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Technical Note

Scale Effects on the Discharge Coefficient of Ogee Spillway with an Arc in Plan and Converging Training Walls

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ABSTRACT: Dam spillways are the structures that lead rightly and safely the outflow downstream, so that the dam integrity can be guaranteed. Many accidents with dams have been caused by an inadequate spillway design or insufficient capacity. To accurately respond the hydraulic spillways, designers use physical modeling for designing this kind of structures. The scale effect in the spillway modeling, as a result, leads to the difference between the measured data and the prototype. In this study, an experimental model of Germi-Chay Mianeh dam spillway was made in three 1:100, 1:75, and 1:50 scales. Then, the water level in upstream of the spillway crest was measured in seven discharges and compared to 1:50 scale (basic scale), the percentage of water level difference on the crest was calculated in two physical models with 1:100 and 1:75 scales. Results revealed that as the scales of ogee spillway with an arc in plan and converging training walls decrease using Froude simulation, the effect of viscosity and surface tension increase in turn resulting in decreasing discharge coefficient. In this study, the scale effect in discharge coefficient ogee spillway was stated with K' equation. Using model family approved that the minimum Reynolds and Weber numbers which are 3.1×10^4 and 270, respectively indicated the minimum scale effect and thus, it is possible to avoid the effect of viscosity and surface tension in ogee spillway with an arc in plan and with converging training walls. Moreover, results obtained from the small scale which has been simulated using Froude simulation could be extrapolated to the prototype.

Keywords: Discharge Coefficient, Ogee Spillway, Physical Modeling, Scale Effect, Surface Tension, Viscosity.

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INTRODUCTION

When the water elevation in the lake behind the dam is maximized and another flood occurs, a device must have been installed on the dam so that the excess water can be discharged. The hydraulic structure which is used to meet this demand is called Spillway. In other words, spillways, whose forms and dimensions are a function of geographical and hydrological conditions of the region in which they have been built, are used significantly to control elevation and volume of water in the lake behind the dam. Due to limits in construction and design, labyrinth and side channel spillways are sometimes used unavoidably. In these cases, distribution of flow might experience some significant deviations from the assumptions which have already been taken into account during the design phase. Such effects might result in an inappropriate operation and disturb the normal performance of structure unless they are experimentally tested during design phase. Thus, overlooking such a prominent issue during the design phase might impose exorbitant costs in operation period.

The most common and cheapest spillway that could pass lots of water over is ogee spillway. The ogee spillway has a control weir that is ogee-shaped (S shaped) in profile. The upper curve of the ogee spillway ordinarily conforms closely to the profile of the lower nappe of a ventilated sheet falling from a sharp-crested weir. Flow over the crest adheres to the face of the profile by preventing access of air to the underside of the sheet. For discharges at designed head, the flow glides over the crest with no interference from the boundary surface and attains near-maximum discharge efficiency. The profile below the upper curve of the ogee is continued tangent along a slope to support the sheet on the face of the overflow (EUA-Bureau of Reclamation, 1987).

The capacity of the stream of a spillway greatly signifies the length of spillway and the shape of crest. The spillway with an arc in plan has some priorities over straight structures. This kind of spillway increases the length of crest on a given channel width and leads to an increase in flow capacity for a given upstream head. The spillway, therefore, preserves a more constant upstream depth and needs less free board compared to linear weirs (Crookston, 2010). To control the upstream water level and increase the flow capacity, the spillway with an arc in plan is often considered as the desired one. Due to limits in many geometric design variables, designers might find an optimized design for a particular position challenging, thus designers use physical modeling for designing this kind of structures. (Johnson and Savage, 2006).

Physical models of spillways are usually displayed in much smaller size than the size of prototype and studied in the laboratory under controlled conditions. Using experimental models (with controlled flow conditions), a prototype behavior of spillway is predicted (Chanson, 2004). Designers should control the scale effect of model and build a model that best simulates the key aspects of the prototype. It means that one may need many models to examine different aspects of prototype processes. Undesired side effects in the model are associated with those variables which are not scaled according to the simulation needs. These effects arise because one standard of dynamic simulation might be merely considered in the model (Ettema et al., 2005). To establish a complete dynamic similarity, all major forces (such as the viscosity, pressure, surface tension, etc.) should be considered (Fox et al., 2011). To determine the scale effects on the model results, a series of scale models can be used. In other words, several models in different scales should be built from one prototype. If the prototype data is inadequate, scale series test is also regarded quite beneficial. So many results of the prototype can be achieved through extrapolation from modeling studies. However, extreme care must be taken in applying these methods (Ettema et al., 2005).

To simulate the flow in a structure, physical modeling is used to properly design the hydraulic structures. One of the problems using physical modeling is scale effect which makes the decrease of viscosity effect and surface tension forces almost impossible. Thus, the effect of these forces increases in the model. Spillway simulation models are based on Froude simulation law and they are valid when the effects of surface tension and viscosity are small and it is possible to avoid scale effects. In spillways, Reynolds number must be greater than 1×105 and Weber number must be greater than 500 so that viscosity and surface tension effects are neglected (Fais and Genovez, 2008).

The conventional ogee spillway equation is written as follows:

$$Q = \frac{2}{3} C_d \sqrt{2g} L H^{\frac{3}{2}} \quad (1)$$

where Q: is spillway discharge; L: is spillways crest length; H: is head over the spillway crest; g: is gravitational acceleration and C_d: is discharge coefficient

Rehbock (1929) accounted for the effect of surface tension and proposed the following Eq. (2) for C_d (Ghodsian, 1998):

$$C_d = 0.611 + 0.075\frac{H}{W} + \frac{0.36}{H\sqrt{\frac{\rho g}{\sigma}} - 1} \quad (2)$$

where W: is spillway elevation (m); ρ: is fluid density (kg/m^3) and σ: is surface tension of fluid (N/m). On the other hand, Sarginson (1972) developed the following Eq. (3) for C_d which involved the surface tension correction term (Ghodsian, 1998):

$$C_d = 0.613 + 0.0745\frac{H}{W} + \frac{1.492\sigma}{\rho g H^2} \quad (3)$$

Kindsvater and Carter (1957) found that effect of viscosity and surface tension in a spillway flow can be considered by increasing the spillway head by 0.001 m and reducing the length by 0.0009 m. Thus, the considered equation for C_d follows Eq. (4). It is of note that the dimensional heterogeneous form of the above-mentioned equation is valid only in its present form in SI unit.

$$C_d = (0.611 + 0.075\frac{H}{W})(1 - \frac{0.0009}{L})(1 + \frac{0.001}{H})^{1.5} \quad (4)$$

Ranga Raju and Asawa (1977) proposed the following Eq. (5) for C_d:

$$C_d = (0.611 + 0.075\frac{H}{W})K \quad (5)$$

where K: is a correction factor which was graphically related to, and υ: is the kinematic viscosity of fluid (Rajo and Asawa, 1977).

Eq. (6) was given for viscosity and surface tension correction factor K by Gill based on Ranga Raju and Asawa (1977) work, (Ghodsian, 1998):

$$K = (1.576 - 0.088\log_e(We^{0.6}Re^{0.2}) \quad (6)$$

where Re: is Reynolds number and We: is Weber number.

Considering the viscosity and surface tension effects in a rectangular weir, Ghodsian (1998) introduced discharge coefficient of weir as Eq. (7).

$$C_d = (0.611 + 0.075\frac{H}{W} + \frac{0.84}{(\frac{gH^2}{\upsilon}\sqrt{\frac{\rho H}{\sigma}} - 1)^{0.27}} \quad (7)$$

Furthermore, it would be useful to refer to some studies which have been carried out on the scale effect on hydraulic structures. Boes (2000) studied the scale effects in modeling the flow in laboratory using model family on two-phase flow over stepped spillway to investigate the impact of scale model on the aeration process. Using model family, he showed the ignorable scale effect in models with scales smaller than that of prototype which have been minimized by Froude law, in case that the minimum numbers of Reynolds and Weber provide and, respectively. For smaller models, scale effects due to surface tension and viscosity will increase. Boes and Hager (2003) studied the characteristics of two-phase stepped spillway by skimming flow regime. Results showed the minimum Reynolds number that requires the minimum scale effect in physical modeling of two phase air-water flow. For the effect of viscosity and surface tension to be ignored, the minimum numbers of Reynolds and Weber have been respectively considered 10^5 and 100, compared to gravitational and inertial forces in Froude simulation (Boes and Hager, 2003).

Gonzalez and Chanson (2004) studied the scale effects in stepped spillways with mild slope in air-water flows in laboratory. The results showed significant scale effects in bubble count rate, turbulence intensity and bubble chord sizes. Gonzalez and Chanson (2005), studied flow turbulence for flow resistance in skimming flow in stepped spillways. The results of large-scale physical model with Reynolds numbers between and were obtained to minimize the potential of scale effects.

Using physical modeling, Chanson (2008) studied the scale effect of stepped spillway. The validity of Froude simulation has been evaluated by analyzing three experiments in gradients (θ = 3.4, 16 and 22) of an embankment dam. This finding indicates that most physical models cannot extrapolate flow conditions without significant scale effect to the prototype and cannot predict energy loss based on Froude simulation due to turbulence and aeration rate.

Murzyn and Chanson (2008), evaluated the scale effects of two-phase flow characteristics in hydraulic jump. Results of the experiment which was carried out based on Froude simulation showed some scale effects in small hydraulic jump in void fraction, the bubble count rate and bubble chord time distribution.

Fais and Genovez (2008) studied the discharge rating curve and scale effect correction in morning glory spillways. Using the spillway model of Paraitinga hydropower, Fais conducted the experiment and compared the results with those attained from two 1:63 and 1:83 scales of the morning glory spillway of Paraitinga Hydropower built by Genovez (2008). The results showed that for low head, Weber number was smaller than the minimum required. Thus, the scale effect appeared. Reynolds number is greater than 105, thus the effect of viscosity can be ignored.

Chanson and Felder (2009) studied dynamic simulation and scale effects in turbulent free flows on stepped spillway. They experimentally measured high-speed two-phase flows on the stepped spillway, the results finally showed some significant scales. Heller (2011) studied the scale effect in hydraulic engineering models between the model and prototype and Froude simulation and Reynolds (in models).

Mortensen et al. (2011) studied Scale effects of air entrained by hydraulic jumps within closed conduits. To determine the significance of these effects in closed conduits, air flow measurements were taken in four different-sized circular pipes with similar Froude numbers. The data from four different pipes showed that size-scale effects of air entrained into hydraulic jumps within closed conduits are negligible.

Pfister and Chanson (2012) studied the scale effects in physical hydraulic engineering models. They refer to a minimum Reynolds number of 2×10^5 to 3×10^5 or a minimum Weber number of 140 to consider also surface tension effects. Chanson and Chachereau (2013) studied the scale effect in two-phase flow properties in hydraulic jump with Froude number = 5.1 and Reynolds numbers to in laboratory. Results showed that most of air-water flow properties with Reynolds number up to could not be extrapolated to the prototype since there is the scale effect in bubble count rate, turbulence, bubble chord time distribution and bubble cluster characteristics.

Pfister et al. (2013) studied the scale effect on discharge rating curve on the Piano Key weirs (PKWs) with cylindrical crests using Flow 3D both in numbers and physical model. They found out that the effect of viscosity and surface tension could be avoided for limits on overflow head for cylindrical radius of spillway crest assuming and for assuming. In cylindrical crests with less than 0.005 m in radius, more limitations are applied where C_{dm} is the model discharge coefficient and C_{dp} is the prototype discharge coefficient. Pfister and Chanson (2014) studied the scale effect in physical modeling of hydraulic structures for two-phase air-water flows simulated using Froude simulation. Results indicated Reynolds and Weber numbers ranges and their combinations in terms of the number of Morton to prevent the scale effect in air-water parameters such as bubble size and turbulence scale.

Castro and Hager (2014) studied the scale effects of round-crested weir flow. Results showed that the minimum round crest radius of curvature = 0.01 and minimum head flow = 0.04 m on weir crest could prevent significant scale effects. At the end, an equation has been considered for scale effect using the correct prediction of round-crested weir flow specifications.

Felder and Chanson (2015) studied scale effects in high velocity air water flows on a stepped spillway. Results showed that the void fraction and flow bulking are not much sensitive to scale effects. On another hand, the data analyses confirmed scale effects in terms of bubble count rate, turbulence properties and air bubble and water droplet chord sizes. The findings highlighted that a scaling of the air water flow properties is rarely possible and measurements at a prototype scale are needed to identify the limitations of scaled air water flow experiments.

Erpicum et al. (2016) studied scale effects in physical piano key weirs models. In this study, the size-scale effect, minimum upstream head, and Weber number limits are investigated for four piano key weirs with geometric model scales of 1:1, 1:7, 1:15, and 1:25. Wang and Chanson (2016) studied hydraulic jumps with a particular focus on the scale effects in terms of free surface fluctuation and deformation, bubble advection and diffusion, bubble turbulence interaction and turbulence dissipation in laboratory. The roller surface dynamics were found free of scale effects in terms of fluctuation amplitudes but the characteristic frequencies were scale sensitive. While some air–water flow parameters such as bubble count rate, bubble chord time distribution and bubble grouping behavior could only be correctly quantified at full scale prototype conditions, the aeration level and turbulent scales might be estimated with satisfactory accuracy for engineering applications given a model Reynolds number no less than 4×10 to 6×10^4.

As observed, most of the studies were carried out on scale effects on two-phase hydraulic structures (such as stepped spillway, morning glory spillway, stilling basin, etc.); however, engineers and hydraulic performance designers use physical modeling in designing such structures to be able to react correctly to the spillways and to know the water elevation on the crest and discharge coefficient of spillways. However, the question which should be answered here is the scale in which designers should build the physical model and the probable scale effect on the discharge coefficient of ogee spillway with an arc in plan and converging training wall.

MATERIALS AND METHODS

The Scale Size and Geometric Specifications of Ogee Spillway

The experiment has been carried out in Institute of Soil Conservation and Watershed using physical model of ogee spillway of Germi Chay Mianeh dam (in Iran) in three different 1:100, 1:75 and 1:50 scales. A view of plan and cross section of the spillway are shown in Figures 1 and 2. Table 1 depicts the geometry of the three mentioned scales of the spillway physical model which are stimulated by Froude stimulation.

Physical Modeling of Ogee Spillway

In two models with 1:100 and 1:75 scales, a reservoir with length of 1.20 m, width of 0.7 and depth of 0.5 m and a flume with length of 4 m, width of 0.60 m height of 0.50 m were used. In ogee spillway with the scale of 1:50, a reservoir with a length of 2 m, a width of 1.80, and a depth of 1.20 m and a stilling basin with a length of 2 m, a width of 1.30 m and a height of 0.6 m were used. The ogee profile of Germi Chay spillway has been designed according to USBR standard with design head (H_d) = 3 m. Spillways were carved and built using CNC milling machine with an accuracy of 0.05 mm from Teflon blocks. Training walls and the downstream channel were built of Plexiglas.

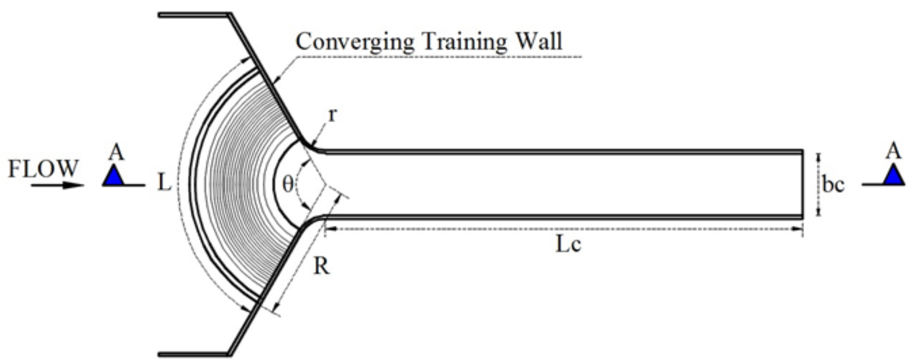

Fig. 1. Spillway plan and downstream channel

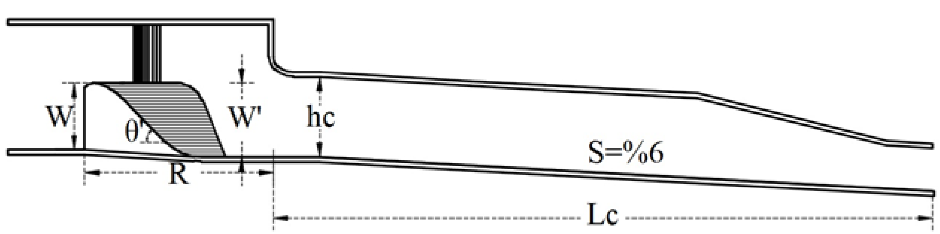

Fig. 2. Spillway cross section A-A

Table 1. The geometry of the spillway

Model Scale	*W* (cm)	*W'* (cm)	*L* (cm)	*R* (cm)	*Θ* (deg)	*R* (cm)	*θ'* (deg)	b_c (cm)	L_c (cm)	h_c (cm)
1:100	7	7.8	42	20	120°	4.5	45°	9	70	8.45
1:75	9.4	10.4	56	26.67	120°	6	45°	12	93.4	11.3
1:50	14	15.6	84	40	120°	9	45°	18	140	16.9

Testing Method

Experiments were carried out with seven discharges, as described in Table 2. To measure the water level in the reservoir, a point gauge with an accuracy of 0.1 mm was used. To supply water, a spiral pump capable of pumping up to 46 liters per second was used and to measure the discharge, a sharp triangular weir with apex angle of 90° was used and water elevation on triangular weir was measured by point gauges with an accuracy of 0.1 mm.

In Figures 3-5 the views of spillway physical model with 1:100, 1:75 and 1:50 scales are respectively shown.

Table 2. Discharge is examined in research for several scales

S. No.	Prototype Discharge (m^3/s)	Physical Models Discharge for 1:100 Scale (lit/s)	Physical Models Discharge for 1:75 Scale (lit/s)	Physical Models Discharge for 1:50 Scale (lit/s)
1	100	1.00	2.05	5.65
2	150	1.50	3.07	8.48
3	200	2.00	4.10	11.31
4	250	2.50	5.13	14.14
5	300	3.00	6.15	16.97
6	338	3.38	6.93	19.12
7	400	4.00	8.11	22.63

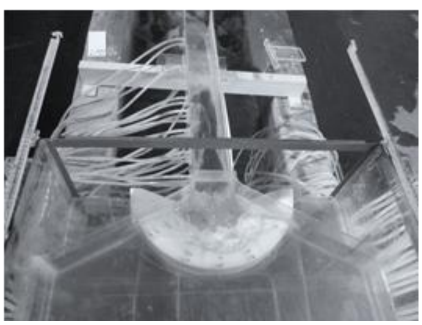

Fig. 3. A view of spillway physical model in scale 1:100

Fig. 4. A view of spillway physical model in scale 1:75

Fig. 5. A view of spillway physical model in scale 1:50

RESULTS AND DISCUSION

Comparing Water Height on Spillway Crest

Figure 6 shows the diagram of head-discharge in three physical models of spillway in 1:100, 1:75 and 1:50 scales. The upstream water elevation on spillway crest (H) divided by design elevation (H_d) was evaluated in dimensionless form and discharge (Q) divided by discharge design (Q_d) was evaluated in dimensionless form. In all three models, by increasing the discharge, the water elevation on the crest increases and H/H_d equals 1 in $Q/Q_d = 1$. It is seen that the water elevation on spillway crest is higher (for two physical models of spillway) in 1:100 and 1:75 scales than in 1:50 scale.

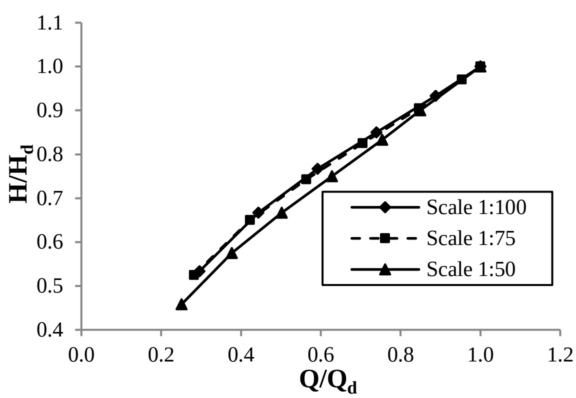

Fig. 6. Discharge – head chart

Physical model of spillway in 1:50 scale, which is the largest scale of measurement in this study, is considered as the basic physical model of spillway model to obtain percentage of water level of spillways difference in 1:75 and 1:100 scales in comparison with the percent of difference in basic model. The percentage of water level difference in upstream (φ) is obtained using Eq. (8).

$$\varphi = \frac{(H/H_d) - (H/H_d)_{(1:50)}}{(H/H_d)_{(1:50)}} \times 100 \qquad (8)$$

where (H/H_d) is the upstream water elevation to the design elevation and ($H/H_{d(1:50)}$) is the upstream water elevation in the physical model in 1:50 scale (basic model) to the design elevation.

In Figure 7, it is observed that in physical model with scale 1:100, the percentage of water level difference, in different discharges is more than that in 1:75 scale. It can be concluded that the smaller the scale is, the more the effect of viscosity and surface tension force will be. This leads to the increase in head on the crest of spillway. The greatest percentage of water level difference was on the crest in 1:100 scale in $Q/Q_d = 0.3$ discharge that was about 16.4% and the smallest percentage of water level difference was in 1:100 scale in $Q/Q_d = 1.18$ discharge that was about 6.3%. In 1:75 scale, the greatest percentage of water level difference was occurred in $Q/Q_d = 0.28$ discharge that was about 14.5% and the smallest was in $Q/Q_d = 1.13$ discharge that was 4.7%. Figure 7 also shows that by increasing the discharge, the percentage of water level difference on the crest decreases in both mentioned scales (1:100 and 1:75). It can be found out that by increasing the discharge, the water elevation on spillway increases and it results in decreasing the effect of viscosity and tension of surface forces. However, it is of note that regarding the small scales, the effects of such forces are significant. According to the results achieved, it can be concluded that scale effect in physical modeling has a significant effect in final prototype results.

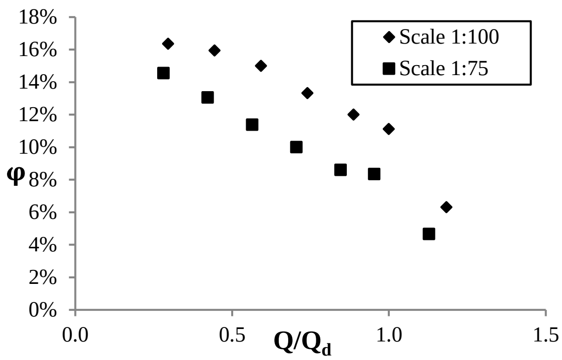

Fig. 7. Discharge diagram of increasing percentage of head compared to scale 1:50

Figures 8 and 9 indicate Reynolds (*Re*) and Weber (*We*) numbers, respectively to water elevation on spillway crest divided by spillway elevation (H/W); by increasing Reynolds and Weber numbers, the water elevation on spillway crest increases in all three physical models in 1:100, 1:75 and 1:50 scales. Figures 8 and 9 show that as the scale reduces, the diagram slope increases. It implies that in (A) a constant Reynolds number (Figure 8) and (B) a constant Weber number (Figure 9) as the scale reduces (scale 1:100), the effect of viscosity and surface tension increase and such effects increase the water elevation in 1:100 scale. Regarding the low effect of viscosity and tension of surface in 1:50 scale, the water elevation on ogee spillway crest is much closer to that of the prototype.

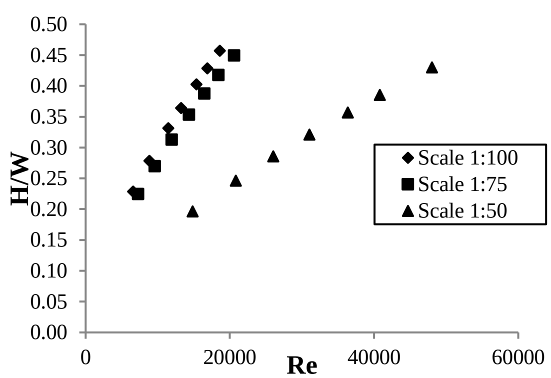

Fig. 8. Reynolds number diagram to water elevation on the spillway crest

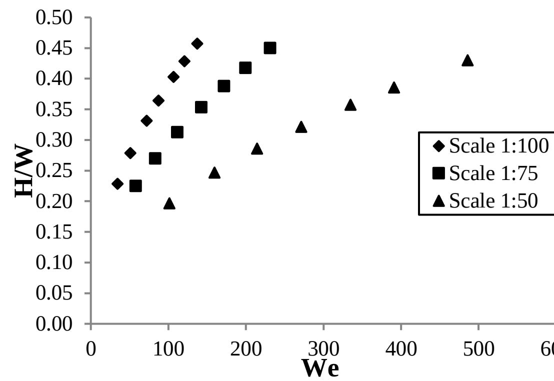

Fig. 9. Weber number diagram to water elevation on the spillway crest

Comparing Discharge Coefficient of Spillway

Figure 10 indicates discharge diagram - discharge coefficient in three physical models in 1:100, 1:75 and 1:50 scales. The discharge coefficient (C) divided by discharge coefficient of design (C_d) was evaluated in dimensionless form, and discharge (Q) divided by design discharge (Q_d) was evaluated in dimensionless form Q/Q_d . In all three physical models of spillway in 1:100, 1:75 and 1:50 scales, the discharge coefficient increases if discharge increases and in $Q/Q_d = 1, C/C_d = 1$.

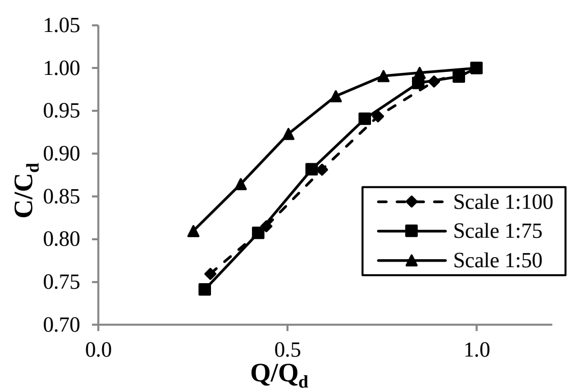

Fig. 10. Discharge diagram- discharge coefficient chart

In Figure 7, it is observed that on a given discharge, in a comparison between 1:100 and 1:75 scales with 1:50 scale (basic scale), the percentage of water level increase on the crest is higher in 1:100 scale than in 1:75 scale. In Figure 11, it is observed that the increase of head on a given discharge leads to the increase in the percentage of discharge coefficient. It can be concluded that on a constant discharge, the smaller the scale is, the more the effect of viscosity and surface tension forces will be. It will lead to the increase of false head on the crest of spillway and consequently the decrease of discharge coefficient. The greatest percentage of discharge coefficient decrease was in 1:100 scale in $Q/Q_d = 0.3$ discharge that was 20.3%, and the smallest was in $Q/Q_d = 1.18$ discharge that was 8.8%. In 1:75 scale, the greatest percentage of discharge decrease was at $Q/Q_d = 0.28$ that was 18.4% and the smallest was at $Q/Q_d = 1.13$ that was 6.6%. Figure 11 also shows that by increasing discharge, the percentage of discharge coefficient decrease will reduce in both 1:100 and 1:75 scales in comparison with 1:50 scale. It can be concluded that by increasing the discharge, the water elevation on the crest will increase and this will lead to the reduction of effect of viscosity and surface tension force. Regarding the fact that the scale is small, the effect of these forces is significant. The percentage of discharge coefficient decrease (α) is obtained from Eq. (9):

$$\alpha = \frac{C - C_{(1:50)}}{C_{(1:50)}} \times 100 \qquad (9)$$

where C: is discharge coefficient and $C_{(1:50)}$: is the discharge coefficient in 1:50 scale (basic model).

In Figure 12, it is observed that by increasing the water elevation on the crest of spillway, the discharge coefficient will increase in all three models in which is $H/H_d = 1$ is $C/C_d = 1$.

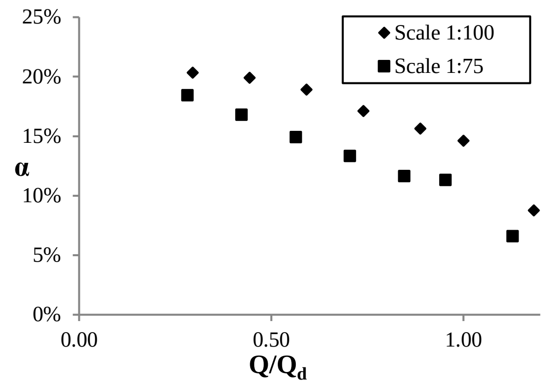

Fig. 11. The diagram of discharge to the percentage of the increase of discharge coefficient compared to the scale 1:50

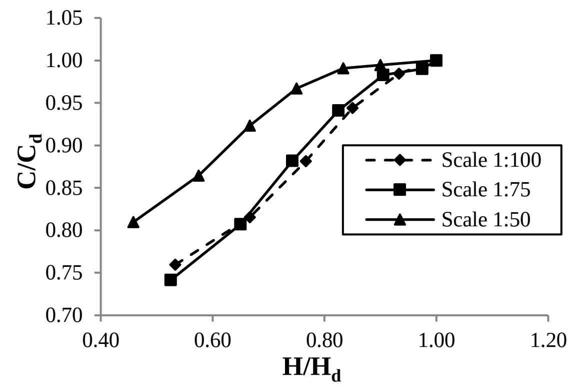

Fig. 12. Head- discharge coefficient chart

Dimensional Analysis and the Relationship of the Scale Effect on Discharge Coefficient

In the flows over spillway, effects of governing gravity and Froude number ($Fr=V/\sqrt{gH}$) are always dominant and as a result, the spillway is built according to Froude simulation. In the small-scale physical model of the spillway, since fluid properties such as viscosity and surface tension increase, they should be considered in the review of hydraulic function of spillway. The amount of discharge on the ogee spillway is obtained from Eq. (1). For C_d value in Eq. (1), the researchers gave different relationships each of which covers the effect of spillway geometry and viscosity and surface tension of the fluid. In this study the amount of scale effect on ogee spillway with an arc in plan and converging training walls is obtained by multiplying K' parameter in Eq. (1) which is shown in Eq. (10).

$$Q = (\frac{2}{3}C_d\sqrt{2g}LH^{\frac{3}{2}})K' \quad (10)$$

where K': is a function of Reynolds number and Weber number, Eq. (11). All data attained from the three models was used to measure effect of viscosity and surface tension.

$$K' = f(Re, We) \quad (11)$$

Both Reynolds and Weber numbers are obtained from Eqs. (12) and (13):

$$Re = \frac{g^{0.5}H^{1.5}}{\upsilon} \quad (12)$$

$$We = \frac{\gamma H^2}{\sigma} \quad (13)$$

The value of C_d for ogee spillway with an arc in plan and converging training walls is obtained from Eq. (14):

$$C_d = (0.611 + 0.075\frac{H}{W})K' \quad (14)$$

where $(0.611 + 0.075\frac{H}{W})$ is the effect of spillway geometry. K' is achieved based on the nonlinear regression as shown in Eq. (15).

$$K' = 0.94 + \frac{33.02}{Re^{0.2}We^{0.6}} \quad (15)$$

The computed discharge coefficient $C_{d(cal)}$ is compared to the observed discharge coefficient to obtain the percentage error as shown in Eq. (16):

$$\varepsilon_i = \frac{C_{d(cal)i} - C_{d(obs)}}{C_{d(obs)}} \times 100 \quad (16)$$

Using Eq. (17) the average of error percentage, E, is achieved for the entire set of N.

$$E = \frac{\sum_{i=1}^{N}|\varepsilon_i|}{N} \quad (17)$$

The average error percentage for Eq. (14) is E = 2.5% and the correlation coefficient (RSQ) for Eq. (14) equals 0.93. K' value, can be obtained either using figure (13) based on Reynolds and Weber numbers or Eq. (15). In Figure 13 it can be seen that as $We^{0.6}Re^{0.2}$ increase, the value of K' bends toward 1. As a result, as Reynolds and Weber numbers increase, the effect of viscosity and surface tension can be neglected.

The value of K' in Reynolds number greater than 3.1×10^4 and Weber number greater than 270 and $We^{0.6}Re^{0.2} > 300$ bend toward 1 the effect of viscosity and surface tension, as a result, can be neglected. When $We^{0.6}Re^{0.2}$ is smaller than 300, the value of K' is greater than unite, i.e. it is possible to obtain K' from Figure 13. The value of K' in Figure 14 has been compared with the value of K' obtained by Ranga Raju and Asawa (1977).

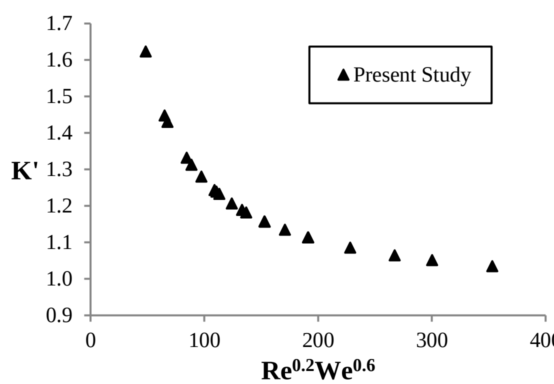

Fig. 13. The effect of viscosity and surface tension on the ogee spillway

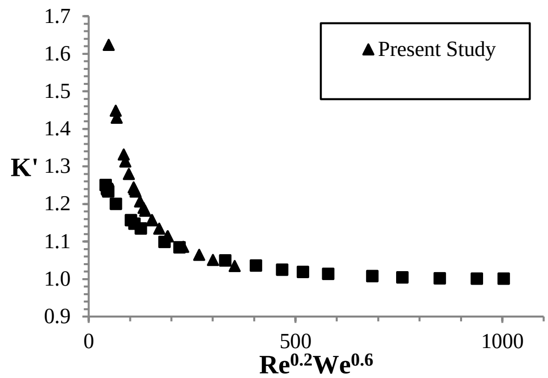

Fig. 14. The comparison of the effect of viscosity and surface tension on spillway

The average error percentage, E, was calculated for all data of this study using available approaches described in Table 3.

Table 3. The Comparison of existing approaches

S. No.	Investigator	Eq. No	E	Percentage Departure from Eq. (14)
1	Rehbock	(2)	12.3	12.4
2	Sarginson	(3)	15	15.1
3	Kindsvater & carter	(4)	13.1	15.1
4	Gill	(6)	6.8	6.1
5	Ghodsian	(7)	12.9	13.1
6	Present study	(14)	2.5	0.0

Figure 15 depicts the diagram of discharge coefficient to the water elevation on the crest in ogee spillway with an arc in plan and converging training walls in physical model in 1:50 scale and USBR. This figure shows that the discharge coefficient diagram to water elevation in $H/H_d = 0.75$ coordinates with USBR standard. In this model, the head of design (H_d) is 6 cm and the value of H = 4.5 cm. This value of H is the minimum water elevation on the crest of spillway with an arc in plan and converging training walls to avoid the effect of viscosity and surface tension. It is also worth mentioning that the range of $We^{0.6}Re^{0.2}$ coordinates with the water elevation of 4.5 cm.

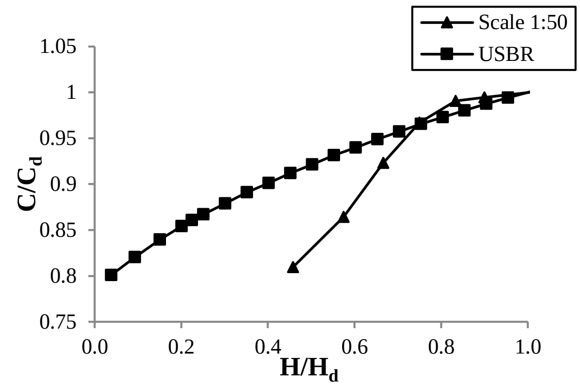

Fig. 15. The comparison of discharge coefficient to water high in spillway model with the scale 1:50 and USBR standard

CONCLUSIONS

The scale effect on ogee spillway with an arc in plan and converging training walls was studied using model family and in laboratory. Results showed that in discharge $Q/Q_d = 0.3$, the discharge coefficient percentage of decrease in the model in 1:100 and 1:75 scales equals to 20.3% and 18.4%, respectively compared to the basic scale. In larger discharges, however, where the water elevation over spillway increases, the effect of viscosity and surface tension decrease and as scales reduce, the effect of such forces decreases; in discharge $Q/Q_d = 1.18$, the discharge coefficient percentage of decrease in model in 1:100 and 1:75 scales equals to 8.8% and 6.6%, respectively compared to the basic model. Results revealed that as the scales of ogee spillway with an arc in plan and converging training walls decrease using Froude simulation, the effect of viscosity and surface tension increase in turn resulting in decreasing discharge coefficient. In this study, the scale effect in discharge coefficient with an arc in plan and converging training walls was stated with K' relation where the value of K' is in range of $We^{0.6}Re^{0.2} > 350$ and it is possible to neglect the effect of viscosity and surface tension. The range of $We^{0.6}Re^{0.2}$ with the minimum water elevation of 4.5 cm on the spillway crest corresponds with neglecting the scale effect.

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