CIVL4120/7020 Advanced open channel hydraulics and design - TUTORIALS (5)

Hydraulic design of dams and weirs

(1) An overflow spillway is to be designed with an un-gated broad-crest followed by a stepped chute and a hydraulic jump dissipator. The width of the crest, chute and dissipation basin will be 75-m.
The crest level will be at 70.0 m R.L. and the design head above crest level will be 2.4 m. The chute slope will be set at 45 degrees and the step height will be 0.5-m. The elevation of the chute toe will be set at 42.0 m R.L.. The stepped chute will be followed (without transition section) by a horizontal channel which ends with a broad-crested weir, designed to record flow rates as well as to raise the tailwater level.
(1) Calculate the maximum discharge capacity of the spillway.
(2) Calculate the flow velocity at the toe of the chute.
(3) Calculate the residual power at the end of the chute (give the SI units). Comment.
(4) Compute the jump height rating level (J.H.R.L.) at design flow conditions (for a hydraulic jump dissipator).
(5) Determine the height of the broad-crested weir necessary at the downstream end of the dissipation basin to raise artificially the tailwater level to match the J.H.R.L. for the design flow rate.
(6) Compute the horizontal force acting on the (downstream) broad-crested weir at design inflow conditions. In what direction will the hydrodynamic force be acting on the weir : i.e., upstream or downstream ?
(7) If a standard stilling basin (e.g. USBR, SAF) is to be designed, as an alternative, what standard stilling basin design would you select : (a) USBR Type II, (b) USBR Type III, (c) USBR Type IV, (d) SAF ?

Notes
- In computing the velocity at the prototype spillway toe, allow for energy losses by using results presented during the lecture (Figure 19.1, textbook p. 408).
- Assume a skimming flow regime above the stepped chute.
- The residual power equals $\rho*g*Q*H_{res}$ where Q is the total discharge and H_{res} is the total head (at chute toe) taking the chute toe elevation as datum.
Note that a result summary is provided to assist with the calculations.

	Value	Units
Maximum discharge		
Flow velocity at the toe of the chute		
Jump height rating level (J.H.R.L.) at design flow conditions		
Height of broad-crested weir		
Alternate design : standard stilling basin		

Solution
Q_{max} = 475 m^3/s. V = 15.2 m/s. Δz_o = 1.9 m (weir height). Stilling basin USBR Type III or SAF.

(2) Discharge capacity of a spillway crest
An overflow spillway is to be designed with an un-gated crest followed by a steep smooth chute and a hydraulic jump dissipator. The width of the crest, chute and dissipation basin will be 22-m.
The crest level will be at 135.0 m A.H.D. and the design head above crest level will be 2.7 m. The chute slope will be set at 45º. The elevation of the chute toe will be set at 126.9 m A.H.D.. The steep chute will be followed by a horizontal channel with a stilling basin.
(a) Calculate the maximum discharge capacity of the spillway for an ogee crest design.
(b) Calculate the discharge capacity of the ogee crest design for non-design flow with upstream head above crest ranging from 0 to 3.0 m.

(c) Design a circular crest design with a discharge capacity within 5% of the above ogee crest design at design flow.
(d) Compare the discharge capacity of the circular crest and ogee crest designs for non-design flow with upstream head above crest ranging from 0 to 3.0 m.

Solution
(a) Q_{des} = 213 m^3/s, $(C_D)_{des}$ = 1.28
(c) R = 3 , Q_{des} = 203 m^3/s, $(C_D)_{des}$ = 1.22
(d)

Max. reservoir Elev. m AHD	E_1 m	Q broad-crest m^3/s	Q circular m^3/s	Q ogee m^3/s	Remarks
137.70	2.70	166.3	203.0	213.0	Design flow.
135.50	0.50	13.3	12.0	14.3	Less than design flow.
136.00	1.00	37.5	39.0	43.0	Less than design flow.
136.50	1.50	68.9	77.0	81.0	Less than design flow.
137.00	2.00	106.0	125.0	129.0	Less than design flow.
137.50	2.50	148.2	182.0	186.0	Less than design flow.
138.00	3.00	194.8	247.0	254.0	More than design flow.

Comments
(a) Check relative weir crest height (Table 19.4, textbook). For comparison, a broad-crest design would yields: Q_{des} = 166 m^3/s
(b) Non design flow conditions (Fig. 19.9, textbook).
(c) Estimate crest radius. Must be meaningful. (Can it be built ? Is it safe ?)
(d) The differences between circular and ogee crest designs are small. Why would you choose a broad-crest ? (Rubber dam upgrade possibly.)

(3) A weir is to have an open channel spillway with an overflow crest, a smooth-invert chute and a hydraulic jump energy dissipator. Considerations of storage requirements and risk analysis applied to the "design flood event" have set the elevation of the spillway crest 98.0 m R.L. and the width of the spillway crest at B = 105 m. The maximum flow over the spillway when the design flood is routed through the storage for these conditions is 1,300 m^3/s. (Note : the peak INFLOW into the reservoir is 3,500 m^3/s.)
Three spillway crest configurations will be considered. The chute slope is 1V:0.8H (i.e. about 51.3 degrees). The average bed level downstream of the spillway is R.L. 56.9 m and the tailwater rating curve (T.W.R.C.) downstream of the dam is defined as follows :

Discharge (m^3/s)	T.W.R.L. (m)
25	58.5
50	58.95
100	59.6
150	60.0
250	60.65
400	61.45
520	61.9
800	62.75
1000	63.35
1300	64.1
1800	65.2

+ Design four options for the hydraulic jump stilling basin to dissipate the energy at the foot of the spillway as follows :

(A) Broad crest, followed by a smooth concrete chute with apron level lowered to match the Jump Height Rating Level (J.H.R.L.) to the T.W.R.L. at design flow.

(B) Circular crest, followed by a smooth concrete chute with apron level lowered to match the Jump Height Rating Level (J.H.R.L.) to the T.W.R.L. at design flow.

The circular crest will have a 4-m radius for ease of construction.

(C) An Ogee crest, followed by a smooth concrete chute with apron level lowered to match the Jump Height Rating Curve (J.H.R.C.) to the T.W.R.C..

(D) An Ogee crest, followed by a smooth concrete chute with apron level set at 56.9 m R.L. (i.e. average bed level) BUT spillway width B is changed to match the Jump Height Rating Level (J.H.R.L.) to the T.W.R.L. at design flow.

The spillway crest shape has been chosen so that the discharge coefficient at the maximum flow is 2.15 (SI units). For the purpose of the tutorial, the discharge coefficient may be assumed to decrease linearly with discharge down to a value of 1.82 at very small discharges.

+ In each case use a sloping apron section if this will improve the efficiency and/or economics of the basin.

+ In computing the velocity at the foot of the spillway, allow for energy losses using chart given in lecture (Figure 19.1, textbook p. 408).

Note that a result summary is provided to assist with the calculations.

	Value				Units
	Design A	Design B	Design C	Design D	
Maximum reservoir elevation					
Crest dimensionless discharge coefficient	1.0				--
Flow velocity at the toe of the chute					
Apron elevation					
Chute width					
Alternate design : standard stilling basin					

Solution

	Value				Units
	Design A Broad crest	Design B Circular crest	Design C Ogee crest	Design D Ogee crest	
Maximum reservoir elevation	101.75	101.28	101.21	101.40	m R.L.
Crest dimensionless discharge coefficient	1.0	1.22	1.26	1.26	--
Flow velocity at the toe of the chute	25.6	25.5	25.4	25.2	m/s
Apron elevation	56.32	56.30	56.30	56.30	m R.L.
Chute width	105	105	105	122	m

(4) (1997 E2321 End-of-Semester Examination)

An overflow spillway is to be designed with an un-gated broad-crest followed by a stepped chute and a hydraulic jump dissipator. The width of the crest, chute and dissipation basin will be 25-m. The crest level will be at 96.3 m R.L. and the design head above crest level will be 3.1 m. The chute slope will be set at 51.3 degrees and the step height will be 1-m. The elevation of the chute toe will be set at 78.3 m R.L.. The stepped chute will be followed (without transition section) by a horizontal channel which ends with a broad-crested weir, designed to record flow rates as well as to raise the tailwater level.

The spillway design will be tested in laboratory to verify/check the non-design flow performances. A 50:1 scale model of the spillway is to be built. Discharges ranging between the maximum flow rate and 10% of the maximum flow rate are to be reproduced in the model.

(a) Calculate the maximum discharge capacity of the spillway.

(b) Determine the maximum model discharge required.

(c) Determine the minimum prototype discharge for which negligible scale effects occur in the model. (Comment on your result)

(d) What will be the scale for the force ratio ?

(e) Operation of the basin may result in unsteady wave propagation downstream of the stilling basin with wave amplitude of about 0.05 m and wave period of 47 seconds (model observations).

(i) Compute the prototype wave amplitude.

(ii) Compute the prototype wave period.

Solution

Q_{max} = 233 m^3/s (prototype). Q_{max} = 0.0131 m^3/s (model). Q_{min}= 44 m^3/s (prototype).

<u>More exercises in textbook pp. 424-430, 476-480, & 483-484.</u>
Lecture material: pp. 391-439 & 485-492.
Revision material: pp. 37-39, 53-63, 75-81.
"The Hydraulics of Open Channel Flow: An Introduction", *Butterworth-Heinemann Publ.*, 2nd edition, Oxford, UK, 2004.