# COMPUTATION OF THE LEVEE BREACH BY OVERFLOW

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As for the levee breach, it is known that overflow is the major factor. Parameters about the levee breach by overflow have been empirically connected. For example, breach width and river width have been investigated so far. However, it is difficult for these methodologies to apply to various areas and to explain the mechanism of the levee breach by overflow. Therefore it is necessary to analyze the levee breach by overflow based on the theoretical equations. Thus this study aims to develop the fundamental method to calculate the process based on the one dimensional shallow water equation and sediment transport equation. In the sediment transport equation, only suspended sediment is deal with because suspended sediment exceeds bed load on the downstream slope of the levee. The computational results were compared with those of experiments conducted by using the actual old levee by Ministry of Land, Infrastructure, Transport and Tourism(MLIT). The comparison shows good agreement qualitatively.

***Key Words :*** *Levee breach, Overflow, Scouring, Suspended sediment*

## 1. INTRODUCTION

Traditional design philosophy for flood-control levee is that levee design should be decided by allowing flood which has possibilities to occur once in several decades. The scale of levee design is generally assessed by using annual exceedance probability of design rainfall quantities and is decided through the level of importance for each river. The level of importance is generally classified the major section of the first grade rivers into class A or B and the other sections of the first grade rivers and the second grade rivers into class C or D. The annual exceedance probability of design rainfall quantities are provided that of the class A are over two hundreds years, of the class B are over one hundred under two hundreds years, of the class C are over fifty under one hundred years, of the class D are over ten under fifty years and of the class E are under ten years. So, levees are weak for the overflow. Actually the overflow is the major factor for the levee breach. In order to consider accurate protective measures, it is necessary to understand the levee breach mechanism by overflow.

In the past, parameters about the levee breach by overflow had been related empirically in many studies. For example, MacDonald and Langridge-Monopolis (1984) connected breach shape, breach size, breach development time and peak outflows empirically[1)], Wahl (1998) connected breach width with time of failure empirically[2)]. However, it is difficult for these methodologies to apply to various areas and to explain the mechanism of the levee breach by overflow. Therefore it is necessary to analyze the levee breach by overflow based on the theoretical equations.

Thus this study aims to develop the fundamental method to calculate the process based on the one dimensional shallow water equation and sediment transport equation.

## 2. METHOD OF NUMERICAL ANALYSIS

### (1) Flow computation

One dimensional shallow water equations for continuity and momentum are written as follows,

$$\frac{\partial \eta}{\partial t}+\frac{1}{B}\frac{\partial Q}{\partial x}=0, \qquad (1)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\frac{Q^2}{A}=-gDB\frac{\partial \eta}{\partial x}-\frac{n^2 g}{D^{7/3}}\frac{|Q|}{B}Q \qquad (2)$$

where $\eta$ = water surface elevation, $Q$ = flow discharge, $B$ = width, $A$ = cross section area of water flow, $g$ = gravitational acceleration, $D$ = depth of water, $n$ = Manning's roughness coefficient.

These equations were solved by the finite difference method. The convective term is expanded by the upwind scheme which enables stable computation of the transition from the super critical flow on the levee slope through the hydraulic jump to the subcritical flow after the toe of the levee slope.

### (2) Sediment transport computation

In the super critical flow, the shear velocity is much larger than the settling velocity of the levee surface material. Therefore we considered only suspended sediment transport as the first approximation. The transport equation is given by,

$$\frac{\partial \overline{C}}{\partial t}+\frac{1}{BD}\frac{\partial(\overline{C}Q)}{\partial x}=\frac{\overline{C}}{BD}\left(\frac{\partial Q}{\partial x}\right)+\frac{\partial}{\partial x}\left(\overline{\varepsilon}_x\frac{\partial \overline{C}}{\partial x}\right)-\frac{w_0}{D}C_{bottom}+\frac{w_0}{D}C_a \qquad (3)$$

where $\overline{C}$ = volumetric suspended sediment concentration averaged over depth, $w_0$ = settling velocity, $\overline{\varepsilon}_x$ = diffusion coefficient at average of depth. The third and fourth terms of right handside indicate settling flux and erosion flux, respectively.

Although we are dealing with the vertically averaged concentration, the settling flux requires the bottom concentration which was estimated by assuming Rouse expression shown by,

$$C_{bottom}=\overline{C}\left[\frac{1}{1-z_a^*}\int_{z_a^*}^{1}\left[\left(\frac{1-z^*}{z^*}\right)\left(\frac{z_a^*}{1-z_a^*}\right)\right]^{R_0}dz^*\right]^{-1} \qquad (4)$$

where $a$ = reference height, $R_0(\equiv \sigma_s w_0/\kappa u_*)$ = Rouse number, $\sigma_s$ =eddy flow Schmidt number, $\kappa$ =Karman number, $u_*$ =friction velocity.

The erosion flux was evaluated by using van Rijn's expression(1993) as,

$$C_a=0.015 p_d \frac{d}{a}\frac{T_*^{1.5}}{d_*^{0.3}}, \quad T_*=\frac{(\theta-\theta_c)}{\theta_c} \qquad (5)$$

where $d$ = sediment diameter, $d_*$ = non-dimensional diameter, $\theta$ = Shields parameter, $\theta_c$ = critical Shields parameter, $p_d$ = existence portion of the considering diameter. Critical Shields parameter was decided by considering cohesive after Righetti and Lucarelli (2007)[3]. $\overline{C}$ , $C_a$ and $C_{bottom}$ are volumetric concentrations. $C_a$ was calculated about thirty times as small as in case of considering cohesive.

It is possible to assess whether bed load exceeds suspended sediment or the opposite by using fraction of settling and friction velocities. Following condition is formed where suspended sediment exceeds bed load[4].

$$\frac{u_*}{w_0}>1.67 \qquad (6)$$

It was decided that only suspended sediment was dealed with because $u_*/w_0>>1.67$ on the slope of the levee.

### (3) Morphological change

The elevation of the levee surface, $z_b$ changes by the difference of two fluxes of settling and erosion like,

$$\frac{\partial z_b}{\partial t}=\frac{w_0}{1-\gamma}\left(C_{bottom}-C_a\right) \qquad (7)$$

where $\gamma$ = porosity of the levee material. This equation indicates erosion and sedimentation occur for $C_{bottom}<C_a$ , $C_{bottom}>C_a$ respectively. For the simplicity of the computation, the morphological change was not reflected for the flow computation.

## 3. LEVEE BREACH EXPERIMENT

MLIT conducted levee breach experiments by using actual old levee of the Sukawa, Yamagata Prefecture, Japan in December, 2006. The evolution of levee topography is shown in **Fig.1**. The surface layer of the levee was made by the mixture of sandy silt and pebbles. The discharge of the overflow was 1 $m^3/s$ for the width of 4 m. The discharge was kept for about 2 hours. The deformation of the levee shape is shown in **Fig.2**.

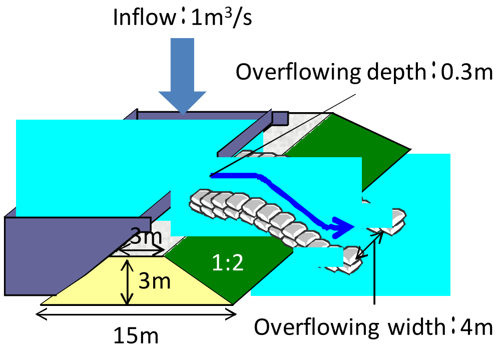


**Fig.1** Experimental setup of the levee scouring by overflow after materials given by MLIT[5].

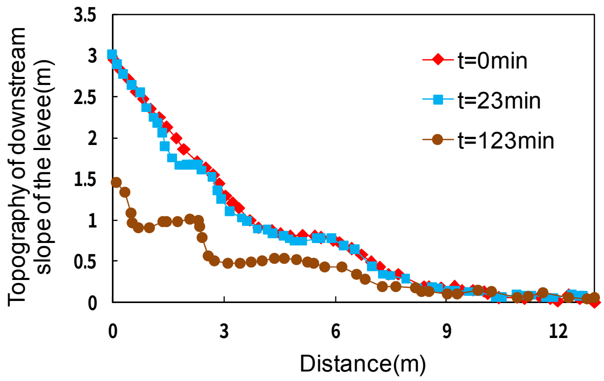


**Fig.2** Evolution of levee topography in the course of overflow experimentation after materials given by MLIT[5].

In this experiment, overflow was separated to several spans in order to investigate the surface condition. **Figure 3** is the picture just after starting to overflow. Overflow started to scour around the upside of the levee slope just after starting to overflow. And, the sideslope of the levee fell down several times during overflow. Finally the levee was broken at summing up time 123 min. **Figure 4** is the picture just after breach.

## 4. CONDITION OF COMPUTATION

**Figure 5** shows computation conditions which correspond to MLIT's experiment. Two cases of particle diameter, 600 $\mu$m which corresponds to the surface material, and 60 $\mu$m for inner material were conducted. The time step of 0.0001 sec is selected to satisfy the Courand-Friedrichs-Lewy stability condition for the grid interval of 0.1 m.

**Fig.3** Photograph at t=0 min taken by MLIT[5].

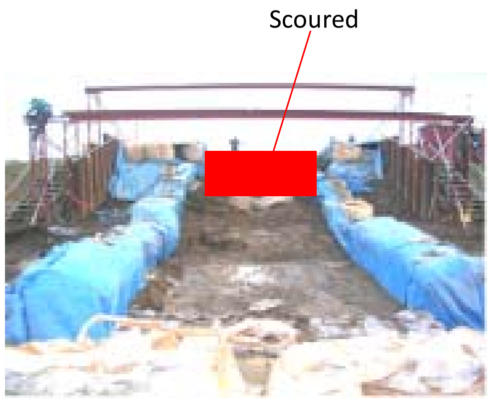


**Fig.4** Photograph at t=123 min taken by MLIT[5].

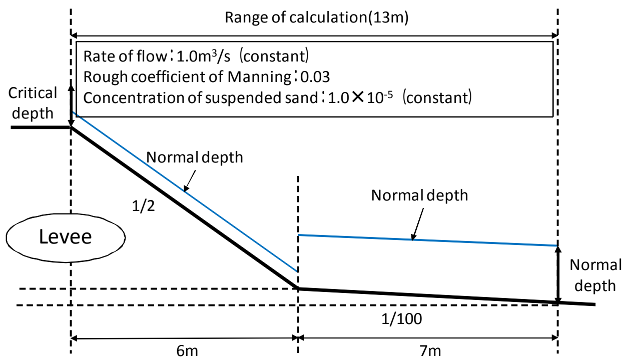


**Fig.5** Condition of calculation[5].

## 5. RESULTS AND DISCUSSION

### (1) Suspended sediment concentration

Figure 6 and 7 show the distributions of $C_a$, $C_{bottom}$ and $\overline{C}$ when the flow is steady state. Erosion occurs where $C_a > C_{bottom}$ and sedimentation occurs where $C_a < C_{bottom}$.

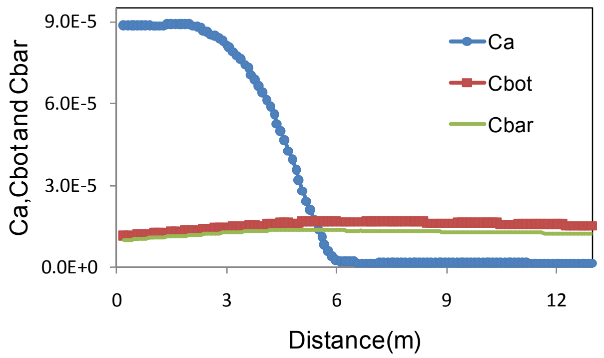


**Fig.6** Calculated profiles of concentrations with horizontal distance, in case with sediment diameter 60 $\mu$ m. Point x= 6 m is levee toe.

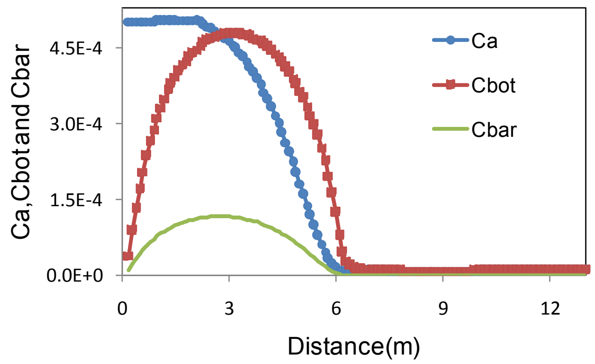


**Fig.7** Calculated profiles of concentrations with horizontal distance, in case with sediment diameter 600 $\mu$ m. Point x= 6 m is levee toe.

### (2) Morphological change

**Figures 8** and **9** show comparisons of the morphological change at t= 23 min and 123 min respectively. The surface layer of the levee was scoured at t= 23 min and the whole levee was completely broken at t= 123min.

Although the computation results underestimate the experimental results, erosion and sedimentation areas in computation correspond with those in experiment respectively.

## 6. CONCLUSIONS

We proposed simple model of suspended sediment transport which considers erosion and sedimentation fluxes independently. The real scale experiment results were reproduced by our computation qualitatively.

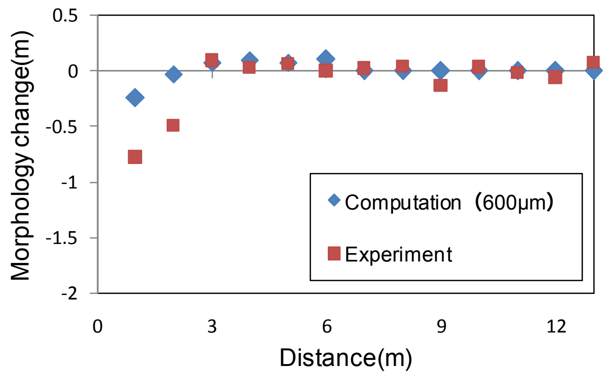


**Fig.8** Morphological change at t= 23min.

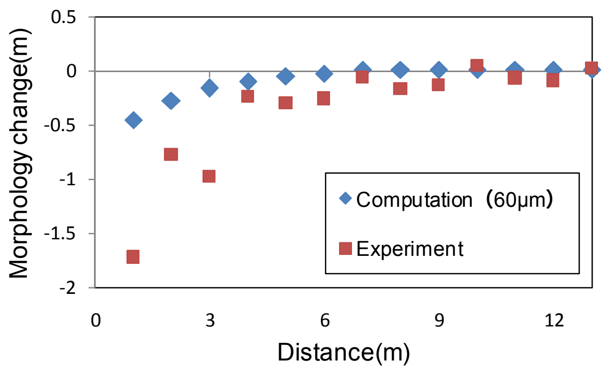


**Fig.9** Morphological change at t= 123min.

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