THE SAFETY FACTOR ANALYSIS OF THE MARINE SLOPE STABILITY MODEL ON THE ACCESS CHANNEL OF MARINE CENTRE PLAN CIREBON, WEST JAVA.

By :

Franto Novico[1], Nur Adi Kristanto[1] and Purnomo Rahardjo[1]

(Manuscript received 23-August-2010)

ABSTRACT

This study is focused on access channel model that safety factors of some slopes stability would be investigated. Plaxis version 8 is applied to analyze a magnitude of safety factors and displacements based on three different slopes of access channel there are 30°, 45° and 60°.

Furthermore, parameters are adopted from geotechnical drilling and laboratory tests. A finite element is applied as a simple model to analyze within a Mohr-coulomb equation. Based on soil data analyses on Marine Center Plan, indicates low safety factor and high deformation.

As results, 10 to 40 meters deformation of the slopes and 0.80 to 2.34 of safety factor are obtained of the models. For that reason, a combination between slope channel and infrastructure must be considered.

Keywords: Safety factor, slope stability, access channel, *Marine centre*, Plaxis

SARI

Kajian ini dilakukan terhadap faktor keamanan dari beberapa jenis kemiringan dinding alur pelayaran yang selanjutnya dilakukan pemodelan dengan menggunakan alur pelayaran Besarnya keruntuhan dan faktor keamanan pada beberapa sudut kemiringan yang berbeda telah dianalisis dengan menggunakan perangkat lunak geoteknik Plaxis Versi 8.

Tiga jenis kemiringan yang berbeda telah dibuat yaitu sudut kemiringan 30°, 45° dan 60°. Sebagai data masukan, parameter diambil berdasarkan hasil pemboran geoteknik yang telah dianalisis di laboratorium. Model sederhana elemen terbatas telah dibuat dan dianalisis berdasarkan persamaan Mohr-Coulumb. Berdasarkan analisis data tanah pada rencana Marine Centre menunjukan faktor keamanan yang rendah dan deformasi yang besar.

Total deformasi yang dihasilkan berkisar 10-40 meter dengan nilai faktor keamanan 0,80~2,34. Oleh karena itu, dari hasil tersebut perlu dipertimbangkan untuk mengkombinasikan kemiringan alur dengan infrastruktur.

***Kata kunci** : faktor keamanan, kemiringan lereng, alur pelayaran, Marine centre, Plaxis*

1. Marine Geological Institute of Indonesia, Jl. Dr. Junjunan No. 236 Bandung 40174 Indonesia

INTRODUCTION

A Marine Center is a master design of marine institutes in Indonesia where all the activities would be gathered in one place. Cirebon as one of alternative location has prepared not only for the buildings but also for the port of the research vessels. It is designed in two alternative models, the first is using access channel and the other is using a trestle.

The access channel is planned behind of the Marine Geological Institute’s Cirebon office. As has been known, the access channel is one of the important parts of the port facilities. It is caused by the access channel is a place where ships may in passing the port to load and unload. Therefore, achieving a good design of access channel will increase a safety of marine traffic in the port.

To obtain a good design of the access channel therefore it is important to note down parameters that influence the character of the access channel. A marine sediment, hydro-oceanographic, morphology of sea floor and earthquake play an important role in determining of the sedimentation and the slope stability of the access channel. However, all those parameters will not be conducted in this investigation because this is only performing by analyzing the condition of soil versus slope stability. That condition is a safety factor analysis which is very important to figure out characteristics of the soil in the access channel plan.

A simple model should be completed in order to get information about a natural safety factor on the slope of the access channel at Marine Centre plan Cirebon. As a simple model, hydro-oceanographic and seismic activities are not taken into account. In addition, determining a safer slope would be presented by comparing safety factor of some slopes.

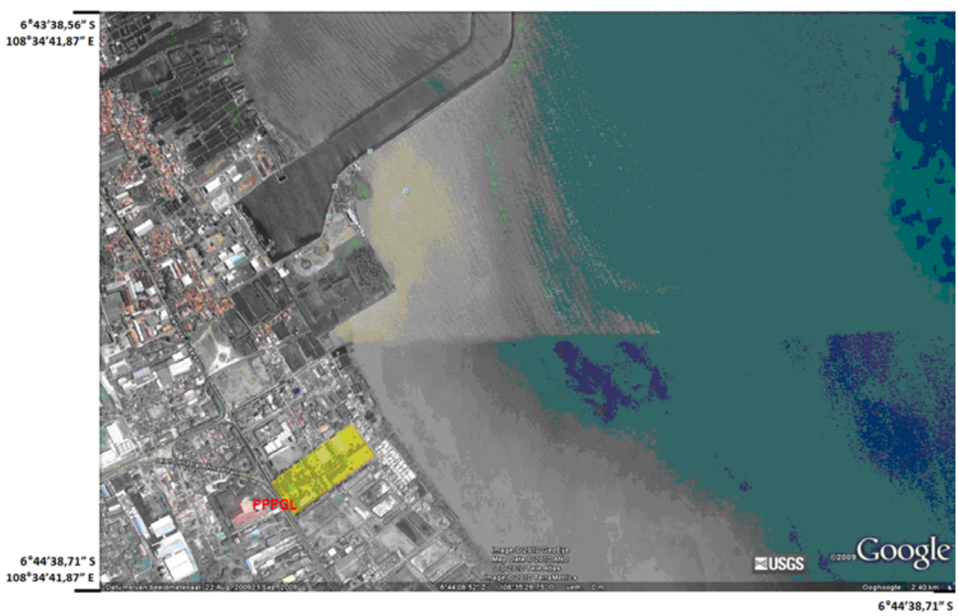


Figure 1. The access channel at Marine Centre plan Cirebon (Google Earth, September 21st 2009)

An understanding of a safety factor of natural slope stability would not be said as a simple effort, especially in the sea floor which contains mud, clay and organic matters. Nevertheless, clay organic on the sea floor is assumed as the weakest soil among the others.

Geological and Geotechnical Condition

Based on Cirebon geological map by Suwarna, et al 1996, it can be seen a stratigraphy was classified as 3 types of lithology: quaternary, tertiary and intrusive rocks. One of the material content of quaternary rock is stream recent sediment where the marine centre plan located. The stream recent sediment could be obtained by drilling or seismic activity. In general, Ewing, et al, (1996 in Kenneth, 1982) classified three types of marine sediment sequence, they are unconsolidated sediment, semi consolidated sediment and consolidated sediment. Based on geotechnical laboratory test it can be identified the marine sediment in the access channel plan is unconsolidated sediment (Rahardjo, et al, 2005).

In addition, a geotechnical drilling has been terminated of 40.45 meters depth at coordinate 108°35’40.1” E, 6°44’0.3”S. As a result, it can be seen at Figure 2 which has a 4 type of soil layers.

METHODS

Model Setup

The model is analyzed by using PLAXIS V.8 Finite Element (FE) program. Two-dimensional (2D), plane strain FE modelling is carried out as shown in Figure 3. The dimensions are in meters giving and fixed boundary conditions are applied at the bottom of the FE model considering no deformations to occur at 20 meter depths. Soil layer is divided into 4 layers following the drilling result, Figure 2. As boundaries, the right side model is restricted of 17 meters whereas on the

Table 1. Model input based on bore hole 1 (Raharjo, et al, 2005)

Parameter	Name	Unit	Clay organic (*)	Marine clay	Marine sand	Marine clay 2
Material model	Model	-	MC	MC	MC	MC
Type of behaviour	Type	-	Drained	Drained	Drained	Drained
Unit weight upper phreatic level	γ_{unsat}	kN/m^3	6.30	10.10	12.49	11.47
Unit weight below phreatic level	γ_{sat}	kN/m^3	13.52	15.93	17.44	16.22
Horizontal permea-bility	k_x	m/day	1E^{-03}	1E^{-03}	1	1E^{-03}
Vertical permeability	k_y	m/day	1E^{-03}	1E^{-03}	1	1E^{-03}
Young’s modulus	E_{ref}	kN/m^2	1E^{+04}	1E^{+04}	1,3E^{+04}	1E^{+04}
Poisson’s ratio	V	-	0.35	0,35	0.30	0.35
Cohesion	c_{ref}	kN/m^2	3.978	25.24	19.990	41.830
Friction angle	φ	°	1.723	7.093	7.693	10.233
Shear Modulus	G	kN/m^2	3703.704	3703.704	5000	3703.704

(*) clay organic adopted from bore hole 2

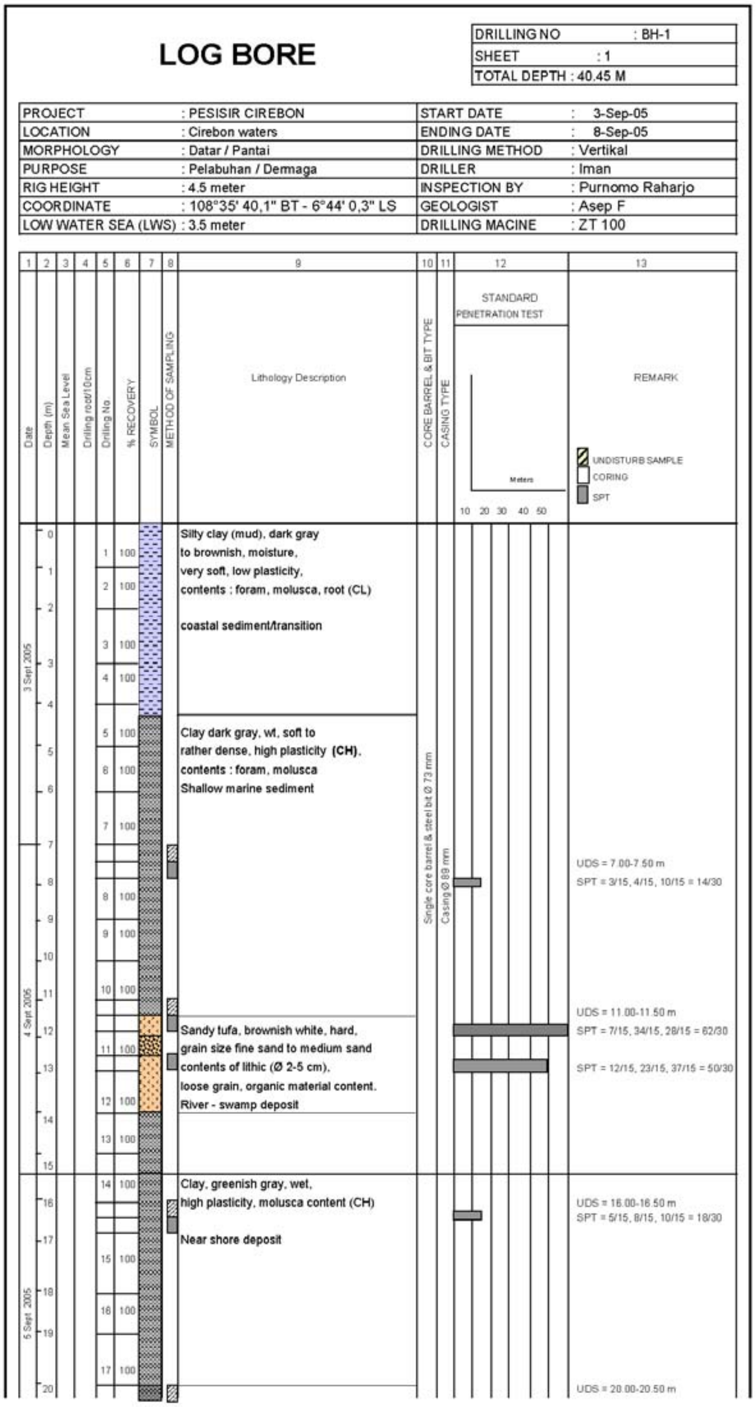
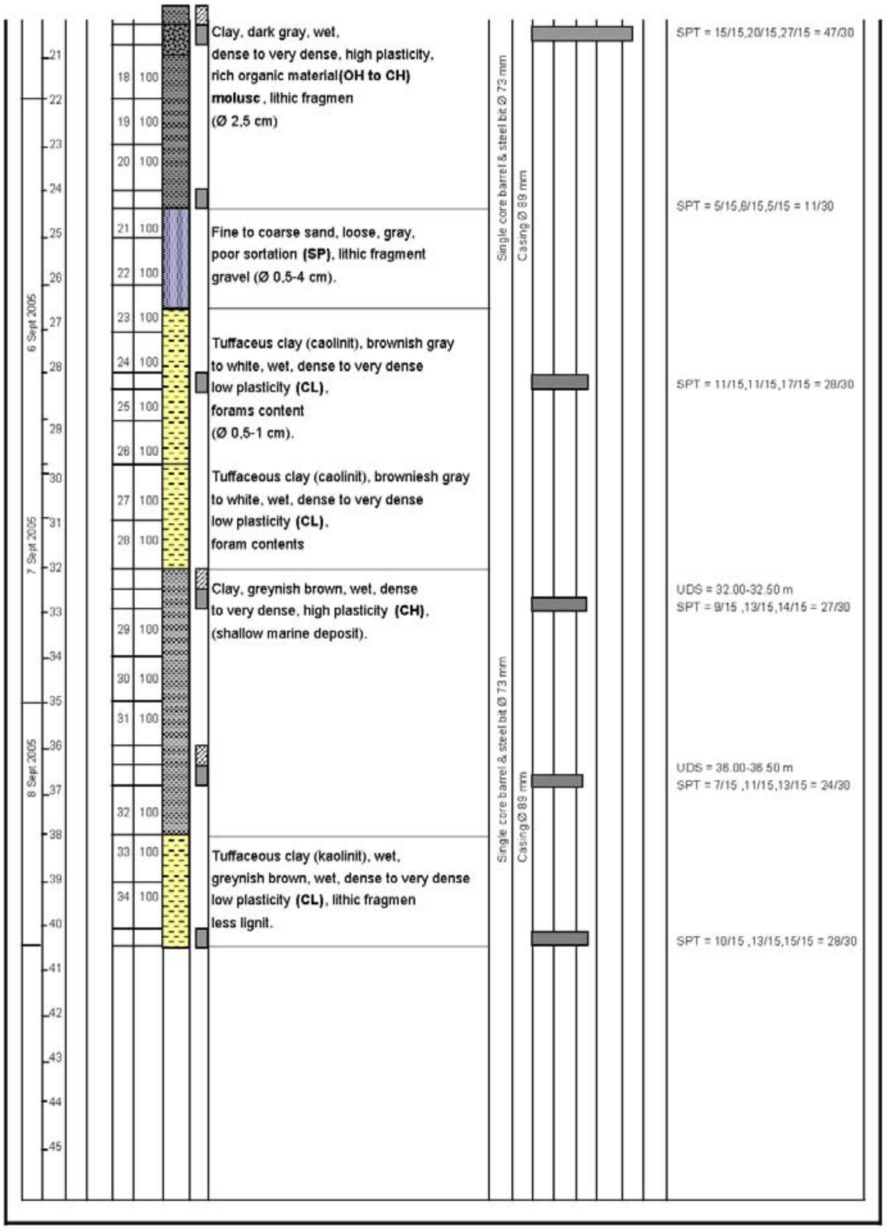


Figure 2. Bore hole 1 at access channel planned (Rahardjo, et al, 2005)

Figure 2. Continued...



left side is 14 to 26 meters. As a simple model, the Mohr Coulumb elasto-plastic constitutive soil model is applied for all layers in drained conditions. All the soil parameters of each layer are applied as referring to the data given in Table 1. In addition, the water level is planned for +5 meters depth. It is assumed based on the position of the borehole 1 where it has a high water level condition approximately -5 meters. Furthermore, due to a technical problem the soil data of 4.5 meters depth of borehole one is loosed therefore a soil data of borehole two is considered to approve which has a completed data of 4,5 meters depth.

The Mohr-Coulomb equation

The full Mohr-Coulomb yield condition consists of six yield functions when formulated in terms of principal stresses (see for instance Smith & Griffith, 1982):

$$f_{1a} = ½ (\sigma'_2-\sigma'_3)+ ½ (\sigma'_2+\sigma"_3)\sin\sigma\varphi - c \cos \varphi \leq 0$$
$$f_{1a} = ½ (\sigma'_3-\sigma'_2)+ ½ (\sigma'_3+\sigma"_2)\sin\sigma\varphi - c \cos \varphi \leq 0$$
$$f_{1a} = ½ (\sigma'_3-\sigma'_1)+ ½ (\sigma'_3+\sigma"_1)\sin\sigma\varphi - c \cos \varphi \leq 0$$
$$f_{1a} = ½ (\sigma'_1-\sigma'_3)+ ½ (\sigma'_1+\sigma"_3)\sin\sigma\varphi - c \cos \varphi \leq 0$$
$$f_{1a} = ½ (\sigma'_1-\sigma'_2)+ ½ (\sigma'_1+\sigma"_2)\sin\sigma\varphi - c \cos \varphi \leq 0$$
$$f_{1a} = ½ (\sigma'_2-\sigma'_1)+ ½ (\sigma'_2+\sigma"_1)\sin\sigma\varphi - c \cos \varphi \leq 0$$

The two plastic model parameters appearing in the yield functions are the well-known friction angle φ and the cohesion c. The condition $f = 0$ for all yield functions together (where f_i is used to denote each individual yield function) represent a hexagonal cone in principal stress space as shown in Figure 3, (Plaxis Manual, 2006).

Implementing the Mohr-Coulomb model for general stress states, special treatment is required for the intersection of two yield surfaces. In PLAXIS, however, the exact form of the full Mohr-Coulomb model is implemented, using a sharp transition from one yield surface to another. For a detailed description of the corner treatment the reader is referred to the literature (Koiter, 1960; van Langen & Vermeer, 1990). Furthermore, the Mohr-Coulomb model requires a total of five parameters, which can be obtained from basic tests on soil samples. These parameters with their standard units are listed: young's modulus E (kN/m^2), poisson's ratio ν (-), friction angle φ (°), cohesion c (kN/m^2) and dilatancy angle ψ (°).

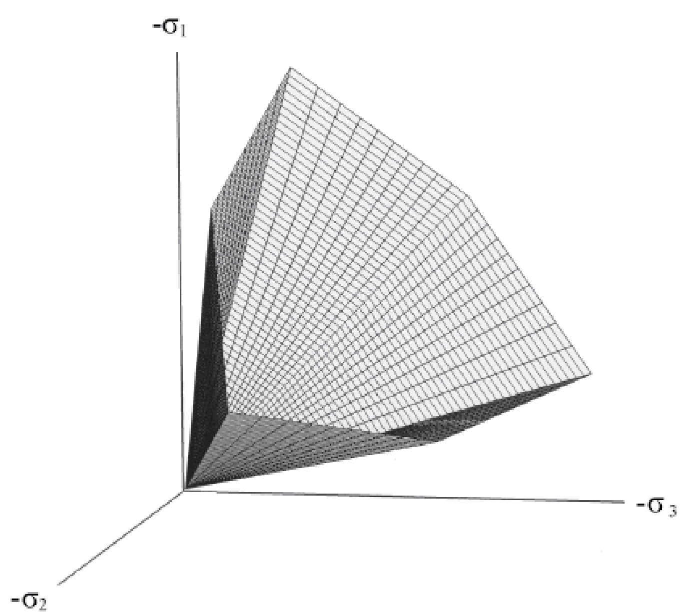


Figure 3. The Mohr-Coulomb yield surface in principal stress space (c = 0)

The safety factor analysis *(phi-c reduction)*

Basically, the limit equilibrium method has been widely applied to analyze slope stability since early 1900. It was started by Fellenius, 1936, Petterson, 1955 and refined by other scientist such as Bishop, 1955, Morgenstern and Price, 1965. However, since the number of unknowns is larger than the available equations, additional assumptions are necessary. The resulting normal and shear components (N and T, respectively) at the slip surface are calculated from the slice geometry and the limit stress condition. In an iterative procedure the overall factor of safety can be determined from the ratio between driving and resisting shear forces along the slip surface. Different limit equilibrium methods use different assumptions regarding the inclination of the earth pressure component E and the equilibrium conditions which are satisfied at each slice (Kupka, et al., 2008).

In addition, other method is so-called φ,c-reduction which can be used to determine a critical slip surface which associates with safety factor. This method has been effectively practiced by numerous authors e.g. Dawson, et al. (1999) and Griffiths (1999) and is increasingly incorporated in commercial finite element codes like PLAXIS (Brinkgreve, 2002).

In the Phi-c reduction approach the strength parameters tan φ and c of the soil are successively reduced until failure of the structure occurs. The strength of interfaces, if used, is reduced in the same way. The strength of structural objects like plates and anchors is not influenced by Phi-c reduction. The total multiplier ΣMsf is used to define the value of the soil strength parameters at a given stage in the analysis:

$$\sum Msf = \frac{\tan \varphi_{input}}{\tan \varphi_{reduced}} = \frac{c_{input}}{c_{reduced}}$$

Where the strength parameters with the subscript 'input' refer to the properties entered in the material sets and parameters with the subscript 'reduced' refer to the reduced values used in the analysis. ΣMsf is set to 1.0 at the start of a calculation to set all material strengths to their unreduced values (Plaxis Manual, 2006).

Scenarios Models

Three models have been created to analyze a deformation and a safety factor. They are slopes of 30°, 45° and 60°. Based on these models, it could be expected they would provide about landslide deformations and a safety factor remarks. For those reasons, connectivity in the models has been created, Figure 4. Moreover, the same values of all parameters are applied for all scenarios. It should be done as a comparison among those scenarios.

RESULTS

Deformation and Safety Factor

As input data, five main parameters is adopted from laboratory test while others parameters are used as default values. Applying more than hundred steps of *phi-c reduction* calculation therefore every model has a different magnitude of deformation. It can be seen at Figure 5 which a left side is a horizontal deformation and the other of vertical. Based on *phi-c reduction* analysis showed a horizontal deformation took placed more than 95% of total deformation. However, the biggest collapse scale can be found among models are different. A bigger slope has a horizontal collapse zone at the corner of the bottom channel while a vertical took placed at the top of the wall (Figure 5).

Furthermore, a total deformation of each model can be found at Figure 6. The total amount consist of x and y direction of the displacement. It means a horizontal and vertical displacement of each material in the model.

As shown in the Figure 6, an increasing of a slope yields much more displacement. It can be seen approximately 42 m of total displacement was reached of 60° slope (Table

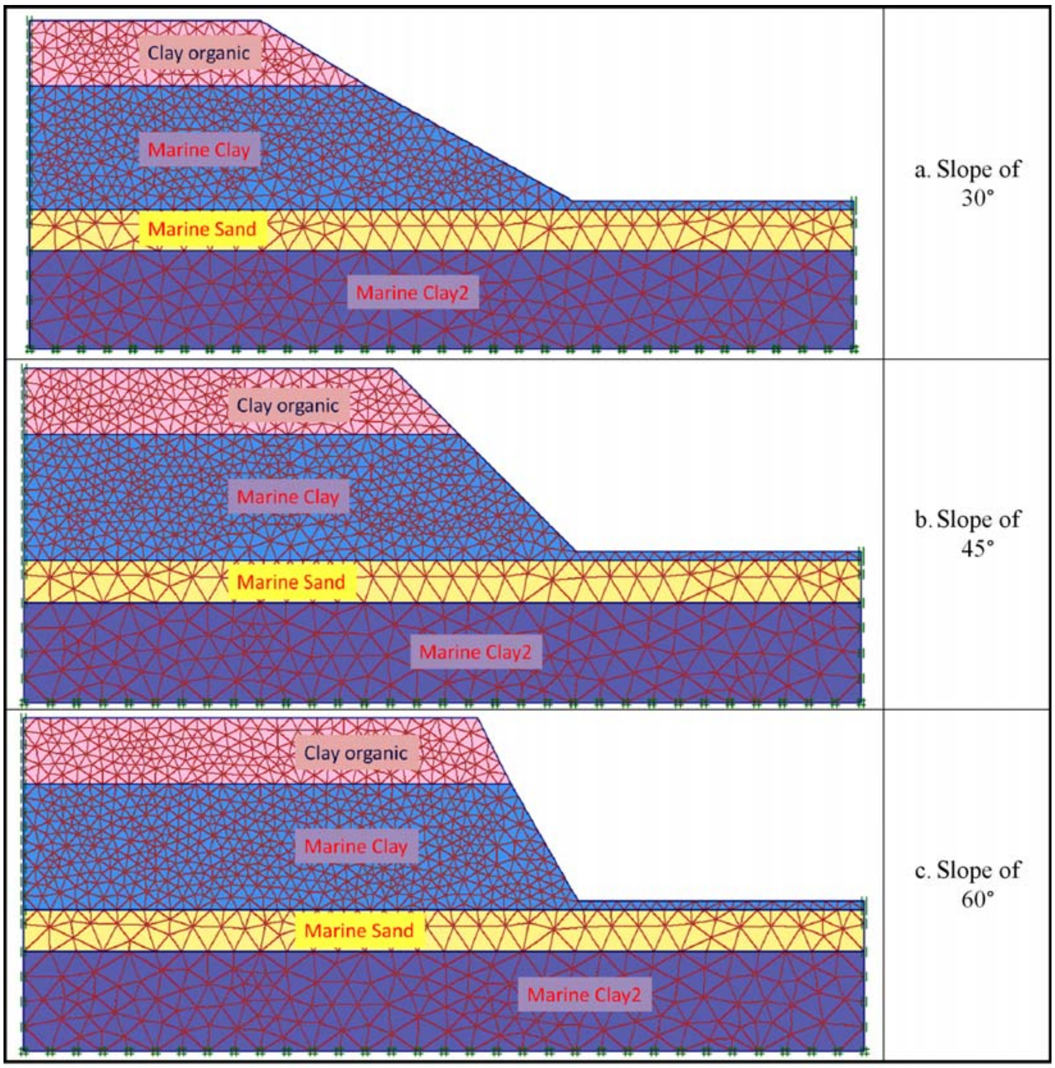


Figure 4. Set up model of each scenarios

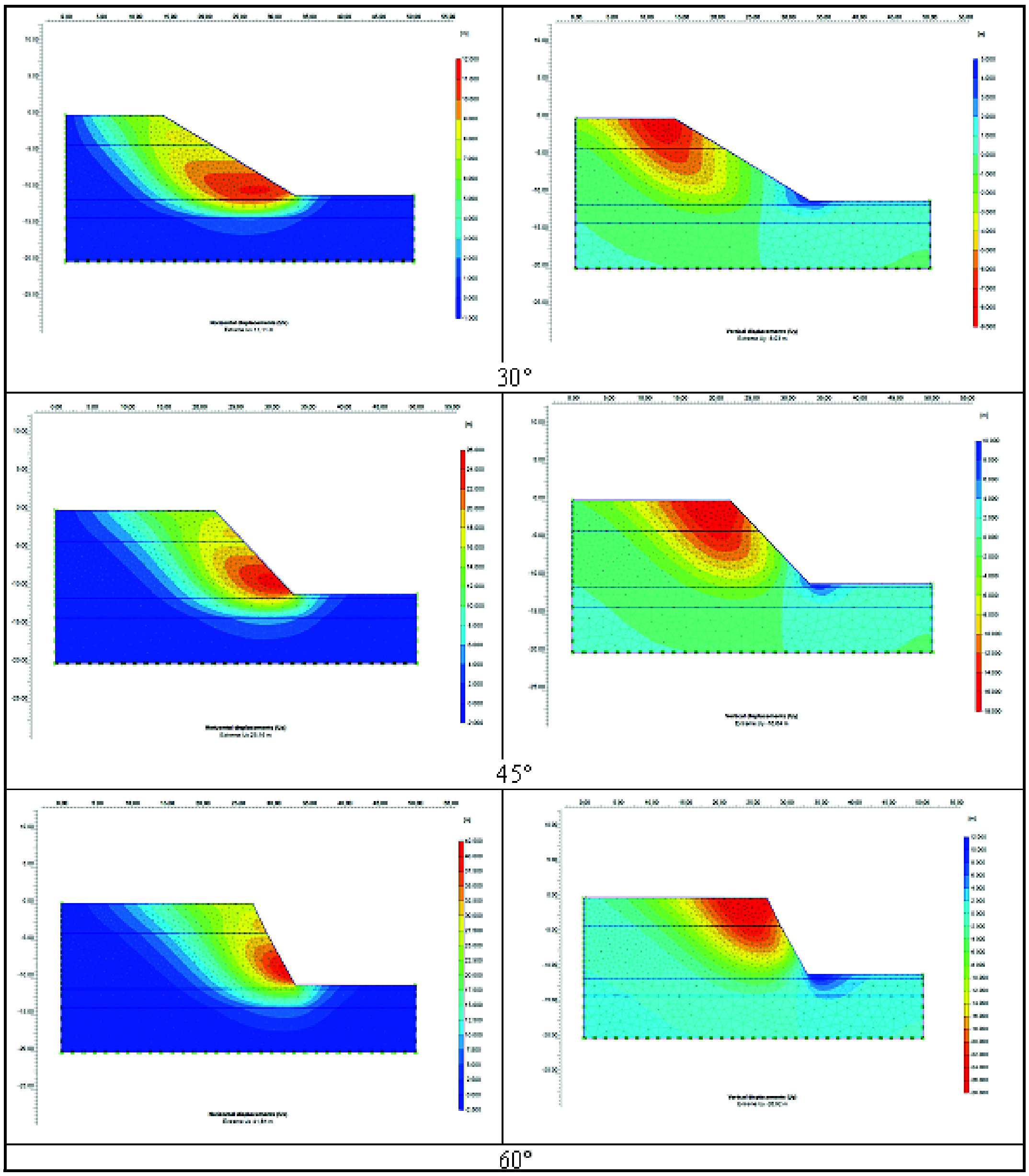
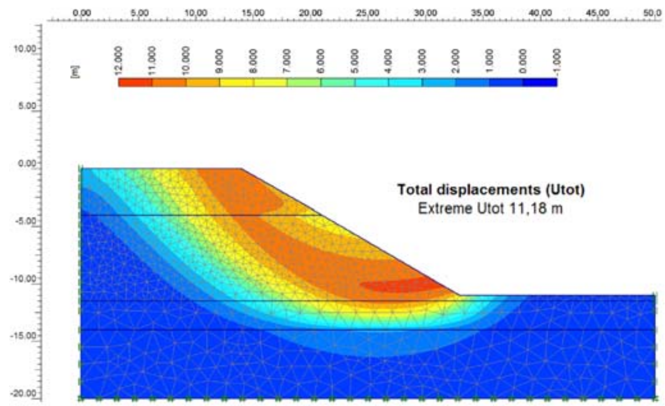
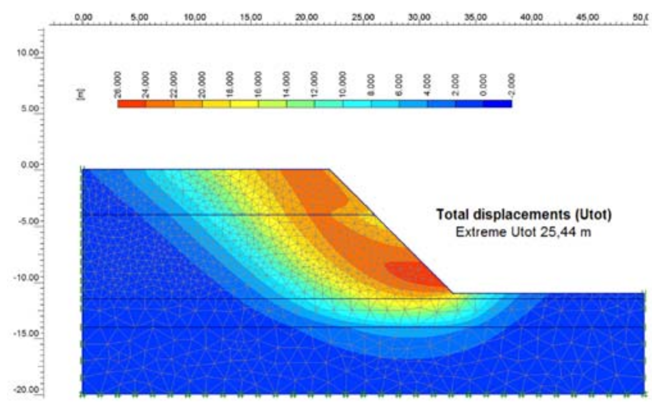


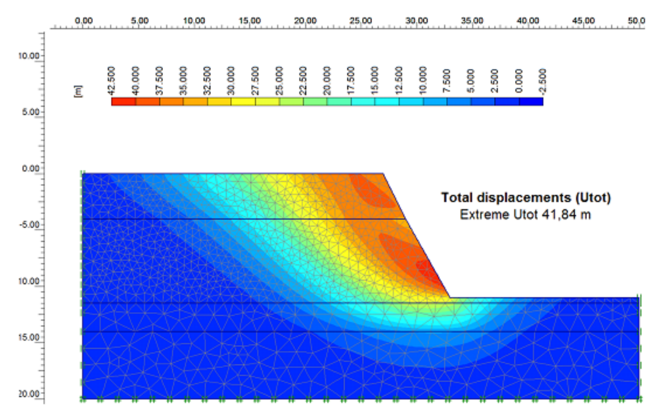
Figure 5. Horizontal and vertical displacement



a. 30°



a. 45°



a. 60°

Figure 6. Total displacement

2), that means a horizontal movement on the seabed attains almost four times of vertical height of the channel. In fact, the phenomenon could be different, it might be caused by a material composition along seabed and hydro-oceanography upper ground. Even so, as described at the aim, therefore a magnitude of a natural displacement of the materials could be reached of this simulation. Moreover, a high number of displacements should be investigated across channel related with a silting on the channel.

At Figure 7, we can see a level of a safety factor among three models. This is interesting enough, since a calculation reaches below 100 steps tends to increase, on the other hand it shows decreasing before reached a stable condition. All tendencies could be said have a similar form except a 60° slope which could not accomplish a stable condition.

DISCUSSION

As we can see, trend lines have a similar form until reaching a stable condition, figure 10. However, a little bit weird could be found on 60° slope which it could not achieve a stable condition and continuously dropped below unstable value (less than 1). As assumptions, this anomaly might be caused by overburden of the soil itself so caused a slope collapsed.

As informed in geology and geotechnical conditions section where borehole one (BH1) presents some types of a soil around the coast. Consequently, it should not be said the result can be represented the soil characteristic along access channel.

CONCLUSIONS

As a simple model, Plaxis could be said succeed within describes a displacement and a safety factor. However, some remarks have been concluded as below,

- Geotechnical data should be collected by considering variation of the soil characteristics
- Safety factors have an opposite values compared with slopes on the channel
- Plaxis gave a good enough description of a safety factor of the slope.
- Soft and hard structures could be combined in order to attain much higher a safety number.

ACKNOWLEDGEMENT

The authors would like to thanks to The director of Marine Geological Institute and Team members for the support, discussion and inputs.

Table 2. Total displacement among 3 models

Slope	Total displacement (m)
30	11.18
45	25.44
60	41.84

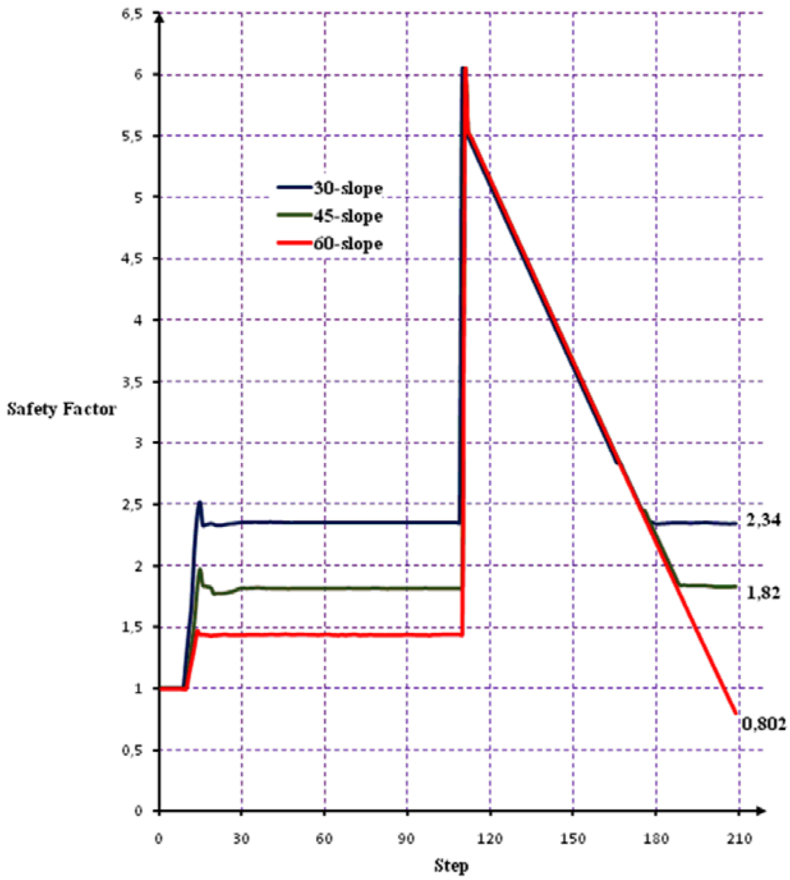


Figure 7. Safety factor of three different slopes

REFERENCES

Bishop, A.W., 1955. "The Use of Slip Circle in the Stability Analysis of Earth Slope" *Geotechnique*, Vol 5(1),1 7-17.

Brinkgreve R.B.J., editor. 2002. PLAXIS 2D – Version 8, www.plaxis.nl, A.A. Balkema Publishers.

Dawson E.M.; Roth W.H., Drescher A. 1999. Slope stability analysis by strength reduction. *Géotechnique*, 49(6), 835-840.

Griffiths D.V. 1999. Slope stability analysis by finite elements. *Géotechnique*, 49(3), 387-403

Fellenius W. 1936. Calculation of the Stability of Earth Dams. *Proc. of the Second Congress of Large Dams*, Vol. 4, 445-463

Google Earth, September 21st 2009, Satellite Images

Kellezi, L., Allkja,S., Hansen, P,B., 2005. Landslide FE stability analysis. In *Proceedings of the IACMAG*, Italy, 545-553.

Koiter, W.T., (1960). General Theorems for Elastic-Plastic Solids. In: Progress in Solid Mechanics (eds. I.N. Sneddon, R. Hill), Vol. 1., North-Holland, Amsterdam, pp. 165-221.

Kristanto, NA., 2006. *Pengaruh Sifat Keteknikan Sedimen Laut Resen Terhadap Kemantapan Lereng pada Rencana Alur Dermaga Marine Center PPPGL Cirebon*, Thesis, Bandung Institute of Technology (Unpublished).

Kupka, M., Herle, I., Arnold, M., 2008, Advanced Calculations of Safety Factors for Slope Stability. In *The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics* (IACMAG), India.

Morgenstern N.R., Price V.E. 1965. The analysis of the stability of general slip surfaces, *Géotechnique*, 15(1), 79-93

Petterson K.E. 1955. The Early History of Circular Sliding Surfaces, *Géotechnique*, 5(4), 275-296.

Raharjo, P., Novico, F., Budiono,K, 2005, *Penyelidikan Potensi Sumber Daya Mineral dan Daya Dukung Kawasan Pesisir Kabupaten Cirebon,* Pusat Penelitian dan Pengembangan Geologi Kelautan, (Intern Report)

Smith, I.M and Griffith, D.V., 1982. *Programming the Finite Element Method*, Second Edition. John Wiley & Sons, Chisester, U.K.

Suwarna, N., P.H. Silitonga, dan M.Masria, 1996, *Peta Geologi Lembar Cirebon*, PPPG, Bandung.

Van Langen, H and Vermeer, P.A.,1990. Automatic Step Size Correction for Non-Associated Plasticity Problems. *Int. J. Num. Meth. Eng*., Vol. 29, pp. 579-598.