Experimental Study on the Similarity of Embankment Scouring by Overflow Under Centrifugal Field

Kyushu Institute of Technology, Student Member, ○Jinting WAN, Xu Huang, Masashi Ikeda
Kyushu Institute of Technology, Regular Member, Akihiko Hirooka, Hideo Nagase

1. Introduction

On September, 2015, due to the double effects of typhoon No.17 and No.18, rainstorm attracted the Kanto area and Tohoku area. For the Kinugawa River, as the continuous rain, a large amount of rainwater gathered together, and the river water level rose to the top of the embankment, then the embankment was badly damaged and the disasters were happened, it led to a massive loss of properties and human lives. Embankments are always playing an important role in protection of our properties and our lives, which are applied to resist the flood flowing. So it's important to build high strength embankments to withstand powerful overflow, but it's necessary to understand the differences of damage degrees on different conditions, and in this research, seven cases were carried out on researching the damage mechanisms and looking for whether there are some similarities exist, which have been done under the centrifugal field due to the overflow acting on models of the embankment slope.

2. Centrifuge Modeling Test

In order to clarify the overflow damage mechanisms on the embankment and find out the similarity of scouring phenomenon in the centrifugal field, the centrifuge modeling test is used as the research method. The experiment system is shown in Fig.1. In this research, seven cases were carried out which including case a~c, case 1~4. On the other hand, three soil samples were used which sample 1 with silt:Toyoura sand = 1:2 (used in case a, b, c), sample 2 with Silica sand #7: DL-clay = 8:1(non-plastic soil and used in case 1, 3) and for sample 3 with Silica sand #7: DL-clay = 1:10 (non-plastic soil and sued in case 2, 4). In this research, case a to case c were used for seeking damage mechanisms, case 1 and case 4 were planned for the research of scouring phenomenon similarity in centrifugal field. To research the similarity of scouring phenomenon, other influence factors must be uniform in the different compared cases which with different soil samples by using different fluids, one of them that we need to control is the seepage velocity and make the seepage become same in centrifugal field, where the seepage velocity is N times faster than the one which in the gravity field, one way to control this is to change the effective particle size, according to Goodings' research, there is opportunity for decreasing the velocity of seepage in the model by reducing the effective particle size of the prototype soil for use in the model using the ratio $D_{10m}/D_{10p}=1/\sqrt{N}$. Another method is to increase the viscosity of the fluid, the seepage velocity is expressed as $k=K(\rho_w g/\mu)$ with absolute premeability coefficient $K$and viscosity of the fluid μ, then if applying Darcy's law, the similarity rate will be like $v_p/v_m=[K_p(\gamma_w)_p\mu_m]/[\rho_w(Ng)\mu_p]=\mu_m/(N\mu_p)$. Here, the fluid in prototype is water, therefore, if changing the viscosity of the fluid in model into N times of the prototype, it's possible to keep the seepage velocity uniform. The seepage velosity of the fluid which by using 0.6% METOLOSE is just 1/32 times of the water basing on the results of permeability test, so the seepage velocity will be same both in model and in prototype if in 32G centrifugal field. Besides, the effective particle size of sample 2 is almost $\sqrt{32}$ times larger than sample 3. Therefore, case 1 with the cond-

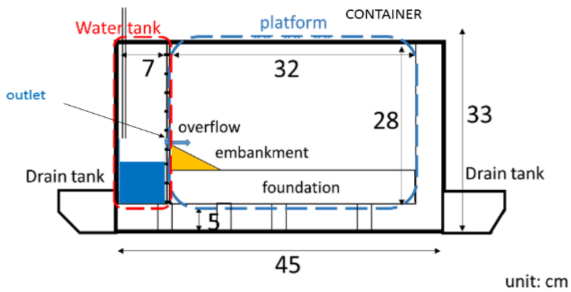

Fig.1 Experiment System

Table.1 Cases and Conditions

Case	Fluid	Soil Sample	Centrifugal Acceleration(G)	Model Height(cm)	Drainage Method	Prototype Height(m)	Slope Gradie
a	Water	1	50	4.0	Continuous	2.0	1:2
b			36	5.6			
c			28	7.2			
1	0.6% METOLOSE	2	32	6.2	Discontinuous		
2		3					
3	Water	2					
4		3					

Key Words : overflow, embankment, damage machanism, similarity, centrifuge field, centrifuge modeling test.

〒804-8550 福岡県北九州市戸畑区仙水町 1—1【九州工業大学】 TEL：093-884-3113

itions of METOLOSE and the soil sample 2, case 4 with the conditions of water and the soil sample 3, both of cases have same seepage phenomenon. The research of similarity of scouring phenomenon can be analyzed by these two cases. As the cases and the conditions of expriment are shown in the Table.1. It's necessary to stress that in this research the overflow was occurred by using water and the 0.6% METOLOSE with draining fluid continuously or discontinuously, and the former means draining fluid without stop until the embankment was damaged, the latter means draining fluid every 5s and stopping 30s, and then keeping doing this repeatedly until the embankment was damaged.

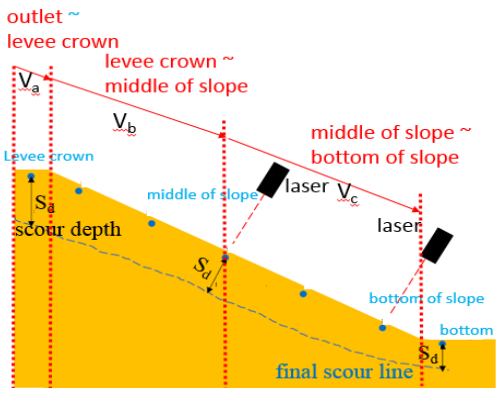

Fig.2 Simplified Model

3. Results and Discussions

For the results of this research from case a to case c which were aimed at seeking damage mechanisms, all of three cases nearly had similar phenomena of scouring, the initial scour happened mostly at the bottom of the slope after overflow, then scour developed continually towards the levee crown, and finally the levee crown got overall damaged. For case 1 and case 4, we main used them for finding out scouring phenomenon similarity, case 2 and case 3 for comparisons with case 1 and case 4, but here we main give out the data of case 1 and case 4. In this research, the lasers were set to measure the scour depth every time after draining water like Fig.2. For the flow velocity, we used V=L/t(L:length of slope;t=time) to calculate(V_a, V_b, Vc). In order to analyze similarity of scouring, we need to introduce the dimensionless tractive force, which could be calculated by equation $\tau^*=v^2C_D/[2(\sigma/\rho-1)gd]$,V:flow velocity; σ:soil particle density; ρ:flow density; d:soil particle size, for the two cases, it's shown in Table.2. According to the data from the lasers, we can draw the curves of each case like Fig.3, and then we can draw the approximate line and get the expression, we know the coefficients of x represent the scour depth speed in every 5s, so we can calculate the scour depth speed of every second like the red part of the graph. At the middle of slope, the ratio of scour depth speed is 0.17164/0.01398=12.28, and the ratio of dimensionless tractive force is 41.797/3.297=12.68, at the bottom of slope, the ratio of scour depth speed is 0.14042/0.01650 = 8.51, and the ratio of dimensionless tractive force is 108.589/12.031=9.03. So we found out the ratio of scour depth speed is nearly equal to the ratio of dimensionless tractive force.

Table.2 Calculations of V and τ^*

Case 1(soil sample 2 with METOLOSE)			
place	v		τ^*
Outlet~levee crown	v_a	0.20	0.264
Levee crown~middle of slope	v_b	0.83	3.297
Middle of slope~bottom of slope	v_c	1.65	12.031
Case 4 (soil sample 3 with water)			
Place	v		τ^*
Outlet~levee crown	v_a	0.30	1.675
Levee crown~middle of slope	v_b	1.45	41.797
Middle of slope~bottom of slope	v_c	2.30	108.589

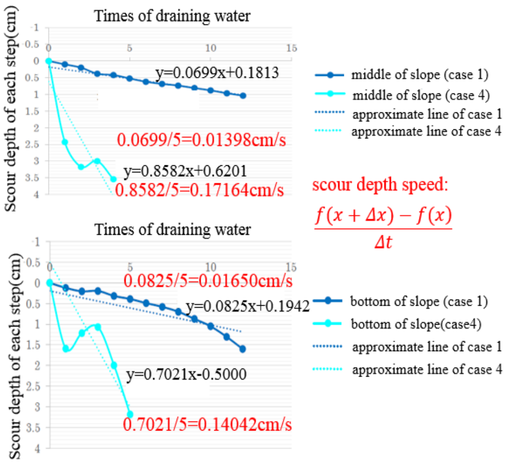

Fig.3 Curves of Case 1 and Case 4

4. Summaries

1. About damage mechanisms

Firstly, the overall slope got scoured widely and then along the weak positions, the initial gully generated. After that, the gully gradually developed to a ladder shape and became deeper, then the development of gully towards the levee crown and broadened at the same time. Finally, the overall levee crown was damaged. For this unsaturated case, the development of gully was nearly along the slope-parallel line.

2. Similarity of the scouring phenomenon

If controlling the seepage phenomenon same in the centrifugal field, the scouring phenomenon of the compared models, which used the non-plastic soil samples, had a similarity between the scour depth and the dimentionless tractive force, and it's the ratio of the dimensionless tractive force is almost equal to the ratio of the scour speed.