

# SLOPE STABILITY AND DEFORMATION ANALYSIS UNDER DRAWDOWN CONDITIONS (CASE STUDY: RAMA 9 RESERVOIR)

## Article history

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## Graphical abstract



## Abstract

The Rapid drawdown condition is one of the most dangerous conditions for earth slopes. The change of water level in reservoir always causes a slope failure. This paper presents an investigation on the slope stability of the Rama 9 Reservoir under different drawdown conditions depending on the drawdown ratio, the drawdown rate and the loading conditions. Finite element analysis program PLAXIS 2D 2012 were applied to define the displacement and the factor of safety for slopes at selected positions. The results shown that, in the rapid drawdown condition for the drawdown ratio of 0.75, the factor of safety is 1.16. In the slow drawdown condition for the drawdown ratio of 1.00, the factor of safety is 1.26. Both are less than the ratio of allowable security value of 1.3. For the Rama 9 Reservoir, the reduction of the water level should be controlled more carefully.

Keywords: Slope stability, Deformation, Drawdown, Finite element analysis

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## 1.0 INTRODUCTION

The rapid drawdown condition occurs when a slope that is used to retain water experiences a rapid (sudden) lowering of the water level and the internal pore pressures in the slope cannot reduce fast enough. During rapid drawdown, the stabilizing effect of the water on the upstream face is lost, but the pore-water pressures within the embankment may remain high. Seepage and hydrodynamic pressures create downward forces acting on the upstream slope. Those are adverse to the stability and create a critical condition to the upstream slope. Although the slope will not failure in that moment, but if the water is flowing into the sloping embankment pond again, the force necessary to cause the flow of water can cause the failure of the embankment slope [1]. Such incidents often occurred in the past, either in the slope of the natural or man-made dams, such as in Pilar Silva Santos, South of San Francisco, Walter Bull clay dam in Alabama, Monteiro river banks [2]. Drawdown rates of 0.1 m/day are common. Drawdown rate of

0.5 m/day are quite significant. 1 m/day and higher rates are rather exceptional. Reverse pumping storage schemes may lead to such fast water level changes in reservoir levels [1].

The Rama 9 Reservoir locates at Klong five, Pathumthani, Thailand, consisting of two ponds with the water storage capacity of approximately 20.8 million cubic meters and 39.1 million cubic meters, respectively [3]. The layout of the Rama 9 Reservoir is shown in Figure 1. Due to the dramatically increased water demand, the water level of the Rama 9 Reservoir changed sharply. So, stability analysis during rapid drawdown is an important consideration for managers. The slope stability against landslide risk is represented by the factor of safety.

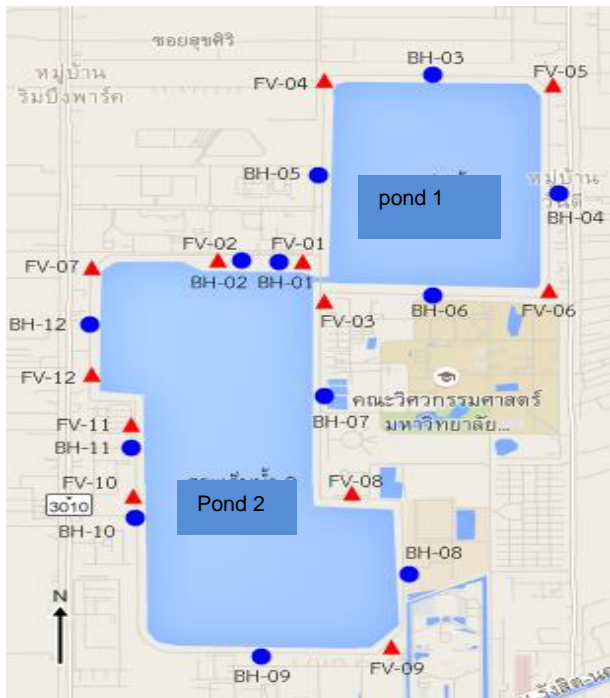


Figure 1 Layout of the Rama 9 Reservoir

Traditional limit equilibrium methods and finite element method are often used to evaluate the safety of slope ratio (Factor of Safety, FS.) [1, 4]. In the case of embankment materials draining slowly (Short-term), parameters used in the analysis is the total stress (total stress analysis). In the case of the embankment materials draining quickly (Long-term), parameters used in the analysis is the effective stress (effective stress analysis) [5]. For slope stability analysis under conditions of reduced water level (Drawdown) both parameters may be used. For example, Corps of Engineers Method [6], Lowe's and Karafiath's Method [7], Duncan, Wright and Wong Method [8] use the parameter of total stress (total stress analysis). In the method proposed by Svano and Nordal [9], effective stress (effective stress analysis) is used. Normally the total stress (total stress analysis) are use more widely because of the difficulty to find the pore water pressures.

In this paper, the finite element software, PLAXIS 2D 2012, is used to take the slope stability analysis for Rama 9 Reservoir in Thailand. Depending on the factors such as drawdown ratio, drawdown rate and terms of the weight, the factor of safety was calculated by using Phi-C-Reduction method and considering the elastoplastic behavior of the embankment materials.

## 2.0 CROSS-SECTION SURVEYS AND SOIL PROPERTY TESTS

### 2.1 Soil Property Tests

Exploratory drilling and soil sampling were taken in order to know the soil properties and the strengths of the soil at various depths by the field vane shear test. The positions of total 12 sampling points, FV-01 to FV-12, and exploratory drilling survey of 12 holes with depth of approximately 30 m, BH-01 to BH-12, are shown in Figure 1. Exploration drilling using a drill precession to collect soil samples in static conditions (Undisturbed Sample) for soft clay and in transformational conditions (Disturbed Sample) for hard soil. The Standard Penetration Test (SPT) was applied. In this paper, taken as example, the slope stability and movement of embankment slope on the north bank of the second pond in the Rama 9 Reservoir were analyzed based on the data from two drill holes, BH-01 and BH-02 (shown in Figure 1).

For the embankment slopes, from the top 0.00 m down to -2.00 m, there is the layer of reclamation soil. From -2.00 m down to -10.00 m, there is the layer of very soft to medium stiff clay which has high moisture content in the soil and high plasticity. From -10.00 m down to -19.00 m, there is the layer of stiff clay, which has low moisture in the soil and low plasticity. From -19.00 m down to -30.00 m there is the layer of stiff to hard clay, which has low moisture in the soil and low plasticity.

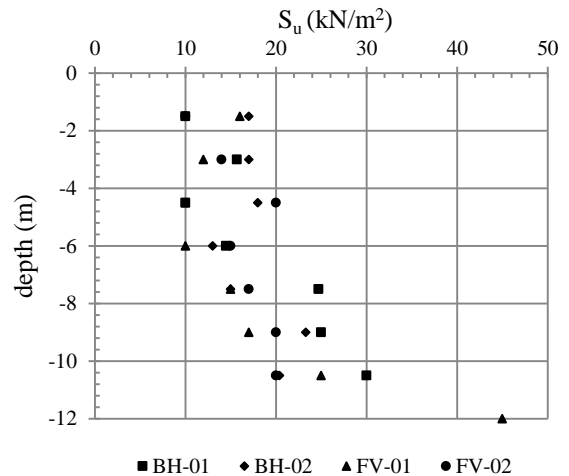


Figure 2 Shear strength of soils at different depth

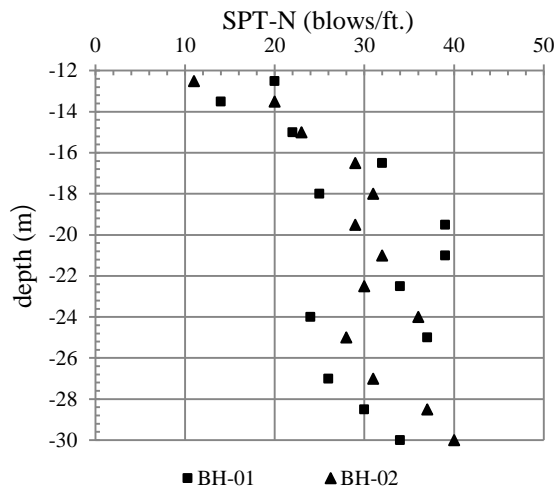


Figure 3 Strength of soil at different depth

The results of unconfined compression test shown that (see Figure 2), from the depth 0.00 m down to -8.00 m the shear strength of the soil in two holes are similar. From the depth -8.00 m down, the shear strength of soil increased. The results of standard penetration test shown that (see Figure 3), from -12.00 m the strength of soil increased with the depth. From -19.00 m down, the strength became constant. Table 1 collects the data of various parameters used to analyze slope stability.

Table 1 The parameters used in the analysis

parameters	Soil (m)		
	+2.20 to -10.00	-10.00 to -19.00	-19.00 to -30.00
<b>Material Model</b>	Mohr-Colomb	Mohr-Colomb	Mohr-Colomb
<b>Consistency</b>	Soft clay	Stiff clay	Hard clay
<b>Unit weight of soil (kN/m<sup>3</sup>)</b>	16.20	19.65	20.5
<b>Permeability (m/d)</b>	2.7x10 <sup>-4</sup>	8x10 <sup>-6</sup>	1x10 <sup>-7</sup>
<b>Cohesion (kN/m<sup>2</sup>)</b>	18	110	180
<b>Internal friction angle (°)</b>	0	0	0
<b>Dilatancy angle (°)</b>	0	0	0
<b>Poisson's ratio</b>	0.3	0.35	0.35
<b>Reference stiffness modulus (kN/m<sup>2</sup>)</b>	150S <sub>u</sub>	250S <sub>u</sub>	500S <sub>u</sub>

### 2.2 Water Table Observation

Groundwater level plays a key role in the stability of the slope. So it is important to measure the groundwater levels at different drill holes. What is needed to do is that in all drilled holes used for measure the water level exploratory gauge

(Standpipe pizometer) should be installed. The hole is about 100 mm in diameter and 5 m in depth. PVC pipe with diameter of 55 mm was plug into it to the depth of 4 m. It is used to check the water level regularly.

Standpipe pizometer study was done to measure the water level in Rama 9 on Oct. 31, 2014, Nov. 21, 2014 and Mar. 19, 2015. As the values shown in Figure 4, the groundwater level measured from the mean sea level down to the surface of the water level in the pond at the surveyed soil was 1.75m, 1.71 m and 1.36 m. It was observed that the groundwater level of the Rama 9 Reservoir changed about 0.40 m.

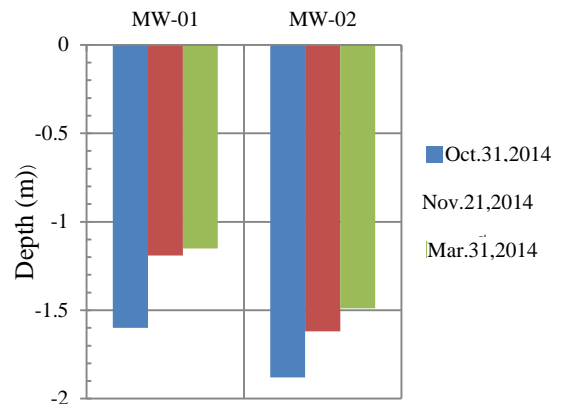
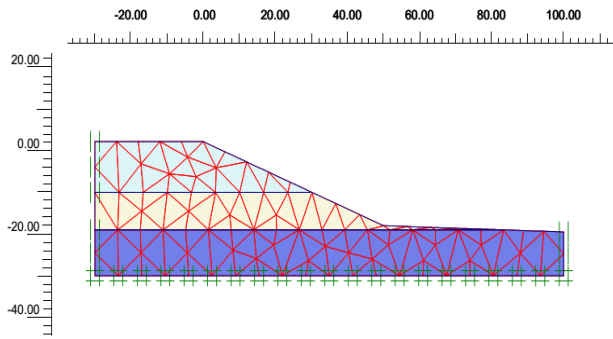


Figure 4 Groundwater levels

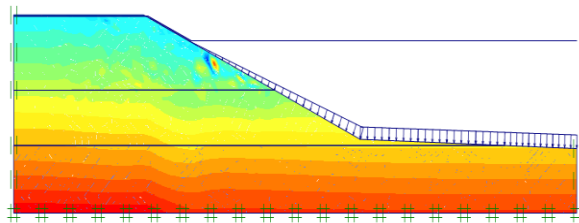
### 3.0 ANALYSIS OF DEFORMATION AND STABILITY OF THE EMBANKMENT SLOPE

In this paper, analysis of deformation and stability of embankment slope were taken for the north bank slopes in the second pond of the Rama 9 Reservoir. FEM were used to analyze in two different cases, according to the lowering rate of the water level (Drawdown rate, R). For the rapid drawdown condition, the drawdown rate is 0.30m/day. The groundwater level in embankment slope initially is above the sea level. When the water in the pond is reduced, the excess pore pressure results that the water can't be discharged in time. Short-term undrained material behavior (undrained) should be considered. For the slow drawdown condition, the drawdown rate is 0.10m/day. The long-term drainage material behavior (drained) should be considered. In both conditions, it is set up that the water level is reduced from +2.00 m to -2.00 m, relative to the sea level. The factor of safety is calculated to examine the stability and the deformation of embankment slope when the drawdown ratio (Drawdown ratio =  $L / H$ ,  $L$  is the drawdown water level;  $H$  is the initial water level) is equal to 1.00, 0.75, 0.50 and 0.25. In the program PLAXIS 2D 2012, the embankment slopes are meshed in two-dimensional (Plane – Strain) using triangular element, as shown in Figure 5. The pore pressure analysis consists of two parts, active pore pressure and excess pore pressure, as shown in Figure 6 and Figure

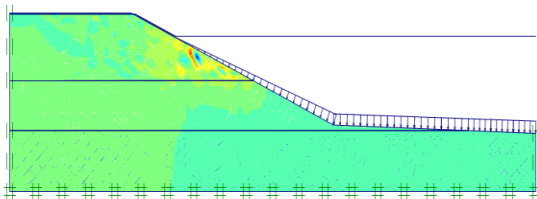
7. Both of them would occur in the embankment slope and affect the slope stability.



Connectivities  
**Figure 5** Mesh of model



**Figure 6** Analysis of active pore pressure



**Figure 7** Analysis of excess pore pressure

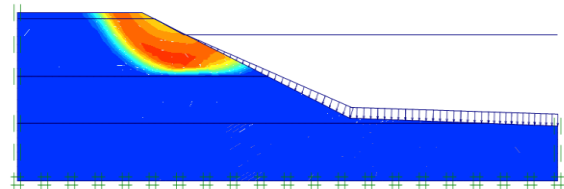
### 3.1 Analysis of Deformation

The deformation analysis use program PLAXIS 2D 2012 in the undrained behavior. The basic theory applied for analysis comes from the continuum mechanics. It is assumed that the soil contains pore and pore water pressure. The effective stress is used as parameter to calculate the stress and the actual water pressure. Material is modelled in nonlinear elastoplastic behavior and Mohr-Coulomb is used to solve problems.

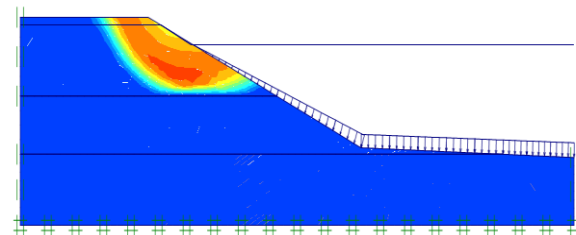
The deformation modes of the embankment slopes along the contour lines in two cases, slow drawdown and rapid drawdown, are shown in Figure 8. The deformation of the embankment slope due to the reduction of water levels in the rapid drawdown is

more than that in the slow drawdown conditions, with the deformation of 0.42 cm and 0.34 cm, respectively.

The relationship between deformation to height ratio and the drawdown ratio ( $L/H$ ) is presented in Figure 9. In the slow drawdown condition, when the drawdown ratio is equal to 0.25, 0.50, 0.75, and 1.00, the deformation to height ratio in the direction  $U_x$  is equal to 1.15%, 2.25%, 4.255 and 6.25%, respectively, and in the direction  $U_y$  -1.63%, -2.50%, -5.00% and -6.505, respectively. In the rapid drawdown condition, corresponding to the drawdown ratio of 0.25, 0.50, 0.75, and 1.00, the deformation to height ratio in the direction  $U_x$  is 1.50%, 4.15%, 6.00% and 7.50%, respectively, and in the direction  $U_y$  -1.75%, -4.00%, -5.75% and -6.50%, respectively. It can be seen that, the deformation of embankment slope increased with the drawdown ratio. Either in the direction  $U_x$  or  $U_y$ , the deformation of embankment slope in the rapid drawdown condition is more than in the slow drawdown condition.

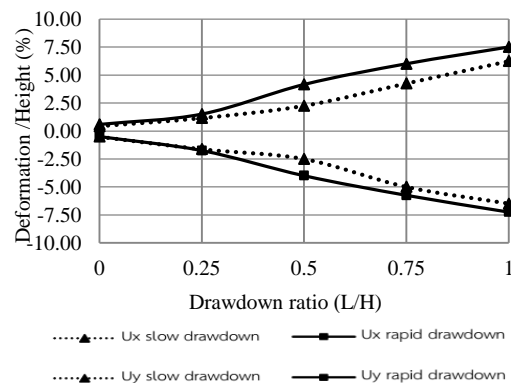


(a) slow drawdown



(b) rapid drawdown

**Figure 8** Deformation of the embankment slope



**Figure 9** Relationship between deformation to height ratio and drawdown ratio ( $L/H$ )

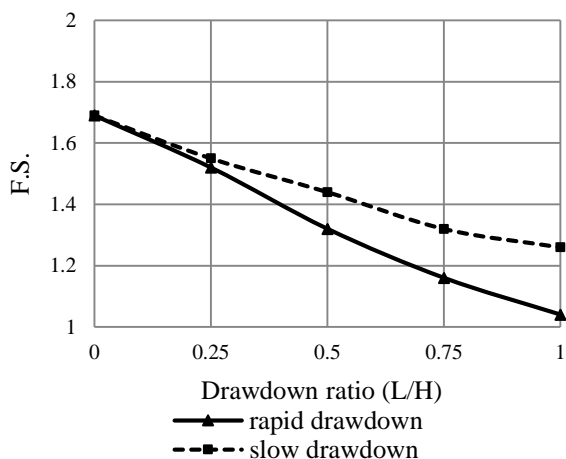
### 3.2 Stability Analysis

The slope stability analysis of embankment in this paper was taken by using Plaxis 2D 2012. In order to determine the stress from the analysis results of displacement and consolidation, the method of phi-c reduction can be used to calculate the safety factor. In this approach, the cohesion and the tangent of the friction angle are reduced, as shown in Equation 1.

$$\Sigma Msf = \frac{\tan\theta_{input}}{\tan\theta_{reduc}} = \frac{C_{input}}{C_{reduc}} \quad (1)$$

The displacement analysis using models of Mohr - Coulomb will be able to find the  $\Sigma Msf$  which is called the factor of safety (FS). The reduction of strength parameters is controlled by the total multiplier  $\Sigma Msf$ . This parameter is increased in a step-by-step procedure until failure occurs [10].

The slope stability against landslide risk is presented by the factor of safety. Phi-C Reduction method was used to examine the stability for the north embankment slopes in the second pond. The relationship between factor of safety (FS.) and the drawdown ratio (L/H) in rapid drawdown and slow drawdown conditions are graphed in Figure 10. In the slow drawdown condition, when the drawdown ratio is equal to 0.25, 0.5, 0.75 and 1, the FS. is equal to 1.52, 1.44, 1.32 and 1.26, respectively. In the rapid drawdown conditions, corresponding to the drawdown ratio of 0.25, 0.5, 0.75 and 1, the FS. is equal to 1.48, 1.32, 1.16 and 1.04, respectively. It is clear that, the stability of embankment slope in rapid drawdown condition decreased more sharply with the increase of drawdown ratio than in slow drawdown condition.



**Figure 10** Relationship between FS. and the drawdown ratio (L / H)

### 4.0 CONCLUSIONS

In this study the maximum depth measured in the Rama 9 Reservoir is 21.41m. The ground of embankment slope has the layer of thick soft clay approximately 10–12 m, with relatively high liquidity index (LI) of the value 0.9 to 1.0. When the water levels changed, the total stress of soil changed with. Then the soil became liquefied so that reduced the stability of the embankment slope, which may lead to potentially disaster occur.

Using program PLAXIS 2D 2012, the stability of the embankment slope on the north of the second pond in the Rama 9 Reservoir was examined. In the rapid drawdown condition for the drawdown ratio of 0.75, the factor of safety is 1.16, less than the ratio of allowable security value of 1.3. In the slow drawdown condition for the drawdown ratio of 1.00, the factor of safety is 1.26, also less than the ratio of allowable security value of 1.3. It means that, when the water is needed to draw for application in the Rama 9 Reservoir, the reduction of the water level should be controlled. If the drop of water levels is too quick, displacement of the embankment slope would occurred regularly, which is dangerous for the embankment.

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