CIVL3140 Introduction to Open Channel Hydraulics - TUTORIAL 5: Hydraulic analysis and design of Standard and MEL Culverts

The course is a professional subject in which the students are expected to have a sound knowledge of the basic principles of continuity, energy and momentum, and understand the principles of fluid flow motion. The students should have completed successfully the core course Fluid mechanics 1 in semester 1 (CIVL3130).

Past course results demonstrated a very strong correlation between the attendance of tutorials during the semester, the performances at the end-of-semester examination, and the overall course result.

Question 1

A culvert is required to pass 120m^3/s under a road embankment crossing a 350m wide flood plain with gradient 0.004. The equilibrium flow depth on the flood plain is expected to be 1.6m. The embankment is 20m wide at the base. Available precast cells are 2400×2100RCBC (span × height in mm), with leg thickness of 70mm. 30degree flared wingwalls are being used.

Find:

a) the capacity a 9 cell standard box culvert operating under inlet control with no afflux

b) the number of cells required to pass Q=120m^3/s with no afflux and assuming inlet control

c) whether inlet or outlet control occurs for 9 cells and Q=120m^3/s.

(Approx answers: 71m^3/s, 16 cells, outlet control)

Question 2

A culvert is required to pass 12.3m^3/s under an embankment which is 30m wide at the base. At the centreline of the embankment, the ground level is 14.2m AHD and the water level is expected to be 15.6m AHD. The embankment crosses a waterway 8m wide with gradient 0.008. The culvert will be a multi-cell pipe structure, with precast 1650RCP (diameter in mm). Each cell may be assumed square edged and k_e=0.5.

a) Design a standard pipe culvert (invert at ground level) for this discharge, operating under **inlet** control and with no afflux.

b) If the number of cells is reduced to 2, calculate the afflux assuming inlet control, but check this assumption.

c) Design a standard pipe culvert (invert at ground level) for this discharge, operating under **outlet** control and with no afflux.

(Approx answers: 4 cells,0.86m, 4 cells)

Question 3

A new road is proposed which crosses a flood plain (gradient 3.5m/km) using an embankment 30m wide at the base. The minor design storm is Q=62m^3/s and the ground level is 31.2m AHD and the water level is expected to be 33m AHD. Existing properties upstream of the proposed road are already flood affected and the authorities require no adverse impacts on these properties from the proposed road. Precast cells are available, 2400×2100RCBC. 5 cells have been proposed in a preliminary design. 90degree wingwalls are being used with k_e=0.5.

a) Using the preliminary design, estimate the culvert capacity.

b) How many cells are required to achieve the design criteria?

c) After consultation with property owners, it has been decided that 10cm afflux is acceptable. Does this change your answers in b) and by how much?

(Approx answers: 27.5m^3/s,12 cells, 3 less cells)

Question 4

A hydraulic jump was observed in the inlet fan of a recently constructed MEL. The inlet fan design consisted of a linear sloping bed from 16.2m AHD at the inlet lip to 15.6mAHD at the barrel entrance with channel width varying from 20m at the inlet lip to 10.8m at the barrel entrance. A survey indicates that these dimensions have been achieved and that halfway along the inlet fan the bed elevation and inlet width was 15.9mAHD and 13.5m respectively. The estimated specific energy on the floodplain was E=1.6m when the hydraulic jump was observed.

a) Estimate the flow rate at the inlet fan lip, half way along the inlet fan and at the barrel entrance assuming critical flow conditions
b) Is there a hydraulic control within the inlet fan?
c) From your calculations, what was the discharge during the storm?
d) Determine why the hydraulic jump occurred in the inlet fan.

(Approx answers: a) 69m^3/s, 65m^3/s, 68m^3/s, c) <= 65 m^3/s)

Question 5

For the conditions in Q1, design a MEL culvert (simple method, no afflux) assuming a concrete waterway. The maximum excavation depth allowable is 0.9m. Available precast cells are 2400×2100RCBC, with leg thickness of 70mm. Specify the inlet and outlet lip widths, the barrel waterway width, the final excavation depth and inlet and outlet fan lengths. Check exit losses and comment on the practicality of a simple MEL design in this case.

(Approx ans: B=34.8m, 8 cells, -0.78m, 17.4m, 34.8m)

Question 6

A culvert is required to pass 66m^3/s under an embankment which is 30m wide at the base. At the centreline of the embankment, the ground level is AHD 34.15m and the water level is expected to be AHD 36.03m. The embankment crosses a flood plain 75m wide with gradient 0.0035. The culvert will be a multi-cell box structure, with precast units 1.8m high and 2.3m wide. The wall thickness is 0.15m and each cell may be assumed square edged, k_e=0.5.

Give an outline design for an MEL culvert (simple method, no afflux) where the maximum depth of excavation allowable is –1.1m below the natural level. Assume a concrete waterway. Specify the inlet and outlet lip widths, the barrel waterway width and the final excavation depth.

(Approx ans/design choice: B=15m, B=11.5m, Δz=-0.36m)

Question 7

An MEL culvert is to be designed to carry a flow of 100m^3/s from a floodplain 80m wide and with normal flow depth of 1.7m. The barrel is to be excavated to maximum of 0.8m below the natural ground level. Find the barrel slope which equals the critical slope if k_s=3mm and the flow in the barrel is at critical conditions.

(Approx ans: q_B=6.85m^2/s, B_B=14.6m, S_c=0.0026)

Question 8

An MEL culvert design is required to discharge 32m^3/s under a 100m wide embankment. The flood plain is 65m wide, gradient of 0.005 and with normal depth of 1.5m. Rock exists –1.1m below ground level. Design the system (simple method, no afflux), specifying the inlet and outlet lip widths, the barrel waterway width, the final excavation depth and inlet and outlet fan lengths. Check exit losses and comment on the practicality of the design.

(Ans for Δz=-1.1m: B=10.2m, 4.47m, 5.1m, 10.2m, should work well)

Question 9

A waterway crossing is to be designed to carry a flow of $80m^3/s$ from a 60m wide flood plain under a road which is 30m wide at the base. The normal depth in the floodplain is 1.8m and the bed slope is 1/200.

a) Design a standard box culvert to discharge the flow with no afflux and operating under inlet flow control and assuming a wing wall flare of 45°. The culvert is to be constructed from concrete box cells with inside dimensions 1.8m wide by 1.5m high, wall thickness of 0.1m. Assume square edged inlets (k_e=0.5). Specify the number of cells required and the total width of the culvert. Firstly, assume inlet control. Secondly, check if this is the correct assumption and revise if required.

(Ans: 12, 22.9m, then 16, 30.5m)

b) If the number of cells is reduced to 10 cells, find the afflux (rise in the upstream water level). Firstly, assume inlet control. Secondly, check if this is the correct assumption and revise if required.

(Ans: 0.3m, then 0.6m)

c) design an MEL culvert using the simple method so that no afflux occurs when the maximum depth of excavation is 0.9 m. Any cell width may be used. Specify the barrel width, the inlet and outlet lip widths and recommend minimum inlet/outlet fan lengths and the minimum barrel height. Check if the exit loss is less than the head loss available if the actual depth at the outlet is equal to the normal depth on the floodplain.

(Ans: 10.4m, B_{inlet}= B_{outlet}=19m, 0.5B_{inlet}, B_{inlet}, 2.2m, exit loss 45% of available head loss)

Revision problems

Each and every student is strongly encouraged to work on the Revision exercises and Problems in the textbook, pages 480-485. Further relevant information is listed in the textbook, pages 440-475.

Textbook

More exercises in textbook pp. 471-475 and 480-485.
"The Hydraulics of Open Channel Flow: An Introduction", *Butterworth-Heinemann Publ.*, Oxford, UK, 2004.