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APPLYING REASONABLE CONSTRUCTION TECHNOLOGY IN FOUNDATION TREATMENT FOR BASEMENTS OF HIGH-RISE BUILDINGS CONSTRUCTED ALONG THE BEACH OF VIETNAM

Abstract. *With the advantage of having a sea route stretching along with the territory, Vietnam owns over 2,700 large and small islands, of which Phu Quoc is the largest island of Vietnam, with a total area of 589.23km^2 and 150km of long, sandy coastline smooth white. To serve the growing tourism industry here, the local government has built many high-rise buildings, including the project of Huong Bien 1-Phu Quoc Hotel, which was built in the densest urban area of the island. Difficult construction conditions: the construction site is narrow, only 25m from the coast. In addition, the project has a long, narrow basement, located on complex geology, affected by the surrounding tides, so it causes many difficulties for contractors when working. Many risk factors that may occur during the construction process pose a difficult problem for engineers foundation: cost savings while ensuring absolute safety and especially not cause subsidence, cracking the foundations for the neighboring buildings. This paper presents a method to effectively deal with diaphragm walls in soil by a system of small diameter drilled fin piles with steel pipes outside filled with cement mortar, which has been successfully handled by engineers and contractors' experts, from which to draw some useful experience for the construction of high-rise projects near the coast soon in Vietnam.*

Keywords: *High-rise building, diaphragm wall, hard rock foundation, steel pipe.*

1. Introduction

Currently, in Vietnam, high-rise buildings are built a lot in big cities, and Huong Bien 1 - Phu Quoc hotel, is also such a high-rise building. The project is located at 1 Vo Thi Sau street, Duong Dong town, Phu Quoc district, Kien Giang province. Huong Bien 1 Hotel has a scale of 1 basement, and 9 floating floors, the work is a unique combination of architecture and very aerodynamic shape in terms of mechanics: "The boat on the immense waves in the beautiful pearl island waters".

Fig 1. **Architecture with the aerodynamic shape of the hotel's unique Huong Bien 1.**

During the design process, the engineers of the project have found that the risks related to the deepening may occur such as: risks in the survey, design calculations and during the deep pit construction. There are also other factors equally as: stormy weather, changes in government policy... Special risks can occur at any time during the construction of the underground part because the work is very complicated, shaped like a boat: the first section is about 36m narrow; extension: 67m, construction length 240m and depth to basement: -4m (wastewater treatment tank: 40m long and -7m deep from the ground). The geology of this area is also very complicated: the soil layers change from layer 1, which is fine-grained sand, gray-white, in a loose state, to layer 2, which is red-brown clay, in a hard state., and layer 3 is sand mixed with clay, yellow-brown color, white-gray color, layer thickness from 1 to 3m, in addition, below layer 3 can meet thick, hard foundation rock (cote <-4m to -4m) and has a gentle slope towards the coast. Therefore, the analysis and calculation of basement excavation must assume in 3 possible cases:

– Case 1: Dig the soil to the cote -4m, meet the rock layer in the cote below 4m, and must drill into the rock 1m (make sure the pile is attached to the rock at least 1m from the cote -4m).

– Case 2: Dig the soil to the cote -4m if no rock is encountered, continue drilling, if the drilling depth is less than 2m and encounter rock, continue drilling to ensure that the pile is embedded in the rock for at least 1m.

– Case 3: Dig the soil to the cote -4m, but have not met the rock, continue drilling, if the drilling depth is greater than 3m still no rock, then stop drilling at the cote -7m compared to the cote ±0.000. Ensure the pile is embedded in the soil at least 3m from cote -4m.

From the above analysis, engineers of Huong Bien 1 Hotel project simulated the construction method of the underground part of the project for 3 cases using Plaxis 8.5 software to measure possible adverse situations when building the basement next to the night market in the center of Phu Quoc island.

2. Analysis of the reasonable selection of construction solutions

Because the project is located on a narrow plot of land and is surrounded by important traffic routes in the center of Phu Quoc city and the foundation is built on complex geology. There are also underground works such as manholes, sewers, other existing underground technical systems of Duong Dong town - Phu Quoc city. It is required during the construction process not to cause subsidence, cracking and especially noise for neighboring residential buildings, especially to ensure safety for the bustling operation of the night market right next to the work [1]. To choose the appropriate construction methodology, engineers in project management, supervision consultants, design consultants and construction contractors have proposed two possible options:

2.1. Option 1: Using shaped steel support (shoring system) [6].

2.1.1 Advantages:

– Quick installation and dismantling;

– Flexible and efficient;

– Can be rented, reused many times;

– Connecting bolts' flexibility and convenience can be used instead of welding or cutting method traditional.

2.1.2 Disadvantages:

– Corrosion in the working environment (when using section steel to build structures near the sea).

– When the construction length is up to several meters, many joints must be used for bonding, which reduces the overall stiffness and causes lateral displacement and excavation instability due to deformation of the joints.

Fig 2. **Shoring system combined with Larsen sheet wall.**

2.2. Option 2: Using a small diameter drilled fin pile system with steel pipes outside and filled with cement mortar inside [2].

The small diameter fin pile system has been widely used in the construction of basements in HCMC and neighboring provinces. For example, the 16-story building No. 475A Dien Bien Phu, Binh Thanh district used 15m-long D400 diaphragm piles to make diaphragm walls when constructing two basements at a depth of 7m. Similarly, 141 Dien Bien Phu building was built according to this technology.

2.2.1 Advantages:

– Small noise and vibration during construction;

– Can be applied to great depths, suitable for many different geological conditions;

– The diaphragm walls form the outer wall of the basement to increase stability after the construction is completed.

2.2.2 Disadvantages:

– Long construction time;

– The construction site is muddy due to the Bentonite mud used to stabilize the wall pipe during the drilling process;

– High construction cost;

– Cannot be applied if there is a sand flow phenomenon.

Fig 3. **Stabilization of diaphragm wall by bored pile D300.**

Comments: Geological documents show that the distribution of soil layers is very complex, including soft soil layer 1 and layer 2: fine-grained sand, grayish-white color, at a depth of -3.6m from the ground, in addition, the narrow, long and deep basement structure also hinders the construction. Therefore, stakeholders choose the optimal option is to use a basement with reinforced concrete diaphragm wall 300mm thick, using concrete M. 350, and is embedded 1m into the rock below. The whole diaphragm wall system is built with 130mm diaphragm piles, drilled with Ø114 steel pipes, 2.8mm thick, filled with mortar inside, expected to be completed after 5 months of construction.

2.3. Analysis and calculation of bored pile diaphragm wall with steel pipe and filled with cement mortar inside

2.3.1 Analysis of the computational model by Plaxis 8.5 software.

a. Case 1: Dig the soil to cote -4m, meet rock layer at cote < - 4m, continue drilling into rock 1m (steel pile attached to rock 1m from cote -4m).

– Parameters of diaphragm wall with a bored pile:

+ Diameter D130mm. Steel pipe Ø114mm, thickness: t = 2.8mm

+ Length of pile: L = 5÷7m;

– Calculated load used in the model:

+ Live load on major roads is 20 kN/m^2;

+ Loading construction vehicles is 10 kN/m^2.

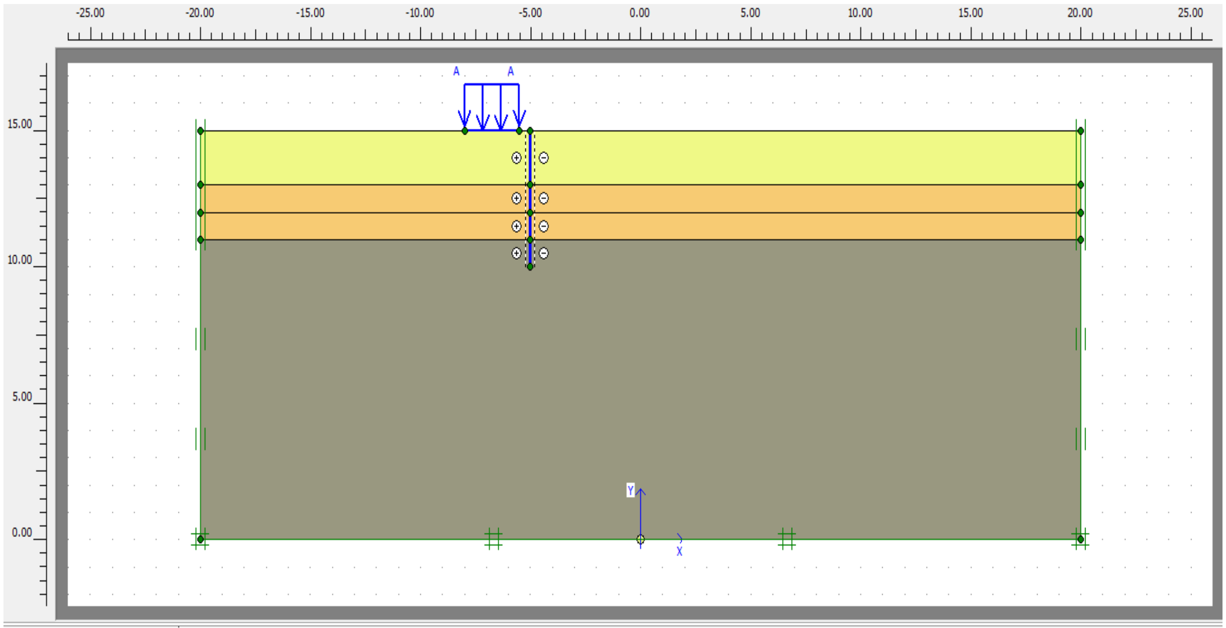

Fig 4. **Model of the pile drilled into the rock layer at a depth of less than 4m, embedded in the rock 1m.**

Input data

Table 1

Mechanical parameters of diaphragm wall

	Symbols	Value	Unit
Type of model	Material type		
Axial stiffness	EA	3.2x10^6	kN/m
Flexural stiffness	EI	4.5x10^3	kNm^2/m
Poisson ratio	υ	0.3	

Table 2

Parameters of soil layers used in Plaxis.

Parameters of soil layers	Units	Layer 1 Fine-grained sand, gray-white	Layer 2 Red-brown clay, in a hard state	Layer 3 Sand mixed with clay, yellow-brown color
		Drained	Un-drained	Un-drained
□**unsat**	[kN/m³]	16.9	16.8	24.9
□**sat**	[kN/m³]	20	20.6	25
□	[-]	0.3	0.3	0.3
cref	[kN/m²]	1	38.4	200
□	[°]	18	21	45
Rinter	-	0.8	0.9	0.5

Analytical results of case 1:

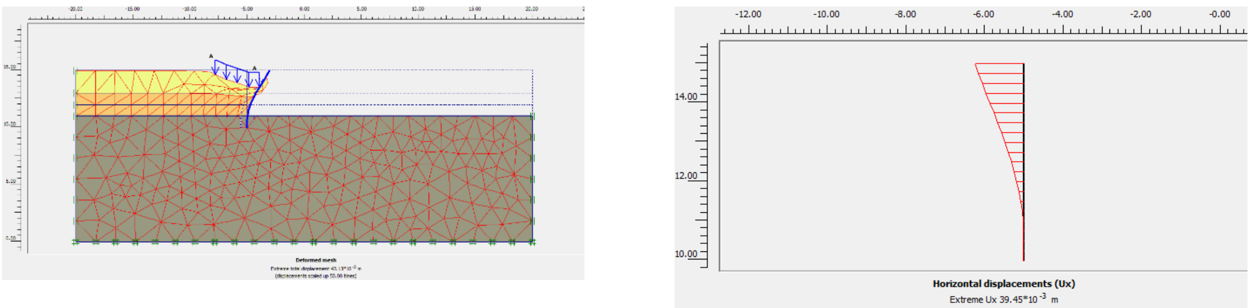

Fig 5. **Maximum horizontal displacement in excavation side U_x = 39.45 mm**

b. Case 2: Dig the soil to the cote -4m but have not met the rock continue to drill, if the drilling depth is less than 2m to meet the rock, then continue to drill into the rock more than 1m.

Analytical results of case 2:

Estimated displacement of the total diaphragm wall in case 2 when digging to the bottom at cote -4.00m

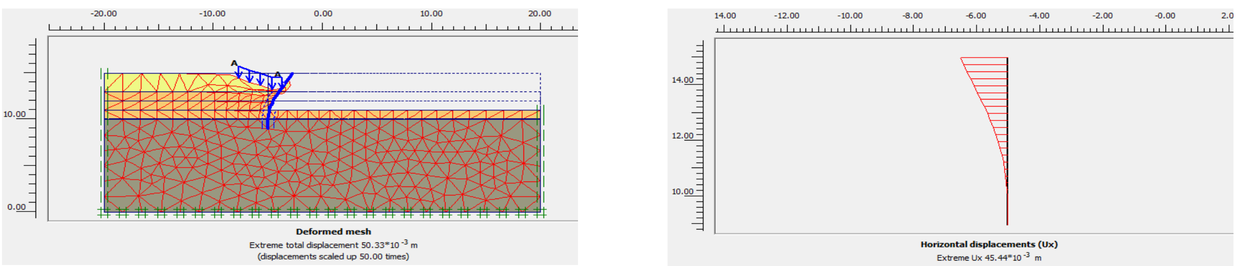

Fig 6. **Maximum horizontal displacement in excavation side U_x = 45.44 mm**

c. Case 3: Dig the soil to the cote -4m if no rock is encountered, then continue drilling, if the drilling depth is greater than 3m still no rock, it is recommended to stop drilling at a depth of cote -3m compared to the bottom of the excavation pit (corresponding to a depth of -7m compared to the cote ±0.00m)

Analytical results of case 3:

Estimated displacement of the total diaphragm wall in case 3 when digging to the bottom at cote -4.00m

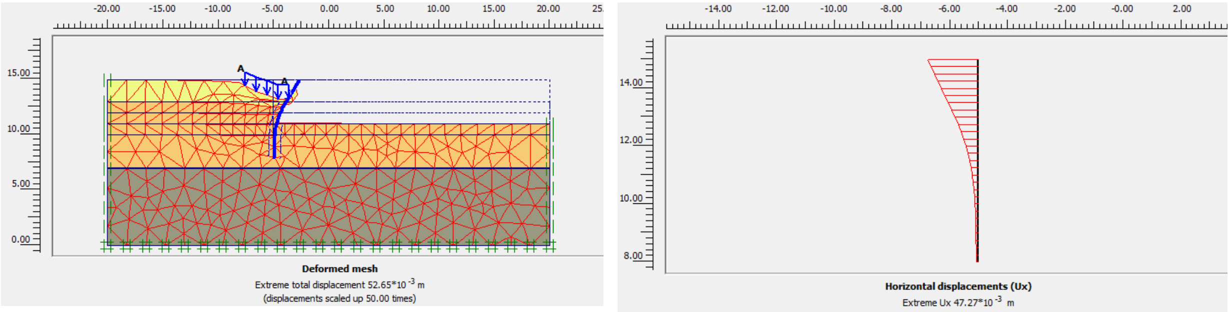

Fig. 7. **Maximum horizontal displacement in excavation side U_x = 47.27 mm**

2.3.2 Diagram of moment envelope in diaphragm wall

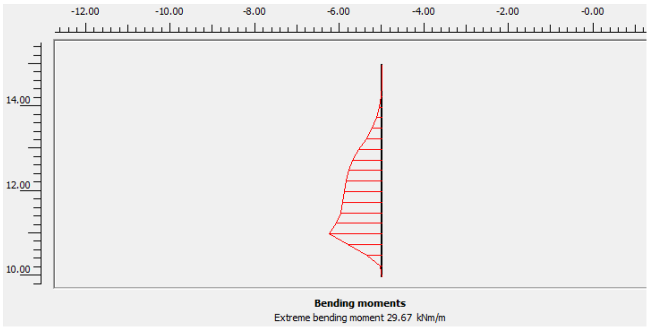

Fig. 8. **M_{max}=29.67kN.m/m of case 1 when digging to the cote -4m**

Through analysis, we see that case 1 gives a larger torque result on the envelope chart than the other 2 cases. Therefore, we will use this result to test the bending resistance of steel pipe piles.

2.4 Testing the strength of steel pipe

According to TCVN 5575:2012 "Steel structures - Design standards" [3], the bearing capacity of steel pipes is calculated through stress testing of pipes and refers to the construction experience of similar projects. The calculation steps are as follows:

a. Input parameters of materials: CT3 steel, with tensile strength f= 210 Mpa, elastic modulus E = 2.1x10^4 Mpa

b. Testing of both flexural and compression of hollow steel pipes with diameter D130, towel-shaped cross section, thickness t=2.8mm, with:

– Outer Diameter D = 130mm = 13cm.

– Inner diameter d = 124.4mm = 12.44cm.

– Moment of inertia of the donut shape:

$$J_x = J_y = \frac{\pi D^4}{64} - \frac{\pi d^4}{64} = \frac{\pi 13^4}{64} - \frac{\pi 12.44^4}{64} = 266.4cm^4$$

– Cross-sectional area:

$$A = \frac{\pi D^2}{4} - \frac{\pi d^2}{4} = \frac{\pi 13^2}{4} - \frac{\pi 12.44^2}{4} = 11.2cm^2$$

– Check stresses in the pipe

$$\sigma = \frac{-N_{\max}}{A} + \frac{M_{\max}}{J_x} y_{\max} = \frac{-7.47}{11.2} + \frac{296.7}{266.4} 6.5 = 6.5723kN/cm^2$$
$$= 657.23kG/cm^2$$

– Check:

$$\sigma < f$$

Thus, with the given section and material for making steel pipes, it can be concluded: steel pipes for piles have sufficient bearing capacity.

3. Conclusions and recommendations

3.1 Conclusion

The authors generalize process diaphragm wall construction using small diameter bored pile system using steel pipe and grouting inside to stable diaphragm wall of the hotel Huong Bien 1.

Compare and choose a reasonable underground construction option for projects with complex and narrow ground located on complex geology with thick rock formations above the ground at depths above or below 4m. In addition, 25m from the shoreline is affected by tides and causes difficulties while drilling. The construction unit's choice of diaphragm wall solution with a small-diameter bored pile system using steel pipes and internal grouting not only brings economic efficiency to the investor but also brings absolute safety to the construction sites. Neighboring construction works, especially the busiest and most crowded night streets on Phu Quoc island are not interrupted.

Simulate and calculate the influence of the pile system on the 7m long DW300 diaphragm wall using Plaxis 2D software. The calculation result is that displacement at cote -4.0m is 47.3 mm for diaphragm wall of steel pipe filled with mortar. The actual displacements are within the allowable limits according to the design standard of the wall in soil BS 5930:1999 (UK); or according to Vietnamese standards such as TCVN 5575 - 2012: Steel structures - Design standards, TCXDVN 205:1998: Pile foundations - Design standards.

3.2 Recommendations

Regarding the standard system, State management agencies need to develop a system of standards for design, construction and acceptance for small-diameter bored pile diaphragm wall system using steel pipes and grouting inside. are quite popular in Vietnam but now use foreign standards to apply in practice in Vietnam.

Regarding the inspection and evaluation process, through the experience drawn from the construction of Huong Bien 1 Hotel, Phu Quoc, Kien Giang, we recommend the parties such as: Owner, Supervisor, Construction Unit, the subcontractor will coordinate the process as a basis for submission to the State's construction licensing authorities for consideration to recommend investors of works of similar scale to apply to save money. Construction cost savings to better serve construction in Vietnam soon.

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