

Problem Set 8

Due on Monday, May 1st

Important note: Please start a new sheet of paper for each problem in the problem set. Write the names of the group members who contributed to the solution at the beginning of each problem.

Problem 1

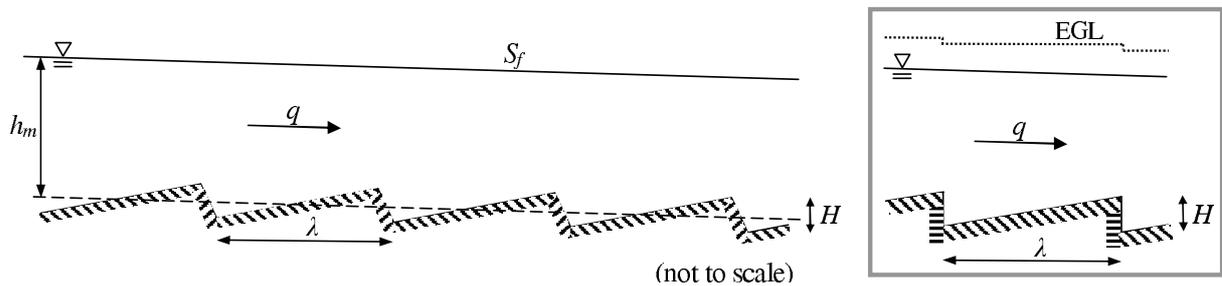


Figure 1: Dunes on channel bed in Problem 1.

Figure 1 shows a long wide rectangular straight channel with sand dunes on the bottom. The dunes have a height $H = 1 \text{ m}$ and a length $\lambda = 30 \text{ m}$. The average channel depth is $h_m = 5 \text{ m}$ and the flowrate per unit width is $q = 5 \text{ m}^2/\text{s}$. The dune geometry can be simplified by assuming the downstream slope to be vertical, as shown in the insert. Account only for headloss in the flow expansion from dune crest to dune trough, as represented by the EGL in the insert.

- Assume the water surface to be straight and sloping by an angle $\sin \beta = S_f$ relative to horizontal, with $S_f = S_0 =$ average slope of the bottom, and estimate the velocity head over the dune crest and over the dune trough. Use your estimates of the velocity heads to argue that the assumption of straight surface is a good one. (The take-home conclusion is that the surface shape is insensitive to the bottom bedforms provided that the Froude number is much smaller than 1).
- Calculate the headloss due to the sudden flow expansion from dune crest to dune trough.
- Estimate the average slope of the surface, S_f . To this end, calculate an average headloss per unit length of the channel by distributing the headloss obtained in **b** evenly over the dune length. Neglect all other losses.
- Calculate Manning's n for this channel.
- What would be the roughness ϵ of an equivalent channel with a uniformly rough bottom?

Problem 2

Water in a rectangular channel of constant (small) slope flows into a gradual short contraction section, as shown in top view in Figure 2. The upstream depth is $h_1 = 0.6 \text{ m}$, the upstream width is $b_1 = 1.5 \text{ m}$, and the flowrate is $Q = 1 \text{ m}^3/\text{s}$.

- Show that the flow is subcritical upstream the contraction.
- Calculate the minimum value of the downstream width, b_2 , so that the flow stays subcritical along the contraction. Calculate also the corresponding downstream depth, h_2 .
- With the values determined in **b**, sketch the specific energy diagrams for the flow upstream and downstream the contraction. On this sketch, plot the trajectory representing the flow transition along the contraction.

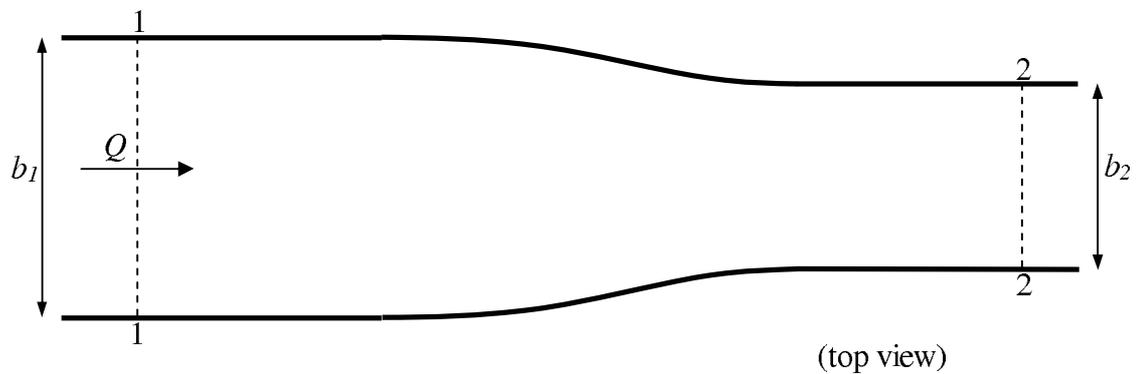


Figure 2: Channel contraction in Problem 2.

Problem 3

Flow from a reservoir passes over a rounded crest into a rectangular channel (the spillway) running down the face of a 100 m dam (Figure 3). The level in the reservoir is H above the elevation of the spillway crest. The spillway is $b = 10$ m wide and the slope of the face of the dam is 1.2 vertical on 1.0 horizontal. The spillway has a flow resistance given by Chezy's Equation with $C = 50$ (in SI units).

a) Assume that the flow from the reservoir passes through critical depth at the spillway crest. Show that this leads to a discharge over the dam *per unit width*

$$q = 0.54\sqrt{g}H^{3/2}$$

and evaluate the discharge for $H = 3$ m.

b) For a discharge of $q = 9.0$ m³/s *per meter width* of the spillway channel determine the normal depth h_n corresponding to steady uniform flow using Chezy's Equation. Determine also the corresponding velocity, V_n , and the Froude number. Is the flow sub- or supercritical?

c) For the discharge of $q = 9.0$ m³/s *per meter width*, the depth at the toe of the dam as the flow enters a horizontal concrete lined channel (the stilling basin) is measured to be $h_1 = 0.4$ m. Determine the downstream depth, h_2 , and the corresponding velocity, V_2 , of the unassisted hydraulic jump forming in the stilling basin.

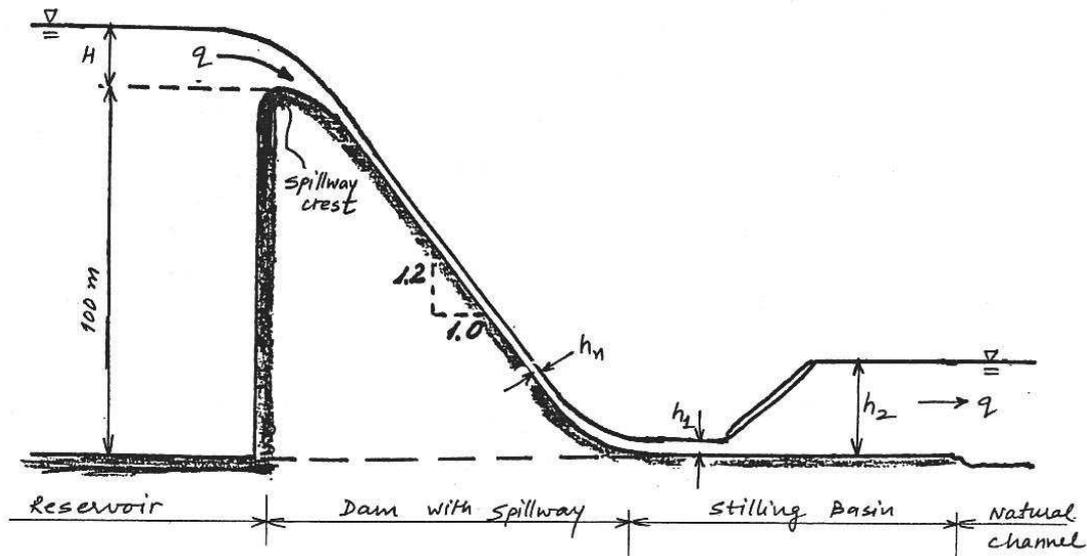


Figure 3: Spillway in Problem 3.

Problem 4

Very high velocity free surface flows may occur at the toe of dam spillways (See for example Problem 3). Before this flow can safely enter a natural waterway, its high velocity must be reduced. The hydraulic jump is an extremely efficient mechanism by which a high velocity flow is transformed into a low velocity, and therefore less erosive, flow. This transformation, i.e., the hydraulic jump, at the toe of the spillway takes place in a so-called stilling basin. To fix the location of the jump, the stilling basin is usually equipped with baffles that produce a drag force on the fluid.

A baffled stilling basin is shown in Figure 4. It consists of a rectangular channel with a continuous baffle of height $H = 0.5 \text{ m}$ spanning the width of the channel. The inflow depth and velocity are $h_1 = 1.0 \text{ m}$ and $V_1 = 30 \text{ m/s}$, respectively, and the drag coefficient for the baffle is $C_D = 0.6$. Problem is plane; treat it per unit width.

- For a baffle location near the start of the jump, i.e., with an approach velocity near V_1 , determine the drag force exerted by the flow on the baffle.
- Neglecting boundary friction and gravity, determine the depth, h_2 , and velocity, V_2 , corresponding to subcritical flow downstream of the baffle-assisted hydraulic jump.
- Determine the headloss and the rate of energy dissipated (in HP = 745 Watts) associated with the jump.
- Given the same V_1 and h_1 , would you expect the downstream depth (h_2) for an unassisted (free) hydraulic jump to be greater or smaller than the value obtained for the baffle-assisted jump? (Justify your answer by physical reasoning, not by solving the unassisted jump and comparing results.)
- Given the same V_1 and h_1 , would you expect the headloss for an unassisted hydraulic jump to be greater or smaller than the value obtained for the baffle-assisted jump? (Again, justify your answer by physical reasoning.)

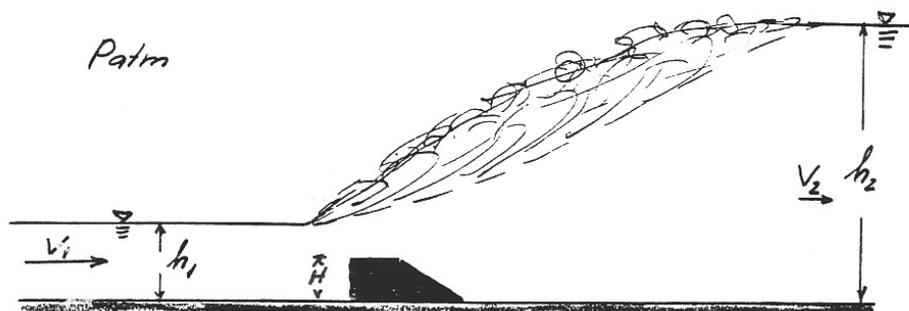


Figure 4: Baffled stilling basin in Problem 4.

Problem 5

Close to the middle reach of a natural channel, a cofferdam dam enclosure is constructed, as shown in Figure 5, in order to enable the concrete foundations for a bridge pier to be constructed. The cofferdam is 15 m wide and 50 m long and has rounded corners to minimize its effect on the flow in the channel. The channel width is $b = 50$ m, the channel depths upstream and downstream the cofferdam are $h_1 = 6.6$ m and $h_3 = 6.5$ m, respectively, and the discharge is $Q = 1000$ m³/s.

- Estimate the total force on the cofferdam structure from the flow in the channel.
- Estimate the headloss caused by the cofferdam, ΔH_{1-3} .
- Estimate the depth, h_2 , and the velocity, V_2 , of the flow where the channel width is a minimum due to the presence of the cofferdam.
- With everything else unchanged, would the flow be able to pass the cofferdam if its width were increased from 15 m to 20 m?

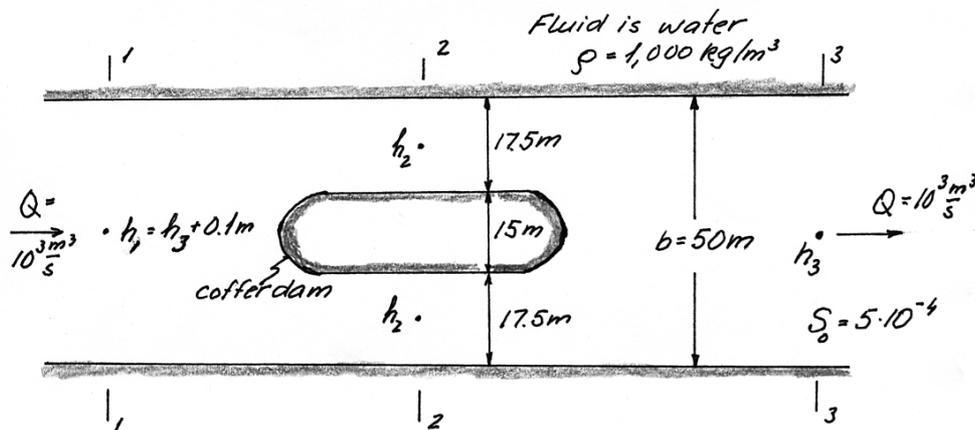


Figure 5: Cofferdam dam enclosure in a channel in Problem 5.

Problem 6

The sketches (1) and (2) in Figure 6 depict two different phenomena. Sketch (1) shows an unassisted hydraulic jump from point A to point B ; sketch (2) shows flow under a gate from point C to point D . For each flow phenomenon, show the location of these points on the h vs. E and the h vs. MP diagrams, which are provided on next page (Figure 7).

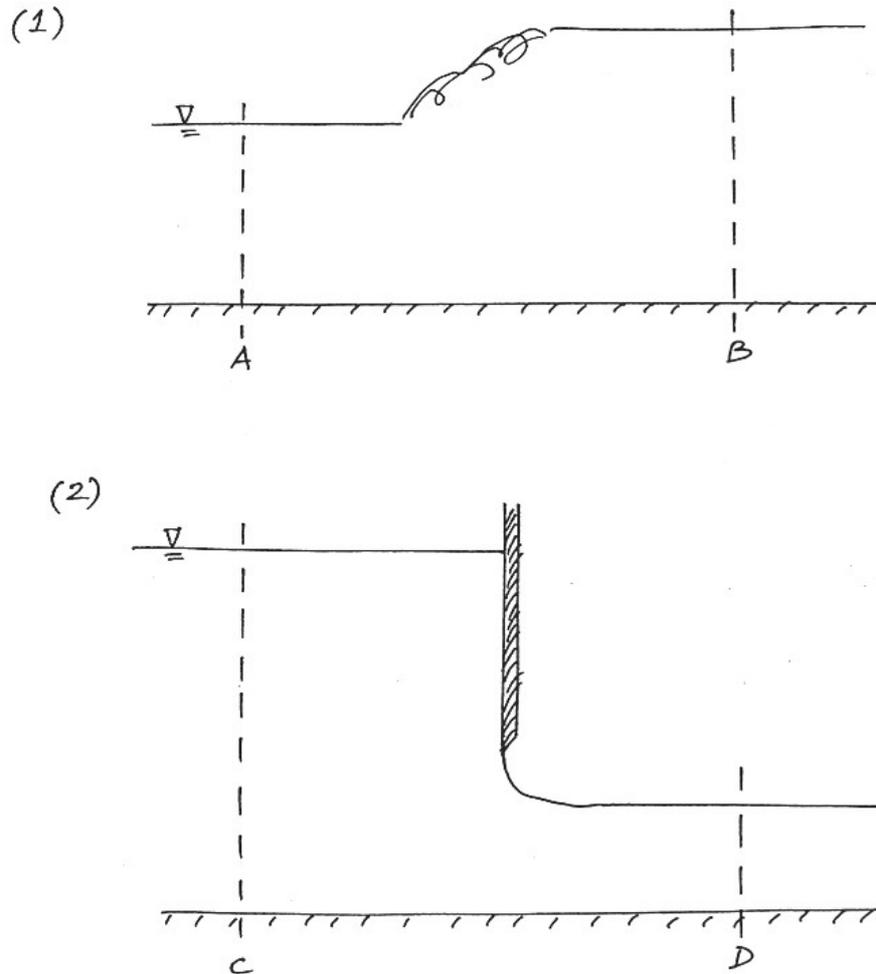


Figure 6: (1) Hydraulic jump and (2) flow under a gate in Problem 6.

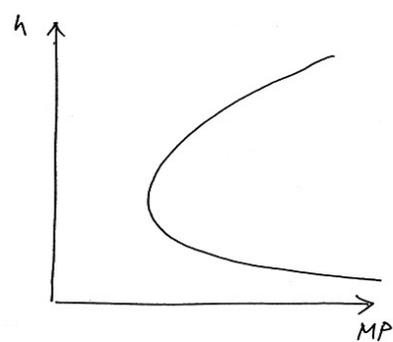
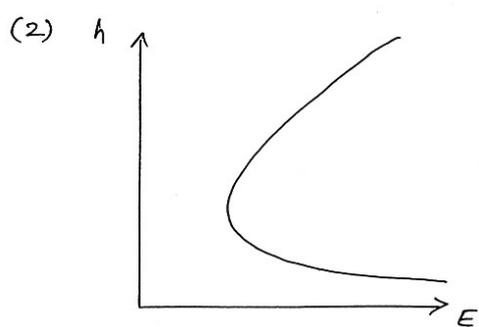
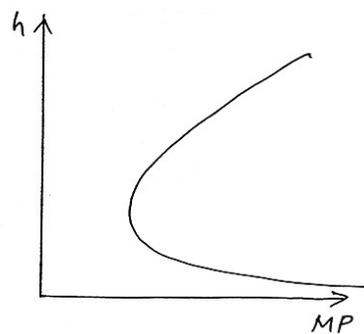
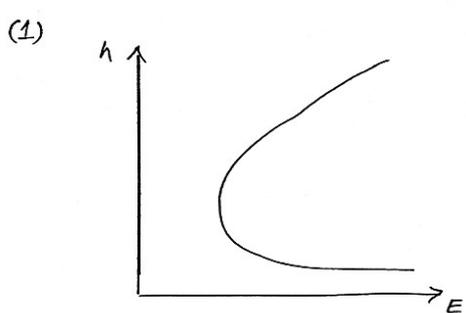


Figure 7: Diagrams for Problem 6.