Cyclic drawdown of water causing the slope failure of canal and dam

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ABSTRACT

Man-made structure such as dam or excavated canal are subjected to change in water level in its lifetime. Safety analysis of sudden drawdown case is common in slope design. However, in general practice the analysis does not consider the accumulation of shear strain that might occur with each drawdown event. This accumulation may eventually reduce the shear strength soil and cause the unbalance of slope. Recently, two different earth structure in Thailand, Pa Bon dam and canal slope in soft Bangkok clay area, failed after several years of service. The slope of those structures experienced the sudden drawdown for many years. Coupled stress and strain analysis reveals that the strain accumulation during each drawdown cycle caused the reduction of shear strength and was the major cause of failure. By knowing this, design code may need to add additional design case in order to cover this mode of failure.

Keywords: Slope failure, Sudden drawdown, Coupled Stress Analysis, Numerical Modelling

1 INTRODUCTION

Pa Bon dam located in the southern part of Thailand. The operation of dam started in 2004 and has been in operation till date. However, the first movement of upstream slope was observed in the year 2014. Repair work had been carried out after the first movement but the movement still occurred whenever the reservoir water level was drawn down. This is not the first case, Huai Ta Ju dam in the northeastern part of Thailand also has the same behavior but it was not as lucky as Pa Bon dam, the upstream slope failed after 20 years of reservoir water cycles. Fortunately, the failure did not cause the dam breach. Similarity, the failure behavior occurred in the excavated canal slope located in the Bangkok soft clay area. There also a case where the extreme drought caused those slopes to fail as well. The detail analysis these two cases have been briefly described in this paper.

2 PA BON DAM SLOPE MOVEMENT

Pa Bon dam is a zoned dam located at southern part of Thailand. The typical cross section of the dam is shown in Figure 2. The operation of the dam started in 2004 and was operating without any hindrance until the year 2014 when the first movement was observed in the slope of embankment structure. The dam was operated after minor rehabilitation but it continued to move each year with drawdown of water. The actual water level since the filling of dam is shown in Figure 3. It can be seen that the dam had experience several sudden drawdown before the observation of slope movement but no movement was observed prior to 2014. The fastest drawdown rate was 10.76 m/day and the largest drawdown distance is 24.33 m. Figure 1 shows the photo of the movement on the dam slope and this movement increased each year with the decrease in water level.

Figure 1: Photograph showing the movement of Pa Bon Dam after first movement

Couple stress analysis reveals that the factor of safety of slope start to reduce significantly when the reduction of water level was substantial. After that the slope started to move each year even though the drawdown rate and distance was smaller than previous year. Residual soil strength testing was carried out from

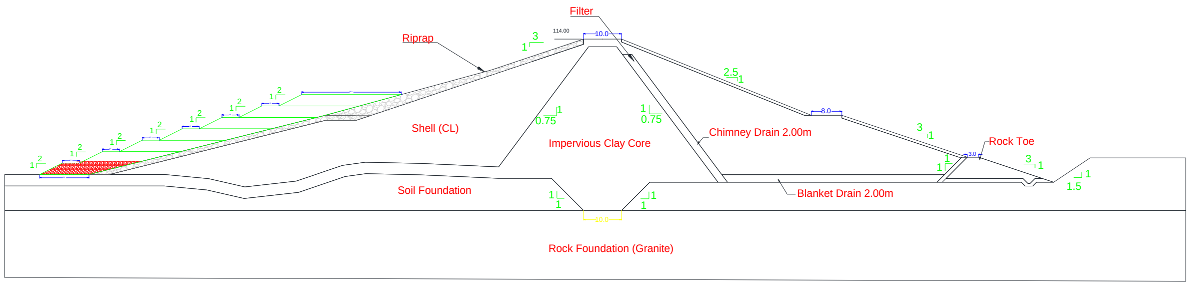

Figure 2: Cross Section of Pa Bon Dam

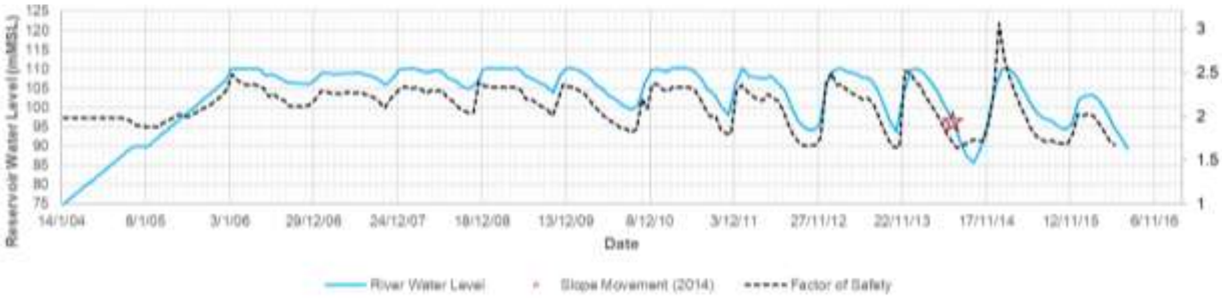

Figure 3: Variation of Safety Factor with Water Level of Pa Bon Dam

collected dam material (Head, 2011; Mesri & Huvaj-Sarihan, 2012; Stark & Hussain, 2010). Slope stability analysis showed that the factor of safety decreased with decrease in water level but no failure was obtained analyzing the slope at peak strength (Figure 3) hence, the analysis was based on the assumption that the strength of dam material had reached the residual stage due to cyclic loading of water leading to the movement of the slope. The shear strain with passage of time was calculated for the soil after reaching the residual state using both Mohr Coulomb and Modified Cam Clay Model as shown in Figure 4. Strain softening behavior leading to progressive failure on embankment has been successfully determined by using MCC model (Chai & Carter, 2009) .

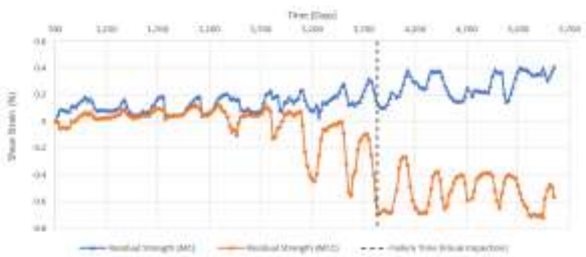

Figure 4: Shear Strain with Passage of Time for Pa Bon Dam (MC and MCC model)

It can be observed that the shear strain was accumulating with the passage of time and has been the cause for the reduction of shear strength. This result resembled to the numerical analysis and laboratory test conducted for the samples of three gorges dam (Chen, Zhang, & Chan, 2018). The accumulation of shear strain was found to be directly proportional to the height of drawdown. Following the movement each year, upstream berm were designed to reduce the slope movement as shown in Figure 2. In a mean time, the reservoir water level is controlled and maintained at higher level until the dry season.

3 CANAL SLOPE FAILURE

Lower Chao Phya basin consist of marine clay deposit called Bangkok soft clay which thickness of 8-12m. These area are suitable for rice production and are in need of irrigation canal to supply water all year round. These canals were built systematically in this area as shown in Figure 5 and later was modified to be a foundation of road embankment (Figure 6).

Figure 5 : Systematic Canal located at Lower Chao Phya Basin

Statistically, it is observed that every certain year there is the failure of canal slope. Even though there are several possible causes of failure, on the basis of information available, it was hypothesized that the failure had occurred due to sudden drawdown of water due to prolong drought. The fluctuation of water level in canal is presented in Figure 9.

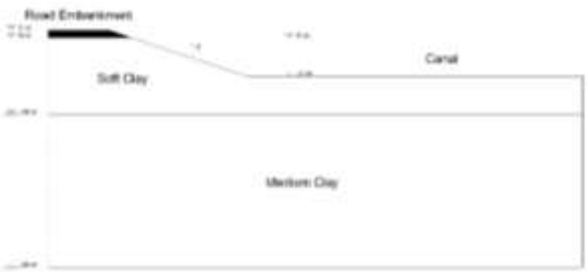

Figure 6: Road Embankment Foundation

Figure 7 : Failure of embankment along Canal Bank

Couple stress-pore water pressure analysis was carried out and it was determined that the factor of safety of slope greater than unity at the time of failure as well. The slope stability analysis in this case too showed the fluctuation of safety factor with water level but no failure was obtained analyzing the slope in peak strength (Figure 9). The shear strain was calculated for the slope using both MC and MCC model and it showed that the shear strain was accumulating with passage of time. The accumulation observed in MCC model was very significant as compared to MC model.

The movement of the slope was also observed at the different section of the canal. The behavior of the soil was tested in centrifuge model (Figure 11) with actual variance of the water level (Sasingha & Soralump, 2017) . The failure of the slope is shown in Figure 10 . After the slope movement, test was conducted by using the pile and without the use of pile. It was found out that the pile can be used for the stabilizing the slide slope

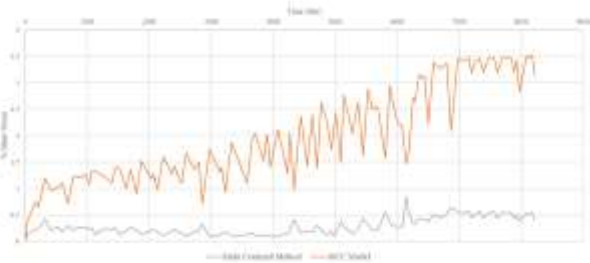

Figure 8: Shear Strain with Passage of Time for Pa Bon Dam (MC and MCC model)

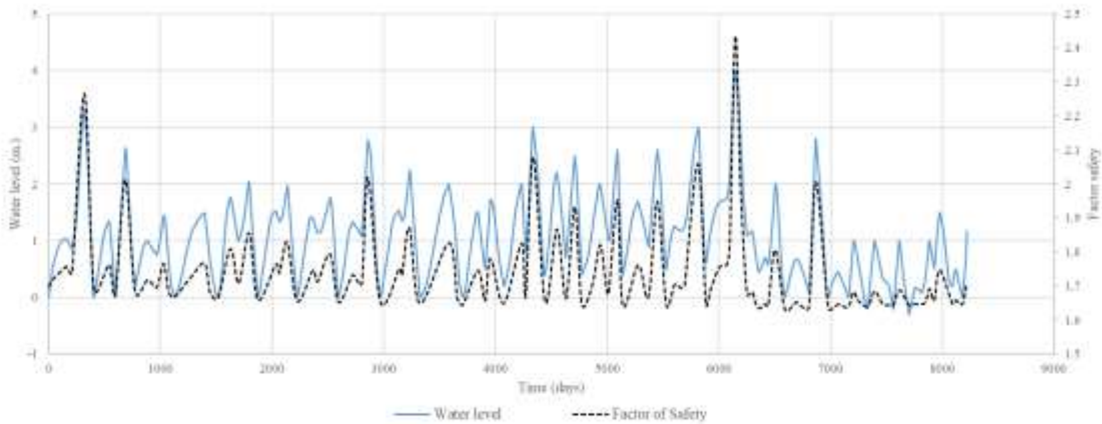

Figure 9 : Figure showing the variation of safety factor with water level with passage of time

Figure 10: Failure of Road Along the canal (Sasingha & Soralump, 2017)

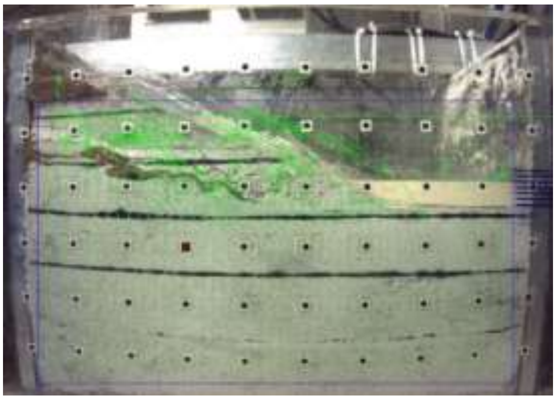

Figure 11: Photo of centrifuge testing to simulate the effect of repeated drawdown

4 MITIGATION MEASURES OF STRAIN ACCUMULATION DUE TO SUDDEN DRAWDOWN

During the design of slope, cyclic accumulation of shear strain is not considered as a major concern but various cases were encountered where movement of the slope might have occurred due to cyclic drawdown of water. To prevent the failure of slope due to accumulated strain from cyclic sudden drawdown, the following mitigation measures have been are proposed:

1. Increase the required FS during the design for the case of sudden drawdown. This methods helps in minimizing the strain movement in each drawdown cycle.
2. Strengthening the slope can be carried out by the use of piles (He, Hazarika, Yasufuku, & Han, 2015). This has been successfully done in many road along the irrigation canal in soft Bangkok clay area. Short wooden piles were used to reinforce the slope and reduce accumulation.

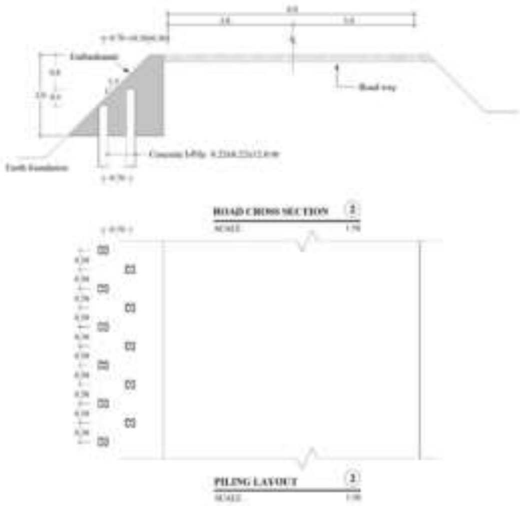

Figure 12: Reinforcement of Slope using Short Wooden Piles

5. CONCLUSION

From the above case studies of embankment failure of canal slope and slope movement of 2 embankment dam is Thailand, following conclusion can be drawn:

1. Failure can be mitigated by designing the dam considering the cyclic impact of water during the sudden drawdown each year
2. Analysis regarding drawdown depth, height of dam and slope of dam structure requires further investigation
3. The mitigation measure proposed in Section 4 should be used for preliminary increasing the shear strength of the slope structure

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