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Discussion

Modelling dike breaching due to overtopping

By LUKAS SCHMOCKER and WILLI H. HAGER, Journal of Hydraulic Research Vol. 47, No. 5 (2009), pp. 585–597

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The Authors are to be commended for having made a significant effort to clarify some aspects of physical modelling of dike breaching due to overtopping. This phenomenon was experimentally also investigated at the University of Belgrade, using different model properties. Effects of cohesion and seepage were included in an attempt to simulate the physics as much as possible (Jovanović 1988). An overtopped earth structure was exposed to effects of gravity, shear stresses due to overflowing water, hydrostatic pressures, forces of cohesion, and pore pressures which developed as saturation takes place. Since all these factors affect the structural stability, they need to be accounted for when specifying the similitude conditions for scale model investigations.

1 Similitude conditions

1.1 *Weir flow*

Neglecting viscous effects in an accelerating free-surface flow, only the Froude similitude is relevant as $\mathsf{F}_* = \mathsf{F}_m/\mathsf{F}_p = 1$, where F is the Froude number, and subscripts '$*$', 'p', and 'm' denote scale, prototype, and model, respectively. From this condition, scales for various hydraulic variables can be defined, once the length scale L_* is chosen.

A similitude condition pertaining to the shear stresses induced on the solid surface by the overflowing water needs to be introduced. This effect may be quantified by the friction coefficient

$$C_\tau = f(\mathsf{R}, k/h) \tag{D1}$$

where R is the Reynolds number, k the absolute surface roughness, and h the flow depth. As the viscous effect may be neglected in fully developed turbulent flow, the friction coefficient in Eq. (D1) is independent of R, thus

$$(k/h)_* = 1 \quad \text{and} \quad k_* = h_* = L_* \tag{D2}$$

If the absolute roughness k is represented by the characteristic sand grain size d_{90}, Eq. (D2) reads

$$(d_{90})_* = L_* \tag{D3}$$

1.2 *Seepage*

Although surface shear on the water–solid interface is the dominant factor of the erosion process, similitude conditions for seepage and pore pressures must also be considered to reproduce the overall physical behaviour of the structure. Seepage is well reproduced in scale models if the following conditions for density of the saturated material ρ'_s, porosity n, and hydraulic conductivity K are satisfied

$$\rho'_{s*} = 1; \quad n_* = 1; \quad K_* = L_*^{1/2} \tag{D4}$$

If the Hazen relation $K \propto {d_{10}}^2$ is applied with d_{10} equal to characteristic grain size, Eq. (D4) becomes

$$(d_{10})_* = L_*^{1/4} \tag{D5}$$

1.3 *Geomechanics and rheology*

The theory of geo-mechanical and rheological similitudes is important for experimental research of soil stability limits. The basic postulate is that similarity of impact of gravity (weight) and inertial force is only possible if the scale model and the prototype are made of the same material (Mandel 1961, Weber 1971). As this is often not feasible, the scale model needs to be built of some "equivalent" material, composed in such a way that its mechanical and rheological characteristics are related to the prototype material through the scales for stresses, strain, and time. Composition of the equivalent material should ensure that, for a chosen length scale L_*, deformations of the

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Table D1 Composition of equivalent material

Physical property	Scale
Density of saturated material	$\rho'_{s*} = 1$
Angle of internal friction	$\phi_* = 1$
Stresses/pore pressures	$\sigma_* = p_* = L_*$
Cohesion	$C_* = L_*$
Young's elasticity module	$E_* = 1$
Poisson's plasticity	$\nu_* = 1$

model and prototype structures are geometrically similar. Characteristic scales are given in Table D1.

2. Results of laboratory investigations

Dike scale models were built in a 22 m long, 1 m wide laboratory flume. Uniform dike overtopping was ensured. High-speed photography was the principal recording technique (Fig. D1).

Dike models were 0.2–0.5 m high, with slopes upstream 1 : 1.5, and downstream 1 : 2. The ratio of model volume to the upstream storage volume was 1 : 25, and the discharge 4.0 l/s.

3. Composition of equivalent material

Taking into account previously defined hydraulic and rheological scales, the equivalent material was composed satisfying the following conditions:

- grain size relevant for surface roughness (3),
- grain size relevant for seepage (5),
- hydraulic conductivity (4),
- cohesion (Table 1).

The characteristics of the sand mixture were $d_{10} = 0.13$ mm, $d_{50} = 0.20$ mm, $d_{90} = 0.25$ mm, $d_{60}/d_{10} = 1.54$, $\sigma_g = (d_{84}/d_{16})^{1/2} = 1.22$, $\phi = 32$–$34°$, $\rho'_s = 1.90$–1.93 t/m^3, wet content $w = 19.6$–22.5%, cohesive additive kaolin 2%, $C = 10$–30 mbar, $K = 10^{-8}$ m/s.

Recorded data for four tests are presented. In Test 3, a strong bentonite additive with content of 3% was used, increasing cohesion to 50 mbar. Figure 2 shows the relationship between dimensionless discharge and the erosion number E (Sametz 1981, Jovanović 1988),

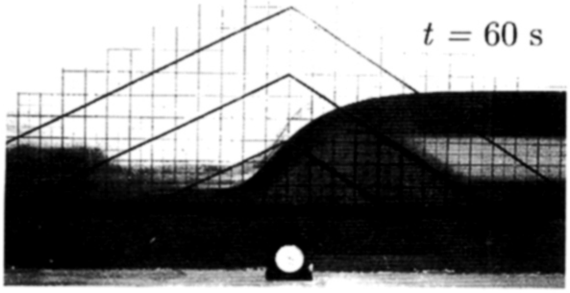

Figure D1 Erosion of dike scale model

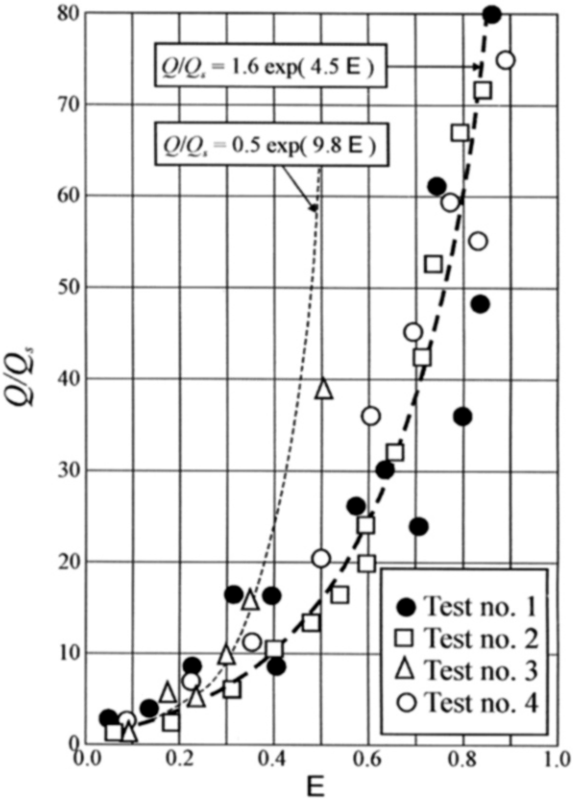

Figure D2 Degree of erosion E related to the ratio of water discharge Q and solid discharge Q_s

$$\mathsf{E} = V_e/V_o = (V_o - V)/V_o = 1 - (V/V_o), \tag{D6}$$

representing the degree of reduction of the dike volume during the erosion process, with V_o equal to the initial dike volume, V the instantaneous dike volume, and $V_e = V_o - V$ the volume of eroded material.

4. Scale effects and extrapolation of results

Scale effects are manifested by discrepancies between measured values and values to be expected from the similarity laws. The discrepancies are larger as the model scale is reduced. An analysis from this study indicated that results are valid as long as the length scale is not smaller than 1 : 15, generally in agreement with the conclusion of Dunglas and Fayoux (1972). It means that the results of the presented tests may be extrapolated to real, prototype dikes not higher than 5 m, with typical side slopes of 1 : 1.5 and 1 : 2, made of sandy cohesive materials. The maximum unit discharges during overtopping of such structures are less than 50 m^2/s, and the total failure duration 300–600 s. Typical structures of this type are small earth dams, levees, dikes, and emergency fuse plugs. Accordingly, the results presented by the authors are within these limits.

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Reply by the Authors

The Authors would like to thank the Discusser for his valuable comments and the interest in our work. A different similitude approach is described focusing on shear stresses, seepage and geo-mechanical aspects. The results support the Authors' investigation and are useful for future work, especially regarding the upscaling of the obtained results to prototype dikes.

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