# CENTRIFUGE MODELING OF RIVERBANK FAILURE DURING A DECLINE IN THE WATER LEVEL

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Riverbank erosions along the Mekong River have caused serious problems. In a dry season, the river level drops with about 10m in Vientiane city, and then riverbanks have often failed. The effect of the water level dropping on the riverbank stability was qualitatively examined with the centrifuge modeling. The particle size distribution of the soil and the stratum of the model ground were made to be similar to that of in-situ ground. The stratum of the model ground is composed of the upper clay layer (CMC) with the depth of about 7m and the lower silty-sand layer (MS). The experimental results showed that the water level dropping caused the slope failure of the river bank. Piping on the slope of MS layer was observed in some cases. The occurrence of the piping depends on the particle size distribution of MS layer, and causes the progressive failure of the slope.

***Key Words :*** *centrifuge modeling, riverbank erosion, slope failure, piping*

## 1. INTRODUCTION

The Mekong River, which is the largest river in the South-East Asia, is blessed with rich water resources, forest resources and aquatic resources. However, the Mekong River holds various problems and bank erosions are most serious[1)]. Vientiane, capital city of Lao PDR, is in a monsoon region with dry and rainy seasons. The bank erosions have often been observed not only in the rainy season but in the dry season when the river level drops with about 10m[1)]. It is possible that seepage flow in the back ground influences the failure in the dry season. In order to clarify the failure mechanism based on soil mechanics, we conducted field measurements, laboratory tests, centrifuge model tests and numerical analyses[2)]. In this paper, we mainly discuss the results of centrifuge model tests.

Most past studies in hydraulic engineering have focused on riverbank erosion during flood and the rise in river level[3)]. Geotechnical centrifuge modeling on the stability of riverbank have studied the seepage failure during the rise in river level or rainfall infiltration[4)-7)]. This study discusses the seepage failure during the decline in the river level. Moreover, the model of the riverbank in most past studies used a single and homogeneous material. This study uses the riverbank model with two different soil layers, and discusses the influence of material properties on the seepage failure.

## 2. TEST PROCEDURE OF CENTRIFUGE MODELING

Five centrifuge model tests were performed in order to discuss the mechanism of slope failure qualitatively. The geotechnical centrifuge facility in PHRI[8] was used in this study. **Fig. 1** shows the model configuration in the model scale and the locations of transducers. The model configuration was determined from the in-situ configuration of a riverbank with the steepest bank slope[2]. The configurations were almost same among five cases. Fundamental case 1 roughly corresponds to the in-situ soil conditions. In case 1, the failure mechanism of the in-situ riverbank is discussed. In other cases 2-5, the influence of soil properties and decline rate of water level are examined.

The upper soil layer was a cement mixed clay (CMC) and the lower soil layer was a mixed soil (MS). The CMC and MS layers corresponded to LC and LS layers at the in-situ soil profile[2]. The CMC layer was made of fine silica sand (Soma sand #8), DL clay, kaolin and Portland cement (early strength) with the dry weight ratio of 1.0: 2.0: 1.8: 0.2. The properties of CMC layer were almost same among all cases. The MS was made of silica sand (Soma sand #6) and fine silica sand (Soma sand #8) with the dry weight ratio of 1: 2 in fundamental case 1. The grain size distribution of MS layer in case 1 roughly agreed with that of in-situ LS layer in **Fig. 2**. In other cases, the grain size distributions of MS layer were parametrically changed. Finer grain size distributions were used in case 2 and 4 in **Fig. 2**. The case 3 and 5 had middle distributions between case 1 and 2. **Table 1** shows the physical properties in CMC and MS layers in all cases. **Table 2** shows the undrained shear strengths in MS layer by a hand bane after the tests. The hand bane is the height of 40 mm and the width of 20 mm. The shear strengths in cases 2 and 4 are smaller than that in cases 3 and 5. These results correspond to the differences in void ratios in MS layer.

The water tank placed behind the ground kept the ground water level. Pore water pressure transducers on the bottom and a displacement transducer on the shoulder of the slope were placed in **Fig. 1**. Some targets were placed on the slope of MS layer in order to observe piping. Piping in this study is defined as the outflow of soil particles in MS layer. The piping can be observed in the monitor camera during the experiment. Some noodles were placed on the lateral side of the ground in order to observe the ground deformation. After setting of the model ground and transducers, the centrifugal acceleration of 50 g was gradually applied. The drainage pipe at the left side of the container was opened in order to decrease the water level after the completion of 50 g. The decline rate was 1.03m/day in prototype scale. In case 5, the drainage was temporally stopped immediately after the occurrence of piping, and the progress of piping was observed with the constant water level. After the observation, the drainage pipe was opened again.

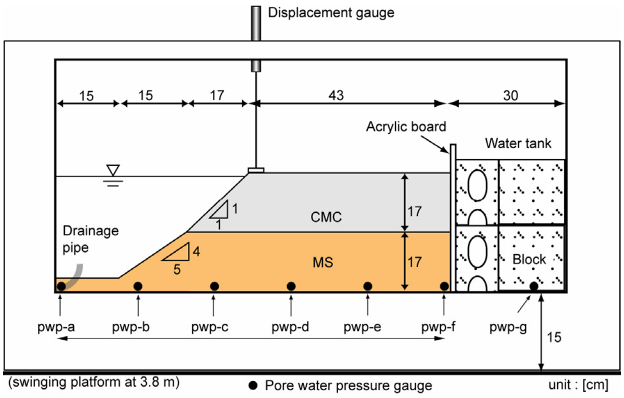


**Fig.1** Model configuration in the model scale and the locations of transducers

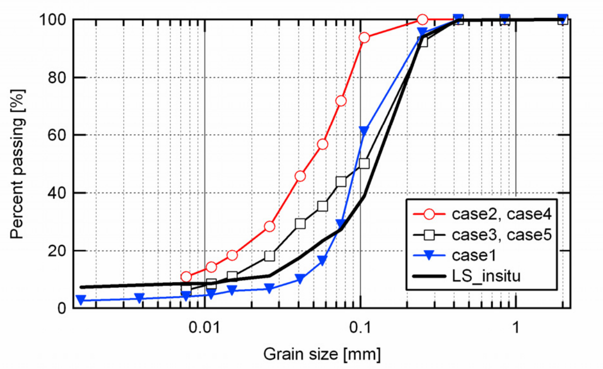


**Fig.2** Grain size distributions of MS layer

**Table 1** Physical properties in CMC and MS layers

| Soil samples | Case | Soil particle density [g/cm$^3$] | Hydraulic conductivity [cm/s] | Dry density [g/cm$^3$] | Void ratio |
|---|---|---|---|---|---|
| MS | case1 | 2.655 | 1.05e-3 | 1.477 | 0.691 |
| | case2 | 2.695 | 6.99e-5 | 1.488 | 0.811 |
| | case3 | 2.666 | 5.68e-5 | 1.683 | 0.584 |
| | case4 | 2.695 | 6.99e-5 | 1.488 | 0.811 |
| | case5 | 2.666 | 5.68e-5 | 1.683 | 0.584 |
| CMC | case1 | 2.676 | 1.77e-5 | 1.060 | 1.525 |
| | case2 | 2.699 | 1.39e-6 | 1.085 | 1.486 |
| | case3 | 2.699 | 1.39e-6 | 1.085 | 1.486 |
| | case4 | 2.699 | 1.39e-6 | 1.085 | 1.486 |
| | case5 | 2.699 | 1.39e-6 | 1.085 | 1.486 |

**Table 2** Undrained shear strengths in MS layer

| Case | Depth [m] | Shear stress [kPa] |
|---|---|---|
| case2 | 2.0 | 5.0 |
| | 6.0 | 6.4 |
| case3 | 2.0 | 12.7 |
| | 6.0 | 11.0 |
| case4 | 2.0 | 9.4 |
| | 6.0 | 5.7 |
| case5 | 2.0 | 11.4 |
| | 6.0 | 12.7 |

Depth: test depth in prototype scale

## 3. TEST RESULTS OF CENTRIFUGE MODELING

All results are illustrated in prototype scale. The results in cases 1, 3 and 4 are mainly discussed here.

### (1) Case 1

**Fig. 3** shows the time histories of pore water pressure and vertical displacement on the shoulder in case 1. The zero time means the time when the centrifugal acceleration reaches 50g. The pore water pressure at "pwp-a" corresponds to the water level. The pore water pressure at "pwp-e, f and g" did not decrease largely due to low permeability of the ground. After about 8 days from the start of decline in the water level, piping at the slope of MS layer was observed. **Fig. 4** shows the photos of outflow from MS layer after the test. Some cracks were observed in the CMC in **Fig. 4**. Nevertheless, the vertical displacement on the shoulder was very small and the slope failure was not observed in case 1.

### (2) Case 3

In case 3, cracks in CMC layer were observed when 46 g was applied before the drainage. **Fig. 5** shows the time histories of pore water pressure and vertical displacement on the shoulder in case 3. After about 5 days from the start of decline in the water level, some targets on the MS slope were flushed away with piping in **Fig. 6** (a). The piping accelerated the deformation rate in **Fig. 5**. After about 7 days, the piping progressed in **Fig. 6** (b) and the displacement rapidly increased in **Fig. 5**. Finally the slope failed along the red line in **Fig. 6** (c). Some cracks were observed in the CMC layer and the shear band passed through both the CMC and MS layers.

### (3) Case 4

In case 4, cracks in CMC layer were observed when 25 g was applied before the drainage. **Fig. 7** shows the time histories of pore water pressure and vertical displacement on the shoulder in case 4. After about 9 days from the start of decline in the water level, the deformations of noodles toward water side were observed along the red lines A and B in **Fig. 8** (a) and the displacement rapidly increased in **Fig. 7**. Finally the slope failed along the red lines C and D in **Fig. 8** (b). No piping was observed in case 4.

### (4) Discussion

The piping on MS layer was observed in cases 1, 3 and 5. In the case 1, the slope failure was not observed. In the cases 3 and 5 with piping, the slope progressively failed during piping. In the cases 2 and 4 without piping, on the other hand, the slope rapidly

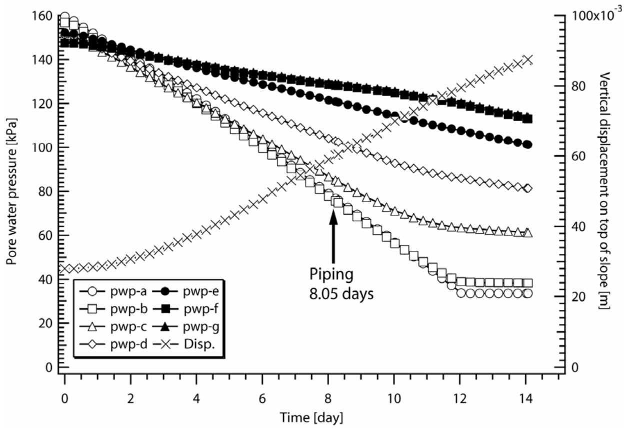

**Fig.3** Time histories of pore water pressure and vertical displacement on the shoulder in case 1

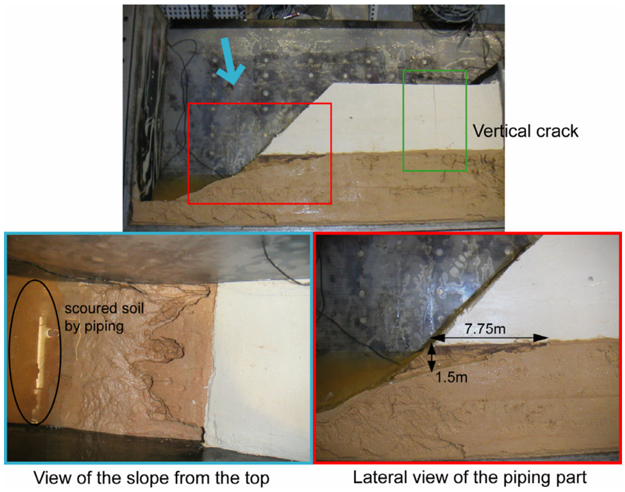

**Fig.4** Outflow from MS layer after the test in case 1

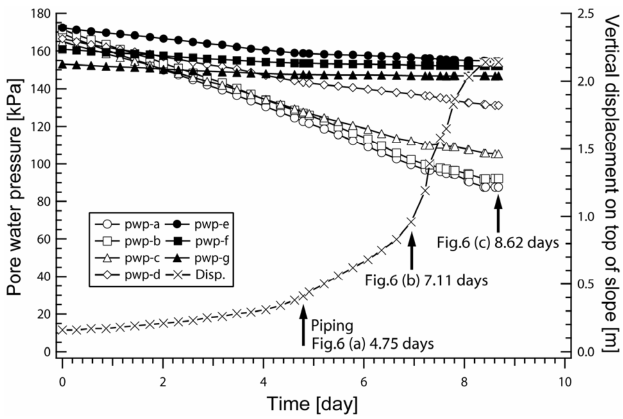

**Fig.5** Time histories of pore water pressure and vertical displacement on the shoulder in case 3

failed. **Fig. 9** summarizes the time histories of vertical displacement on the shoulder in all cases. In case 3, the displacement rate on the shoulder during piping (P3, 4.75-6.94 days) was 0.251m/day and that during failure (F3, 6.94-8.07) was 0.947m/day. In case 4, the displacement rate on the shoulder during failure (F4, 8.68-9.83 days) was 0.957m/day. The occurrence of piping and the process of slope failure strongly depended on the grain size distribution and

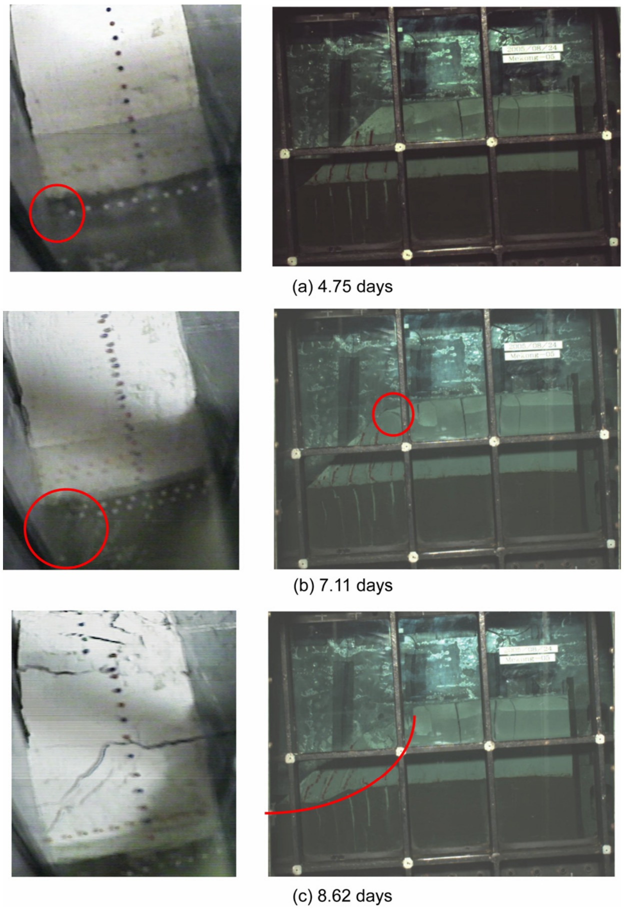

**Fig.6** Targets on MS layer and deformation of the slope in case 3

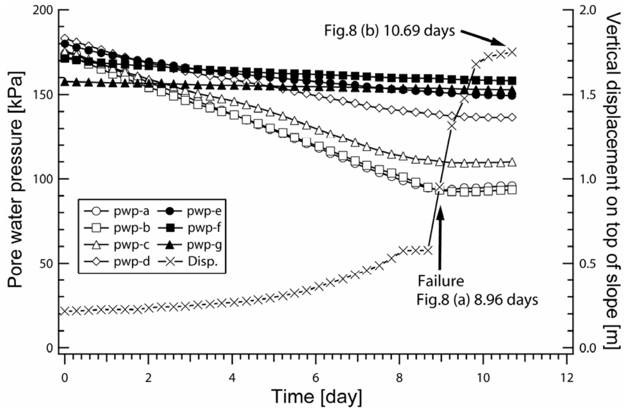

**Fig.7** Time histories of pore water pressure and vertical displacement on the shoulder in case 4

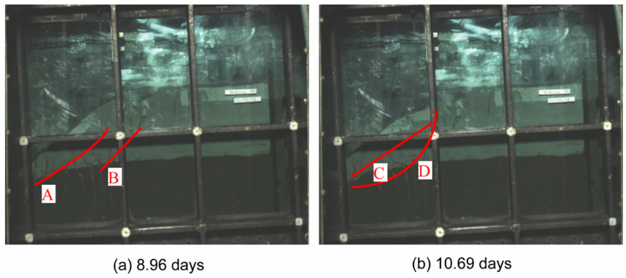

**Fig.8** Deformation of the slope in case 4

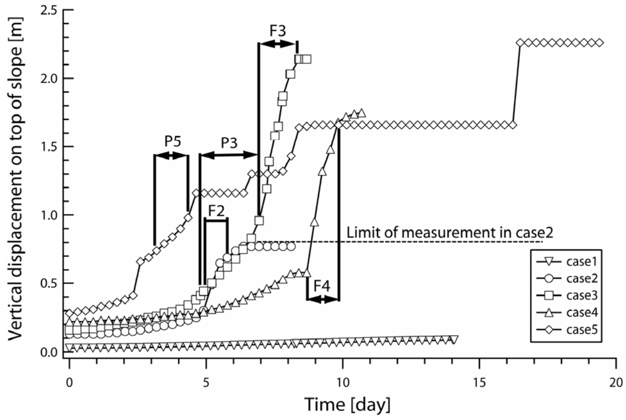

**Fig.9** Time histories of vertical displacement on the shoulder in all cases

strength of back ground. The occurrence of piping caused the progressive failure of riverbank. Although the undrained shear strength of MS layer in case 3 was larger than that in case 4 in **Table 2**, the significant deformation in case 3 started earlier than case 4. It is possible that the piping causes the decrease in the shear stiffness and strength of MS layer.

The unconfined compression strength of the CMC was about 60 kPa less than the in-situ strength of LC layer[2)]. Moreover, there are no data of the in-situ strength of LS layer. Further quantitative investigation is needed in order to discuss the stability of in-situ riverbank slope.

## 4. CONCLUSIONS

The effect of the water level dropping on the riverbank stability was qualitatively examined with the centrifuge modeling. The stratum of the model ground is composed of upper clay layer (CMC) with the depth of about 7m and lower silty-sand layer (MS). The experimental results showed that the water level dropping caused the slope failure of the riverbank. Piping on the slope of MS layer was observed in some cases. The occurrence of the piping depends on the particle size gradation of MS layer, and causes the progressive failure of the slope.

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in all parts.

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