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Reconstruction of Sheikhbahaie Dam of Kashan-Iran (Determination of Sediments Filled in Dam Reservoir)

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Abstract: The final destiny of each storage dam is filled with sediments. Ghohrood dam was filled with sediments in 1956 due to great flood happened after about 370 years of its hydraulic capacities as water reservoir gone out of duties. Generally, to reconstruct sediment filled dams; there are some considerable ways to include sediment discharge such as raise dam height and finally, construct a new dam on the river. In reconstruction plan of the dam, these three alternatives were surveyed and carefully studied. At last, following technical solutions as executable, economical and topographical ways were investigated. It was suggested that the dam wall height should be raised up to about 8 meters. In this paper, reconstruction methods of the dam were studied through analysis of various cases. The appropriate solution was specified and performed. The designated solution was technically and economically evaluated. In addition, the dam in terms of structural details of operations such as dam stability calculations, increase in reservoir capacity and water reservoir planning for the dam water were discussed.

Key words: Sheikhbahaie dam · Kashan · Dam height · Sediments · Stability of dam structure

INTRODUCTION

The old Sheikhbahaie dam of Ghohrood, Kashan is one of the oldest dams in Iran with 420 years of history and still is functioning as local populations are benefited from the dam. Body of the dam, which is referred to constructions materials has significant structural properties. In 1956, Ghohrood dam was filled with sediments after 369 years of operations; caused by a huge and devastative flood. That was the main reason the dam goes out of function. Generally, to reconstruct sediment filled dams there are some considerable ways, including sediment discharge, increase dam height and finally construct a new dam on another part of the river. These three solutions were investigated in reconstruction researches for Ghohrood dam. Technique of sediment discharge [1, 2], the sediment volume removed from reservoir was not great enough to control water supply of Ghohrood village [2]. Therefore, various methods to discharge and transfer the sediments, such as conveyor belt, were studied. However, after several observations and regarding to the location conditions of the dam, discharge method was found out to be economically and technologically unacceptable [3]. Typically, sediment discharge is economical if the sediments would be useable and valuable. Since no other appropriate location to construct a new dam was specified, it was suggested to increase the dam height as high as 8 meters. Topography and topographical calculations have related the relationship between dam height and dam site. The reservoir volume, were simultaneously performed by hydrological and geological studies. The dam water reservoir planning was based on hydrodynamic requirements of the dam. Then, hydraulic and construction plan of the dam and the related equipment, such as spillway and outlet, were analyzed. In this paper, reconstruction methods of the dam was investigated by analysis of several alternatives and evaluation of various cases. The appropriate solution was specified and performed. Also the dam was technically and economically evaluated. Dam in terms of structure details of operations, dam stability calculations, increase reservoir capacity and planning for the dam water, are discussed.

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Fig. 1: Ghohrood dam after raised the dam height

Location and Climatic Conditions: Ghohrood gravity dam of Kashan (Isfahan, Iran), is located 30 kilometers far from south-east of Kashan with coordinates: N33-43. Latitude and E51- 27 longitude and 1850 meters from sea level, on Ghohrood river. Several springs joined to Ghohrood river on its flow. According to the data obtained maximum, average and minimum of rainfall in a 21 years statistical period, are 252, 45 and 140 mm, respectively. Average annual evaporation is 1300 mm and average annual temperature is 19.5°C in dam site. As the most important part of rainfall in winter and spring are unusable and most of rainfall may be in form of floods. The performance of the dam in water management, as a storage dam and water controller in winter and early spring and gradual usage of the stored water in summer, is very critical. The basin of Ghohrood river is located in the east hillsides of Karkas mountains, between N33- 35, N33- 43 latitudes and E51-22, E51-29 longitudes, 40 kilometers far from south of Kashan. Average basin height is 2500 m from sea level. The slope extension of drainage basin is northern - southern and about 10 percent. The basin area to the dam site is 79.3 km^2 with long tree shape channel networks (shape factor of 0.26) and a compaction factor of 1.25 and main river length of 13 km. The height leveling is varied from 3000m in southern extremity ridge to 1900 m in dam site. Flood peak discharge in one thousand year period of the basin is estimated to be 76 m^3/s, average annual runoff, 6-8 million m^3 and probable maximum flood discharge (PMF), 100 m^3/s [4, 5]. Figure 1 demonstrates Ghohrood dam height after it was raised for additional 8 m.

The historical background and initial properties of Sheikhbahaie dam of Ghohrood, Kashan (before reconstruction) are itemized as follows:

- Purpose of construction: Irrigation of 350 Ha and controlling floods and drinking water.
- Kind of dam: gravity dam with masonry materials (stone and mortar).
- Date of construction: 1591.
- Kind of foundation: sandstone.
- Reservoir volume: 550,000 m^3.
- Kind of spillway: no spillway.
- Dam crest height: 1875 m.
- Normal dam height: 1865 m.
- System of water intake: intake tower as high as dam, including trash rack and sliding gate.
- Dam, wall height: 25 m (40 m from foundation).
- Crest length: 110 m.
- Crest width: 20 m.
- Width of dam floor: 30 m.
- Maximum thickness in base: 33 m.
- Upstream wall slope: vertical.
- Downstream wall slope: 2 vertical to 1 horizontal.
- Area of Lake: 37600 m^2.

Figure 2 shows Ghohrood dam and its reservoir before sediment discharge and reconstruction.

Purpose of Dam Reconstruction: The purpose of raising the dam height was to increase the efficient capacity of dam lake and storage more water in reservoir in order to irrigate the farming lands on upstream villages (Hosein Abad and Eslam Abad) and Safi Abad plain of Kashan, to supply drinking water of Kashan and its downstream villages (Hosein Abad and Islam Abad). In addition, dam served as controlling strong floods on upstream of the

Fig. 2: Ghohrood dam and its reservoir before reconstruction

Fig. 3: Reconstructed dam and its reservoir

dam, from Ghamsar and Ghohrood during rainy seasons. Also due to whole limitation of reservoir volume and water amount of Ghohrood river and water requirements, it was predicted that the reservoir should be significantly discharged on annual bases. These frequent fillings and discharges may result in washing aggregated sediments behind the dam. Some important and effective factors in this plan are [5]:

- Rock bed: The rock bed is very strong and extends to ten meters down to the earth.
- Friction coefficient of dam materials with dam floor: This coefficient is a determining factor for dam sliding which is equal to 0.06.
- Allowable shearing stress between dam floor and the rock bed: A minimum value was considered for the allowable shearing stress which has a determining role in dam sliding. 4. Strength of dam body and wall.
- Conditions of the sediments resided behind the dam: The silt pressure on the dam was very slight.
- Topographic conditions on downstream of the dam: Mountains located in front of the dam are such that prevent sliding and overturning of the dam and reduce the clear span of the dam to about 30 meters.
- Geometrical dimensions of the dam: Geometrical dimensions of this dam are relatively large in compared to other gravity dams, so that the wall thickness is considerable in all dimensions.
- Density of the dam: Density of materials in this dam is 2.3 ton/m. finally, regarding to all these factors, raising the height of dam wall was limited to 8 meters.

Figure 3 shows the reconstructed dam and its water reservoir.

Geology of Dam Area:

- The studied area is stratigraphically located on spread silty sediments, silt stones and grey to dark line silts, which belong to early Jurassic period. On these sediments, in water shed mountains of Ghohrood dam site, there are sandy or dolomite limes of bottom Cretaceous with a WN-ES direction and a WS slope of about 60 to 65 degrees.
- In terms of tectonics, the area is affected by some forces and many fractures were observed. Especially in dam site, there is a big failure with a EN-WS direction belonged to the third geological age. It seems that no new tectonic activity has been occurred in past few decades, referring to the history of the dam construction.
- In terms of geology, dam site and materials, the base rock below the dam, on which the dam foundation is located, extends more than a hundred meter down to the earth. Thus, by raising the dam height, no problem occurred in foundation strength. Rock of the dam site is sandstone with a very low permeability and there is no water permeability from the bottom of the dam. Also, permeability of river bed on upstream and downstream was very slight.
- In terms of geomorphology: Ghohrood river flows upon an eroded valley, which is created by this river, with a relatively high slope, the valley has sheared itself and has been lowered. In some points, the valley becomes very tight, such that the river flows just upon the bed floor. Observing the alluvial terraces on the river bed showed the changes in bed stone or in the path of the river bed and various alternations of granulating in alluvial material, showed various changes in the regime of river which defines annual variations for the water flow of river.

Regarding to the compact sandstone limes, bottom gullies and conditions of the slope and their extension, which are almost along the dam wall and also the steep slope along the reservoir (vertical to the water flow), the dam site seems to be appropriate for reconstruction of the dam. The only weakness of this area was its tectonic failure conditions, which naturally does not constraint the reconstruction because of the amount of water reserved, lower than one million m^3/ per year, non-activity of the current failure and its natural agglomeration with cement materials [6].

Dam Reservoir and the Sediments: Volume of the dam reservoir was filled by sediment after the flood in 1956. Parts of these sediments washed out between 1956 to 1981 and volume of the reservoir is estimated to be more than 250000 m^3. Therefore, it was necessary to determine the discharge of the sediments behind it. Volume of reservoir is determined and level- height and volume-height plots were illustrated [1]. Area of the reservoir was 37582 m^2 in average height of 1875 m and the volume estimated to be 536587 m^3after sediment discharge. Thus, the volume of sediments which was discharged from the reservoir by mechanical equipments was obtained more than 285462 m^3. By raising the dam height up to 8 m, the reservoir volume increased up to about 1 million m^3 [7, 8].

About Types of Sediments: Sand stone, gully and siltstone are observed in south parts of Ghohrood valley. Flood destructions and sediment deposits were observed in south and about 200 m far from the dam. Complex variation of block stones was observed in parts near to Ghohrood dam. Erosion and carrying the fine grain materials from granite stone decomposition were observed in the entry of draining basin of Ghohrood dam from south. In addition to natural reactions mentioned above on drain age basin of the dam, human effects the sediment load of floods to develop and reinforce them are also very important.

Fig. 4: Erosion of reservoir floor

Figure 4 shows erosion occurred in the reservoir floor of the dam. It is needed to consider the farming lands and gardens created in a wide area of the valley floodway. Sediments behind the dam are silty and loose and the resulted pressure of them is slight. From dam wall to about 200 meters to upstream there were fine grain sediments which their diameters are less than 5 mm and are rarely less than 10 mm. Flood flow with a maximum rate of 1.15 m/s, may carried out these articles and resided them behind the dam. This rate was obtained. For a flood with a flow discharge rate of about 11 m^3/s proportional to the cross section and slope of the river bed in upstream [9].

Constructing the Dam Body: The old structure of dam was constructed from unreinforced masonry (stone and mortar) and from gravity kind and volume of the rock operations estimated to be 40000 m^3. Stone materials of the structure are stiff stones from bed rocks and the mortar applied is from hydraulic lime. Regarding to these explanations to increase the dam height, the following modifications were applied:

Rocky Materials: The dam was reconstructed by rock and lime cement mortar. The rocks in dam site, which are lime stone with high strength, were appropriate to prepare masonry for the dam. These flag stones, available in the east side of the dam valley and the local road on downstream, were used with minimum costs by rock blasting or even a lever. On the east upstream of the dam there is a relatively large valley which on its north part, the required rocks were available to construct the dam body. Since the angle of rock extension, is geologically vertical, it was easy to destroy them and apply for dam construction. The distance of these rocks front from dam wall is about 300 m.

For the Required Mortar: A lime cement mortar (100 kg of cement and 200 kg of lime in 1 $m^3$of mortar) was used.

Way of Access to the Dam: The dam is located in a relatively tight valley and there is no way to access the dam from downstream. In order to access Ghohrood dam from upstream, there is a dirt road toward dam structure (with a distance of 2500 m). A mountain shearing has been operated to make this road in 500 to 600 meters far from upstream of the dam [2]. The dirt road having access to the dam is shown in Figure 5.

Fig. 5: Access way to the dam

Reconstruction Operation of Reservoir and Increase the Dam Height: During reconstruction process of raising the height of the dam and planning side equipments for the dam, the following cases have been considered [7, 9]:

- Extending the slope of down stream wall has been continued to upstream such that the total height of dam did not exceed from 33 m.
- An expansion joint has been created in each 10 m of the dam structure (in double direction) and the construction height has not been exceeded from 1.5 m on each row. These expansion joints have been prepared with a 10 cm width and filled later with cement and mortar.
- Before the operation of increasing dam height, the down gate of the dam started to be built 1855.21 high from sea level in order to wash out the discharge and the silty sediments aggregated behind the dam as possibly after alternative opening and closing.
- During the rise of dam wall, the situation of drainage sump of the dam was remained on its initial position and old form. The dam structure was extended to the upper level of the dam wall. This sump was used to install the down gate and to control discharge.
- On the dam wall, a water outlet as a pipe, was also made in level 1871 high from sea level. Outlet of the second water way is located in chute spillway and helps discharge of reservoir water more quickly, if more discharge was required.
- The volume of the rock operation to increase the dam height up to 8 m was 14400 m^3. Length of crest equals to 125 m in height of 33 m of the dam floor. In order to avoid useless elongation of crest length and reduce the costs, the length of dam wall has been reduced by making an arch on the west front of the dam. On this point, hydrostatic pressures are not much strong, as the mountain has obstructed the dam on the west front.
- Constructing sediment catcher groyne: A sediment catcher groyne (SCG) has been constructed on the upstream about 2 km far from the dam to intake the sediments of the river. Position of this SCG is located on a part of valley with a relatively low width and an average height of about 1.5 to 2 m. This SCG is made of gable wall. SCG obstructs the entry of fine suspended articles into the reservoir, until a flood occurs with a discharge flow less than 0 m^3/s. If so, refilling the dam is probable once in each 20 years.
- The intake tower on upstream and bond to the vertically wall, with the same height of the dam and approximate diameter of 3 m, has been extended on the floor of tower. A steel pipe with 30 m length and 30 cm diameter is located vertically with a slope of 3%. Outlet of the pipe in level is 1857 m. A metal ladder was built to access the downstream of the dam. On the upstream, the steel pipe of water- level gauge for the reservoir, with hatches in form of square and dimensions of 15 15 cm^2 and the same distances of 2 m from top to the bottom, has been provided. The cost of reconstruction, according to the list of prices in 1981, including dam wall, spillway and outlet channel and rebuilding the old outlet channel estimated equivalent to $63 million [4].

Properties of Sheikhbahaie dam of Ghohrood Kashan after reconstruction:

- Dam wall height: 33m.
- Crest length: 125 m - Date of plan operation: 1981-1983.
- Lake of area: 76220 m^2.
- Reservoir volume: 990000 m^3.
- Level of dam crest: 1883 m.

Kind of Spillway: Steel free spill way in the middle of the crest. Crest width: 16 m. Width of dam floor: 30 m Maximum thickness in base: 33 m Slope of upstream wall: Vertical slope of downstream wall: 2 vertical to 1 horizontal, Normal level of dam: 1873 Volume of the rock operations: 14400 m^3 Properties of spillway:

- Length of spillway: 10 m.
- Height of spillway: 2m.
- Chute length of spillway: 35 m.
- Discharge capacity: 55 m^3/s.

Figure 6 demonstrate the position of upstream of the dam spillway.

Fig. 6: Upstream of dam spillway

Table 1: Safety factors dam at two different conditions (normal and seismic)

Controlling the dam stability (height:33m)	Normal conditions (no quake)	Horizontal quake conditions	Effect of horizontal quakes
Safety factor against overturning Allowable value>1.5	1.90	1.60	1.52
Safety factor against overturning Allowable value>1-1.5	1.33	1.15	1.02
Allowable sliding factor <0.6	0.45	0.52	6.59
Shearing-friction factor	2.86	4.55	4.10

Table 2: Stress values dam (empty, full) at two different heights (25, 33 meters) in normal condition

	Stress in downstream (normal conditions)			
	Empty dam		Full dam	
Height (m)	Vertical stress kg/cm^2	Stress along the wall slope	Vertical stress kg/cm^2	Stress along the wall slope
25	1.92	2.40	3.87	4.84
33	1.54	1.93	5.50	6.87
	Stress in upstream (normal conditions)			
25	9.46	-	5.50	-
33	7.45	-	5.50	-

Table 3: Stress values dam (empty, full) at two heights (25, 33 meters) and seismic condition

	Stress in downstream (Quake)			
	Empty dam		Full dam	
Height (m)	Vertical stress kg/cm^2	Stress along the wall slope	Vertical stress kg/cm^2	Stress along the wall slope
25		1.03	4.13	5.16
33	Almost Zero	Almost Zero	7.70	9.63
	Stress in upstream (Quake)			
25	8.55	-	5.24	-
33	11.0	-	3.30	-

Stability of the Dam: In the case of gravity dams, controlling the overturning, stability and the stress forced into the dam, for both full and empty situation of the dam and also for normal and quake conditions, are considerable [10-12]. Safety factor was assumed 1.5 against overturning and 1- 1.5 against sliding. Shearing - friction safety factor was assumed more than 4 in normal loading and more than 2.5 in quake. Quake acceleration was assumed 0.1g for both vertical and horizontal directions [10].

Table 1 shows necessary safety factors at normal and earthquake conditions. Table 2 evaluates the stress values on dam at empty and full positions at two different heights (25, 33 meters) and in normal condition. Table 3 shows the stress values of the dam at seismic condition, empty and full positions at two different heights (25, 33 meters).

CONCLUSION

Sheikhbahaie dam in Ghohrood of Kashan, after about 360 years of its operation and utilization, was finally filled with sediments by the huge amount of heavy sediment flood in 1956, so it was out of operation and unused. During the preliminary studies of reconstruction plan for Ghohrood dam, to reconstruct the dam, in addition to sediment discharge the dam height was increased up to 8 m. By increasing the dam height in addition to control the upstream floods, efficient volume of the dam reservoir has increased up to 30 percents. Farming lands irrigation and the flow rate of drinking water in downstream area including the villages and the city of Kashan was also increased up to 15 percents.

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