Experimental and Numerical Investigations on Hydraulic Barrier Bottom Plug for Deep Excavations: A Case Study

An Phung Vinh

Abstract: ***In Vietnam, the solution of designing and constructing deep foundation pits with the geology of sandy or clayey sand is very difficult, especially in case soil mix mud. In some deep foundation pits, the unreasonable treatment solution causes the bottom plug of the foundation pit to be pushed up to the foundation pit or not to pump a foundation pit dried. Solving those problems, this article introduces a particular case study, sealing the bottom of the foundation pit for nº14 of Yen Xa drainage works with the Jet grouted bottom plug hydraulic barriers. To treat the soft soil layer, mix organic without breaking the upper soil layers, this solution uses Jet-grouting technology with a mixture of materials including cement, fly ash, blast furnace slag, lime in a reasonable proportion to ensure waterproof and not uplift the massive bottom plug hydraulic barriers when excavating soil in the pit. Results of calculation and acceptance after the foundation pit is completed show that this is a good solution, high reliability and can be applied to seal the bottom of the foundation pit in similar geological conditions.***

Keywords: Jet grouting, Jet grouted bottom plug, massive bottom plug hydraulic barriers.

I. INTRODUCTION

Yen Xa Wasterwater treatment project is the largest and urgent project of Ha Noi (The capital of Vietnam) on wastewater treatment with capacity 270.000 m^3/day. The project uses Japanese ODA through JapanInternational Cooperation Agency (JICA). The project consists of many different items, including items of underground culverts constructed by pipe jacking method. To construct this item, the temporary jacking are needed. Among them is the temporary jacking shaft nº14, which is one of the first jacketed shafts, was designed and constructed to model for other shafts. This is a shaft with the bottom of the foundation located on a sandy clay layer, easily uplifted or permeated on a bottom plug. Design and construction solutions are quite complicated because steel piles can only be built with a finite length, not enough length to stabilize the natural soil at the bottom of the foundation pit. If piling the steel piles to a certain length, then excavate the foundation pit, pour concrete to create a massive bottom plug, the bottom of the foundation pit will be pushed up and difficult to dry the foundation pit. In this case, the contractor's design and construction solution are to firstly pile steel sheet piles around the foundation pit. Next, create a Jet-grouted bottom plug in the underlying layer using Jet Grouting technology. Then excavate the foundation pit to the design level. The results after digging the foundation pit show that, the foundation pit is completely dry, good quality, meeting the technical requirements.

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II. THE SOLUTION TO DESIGN SHAFT

A. Design options [6]

As a part of the project, dimensions of temporary jacking shaft no14 are WxL = 7.2x8.0 m, and depth of 14.1 m, surface ground level is +3.0 m, groundwater level is +1.0 m. The soil layers at the foundation pit location include: (1) Layer 1 is clay, sandy clay, yellowish-brown, gray, stiff, with a thickness of 2.5 m; (2) Layer 2 is sandy clay, mud, mix organic, very soft to soft, with a thickness of 16.1 m; (3) Layer 3 is silty sand, fine sand, brownish-gray, sandwiched clay sand, plasticity status, with a thickness of 6.11 m. The stratigraphic description is shown in Fig. 1. The properties of soil layers used in calculations are shown in table I.

Table- I: Property of soil layers

Layers	Geological description	Soil properties		
		γ_{tc} (kN/m^3)	C (kN/m^2)	φ (°)
Layer 1	clay, sandy clay, yellowish-brown, gray, stiff	18.0	12.0	10.0
Layer 2	sandy clay, mud, mix organic, very soft to soft	18.5	13.0	12.0
Layer 3	silty sand, fine sand, brownish-gray, sandwiched clay sand, plasticity status	18.5	15.0	14.0

Requirements for the shaft must be dry, not uplift the bottom plug when digging soil in the foundation pit to the level -11.0 m. The design solution is to create a massive bottom plug hydraulic barrier with a thickness of 3.5 m, level of the top of the bottom plug at -11.0 m, and the bottom plug at -14.6 m. Drilling length is 18.1 m from the ground level +3,0. Plan and cross- section of the foundation pit are shown in Fig. 2 and Fig. 3.

B. Calculation results

Diagram and calculation method

The calculation diagram is the two-dimension problem as shown in Fig. 4. The structure supporting the foundation pit is Larsen IV steel sheet, with 6 struts made of H300 steel, calculated parameters are shown in table II and table III.

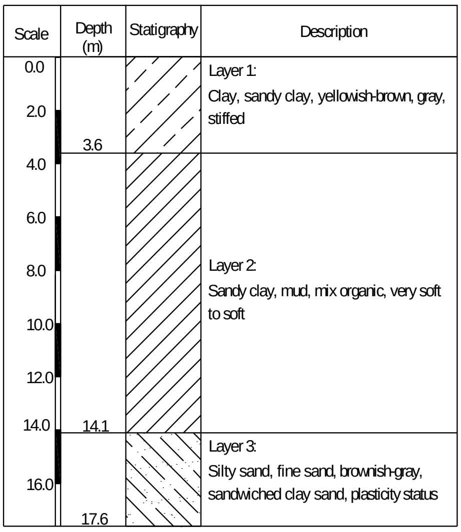


Fig. 1. Stratigraphic description

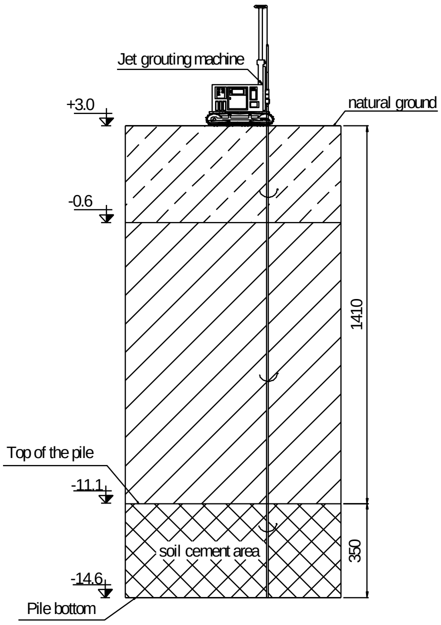


Fig. 2. Cross section the foundation pit

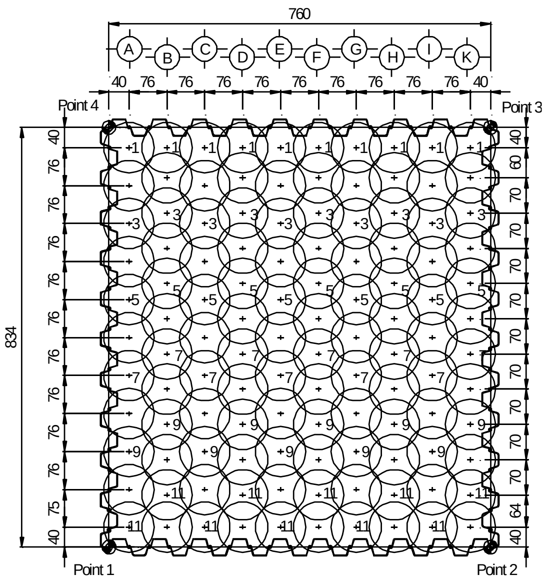


Fig. 3. Plan of the foundation pit

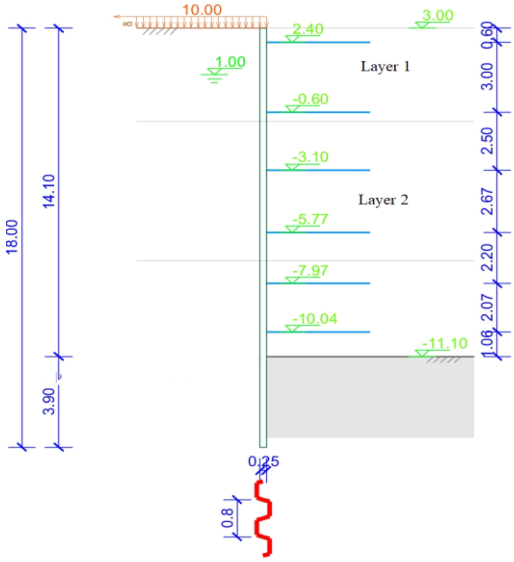


Fig. 4. Schematic Diagram

Table- II: Properties of Larsen IV steel sheet

Geometric dimensions			Item	Weight/md (kg)
Width (mm)	*Length (m)*	*Thickness (mm)*		
400	125	13	Larsen IV steel sheet	60

Table- III: Properties of Larsen IV steel sheet

Item	Geometric dimensions					Weight (kg/m)
	Height beam H (mm)	*Wing width B (mm)*	*Thickness t_1(mm)*	*Thickness swing t_2 (mm)*	*Length (m)*	
Steel H300	300	300	10	15	6/12	94

The massive bottom plug hydraulic barriers is made of soil-cement material. The properties of soil-cement as shows in table IV. The activities load around the edge of the foundation pit is equal to P=10 kN/m^2.

Table- IV: Properties of soil-cement

Items	Geometric dimensions			Unconfined compression strength q_u (Mpa)
	Top level (m)	Bottom level (m)	Diameter (m)	
Soil-cement Column	-11,1	-14,6	1,0	0,7 ~ 1,0
Massive bottom plug hydraulic barriers	-11,1	-14,6	-	0,7 ~ 1,0

Case and steps calculation

The calculation for the construction of foundation pit, activities load in this case includes: (1) Active soil pressure on the Larsen wall; (2) Groundwater pressure; (3) Construction load around pit edge.

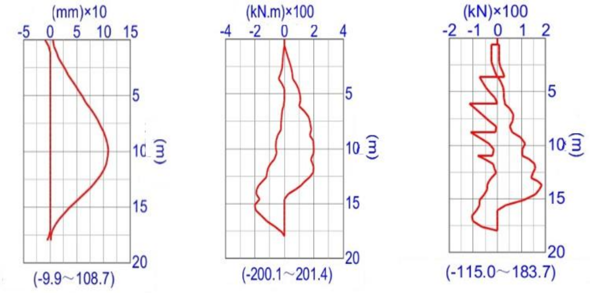
The calculation steps are in the order of construction steps, as follows:

▪ Step 1: Construction of larsen IV steel piles around the foundation pit; Step 2: Construction of soil-cement piles to create Jet grouted bottom plug. Level the top Jet grouted bottom plug -11.1 (m), level the bottom of Jet grouted bottom plug -14.6 (m), Jet grouted bottom plug area 7.2 m x 8.0 m. Wait 28 days for the compression strength of soil-cement reached to design strength;

▪ Step 3: Excavate soil to the level +2.4 m and support the first strut. Next, excavate soil to level -0.6 m and support the second strut. Next, excavate soil to level -3.6 m and support the third strut. Next, excavate soil to level -5.77 m and support the fourth strut. Next, excavate soil to level -7.97 m and support the fifth strut. Next, excavate soil to level -10.04 m and support the 6th strut. Finally, excavate soil to level -11.0 m.

Results

The numerical simulation software used for this calculation is copyrighted FRWS 7.0 software. The results are shown in Fig. 5, Fig. 6.



Displacement (mm)x10 Moment (kN.m)x100 Shear force (kN)x100

Fig. 5. Internal strength and displacement of steel sheet piles

Displacement and internal force of steel sheet piles: The maximum displacement value of the Larsen IV sheet pile wall is 10.87 cm at a depth of 10 m. And the maximum torque is 201,4 kN.m. That results are shown in Fig. 5.

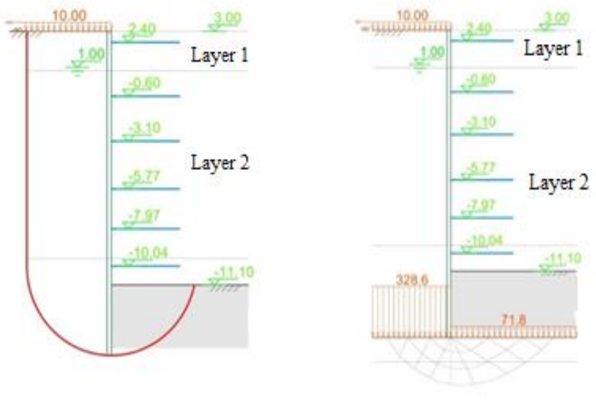


Fig. 6. Schematic of overall stability and bearing capacity

Results of the calculation of overall stability and pushing the bottom of the Jet grouted bottom plug: Sliding safety factor K = 1,46 > [K] = 1,25 ensure safety; The safety factor of pushing the Jet grouted bottom plug F_s = 1,63> [F_s] = 1,15 ensure safety. That results are shown in Fig. 6.

Conclusion: The calculation results of the foundation pit show that it is safe.

C. Design components of soil-cement of massive bottom plug hydraulic barriers

The design of grouting components to create massive bottom plug hydraulic barriers plays an important role, deciding the success of the solution. Experience with similar projects shows that, with the soil conditions at the location of the soil-cement column is weak clay mixed with sand (*sandy clay, mud, mix organic, very soft to soft*), it may be necessary to use cement 500 to 700 kg for 1m^3 soil-cement column with diameter 0,8m, even so, it is not sure that mortar soil-cement mixture will become solid. However, using a large amount of cement is not only costly but sometimes disadvantageous because the soil has an organic content that inhibits the hydration reaction of cement. To handle the phenomenon of limiting hydration of cement mortar, there have been many theoretical and empirical studies conducted in the world [8] [9]. One of the most effective methods that have been applied to popularity in the world is the use of a mixture of fly ash, slag, and cement. The fly ash and slag are the products of emissions from thermal power plants, chemical plants, fertilizer plants, and other industrial facilities. Ash, slag, lime have properties consistent with the standards, to make additives, raw materials for production of construction materials, or used in construction works (leveling, treatment the weak foundation...). In Vietnam, there are some of studying on the jet-grouting mortar components for construction on weak clay, high organic matter, and saline alum, but most of these are individual studies [1], [2], [3], [4], [6], [7] [10], [11]. There was a good study, includes a field experiment was conducted at Soc Trang Thermal Power Plant by Consultant and Inspection Joint Stock Company of Construction Technology and Equipment (Coninco., JSC) and SEJONG E&C CO., LTD Company. Researched results have been compiled into the basic standard: TCCS 85:2018/VASECT "Consolidating soft ground using the fly ash and blast furnace slag-specimen making procedures and determination of Aggregate". Based on these research results, the Hydraulic construction Institute (HYCI) and Vietnam Investment Consulting and Technology Transferring Joint Stock Company (VICTS., JSC) have repeatedly applied to actual works [3], [7] obtained good results, shortened testing time, speeded up the construction speed. From those results, at this project, suggest uses materials as table V:

Table- V: Binder content in 1m^3 of soil-cement column

Binder content in 1m^3 mixture (kg/m^3)	Blast furnace slag (%)	Lime (%)	Fly ash (%)	Cement (%)	Water (l)
300 kg/m^3	35	35	20	10	700

D. Constructed and tested to assess the quality of Jet-grouted bottom plug

The construction proceeds based on the following steps: (1) Locating soil-cement column; (2) Moving the Jet-grouting machine into design position;

(3) start to drill down, and creating high-pressure jet water through the drill down to the elevation of -14.6m; (4) Start grouting from high-pressure pumps with specified pressure 200 at through a high-pressure pump system that connects the grout pump to the drill bit. The mortar mixture is sprayed from the tip of the drill to beat the land around the drill bit. At the same time, the drill was rotating and retracting to the elevation -11.1m, then stop the grouting. Pull up the drill rod and move to another soil-cement column position. The soil-cement column is constructed in the order of number odd first, even after, as shown in Fig. 7. In the process of drilling down and pull up, it has to be marked to ensure a sufficient length of 3.0m. Control the grout pump pressure gauge on the high-pressure grout pump and grout flow meter to ensure design pressure.

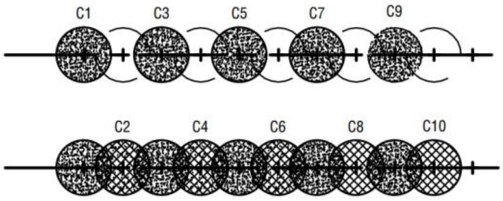


Fig. 7. Soil-cement column are constructed in the order

After 28 days, since the last soil cement pile was constructed, drill at three locations on the massive bottom plug hydraulic barriers to take a sample to assess the construction quality, take 100% of core samples over the length of the borehole. At E2 soil-cement column, the sample was taken from a depth of 0.5 m ÷ 1.0 m. At the B9 soil-cement column, the sample was taken from a depth of 1,0 m ÷ 1,5 m, and at the I9 soil-cement column, the sample was taken at a depth of 0.0÷0.5 m. Visually, the whole sample has a high uniformity, density, little mixed with foreign objects, see Fig. 8 and 9.

Fig. 8. The long core samples 0.5 m in E2

Fig. 9. The failure sample during a compression test

The sample was preserved and transported in accordance with the provisions of TCVN 2683: 2012 to Golden Earth Institute for testing. Each soil-cement core sample was made into 6 samples to conduct the experiment. The total number of samples tested was 18 samples. Of these, 9 samples were used for compression testing to determine the uncompressed compressive strength and 9 samples were used for determination of permeability. The testing of compressive samples to determine the strength of uncompressed compressive strength shall comply with TCVN 9906: 2014. Experimental work to determine the permeability coefficient was carried out in accordance with TCVN 8723: 2012. Experimental results show that 100% of core samples meet requirements, $q_u \geq 1$ Mpa, see Table VI.

E. Execution of pit excavation, assessment of pit quality

Based on the experimental results to determine the unconfined compression strength of massive bottom plug hydraulic barriers, after 28 days after the completion of the final soil-cement column. The pit was excavated by excavators machine in the following order:

- Excavating soil to the elevation of +2.4 m and supporting the first strut;
- Excavating soil to the elevation of -0.6 m and supporting the second strut;

Fig.10. Start construction of the massive bottom plug hydraulic barriers

Fig. 11. Excavating soil to the elevation of -11.0 m and finished the pit

- Excavating soil to the elevation of -3.6 m and supporting the third strut;
- Excavating soil to the elevation of -5.77 m and supporting the fourth strut;
- Excavating soil to the elevation of -7.97 m and supporting the fifth strut;
- Excavating soil to the elevation of -10.04 m and supporting the 6th strut;
- Excavating soil to the elevation of -11.0 m and finished the pit.

Table- VI: Summary of experimental results of soil-cement materials

Items	Average sample diameter (m)	Average sample height (m)	Average sample weight (kg)	Uncompressed compressive strength (kN/m2)	Permeability coefficient k (m/s)
E2 column	7,05	14,10	1013,3	2533	$3,00x10^{-6}$
B9 column	6,47	14,24	763,84	2930	$1,27x10^{-6}$
I9 column	6,25	14,30	694,43	3168	$2,27x10^{-6}$

The result of the excavated of the pit show that the bottom of Jet grouted bottom plug pit was 10.1m deep under the water table, completely dry, see Fig. 10 and 11. The bottom of the Jet grouted bottom plug was hard enough for the construction equipment to move easily. There was no displacement in the wall and the bottom of the pit.

III. CONCLUSION

In addition to soft soil treatment applications, waterproofing of dikes and earth dams, currently, Jet grouting technology has been applied in the design and construction of pits because of the special features of construction equipment, such as the ability to execute in the limited areas, ability to handle deep without affecting the topsoil layers. The compressive strength and the waterproofing ability of the soil-cement material may vary according to specific requirements. Although the cost is relatively high compared to other solutions, this solution still is being widely applied for deep pits, high water level, the bottom of the pit is located on the soil layer with a large permeability coefficient. As a result, his solution can be considered as one of the highly reliable and safe solutions in Vietnam, as the massive bottom plug hydraulic barriers of shaft nº14 is one of the most obvious evidence.

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