DOI: *http://doi.org/10.21698/simi.2019.fp01*

A NEW APPROACH TO DETERMINE THE DISCHARGE PASSING OVER OGEE SPILLWAY

Ali Yildiz, Alpaslan Yarar, Ali İhsan Marti, Öznur Kocaer

Konya Technical University Civil Engineering Department, Konya, ayarar@ktun.edu.tr, ayildiz @ktun.edu.tr, aimarti@ktun.edu.tr, oznurkocaer3@gmail.com, Turkey

Abstract
The main purpose of this study is investigation of flow over an ogee spillway experimentally and comparison with the analytical results. An experimental study was conducted to obtain discharges and heads over an ogee spillway. 30 different discharge and flow depths of flow in physical model were measured. Nondimensional discharge and flow depth curves are used to compare the results. Experimental results indicate that some regulations can be done in analytical formulas. In this way the analytical results can be get more accurately.

Keywords: *analytical study, experimental investigation, Ogee Spillway*

Introduction
The ogee spillway is one of the most studied hydraulic structures because of its superb hydraulic characteristics. Ogee spillways are used for controlling the discharges and water levels in reservoir in dams. A spillway should have an economical and functional design, therefore the hydraulic parameters such as discharge, flow depth and velocity should be known accurately. Although much of information about ogee spillways is understood, any derivation from standard parameters such as flow depths and crest shape can change flow parameters. It should be known that these small changes whether or not affect spillway performances.

Many researches made considerable works to determine most efficient parabolic crest shape of the ogee spillway and different methods are used depending on the relative height (P/H). Many of these methods are based on an extensive series of experiments conducted on weirs at the U. S. Bureau of Reclamation Laboratory (Bradley 1952) defining the profile of the lower nappe of flow over a sharp-crested weir for a wide range of relative heights and upstream face slopes. The design methods presented by the U. S. Army Engineer Waterways Experiment Station, Corps of Engineers (Maynord 1985) and the (USBR 1987) are probably the most widely used methods in the hydraulic engineering.

Experimental studies have been basis of numerical studies such as computational fluid dynamics (CFD). The researchers (Savage and Johnson 2001) compared the discharge characteristics and pressure distribution for flows passing over an ogee spillway using a physical model, a numerical model. Dargahi 2006) used a physical and numerical model to compare surface profile and discharge coefficients. The researchers (Hu and Friends 2018) used a numerical model to analyze performance of piano key weirs. According to results of numerical model, some new formulas are driven by him to improve accuracy of the design and structural optimization of piano key weirs.

In this study, a physical model of standard ogee spillway which was built in laboratory is used. Discharge and head over spillway were measured. Discharge values, depending on head over the spillway, were also calculated using analytical formula. The correlation between the experimental and the analytical results of discharges was investigated. And some regulations on the formula were suggested to increase the correlation between the results.

Materials and Methods

The ogee spillway is a control weir having an ogee (S-shaped) overflow profile. It is one of the most used spillway type in hydraulic structures because of its ability to pass flood flow out of reservoir safely. Ogee spillway idea is first recommended by Muller (1908).

The general equation for discharge over an ogee crested spillway is given as:

$$Q = C x L x H^{1.5} \quad (1)$$

where;

Q= discharge, L= crest width, C= discharge coefficient and H=total head over ogee spillway.

The relationship of discharge coefficient, C_o, to various values of P/H_o, is given in Figure-1 where C_o is design discharge coefficient and H_o is design head.

Discharge coefficient ratio C/C_o continues to increase with H/H_o as shown Figure-2 up to maximum value of head ratio (H/H_o). The curve on the Figure 2 depends on:

$$C/C_0 = 0.03x\left(H/H_0\right)^3 - 0.14x\left(H/H_0\right)^2 + 0.32x\left(H/H_0\right) + 0.79 \quad (2)$$

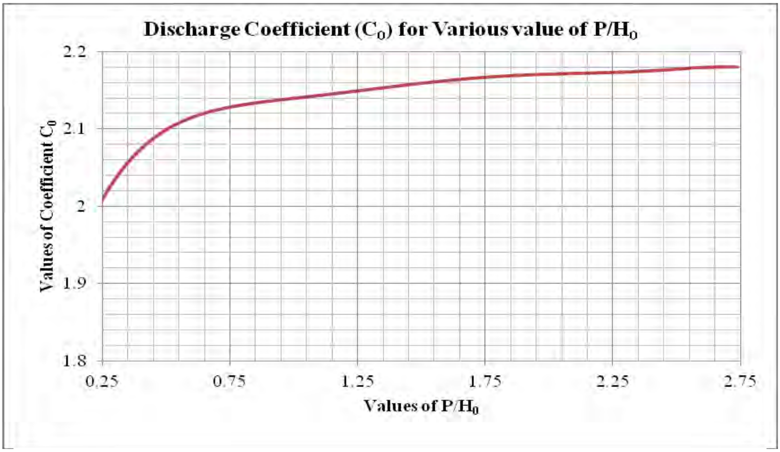

Figure 1. Discharge coefficient for vertical-faced ogee spillway (USBR 1987)

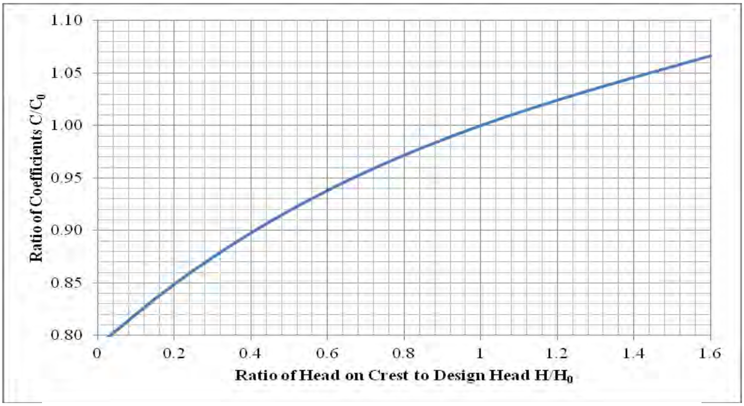

Figure 2. Discharge coefficient for various total head (USBR, 1987**)**

In the laboratory, the ogee spillway model was placed in a test flume. The test flume is a open channel which was made of plexiglas. The open channel is 400 cm long, 7, 5 cm wide and 15 cm high and has a zero bottom slope. The open channel has a closed water circulation system and the flow supplied by an upstream reservoir tank via a pump. Screens are placed at the upstream face of the reservoir tank in order to prevent waves and to obtain uniform flow conditions along the channel. The screens are behaving as wave-breaking and provide a smooth water surface profile before the ogee spillway.

An ogee spillway was placed at the tail of the channel then flow depths and flow rates are adjusted by a valve. Total head over the ogee spillway is measured by limnimeter and discharges are calculated by measuring volume changes depending on time in measurement tank (Figure 3).

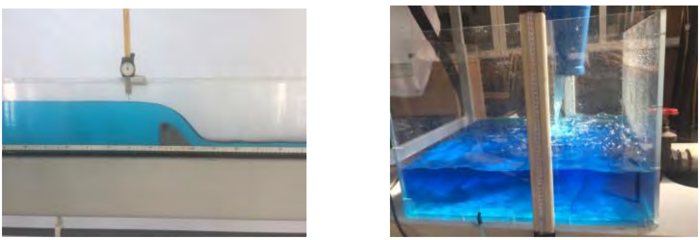

Figure 3.
a) Water surface profile **b)** Discharge measurement tank

A control valve was used for controlling discharge in the model. Experiments are conducted for 16 different total head over the ogee spillway ranging from $H/H_o=0.28$ to $H/H_o=1.43$. Heights are measured by using limnimetre from top of the crest to water surfaces. Limnimetre is placed at the distance of 0.06 m back from the ogee spillway in order to neglect approach velocity. To get more accurate results, discharge-total head relation curve is obtained (Figure 4). The curve shows increment in discharge is compatible with increase in total head.

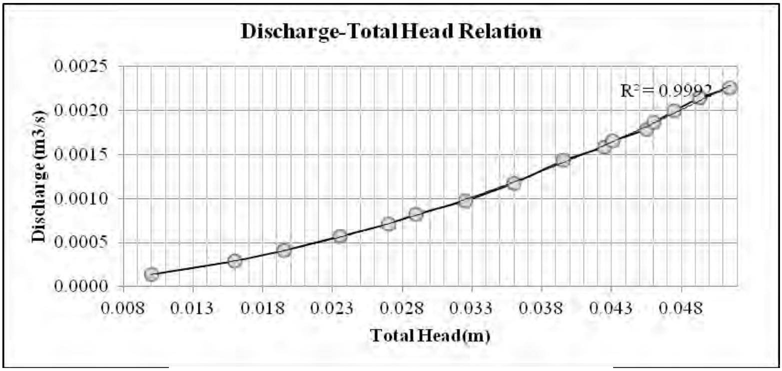

Figure 4. Discharge-Total head relation curve

Physical model of the ogee spillway used in experiments is fabricated from stainless steel. Design head of the ogee spillway chosen H_o=0.035 m. Ogee spillway model is 0.07 m high (crest height), 0.075 m wide same as with channel width and 0.085 m long.

Results and Discussion

Discharge values and flow depths investigated by experimental study which is conducted in laboratory were compared with analytical calculations. The main objective of the comparison was to determine success of the results. Table-1 shows the total head and discharges results obtained by analytical calculations depends on equation 1 and equation 2 and physical model. Theoretical USBR values are computed by using total head get from physical experiments. Also the design parameters for ogee spillway are shown on the table. The design head (H_o) is set 0.036 m, then according to this value corresponding design discharge coefficient (C_o) and design discharge (Q_o) is computed as 2.15 and 0.0011 m^3/s relatively. The graphs for the discharges are given in Figure 5.

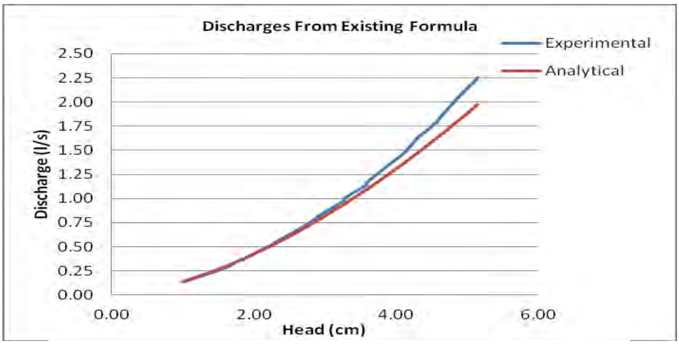

Figure 5. Comparison of analytical and experimental results

Table 1. Results from analytical calculations and physical modeling

	USBR (P=0,07	H_0=0,036	C_0=2,15)		Physical
H_e(m)	H_e / H_0	C/C_0	C	Q (m^3/s)	Q (m^3/s)
0.0100	0.28	0.87	1.87	1.40E-04	1.37E-04
0.0138	0.38	0.89	1.92	2.34E-04	2.30E-04
0.0160	0.44	0.91	1.95	2.96E-04	2.86E-04
0.0182	0.51	0.92	1.98	3.64E-04	3.71E-04
0.0195	0.54	0.93	1.99	4.07E-04	4.12E-04
0.0217	0.60	0.94	2.02	4.84E-04	4.98E-04
0.0223	0.62	0.94	2.02	5.06E-04	5.13E-04
0.0235	0.65	0.95	2.04	5.50E-04	5.71E-04
0.0248	0.69	0.95	2.05	6.01E-04	6.21E-04
0.0270	0.75	0.96	2.07	6.90E-04	7.14E-04
0.0288	0.80	0.97	2.09	7.66E-04	8.01E-04
0.0290	0.81	0.97	2.09	7.75E-04	8.16E-04
0.0325	0.90	0.99	2.12	9.32E-04	9.74E-04
0.0328	0.91	0.99	2.12	9.46E-04	1.01E-03
0.0358	0.99	1.00	2.15	1.09E-03	1.14E-03
0.0360	1.00	1.00	2.15	1.10E-03	1.17E-03
0.0360	1.00	1.00	2.15	1.10E-03	1.17E-03
0.0384	1.07	1.01	2.17	1.22E-03	1.32E-03
0.0395	1.10	1.01	2.18	1.28E-03	1.38E-03
0.0412	1.14	1.02	2.19	1.37E-03	1.48E-03
0.0425	1.18	1.02	2.20	1.44E-03	1.59E-03
0.0433	1.20	1.02	2.20	1.49E-03	1.65E-03
0.0445	1.24	1.03	2.21	1.56E-03	1.71E-03
0.0455	1.26	1.03	2.22	1.61E-03	1.79E-03
0.0457	1.27	1.03	2.22	1.63E-03	1.79E-03
0.0460	1.28	1.03	2.22	1.64E-03	1.82E-03
0.0475	1.32	1.04	2.23	1.73E-03	1.95E-03
0.0493	1.37	1.04	2.24	1.84E-03	2.09E-03
0.0512	1.42	1.05	2.25	1.96E-03	2.23E-03
0.0515	1.43	1.05	2.26	1.98E-03	2.25E-03

If we calculate the discharges according the suggested formula given in Eq. 4 new discharges values is given in Table 2 and the graphs are given in Figure 6.

$$C/C_0 = 0.24x\left(H/H_0\right)^3 - 0.56x\left(H/H_0\right)^2 + 0.64x\left(H/H_0\right) + 0.79 \quad (4)$$

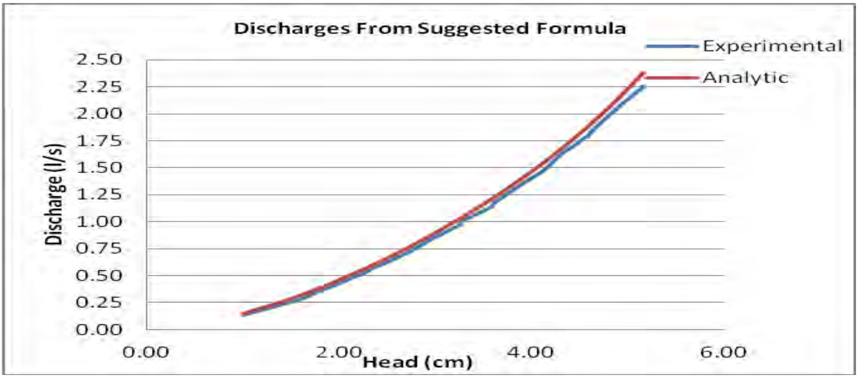

Figure 6. Comparison of analytical and experimental results

Table 2. Results got from new formula and physical modeling

	USBR (P=0.07	H_0=0.036	C_0=2.15)		Physical
H_e(m)	H_e / H_0	C/C_0	C	Q (m^3/s)	Q (m^3/s)
0.0100	0.56	0.93	2.00	1.50E-04	1.37E-04
0.0138	0.77	0.97	2.08	2.53E-04	2.30E-04
0.0160	0.89	0.98	2.12	3.21E-04	2.86E-04
0.0182	1.01	1.00	2.15	3.96E-04	3.71E-04
0.0195	1.08	1.01	2.17	4.44E-04	4.12E-04
0.0217	1.21	1.02	2.20	5.28E-04	4.98E-04
0.0223	1.24	1.03	2.21	5.52E-04	5.13E-04
0.0235	1.31	1.04	2.23	6.02E-04	5.71E-04
0.0248	1.38	1.04	2.24	6.57E-04	6.21E-04
0.0270	1.50	1.06	2.27	7.56E-04	7.14E-04
0.0288	1.60	1.07	2.29	8.41E-04	8.01E-04
0.0290	1.61	1.07	2.30	8.50E-04	8.16E-04
0.0325	1.81	1.09	2.34	1.03E-03	9.74E-04
0.0328	1.82	1.09	2.34	1.04E-03	1.01E-03
0.0358	1.99	1.11	2.38	1.21E-03	1.14E-03
0.0360	2.00	1.11	2.39	1.22E-03	1.17E-03
0.0384	2.13	1.13	2.42	1.37E-03	1.32E-03
0.0395	2.19	1.14	2.44	1.44E-03	1.38E-03
0.0412	2.29	1.15	2.47	1.55E-03	1.48E-03
0.0425	2.36	1.16	2.49	1.64E-03	1.59E-03
0.0433	2.41	1.17	2.51	1.70E-03	1.65E-03
0.0445	2.47	1.18	2.53	1.78E-03	1.71E-03
0.0455	2.53	1.19	2.56	1.86E-03	1.79E-03
0.0457	2.54	1.19	2.56	1.88E-03	1.79E-03
0.0460	2.56	1.19	2.57	1.90E-03	1.82E-03
0.0475	2.64	1.21	2.60	2.02E-03	1.95E-03
0.0493	2.74	1.23	2.65	2.18E-03	2.09E-03
0.0512	2.84	1.26	2.70	2.35E-03	2.23E-03
0.0515	2.86	1.26	2.71	2.38E-03	2.25E-03

Conclusions

In this study an experimental setup was used to obtain discharge values and total head over an ogee spillway. Total heads and corresponding discharge values were measured for 16 different water lever before the ogee spillway. Discharges were also calculated by formula depending on the discharge coefficient formula. And a new discharge coefficient formula was suggested to calculate the discharges. It was seen that the discharge values calculated by new coefficient formula were closer to the experimental results than other formulas according to the both graphs. In case of flood. More accurate discharge calculation can be get than the existing formula.

References

Bradley, JN 1952, United State Department of the Interior Bureau of Reclamation, Discharge

Dargahi, B 2006, 'Experimental Study and 3D Numerical Simulations for a Free-Overflow Spillway', *Journal of Hydraulic Engineering,* vol.132, no.9, pp. 899-907

Hu, H, Qian Z, Yang, W, Hou, D & Du L 2018, 'Numerical Study of Characteristic and Discharge Capacity of Pianı Key Weirs', *Flow Measurement and Instrumentation*, vol. 62, pp. 27-32

Maynor, ST, US Army Corps of Engineers, 1985, General Spillway Investigation. USACE Final Report. Washington DC. 6-10

Muller, R, 1908, Development of Practical Type of Concrete Spillway Dam. Engineering Rec, 58, 461

Savage, M & Johnson, MC, 2001, 'Flow Over Ogee Spillway: Physical and Numerical Model Case Study', *Journal of Hydraulic Engineering*, vol.127, no.8, pp.640-649

US Department of the Interior Bureau of Reclamation. 1987. Design of Small Dams. USBR. Washington DC. 365-380