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Cuong Ha-Minh · Anh Minh Tang · Tinh Quoc Bui · Xuan Hong Vu · Dat Vu Khoa Huynh *Editors*

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Combination of Cement Deep Mixing (CDM) and Steel Sheet Piles for the Cofferdam Used in Construction of Deep Foundation Pit in Soft Ground in the Mekong Delta Coast

Tao Nguyen Quang, Bui The Anh, Thanh Vu Cong, and Tri Mai Cao

Abstract Cofferdam foundation is defined as a temporary structure which is used to prevent soil erosion in the construction area as well as to prevent water from entering the excavated area when excavation is to be done by digging deeper along the river bank or coast. Most of the works such as dams, locks, bridge footings and water intakes of thermal power plants have deep and wide foundation pits leading to very large cofferdam. In fact, the cofferdam for such works are usually made of specialized steel sheet piles and combined with shoring frames. The specialized steel sheet piles are not popular in the market meanwhile the shoring frame reduces the work space and increases the complication of construction works. Based on research and experience from projects in the Mekong Delta, the cofferdam for the deep and wide foundation pits made by combining between soil cement columns with common steel sheet piles is the reasonable solution. This solution not only does not need specialized steel sheet piles but also takes advantage of local materials, moreover, increasing the work space because it does not need a shoring frame. This paper is going to present the cofferdam used in construction of deep and wide foundation pits under the soft soil of the Song Hau thermal power plant by combining cement deep mixing (CDM) with common steel sheet piles.

Keywords Cofferdam · Deep and wide foundation pit · Soft soil · CDM

1 Introduction

The most area of the Mekong Delta coast in Vietnam has a surface soil layer that is very soft. The soft soil layer varies from about 10 m to approximately 20 m [1]. The main soil types are Very Soft—Soft Clay dark grey, including silt, clay mixed with

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sand, dark gray color; clay, etc. (Fig. 1). Therefore, it is very difficult for construction work in general, especially deep and wide foundation pits. A cofferdam is a temporary structure designed to keep water out of the foundation pits during the construction. The cofferdam is built to make a dry work environment. There are a lot of types of cofferdam solutions, depending upon the depth, soil conditions, and fluctuations in the water level and type of material. Some types of cofferdams are as follows: earthfill, rockfill, single or double sheet piles wall, or Cellular cofferdam [2].

Earthfill cofferdams are the simplest type of cofferdam. It is used when the water depth is shallow, 1.0–2.0 m and the velocity of water flow is slow. It is built using the local available material such as clay, fine sand or even soil. It is reasonable to use in most foundation soil types (Fig. 2a).

Rockfill cofferdams are made from rock and the prevented water layer. It is preferred when the rock is available easily at the construction site. It is reasonable to use when the water depth is not too high, the water flow is turbulent and soft to stiff foundation soil (Fig. 2b).

Nowadays, a geotube cofferdam is one of the popular solutions, it is very simple. It has the advantages of both earthfill and rockfill cofferdam (Fig. 3).

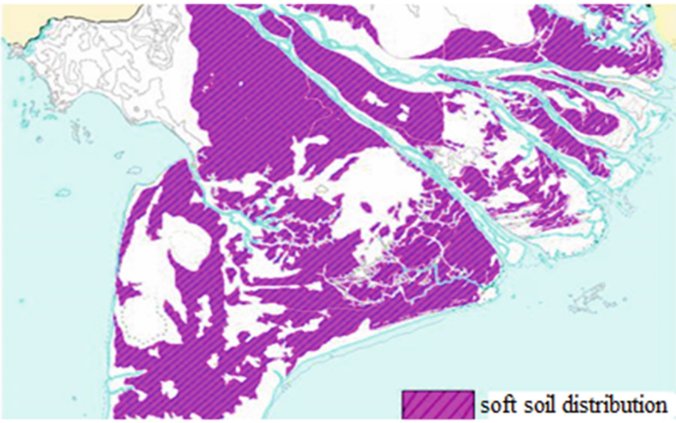

Fig. 1 Distribution of soft surface soil layer in the Mekong Delta [1]

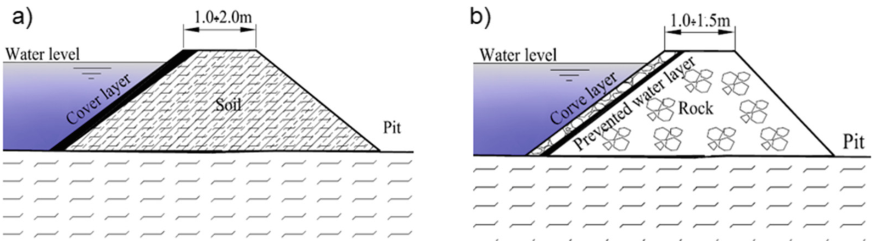

Fig. 2 Cross-section of cofferdam: **a** Earthfill cofferdam; **b** Rockfill cofferdam

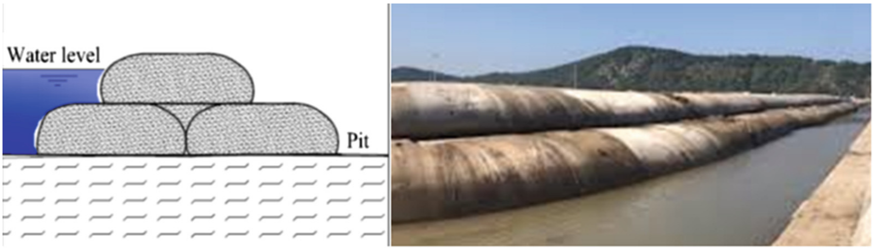

Fig. 3 Geotube cofferdam (internet)

Single or double wall cofferdam. The cofferdam is made of one or two rows of sheet piles driven into the ground and connected together by a shoring system, that is reasonable for most of the depth of the water. Such cofferdams can additionally be used up to a depth of 25 m water. Single wall cofferdam is used when the area to be surrounded is small or the water depth is shallow. A single wall cofferdam or double wall cofferdam is costly when the enclosure area is large and the water depth is high. It is very common and fitting on most types of foundation soil (Fig. 4).

When the water column is too high and the enclosure area is large, common types of cofferdams are uneconomical to use. In these situations cellular cofferdams are useful. It is made by combining steel sheet piles or steel pipe sheet piles to circle. It is used in construction of dams, locks, bridge footings and water intakes of thermal power plants etc. (Fig. 5).

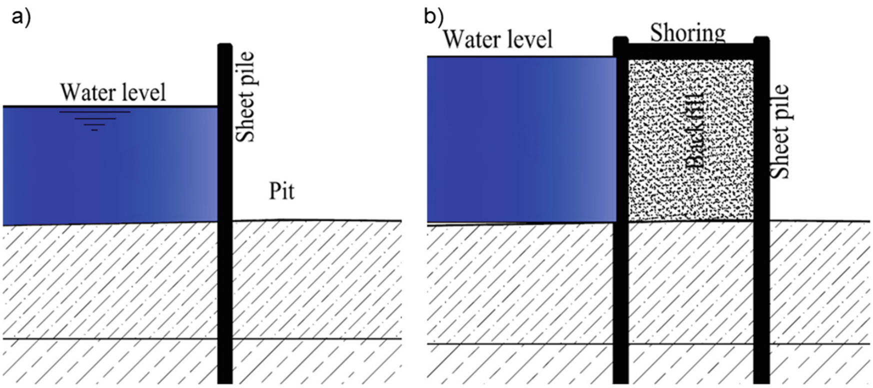

Fig. 4 Cross-section of cofferdam: **a** Single wall; **b** Double wall

Fig. 5 Cellular cofferdam (photo from C.J. Mahan Construction Co)

2 Methodology

2.1 A New Design for the Cofferdam in Soft Ground in the Mekong Delta Coast

Because the soft surface soil layer is too thick, lead to the common solution such as Earthen Cofferdam, Rockfill cofferdam or geotube cofferdam are not confident to use in a cofferdam of deep and wide foundation pit. While the Cellular Cofferdam or big double wall of sheet piles need a specialized steel sheet piles.

Based on research and experience from projects in the Mekong Delta, the cofferdam for the deep and wide foundation pits made by combining between soil cement columns with common steel sheet piles is the reasonable solution (Fig. 6).

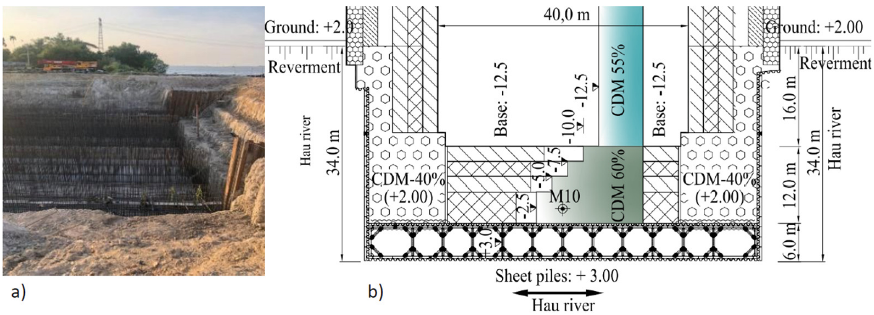

Fig. 6 The cofferdam of the water intake of the Song Hau thermal power plant [3]: **a** Photograph of site; **b** Cofferdam plane

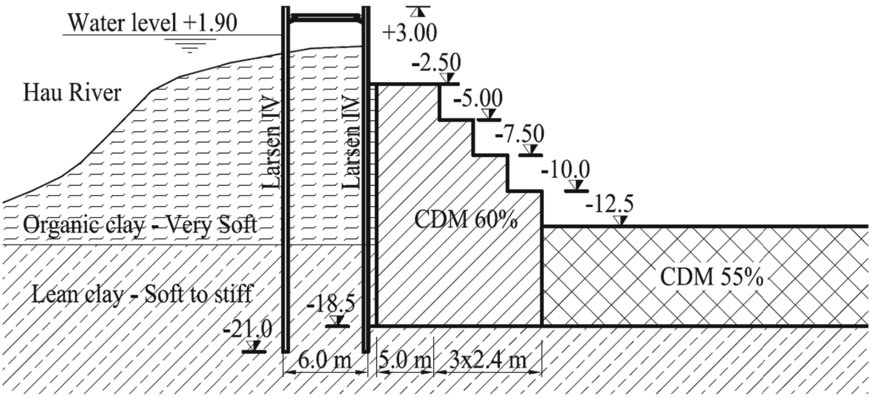

Fig. 7 The solution of cofferdam of the water intake [3]

The water intake of the Song Hau thermal power plant is a reinforced concrete structure, dimensions of length, width and depth are 118 m, 36 m and 145 m sequentially. In order to be able to construct this item, it is necessary to build a cofferdam for the foundation pit. The solution is a combination of CDM and common steel sheet piles.

The cofferdam wall is like a stair step shape, the bottom wall is 12.0m, the top is 5.0 m. The cofferdam body was used CDM with density 60%; unconfined design strength of 1.0 MPa. The base of the pit was reinforced by CDM with density 55% and 6.0 m of thickness to waterproof and reduce a horizontal displacement of cofferdam or foundation of the pit. The steel sheet piles wall to protect the pit from level −2.5 m, this is the backfill layer, this layer is not reasonable to retain by CDM, beside, the steel wall contributes to protect the slope when CDM drilling (Fig. 7).

2.2 Numerical Model

To calculate stability, displacement of the water intake cofferdam in three construction phases, the Plaxis 2D software were used. Plaxis 2D is a software to perform two-dimensional finite element analysis of deformation and stability in geotechnical engineering and rock mechanics.

In particular, the declaration of the diagram in Plaxis 2D software is implemented for two cases including Short-term and Long term, while the soil foundation is described by the Mohr-Coulomb (MC) model and Soft soil (SS) model.

Using Plaxis 2D software to calculate cofferdam stability and displacement in the construction stages of the water intake of Song Hau 1 Thermal Power Plant. Three phases were analyzed as a Table 4. Calculation of physico-mechanical properties of equivalent background [4]:

$$c_t = a \cdot c_c + (1 - a) \cdot c_u$$

$$E_t = a \cdot E_c + (1 - a) \cdot E_u$$

a—Improvement area ratio, $a = nA_c/B_s$; B_s—Width of improved ground;
n—Number of column in 1m of wall length; A_c—Area of column section.
c_u, E_u—Physico-mechanical properties of natural background, calculated by weighting method the multiple layers;
$c_{tđ}$, $E_{tđ}$—Equivalent properties of mixture of soil after reinforcement.

The parameters of the cement deep mixing column that was used for the water intake cofferdam are shown in Table 1.

Analyzing the stability and displacement in short-term with the boundary conditions on the river water level is +1.9 m and the soil parameters show in Table 2.

Table 1 Parameters of desinged cement deep mixing [3]

No	Identification	Unit	Value	Note
1	Diameter, D	m	0.8	
3	Unconfined compressive strength, q_u	kN/m^2	1000	
4	Undrained shear strength, $c_u = 1/2.f_r.f_c.q_u$	kN/m^2	325	
	$f_c = 0.187\ln(t) + 0.375$		1	t = 28 (day)
	$f_r = (0.65 \div 0.9)$		0.65	
5	Angle of internal friction, φ’	o	0	
6	Unit weight, ϒ	kN/m^3	1.1 Υ_{soil}	
7	Modulus of elasticity, $E_c = 150q_u$	kN/m^2	150,000	

Table 2 Soil parameters in short-term analysis [3]

No	Identification	Unit	Layer	Layer	Layer
			Sand	2	3
1	Level	m	–	Ground ÷ −13.7	−13.7 ÷ −60
2	Material model		MC	MC	MC
3	Drainage type		Drained	Drained	Drained
4	Unsaturated weight, Υ_{unsat}	kN/m^3	18.00	15.63	18.74
5	Saturated weight, Υ_{sat}	kN/m^3	18.00	16.00	19.16
6	Permeability, k	m/day	1	7.1E–5	8.0E–4
7	Initial void ratio, e_{init}		–	1.661	1.038
8	Young’s modulus, E_u	kN/m^2	30,000	1580	11,240
9	Poisson’s ratio, ν_u		0.3	0.495	0.495
10	Undrained shear strength, S_u	kN/m^2	–	7.90	73.00
11	Friction angle, φ	o	25	–	–

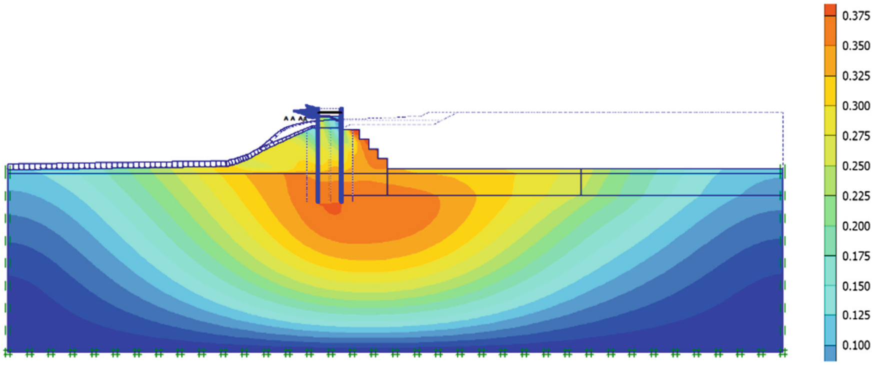

Fig. 8 Displacement of cofferdam when excavate to −12.5 m ($u_{max} = 0.41$ m), $Fs = 1.84$

3 Results

3.1 Numerical Results

The result of stability and displacement of cofferdam are shown in Fig. 8. The results show that the displacement of cofferdam was too large, therefore the short-term analyzing model is not reasonable.

Analyzing the stability and displacement in long-term with the boundary conditions on the river water level is +1.9 m and the soil parameters show in Table 3.

The results of stability and displacement of cofferdam when excavating to base (−12.5 m) are show in Fig. 9. Table 4 show calculation summary result of three phases.

3.2 The Measured Data of Horizontal Displacement in the Field

During the construction process, the measurement and monitoring of the horizontal displacement of the cofferdam are carried out continuously [5]. The monitoring results at point M10 (Fig. 10) show the largest peak displacement of CDM wall is 87.6 mm. Figure 10 show the horizontal displacement of the cofferdam at some times (the excavated work was completed on 16/12/2020).

Table 3 Soil parameters in long-term analysis [3]

No	Identification	Unit	Layer wall	Layer base	Layer 2	Layer 3
1	Level	m	–		Ground ÷ −13.7	−13.7 ÷ v60
2	Material model		MC		SS	HS
3	Drainage type		Ud		Ud	Ud
4	Unsaturated weight, Υ_{unsat}	kN/m^3	17.9	19.82	15.63	18.74
5	Saturated weight, Υ_{sat}	kN/m^3	17.9	19.82	16.00	19.16
6	Permeability, k	m/day	8.0E–7	8.0E–7	7.1E–5	8.0E–4
8	Compression index, C_c	kN/m^2	–		0.610	–
9	Swelling index, C_s		–		0.118	–
10	Initial void ratio, e_{init}	kN/m^2	–		1.661	1.038
11	Secant modulus, $E_{50}{}^{ref}$	kN/m^2	–		–	6907
12	Tangent modulus, $E_{oed}{}^{ref}$	kN/m^2	–		–	6081
13	Unloading / reloading modulus, $E_{ur}{}^{ref}$	kN/m^2	–		–	20721
14	Power, m		–		–	1
15	Young's modulus, E	kN/m^2	90,632	86,763	–	–
16	Poisson's ratio, ν		0.3	0.3	–	–
17	Effective cohesion, c'	kN/m^2	198.2	206.2	14.60	33.60
18	Effective friction angle, φ'	o	–	–	16.80	20.50

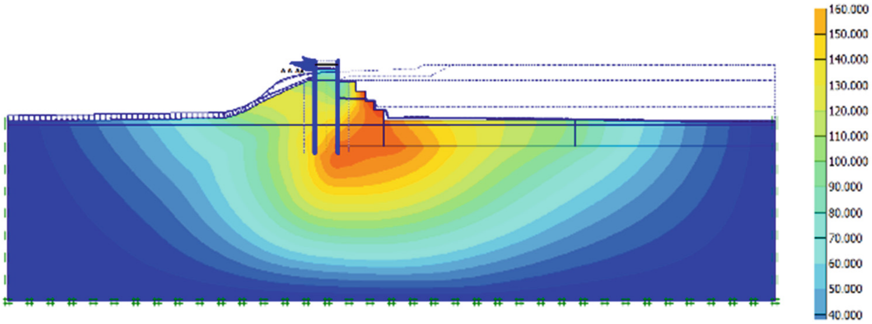

Fig. 9 Displacement of cofferdam when excavate to −12.5 m (u_{max} = 0.193 m), Fs = 1.95

Table 4 Summary table of calculation result

Phase	Construction work	Top displasment of ocofferdam (mm)		Bending moments of Larsen IV + I350 (kNm/m)	Stability coefficient
		CDM	Larsen IV + I350		
1	Excavation work to −2.0 m	81	43	106.5	2.85
2	Excavation work to −9.00 m	163	133	107.8	2.39
3	Excavation work to −12.50 m	193	180	111.4	1.95

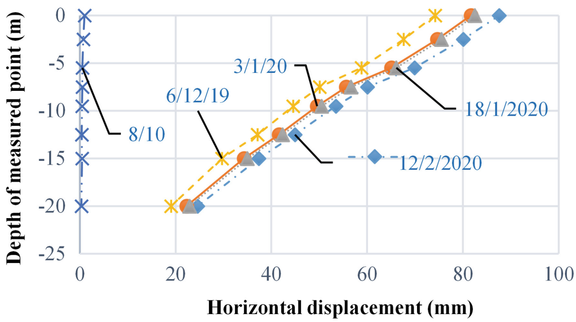

Fig. 10 The horizontal displacement in the field (u_{max} = 87.6 mm)

3.3 Discussions

- The horizontal displacement distributed according to the depth matches the displacement trend of cofferdam in the forecast calculation results;
- The first stage horizontal displacement when constructing the excavation hole in the first 2 months is quite small. After excavation to the design level of −12.5 m (ND), the displacement increases significantly in about 10 days. After that, the horizontal displacement tends to be stable and does not increase;
- The horizontal displacement at the highest peak is 87.6 mm, which is smaller than the forecast at 193.0 mm. This different is caused by safety factors in analyzing such as parameters of designed CDM, outside water level.
- The foundation horizontal displacement of the pit is significant (45.0 ÷ 55.0 mm), this displacement will affect the foundation structures, so It is necessary to have calculations to check the effect of displacement on the related structures.

4 Conclusion

The cofferdam for the deep and wide foundation pits to construct dock, locks, water intakes of thermal power plants etc., is a challenge for design and construction. Based on researching and experience from projects in the Mekong Delta, the cofferdam for the deep and wide foundation pits made by combining between soil cement columns with common steel sheet piles is the reasonable solution. This solution not only does not need specialized steel sheet piles but also takes advantage of common materials, moreover, the stair step shape makes a safer sense more than the vertical form when working in a pit. In addition, the displacement of the ground caused by the cofferdam of the deep and wide foundation pits is significant, especially the soft base, so the designer should consider the effect of this displacement on related structures.

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