# 2018-AIP-Togani(Behavior of leeve on softsoil) (1)-2-7

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# Behaviour of Levee on Softsoil Caused by Rapid Drawdown

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**Abstract.** Rapid Drawdown is a condition where the water elevation that has reached the peak suddenly drops. As the water level reaches the peak, hydrostatic pressure helps in the stability of the slope. When water elevation decreases there will be two effects. First, reduced hydrostatic pressure and second, modification of pore water pressure. Rapid draw down usually comon in hydraulic structure such as dam and levee. This study will discuss behaviour of levee on softsoil caused by rapid drawdown. The analysis based on method which developed by US Army Corps Engineer and modified method which developed by Duncan, Wright, dan Wong. Results of analysis show that in drawdown condition, at 1 m drop of water, safety factor obtained based on US Army Corps Engineer method was 1.16 and 0.976 while based on Duncan, Wright, and Wong methods were 1.244 and 1.117. At 0.5 m water level, safety factor based on US Army Corps Engineer method was 1.287 and 1.09 while Duncan, Wright, and Wong were 1.357 and 1.194.

## INTRODUCTION

Rapid drawdown is a condition in which water level suddenly down after a long period in the water level in normal conditions. When water level decreases, it will be two effects. First, changes in pore water pressure and second, reduced of hydrostatic pressure. If the velocity of lowering water level too fast, it will result in a dissipation of pore water pressure inside the slope and excess pore water pressure can result in collapse of the slope[1]. Rapid drawdown cases usually common in embankment dam and levee.

Analysis of real cases the effects of water drawdown on the stability of slopes and dams have been simulate by numerical analysis in the case of Glen Shira dam and Canalles landslide presented by Alonso and Pinyol[1] and Pinyol[2]. Previous researched by Berilgen[3] have been discussed an investigation of slope stability during drawdown depending on the soil permeability, drawdown rate and drawdown ratio, considering the nonlinear material and loading conditions using finite element method. Stephenson[4] conduct simulation of lowering of phreatic line in embankment following in sudden drawdown with non equilibrium equation for flow in porous media. The safety of levee protection under rapid drawdown condition have been studied by numerically modeling as a coupled problem of transient seepage-deformation in a saturated/unsaturated medium by finite element method[5].

Rapid drawdown of Levee in the downstream can be occured because of operation of the dam in the upstream to release water for flood control. Sometimes, Levee in the downstream stay on soft soil. Soft soil generally as clay and organic soil. In this article, soft clay will be discussed. Soft soil refers to deposits having potential for high compressibility and possessing low strength. Unconfined compressive strength or undrained shear strength can describe the shear strength of a clay. Clay is regarded as very soft if its unconfined compressive strength is less than 25 kPa and as soft when the strength is in the range of 25 to 50 kPa[6].

Finite Element or limit equilibrium can use to analyze behaviour of rapid drawdown. Limit equilibrium can give information of safety factor of the slope, beside finite element can analyze transient condition of drawdown. In this study, behaviour of levee stability on soft soil caused of rapid drawdown will be discussed. Analysis of rapid drawdown based on limit equilibrium method which developed by US Army Corps of Engineers[7] and modified method which developed by Duncan, Wright, dan Wong[7].

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## METHODS FOR ANALYZING RAPID DRAWDOWN

Levee become saturated by seepage during a prolonged high reservoir stage. When water level goes down rapidly, pore water can not escape, excess pore water pressure will be appeared and reduced stability of levee. Limit equilibrium for rapid drawdown analysis assumed that drawdown very fast and no drainage occurred in the material because of low permeability. US Army Corps of Engineers presented procedure calculation for drawdown safety factor in 1970. In the other hand, Lowe and Karafiath[7] proposed other method then modified by Wright and Duncan[7] and Duncan, Wright and Wong[7].

US Army Corps of Engineers method involves two steps of stability calculations for each trial slip surface. The first step of calculations is performed for the conditions before drawdown, and is used to estimate the effective stresses to which the soil is consolidated before drawdown. On the other hand, a factor of safety is computed in the first step of calculations, the purpose of the first set of calculations is to compute the consolidation stresses. The effective stresses before drawdown are used to find the undrained shear strengths that would occur during rapid drawdown. These shear strengths are then used to perform a second step of stability calculations for conditions immediately after drawdown. The factor of safety from the second step of calculations is the factor of safety for the rapid drawdown condition[7].

The soil strengths and pore water pressures used in the rapid drawdown analysis are the same as those used for the long-term analysis of the steady seepage condition. Effective stress shear strength parameters derived from Consolidated-Undrained (CU) tests with pore water pressure measurements, or from Consolidated-Drained (CD) tests should be used[7].

For undrained material, the shear strength can be determined from isotropic consolidated undrained (CU) laboratory tests. The total stress R envelope can be constructed as shown below.

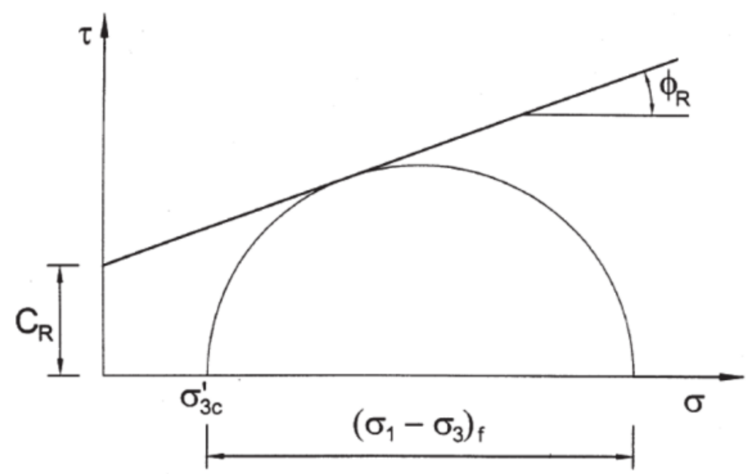


**FIGURE 1.** Mohr Coulumb Diagram[7]

Where $\sigma_{3c}$' is the effective stress during (isotropic) consolidation and ($\sigma_1$ - $\sigma_3$) is the principal stress difference at failure. From the same laboratory test data, it is possible to construct a Kc = 1 envelope instead as shown below.

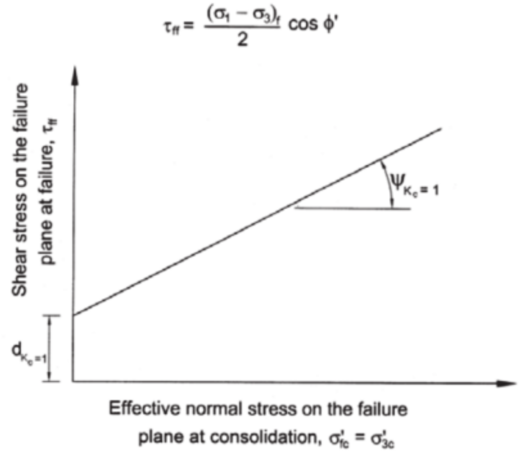


**FIGURE 2.** Shear Strength Envelope from istropically consolidated Undrained Condition[7]

These two different envelopes are related through the following equations:

$$d_{k_c=1} = c_r\left(\frac{\cos\varphi_r \cos\varphi\prime}{1-\sin\varphi_r}\right) \tag{1}$$

$$\psi_{k_c=1} = \tan^{-1}\left(\frac{\cos\varphi_r \cos\varphi\prime}{1-\sin\varphi_r}\right) \tag{2}$$

Where φ′ is the undrained friction angle.

US Army Corps of Engineer method to perform the limit equilibrium analysis, the Army Corps method requires the R envelope. If the Kc = 1 envelope is entered instead, then it is converted using the above equations. The R envelope is then combined with the effective stress envelope to avoid relying on elevated shear strengths that result from negative pore pressures. The composite envelope is shown below.

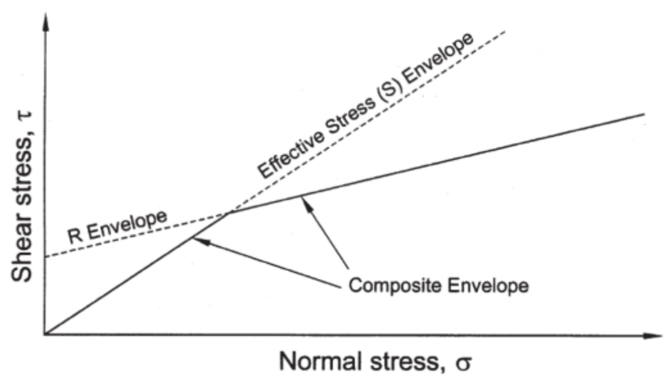


**FIGURE 3.** Composite of Shear Strength Envelope[7]

Duncan, Wright and Wong[7] method involves either two or three separate slope stability calculations for each trial slip surface. The first computation is the same as that for the Corps of Engineers procedure and is used to calculate the effective stresses to which the soil is consolidated before drawdown. The second step of computations is performed using undrained shear strengths corresponding to the effective consolidation stresses calculated in the first stage. If the drained shear strength is less than the undrained shear strength for any slices, a third step of calculations is performed, using drained shear strengths for those slices. The factor of safety from the last stage (the second or third stage) is the factor of safety after rapid drawdown[7].

The Lowe and Karafiath[7] and the Duncan Wright and Wong[7] methods require the Kc = 1 envelope. If the R envelope is entered instead, then it is converted using the above equations. Kc = 1 refers to an isotropically consolidated state. To get the envelope for an anisotropically consolidated material (where Kc ≠ 1) the drained failure envelope is plotted on the same graph. The drained envelope is assumed to represent the undrained shear strength of the soil at maximum allowable Kc (i.e. the value of Kc that results in failure during consolidation). The envelope to be used in the analysis is then interpolated between the two, using the value of Kc for each slice in the limit equilibrium analysis of the slope prior to drawdown.

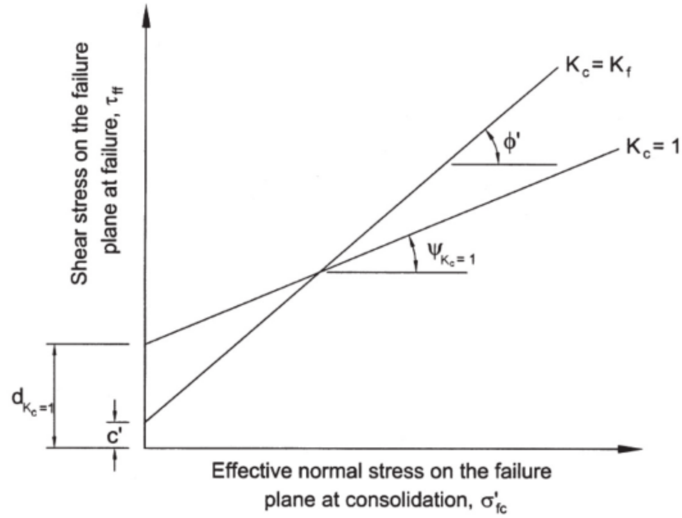


**FIGURE 4.** Shear Strength Envelope used for improved procedure for rapid drawdown analysis[7]

Once the envelope is defined, the limit equilibrium analysis is performed for the second stage (after drawdown) using the new shear strengths. In the Duncan, Wright and Wong method, a third stage of computation is also performed. In this stage, the effective stress on the bottom of each slice (after drawdown) is calculated and if the drained shear strength is less than the undrained shear strength, then the drained shear strength is used instead.

## RESULTS AND DISCUSSION

Slope stability analysis using the morgenstern-price method. The analysis is carried out under normal conditions and subsequently in drawdown condition. The levee height is set at 3 m. Under normal conditions simulated based on the angle of the slope and the value of the friction angle. While the drawdown conditions are simulated based on the friction angle and the water level drop. Material properties of soft soil are considered in drawdown analysis shown in Table 1.

**TABLE 1.** Materials Properties for The Soft Soil Considered in The Rapid Drawdown Analysis

| Material Properties | Symbol | Unit | Value |
|---|---|---|---|
| **Soft Soil** | | | |
| Unit weight of soil (Unsaturated) | $\gamma_{unsat}$ | $kN/m^3$ | 17 |
| Unit weight of soil (Saturated) | $\gamma_{sat}$ | $kN/m^3$ | 18 |
| Cohesion | c’ | kPa | 5 |
| Internal friction angle | φ’ | degree | 10 |

In normal water level conditions, the calculation results show the safety factor depends on the value of the effective stress parameters and the angle of the slope. The larger the effective stress parameter the safety factor will increase. In addition, the slope angle is smaller then the safety factor will increase. The results of the analysis can be seen in the following figure:

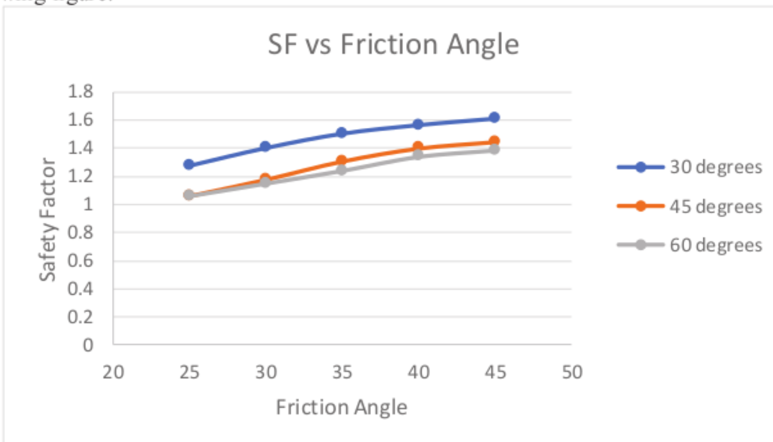


**FIGURE 5** Safety Factor of Slope Based on Friction Angle and Slope Angle

The drawdown analysis is based on US Army Corps Engineer and Duncan, Wright, and Wong methods. Under drawdown conditions, the levee safety factor are simulated based on the decrease of the water level and the internal friction angle. On the higher decrease of the water level the safety factor will be smaller. While the larger the friction angle, the safety factor will be greater. The simulation results show that the safety factor is greater than 1, obtained in the condition where the levee decreased the drawdown by 0.5 m. The simulation results can be seen in the following figure:

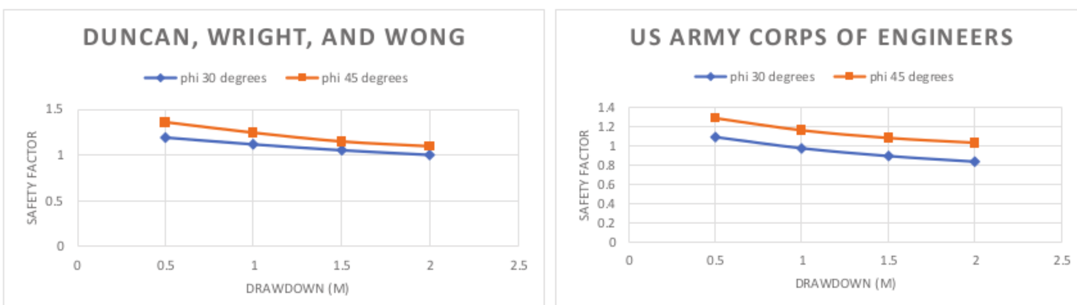


**FIGURE 6** Safety Factor Based on Drawdown and Friction Angle

## CONCLUSION

In this study, simulation was done before drawdown and after drawdown. Before the drawdown, the safety factor depends on the effective stress parameters and slope angle. The greater of the effective stress parameters will be the higher the safety factor, otherwise the higher the slope angle will be the smaller the safety factor.

In Drawdown condition, at 1 m drop of water, safety factor obtained based on US Army Corps Engineer method was 1.16 and 0.976 while based on Duncan, Wright, and Wong methods were 1.244 and 1.117. At 0.5 m water level, safety factor based on US Army Corps Engineer method was 1.287 and 1.09 while Duncan, Wright, and Wong were 1.357 and 1.194. The value of the safety factor depends on the shear strength of the soil under undrained or drained conditions. so that on the flood gate operation, the drawdown should be no more than 0.5 m.

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