increased tensile resistance. By comparison, using hotdog anchor could reduce the length, increase the lateral spacing and then, 20~35% construction cost could be decreased compared to the pack ground anchor.

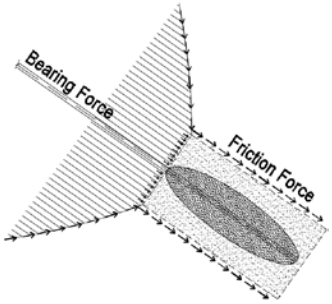

Fig.3 Load transmission distribution (modified from Dean, 2018)

3. DESIGN DEEP EXCAVATION IN SOFT SOIL: A CASE STUDY IN SOUTHERN VIETNAM

3.1 Project Information

The building with 34-story high building and three basements levels are constructed on a complex geological condition where the thick soft clay is predominant. The size of this excavation is 193m long, 82m wide and about 15m deep. Figure 4 illustrates the plan view of the project.

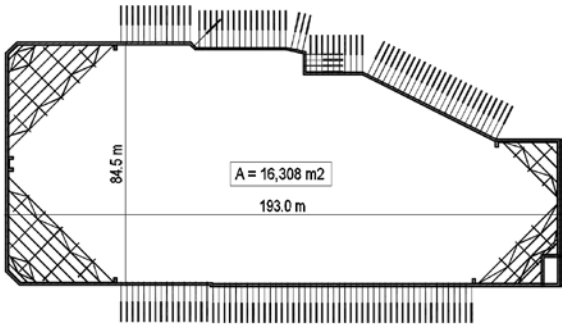

Fig.4 Plan view of the project

Two methods for support have been considered including the hotdog anchor and the pack anchor. Note that the pack anchor is developed from the conventional anchor but the anchor bulb is larger, e.g., 0.2 m in diameter. Both bonding parts are placed in the stiff soil layer. 12m in length and 0.4m in diameter of grout body for hotdog anchor and 18m-length and 0.2m-diameter of grout body for the other are applied (Figure 6a and 6b). The groundwater table observed at approximately 3m below the ground level.

The soil profile is shown in Figure 5. The design and construction for the project are challenged by the soft subsurface condition which contains approximately 30 m thick clayey strata below the ground. As shown in Figure 6a and 6b, the excavation is almost embedded in thick layers of very soft to soft clay (SPT-N30 values, {1-3} to very soft clay, {10-14} to stiff clay). In particular, the thickness of the very soft clay is approximately 10 m, unit weight is averaged 15.1 kN/m^3, void ratio measured at 2.28 and SPT ranges from 1 to 3. Following this, a medium clay layer with a higher SPT value (average ~13) and the thickness ranges from 8 to 10m could be a base for anchor installation. Undrained strength of the soil is calculated from vane shear tests and also triaxial tests results (UU and CU tests) (Figure 5). More details about the geological and hydrological conditions in Southern Vietnam could refer to Thoang and Giao (2015), Pham et al. (2002), Giao et al. (2008).

3.2 Design Solutions

Considering the existence of the thick very soft clay layer could cause the failure of the anchors, grout body is designed to embed into the stiff soil layer. In detail, hotdog anchor: four layers of the anchor are installed, with the 12m-bond length for each, free length ranges from 23m and 18m for the first and second layers, 13m and 7m for 3rd and 4th layers respectively (Figure 6a). The horizontal spacing used for hotdog anchor is 2m. Meanwhile, for pack anchor, as shown in Figure 6b, in order to meet the requirement of ground movement, 18m in length of grout body for the 1st layer and 16m in length for the other layers are applied. The free length for each was 18m, 15m, 8m, and 6m in turn. The spacing used for the pack anchor is 1.7m.

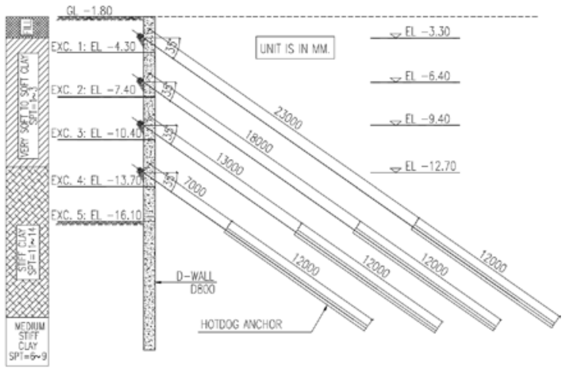

Fig.6a Cross-section of the hotdog anchor system

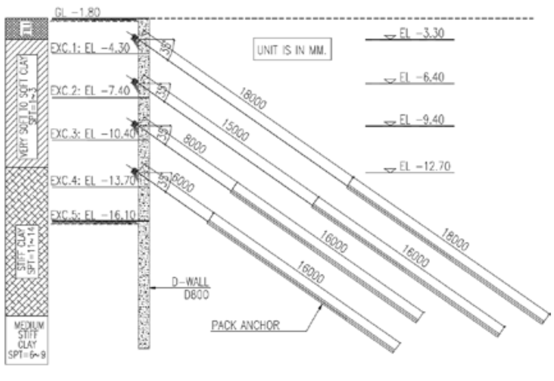

Fig. 6b Cross-section of the pack anchor system

3.3 Numerical Modeling

Finite element program Plaxis 2D version 2018 with plane strain models have been used. In which, clay is simulated using the Mohr-Coulomb (MC) model with undrained B type. The value of soil stiffness might be estimated using the empirical correlation between undrained shear strength and plasticity index proposed by Duncan and

Buchignani (1976) as presented in Figure 7. The soil model parameters are presented in Table 1.

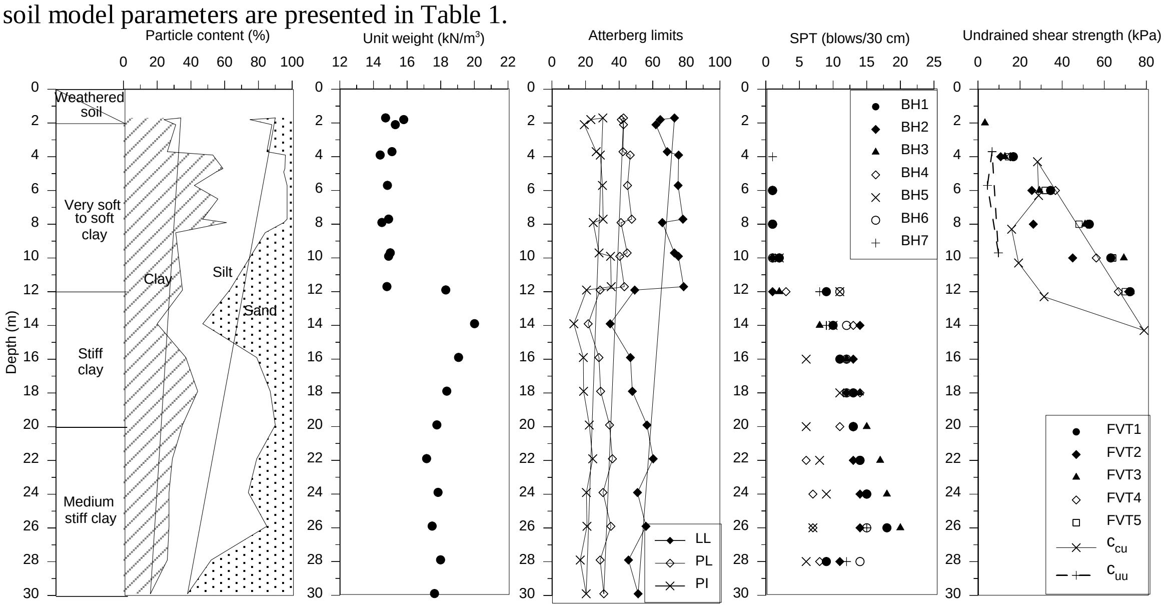

Fig.5 Soil profile in the case study (a) Particle content; (b) Unit weight; (c) Atterberg limits; (d) SPT; (e) Undrained shear strength

Anchor structures are modeled using element beam row in Plaxis 2D. The trial pullout tests have been done for the project and it is pointed out that the soil-reinforcement interaction acquired from the tests is more significant than unity (Wang and Richwein, 2002). Thus, the “Rigid Interface” in the default setting between soil and anchor can be adopted in the analyses. The model properties of the anchor rod and bonding part are shown in Tables 2 and 3, respectively. The input parameters for the diaphragm wall are also presented in Table 4. The numerical model meshes for the two support systems are shown in Figure 8a and Figure 8b.

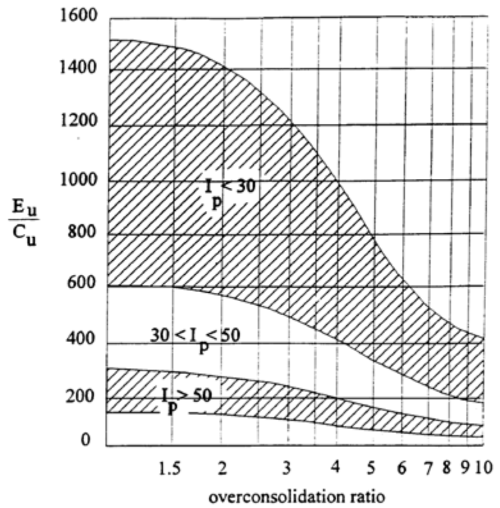

Fig.7 Empirical correlation for the stiffness of clay (Duncan and Buchignani, 1976)

Table 1 Input parameters of clay

Soil type	Type of undrained	Unit weight γ (kN/m^3)	Undrained strength Su (kPa)	Modulus E (kPa)
Very soft to soft clay	UD(B)	15.1	30	6,000
Stiff clay	UD(B)	19.3	72	32,400
Medium stiff clay	UD(B)	18.8	60	24,000

Table 2 Properties of the anchor rod

Parameter	Hotdog	Pack	Unit
Material type	Elastic	Elastic	-
Normal stiffness	1.12E5	9.87E4	kN
Spacing out of the plane	2.0	1.7	m
Pre-stressed	350	210	kN

Table 3 Properties of grout body

Parameter	Hotdog	Pack	Unit
Material type	Elastic	Elastic	-
Normal stiffness	8.9E5	3.5E5	kN
Length	12	16	m

Table 4 Parameters of D-wall for both two cases

Parameter	Diaphragm wall	Unit
Material type	Elastic	-
EA	2.60E7	kN/m
EI	1.39E6	kNm^2/m
w	5.84	kN/m/m
Poission’s ratio	0.15	-

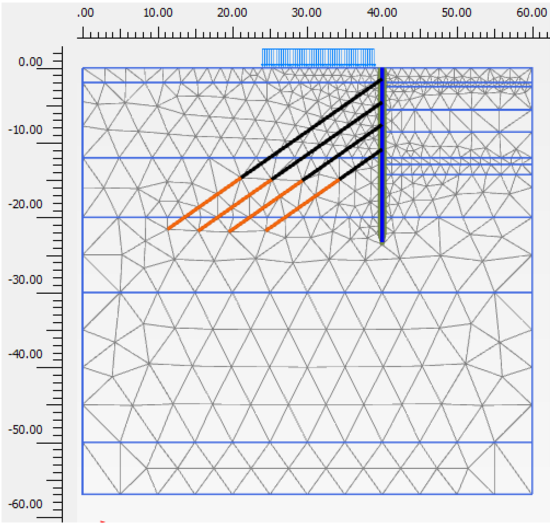

Fig.8a Mesh of the hotdog anchor numerical model

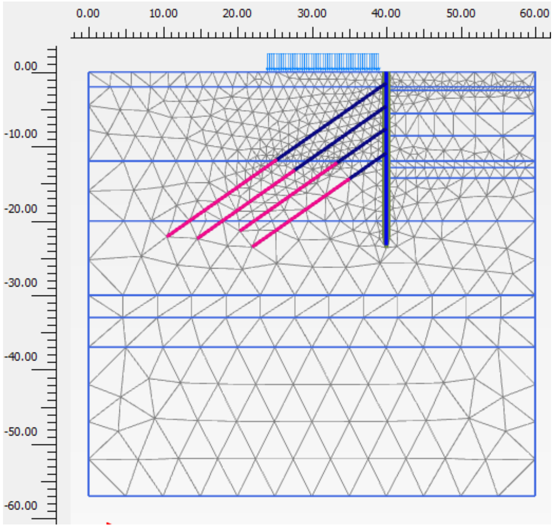

Fig.8b Mesh of the pack anchor numerical model

3.4 Proof Test

Bearing capacity of the tie-back wall is a function of several factors such as the uniform of soil layers, the existence of groundwater and also the appropriate installation method. The more accurate parameters are, the more reliable the results are. Therefore, before the mass production of the ground anchors, trial pullout tests are required to ensure the reasonable design. In the case, the tests have been conducted according to Geotechnical engineering circular no. 4: Ground anchors and anchored systems (No. FHWA-IF-99-015) with two for the hotdog and one for the other. The information and results of the proof tests are shown in Table 5 and Figure 9a and 9b, respectively.

For each proof test, the anchors were tested using five cycles of loading. The load-displacement response of a hotdog anchor is shown in Figure 8a. After the first four-cycle, the anchor had shown the elastic movement upon loading. At the fifth cycle, the result showed a plastic deformation, which indicated the safety load carrying was in the range of 550 kN to 650 kN. As shown in Figure 8b, the load-displacement curves of both have been done. It can be seen that with the same load applied, the deformation of the pack anchor tends to slightly larger than the hotdog anchors. In addition, while the pack anchor shows the elastic results at approximately 550 kN, the others could reach about 650 kN. The bearing capacity of the anchors was also manually calculated according to BS 8081-1989. The results showed the values of 530 kN and 440 kN for the hotdog and the pack anchor respectively. As the results of the pull out tests, the design value that counts for the factor of safety for the hotdog and the pack anchor are 500 and 423 kN respectively (a factor of safety 1.3 is applied in design according to JIS Ground Anchor Association temporary anchor design standard).

Table 5 Anchor parameters using for pull out tests

Anchor	Dia. of grout (m)	Free length (m)	Bond length (m)	Angle (°)	No. of Strand
Hotdog 1	0.4	19	12	35	4(**)
Hotdog 2	0.4	19	12	35	4(**)
Pack	0.2	20	18	35	5(*)

(**) Diameter of strand 15.2mm
(*) Diameter of strand 12.7mm

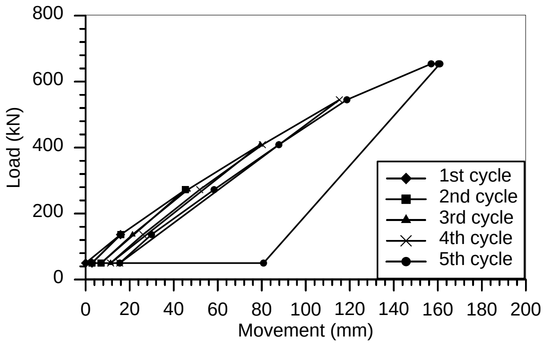

Fig.9a Load–displacement response of hotdog 1 under testing cycles

3.5 Results of Design

The lateral wall movement of two kinds of anchors is presented in Figure 10. Generally, the expected values of D-wall displacement in the case of using hotdog anchors seem to be slightly smaller than the other case. At the first steps, the differences are not as large as at the final steps. It could be concluded that the hotdog system has unnoticeably higher stiffness than the pack system. The maximum value for both cases is approximately 6.5 cm ($\delta_{max}/H = 0.4\%$) at the final excavation step and occurs at two-third of excavation depth. Also, since the first and second anchor levels were installed, the movement of the top of the wall increases unremarkably in the next excavation steps.

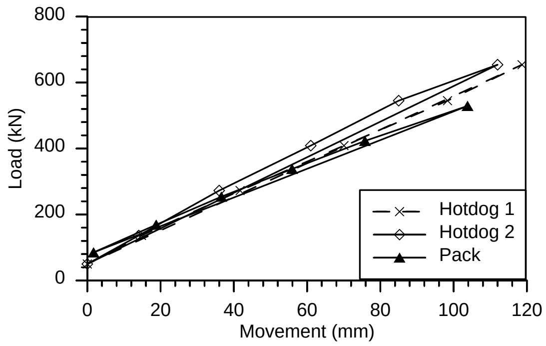

Fig.9b Load–displacement curve of proof tests

With regards to the influence of the stiffness of the retaining system (retaining wall, supporting system), a large number of approaches have been deducted. A summary of 300 deep excavations worldwide conducted by Long (2001) indicated that there are small differences in the average horizontal wall displacement among support systems (anchored, propped and top-down systems). Moormann (2002) also studied more than 530 international cases mainly in soft ground ($S_u \leq 75$ kPa). It is concluded that there is no empirical relationship between the kind of retaining systems and deep excavation performance. In addition, in all cases, the maximum horizontal displacement δ_{max} is frequently measured in depth of 0.5H to 1.0H below the ground surface (Moormann, 2002). It is agreed with the predicted movement in the case of hotdog and pack anchors. Particularly, Hung (2015) reviewed more than 50 deep excavation projects mainly for basements of building and infrastructures in the Ho Chi Minh city soft clay. The most common retaining structure is a diaphragm wall with the depth of excavation ranges from 8 to 24m. And only internal bracing used for support. The ratio between the lateral wall and excavation depth (δ_{max}/H) varied from 0.15% to 1% and averaged at 0.61%. The δ_{max}/H for both two cases with anchors is around 0.4% and within the range of Hung (2015).

Meanwhile, the bending moment of the diaphragm walls of the support systems is shown in Figure 11. An insignificant larger of bending moment of the pack anchors compare to hotdog anchors is recorded. The maximum value for the 800 mm-diaphragm walls is approximately 600 kN.m for both cases occurring at the middle of anchor heads.

In the case, with the same number of anchor layers applied, the hotdog anchor could reduce 33% in length of grout body. Also, the horizontal spacing is 2 m compared to 1.7 m of the pack anchor. Those are meaningful in practice because the challenge could come from the length of the anchor itself since the longer it is, the more vulnerable error during installation is. In other words, by decreasing the length of the anchor, construction risk related to the elongation of the anchor rod could be controlled easily. Also, this is crucial for expanding the scope of the hotdog anchor uses (e.g. congested urban area, stiff soil lies sandwich between soft layers).

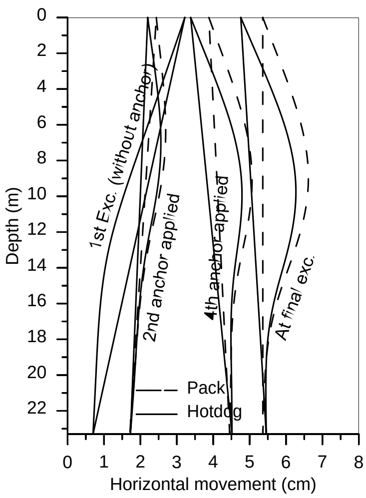

Fig.10 Displacement of the tie-back wall

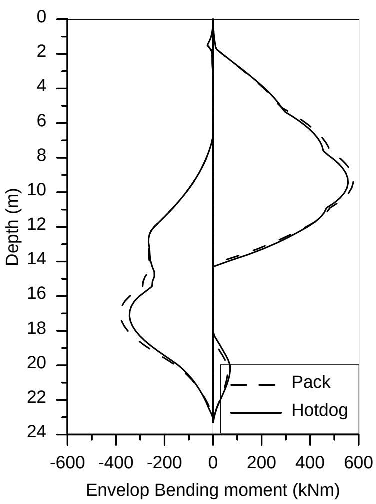

Fig.11 Envelop bending moment

The values of anchor force during five steps of excavation are also shown in Table 6. The result shows that the force in each hotdog anchor is larger than the other. It could be explained by the number of applied pack anchor is larger than hotdog anchor (the spacing for the pack is 1.7m compared to 2m for the hotdog one). In addition, the maximum loading force on hotdog anchor is 251.8 which is less than the bearing capacity of anchor (500 kN). While a similar behavior for pack anchor is also observed (Table 6).

Table 6 Anchor force during excavation

Anchor row	Anchor force (kN)			
	Exc.2	Exc.3	Exc.4	Exc.5
1	259.8 (215.0)	251.3 (213.6)	249.7 (216.0)	247.2 (209.4)
2	-	254.6 (182.3)	251.8 (183.5)	246.7 (176.2)
3	-	-	246.3 (183.2)	237.9 (175.1)
4	-	-	-	244.6 (177.6)

Values in '()' are for pack anchors.

4. CONCLUSIONS

The performances of the pack anchor and the new anchor type installed in thick soft soil strata were studied based on the trial pullout tests and also the modeling using the finite element program. Base on the test and simulation results, the following conclusions could be drawn:

1) Compared with the pack anchor, the use of hotdog anchor could reduce the length (in bond length and also the total) and increase the anchor spacing by expanding the bonding diameter to 2.5 ~ 3 times. The shortening of the length is crucial for anchor installed in complex geological conditions and also for rod elongation controlling.
2) The pullout test results showed the good bearing capacity of hotdog anchor under loading in clay. The test indicated the 12m bond length and 0.4m in diameter of hotdog anchor in the stiff clay (SPT ~ 13) could stand at around 650 kN after four cycles of loading. Meanwhile, with 18m bond length and 0.2 m-diameter pack anchor, and the same geological condition, the bearing force is approximately 550 kN.
3) According to the case design of both two anchor types, the use of hotdog anchor to retain the diaphragm wall in the thick clay strata is reasonable since the movement and a bending moment of the diaphragm in the simulation wall are in the acceptable zone.

5. ACKNOWLEDGMENT

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