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STABILITY ANALYSIS OF A DOUBLE-ROW PILE BREAKWATER SUBJECTED TO COMBINED LOADING IN MEKONG DELTA

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ABSTRACT: Double-row pile breakwater is one of the vertical-front breakwaters using concrete piles applied in some parts of Mekong Delta. Structure of this breakwater mainly includes two rows of closely spaced piles and a rock core between them, frames are made of double-row pile that connected by reinforced concrete longitudial and transveral beam, rock core has constructed interior of it. The piles penetrate into the seabed and fasten the rock core against wave action. The geometrical size of the breakwater is smaller than traditional trapezoidal rubble-mound breakwater. It's built on soft clay soils with low vertical loading and large horizontal loading. Some projects have been constructed and began to be effective but stability problem is not considered fully. This study presents research on analytical and numerical analysis for stability of double-row pile breakwater subjected to combined loading. On this basis, the authors developed method to calculate bearing capacity of this breakwater on soft clay soils.

Keywords: Double-row pile breakwater, soft clay, combined loading, stability analysis.

1. INTRODUCTION

Recently, provinces and cities in the Mekong Delta have suffered land erosion for decades, with hundreds of hectares being washed away along with many houses, especially in Ca Mau province, Vietnam. There are about 245 km long shoreline of Ca Mau Province are affected by severe erosion.

To adapt climate change and sea water rises, Ca Mau province has mobilized many local resources and central investment to build construction against critical erosion that threatening the safety of sea dykes. In many locations, erosion occurs in the form of developing gaps in the mangrove forest, which interrupt the remaining headlands covered with mangrove vegetation, Albers (2010). Several solutions were performed to protect shoreline: a) Wave breaking fence using two layers of melaleuca poles b) Gabions used as breakwater c) T-shaped bamboo fences, d) Vertical-front breakwaters using concrete piles. Recently, a new-types of breakwater is double-row pile structure with rock core has been used as offshore breakwaters and groins, as shown in Fig. 1 (Nguyen Huu Nhan, 2015). The double-row pile breakwaters are also applied in Dongying City, China (Liu, 2012).

The double-row pile breakwater mainly includestwo rows of closly spaced piles connected by reinforced concrete beam to keep the rock core against wave impact. Liu (2012) presented the analytical solution of the wave-absorbing performance of this breakwater.. Nguyen Huu Nhan (2015) assessed the impacts by computer model coupled hydrodynamics, spectral sea wave on shallow water coastal zone with this breakwater and presented the big effectives for alluvial accumulating, stopping rip circulation and wave action, protecting coastal line and mangrove belt. In this study, the authors research into stability analysis of a double-row pile breakwater subjected to combined loading in Mekong Delta in general and in particular to Ca Mau province.

2. DOUBLE-ROW PILE BREAKWATER

This breakwater which is combination of concrete piles with rock filling, was implemented. Two rows of concrete piles had been driven through the mud layer down to a more stable layer, fixed on the top of the piles with a concrete frame. The gap between these rows, approximately 1.5 m – 2 m, was filled with riprap to guarantee a high level of wave energy absorption as well as a certain degree of permeability to ensure sediments can still reach the lee side area of the breakwater (Albers, 2010). Figure 1 shows these vertical-front breakwaters,

(a) under construction

(b) completed.

The structure of this breakwater is sturdy, high durability. Although some disadvantages as difficult to

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move to other places, this breakwater seems to be applied widely for dissipation of wave energy to protect the coastal zone in Mekong Delta.

(a)

(b)

Fig. 1 Double-row pile breakwater

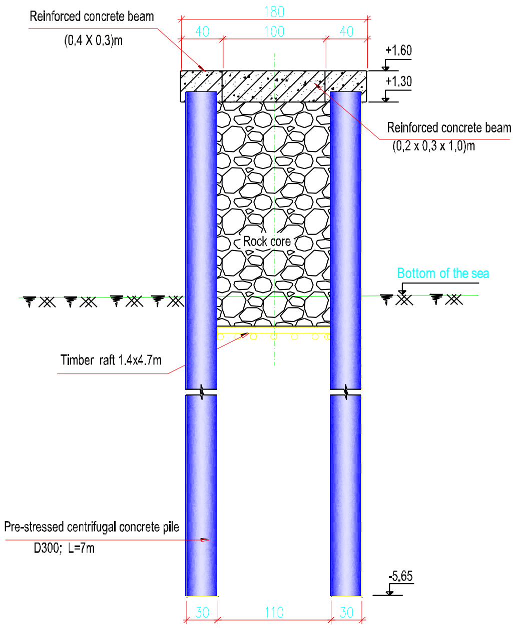

Fig. 2 Cross section of double-row pile breakwater

3. STABILITY ANALYSIS

3.1. Wave forces

Wave Pressure on the front face of an upright wall are caculated by Goda's method (OCDI, 2009). This method assumes that wave pressures on the upright wall can be represented by a trapezoidal distribution, with the highest pressure at the still water level regardless of the wave conditions. Wave pressure characteristics are considered the influence of relative depth to wave length on the pulsating component Goda (1974).

$$\eta^*_G = 0,75\left(1+\cos\beta\right)\lambda_1 H_D$$

$$p_1 = 0,5\left(1+\cos\beta\right)\left(\alpha_1\lambda_1 + \alpha_2\lambda_2\cos^2\beta\right)\rho_0 g H_D$$

$$p_2 = \frac{p_1}{\cosh\left(2\pi h/L\right)} \qquad (2)$$

$$p_3 = \alpha_3 p_1$$

where:

η^*_G : height above still water level at which intensity of wave pressure equals zero (m)

p_1 : intensity of wave pressure at still water level (kN/m^2)

p_2 : intensity of wave pressure at sea bottom (kN/m^2)

p_3 : intensity of wave pressure at the toe of upright wall (kN/m^2)

ρ_0 : density of water (t/m^3)

g : gravitational acceleration (m/s^2)

β : angle between the line normal to the upright wall and the direction of wave approach.The angle shall be reduced by 15º, but the resultant angle shall be no less than 0º. This correction provides a safety margin against uncertainty in the wave direction.

λ_1, λ_2 : wave pressure modification factors (1.0 is the standard value)

h : water depth in front of upright wall (m)

L : wave length at water depth h used in the calculation as specified in the equation (3) below (m)

H_D : wave height used in calculation as specified below (m);

$$\alpha_1 = 0.6 + \frac{1}{2}\left\{\frac{4\pi h/L}{\sinh(4\pi h/L)}\right\}^2$$

$$\alpha_3 = 1 - \frac{h'}{h}\left\{1 - \frac{1}{\cosh(2\pi h/L)}\right\} \qquad (3)$$

Where:

h_b: water depth at an offshore distance of 5 times the significant wave height from the upright wall (m)

d: water depth at the crest of either the foot protection works or the mound armoring units of whichever is higher (m)

h': water depth at the toe of upright wall (m)

Uplift beneath Upright Wall

The uplift acting on the bottom of an upright wall is described by a triangular distribution, with the pressure intensity at the front toe pu given by the following equation and 0 at the rear toe

$$p_u = 0,5\left(1+\cos\beta\right)\alpha_1\alpha_3\lambda_3\rho_0 g H_D \qquad (4)$$

Where:

p_u: uplift pressure acting at front toe of upright wall (kN/m2)

λ_3: uplift pressure modification factor (1.0 is the standard value)

Table 1 show parameters for double pile breakwater in protecting the west coast of Ca Mau province.

Wave force acts in front face of breakwater as shown in Fig. 3, Ws is total of wave force, sum of Ws1 and Ws2. From wave parameter presents in table 1 and model in Fig. 3, wave forces are calculated as shown in Table 2.

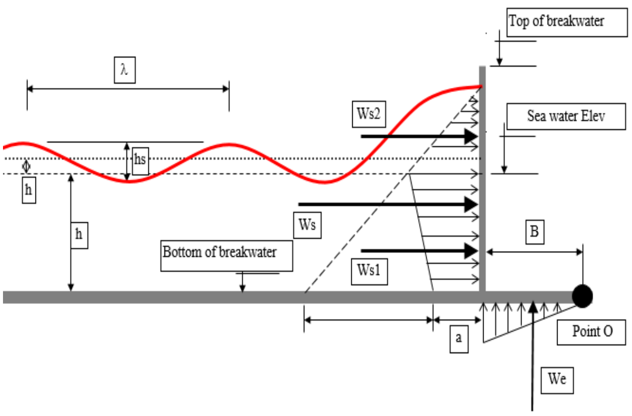

Fig. 3 Wave forces on pile breakwater

3.2. Analytical calculation of pile length

Assume pile length includes the upper part H(m) and the lower part (in soft soil) d_1(m), sum up a total moment with referent rotated point C1 as shown in Fig 4.:

$$\sum M_{C1}^{g} - \sum M_{C1}^{l} = 0 \quad (5)$$

Solving equation (5) to identify variable d_1 (m), this structure is stability, it is necessary to lengthen pile. So pile embedment in soft soil d_2= (1.1 – 1.2)d_1. For this breakwater in Ca Mau province, we identify the total length of the concrete pile is 7.0m, with safety factor FS= 1.610.

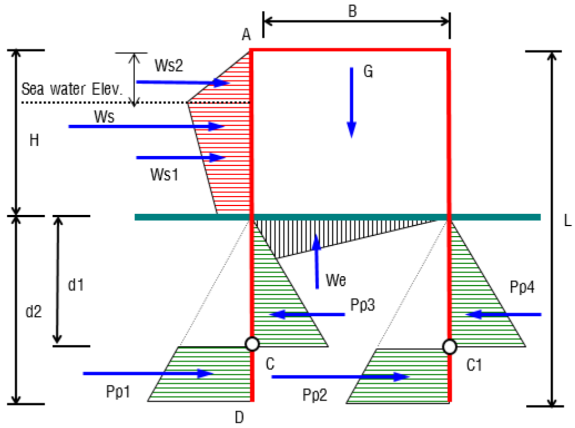

Fig. 4 Model for calculating pile length

Table 1 Wave and structure parameters

Water depth d (m)	Wave height H_D(m)	Wave length L(m)	Height H(m)	Width B(m)	β (deg)	cosβ	λ_1	λ_2	λ_3
1.76	1.4	28.0	2.6	1.6	0	1.0	1.0	0	1.0

Table 2 Caculated wave forces

α_1	α_2	α_3	η^* (m)	p_1 (kN/m^2)	p_2 (kN/m^2)	p_3 (kN/m^2)	p_u (kN/m^2)
1.01	0.0	0.93	1.7	11.55	10.78	10.78	12.38

3.3. Numerical analysis

This study adopts a numerical approach using a finite element package PLAXIS 2D, developed by PLAXIS BV, Netherlands which has especially been developed for deformation and stability analyses of soil and rock mechanics problems. Soil model using Soft soil Model. The soil properties obtained from laboratory tests were used to determine the input parameters are shown in Table 3. The structure properties which acts as an elastic behavior are also presented in Table 4. In current analysis, the model boundaries are assigned to standard fixities. Selection of standard fixity condition automatically imposes a general set of boundary conditions to the model geometry. These boundary conditions are: Vertical geometry lines whose X-coordinate is the lowest or highest X-coordinate in the model attain horizontal fixity (ux=0). Horizontal geometry lines whose Y-coordinate is the lowest Y-coordinate in the model attain full fixity (ux=uy=0).

The ratio of perforated hollow area of row piles at the front of breakwater is 50% in this study. The authors perform two cases of combined loading with total of horizontal wave force in Case 1 and a half of horizontal wave force in Case 2 that considered the ratio of the perforated hollow area i50%. Finite element method is used to analysis stress and strain of soil foundation, safety factor against stability, and internal force of concrete piles of breakwater in two cases.

Table 3 Material properties for soils

Material	Soil type	γ_{wet}	γ_{sat}	E	φ	ψ	c_{ref}	λ*	κ*
		$kN.m^{-3}$	$kN.m^{-3}$	$kN.m^{-2}$	degree		$kN.m^{-3}$	-	-
Soft clay	SSC	14.5	15.0	-	18	-	8.6	0.2	0.02
Hard clay	MC	16,2	16,5	5.500	20	-	12	-	-

Table 4 Material properties for structure

Item	Material	EA	EI	d	w	υ	R_{inter}
		kN	$kN.m^2$	m	$kN.m^{-2}$		-
Pile	Elastic	1.36E+06	2.08E+04	0.43	1.131	0.2	1
Beam	Elastic	3.33E+06	2.50E+04	0.30	2.250	0.2	1

The mesh uses 15 noded element, with 872 elements, 7711 nodes, 10464 number of stress points in Fig. 5. Procedure to analysis is corresponding to real construction. Firstly, double-row pile are penetrated into the soil. Secondly, the concrete beams that connect row-piles in longitudinal and transversal direction, are constructed. Finally, rock inside them are performed gradually to reduce normal stress on soft clay.

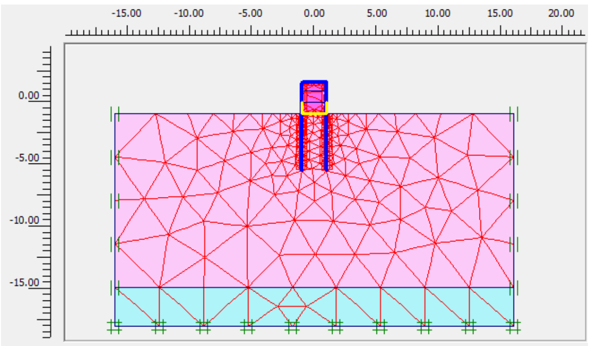

Fig. 5 EFM model of double-row pile breakwater

Total displacement at final stage in two cases, extreme value is 0,119m for Case 1 (Fig. 6) and 0,071m for Case 2 (Fig. 7). Extreme bending moment of row piles at the sea side as shown in Fig. 8. Extreme bending moment is 18.45 (kNm/m) in Case 1, 15.83 (kNm/m) in Case 2.

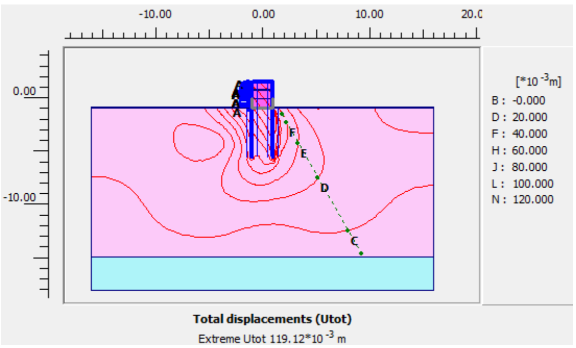

Fig. 6 Total displacement (m) in Case 1

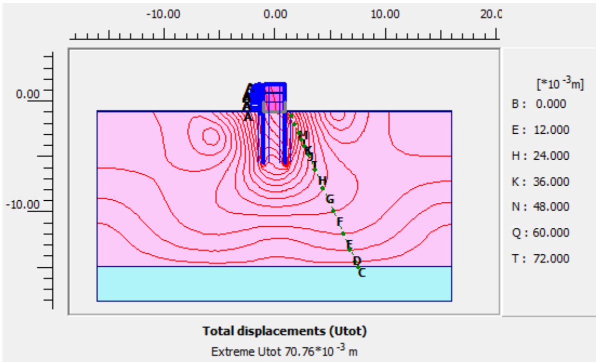

Fig. 7 Total displacement (m) in Case 2

The reduction of moment is not proportional with reduction of wave forces is a half because the row piles work as frame connectivity in Case 2 of Fig.7 and Fig.8

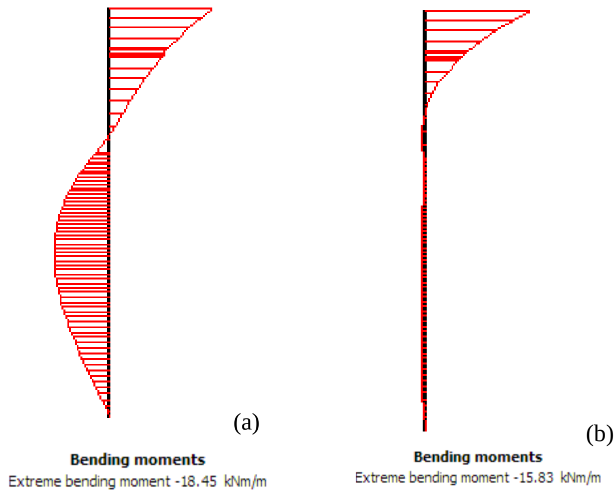

Fig. 8 Bending moments (kN.m) of piles at the sea side, (a) Case 1, (b) Case 2

Extreme bending moment of row piles at the shore side as shown in Fig. 9. Extreme bending moment is 18.45 (kNm/m) for Case 1, 15.83 (kNm/m) for Case 2. The reduction of moment is not proportional with reduction of wave forces is a half because the row piles work as frame connectivity.

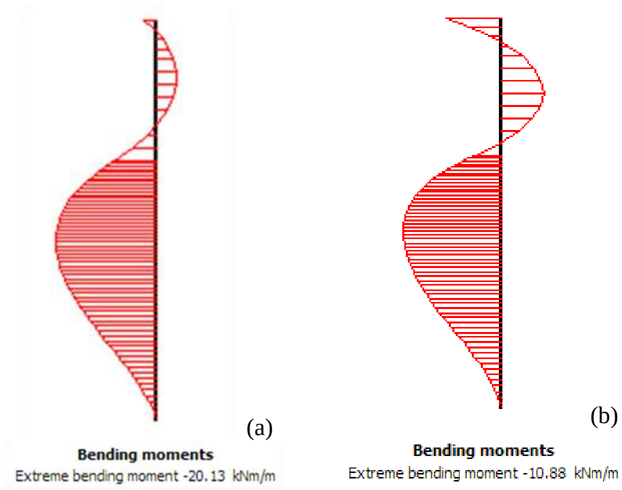

Fig. 9 Bending moments (kN.m) of piles at the shore side, (a) Case 1, (b) Case 2

Stability of breakwater analyzed by phi-c reduction method, safety factor is specified FS= 1,631 (Fig. 10) for Case 1, FS= 1.945 for Case 2. For case 1, safety factor is a good agreement with analytical calculation, FS= 1.610.

Incremental multipliers		Total multipliers	
Mdisp:	0.000	Σ-Mdisp:	1.000
MloadA:	0.000	Σ-MloadA:	1.000
MloadB:	0.000	Σ-MloadB:	1.000
Mweight:	0.000	Σ-Mweight:	1.000
Maccel:	0.000	Σ-Maccel:	0.000
Msf:	0.001	Σ-Msf:	1.631
Increment:	0.000	End time:	0.000
Increment:	0.000	End time:	0.000

Fig. 10 Safety Factor in Case 1

Incremental multipliers		Total multipliers	
Mdisp:	0.000	Σ-Mdisp:	1.000
MloadA:	0.000	Σ-MloadA:	1.000
MloadB:	0.000	Σ-MloadB:	1.000
Mweight:	0.000	Σ-Mweight:	1.000
Maccel:	0.000	Σ-Maccel:	0.000
Msf:	0.000	Σ-Msf:	1.945
Increment:	0.000	End time:	0.000
Increment:	0.000	End time:	0.000

Fig. 11 Safety Factor in Case 2

4. CONCLUSIONS

Double-row pile breakwater is one of effective solutions to protect the west coast of Ca Mau Province. Through site-specific assessment recently, there is signifcant sedimentation behind double-row pile breakwaters.

In this paper, the authors presented a method to identify the pile length for this breakwater through equilibrium moment. Sliding and overturning safety factor of the breakwater are analyzed and appropriate pile length 7.0 (m) is calculated for the specific geological condition in the west coast of Ca Mau province. Finite element method is used to analyze the internal forces of concrete pile and stability of the breakwater. It is found that the general safety factor calculated by numerical analysis is in good agreement with analytical caculation.

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