Novel hydraulic structures and water management in Iran: a historical perspective

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Novel hydraulic structures and water management in Iran:
A historical perspective

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Summary. Iran is located in an arid, semi-arid region. Due to the unfavorable distribution of surface water, to fulfill water demands and fluctuation of yearly seasonal streams, Iranian people have tried to provide a better condition for utilization of water as a vital matter. This paper intends to acquaint the readers with some of the famous Iranian historical water monuments.

Keywords. Historic – Water – Monuments – Iran – Qanat – Ab anbar – Dam.

Structures hydrauliques et gestion de l'eau en Iran : une perspective historique

Résumé. *L'Iran est situé dans une région aride, semi-aride. La répartition défavorable des eaux de surface a conduit la population iranienne à créer de meilleures conditions d'utilisation d'une ressource aussi vitale que l'eau pour faire face à la demande et aux fluctuations des débits saisonniers annuels. Ce travail vise à faire connaître certains des monuments hydrauliques historiques parmi les plus fameux de l'Iran.*

Mots-clés. Historique – Eau – Monuments – Iran – Qanat – Ab anbar – Barrage.

I - Introduction

Iran is located in an arid, semi-arid region. Due to the unfavorable distribution of surface water, to fulfill water demands and fluctuation of yearly seasonal streams, Iranian people have tried to provide a better condition for utilization of water as a vital matter.

Iran is located in the south of Asia between 44º 02´ and 63º 20´ eastern longitude and 25º 03´ to 39º 46´ northern latitude. The country covers an area of about 1.648 million km^2.

Iran is bordered on the north by Armenia, Azerbaijan, Caspian Sea and Turkmenistan; on the east by Afghanistan and Pakistan; on the south by Oman Sea, Strait of Hormuz and Persian Gulf; and on the west by Iraq and Turkey (**Fig. 1**).

Climatologically, Iran is situated in the arid and semi-arid regions of the world. Of the total area, 13% has a cold and mountainous weather, 14% has a moderate climate and the remaining 73% is covered by dry weather.

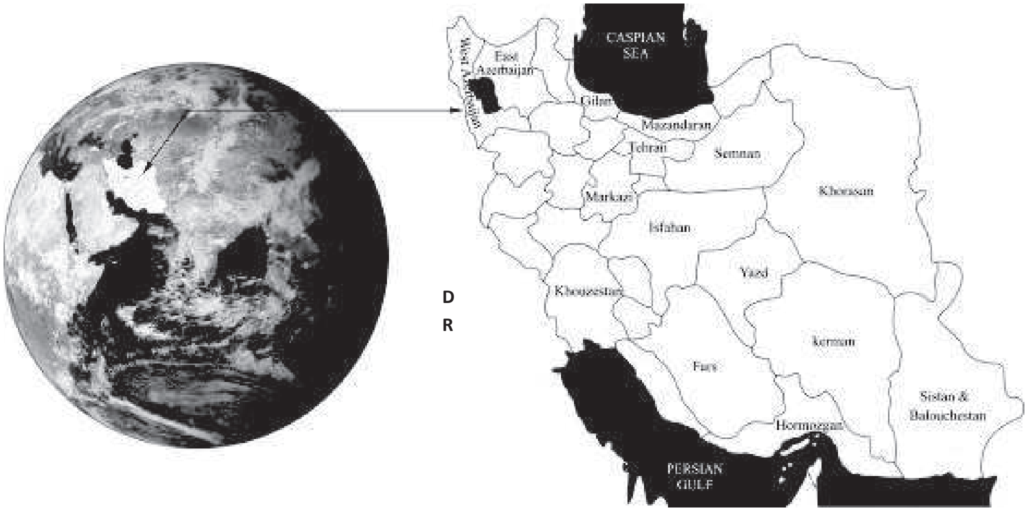

Figure 1. Map of Iran.

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Figure 2. A water bearer in old Tehran.

Water balance of the country according to 30 years of data shows that the average annual precipitation is 250 mm. 30% of the precipitation occurs in the form of snow and the rest in the form of rain.

Principal uses are categorized in different sectors in the country. Although uses in the agriculture sector is much more dominant in comparison with the other (i.e. Industrial and urban and rural), it has had much less growth.

From the point of view of the number of dams under construction in the country, Iran is among the first countries in the world. A great deal of emphasizes has been placed on the surface runoff control and optimized utilization of these resources and their high potential.

At present the Ministry of Energy of I.R. Iran, realizing the importance of control and optimum utilization of water. The specifications of the water supply services are: more than 130 reservoir dams with regulating capacity of 34 billion cubic meters, major irrigation and drainage networks in 1.5 million hectares, minor irrigation and drainage networks in 0.7 million hectares, hydropower plants with a capacity of 11000 megawatts and finally 110,000 deep wells and 300,000 semi-deep wells with total capacity of 44 billion cubic meters.

The archaeological survey's findings indicate that human being lived in various part of Iran as long as 15,000 years ago. Persia was a Cradle of Science in earlier times. The civilization in the western part of the Iranian plateau flourished 5000 years ago and they invented cuneiform writing. Discoveries prove that Iranians were peaceful and ingenious people in the second and third millennium BC who cultivated land and raised crops.

The first Iranian lived in meadows to feed their livestock. Some of them became familiar with techniques of irrigation and chose to be farmers. The importance of irrigation is pronounced in Iranian ceremonies, traditions and religious beliefs. Water has been depicted in many Zoroastrians and Anahit was believed as the Goddess of water. Lack of water in Iran affected the Iranian history and culture.

Dam construction in Iran dates back to the ancient times. Iranians are credited for invention subterranean canals (Qanats) which is well-known in the world.

II - Qanat (Kareez)

Qanat or kareez is a technical method used to provide a reliable supply of water to human settlements or for irrigation in hot, arid and semi-arid climates. The origin of this technology dates back to the ancient Persian Empire (**Fig. 3**).

The main idea to construct the qanat was to access and transfer of groundwater by sinking a series of wells and linking them underground.

The construction of qanats by Iranians dates back to 3000 to 4000 years ago. In particular, the oldest and largest known qanat is located in the Iranian city of Gonabad which after 2700 years still provides drinking and agricultural water. Its main well depth is more than 360 meters and its length is 45 kilometers. Yazd and Kerman are also known zones for their dependence with an extensive system of qanats (**Fig. 4**).

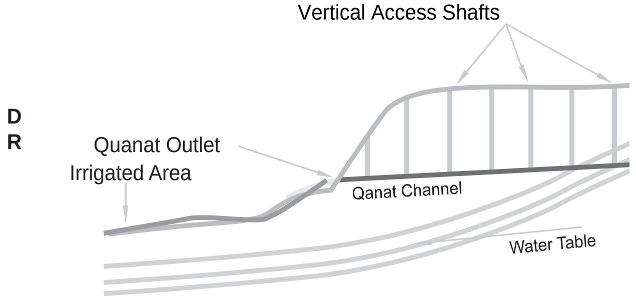

Figure 3. Qanat Construction.

Persia is currently benefiting from 31000 active qanats producing some 9 billion cubic meters of the groundwater and forming some 15% of the aquifer discharge which is annually mined across the country. This huge amount of water is amazingly conveyed just by means of gravity. Since no electric or fossil energy is employed, this system is pollution free and bears no environmental contaminants.

Qanat technology is not only an Iranian system of water mining, but also has overshadowed our economic, social and cultural outlooks since three thousand years ago. However due to the development of tube wells some of the qanats are going dry. Even then there are 50,000 qanats in Iran and nearly 75 % of them are still working.

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Figure 4. A view of qanats in Yazd Province.

III - Water supply and water treatment system

Transfer and distribution of water in the past was performed using earthenware pipelines. This system was also used in the Takht-Jamshid Palace just to discharge the sewerage network and it can be seen that this method was not changed so much during the past 2500 years. (**Fig. 5**)

The oldest physical water treatment system in the world named in Chogha Zanbil (**Fig. 6**) was built approximately 3000 years ago that located next to the Ziggurat of Chogha Zanbil in city of Susa.

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Figure 5. The general layout of the open air water ways in the Takht-Jamshid palace.

Water was transferred from Karkheh River (on the west of Susa) to a sedimentation basin and then the town over a distance of 45 ^{Km} via an open canal. The reservoir with dimensions of 70.1^{m} length, 7.25 ^{m} wide and 44.35 ^{m} depth has a capacity of 350^{m3}. Materials such as tar and brick were used for building the structure. Once the reservoir was filled to maximum level, the physically treated and de-silted water flowed in to the basin (located at a higher elevation) via the nine mentioned conduits.

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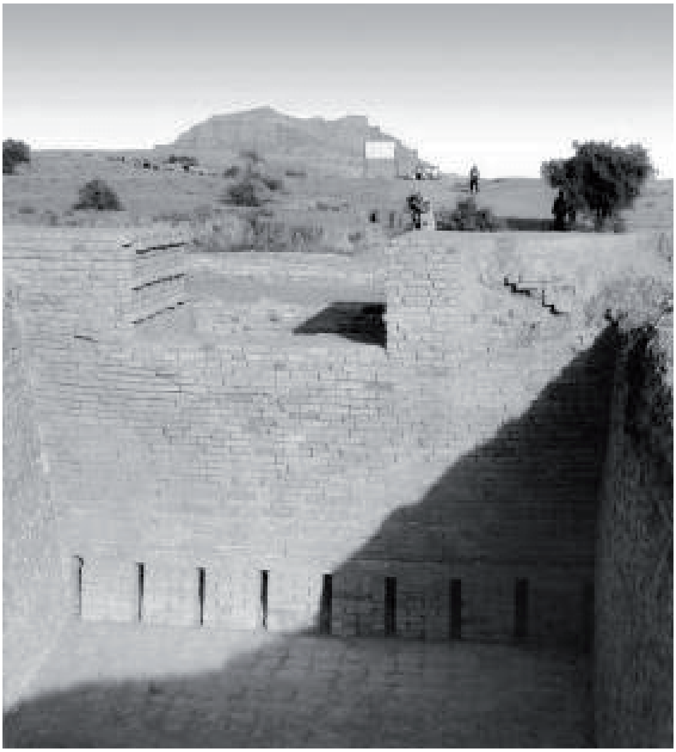

Figure 6. Physical water treatment basin, Chogha Zanbil temple.

IV - Subterranean water reservoirs

1. Ab Anbar, Water Warehouse

Subterranean water reservoirs (Ab Anbars) are historic hydraulic structure of Iran for drinking water supply that still persists in some regions of Iran. The main purpose of this structure was supplying water demands of the passing caravans as well as people living close by. Subterranean water reservoirs were cylindrical in shape with arched ceiling and usually located in arid lands. In some regions, wind towers are also built for cooling and aerating water. Access to collect water was by a staircase going deep down to the lowest level of the reservoir. The storage capacities of these reservoirs vary from 300 to 3000 m^3 (**Fig. 7 and 8**).

The construction material used for Subterranean water reservoirs were very tough and extensively used a special mortar called Sarooj made of sand, clay, egg whites, lime, goat hair, and ash in specific proportions, depending on location and climate of the city.

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Figure 7. Amir Chaghmagh Water Reservoir, Yazd.

This mixture was thought to be completely water impenetrable. The walls of the storage were often 2 meters thick, and special bricks had to be used.

These bricks were especially baked for water reservoirs (Ab Anbars) and were called Ajor Ab Anbari. Some water reservoirs (Ab Anbars) were so big that they would be built underneath caravanserais such as the water reservoir (Ab Anbar) of Haj Agha Ali in Kerman. Sometimes they would also be built under mosques, such as the water reservoir (Ab Anbar) of Vazir near Isfahan.

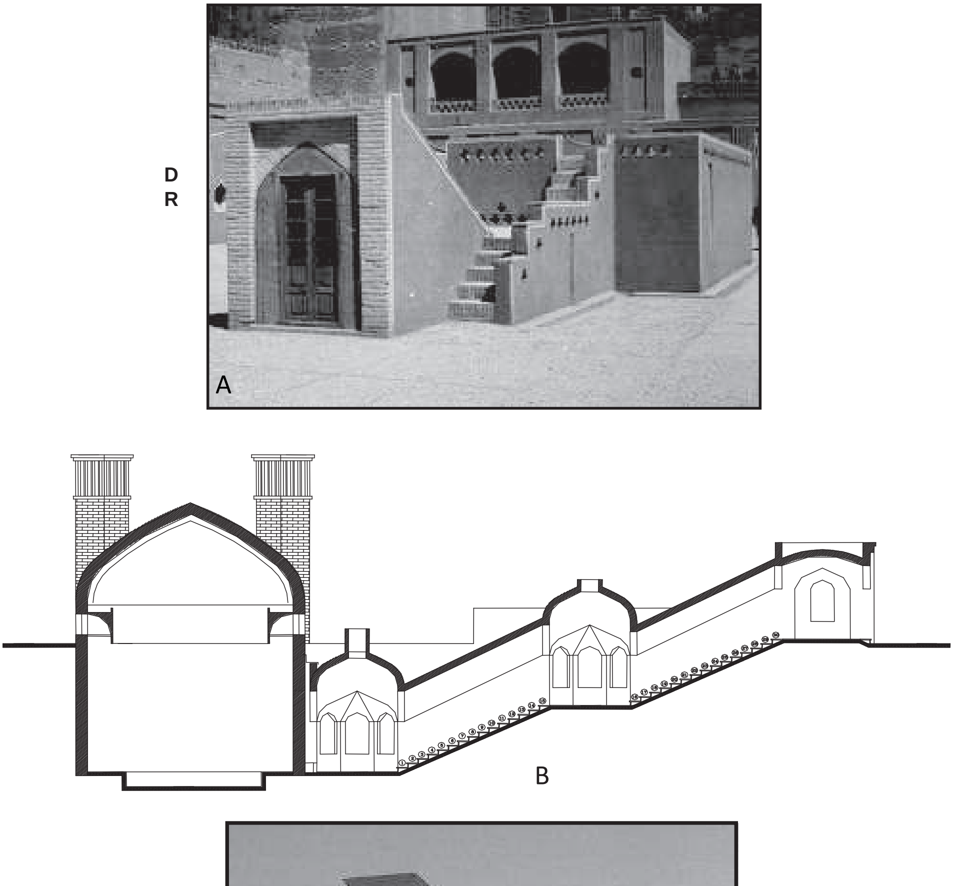

Figure 8. (A) Arg-E-Bam water reservoir (Before earthquake); (B) Cross section of an Ab Anbar; (C) Golshan water reservoir in Yazd Province

V - Dam Building

Iran is located in an arid-semiarid region. Due to the unfavorable distribution of surface water, to fulfill water demands and fluctuation of yearly seasonal streams, people have never ceased their endeavors to provide a better condition for utilization of water as a vital matter.

Dam construction in Iran dates back to the ancient times. Iranians carefully considered the three basic factors, site selection, and foundation condition and construction materials.

In all cases, they fully observed all design and technical requirement and circumstances in the dam site and site selection. Topography and river diversion during construction were also profoundly attended to (**Fig. 9**).

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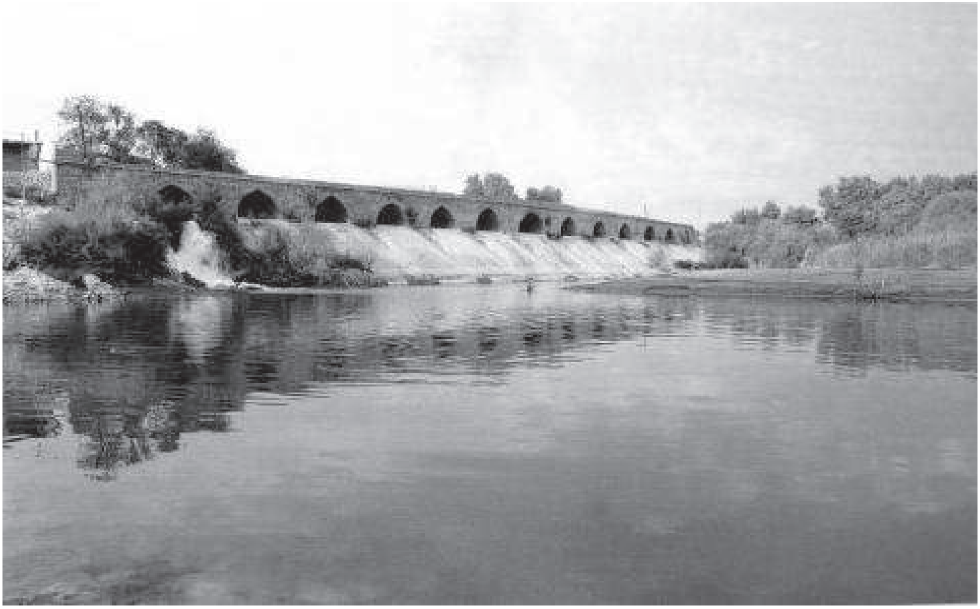

Figure 9. Amir multipurpose dam (Dam, bridge and mill); Age:2000 years.

All Iranian ancient dams are masonry of the following types:

1. Gravity dams

Studies indicate that all the design criteria considered in the recent design of gravity dams were taken into the consideration in the design of Iranian ancient dams. Saveh and Sheshtaraz dams which are over 700 and 900 years old respectively are examples of this type.

2. Arch dams

Iranians perceived the high bearing of arches before Romans. Kebar (one of the oldest arch dams in the world has a height of 26m, a crest length of 55m and a thickness of 5m with an arch radius of 38m which proves the skills of Iranians in dam construction) and Kerrit dams (**Fig. 10**) over 700 and 400 years old respectively are both arch dams.

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Figure 10. Kerrit Dam.

3. Buttress dams

Akhlemad dam (**Fig. 11**) with a crest length of 230m, height of 12 m and reservoir capacity of 3 milion cubic meters and Fariman dam, 400 years old, are both buttress dams. Both dams are still under operation.

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Figure 11. Akhlemad Dam.

Saveh arch dam and Durudzan fill dam are 2 modem structures that have been built very close to the old dam sites. The largest dam by height in Iran is Karun 3 (**Fig. 12**), and the largest dam in Iran by reservoir capacity is the Karkheh dam (**Fig. 13**) which is located in Khouzestan province.

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Figure 12. Karun 3 (dam and hydropower plant).

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Figure 13. Karkheh (dam and hydropower plant).

A quick glimpse at what is the remains of the past, reveals ingenuity of ancient Persians in water engineering and hydraulic works. Arch dams built from excellent materials, some of them 1000 years old, are still functioning here and there, each being a genuine masterpiece.

Modern dam construction industry, especially construction of large dams began 3 decades ago. Investigation and design of large storage dams commenced in 1948 in the framework of mid-range development plans and the dam construction actually began late 1950 s (**Fig. 14**). Controlling surface water has been a major issue in the development plans. At present there are 171 Large dams under construction, 85 large dam under operation and $1668*10^3$ ha construction of main irrigation and drainage networks and Iranian engineers are involved in the study, design, construction, supervision, operation and management of them.

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Figure 14. Dez dam in Khouzestan Province.

VI. Yakh-Chál (Ice-chamber)

A Yakh-chāl (Ice-Chamber) is an ancient natural refrigerator which was mainly built and used in Iran to store ice, but sometimes was used to store food as well. In summer season, people living in nearby villages used to supply their ice demands from these structures. The subterranean space coupled with the thick heat-resistant construction material kept the outside heat from reaching the interior space year round (**Fig. 15**). This ice was from the ancient times used for the making of Faloudeh (the traditional Persian ice cream).

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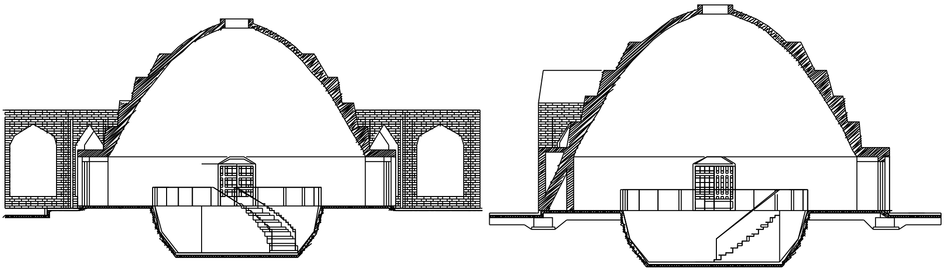

Figure 15. Cross section of a Yakh-chāl.

In 400 BC Iran, Iranians had mastered the technique of storing ice in the middle of summer in the desert. Yakh-chāl was a large underground space (up to 5000 m³) that had thick walls (at least two meters at the base) made out of a special mortar called Sarooj, composed of sand, clay, egg whites, lime, goat hair, and ash in specific proportions, and which was resistant to heat transfer.

This mixture was thought to be completely water impenetrable. The space often had access to a qanat, and often contained a system of wind catchers that could easily bring temperatures inside the space down to frigid levels in summer (**Fig. 16**).

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Figure 16. Arg-E-Bam ice-chamber in Kerman province.

The method of ice production is interesting. In the winter seasons, a certain amount of water used to be stored within the thick and high walls of designated chambers, the bottom surfaces of which were already flattened. The winter cold during the night times was sufficient to produce each night, ice a few centimeters thick. The high walls of the chambers which were constructed in the east-west directions protected the ice, facing north, against the sun rays. This method needed a skilled approach in judging the rate of ice production at each stage. Once the thickness of the ice had reached 30 to 40 cm, it was broken into pieces and then stored in the circular ice-chambers. A few wells were excavated in the bottoms of the ice-chambers to collect the ice melt during the hot seasons. The surfaces of the layer of ice used to be covered with straw to keep one layer separated from the adjacent ones. The ice-chamber also had two corridors: one was used for storing ice blocks in the winter and the other, for taking them out in the summer. Ice-chambers were active in the winter times to store ice and in the summer times to consume it.

The Meybod ice-chamber (**Fig.17**) is the oldest remaining one that is located 50 km north of Yazd city, next to an ancient caravan road. This building has remained intact and it is considered as a perfect example of the architectural style in its own type.

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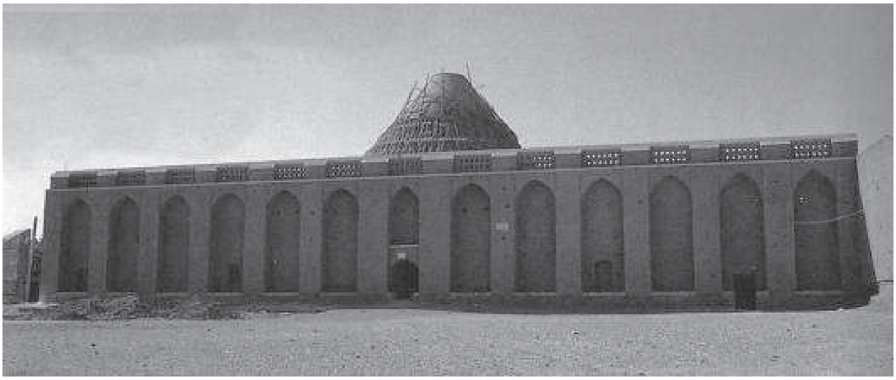

Figure 17. Meybod ice-chamber in Kerman province.

VII - Water mills

One of the skills of ancient Iranians was to make use of the water's hidden power to rotate the stones of the watermills. The roof of a watermill building was usually a dome. Light and air were supplied through a door.

The watermills were powered by the river currents, springs or qanats. Water mills were connected to the water sources by canals'. A conduit just before the mill shaft would act as a bypass when the mill was not in operation. The mill shaft is semi conical in shape and its diameter reduces from top to bottom. This shaft can be plugged by a wooden device which is accessible through a narrow gallery from inside the mill.

The wooden turbine consists of a wooden axle, the diameter of which increases gradually from top to bottom. It has a lower iron tip housed in a pit in the lower millstone, acting as the turbine support. The upper iron tip of the axle is fixed in the upper millstone. This axle is surrounded by some paddles and the whole system is known as the turbine wheel. When a water jet impinges forcefully on the turbine wheel, it rotates, and this in turn causes the upper millstone to be turned. The lower millstone is stationary and the rotation of the upper stone on the lower grinds the grain. There is a hole in the middle of the upper stone, which discharges the grain into the space between the two stones. The two millstones are not truly horizontal, but are slightly inclined which helps the flour to be discharged into the flour bags (**Fig.18**).

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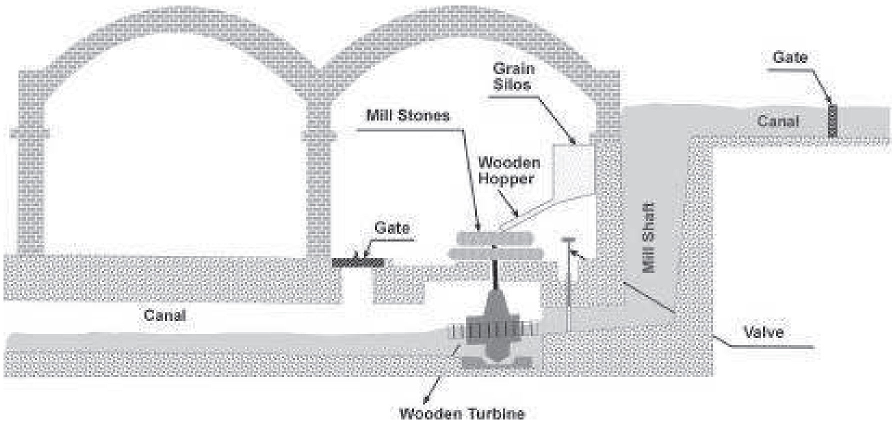

Figure 18. Cross section of a water mill.

The grains are stored in a silo located at the top of the watermill and are discharged through a wooden hopper into the hole dugout in the upper stone. By the rotation of the upper stone and the continuous strokes on the hopper, the grains in the silo discharge down. The water is guided out through a conduit built below the watermill (**Fig.19 and 20**).

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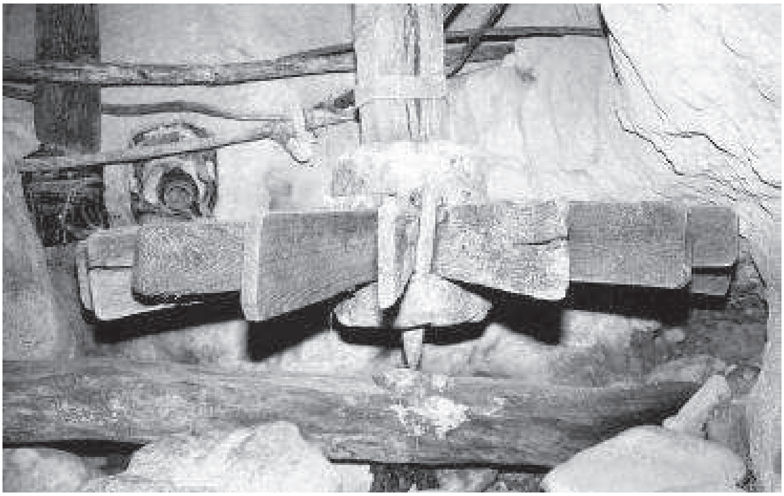

Figure 19. Water mill paddles in Taft in Yazd province.

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Figure 20. Upper millstone in Kashan.

Some parts of the roofed mill compound are designated for the cleaning and screening of the grains and flour production. A space is also foreseen to lodge the animals, which are used to transport the flour bags.

The Gar-Gar and Amir Weir mills were powered by the reservoir water. Kashan town's Fin'-garden watermill was rotated by a spring, whereas Double Stone Water Mill of "Mohammad Abbad – Meybod" (**Fig. 21 and 22**), ancient watermill of Ashkezar, 15 km away from Yazd, and the two hundred year old Taft watermill were all, powered by the neighboring qanats.

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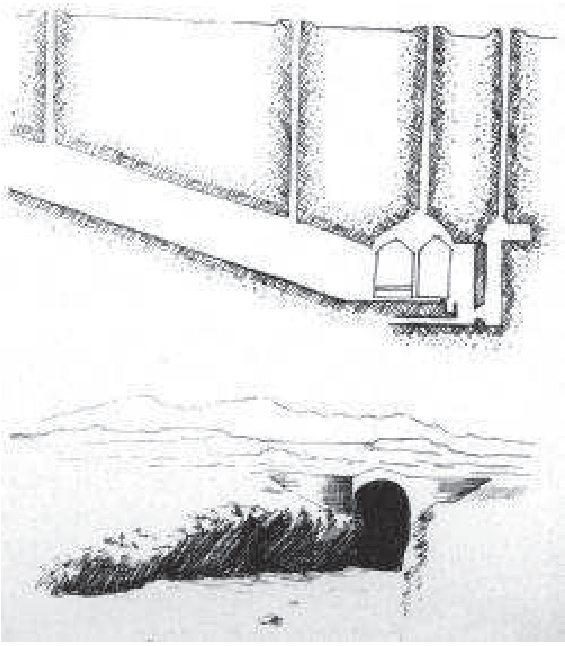

Figure 21. Entrance of double stone water mill of “Mohammad Abbad in Meybod.

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Figure 22. Double stone water mill of “Mohammad Abbad in Meybod.

Double Stone Water Mill of “Mohammad Abbad – Meybod is an amazing hydraulic structure is absolutely unique. It has been created at the depth of 40 meters on qanat gallery in order to grind grains into flour (**Fig. 21 and 22**).

The neighbouring oases supplied their consuming flour from this 150 year old water driven structure. No construction materials had been used to establish this marvelous mill.

The vestibule of the mill is so high that even camels could move back and forth easily and the lateral stables would room cows, donkeys or camels to carry flour. The mill is remotely situated in a deserted area some 8 km. out of “Mohammad Abbad” village which is 50 km. from Yazd.

Dust and slime had filled the mill’s long narrow passage gradually in the course of time due to flood waters which was unblocked by the regional water authorities who made a lot of endeavors to excavate it. This mill is open to visitors’ at present.

VIII -Specific examples

1. Khaju Bridge

Khaju Bridge (**Fig. 23**) is one of the most famous bridges in Isfahan, Iran and has roused the admiration of travelers since the 17th century. Shah Abbas II built it on the foundations of an older bridge around 1650 AD. It has 23 arches and is 105 metres long and 14 metres wide. This bridge is used to connect the town’s old square and roofed bazaar to the new part. The pass way of the bridge is 7.5 meters wide, made of bricks and stones with 21 larger and 26 smaller inlet and outlet channels. The pieces of stone used in this bridge are over 2 meters long and the distance between every channel and the ceiling base is 20 meters. The existing inscriptions suggest that the bridge was repaired in 1873.

The Khaju Bridge is also a weir (the downstream side is formed as a series of steps carrying the water to a much lower level) and consists of a gallery, which being next to river water was a cool and ideal place to spend the time during hot times of the day. The lower level of the bridge may be accessed by pedestrians and remains a popular shady place for relaxing.

Khaju Bridge is a good Iranian water engineering symbol because of employment of integrated urban management system and methods of hydraulic engineer and Iranian architecture together.

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Figure 23. The Khaju bridge in Isfahan province.

2. Measurement in Ancient Iran

Due to the large extent of the country and the variety of the existing water resources, different methods for water flow measurement were developed in various regions, The smaller the volume of water, the more accurate was the measuring method. The “water distribution measurement device” consisted of a flat copper tub, a perforated cup and the stone (an old measuring scale). Wherever there was an abundance of water and no conflict between the farmers, these devices known as water distributors were used on the river junctions to measure and calibrate the flow.

One of ancient Iranian scientist, Sheikhbahayee, designed the best way to measure distribution of the volume of water from Zayandehrour river for agriculture. This method called the Sheikhbahayee’s roll (Toumar-e Sheikh Bahayee) was used for ending the conflicts between farmers who lived around Zayanderoud river.

Also Amrikabir, prime minister in Qajarieh period, transferred water from Karaj river (a city located near Tehran) to Tehran (capital of Iran) and established a roll to distribute water of Karaj river between farmers (**Fig. 24**).

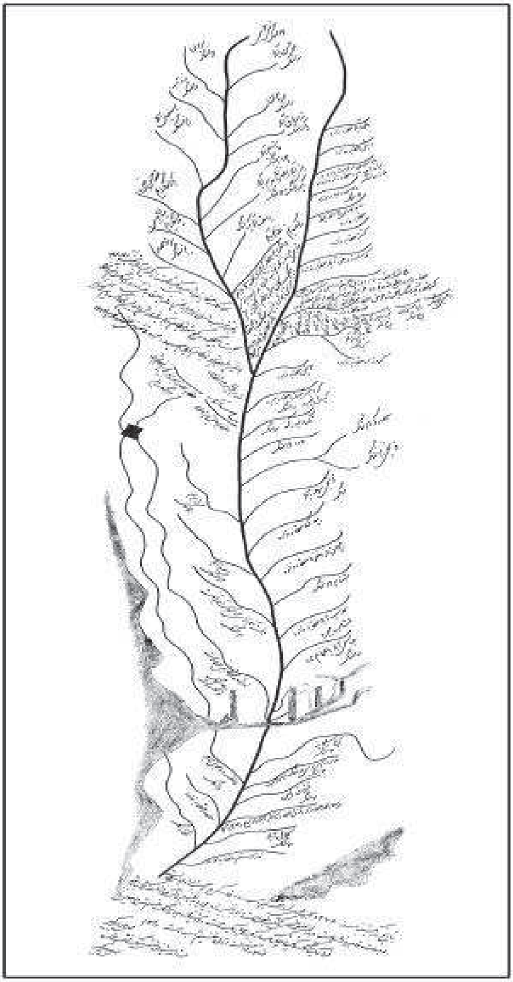

Figure 24. Picture of a roll to distribute water of Karaj river by Amirkabir.

IX - The Oldest Multi-Industrial Complex in the World

1. The Shooshtar water mills

This weir-bridge located in the city of Shooshtar, located 400 meters downstream of the Band-e-Mizan weir and upon the Gar Gar River is a weir-bridge which was built with the purpose of retaining water at a specific elevation. Three main canals and several ancillary canals have been excavated in the sandstone foundation of this structure in order to supply the water required to run at least 32 water mills. Currently the water once used for the running of the water mills flows unhindered in the form of striking waterfalls (**Fig. 25**).

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Figure 25. The Shooshtar water mills.

X - The Oldest River Retaining Wall in the World

The oldest river retaining wall in the world is to be found downstream of the Karkheh dam and was built during the Sassanians period (**Fig. 26**).

This wall was built with the purpose of minimizing the erosion of the river bank and preventing the unforeseen diversion of river flow. It is built of hand hewn stone, brick and Sarooj. This wall is 110 meters in length, 2.5 meters wide and 5 meters high forming a sloping trapezoid alongside the Karkheh River. Modern retaining walls along the Karkheh River are made by joining cement blocks (gabions).

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Figure 26. The oldest river retaining wall in the world in Khouzestan province.

XI - Conclusion

This paper intends to acquaint the readers with some of the famous Iranian historical water monuments. Observing the introduced structures reveals the deep insight of engineering sciences and making efficient employment of available regional materials in ancient time. Qanats, water mills and old dams have been utilized for centuries and compatible with the modern progresses of the engineering sciences. Yakh-chāl (Ice-Chamber) does not have any application today but architectures can utilize some architectural principles and methods of exploitation for designing modern structures. Subterranean water reservoirs (Ab Anbars) can still be use in deserts and arid regions for supplying water demands. Due to the unfavorable distribution of surface water, to fulfill water demands and fluctuation of yearly seasonal streams, people have never ceased their endeavors to provide a better condition for utilization of water as a vital matter. Dam building is a symbol of the widespread engineering methods, precision and accuracy of the past generations that their knowledge and experiences disclose to their modern age descendants. I hope that this paper can be a step forward to inform readers with a shortage review of water situation and some of the reputed historic hydraulic structures across the country of Iran.

Acknowledgement

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