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Oversea Learning Class

of Feng Chia University

Collaboration with Kyoto University

Kyoto, Japan

River embankment failure by overtopping water and resultant flood and sediment hydrographs

Prof. Hajime NAKAGAWA

Disaster Prevention Research Institute,

Kyoto University, Japan

Contents

1. Background

River embankments are principally made of sediments from the several reasons (economic, easy to get the material, easy to repair, easy to stick to foundation ground, easy to modify, good for environment, etc.）.

Cause of river EMB failure

Phenomenon	Cause of REB failure	Form of failure
Overtopping	・Abnormal flood ・Water level rise due to bridge pier, weir, etc. ・Short of river EMB height	Erosion at the top and toe of the slope
Sliding	・Seepage of rainwater into river EMB body ・Seepage of river water due to water level rise	Slope siding
Erosion	・Water collide portion ・Steep slope river	Erosion at the toe of front and back side slope
Leakage of water	・Insufficient protection of river EMB against seepage ・Existence of water channel in the river EMB body	Piping failure boiling

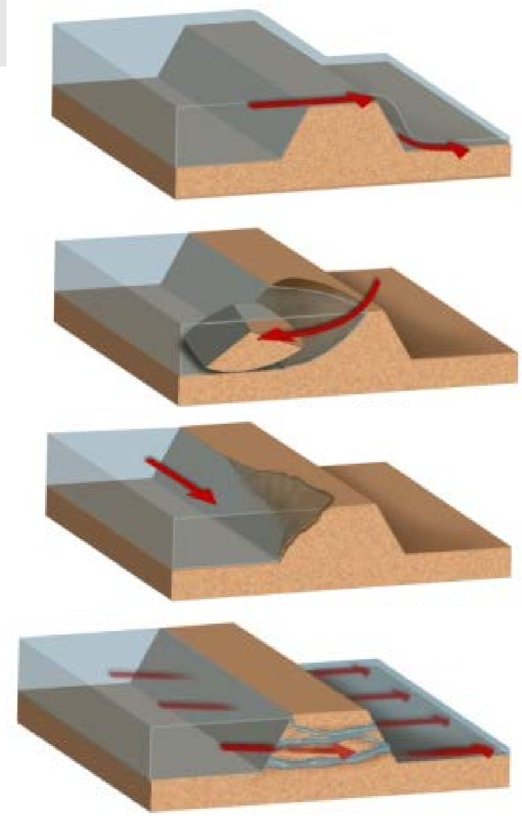

Illustration by Zina Deretsky/National Science Foundation

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Classification of failure form of REB

Damaged form	overtopping	not overtopping	total
Breach	183 (75%)	62 (25%)	245
Partial collapsed (riverside)	26	184	210
Partially collapsed (residential side)	19	37	56
Not damaged	78	0	78
total	306	283	589

Among the cause of river EMB breach, 75% is due to overtopping.

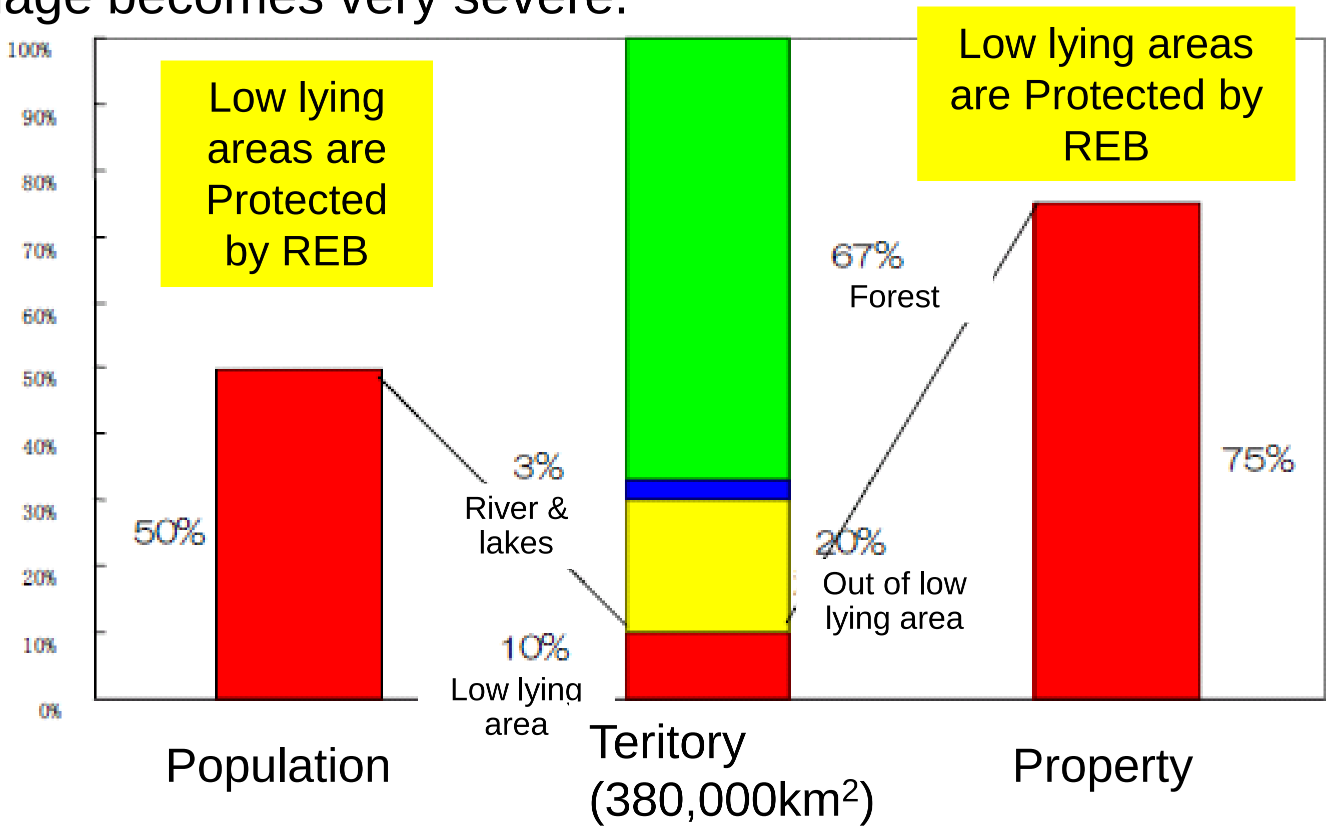
Bank breach of the Kinu River, branch of the Tone River, 2015

1,339 persons were rescued by helicopter.

Photo: NHK

Cities are locating on low-lying area in Japan

In Japan, 50% of population and 75% of property exist in the flood prone area that is 10% of the Japan territory. Therefore, once big flood and bank breach happen, damage becomes very severe.



Landuse in Japan

2. Objectives of this research

Background

1. Precise Cost/Benefit evaluation is indispensable for the investment into the flood improvement measures against river bank breach.

2. Development of evaluation method of effective countermeasures against river bank breach due to over topping of river water has been required.

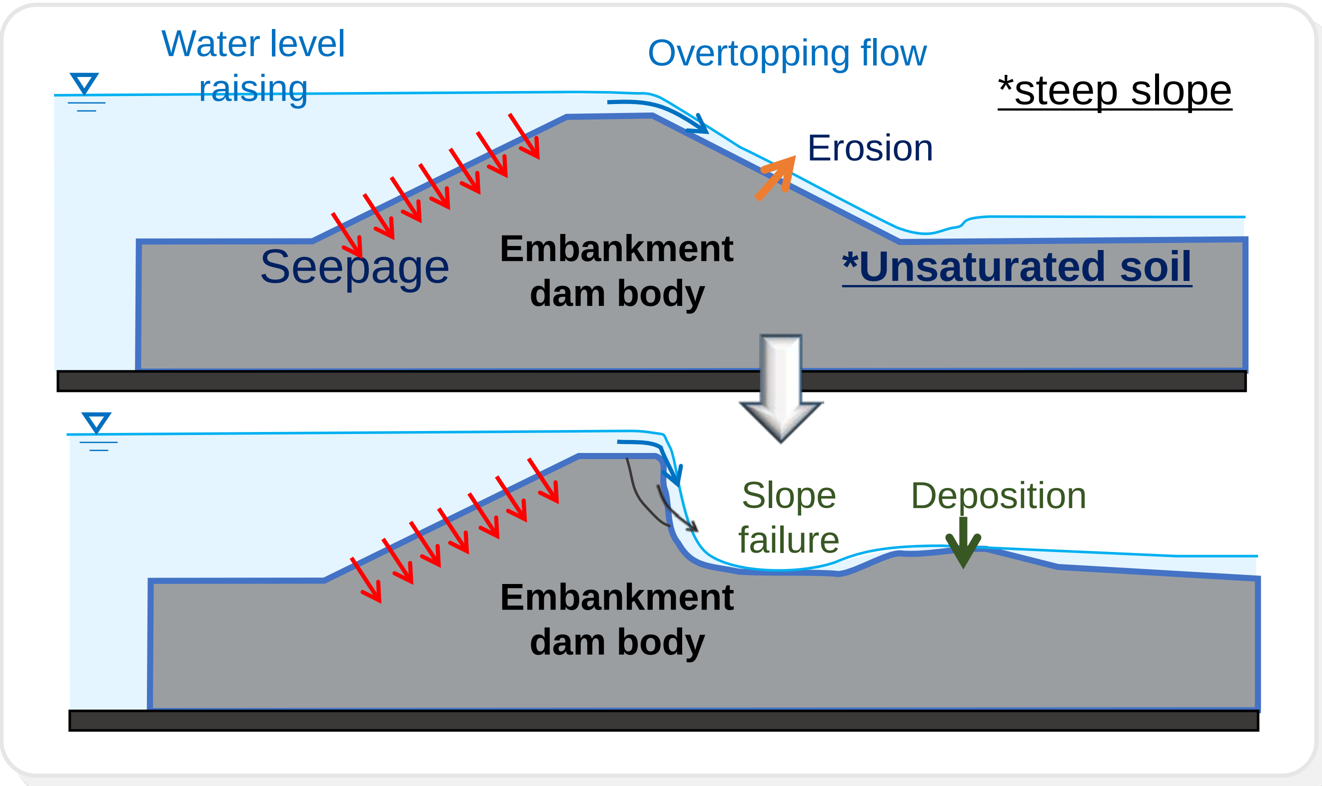
We have been developing the river embankment failure model that can evaluate the erosion process of river embankment due to overtopping. In this study, we carried out the experiments on river embankment failure due to overtopping and got the resultant water and sediment hydrographs.

River EMB of the Jamuna River, Bangladesh (non-cohesive material)

The main objective of this study is to verify the developed model through experimental results from the viewpoint of flood and sediment discharges generated by the river bank breach.

- This study focuses on
  - erosion due to overtopping flow
  - non-cohesive homogeneous sediments
  - water and flood hydrographs due to bank breach

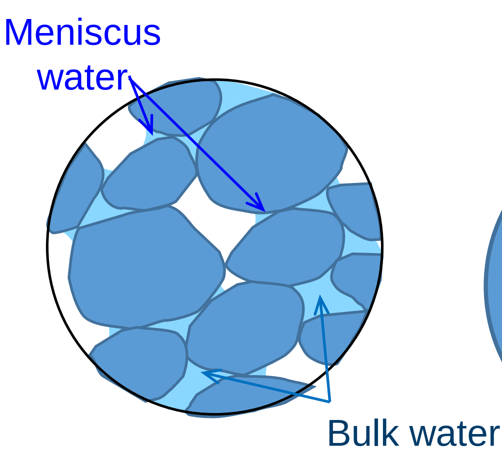
3. Structure of the model

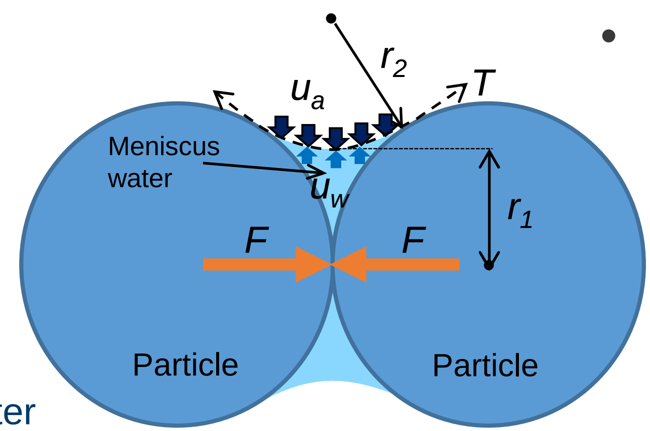


The process of embankment breach by overtopping is very complex because it involves mutually dependent interactions between fluvial hydraulics, sediment transport and embankment stability.

Unsaturated Soils

- In some circumstances, the water in the soil will form meniscus between particles.
- The internal stress is induced by the capillary tension of meniscus water clinging to the contact point of soil particles and acts so as to connect the soil particles tightly.
- Surface tension and interface curvature give rise to a difference between pore-water pressure (u_w) and pore-air pressure (u_a) that is generally equated to matric suction ($=u_a - u_w$).





- Suction：u_a-u_w

$$u_a - u_w = T\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$$

u_a ： pore-air pressure

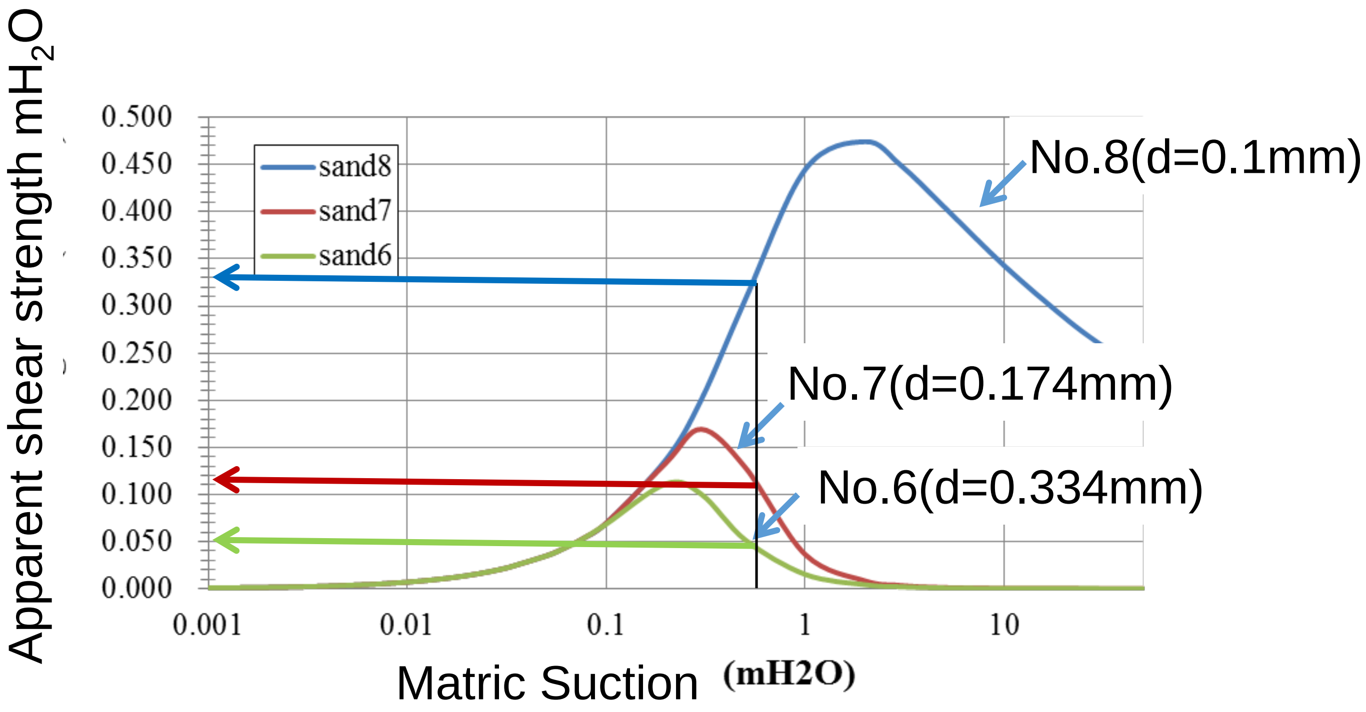
u_w ： pore-water pressure

r_1, r_2 ： radius of curvature of meniscus

T ： surface tension of meniscus water

Fig. Scheme of Unsaturated Soils

Resistance shear stress due to suction is …



In the unsaturated condition, sediment of smaller sized diameter is more difficult to be eroded due to suction.

Critical shear stress of the sediment particles (τ_c)

$$\tau_c \equiv \rho u_{*c}^2 \approx g(\sigma - \rho)d$$

Critical shear stress is almost proportional to sediment diameter. In the saturated condition, smaller the sediment diameter, smaller the critical shear stress, resulting in that the smaller sediment is easy to move and easy to be eroded.

From the viewpoint of sediment diameter, critical shear stress (under the saturated condition) has an inverse tendency to the apparent resistance shear stress due to suction (under the unsaturated condition).

The modeling of this mechanism determines the success or failure of the results simulated.

Governing Equations

1. Seepage analysis in the unsaturated EMB
    + Richards' equation

2. Overtopping flow analysis on the unsaturated EMB
    + Depth averaged model

3. Erosion and deposition analysis on the unsaturated EMB
    + Pick-up rate model（Nakagawa & Tsujimoto, 1985）
        + effect of suction (Vanapalli et al.,1996)

4. Critical shear stress
    + Egiazaroff model (1965) + effect of suction

5. Sediment transport analysis
    + Motion of equation for each sediment particle (Lagrangian model)

6. Topographical change due to erosion and deposition
    + Continuity equation of bed sediment

7. Slope stability analysis
    + Simplified Janbu method

In detail, please refer "Advances in River Sediment Research", CRC Press, 2013

4. Experiments

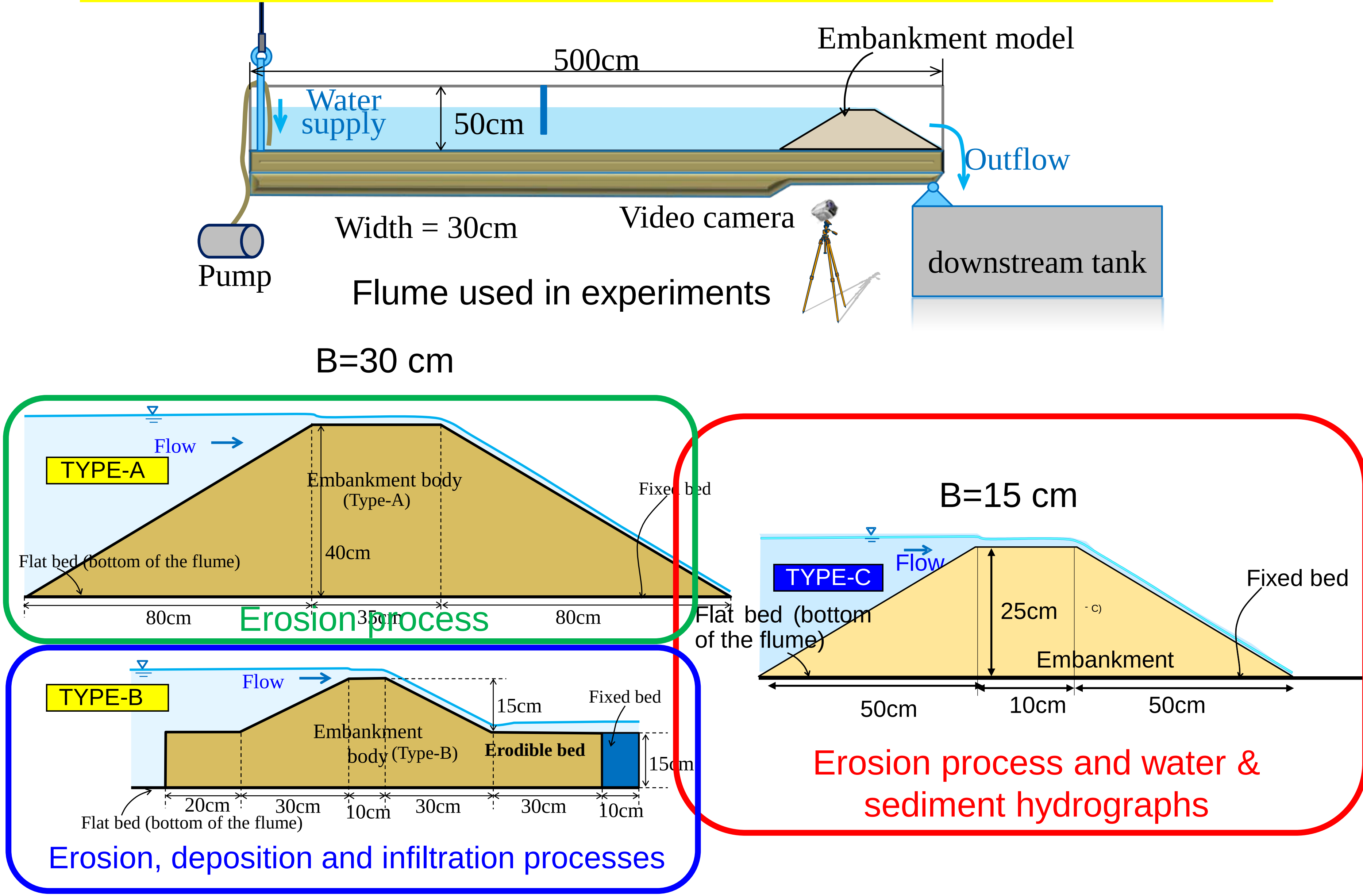


Figure 1. Experimental flume and side view of embankment shapes (TYPE-A , B and C).

Experimental Conditions for Type-A, B, C

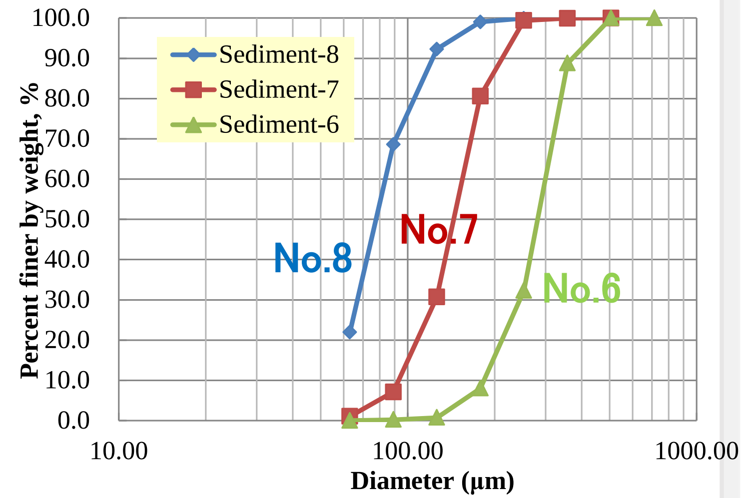
Table – Experimental cases

Case No.	Dam Type	Supply discharge (cm^3/s)	Sediment type	(mm)	Initial moisture content of dam (%)	Porosity of dam body
1	A	7840.0	No.6	0.334	13.0	0.51
2			No.7	0.174	11.5	0.51
3			No.8	0.100	12.0	0.55
4	B	1172.0	No.7	0.174	6.8	0.55
5		-	No.7	0.174	6.8	0.55
6	C	1150.0	No.7	0.174	12.8	0.55

Case 6: water & sediment hydrographs, erosion processes

Case 5: only for seepage experiment (no overtopping)

(Non cohesive sediment)



Grain-side distribution of EMB

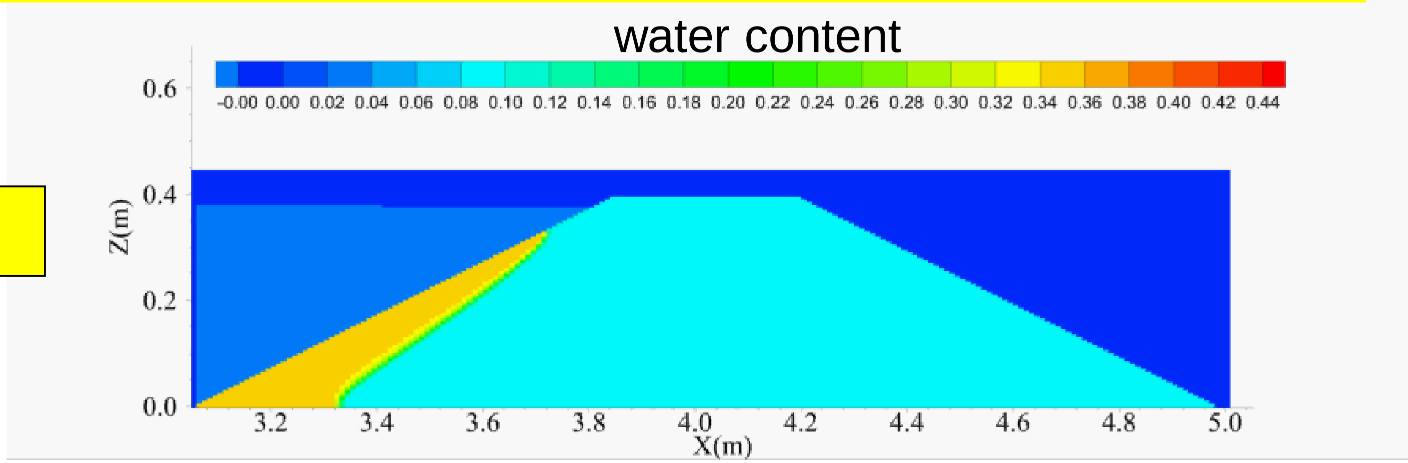
Each sediment size & water conductivity (Dam Type-A,B,C)

Parameters	Sediment-No.6	Sediment-No.7	Sediment-No.8
K_s(m/s)	$2.15*10^{-4}$	$8.75*10^{-5}$	$1.56*10^{-5}$
d_m(mm)	0.334	0.174	0.100
d_{50}(mm)	0.285	0.146	0.078

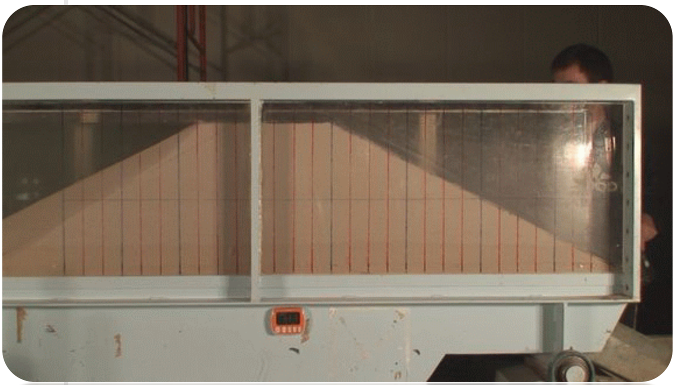
5. Results

(Dam Type-A)

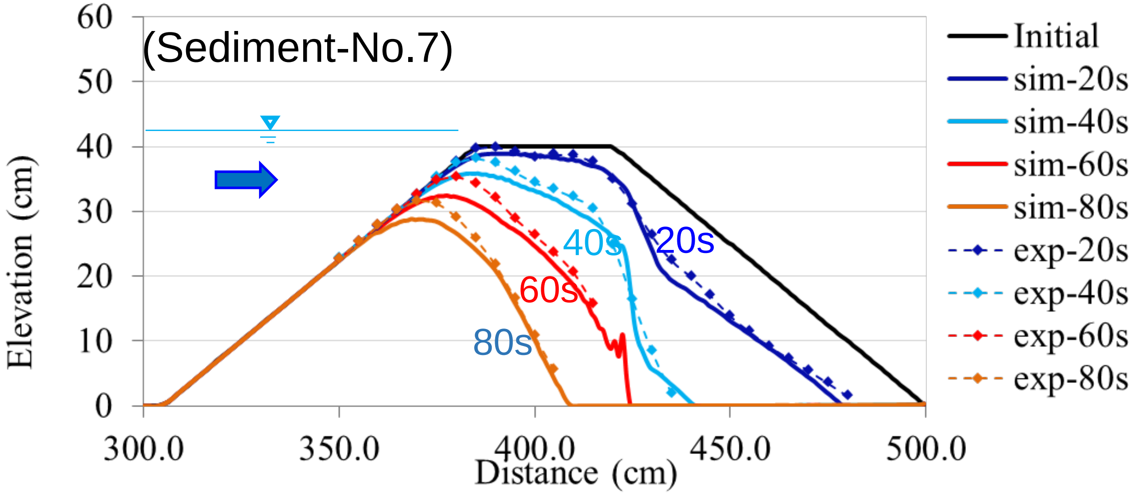
Case 2



Simulated failure process of embankment due to overtopping with volumetric water content variation (Sediment-No.7)



Experimental results (Video data)



Comparisons between simulated and experimental results of failure process (Dam Type-A, Case 2)

Simulated Results

Seepage process inside the EMB

(Dam Type-B)

Case 5

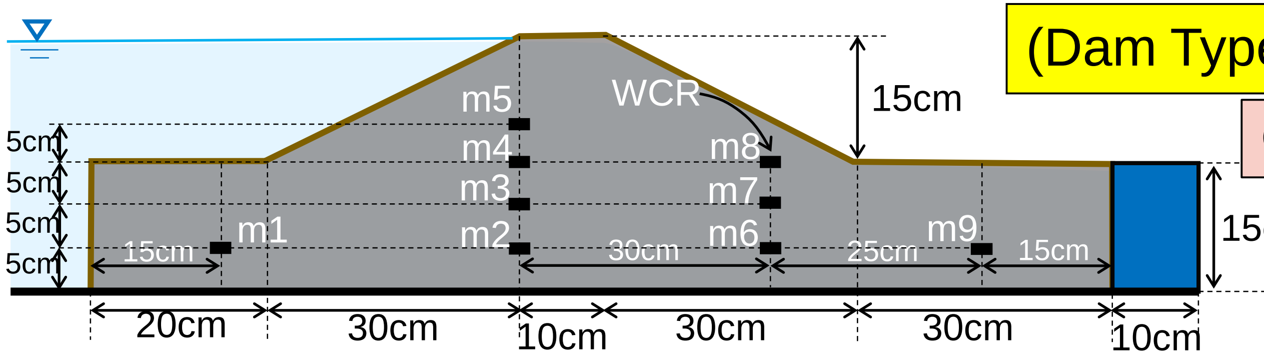


Fig. – Positions of WCRs (m1 to m9) in Case-5

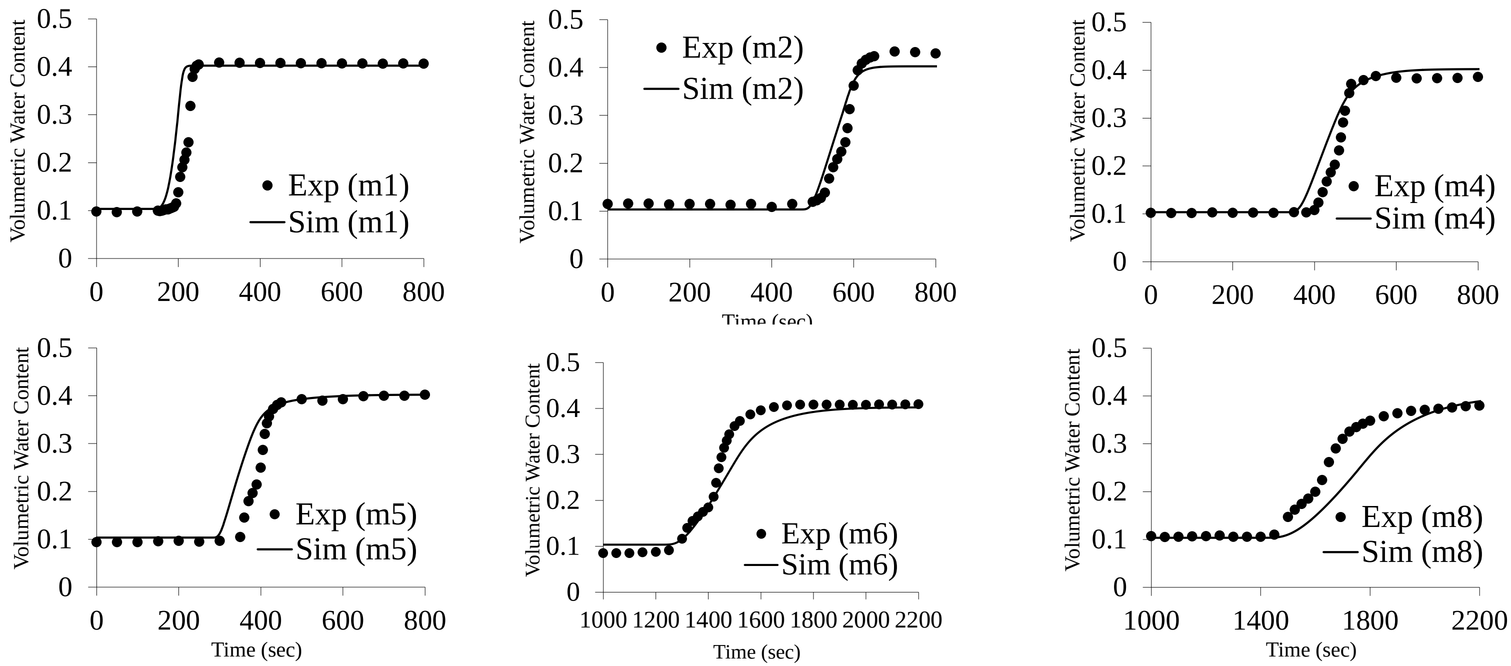
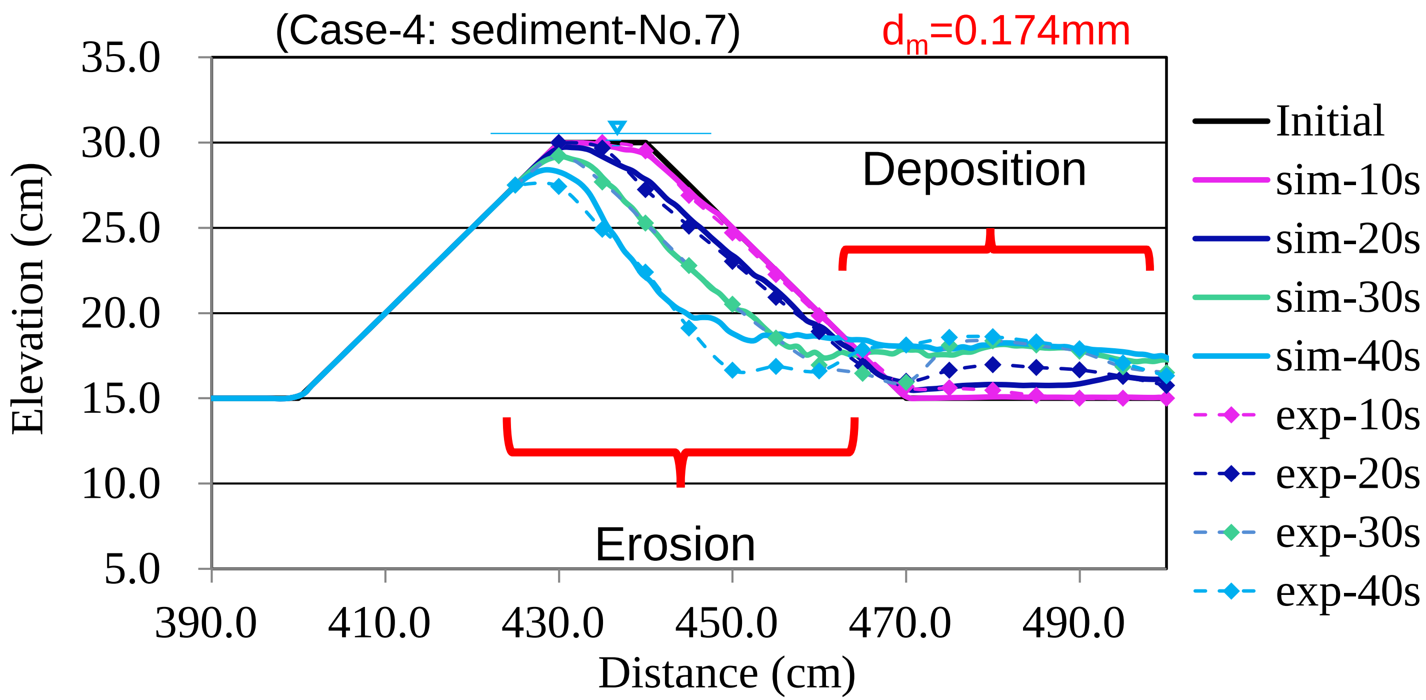


Fig. – Comparisons of simulated and experimental results of temporal moisture variations inside the embankment (Dam Type-B, Case 5)

Embankment shape

(Dam Type-B) Case 4



Comparisons between simulated and experimental results of failure process (Dam Type-B, Case 4)

Embankment shape

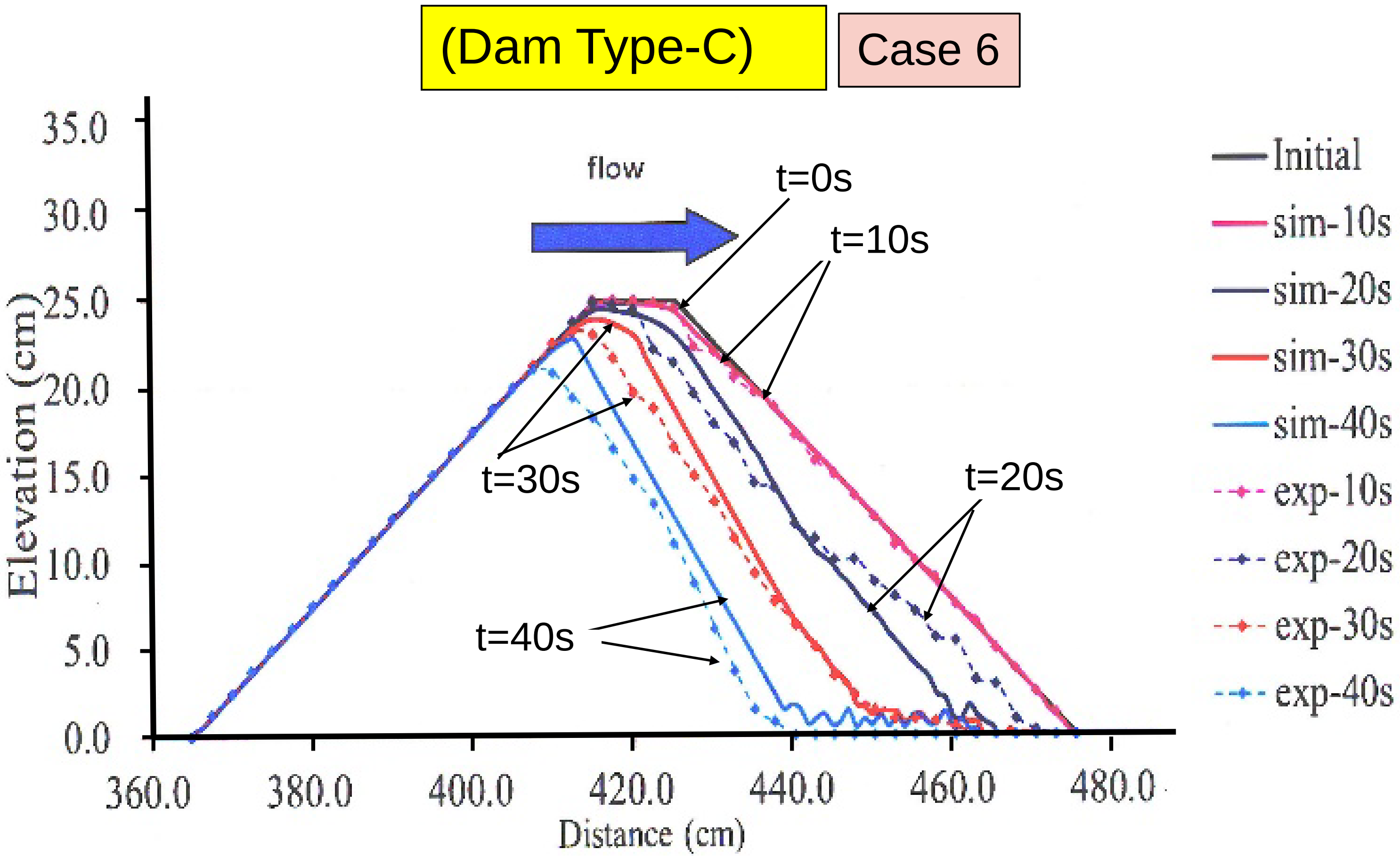


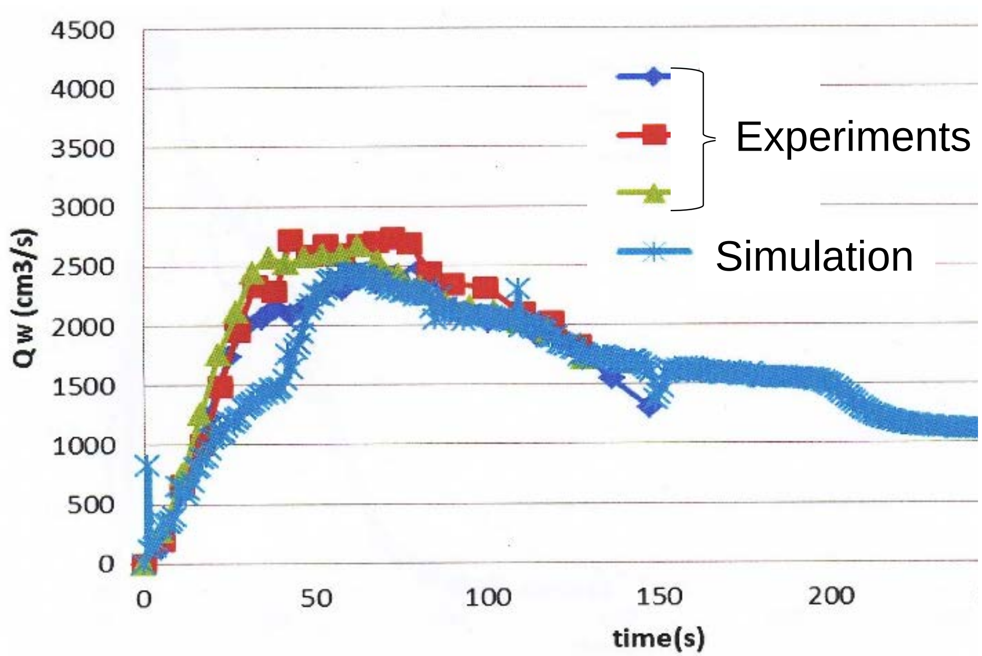
Figure 9. Comparison of simulated and experimental results of embankment shapes (Sediment-No.7, Case 6).

Water discharge

Sediment discharge

(Dam Type-C)

(Sediment-No.7)



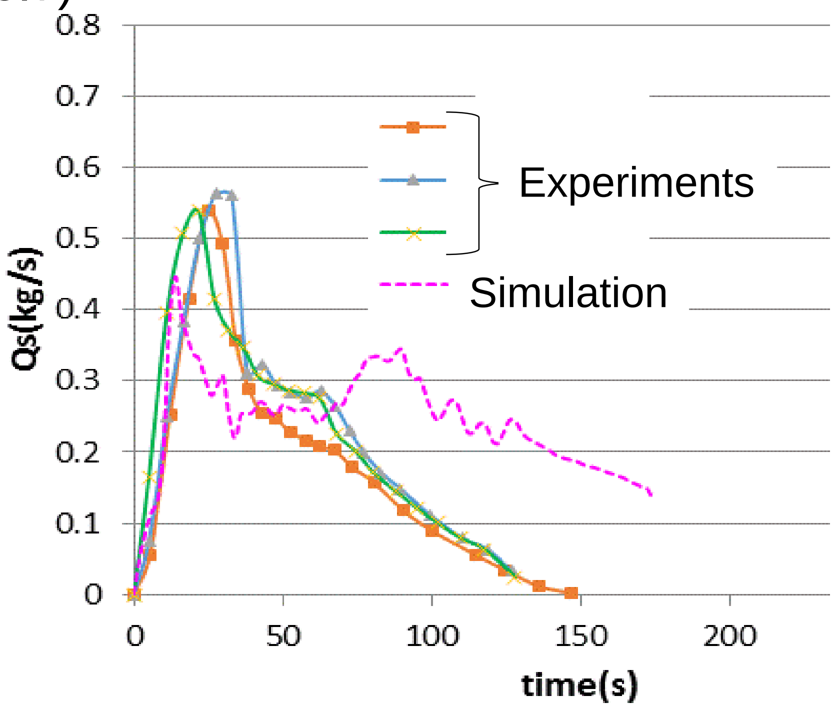


Figure 10. Comparison of simulated and experimental results of inflow flood hydrographs.

Figure 11. Comparison of simulated and experimental results of inflow sediment discharges.

6. Conclusions

In this study, the erosion model of the embankment by overtopping water was verified using some results of laboratory experiments.

- The erosion rate considering increase in resisting shear strength due to suction in the unsaturated sediment is incorporated in the erosion rate in the fully saturated sediment.
- The numerical results of temporal variations of moisture profile inside the embankment, temporal variations of embankment surface erosion, and the deposition behind the embankment were found to be consistent with the experimental results.
- The simulated inflow flood and sediment discharges due to embankment breach for Case-6 (Dam-Type C) show the similar trend to the experimental results, but were a little bit underestimated. Further research is essential to refine the model.

Thank you very much for your kind attention!