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INVESTIGATION OF SERVICE BRIDGE PIERS LOCATED ON SPILLWAY AND EFFECTS ON DISCHARGE

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Abstract
The piers can be placed on the spillway crest to hold the sluice gate for controlling the flow or support a service bridge. In addition, these piers to be placed on spillway body provide air entry to prevent negative pressure on the crest and eliminate the risk of cavitation. However, piers and abutments reduce the flow section area and it may cause increasing in reservoir water level. This contraction in the section varies depending on the thickness of the piers besides shape of the cross section. There are some theoretical methods in literature to calculate reduce in effective length of crest. In this study, experimental studies have been done on circular and square section bridge legs in laboratory environment. The results obtained from the studies showed that there are serious differences between experimental and theoretical calculations.

Keywords*: abutments, bridge Piers, net crest length, Ogee Spillway*

Introduction
Bridges are one of the most important hydraulic structures of civil engineering. The piers are not only used to support the bridges built on rivers, but are also used to support the bridges to provide transportation on the dam bodies built in valley. Services bridges are built top level of the spillways. The columns used for supporting the sluice gate work as bridge piers when water pass between them, gates are open. When planning the reservoir capacity in dams, the effect of piers on flow should be considered.

The bridge piers built on river and the piers built on spillway work in different manner for hydraulically. While water has a speed before and after the piers in river, the velocity of water at the upstream side of pier on the spillway is generally considered zero. Since the bridge and abutments are in the flow area during the lifetime, they are exposed to the structure to ground effect. For this reason, there are many parameters affecting the hydraulic design of the bridge piers. These parameters are flow regime at upstream and downstream side, shape and size of the piers. Therefore, there are several studies conducted for each parameter. In the case of water level rise in reservoir after sudden rainfall, discharge between piers must be calculated accurately in order to transfer excessive water to downstream effectively.

The most important study explaining the effect of the bridge piers on the cross sectional area of flow was performed at by USBR Laboratories. USBR explained reduction in effective crest length depending on the number of piers and piers shape by formulas in report published as name of Design of Small Dams in 1987.

Today, researches are mostly focused on scour at the bottom of piers. Also, several studies have been carried out to prevent or minimize the deterioration caused by flow or the different factors. The researcher (Yarnell, 1934) investigated the effect of pier geometry and maximum scour depth. This study is among the first studies on piers shape. Some researchers (Barbhuiya and Dey 2003), conducted studies on different piers shape. In the study rectangular, half cylindrical and cylindrical pier sections are used. They measured velocity components around piers, turbulence magnitude and kinetic energy. The researchers (Khosnorejad and friends 2012) also studied on local scour around bridge piers.

In this study, experimental studies carried out on an ogee spillway containing piers at top level of crest. It is believed to that piers support a service bridges. The effect of these piers on the flow area and effective crest length of flow was investigated. The results obtained from experiments were compared with results calculated from formulas in the literature.

Materials and Methods

In ogee type spillways, the optimum discharge is obtained when the shape of the crest is close to the ideal form. The shape of the crest is determined by the total head over ogee spillway (H), the slope of upstream face (θ) and crest height (P) of the spillway body (Figure 1). Discharge (Q) over the spillway is calculated by following Formula-1;

$$Q = C * L * H^{\frac{3}{2}} \tag{1}$$

Where; Q is discharge (m^3/s), C is discharge Coefficient, L is effective Length of Crest (m), H is total head over the spillway (m).

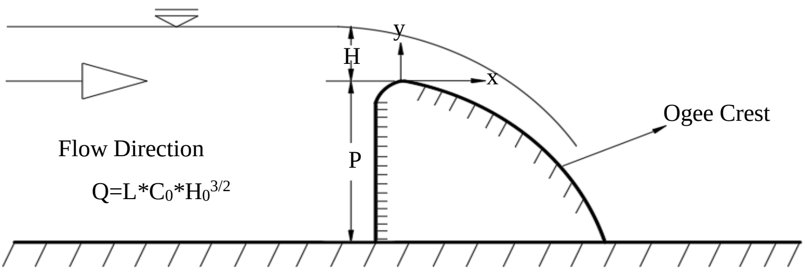


Figure 1. General view of ogee spillway

The ogee spillway used in this study has 30 cm crest length (L=30 cm) and 28 cm crest height (P=28 cm). (Figure 2.)

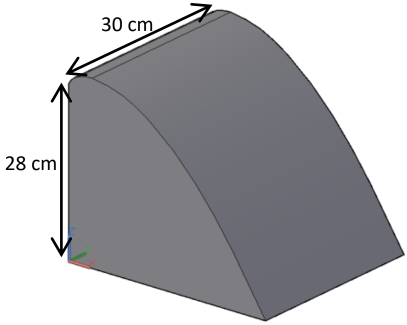


Figure 2. Dimension of ogee spillway used in experiments and actual view of ogee spillway

Piers and abutments placed on spillway cause contraction in flow section reduce the effective crest length and caused reduction in discharge compared with the free flow without piers. Net length of crest is calculated by Formula-2 given below (USBR 1987).

$$L' = L - 2 * (N * K_p + K_a) * H_e \quad (2)$$

Where L is effective crest length in free ogee spillway, L' is net length of crest, N is number of piers, K_p is pier contraction coefficient, K_a is abutment contraction coefficient, H_e is total head over on ogee spillway.

Pier contraction coefficient (K_p) is affected by shape and thickness of the pier, design head over on the ogee spillway (H_d) and approach velocity (V_a). In the situation where the water pass over the ogee with design head (H_d), pier contraction coefficients (K_p) can be taken as below:

For square-nosed piers with rounded corners, K_p=0.02

For round-nosed piers, K_p=0.01

For pointed-nose piers, K_p=0.00

Abutment contraction coefficient (K_a) is affected by shape of the abutment, the angle between wall of abutment and axis of the flow, relation between radius of abutment (r) and design head (H_d) and approach velocity (V_a). In the situation where the water pass over the ogee with design head (H_d), abutment contraction coefficients (K_a) can be taken as below:

For square abutments with headwall at 90° to direction of flow, K_a=0.20

For rounded abutments with head wall at 90° to direction of flow when $0.15 * H_d \leq r \leq 0.5 * H_d$, K_a=0.10

For rounded abutments where $r > 0.5 * H_d$ and head wall is placed to direction of flow not more than angle of 45°, K_a=0.00

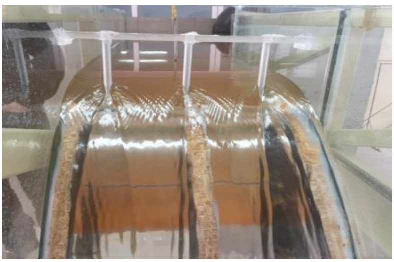
Experimental Setup

Ogee spillway has P=28 height is placed on an open channel which is 650 cm long, 30 cm wide and 50 cm high. The flow on the channel is provided by two pumps with 7.5 kW connected parallel to the system. Two pumps provide discharge in a range from 0 lt/s to 40 lt/sn. Discharge is adapted by a frequency convector which connected to pumps. Discharge is measured by an electromagnetic flow meter which placed on the main pipe. The pumps take water from Reservoir-1 send to Reservoir-2. After reaching a certain level in Reservoir-2, water pass to channel and reach Reservoir-1 again. In this way, the system operates in recirculation (Figure 3.).

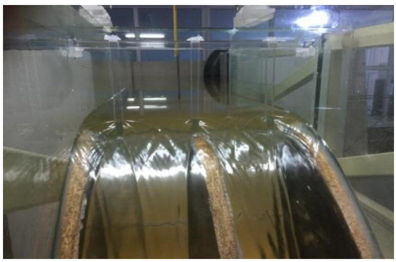
Figure 3. Open channel system used in experiments

Results and Discussion

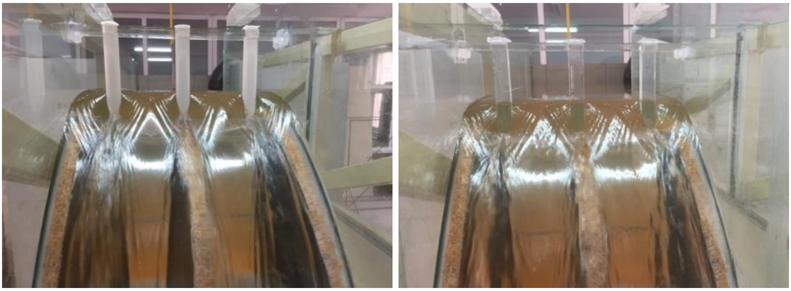
In the experimental study, experiments were carried out on the ogee spillway for free flow without piers firstly. The effect of the piers on the net crest length ($L^{'}$) was investigated by comparing data obtained from the free flow and flow with piers. 3 piers were used in each of the experiment sets. Total head (H_e) and corresponding discharge (Q) values were measured. Total head was measured by limnimetre. Approach velocity of water to upstream side of piers was accepted V_a=0 m/s. Therefore, the energy height of approach velocity H_a=0 m. The set of experiments are listed and shown below with Figure 4.



a) 3 Circular Piers with D=1 cm



b) 3 Square Piers with B=1 cm



c) 3 Circular Piers with D=1 cm **d)** 3 Square Piers with B=1 cm

Figure 4. Experimental setups

All data obtained from 5 experimental setups are shown in Figure 5. When circular and square cross sectional piers with a width of 1 cm and 2 cm are compared, the piers have circular cross section have more efficient discharge (Q) release at same total head (H_e) more than square cross section piers. This is an expected result.

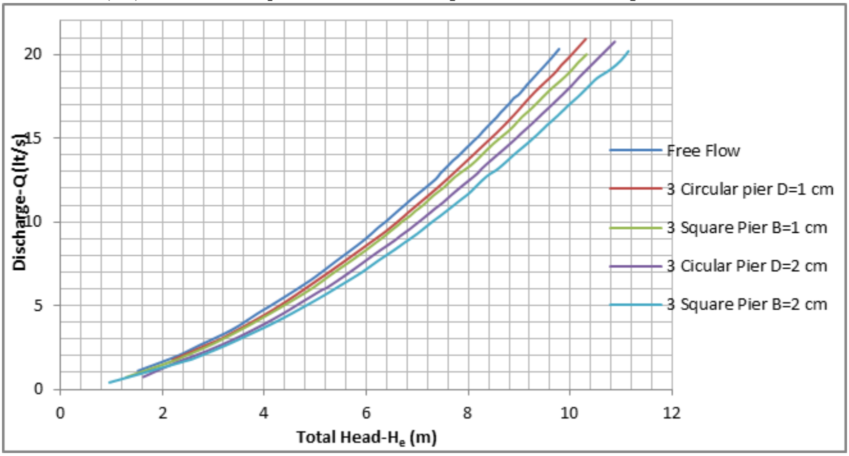


Figure 5. Data obtained from piers have different sizes and cross-sections

However, the discharges (Q) values are calculated by Formula-2 (USBR 1987) with same total heads in the experimental setup for each sets (Figure 7 ÷ Figure 10), there is 10%-15% percent of difference occurs between theoretical and experimental discharges.

The percent of discharge difference between theoretical and experimental studies is around 11% in the square cross sectional piers. This differences increased percent of 15% in the circular cross sections. This is due to the fact that the piers with circular cross section are efficient in discharge, but the theoretical calculation cannot calculate this efficiency well enough.

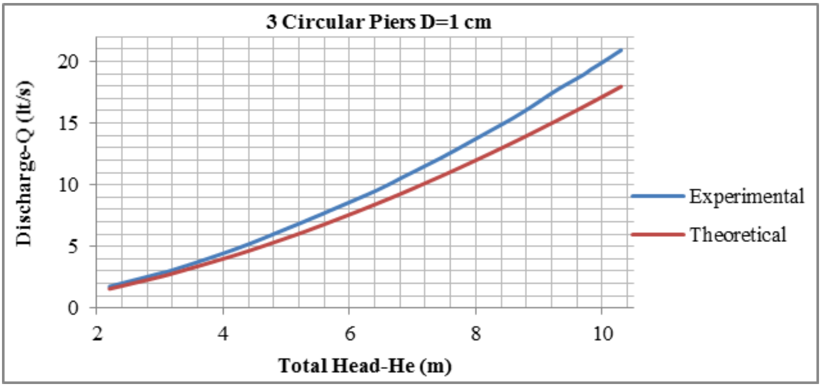


Figure 7. Comparison of experimental and theoretical calculation of discharges for 3 circular piers having D= 1 cm diameter

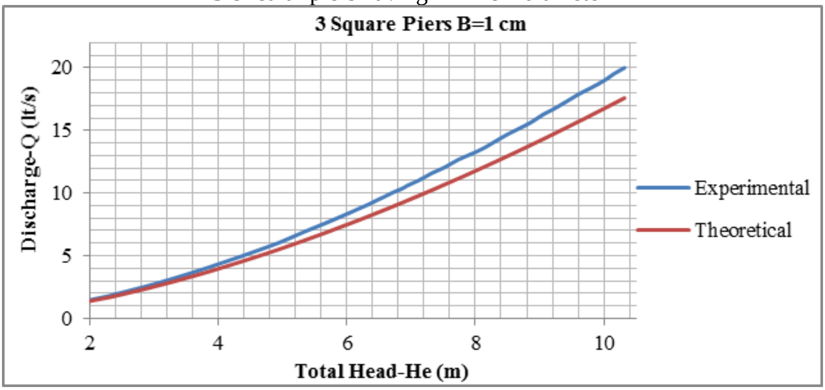


Figure 8. Comparison of experimental and theoretical calculation of discharges for 3 square piers having B= 1 cm size of edge

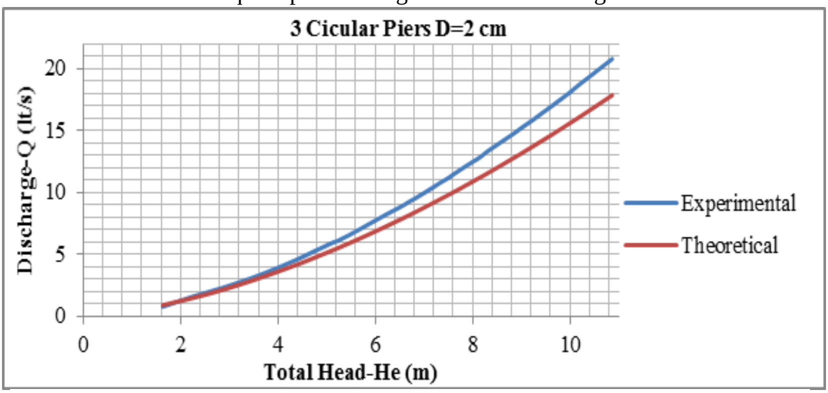


Figure 9. Comparison of experimental and theoretical calculation of discharges for 3 circular piers having D= 2 cm diameter

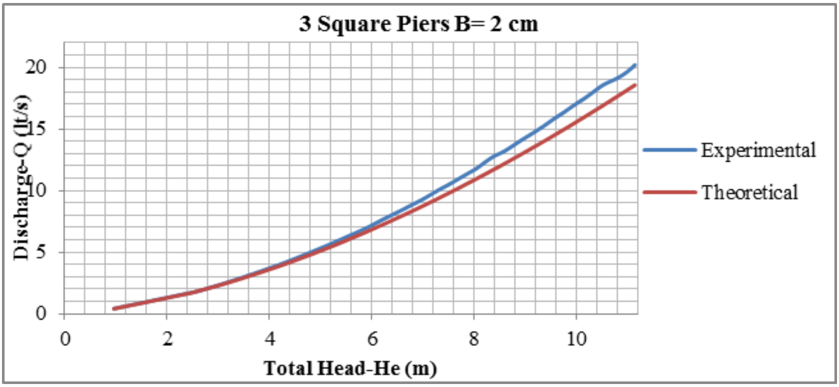


Figure 10. Comparison of experimental and theoretical calculation of discharges for 3 square piers having B= 2 cm size of edge

Conclusions

In this study, an ogee crested spillway was used in the laboratory and bridge piers were placed on it and experimental studies were done for 5 different conditions. The results obtained from experimental studies were compared with the theoretical calculations. This comparison shows that the theoretical calculations give discharge values under estimated than in real life.

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Appendix-Data obtained from experimental setups

FREE FLOW			3 CIRCULAR			3 SQUARE			3 CICULAR			3 SQUARE		
	H_e	Q		H_e	Q		H_e	Q		H_e	Q		H_e	Q
1	1.52	1.10	1	2.20	1.76	1	1.29	0.72	1	1.63	0.75	1	0.96	0.41
2	2.28	1.98	2	2.95	2.76	2	2.30	1.79	2	2.27	1.6	2	2.46	1.70
3	2.76	2.68	3	3.21	3.11	3	2.36	1.88	3	2.87	2.29	3	2.57	1.79
4	3.37	3.57	4	4.20	4.81	4	3.00	2.73	4	3.51	3.15	4	3.25	2.64
5	3.84	4.48	5	5.03	6.50	5	3.61	3.68	5	4.22	4.27	5	4.05	3.77
6	4.23	5.20	6	5.52	7.54	6	4.10	4.51	6	4.7	5.15	6	4.56	4.57
7	4.70	6.11	7	6.12	8.86	7	4.54	5.29	7	5.13	5.94	7	5.05	5.40
8	5.03	6.79	8	6.36	9.39	8	4.95	6.06	8	5.22	6.06	8	5.45	6.13
9	5.41	7.67	9	6.64	10.08	9	5.32	6.88	9	5.56	6.75	9	5.90	6.97
10	5.84	8.64	1	6.83	10.59	10	5.64	7.55	10	5.88	7.45	1	6.24	7.70
11	6.09	9.27	1	7.10	11.28	11	5.98	8.29	11	6.22	8.2	1	6.59	8.42
12	6.23	9.66	1	7.52	12.38	12	6.17	8.73	12	6.54	8.86	1	6.78	8.83
13	6.38	10.02	1	7.90	13.45	13	6.34	9.11	13	6.68	9.2	1	7.00	9.30
14	6.50	10.34	1	8.24	14.42	14	6.46	9.42	14	6.84	9.55	1	7.31	10.0
15	6.63	10.69	1	8.58	15.39	15	6.61	9.78	15	7.15	10.3	1	7.48	10.4
16	6.75	11.00	1	8.90	16.40	16	6.71	10.0	16	7.34	10.7	1	7.70	10.9
17	6.90	11.40	1	9.30	17.75	17	6.86	10.3	17	7.5	11.1	1	7.90	11.4
18	7.35	12.53	1	9.68	18.85	18	6.96	10.6	18	7.66	11.5	1	8.04	11.7
19	7.45	12.90	1	9.82	19.35	19	7.11	11.0	19	7.87	12.1	1	8.35	12.7
20	7.58	13.29	2	9.98	19.85	20	7.32	11.5	20	8.16	12.8	2	8.59	13.1
21	7.70	13.67	2	10.3	20.92	21	7.52	12.0	21	8.32	13.3	2	8.93	14.1
22	7.80	13.92				22	7.73	12.6	22	8.83	14.7	2	9.15	14.6
23	7.90	14.23				23	7.95	13.1	23	9.04	15.3	2	9.36	15.2
24	8.00	14.53				24	8.14	13.6	24	9.25	15.8	2	9.55	15.8
25	8.10	14.83				25	8.49	14.6	25	9.44	16.4	2	9.76	16.3
26	8.20	15.11				26	8.83	15.5	26	9.64	17	2	9.95	16.9
27	8.28	15.39				27	9.05	16.2	27	9.82	17.5	2	10.1	17.5
28	8.37	15.68				28	9.25	16.8	28	10.0	18.1	2	10.3	18.1
29	8.46	15.96				29	9.61	17.9	29	10.1	18.6	2	10.5	18.6
30	8.56	16.27				30	9.80	18.4	30	10.5	19.7	3	10.8	19.1
31	8.64	16.56				31	10.0	18.9	31	10.8	20.7	3	11.0	19.6
32	8.72	16.81				32	10.1	19.5				3	11.1	20.2
33	8.81	17.09				33	10.3	20.0						
34	8.89	17.39												
35	9.00	17.64												
36	9.15	18.19												
37	9.31	18.72												
38	9.47	19.25												