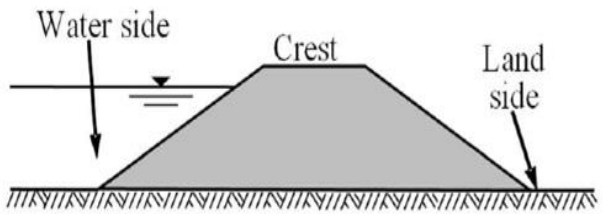
Session 3 : Modélisation numérique et expérimentale des processus sédimentaires

Two-dimensional numerical modeling of overtopping induced levee breaching : application to a field-scale experiment

Lydia KHELOUI (1,2)
Kamal EL KADI ABDERREZZAK (1,2)
Sébastien BOURBAN (1)
Riadh ATA (3)

(1) EDF
(2) Laboratory for Hydraulics Saint-Venant
(3) FLOW-3D

Context and objective



Extreme events → **Overtopping** → **Breach formation, levee failure and floods**

- Human and economic losses

Need for better understanding of breaching processes (physical modeling)

Need for improved numerical modeling

✓ Accurate representation of breach development

⇓

✓ Accurate estimation of breach outflow hydrographs

Dike breach in « Petit Rhône » 2003

Arkansas levee breach 2019

Combined Empirical approach for levee breach modeling

2D HYDRODYNAMIC MODEL:
TELEMAC-2D + BREACH MODULE

User defined parameters
Breach initiation criterion (t_s, Z_s), breach location, breach final dimensions (Z_{Bmin},B_f)

↓

TELEMAC-2D: Flow variables

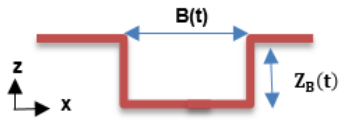
↓ **t_s or Z_s**

↓

BREACH MODULE: Gradual breach widening and deepeing → bottom updating

↓

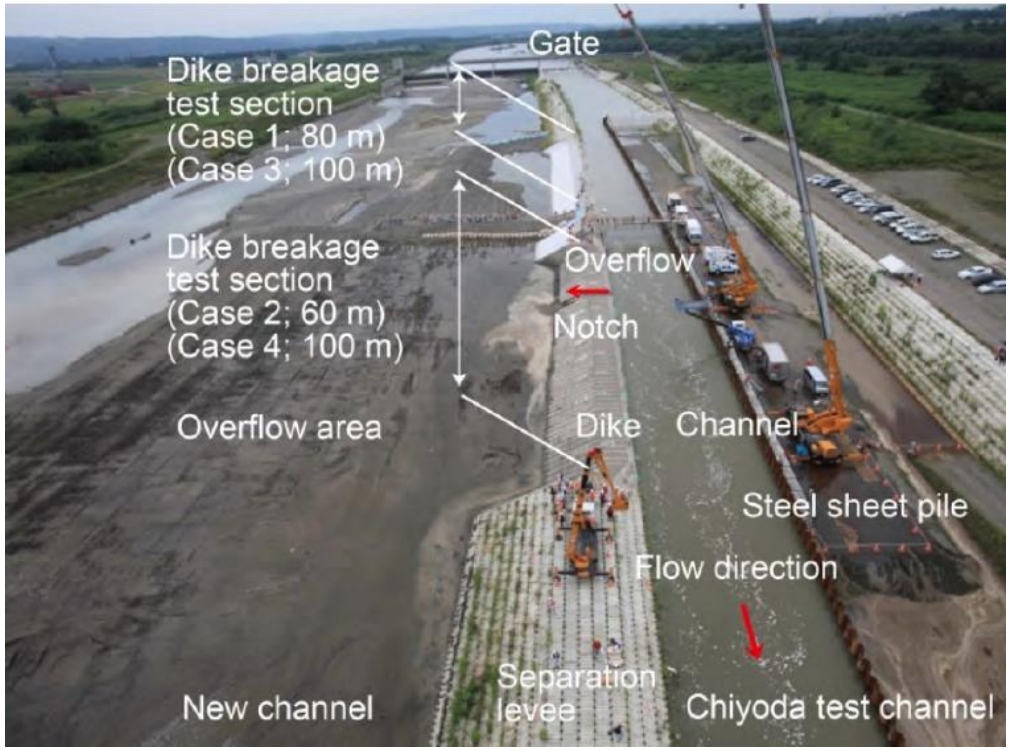
Z_{Bmin} & B_f

Parametric model	Lateral expansion	Vertical expansion
Two stages	$B(t) = V_1(t - t_s) + B_0$ for $(t_s \le t \le t_1)$ $B(t) = V_2(t - t_1) + B(t_1)$ for $(t_1 \le t \le t_f)$	$Z_B(t) = Z_{B0} - \frac{(Z_{B0} - Z_{Bmin})}{T_d}(t - t_s)$ With : $T_d = \frac{t_f - t_s}{\alpha}$ for $(t_s \le t \le T_d)$  Breach logitudinal profile
USBR 1988	$B(t) = 91(t - t_s)$ for $(t_s \le t \le t_f)$	
Von Thun & Gillette 1990	Sand : $B(t) = (4h_w + 61)(t - t_s) + B_0$ for $(t_s \le t \le t_f)$ Clay : $B(t) = 4h_w(t - t_s) + B_0$ for $(t_s \le t \le t_f)$	
Verheij 2002	Sand : $B(t) = 37.2(t - t_s)^{0.51} + B_0$ for $(t_s \le t \le t_f)$ Clay : $B(t) = 13.4(t - t_s)^{0.5} + B_0$ for $(t_s \le t \le t_f)$	
Verheij & Van de Knaap 2003	$B(t) = B_0 + \frac{f_1 g^{0.5}(h_{up} - h_{down})^{1.5}}{ln(10)u_c} ln[1 + \frac{f_2 g}{u_c}(t - t_s)]$	
Modified Froehlich 2008	$B(t) = \beta(t)(B_f - B_0) + B_0$ for $(t_s \le t \le t_f)$ With : $\beta(t) = \frac{1}{2}\{1 + sin[\pi(\frac{(t-t_s)}{(t_f-t_s)} - \frac{1}{2})]\}$	$Z_B(t) = Z_{B0} - \beta_1(Z_{B0} - Z_{Bmin})$ With : $\beta(t) = \frac{1}{2}\{1 + sin[\pi(\frac{(t-t_s)}{T_d} - \frac{1}{2})]\}$  Breach logitudinal profile

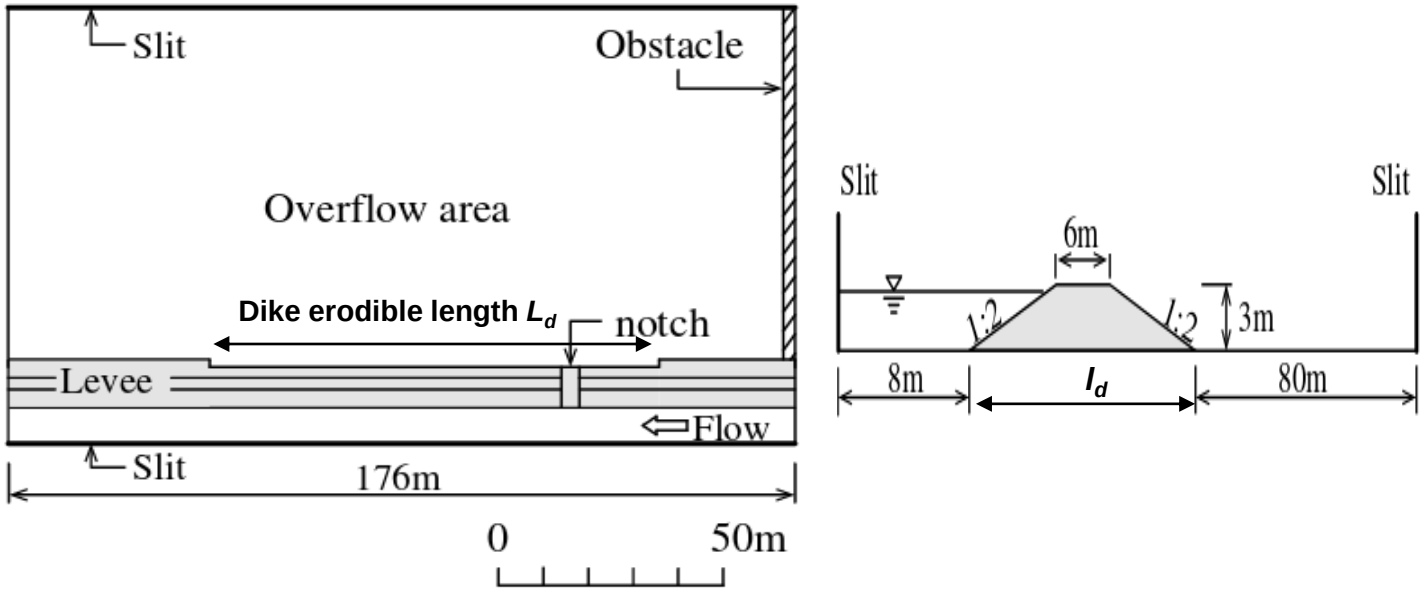
- ✓ B_0 and Z_{B0}: breach initial width and bottom level (m), respectively.
- ✓ B_f and Z_{Bmin}: breach final width and bottom level (m), respectively.
- ✓ t_s : breach initiation time (hr).
- ✓ Z_s : required water level to start breach expansion (m).

- ✓ V_1 and V_2: breach lateral growth rates (m/hr) for first and second stage, respectively.
- ✓ $t_1, t_f,\ T_d$: fist stage end time, lateral breach expansion end time and vertical breach opening duration (hr).
- ✓ h_w: water depth above final breach bottom, at time of failure and breach location (m).
- ✓ $h_{up},\ h_{down}$: hydraulic head upstream and downstream dike (m).
- ✓ $f_1,\ f_2$, : empirical parameters with default range values of [0.5, 5] and [0.01, 1], respectively.
- ✓ u_c: critical flow velocity for the initiation of dike erosion (m/s).

2D hydrodynamic modeling of a field experiment



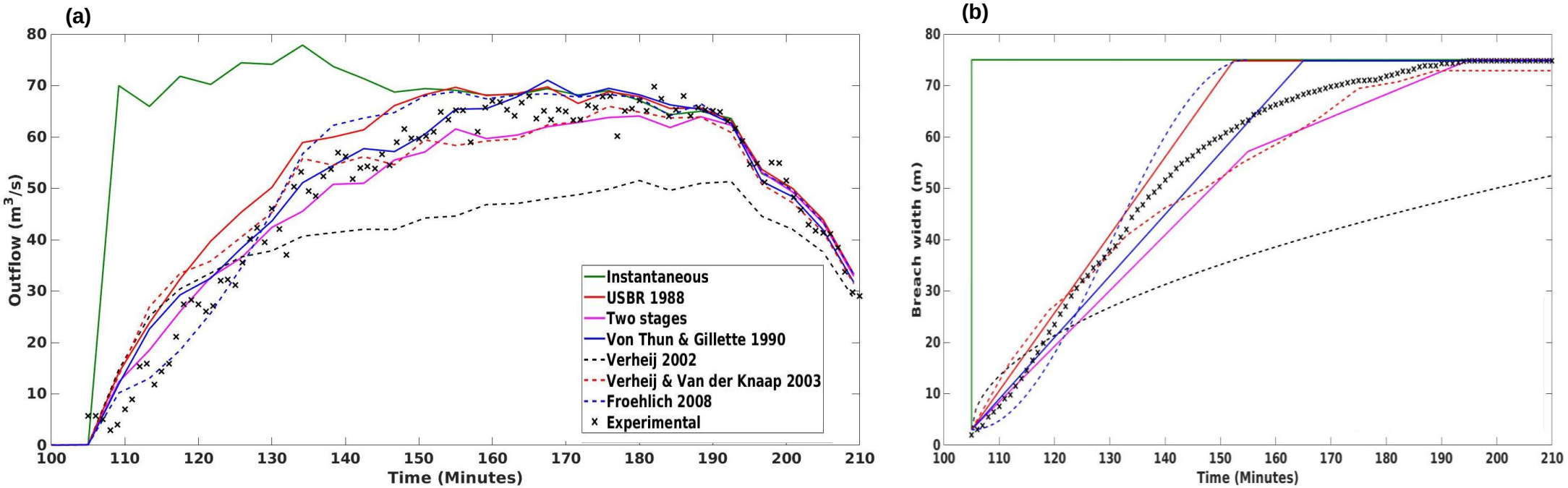
Field scale experimental configuration by Kakinuma & Shimizu (2014)



L_d	l_d	d_{50}	Notch depth	Notch width	Notch location	Bed slope
100 m	18 m	0.74 mm	0.5 m	3 m	20 m from levee upstream end	1/500

Case 4 configuration by Kakinuma & Shimizu (2014)

Results and conclusion



(a) Breach discharge and (b) breach width.

t_s	B_f	t_1	V_1	V_2	f_1	f_2	u_c	T_d
105 min	74.8 m	155 min	65 m/hr	26.7 m/hr	1.3	0.06	0.16 m/s	5 min

User defined model parameters

USBR 1988	Two stages	Von Thun & Gillette 1990	Verheij & Van Der Knaap 2003	Frohelich 2008
10%	5.8%	5.9%	8%	6.5%

Normalized root mean square error on breach outflow

- ✓ Results with the instantaneous breach opening assumption highly overestimate breach outflow.
- ✓ Results of the combined empirical approach achieve a good agreement with experimental data (except for Verheij 2002).
- ✓ Parametric models require user predefined breach characteristics and/or parameters (Verheij & Van der Knaap 2003) ⟹ related uncertainties.
- ✓ Results of the Verheij & Van der Knaap 2003 model depend on the choice of empirical parameters (f_1, f_2 and u_c).