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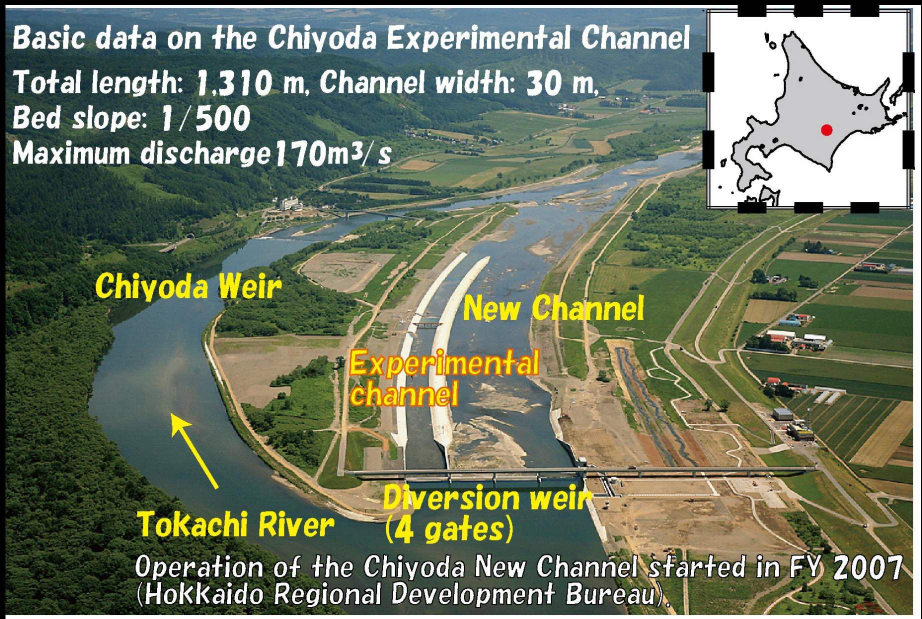
Experiment on a Levee Breach from Overtopping at the World's Largest Experimental Channel

世界最大規模の実験水路を活用した越水破堤実験



Chiyoda Experimental Channel

Total length : 1310m

Channel width : 30m

Maximum discharge : 170m^3/s

CERI COLD REGION

Tomonori SHIMADA

Presentation outline

1. What is the Chiyoda Experimental Channel？
   千代田実験水路とは？

2. Research Plan for Experimental Channel
   実験水路での研究計画

3. Introduction to Overtopping Levee Breach Experiments
   越水破堤実験の紹介

About Chiyoda Experimental Channel

The Chiyoda Experimental Channel was constructed in 2007 using part of the Chiyoda New Channel that had been built in the middle of the Tokachi River as water-control measure.

治水対策として十勝川中流部に整備された千代田新水路の一部を活用して、千代田実験水路が2007年に完成

Phenomena that could not be clarified in conventional model experiments or observed in actual rivers can be examined using the Chiyoda Experimental Channel.

今まで縮尺模型では解明できなかった現象や実河川では観測が非常に困難であった現象などについて、この千代田実験水路を用いることで解明することが可能

Chiyoda Experimental Channel Specifications

The channel was built using one of the four gates of the diversion weir.

実験水路は4門のゲートのうち1門を利用

The flow rate can be controlled using a gate (Maximum discharge 170m^3/s).

実験水路の上流端のゲートで流量をコントロールすることが可能（最大通水可能流量170m3/s）

It has a section with a channel width of 30m, a length of 1300m, and a river bed gradient of 1/500.

水路幅30m、長さ1300m、河床勾配1/500

Research Plan for Experimental Channel

The following areas of investigation were set in the form of long-term experimental research plan as a collaborative effort involving the Hokkaido Regional Development Bureau and the Civil Engineering Research Institute for cold Region.

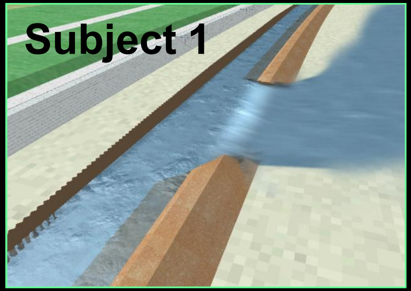
The plans support R&D to solve technical problems in the field and enable systematic and focused R&D associated with river technology.

現場における個々の技術的課題を解決するための技術開発、河川工学に係る体系的・重点的な技術開発のため、北海道開発局と寒地土木研究所の共同研究により、以下のテーマを実験研究長期計画として設定

Research Plan for Experimental Channel

Subject	Main long-term subject
1	Improvement of technology for assessing the functions of dike/protection work 堤防・保護工の機能評価技術の向上
2	Establishment of a tree management method for water control and environmental protection 治水と環境を両立した樹林管理手法の確立
3	Improvement of soil/sand management precision 流域土砂管理の精度向上
4	Improvement of river channel design technology 河道設計技術の向上
5	Clarification of changes in ecological systems after flood disturbance 洪水氾濫後の生態系の変化の把握
6	Improvement of flood prevention technology and awareness 水防技術・意識の向上

Experiment examples



Examination of the levee breach mechanism

破堤口拡幅機構の解明

Flow in ice-jammed rivers

アイスジャム河川の流れ

Flood drills, disaster prevention education for residents

水防訓練、住民への防災教育

Study Background (Experiment on a Levee Breach)

Even today, with progress in river improvement, damage caused by levee breaches still occurs frequently in many parts of Japan.

河川整備が進んでいる今日でも日本各地で破堤による被害が多発

There are concerns that floods with severe damage will become frequent due to climate change.

今後、気候変動の影響により洪水被害が頻発化・激甚化することが懸念

Even though the damage caused by levee breaches is devastating, the process of such breaches initiated by overtopping is not well understood and elucidating the mechanism of levee breaches is important for establishing mitigation techniques.

越水破堤のプロセスは良く分かっておらず、河川堤防の破堤機構の解明は、被害軽減技術の確立に向けて重要な課題

Example of levee breach in the Kinu River (September 2015)

Source:
Geospatial Information Authority of Japan website
(https://www.gsi.go.jp/BOUSAI/H27.taihuu18gou)

Objective

Research on levee breach to date has mainly been based on model tests.

これまでの破堤に関する調査研究は、主に縮尺模型実験などを中心に行われてきた

Full-scale levee breach experiments can be performed in consideration of side-overflow from levee placed longitudinally to the river channel flow as seen with actual rivers.

千代田実験水路では実物大規模で、しかも実河川と同様に河道の流れに対して縦断的に配置された堤防からの横越流による破堤実験が可能

This allows examination of the levee breach process through collection of chronological observation data on the levee and the amount of water flow observed during levee breach.

破堤進行時の堤体および水理量の時系列の観測データを得ることにより、破堤進行過程を解明することが目的

Overview of the experiment and ovsevation

The basic dimensions of the levee are 3m(height), 3m(crown width), and the slope gradient is 1:2.

堤防の基本形状は高さ3m、天端幅3m、法面勾配2割

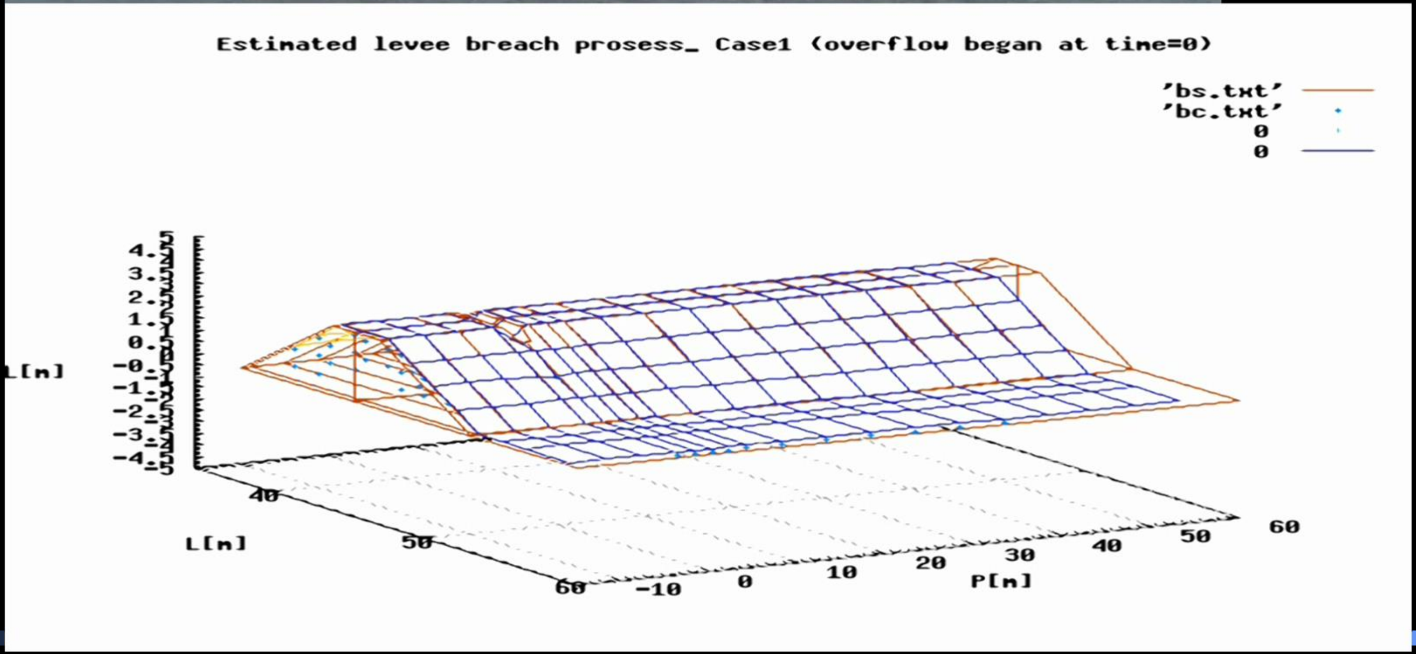
The following main items were observed:

Channel water level, Flow rate, Levee breach shape(clarification of levee breach conditions based on outflow measured by acceleration sensors in the levee) etc.

主な観測項目は、水路内水位、流量観測、破堤形状（堤防内に設置した加速度センサーの流出による堤体崩壊状態の計測）

Situation of experiment

Levee breach process estimation based on acceleration sensor records



Conclusion

In previous studies, the process of width expansion in levee breach was presumed according to only visual observation in scale-model experiments.

これまでの研究では、堤防決壊時の幅拡大過程は模型実験による目視観察のみで推定

This time, the use of acceleration sensors enabled the establishment of an approach for measuring the process of levee breach for the invisible inside of the levee.

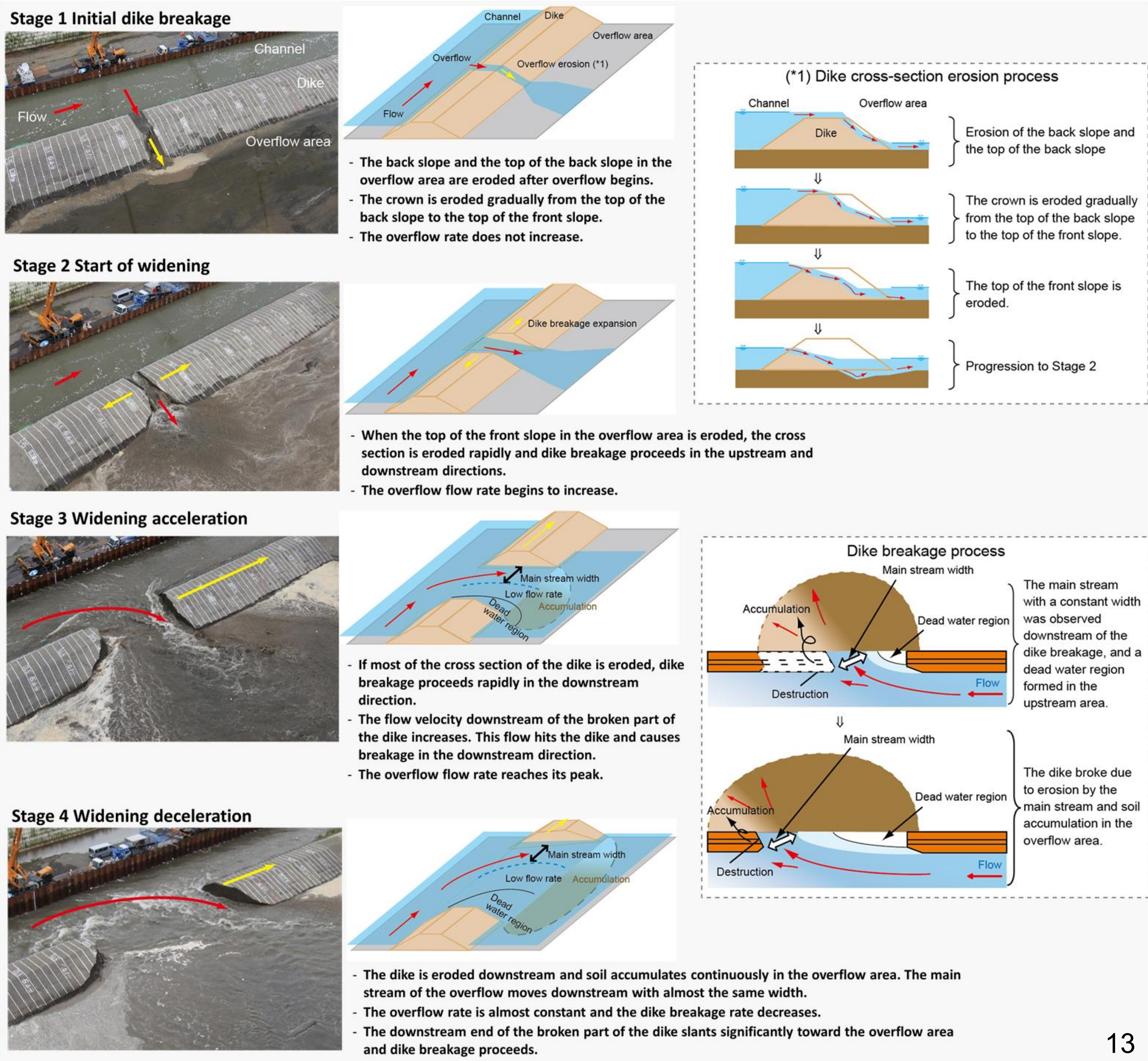
加速度センサーを用いることで、目に見えない堤防内部の堤防決壊過程を計測する手法を確立

The experiment revealed that it proceeds through four stages: (1) the start of levee erosion due to overtopping, (2) the start of widening of a narrow erosion trench across the levee body, (3) the acceleration of the widening of the breach, and (4) the deceleration of the widening of the breach.

この実験により越水から4つの段階（Step1:越水による堤体侵食→Step2:破堤口拡幅開始段階→Step3:破堤口拡幅加速段階→Step4:破堤口拡幅減速段階）を経て破堤が進行することを明らかにした

Reference

The levee breach process can be classified into four stages.



Reference

Summary of relationships linking levee breach extent and hydraulic flow (water depth, flow velocity, etc.)

Levee breach process and hydraulic flow

The quantitative evaluation method based on hydraulic flow for dike breakage was examined.

a) The extent of dike destruction was quantified; b) the extent of dike destruction was calculated based on the test results; c) the amount of water flow required to trigger dike breakage was quantified and the results were organized to determine the dimensionless extent of dike destruction in Cases 1 to 4 and the dimensionless tractive force acting on the dike; and d) the relationship between the extent of dike destruction and tractive force was clarified.

a) Quantification of dike destruction extent

The movement of soil in the river is expressed using a tractive sand equation. The dimensionless extent of dike destruction q* is expressed using Equation (2) based on the typical existing tractive sand Equation (1). The value of q* is calculated from the extent of dike destruction shown in Figure 13 using Equation (3). The extent of destruction and the tractive force acting on the dike were also analyzed. Dike destruction was expressed based on the tractive current phenomenon of dike clod due to the overflow stream, and the extent of dike destruction was considered in terms of tractive sand based on the relationship with the dimensionless tractive force acting on the dike.

$$q_B = 8(\tau_* - \tau_{*c})^{1.5}\sqrt{sgd^3} \quad (1)$$

$$q_* = \frac{q_B}{\sqrt{sgd^3}} = \alpha_*(\tau_* - \tau_{*c})^{\beta_*} \quad (2)$$

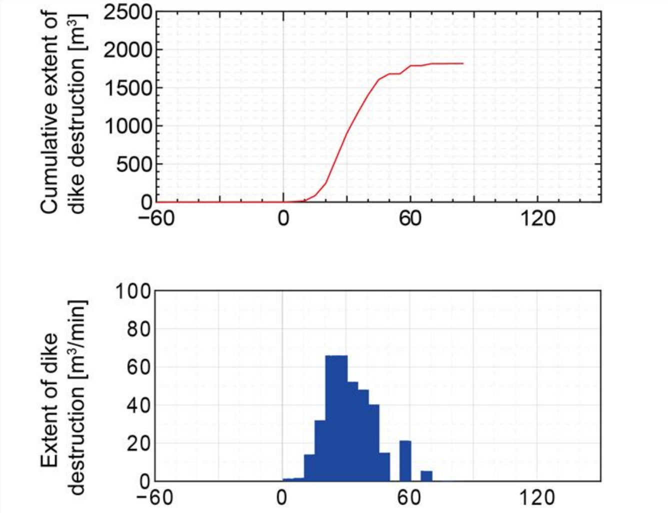
$$q_* = \frac{dV}{dt}\frac{1}{\left(\sqrt{sgd_{50}^3}\, B_m\right)}(1-\lambda) \quad (3)$$

Here, dB: tractive sand per unit width; τ*: dimensionless tractive force; τ*c: dimensionless limit tractive force; s: sand particle specific gravity in water; g: gravitational acceleration; d: sand particle size; q*: dimensionless extent of dike destruction; α*, β*: coefficients; V: extent of dike destruction; t: time; d50: 50% passing sand particle size; Bm: dike bottom width; λ: porosity.

b) Calculation of dike destruction extent

The dike destruction extent, including that of the foundation, was determined based on data from the acceleration sensors in the dike and the foundation (see Figure 13).

The extent of destruction was small immediately after overflow started, but increased rapidly as dike breakage proceeded and decreased after it peaked.



The horizontal axis shows time elapsed since overflow began. [min]

Figure 13 Dike destruction extent (Case 1)

Reference

Summary of relationships linking levee breach extent and hydraulic flow (water depth, flow velocity, etc.)

c) Quantification of hydraulic flow at the broken part of the dike

The flow struck the dike at the downstream end of the opening, causing the progress of breakage. The value for the hydraulic flow near the opening of the broken dike was used as shown in Figure 14 to evaluate the breakage phenomenon.

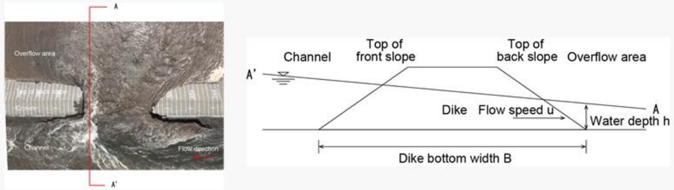


Figure 14 Calculation of hydraulic flow at the broken part of the dike

The dimensionless tractive force τ* acting on the opening of the dike was determined from Equation (4), and the flow velocity u near the back slope of the opening and the roughness coefficient n of the test channel were calculated using a modified Manning's Equation (5).

$$\tau_* = \frac{u_*^2}{sgd} = \frac{hi_e}{sd} \qquad (4)$$

$$i_e = \frac{u^2 n^2}{h^{\frac{4}{3}}} \qquad (5)$$

$$\tau_* = \frac{u^2 n^2}{sd_{50} h^{\frac{1}{3}}} \qquad (6)$$

Here, u*: friction velocity; s: sand particle specific gravity in water; g: gravitational acceleration; d: particle size; h: water depth (at the opening of the dike); ie: energy gradient; u: flow velocity (average determined from PIV image analysis); n: roughness coefficient (test channel value 0.023); h: water depth (determined from 3D image analysis); d50: 50% passing sand particle size.

d) Relationship between extent of dike destruction and tractive force

The dimensionless extent of dike destruction and the dimensionless tractive force were determined from Equations (3) and (6) based on the test results of Cases 1 to 4, and the Equation (7) coefficients α* and β* were obtained.

The relationship between the dimensionless extent of dike destruction and the dimensionless tractive force acting on the dike are shown in Figure 15.

It can be seen that the characteristics and soil texture of the dike differed among cases, but the plot results show a correlation. The relationship between the dimensionless extent of dike destruction and the dimensionless tractive force near the opening of the broken dike can be expressed in a form similar to the tractive sand equation.

$$\frac{dV}{dt}\frac{1}{\left(\sqrt{sgd_{50}^3}B_m\right)}(1-\lambda) = \alpha_*(\tau_* - \tau_{*c})^{\beta_*} \qquad (7)$$

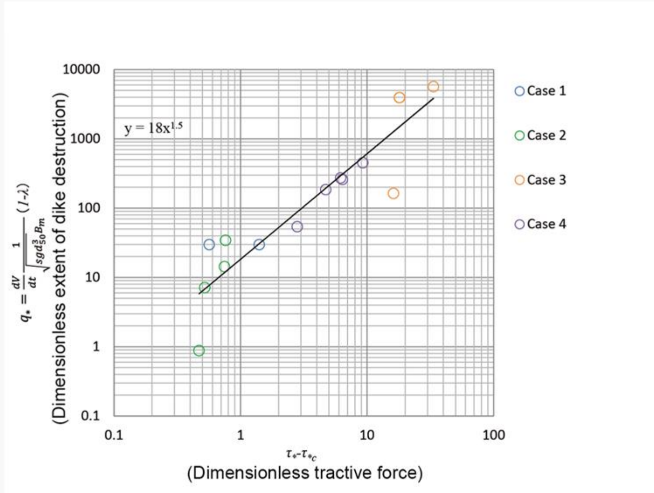


Figure 15 Influence of dimensionless tractive force on the dimensionless extent of dike destruction and the dike itself