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Investigation of Hydraulic Performance of Mollasadra Spillway Using Physical Model Ohammad Karimi

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ABSTRACT

Spillway structures are among the oldest man made hydraulic structures which are used to control and regulate the flow within the reservoir. The spillway structure is too costly and should not be in danger of any damage during operation. cavitations has been recognized to be the most cause of spillway failure therefore in this study physical model of Mollasadra spillway was build with a scale of 1:40 to study the possibility of cavitation occurrence. The model was tested with 9 different flow discharges. the measurement of pressure was obtained at different location and the cavitation index calculated throughout the spillway. The above index was found to be more than $(\sigma = 0.25)$ in all location indicating that no threats for cavitations exist. All the pizometric pressures show a posetive value throughout the spillway.

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INTRODUCTION

Dam spillway is too costly structure which is built to release surplus floodwater that cannot be stored in the dam reservoir. The importance of a safe spillway cannot be over emphasized; many dam failures has been reported by improper design or insufficient spillway capacity. The main cause of spillway failure is due to high flow velocities which induce cavitations and cause serious damages to the spillways of high dams [1]. Increasing flow velocities and as a result decreasing pressures may bring the cavitations index through a critical value, which is called incipient cavitation, and the cavitation start witch can damage the surrounding area. Conversely, increasing the local pressure resulting can reduce the risk of cavitations. Due to the high costs and considerable amount of time required for construction of spillway and serious damages sustained by the structure as a result of cavitations the study of possibility of occurrence of such phenomenon is a major task which has to be conducted before construction of the spillway of the new dams or existing spillways. Predicting flow velocity and pressure along the spillway, which is required to calculate cavitation index, is possible by conducting numerical or physical modeling. Although few numerical models are available, still the physical model is preferred due to lack of data for calibration of numerical models. By conducting physical model tests, the required data is obtained and the possibility of cavitation examined and techniques which may reduce or stop damage is tested. In 1963 investigations showed that the introduction of air through flow can reduce the damage remarkably. Regarding the economical views aspect, several solutions exists [1]. From the physical model test of Amaluza dam spillway in USA it was found that dispersion of a small amount of air through water prism can significantly re duce the risks of cavitation damage [4]. The results showed that about 7.5% of air by volume is needed to stop cavitation damages [2]. The required air quantity to protect a spillway surface from cavitation increases with decrease in surface strength [1]. Application of aerators to prevent cavitation damage was successfully tested for Grand Coulee Dam in USA [3]. Rafi *et al*. conducted physical modeling of Mangala dam spillway for cavitations and aerator optimization. A model scale of 1:36 was applied for geometrical similitude.

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From their study the risk of cavitation was decreased by optimizing the location and dimensions of two aerators along the spillway.

The main objective of the present study is to investigate the cavitations index for Mollasadra spillway dam. Mollasadra reservoir dam has been constructed in Fars Province of Iran on the River Kor, about 60 km upstream of Doroudzan Dam. Mollasadra Dam is 200 km from Shiraz and 20 km from Eqlid County. The general dam specifications are given in Table 1.

Table 1: General Specifications of Mollasadra Dam.

Dam Type	Earth and rock fill with watertight core
Height from bed/subgrade	72 m
Crest length	620 m
River stage at axis	2050 m above sea level
Maximum Normal Operation Level	2115 m above sea level
Dam crest level	2122 m above sea level
Reservoir volume at normal operation level	440 million cubic meters
50-Year sediment volume	29 million cubic meters
Average annual inflow volume	350 million cubic meters

With due consideration of normal elevations for reservoir operation and to conform to design requirements, we assumed a spillway inlet threshold at normal level and spillway length of 88.00 meters. The relations between area/volume and dam height based on the results of Phase 1 studies of Mollasadra Dam are presented in Fig. 1. According to this figure, reservoir volume at elevations 2115 m and 2122 m above sea level are equal to 440 and 703 million cubic meters respectively.

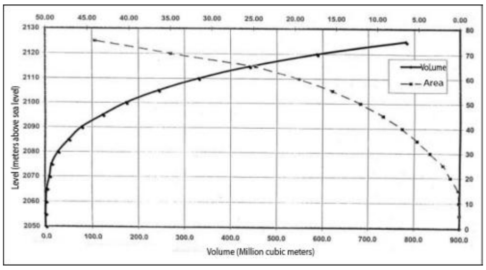

Fig. 1: Area and Volume Relations with Height at Mollasadra Dam Reservoir, Iran.

This dam was designed as an uncontrolled ogee weir (Fig. 2)

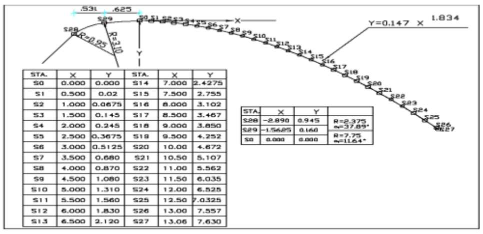

Fig. 2: Details of the Ridge and Spillway Form (Mollasadra Dam report).

MATERIAL AND METHODS

Mollasadra spillway:

The required information for construction of the spillway model was obtained from the studies conducted during Phase 1 of Mollasadra Dam by Shiraz Regional Water Company. This information; hydrological information such as throughput capacity of the river, maximum 10,000 year outflow rate, PMF (probable maximum flood) as well as water level at each flooding (Table 2).

The plan and section drawing of Mollasadra Dam spillway were provided by Aban Pajouh Consulting Engineers Company. For investigating the test results conducted on the spillway section and comparing them with those calculated theoretically during preliminary studies, it is necessary to gather the analytical results as well (Table 3). The general outline of the dam and spillway is shown in Fig. 3.

Physical model:

For the purpose of this study an undisturbed model with geometrical scale of 1:40 was built at Hydraulic laboratory of Islamic Azad University, Eqlid branch. For free surface of flow over spillway, the dynamic

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similarity is achieved based on a Froude similitude since gravity effects are important [5,6]. This is due to the fact that it is not possible to satisfy simultaneously Froude and Reynolds similarities unless the model is constructed in full scale [5]. However for free surface the gravitational force are the dominant force of flow movement; the viscous force is negligible if the flow is fully turbulence. In this study the same concept was used, and Froudian similarity between model and prototype is used to determine the mathematical relationship of flow characteristics between model and prototype which is presented in Table 4

Table 2: Hydrological Information for the Dam River.

River Throughput Capacity (Flood Return Period = 100 Years) (m^3/s)	Maximum Reservoir Water Level for Flood with Return Period of 100 Years (m)	Design Flow Rate (Maximum Flood with a 10,000 year Return Period) (m^3/s)	Maximum Reservoir Water Level for Flood with Return Period of 10,000 Years (m)	Probable Maximum Flood (PMF) (m^3/s)	Maximum Reservoir Water Level at PMF (m)
440	2116	2008	2119.4	3347	2121.1

Table 3: Mollasadra Dam Spillway Specifications.

Crest Length	Invert Level (m)	Crest Level (m)
Weir (m)	Approach Channel (m)	Weir (m)
88	2108	2115

Fig. 3: General Dam and Spillway (left) Outline (Mollasadra Dam report).

Table 4: Scale Ratios (based on the Froude number) for areas, velocities, and flow rates in Mollasadra Dam.

scale	Quantity	Scale Ratio
Area- A_r	$L^2{}_r$	1:1600
Velocity- V_r	$\frac{L_r}{T_r} = L^{\frac{1}{2}}{}_r$	1:6.33
Flow Rate- Q_r	$V_r A_r = L^{\frac{5}{2}}{}_r$	1:10120

The complete range of the expected flow rates in Mollasadra Dam as well as the corresponding values for the dam model based on a scale of L_r =1:40 are presented in Table 5.

Table 5: Peak Hydrograph Flow Rates in Mollasadra Dam and the corresponding Flow Rates obtained for the Model in the Laboratory.

Peak Hydrograph Flow Rates in Mollasadra Dam Prototype (m^3/s)	112.4	151.4	293.7	485	688.5	900	1120	1265	1676
Model Flow Rates (lit/s)	2.53	3.39	6.596	10.8	15.46	20.2	25.16	28.24	37.6

Construction of Spillway Model:

First, the spillway drawing was provided from the existing working drawings and the selected scale (1:40). Then, the required casts were made based on the drawing. Molten PVC was poured into the casts and allowed to cool. Then, the wavy patterns produced on the spillway surface were smoothed out with a brush.

Upon construction of the spillway, we placed it on a platform in the laboratory flume and sealed it with aquarium sealant. A tank was placed behind the spillway for supplying the required flow rate. The model was then placed inside a channel I meter wide and 6 meters long. Based on the 1:40 scale ratio, the model width was taken as 50 cm and the spillway height as 22.5 cm. The spillway was placed on a platform 15 cm in height according to the elevation given in the drawing. In Fig. 4, the completed spillway and chute assembly are demonstrated.

Measurements:

Static Pressure Measurement:

For measuring static pressure in the model, several piezometers were installed along the spillway and at midpoint of the axis. At curved areas, i.e., areas with sudden changes in height and width (crest and spillway curve), more piezometers were installed. Overall, 12 piezometers were used in this model at the crest and spillway curve. The piezometers board was attached beside the flume and the piezometer tubes were guided to the board from the channel floor. Fig 5 shows the arrangement of piezometers on the spillway elevation plan. Table 6 demonstrates the location of the piezometers relative to the assumed coordinate axis.

Fig. 4: View of the Fully Installed Spillway and Chute Assembly.

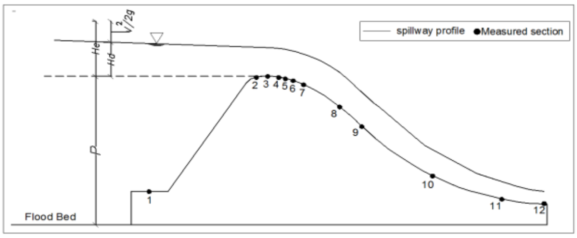

Fig. 5: Piezometer Locations on the Spillway (to 1:40 Scale).

Table 6: Piezometer Locations on the Spillway (to 1:40 Scale) Relative to the Coordinate Axis

Group 1												
Piezometer NO	1	2	3	4	5	6	7	8	9	10	11	12
X	-18.927	-1.562	0.00	1.50	2.50	3.50	5.00	10.00	13.067	22.90	32.50	38.782
Y	17.50	0.16	0.00	0.145	0.3675	0.68	1.31	4.6725	7.63	15.15	18.67	19.487

Flow discharge, velocity and depth:

A micro velocity meter (Micromolline) was used for measuring of the flow velocity. The Micromolline models used were Model 404 (high-speed probe) and Model 403 (low-speed probe). The gauge point scale was used for taking water level profiles along the longitudinal and transversal axes of the model. This device is mounted onto the upper flume axis in the laboratory, and can be moved along the length and width of the model. The sharp rod parallel to the scale is used for water draw-off from the surface points. Water was supplied through a closed circulation system with maximum flow rate of 38 lit/s. The 2000 liter water supply reservoir was placed about 2 meters below ground level. A surge tank (with dimensions of 1m x 0.6m and a height of 0.7 m, installed at a height of 0.4 from the floor) is placed at flume inlet to remove water turbulence. At the flume outlet, there was a 1200 liter stilling basin for water collection as well as measurement of flow rate and discharging water to the feed/supply tank. Water was pumped via a centrifugal pump. At the end of the flume, a 3m x 0.6m x 1m tank was fitted with a standard and calibrated trapezoidal weir for calculating the flow discharge.

RESULTS AND DISCUSSION

3.1. Flow discharge- Elevation Curve:

One of the objective of this study to determine the discharge coefficient of ogee crest of spillway used for Mollasadra spillway. The following discharge-head relation is used for this purpose:

$$Q = C_d L_e H_e^{3/2} \tag{1}$$

where C_d, H_e and L_e are the discharge coefficient, head above the spillway and the effective length, respectively. Based on the data calculated from the nine the values of C_d were determined in Table 7., from Eq .1. as show different flow rates tested.

The average Cd coefficient for the ogee weir of the Mollasadra spillway was calculated to be equal to 2.11.

Piezometric Pressure Variation:

Along the spillway length, twoelve pressure and water head measuring stations were installed. Fig. 7, shows the positive and negative pressure variations along the longitudinal axis of the spillway obtained from the laboratory model.

Table 7: C_d Values obtained for existing Water Heights and Flow in model.

Q(m^3/s)	Hd(cm)	Va(m/s)	Ha(m)	He(cm)	LHe^3/2	Cd
253	1.900	0.050	0.000	1.900	130.962	1.932
339.8	2.000	0.040	0.000	2.000	141.430	2.403
659.639	3.400	0.049	0.000	3.400	313.481	2.104
1089.252	4.800	0.070	0.000	4.800	525.855	2.071
1546.375	6.100	0.078	0.000	6.100	753.352	2.053
2024.299	7.300	0.087	0.000	7.300	986.254	2.053
2515.968	8.300	0.067	0.000	8.300	1195.653	2.104
2840.872	9.100	0.060	0.000	9.100	1372.604	2.070
3760.387	10.800	0.123	0.001	10.801	1774.811	2.119

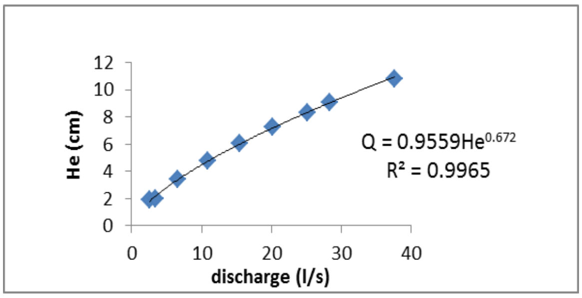

Fig. 6: Flow rate - Ogee Weir Scale Diagram.

Fig. 7: Static Pressure Variations over the Mollasadra Dam Spillway Model.

As can be seen in the static pressure curves based on actual measurements, the minimum pressure at Q=1676 m3/s is exerted at Section 4. This suggests that the most critical corrosion case might occur at any flow rate and not necessarily the maximum flood flow rate. The difference obtained between the calculated and the experimental corrosion factor shows that there is no possibility of any corrosion occurring along the spillway length in Mollasadra Dam.

Flow velocity:

As it has been stated earlier the flow velocity along the spillway model were measured. For all flow discharges tested. The flow depths also have been measured with a point gage. The variation of flow velocity at 12 different stations then was plotted as shown in fig .8. The flow velocity increases from the top of the spillway. The flow velocity reaches to about 16 m/sec when the flow rate is 1676 m3/sec. table 8 slows the maximum flow velocity at the base of spillway for different flow rate tested.

Cavitation investigation:

To prevent corrosion, the positions of the points where pressure might drop below the determined level as a result of increased velocity must be identified. To this end, and for obtaining a quantitative criterion, the Bernoulli equation (energy equation) can be written for two points in a steady flow.

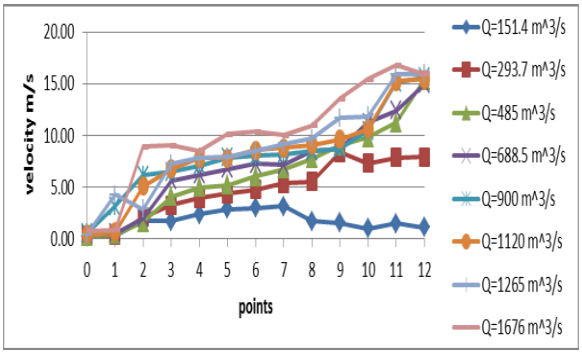

Fig. 8: Variations of Froude Number along the Spillway and Chute.

Table 8: Maximum Velocity and Froude Number at Various Flow Rates.

Flow Rate (m3/s)	293.7	485	688.5	900	1120	1265	1676
Velocity (m/s)	8.0	15.30	15.00	15.60	15.40	15.90	16.00

$$C_P = \frac{P_0 - P_\upsilon}{\frac{1}{2}\rho V_0} \quad (2)$$

The pressure coefficient, Cp, is also called “pressure parameter” or “Euler Number”.

By replacing Cp and substituting Pv for P (liquid vapor pressure at ambient temperature), we obtain:

$$\sigma = \frac{P_0 - P_v}{\frac{1}{2}\rho V_0^{\ 2}} \quad (3)$$

Thus, σ is the ratio of the pressure drop required for evaporating water to the flow pressure reduction potential via kinetic energy.

Along the spillway length, 11 pressure measuring stations were considered. Also, 20 velocity measuring stations were placed at the spillway and the chute. The corrosion coefficient was obtained from Equation 4 as follows:

$$\sigma = \frac{\frac{P_{Atm}}{\gamma} - \frac{p_v}{\gamma} + hCos\theta \pm \left(\frac{h}{g} \times \frac{V_0^{\ 2}}{r}\right)}{\frac{V_0^{\ 2}}{2g}} \quad (4)$$

where:

$-\frac{P_{Atm}}{\gamma}$: Ambient pressure equal to 1 atm in the laboratory (equal to 7.70 m of water or 707 kPa)

$-\frac{Pv}{\gamma}$: Water vapor pressure equal to 0.32 m of water (3.16 kPa) at about 25 degrees centigrade. For considering a proper safety factor in calculations, this value is taken as 1 m of water (9.8 kPa).

hCosθ : Pressure (e.g. water pressure) measured on the structure at various points

$-\frac{V_0^{\ 2}}{2g}$: Head corresponding to velocity (in meters) at the considered section

$\pm\frac{h}{g}\times\frac{V_0^{\ 2}}{r}$: Difference in altitude resulting from curvature, equal to $\frac{hV_0^{\ 2}}{98.1}$ at the spillway where the radius of curvature is r=10 m

Due to the uniform slope of the chute, the $\pm\frac{h}{g}\times\frac{V_0^2}{r}$ parameter arising from pressure difference due to curvature shall be ignored.

By substituting the above parameters in Equation 2 at each measured section, the corrosion coefficient for that section is obtained. Fig. 9 the variations of corrosion coefficient along the longitudinal spillway and chute axes at various flow rates.

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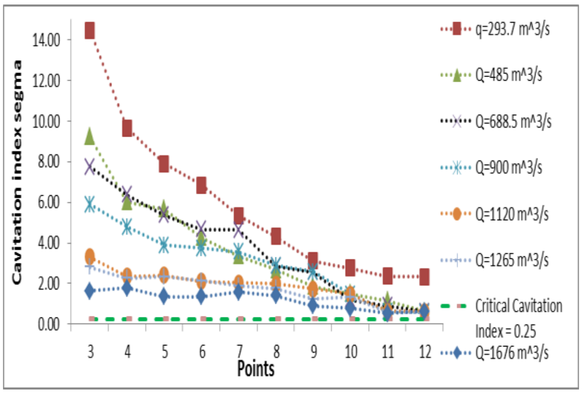

Fig. 9: Variations of Corrosion (Cavitation) Coefficient on the Spillway.

From the corrosion coefficient curves based on the measurements, a minimum corrosion coefficient of $\sigma = 0.545$ was obtained at a flow rate of Q=1676 m3/s at Section 11 (end/outlet of the spillway). This results proves that the most critical case of corrosion might happen at any flow rate and not necessarily at the maximum flood flow rate. In the calculations by the consultant, the corrosion coefficient was obtained as $\sigma = 0.512$. The difference between the theoretical and experimental model results obtained for corrosion factor is due to measurement and scale errors and lies within the acceptable range. Investigation of this matter is not possible in theoretical calculations. Due consideration of the critical corrosion coefficient shows that there is no possibility for any corrosion phenomenon to occur along the spillway length in Mollasadra Dam.

Conclusion:

The main purpose of this study was to conduct a physical modeling of the hydraulic behavior exhibited by water in its flow over the Mollasadra dam spillway in an effort to ensure appropriate performance of the dam during its operation period. To this end, the spillway of the named dam was built to a 1:40 scale. Subsequently, by plotting flow rate variation against the scale and using the general weir formula, a throughput flow rate coefficient of 2.11 was obtained over the spillway. The minimum corrosion coefficient was obtained as $\sigma = 0.545$ at Q=1676 m3/s at Section 11 (chute outlet). The corrosion factor obtained by the consultant through calculation was $\sigma = 0.512$. The difference between these two values, one obtained experimentally from the model and the other obtained through calculation, is within an acceptable limit. Te minimum pressure was obtained at Q=1676 m3/s at Section 4. And the maximum flow velocity way measured a the buse of spillway to be about 16 m/sec for the maximum flow discharge.

Notations:

Q: Flow rate passing over ogee weir obtained from the following calibrated relation (depth in cm and flow rate in lit/s)
Hd: Water height (head) over the spillway
Va: Water velocity inside the tank and velocity of water approaching the spillway
Ha: Equivalent velocity head $H_a = \frac{V_0^2}{2g}$
He: Effective water head/height (He=Ha+Hd)

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