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The ancient dams built by the Timurids (1350 to 1490 A.D.) in North East of Iran

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Abstract: Large reservoir dams of the Timurid era (1350 to 1490 A.D.) in Khorasan province can best display the great ability of Iranian engineers and architects in constructing large water structures. In the first half of the period, two gravity dams of Golestan and Fariman were also built in a similar style and now after 600 years they still stand strong and continue to function. In the second period of the Timurid era, engineers took a daring step by changing the design and building buttress dams of Torogh and Baisonghor (Akhlamad). Employment of multi-purpose structures in these dams marked a major development in the science of dam building. Building water diversion galleries in the dam's body, Bell-Mouth spillway make and Penstock through spillway walls are among the innovations of the engineers of this period. These large water structures indicate the great knowledge and skill of the engineers of the period in dam building. Unfortunately, due the poor quality of the existing materials at that time, construction of some of these dams failed. These engineers thought far ahead of their time and created designs that can still be seen in modern dams after 500 years.

Key words: *Ancient Iranian dams; Timurid era; Gravity dams; Bell-Mouth spillway*

1. Introduction

Water shortage in Iranian plateau multiplies the value of this vital element. Consequently, this country has always strived to achieve and reservoirs water. Throughout the several thousand year old history of Iran, water has always played a key role. Discovery of the remnants of water structure such as dams, cisterns, water channels and wastewater systems and others are indicative of the intelligent use of water resources by ancient Iranians (Kuros and Labbaf, 2007).

The effort that Iranians have put into exploiting water resources is dividable into two main periods. The first period from 1000 B.C. to the end of the Sassanid dynasty in 600 A.D. In this period, Iranians started to build diversion weirs in to control surface water. Among these structures one can mention weirs such as Daryoush, Bahman, Shahpur, Mizan and Amir that date back to 2000 to 2500 years ago in south west of Iran (Kuros and Labbaf, 2007). All of these structures are weir bridges and are built with the purpose of bridging and diverting water. There are channels inside these weirs which carry the water to the mills.

The second period of dam building in Iran started from 1100 to 1620 A.D. In this period, designing and building dams underwent a significant transformation. In a way that for the first time engineers and architects started to build large dams for the purpose of reservoir water. Building such dams posed the problems of making the dam's body watertight, devising a water diversion mechanism for the building phase and a spillway system. At that time, engineers came up with interesting solutions. Furthermore, building each of these structures faced problems which were resolved in the later projects. Arc dams of Kabar and Kart, gravity dams of Saveh, Golestan and Fariman and buttress dams of Torogh and Baisonghor represent the innovative and intelligent efforts made in building weirs. The three essential factors of site selection, the condition of the foundation and employing suitable materials were considered in most of these dams.

Through their innovations in building reservoir dams, the engineers of the Timurid era have undoubtedly brought into existence the most flourishing dam-building period of ancient Iran. The magnificent design and architecture of the Timurid monuments has influenced a major part of Central Asia, from Turkey to India. Years after the extinction of this dynasty, the plan and design of the Timurid constructions were employed in other countries in similar buildings (Allan and Metalwork, 1989).

The present study investigates the dams of Golestan, Fariman, Baisonghor and Torogh in terms of engineering characteristics, material type, constructing conditions and the problems that occur after reservoir water. Due to lack of historical evidence regarding the construction stages and operation of the dams, all the results presented here are based on field studies, drilling results conducted on the body of the dams and eventually comparison of the results with current methods of operation.

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2. History of dam construction in Khorasan

Numerous spoils and the vast lands that came along with the conquest of India, allowed the Timurid the necessary resources and tools to display their glory and grandeur in the form of their magnificent monuments, and for this purpose they employed art and engineering (Blair and Bloom, 1993). They gathered all the great artists, architects and engineers from all the countries under their dominion to Samarkand, the center of their government. In the Timurid era art, architecture and engineering flourished in the center of their government, Khorasan (Allan and Metalwork, 1989).

After Timur's death, his son, Shahrukh, came to power. In his reign (1386 to 1429 A.D.) he erected magnificent monuments around the sanctuary of Imam Reza in Mashhad. In other words, most of the structures of Timurid era in Mashhad and the surrounding areas were built during the reign of Shahrukh and his art lover wife, Khatoon Goharshad (Allan and Metalwork, 1989). At the request of his wife, Shahrukh turned Mashhad into the capital of engineering and architectural innovations. At this time the sanctuary of Imam Reza, as an immensely sacred place, was magnificently reconstructed and modernized. Goharshad mosque was built adjacent to the sanctuary at the order of Khatoon Goharshad (1395 to 1399 A.D.). Presently, Goharshad mosque is considered one of the most beautiful and glorious Islamic monuments. Most of the majestic monuments of the first half of the Timurid era were designed and built by two famous architects, Qavam al-Din Shirazi and his apprentice, Ghias al-Din Shirazi (Pugachenkova, 1981).

The attention Shahrukh devoted to Mashhad resulted in the rapid expansion of the city and its population which in turn increased the need for water. Therefore constructing reservoir dams around the city was on the engineers and architects' agenda. The most important dams remaining from that period include the four dams of Golestan, Fariman, Baisonghor and Torogh (Fig. 1). No inscription has been found in any of these dams to indicate their construction date and therefore there are many controversies in this regard. Correspondences concerning the division of dams' water, ownership of the downstream lands, the material used in the construction, brick laying style, the building method and similarities in the design are among the most important documents used in the estimation of the construction dates of these large water structures. In case of Golestan dam, the most important historical evidence dates back to 550 years ago somewhere between the years 1451 to 1477 A.D.. In this document Sultan Abu Said Mirza, a king of Timurid dynasty, appointed Molana Qutb al-Din Muhammad Khafi as his representative to solve the water sharing dispute of Golestan dam (Navai, 1976). Therefore it can be concluded that the construction date of Golestan dam must have been before this order. Also in other historical documents there are indications that the construction date of Golestan dam was contemporary to Goharshad mosque (1395 to 1399 A.D.). Some believe that Khatoon Goharshad named this dam after her bondwoman, Golestan (Fadai, 1996). Therefore, probably Golestan dam was constructed contemporary to Shahrukh, the second Timurid king, and Goharshad mosque. Furthermore, the similarities between Golestan and Fariman dams in terms of design, geometry, material type, brick dimensions and brick laying style indicates their contemporariness. Considering the contemporariness of Golestan and Fariman dams and Goharshad mosque, perhaps Qavam al-Din Shirazi and Ghias al-Din Shirazi, the most famous architects of that time, played a major role in the construction of these two dams.

Due to its inability to reservoir water and destruction of parts of the spillways and water transmission galleries, Baisonghor dams is neglected by historical documents. The only remaining evidence is the name which in some historical documents is mentioned as Baisonghor the son of Shahrukh. During the reign of his father he was the ruler of western Khorasan. During his rule over western Khorasan and his reign (1430 to 1439 A.D.) he had many contributions to the prosperity of Khorasan province and therefore one can cautiously attribute the construction time of the dam to the reign of Baisonghor.

Although there are no inscriptions mentioning the construction date of Torogh dam, but most historical texts attribute its construction date to the reign of Sultan Hussein Bin Bayqara's era (1454 to 1490 A.D.), last king of Timurid dynasty. In some other historical texts, Torogh dam and its water mill are attributed to Alishir Navayi, minister and close adviser to Sultan Hussein Bin Bayqara and one of the scientists and scholars of the Timurid era (Molavi, 1963). During his ministry, this competent minister constructed many monuments and contributed to the prosperity of Khorasan province (Blair and Bloom, 1993). Considering the similarity of the design of Baisonghor and Torogh dams, it seems that both dams are designed and constructed by one architect. As a result it is possible that Baisonghor and Torogh dams were designed by the apprentices of Qavam al-Din Shirazi and Ghias al-Din Shirazi. It seems that these architects collaborated with their masters in the construction stages of Golestan and Fariman dams and acquired valuable experiences. In designing Baisonghor and Torogh dams, they didn't follow the method of their masters and founded a new style of dam building.

3. Saroj mortar

Resistant and watertight materials are indispensible for reservoir water behind a dam. Saroj mortar is one of the innovations of Iranian architects and was employed before the invention of concrete. Due to its low permeability, Saroj mortar is used in the structures that are in direct contact with water such as cisterns, pools, baths and etc. In addition, it was also used in dams and bridges as the mortar used between stone and brick. Building reservoir dams became widespread at the same time that Saroj mortar became popular in Iran. Although we don't know when exactly architects started to use Saroj, but considering the buildings where this material is employed, one can estimate the history of its usage in the Iranian plateau to 900 years ago (Kuros and Labbaf, 2007).

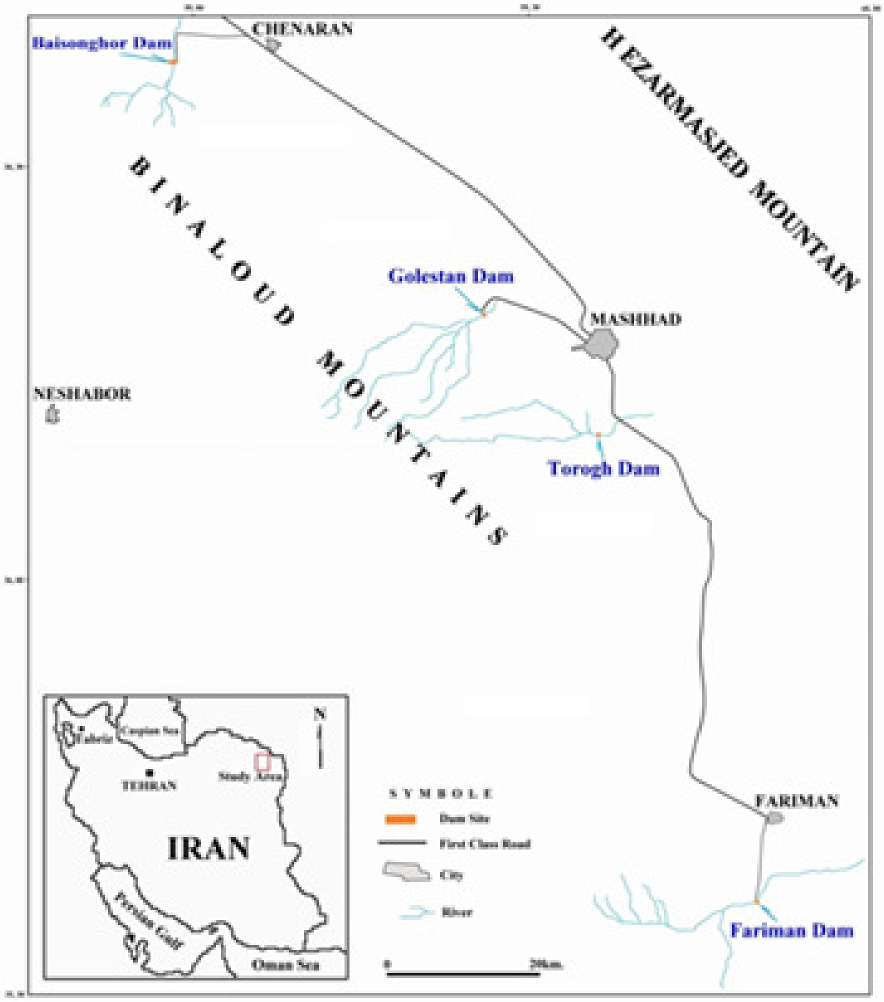

Fig. 1: The location of Golestan, Fariman Baisonghor and Torogh dams relative to the city of Mashhad

It is very difficult to make Saroj. It is obtained by mixing lime, clay, sand, ash and water. In the first stage of creating the material, clay and lime are mixed in the ratio of six to four, and by adding water the initial viscous material is prepared. Then some ash, found in bath furnaces, along with some natural fibers (a type of straw called Loui) is added to the mix. Eventually the material is massaged and pressed for 24 hours using a heavy wheel pulled by animals, so that the mixture is completely homogenous. Ash contains a lot of non-crystalline Silica which when combined with lime slush produces calcium silicate, but this chemical reaction is very slow. Therefore the process of massaging and pressing takes a lot of time. One of the main disadvantages of Saroj mortar is that its volume decreases by becoming hard, which usually entails cracking. The purpose of mixing Loui fibers is to prevent cracking

4. Golestan and Fariman Dams

Golestan and Fariman dams are gravity dams and have pyramidal backside. They almost have identical geometrical characteristics. The dams are built with a height of 15m from the river bed, 100 and 130m crest length, 10m crest width and 25m foundation width. There are 20 to 22 chambers built on the exterior of the dam which gives a special beauty to the whole structure. The pyramidal backside is added to increase the dam's body strength. A major part of the body of the Golestan and Fariman dams are made of rocks and Saroj mortar. In this part, there is a regular network of carved wood, the cross section is 10x10cm and it is 6cm long, which is weaved together. This turns the dam's body into an integrated mass. The wood is covered with a special resin to prevent decay. In order to make the foundation watertight, 2 to 3 meters of the alluvium is removed from the base of both dams and it is filled with rocks and Saroj mortar. Therefore the body of the dam is directly posited on impermeable stones. A harmonious design and use of suitable materials is the reason why they still remain strong and stable after 600 years of contact with water.

The exterior of both dams are covered with bricks and Saroj mortar in the form of a beautiful architecture. The bricks are in two different sizes. The big bricks are 27cm wide and 40cm long and the length and width of the small ones are 29cm. Both brick types are 6cm thick. There is a well-made of bricks in the middle part of both dams in which penstocks and the sedimentation system are located at different levels. There is a spiral stair case on the periphery of the well which allows access to the valves (Fig. 2). To prevent the destruction of the Penstock, large boulders, called Harkareh, are used. The boulders are made of serpentine, and on the inside they are similar to a carved pipe. The valves can be opened or closed using a gear at the mouth of the intake valves.

During all these years most of the Golestan and Fariman dams' reservoir was filled with sediments. Therefore in 1995 the height of Fariman dam was increased by 7 meters. The reservoir capacity of Golestan dam was increased to 5.2 million and Fariman's to 3.7 cubic meters (Fadai, 1996). Furthermore, two shoot type cement spillways were built with three controllable valves in the left side fulcrum of both dams. Much effort has been put into making the added parts similar to the original design. Consequently, 22 chambers were added to the exterior of the dam (Fig. 3).

Fig. 2: brick well and the stare case of Golestan dam for accessing the intake valves

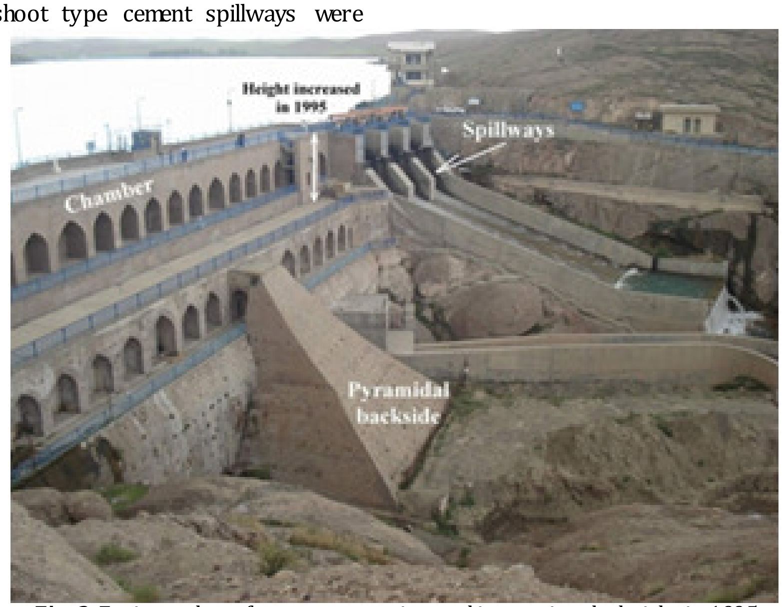

Fig. 3: Fariman dam after reconstruction and increasing the height in 1995

5. Baisonghor dam (Akhlamad)

Naturally, new projects can face problems which in some cases can lead to failure. Baisonghor dam is an example of devising new methods of constructing ancient dams. One of the distinctive features of this dam is the spillway and river diversion system. Although due to the type of the materials used and construction problems this project was not successful, but it has great value as a new method in designing ancient dams.

Baisonghor buttress dam is located in 66 km North West of the city of Mashhad and in North East of Iran (Fig 4). This dam was built in along the course of Akhlamad river, crest length: 230m, crest width: 11m, base width: 14m, height 12m, reservoir capacity: 3 million cubic meters (Fig. 5). The materials used in the construction are bricks and Saroj mortar. Presently due to the destruction of the penstock system and spillways, the dam is not functional.

5.1. Materials used in construction of Baisonghor dam (Akhlamad)

The materials used in this dam consist of limestone, baked bricks and Saroj mortar. Four horizontal galleries and vertical wells are made of baked bricks and Saroj mortar but a major part of the body is made of limestone, 20 to 40cm, and Saroj mortar. They are positioned in a way that Saroj mortar is all around them. Eventually, for beautification purposes, thin rocks are skillfully laid on the exterior of the dam

5.2. Water diversion mechanism

Two meters of the sediments of the river bed were removed before the application of the water diversion system in Baisonghor dam and it was filled with rocks and Saroj mortar. Then four horizontal galleries were built 20 meters apart. The materials used are baked bricks and Saroj mortar. The gallery ceilings are in the form of intersection arched vaults.

Fig 4: Baisonghor dam and accessory structures

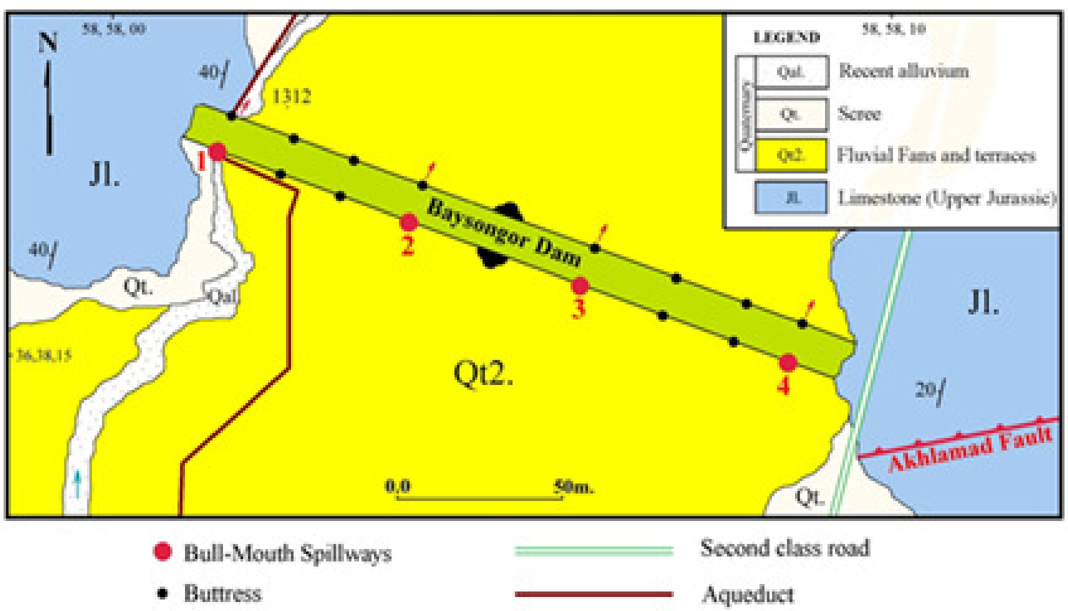

Fig. 5: The location of Baisonghor dam and accessory structures on geological map

Each gallery is 1m wide, 2.5m high and 14m long (Fig 6). In the next stage the course of the river is directed into the galleries. Therefore during the process of construction floods could pass through these four horizontal galleries. Employing this system of water diversion was an intelligent on the part of the engineers of that time.

5.3 Penstock and Overtopping water mechanism

During the construction process Baisonghor dam, a vertical well, 2.5m radius, was built on the entry of each horizontal gallery which was connected to the body. These wells were also made of bricks and Saroj mortar. During the building process the connection locations between the vertical wells and the horizontal galleries were open to let floods pass. Finally in the impoundment phase the connections were closed by bricks and Saroj mortar. Therefore the four horizontal galleries that acted as a water diversion system turned into Bell-Mouthed spillways and penstocks in the operation phase. This intelligent design is a significant step in changing the construction and operation methods of dams.

Fig. 6: Outlet of gallery number 3 and the application of bricks and rocks in Saroj mortar

There are three water stones in each vertical well, with a 30cm internal radius, which are installed inside the bricks and Saroj mortar. This makes water withdrawal possible at various levels. These water stones are made of Serpentine and were brought to the location from the rock mine of Mashhad which is 66 km from the dam site. These stones are cylindrical with a diameter of 50 cm, inside which there is a hole carved with a diameter of 30 cm. At the outlet of each water-stone there is a wooden valve which can be opened or closed by a metal rod from the top of the vertical well. In this way the water withdrawal of this dam is carried out through 12 water stones which are positioned at different levels (Fig. 7).

Fig. 7: vertical well of the spillway number 2 and the water stones used for water withdrawal

5.4. Problems of Bell-Mouthed spillways in Baisonghor dam

600 years ago, the designer of Baisonghor dam employed great skill and the existing materials of his time to build a dam which didn't have any precedence in the history of Iran. In other words, during the long history of dam building in Iran, this dam is the only one which uses Bell-Mouthed spillways. Undoubtedly using Bell-Mouthed spillways in reservoir dams was an intelligent move but due to the poor quality of the materials and implementation problems, this innovative structure turned into its most important weakness. After the construction the ensuing problems made it difficult to operate.

Baisonghor dam's spillways faced two basic problems. First when water entered the system, due to the low resistance of the materials (bricks and Saroj) of the spillway area, this area was destroyed. Frequent restorations, using various materials, are indicative of the repetitive destruction of the upper part of the spillway tower. Following the destruction of the spillway tower during flood times, water entry to the horizontal gallery was increased which resulted in the destruction of the discharge area. If this condition remains unchanged it can cause the total destruction of the spillway tower and severely damage the dam.

The second problem is water leaks from the bottom of the vertical wells in the spillway. Low thickness of the bricks (50 cm) and weakness in water tightness of this area causes water leakage into the horizontal gallery. Therefore water leaks gradually increase and destroy the bottom part of the spillway well. Recently, a little water has been stored adjacent to the vertical wells which leaks into the horizontal gallery. Water leakage happens where bricks and mortar join. This weakness resulted in the gradual water leakage and destruction of the bottom part of the spillway number 1 in the left side fulcrum during the last impoundment (Fig. 4). The destruction of the connection point between the vertical well of the spillway and the horizontal discharge gallery has resulted in the severe erosion of the river bed sediments in the outlet of the gallery number 1.

This innovation in the structure of reservoir dams was a courageous act by the architect. In the new method the problem of water diversion during the long period of dam construction is rectified. In the final phase of the construction the spillway system and penstocks are connected to the horizontal galleries. But in flood times Saroj mortar was rapidly destroyed and caused serious damage. At this point the connection between the well of the spillway and the horizontal gallery and the outlet of the gallery was severely damaged. These damages rendered the dam nonfunctional and the project failed. In spite of the intelligent design devised by the architect, it was not possible using the inferior materials of the time. In other words the design was 500 years ahead of its time and therefore its innovation turned into the biggest weakness of the construction.

5.5. Seepage of water under dam foundation and flanks

Foundation of Baisonghor dam is positioned on 12 to 20 m of coarse alluvial sediments with high permeability. Although the dam was not used much, but water leaks under the body of the dam has washed the sediments under the foundation. Undoubtedly, we continue using the dam the erosion of these parts can result in the destruction of the dam. The flanks are located on Lar formation limestone (upper Jurassic). In these limestone sediments, there are Karst cavities along the bedding surface and fractures. Surely these cavities can contribute to water seepage. The possibility of the contact of water with Lar formation limestone in the reservoir results in the seepage of water in this section.

6. Torogh dam

Torogh gravity dam is 14 kilometers from South of Mashhad and is constructed on Jurassic granite (Fig. 1). The dam is located along the Torogh river and its dimensions are as follows: crest length: 60 m, crest width: 7 m, foundation width: 11 m and height: 20 m. The materials employed in the building of the structure consist of stone, brick and Saroj mortar. The majority of the body is made mainly of granite boulders and Saroj mortar and on the exterior, brick laying is skillfully employed with the thickness of 1 m in order to strengthen and beautify the structure. The materials used for brick laying are baked bricks and Saroj mortar (Fig. 8).

Designing and building of Torogh dam was done years after the construction of Baisonghor dam and therefore many of the problems that manifested in the case of Baisonghor dam were correct in this new structure. The only differences between the two dams are the dimensions of the body, width of the river and the corrective measures taken in response to the initial weaknesses of Baisonghor dam. In the case of Torogh dam, three meters of the sediments of the river bed are removed and the body is posited directly of the granite rocks in order to make the foundation watertight. After filling the river bed with boulders and Saroj mortar, an 11 m long horizontal gallery is built. The gallery is built using baked bricks and Saroj.

The ceiling is in the form of arched vaults. The gallery is 1 m wide, 3 m high and 11 m long. During the process of the construction of the dam, the river is directed into the horizontal gallery and therefore water can during floods. During the construction process, an intake tower is built connected to the body, 6 m diameter, at the entrance of the horizontal gallery using bricks and Saroj mortar. Inside this intake tower there is a well with 1.5 m diameter. There is a big hatch on the upper part of the tower which pours the overflow of water in the middle and lower parts.

Fig. 8: Torogh dam and accessory structures

There are 4 small penstocks for water intake at different levels. There are transverse beams in the well in the form of a staircase to allow access to the intake hatches. During the construction of the dam, the connecting point of the intake tower and the horizontal gallery is open to let floods pass. In the final stage the connection point of the intake tower and the horizontal gallery is closed using bricks and Saroj mortar. Therefore during the construction phase the horizontal gallery acts as a water diversion system and during the operation phase it turns into a spillway and penstock. The high thickness of the intake tower has rectified the problem of the lower parts of the tower being damaged in the previous case.

If we are to make a comparison, the location of Torogh dam is better than Baisonghor dam. Generally, the low river's width, low thickness of the sediments and fewer numbers of floods in Torogh river furnish a better condition for Torogh dam.

It has been 600 years since the construction of Torogh dam and it is still standing strong. The reservoir has been dredged several and times the dam has been used up to the first half of the twentieth century. In 1981, the construction of the Torogh concrete arch dam with the height of 60 m commenced. This dam is located in the distance of 500 m from the old dam. For the purpose of transferring water to the new dam, a tunnel was dug with 4 m diameter in the body of the old dam. Unfortunately this tunnel has completely destroyed a major part of the old structure including the water diversion horizontal gallery.

7. Conclusion

Large reservoir dams of the Timurid era, Golestan, Fariman, Baisonghor and Torogh, tell the tale of an area when dam building engineering flourished. Construction of Fariman and Golestan dams in the first half of the Timurid era indicates the mere copying of the design in other similar reservoir dams, but in the second half of the era we can witness the efforts that engineers and architects put into creating new and innovative designs. One can find many major adjustments in these structures, aimed to cut costs and fix the many constructional and operational problems. These intelligent modifications were valuable experiences in dam building engineering. Although some parts of the spillway system and penstocks of Baisonghor dam were damaged after the first impoundment attempt but it is an excellent and intelligent effort put into creating a unique construction. Undoubtedly, lack of proper materials, such as concrete, were the greatest restraint on the engineers who contemplated innovative ideas. but the modifications made on Torogh dam is suggestive of the gradual growth of dam building technology in this era.

References

Kuros, GR., Labbaf, K.M, 2007. Water and irrigation techniques in ancient Iran. Iranian National Committee on Irrigation and Drainage (IRNCID). P. 199.

Allan, J., Metalwork. R.W., 1989. The arts of Persia, ed.Ferrier, R. W., New Haven : Yale University Press, p. 334.

Blair, S.S., Bloom, M., 1993. The Art and Architecture in Iran and Central Asia (1250 – 1800), Bil University. V. 1, p. 276.

Pugachenkova, G.A., 1981. Chefs-D'oeuvre D'architecture de l'Asie Centrale XIVe-XVe Siecle. Paris: UNESCO, 45-47, 150-155.

Navai, A., 1976. Landlord documents in Iranian history. Bongah Nashre Ketab p. 313. [in Persian]

Fadai, S.A., 1996. Khorasan old dams. Mashkoh 51, 129-144. [in Persian]

Molavi, A.H. 1963. Golestan dam. Astan Gods 17, 1-12. [in Persian]