CIVL4120/7020 Advanced open channel hydraulics and design - TUTORIALS (4)

Unsteady Open Channel Flows. 3- Applications to dam break wave

A 15 m high dam fails suddenly. The dam reservoir had a 13.5 m depth of water and the downstream channel was dry. (1) Calculate the wave front celerity, and the water depth at the origin. (2) Calculate the free-surface profile 2 minutes after failure.
Assume an infinitely long reservoir and use a simple wave analysis ($S_o = S_f = 0$).
Solution
U = 23 m/s, d(x=0) = 6 m.

A vertical sluice shut a trapezoidal channel (3 m bottom width, 1V:3H side slopes). The water depth was 4.2 m upstream of the gate and zero downstream (i.e. dry channel). The gate is suddenly removed. Calculate the negative celerity. Assuming an ideal dam break wave, compute the wave front celerity and the free-surface profile one minute after gate removal.
Solution
The assumption of hydrostatic pressure distribution is valid for $t > 3*\sqrt{d_o/g} \sim 2$ s. That is, the Saint-Venant equations may be applied at t = 60 s. For a trapezoidal channel, the celerity of a small disturbance is :

$$C = \sqrt{g * \frac{A}{B}} = \sqrt{g * \frac{d * (W + d*\cot\delta)}{W + 2 * d * \cot\delta}}$$ (see Textbook, Chapter 3, paragraph 3.4.2)

where W is the bottom width and δ is the sideslope angle with the horizontal (i.e. cotδ = 3).
The celerity of the negative wave is: $- C_o = - 4.7$ m/s. The celerity of the wave front is $U = + 2*C_o = + 9.6$ m/s. Considering a backward characteristics issuing from the dam break wave front, the inverse slope of the C2 characteristics is a constant :

$$\frac{dx}{dt} = V - C = 2 * C_o - 3 * C$$

The integration gives the free-surface profile equation at a given time t :

$$\frac{x}{t} = 2 * \sqrt{g * \frac{d_o * (W + d_o*\cot\delta)}{W + 2 * d_o * \cot\delta}} - 3 * \sqrt{g * \frac{d * (W + d*\cot\delta)}{W + 2 * d * \cot\delta}}$$

At t = 60 s, the free-surface profile between the leading edge of the wave front and the negative wave most upstream location is :

d (m) :	4.2	3	2	1.725	1	0.5	0
x (m) :	-282	-160	-38.4	0	119	231	564

A 5 m high spillway gate fails suddenly. The water depth upstream of the gate was 4.5 m depth and the downstream concrete channel was dry and horizontal. (1) Calculate the wave front location and velocity at t = 30 s. (2) Compute the discharge per unit width at the gate at t = 30 s. (3) Calculate the wave front celerity at t = 2 minutes.
Use the lecture note development for dam break wave with friction. Assume f = 0.03 for a relatively new concrete lining.
Solution
(1) $x_s = 207.6$ m, U = 4.8 m/s. (2) q = 8.85 m^2/s. (3) U = 3.14 m/s

A 65 m high concrete dam fails explosively (i.e. Malpasset dam type failure). The dam reservoir was nearly feel and the depth of water upstream of the dam wall was 61.5 m. The downstream channel was dry and horizontal. (1) At t = 1 minute, calculate the ideal wave front celerity and location. (2) For a real-fluid flow with flow resistance, calculate the ideal wave front celerity and location at t = 1 minute. (3) Calculate the free-surface profile 5 minutes after failure.
Assume an infinitely long reservoir and assume f = 0.08 for the downstream valley roughness.
Use the lecture note development for dam break wave with friction.
Solution
(1) U = 49.1 m/s, x_s = 2.95 km.
(2) U = 16 m/s, x_s = 1.46 km, x_1 = - 0.033 km
(3) U = 9.4 m/s, x_s = 5.8 km, x_1 = - 3.1 km. The free-surface profile is an ideal-fluid flow "parabola" for -7.4 km < x < -3.1 km, and the wave tip region extends for -3.1 km < x < 5.8 km.

A horizontal, rectangular canal is shut by a vertical sluice. There is no flow motion on either side of the gate. The water depth is 3.2 m upstream of the gate and 1.2 m downstream. The gate is suddenly lifted. (1) Calculate the wave front celerity, and the surge front height. (2) Compute the water depth at the gate. Is it a function of time ?
Solution
(1) d_1/d_o = 0.375, U = 5.25 m/s, d_2 - d_1 = d(x=0) = 2.07 m. (2) 0.87 m.

A 35 m high dam fails suddenly. The initial reservoir height was 31 m above the downstream channel invert and the downstream channel was filled with 1.8 m of water initially at rest. (1) Calculate the wave front celerity, and the surge front height. (2) Calculate the wave front location 2 minutes after failure. (3) Predict the water depth 10 minutes after gate opening at two locations : x = 2 km and x = 4 km. *Assume an infinitely long reservoir and use a simple wave analysis (S_o = S_f = 0).*
Solution
(1) d_1/d_o = 0.06, U = 18.1 m/s, d_2 - d_1 = 8.34 m. (2) x_s = 2.2 km (t = 2 minutes). (3) d(x=2 km, t=10 min.) = 11.3 m and d(x=4 km, t=10 min.) = 10.1 m

A senior coastal engineer wants to study sediment motion in the swash zone. For 0.5 m high breaking waves, the resulting swash is somehow similar to a dam break wave running over a dry bed. (1) Assuming an initial reservoir water depth of 0.5 m, calculate the wave front celerity and height at 3 seconds after wave/dam break. (2) Calculate the bed shear stress distribution in the wave front region. (3) Predict the occurrence of bed load motion and sediment suspension at 3 seconds after wave/dam break.
Assume S_o = 0. The beach is made of fine sand (d_{50} = 0.25 mm, d_{90} = 0.85 mm). *Assume f = 0.05. For sea water, ρ = 1024 kg/m^3 and μ = 1.22 E-3 Pa.s.*
Solution
Let select a positive x-direction toward the shore. The dam break wave (d_o = 0.5 m) propagates in a dry channel. The x coordinate is zero (x = 0) at wave breaking (i.e. pseudo-dam site) and the time origin is taken at the start of wave breaking.
(1) U = 1.9 m/s, x_s = 7.6 m.
(2) In the wave front region, V = U. Hence: τ_o = 23 Pa, V_* = 0.15 m/s.
(3) τ_* = 5.6, V_*/w_o = 5.4.

$\tau_* > (\tau_*)_c \Rightarrow$ Bed load motion

$V_*/w_o > 0.2$ to $2 \Rightarrow$ Suspended load

Remarks
+ The above development has a number of limitations. The reservoir is assumed infinite although a breaking wave has a finite volume, and the beach slope is assumed horizontal.

+ The Shields parameter τ_* must be compared with the critical Shields parameter for bed load motion $(\tau_*)_c \sim 0.035$ (Chapter 8, paragraph 8.3). For a 0.25 mm sand particle, the settling velocity is 0.028 m/s. The ratio V_*/w_o is used to assess sediment suspension (Chapter 9, paragraph 9.2).

More exercises in textbook pp. 362-370 &371-373.
"The Hydraulics of Open Channel Flow: An Introduction", *Butterworth-Heinemann Publ.*, 2nd edition, Oxford, UK, 2004.