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Utilization of water power as a Eco-Friend Energy in Watermills, case of Iran, Dezful

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ABSTRACT

Necessity is the mother of invention. The superiority of human over other creatures lies in the fact that he can make tools to satisfy his needs. To make bread, they needed to crush the wheat into powder. To achieve this end, the hard-working people of Khuzestan Province tried to use hydropower by building mill and operating it.

The utilization of *Eco-friend Energy* plays the essential role in the environmental protection in the contemporary age, so that many countries have given the importance to such energies in their national programs. The study demonstrates that the issue has been considered in Iran from the early ages. The recognition of watermills utilization experience in the southwestern region of Iran and especially the northern part of *Khouzestan* province reveals that the use of water energy has been adapted with the daily needs of residents. With regard to the water power transmission mechanism in the studied local watermills known as *Asyab*, a same mechanism in all two types of *Asyabs* is recognizable. Based on the study main achievement, such a power transmission mechanism can be applied in the contemporary age even in other countries to replace the energies derived from the fossil fuels with the water energy as a *Renewable and Eco-friend Energy*

Finally, not only, to preserve such valuable historic remnants is an aid to attract Iran and glob tourists and the people who are interested to know about them, but, Capitalizing on the rewarding continental conditions of Dezful city leads to take economical steps to make a steady progress in using modern technologies such as electricity power.

Introduction

The word "asyab" is composed of two parts, *as* and *ab*. "*As*" means grinding the grain under millstones (1). In Amid Dictionary, "*as*" is defined as two pieces of rounded and smooth stones, of which the bedstone with a mandrel in it is located under the runner stone. The runner stone rotates with the power of man's hand, water, electricity, water, or steam and mills the grains. The emergence of some of the mills was simply derived from human's needs. Watermill facilitated the job of milling the wheat, which was mostly done by women. The thought of inventing watermill was probably crossed the minds of man and woman simultaneously, as the man's job was to water the farms and woman's job was to mill the wheat and the two jobs had one thing in common, watermill. Also, the watermills were located in between the rural houses and the farms and, thus, they were considered to be the middle point of the two. It seems that the earliest millers were women. Men were, at that time, occupied in watering the farms, farming, and ranching. It was women who made wheel, pottery, watermill, and cart and spend their lives working on them. One result of inventing watermills was changing the job share between men and women. Working with hand mills was easy and done by women. But when the watermill was built in a town, women were no longer in responsibility of milling the wheat and men became responsible for carrying the packs of the wheat to the house of the mill. Thus, with the invention of watermill, not only a tradition was changed but also women had more free time to do the rest of their works (2). In the southern part of Iran, in Khuzestan Province and more specifically ancient Dezful town, a rejuvenated river passes through the town. In this river, called Dez River, a number of ship-like structures were built, which are called *osyio* (watermill) by the native people of Dezful. Until 80 years ago, about 60 watermills could be observed in different regions and rural areas of Dezful, including Milky, Grup, Dobandar, Mahmudi, Sorkhe, Shamoun, Suzo, Aghajil, Afshar Castle, to name a few. All of these watermills were built on Dez River or local ditches (3).

What is today known as watermill is a set of water-powered structures which were used as watermills or dykes in the past. According to the conducted studies on the building materials of the watermills, this set was built on account of the constant flow of the river in Dez River of Dezful City when Sasanid dynasty (from AD 224 to AD 651). center formed. In later years, the watermills were modified, in line with the demands of people of the areas. The advent of the watermills dates back to Sasanid period , but the majority of the watermills were built in three parts of the river in Ghajarid (from 1875 to 1925) and Safavid periods (from 1501 to 1736). These structures are made of river bed pebbles, brick, and mortar. The architectural style of these structures is the native and unified architectural style of th

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town. The structure bases of the watermill rooms are made of gypsum, ash, and brick in three rows, with some parts being made of stone. The walls are made of brick, river bed pebble, and mortar. The rooms of these watermills are built 4 meters above the river level and their structure is symmetric, with a ship-like view. These structures were used to regulate the pressure of river flow or to upsurge that flow (4).

Today, only a few of these structures have survived in three regions of Dezful, of which the oldest is under the ancient bridge of Dezful. Another region in which these old structures can be found is downstream and upstream *Golegole* (*Alikale* and upstream dyke) in the north of Dez River. An area which has recently been discovered is under New Bridge (*Osiyo Ra'na*), in which the most architectural structures of the river are found. Until 1968, that is 43 years ago, people have lived in these structures and the watermills were active. How old the Dezful watermills are is not clear, but some books such as *Khuzestan and its old history*, *Shahriyaran Diar* (*Shahriaran land*), and some other books from tourists pointed to the date of the creation of these watermills. Nonetheless, the basis of their claims is nothing but native people beliefs and quotations. The book of *Water and technique of watering in ancient Iran* illustrated a picture of the Sasanid installation in Shapour I empire, in which the watering channels and Dezful watermills are shown. To Dezful residents, the oldness of the earliest structures of Dezful watermills is about 1700 years. Most of the tourists who have seen these structures recounted them as ship-like structures, which are landed in harbor successively. However, it did not take long that the watermills were replaced by the electrical machines and became obsolete. In 1968, the last watermill stopped working.

History And Origin Of Watermills

The Arab-based word for Dezpol or Dezhpol, which is named Dezfil or Dezhpil by the indigenous people, is Desful. In Sasanid period, Dezful was built at the same time that a bridge (Figure 1) was built on Dez River to create a path between Jondi shapour, the new capital of that era, and Shushtar city. Originally, Dezful, until the early 13th century was called *Andamish*. Probably, the word of Dezful was derived from the word *pol* (bridge). Usually, *dez* means fortress, but here it means a strong fortress which is among the most resistant buildings in Iran's mountains. One of the old neighborhoods of the city is *Andamish Ronash*, which is located on the right side of Dezful River and still its ruined remnants can be seen. Dezful city, like Shushtar, was governed by Jondi shapour for a long time and became richer after Jondi shapour was ruined. Then, it was severely damaged, as a result of not fixing its watering network in Sasanid period.

Dezful is a 5000 years old city. That is, it is a city remained from the time that Shush town was known to other civilized regions in the world for its trading interactions. Dezful was the capital of Iran when the first emperor of Iran formed his government. The texture of Dezful city is an indicator of the civilized society and long history of city building, which has considered natural effects and is in harmony with the hot and humid climate of it (5).

Figure 1. Watermills under the new bridge of Dezful city

Roman Grishman, in his book of *Human's Art,* described the watermill system as the oldest archaic watering system in the world and considered it to be of 1400 to 1500 years age. The recent studies corroborate the oldness of these watermills that was estimated by Grishman, too (6). Near Dez River and in the rural area of Dezful, parts of a ruined installation is observed, which are believed to be 1700 years old and have their roots in Sasanid period. These watermills operated until 1968 and the city dwellers called them Osiyo Ra'na. However, Osiyo Ra'na was a name only attributed to the watermills under New Bridge. All of these watermills are similar in the overall appearance of building and their building materials. Unfortunately, only a few of them are remained along the Dez River, which passes through the city. That is, in the region 3 of the city, a number of the watermills have survived but because of being obsolete are under the process of decay and even some of their elements are already destroyed (7). As a matter of fact, there were other watermills which existed in the past in the other areas near Dezful, but now there is no trace of them. For instance, in the eastern side of the river, in a region 100 meters away from New Bridge toward the north of the river, the ruined parts of a watermill can be seen under river water. In another region called Ra'na, about 500 meters further away from the above mentioned place, the remnant of some watermills can also be found. In general, the regions which had watermills are divided into three:

1. Old Bridge, around which the watermills can be seen
2. New Bridge, around which the watermills can be seen
3. Downstream and upstream Golegole watermills in the north of Dez River in *Alikale* region.

Each of these watermills has been built in a different year. Floating watermills of Khuzestan Province and Dez River are located on the west side of Dezful city from north to south. Despite the fact that Dezful and Shushtar cities are less than 75 kilometers far from each other, the number of the watermills in Safavid period in this distance reached 50 to 60, some of which were destroyed by seasonal floods. Dezful watermills are spread in different parts of Dez River. A number of them are situated about 800 meters far from regulator dam of Dez and in the south of Dez River bank mall, some others under New Bridge (Second Bridge), and still others near Old Bridge of the city.

Lord George N Krozon (1889), in the second edition of his book of *Iran and Iran's towns,* states:

Near the headspring of river stream, some watermills are built on the big rocks, which are connected to each other by a weak bridge or pavement. These watermills operate with the stream of the river and have a very beautiful view (8).

Baron Dobed, on page 371 of his records, writes:

A number of watermills are constructed inside the river or on the rocks in the river, where the river flows with high speed. These small islands are connected to each other. At night, when the lanterns of the watermills are lightened by the miller, a fantastic scene is created by the lights (9).

It is worth noting that some of these watermills were called "*Mirzaei* watermills" and were operated throughout the whole year. The others were called "*Abdullah Mirazaei* watermills" and were operated only when the river was in flood. On page 467 of *Lamat Al-Bayan,* Haj Molla Nasrollah Torab, known as Shaker, states:

…. In Dezful city, there is a river, which rotates about 30 watermills or more when it is in shortage of water. At the time the river is in flood, it rotates many (10).The price of Mirzaei watermill (Figure 2) *was ten times more than that of Abdullah*

Mirzaei watermill and both were possessed by a man. One day, the owner of the watermills sold a Mirzaei watermill in a high price. He colluded with the writer of the contract and wanted him to write the word "Abdullah Mirzaei" instead of "Mirzaei". The writer did so and left a space, as much as a word, before the word "Mirzaei". Then, the document was signed and sealed by the seller. The witnesses approved the document. Moezi found out the cheat and refrain from signing and sealing the document, but did not express the reason of his refrain. Then, they add the word "Abdullah" before the word "Mirzaei" and Moezi signed the document. It is said that, after two or three years, the cheat was revealed and people became surprised by finding Moezi's wit and patience. People were astonished that Moezi did not claim the man to be cheater when that person just started to cheat (11).

Figure 2. Rent transaction document of mill stone of Dezful watermills at the time of the Shah of the Qajar period is known as Sheikhieh watermill which amounted to fifteen thousand black money was given to the tenant. This document was equal to eighty Naser-AL-Din Shahi currency.

Source: author.

Sustainable Architecture Of Watermills

Seasons Of Exploiting The Watermills

In Dezful, midstream watermills were mostly used in spring and summer and the watermills of the river bank in winter. In the seasons which amount of fall was decreased, midstream watermills were used because the river flow in this type of watermill was stronger and they operated in both summer and winter. But, in the seasons that the stream of water was elevated and midstream watermills went under the river water, the watermills of the river bank were used. In other words, the reason of operating midstream watermills was the low level of river water and the reason of operating river bank watermills was the high level of river water. Hence, the miller had to transfer their watermill installation in different seasons (winter and fall versus spring and summer) to prevent them from destroying as a result of river spate (20).

Watermill Function

The watermills were used to mill turmeric, gypsum, juniper oil, and sugar, in addition to milling the wheat. These were all done in almost all the watermills but in these watermills, in addition to milling, grinding the wheat was also done. To do this, the miller should increase the distance between the two millstones. There was a rail, which was raised by a strap, between two lumbers. The strap and lumbers were positioned near the millstones. When the millers were taking rest, they raise the strap to prevent the millstones from rotating. The shaft, which is connected to the runner stone via the lumbers, holds the runner stone in a high position(22).

1. Exploiting the potential energy of stream to rotate the watermill and crush the wheat. Besides, the watermill was located in the oil-seed extracting and rice factories

2. Welling up water and directing it toward the downstream lands and gardens with the existing canals

3. Producing hand-made goods in the surrounding areas of watermills

4. Controlling water volume and its movement by building sluices with different sluice gates in the path of stream to carry water to the city and regulate its volume to the amount which is demanded by the inhabitants.

Different Kinds Of Watermills In Iran And The World

Iran's and the world's watermills, which are more than thousands years old, are divided into three categories (Figure 3), depending on their types and functional system: Norse watermill, over-shot wheeled watermill, and floating or under-shot wheeled watermills (12).

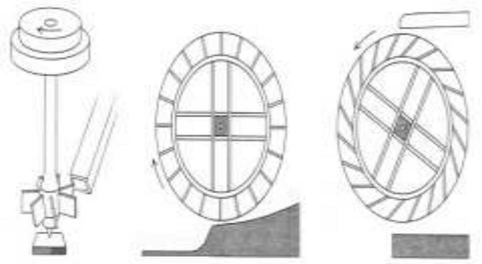

Figure 3 .Watermill designs in order to increase complexity and efficiency, Norse watermill (left), under-shot wheeled watermill (center), and over-shot wheeled watermill (right).

Source: *Reynolds, Terry S.1984. "Medieval Roots of the Industrial Revolution," Scientific American, July pp.122-130.*

Norse Watermill

Norse watermills have vertical axis, to which a number of spoon-like wheel paddles attached (Figure 4). Although some believe its invention to be done by the Greek, the first time that about their construction was discussed was for the palace of Mehrdad, one of the kings of Ashkanid dynasty in Asia Minor (13). According to Estera, this type of watermill reached China after third or fourth centuries and, probably, this transmission to China was done by an Iranian or a Greek in Occident (14). The name of this type of watermill is attributed to it on the basis of its operation. That is, this watermill has a vertical channel in its structure which transfers water from the above level to the bottom and is called Norse sluice. Water which, with pressure, exits from the channel outlet hits the wheel paddles. The wheel paddles rotate the vertical axis, whose end is connected to the millstone, and the millstone grinds the wheat. Norse and upper-shot wheeled watermills were used in the regions which had limited access to water. Generally, these watermills were designed for the shallow rivers, as they rotate with the fall of stream water (15).

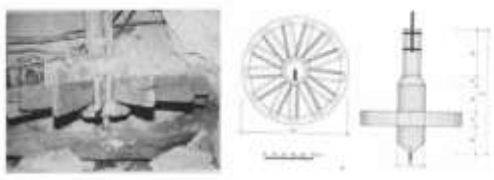

Figure 4. A sample of the turbine wheel of the Norse watermill in Iran

Source: ***Edelberg, Lennart and Schuyler Jones, 1979, Nuristan, Akademische Druck- u. Verlagsanstalt, Graz, Austria.***

Over-Shot Wheeled Watermill

An over-shot wheeled watermill has a horizontal axis, which turns to vertical axis by the gearbox. It is believed that it was invented by Romans in the first century BC (Figure 5) and was introduced to the world by Metroderus, an Iranian traveller, in fourth century AC (16).

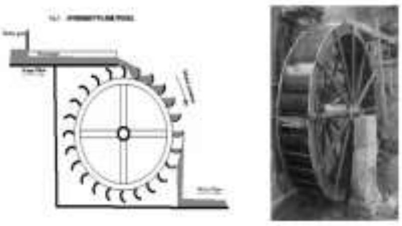

Figure 5. Montell Seely's Waterwheel in Castledale, Utah (2002) (right) and the details of operation (left)

Source: *Gies, Frances and Joseph, 1994. Cathedral, Forge, and Waterwheel: Technology and Invention in the Middle Ages, Harper Perennial, New York.*

Floating Or Under-Shot Wheeled Watermill

The difference between under-shot and over-shot wheeled watermills lies in the system of wheel movement or the wheel paddles and in the place of positioning the wheel. That is, over-shot wheeled watermills were usually built near the river (Figure 6) to be moved by river stream or they were moved by flume water, which fell on the wheel paddles. But floating watermill (as its name suggests) was built in the mid-stream and water moved under its paddles and hit them so that they rotate. Then, the produced energy of the paddles was, by two gearboxes, transmitted to the vertical axis via a horizontal axis. The movement of the vertical axis caused the rotation of the millstone and grinding the wheat. According to Procopius, the wheels of these mills were first developed by a Roman general in 574 (11a). However, nowhere but Dezful is reported to use this type of watermill. Floating watermills were built in flat regions with abundance water. In other words, not all the regions with river could build such watermills. They were designed in a way that they were resistant against the forceful and repeated beats of water flow and even against flood. Thus, the number of these watermills is very scarce and Khuzestan Province is the only place we can see such structures. These mills are designed in a ship-like form so that they can resist against the tides (17).

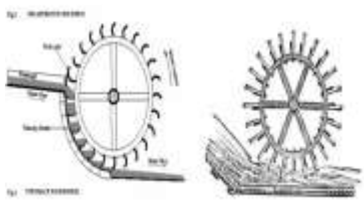

Figure 6. the details of operation of the under-shot wheeled watermill.

Source: *Gies, Frances and Joseph, 1994. Cathedral, Forge, and Waterwheel: Technology and Invention in the Middle Ages, Harper Perennial, New York.*

Architecture And Typology Of The Dezful Watermill

Dezful watermills are built in two floors (Figure 7), of which the first floor was the place for the installation and the second floor was the place for grinding the wheat. The border between the two rooms was a roof, made of wood and covered by thatch. The design of the wall was in a form that wooden lumbers, with 10 to 15 centimeters width and 200 centimeters length, were put in the wall from the two ends to 20 centimeters deep in the wall. Then, it was covered by cane and the canes were covered by thatch and cane leaf. At the end, they were all incrusted by a layer of mortar or lime (Figure 8). The mortar was troweled so that it becomes smooth and uniform on surface. After drying the mortar, a smooth and nonporous surface was produced for the wheat to be collected on.

Source: author

The wall façade, which formed the outer face of the structure, was made of brick, whose inside was filled with a mixture of mortar and bed river pebble which were abundantly available on the bed of the river. Sometimes, the outer façade was built with a blend of pebble and brick. This type of building administration was adopted from the style of Sasanid bridge construction in Dezful, which its remnants are visible under Dezful Bridge.

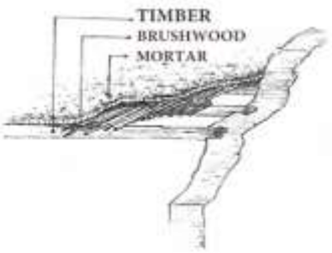

Figure 8. Detailed presentation of the wooden roof of the watermills

Source: author

Dezful watermills were designed in two forms: doublet (or single) watermill and pair watermills (Figure 9). Single watermills were the mills which had only one millstone to operate. That is, they had one single room, called single-stone. Pair watermills were the mills which had two rooms and were also called two-stone. The two rooms were separated from each other by a blade of brick wall. The general aspects of all of these watermills are the same, a two-floor structure with a ship-like nose (Figure 10).

All the watermills were connected to each other as well as the river bank by some bridges. With these bridges, people could carry their wheat, barley, or other grains by horse or other cattle to exchange with flour. The point is that the cattle were stopped near the dykes and, for the rest of the way, the packs of grains were carried by the workers, because the dyke paths were narrow and the cattle could not turn around on them (18). Dezful watermills were all constructed on the bed of Dez River, which has a conglomerate structure. The hydraulically powered structure on the Dez river bed is considered among the firmest conglomerate structure, which in rigidity is similar to concrete.

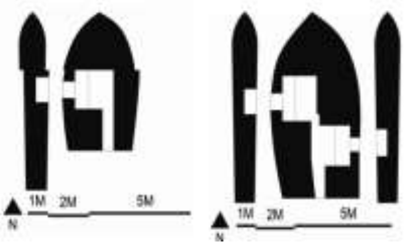

Figure 9. Dezful watermills were designed in two forms: single (right) or pair watermills (left).

Source: author

Figure 10. Facade of wave breaker (surfing) nose of Dezful watermills; the watermills of Dezful had a boat-like nose to resist against the formidable tide of Dez River.

Source: author

Building Materials

The materials, which were used in the structure of the watermills, should be very resistant against humidity and, therefore, were mostly river bed pebbles, brick, mortar and wood. The basis of the structure of these watermills is made of thatch, ash, and brick. The bricks are arranged in three rows and, in some parts, the basis is made of one row of stone. The walls of the structure are made of brick, river bed pebbles, and mortar. The brick sizes are about 7×24×24, 4×18×18, and 3×20×20 centimeters and their colors are yellow and red. The Soil of the brick was supplied from the mines around Dezful city and, then, was baked (Figure 12).

The method of constructing Dezful watermills was called *Sak*. In this method, to construct the wall, all around it was casted by building materials such as brick and mortar. Then, inside the area which was surrounded by brick and mortar, mortar was casted. At the same time river bed pebbles in a non-cast form (or floating) were thrown in it. As a result, the speed of administration of work picked up and a structure similar to the conglomerate structure of the river bed was formed (19).

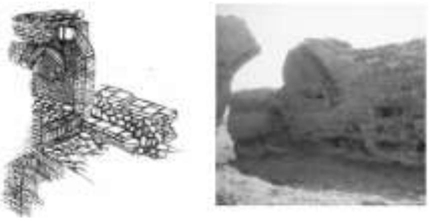

Figure 11. A detailed depiction of the Dezful watermill

Source: author

The outer crust of the walls and Dezful watermills, as was mentioned before, is usually made of brick, but in some parts a mixture of river bed pebble and brick was used. This unique style of wall building is derived from architecture of Sasanid period. The bases of this watermill-bridge, which are built in Sasanid style, can still be observed (Figure 11). To fill the curved parts of the structure, the pieces of crushed bricks were used rather than river bed pebble. This was specifically done to create a new style on the curved lines. All the watermills are in harmony in respect to their structure, construction, and appearance and they follow a certain type of architecture.

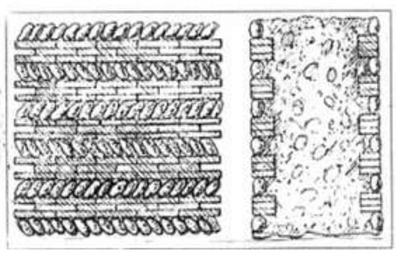

Figure 12. A profile of Sasanid bridge structure, which was used in constructing Dezful watermills in Dezful

Source: author

Water Mills Operation

Ground Floor

When water hits the nose of the watermill, it is redirected to the sluice gate. To control the entrance of water to the sluice, a lumber is placed on the sluice, which supplies water (Figure 13).

Figure 13. View of the watermill sluice gate (right), the plan sluice gate of watermill (center), profile of the watermill sluice gate (left)

Source: author.

When water enters the sluice, it is directed to the narrower side of the sluice and its pressure increases. With the slope that is created in the sluice, the water pressure still goes up more in its way to reach the wheel (Figure 14).

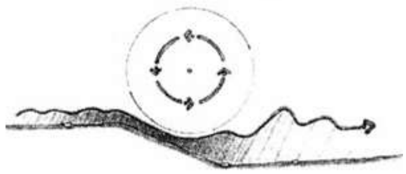

Figure 14. Depiction of increase of water pressure as well as the proportion of the wheel and sloped surface

Source: author.

When water hits the wheel paddles, the paddles rotate and the rotation energy is transmitted to the wooden axis (shaft) and thence *gorgor* and from there to duleh. Duleh transmits this energy to the vertical axis (upright shaft). Since the force is transmitted from bedstone and upright shaft passes through both bedstone and runner stone, it rotates the runner stone and, as a result, flour is produced by the rub of the two stones on each other (Figure 15).

All the above mentioned installation was made of wood. The point is that in fastening different elements of watermill no metal nail was used. Only, in some parts of shaft head in roller bearing, steel was used to decrease the friction and increase rigidity. As long as the installation was directly in contact with water, old methods and tricks were applied to fasten the elements together and make them firm. To strengthen the *gorgor* cogs, for instance, the same method applied to ax head was used. That is, before fitting the cogs on the rim of the *gorgor*, the cogs were covered by cloth. When the wood and cloth came into contact with water, they swell and their volumes doubled. Thus, despite water exerts pressure to the cogs, the cogs did not dislocate. In addition, in places such as the *gorgor* cogs, which should bear much pressure and friction, pear tree wood was used. Pear wood is a very resistant wood against water erosion.

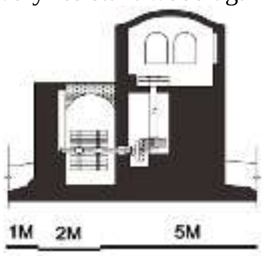

Figure 15. A profile of the watermill and the connection of the installation and *gorgor* room

Source: author

Inside the installation rooms, a reservoir-like space is contrived, in which water was probably collected so that the *gorgor* was in water at the time of its rotation. Water of *gorgor* reservoir was supplied by a branch of the sluice. In some watermills, another channel, in addition to the sluice, was built to take out additional water (Figure 16).

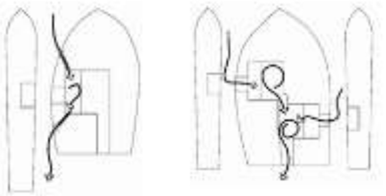

Figure 16. The rooms which redirect water to the watermills
Source: author

Making provision for the damage, done by river flood in fall seasons and entrance of water into installation room, a corridor was built in most of the installation rooms so that it could carry the flood water out of the rooms and prevent the installation from decaying. The bottom of the watermill sluice was covered by pavement to decrease the wear and tear of the sluice bottom and walls. With regard to the rise in the speed of water in sluice and movement of water on the sloping surface, it is necessary that water flow calms down in the sluice end to prevent the flow from damaging to the walls. To this end, in the space after the paddle wheel, the width of the sluice is increased gradually and, as a result, the water flow speed decreases. However, despite decreasing the speed of water flow, some of the elements such as gate are eroded. This is the result of flow of sluice water in the times of increasing the width of sluice. The space of lower floor is more than the upper and about 60 percent of it is occupied with the installation. The reason of filling the lower floor with more installation was to make the structure basis heavy, for the purpose of adding to the resistant of the building against the water pressure.

Upper Floor

The distance between the upper rooms and the river bed is about 4 meters and the upper rooms are built symmetrically. The watermills are built with a ship-like view (Figure 17). This style of architecture was used to decrease or increase water pressure. The upper floor, which is called watermill room, has 30 to 40 centimeters thick walls and is much lighter than the lower floor. The nose of the structure is thick, as it should tolerate the water flow pressure at the time of breaking the tides. As was mentioned before, lower floor was made of wooden timbers, cane, and thatch as well as mortar. The roof of the upper floor is made of mortar and brick in a cross-sectional form. It worth noting that to decrease pressure on the *gorgor* and duleh, the runner stone was built lighter than the bedstone so that it could rotate with little force.

Figure 17. The outer view of the ship foundation which is caulked with gypsum and mortar and filled with mortar
Source: author

The Function Of Watermills As Bridge In Dezful

Dezful watermills are located on a sedimentary and conglomerate bed of the river (12) and are extended on the width of the river successively (Figure 18). Today, the remnants of the watermills can be seen under New Bridge. The arrangement of the watermills was in a way that they act like a dam to direct the river flow to a certain direction. This structure was a Sasanid developed one, which made a cut on the first part of the river and was called dyke.

Figure 18. Bridge, Dezful watermills were extended on the width of the river successively.
Source: author.

In some cases, the connection path of old watermills turns to be a part of that of new structures on the river (the example of such phenomena is seen under the New Bridge of Dezful). By considering the seasonal operation of beside and inside river watermills as well as the extension of watermills to New Bridge and the status of the ruined part of the midstream watermills, we arrived at the conclusion that one of the main reasons of building such watermills was to create a path between the two banks of the river, specifically in the current locus of New Bridge. Regarding the fact that one of the main connection path between resident area and the existing watermills were founded alongside of New Bridge (Figure 19), the above mentioned probability increases. The creation of a raw of bridge-like watermills along New Bridge indicates that accounting the constructed watermills a connective path is sensible (13).

Figure 19. Bridge-watermill of Dezful, spread over the river width successively
Source: author.

Using the set of watermills as a bridge in the area of New Bridge because of the absence of bridge is also another proof for the above mentioned claim. By considering the point that the resident area and watermills of the town were beside the river, it can be said that the suitable path to access different areas and watermills was the surrounding area of New Bridge and Old Bridge. As there was no asphalt route, the watermills were constructed with mortar and river bed pebbles in the form of a narrow path alongside of the river in a way that the path was 1 to 1.5 meters above the ground level. This path became a track for the pass of the cattle and it ended in the river side. Keeping in mind the difference between the levels of river side and resident area, the main way to access this path was created via various sloping paths and stairways. Taking account of the old texture of the city, we can hypothesize that there was no main and always-used road and there were lots of access paths to the river side through the avenues and tracks of the old texture of the city (Figure 20).

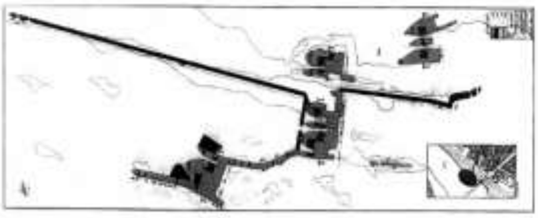

Figure 20. Watermill plans under Old Bridge.
Source: author

Method of Construction

Most of the watermills in Iran are of Norse type. However, there are some over-shot wheeled watermills and Dezful's watermills are of floating (or under-shot wheeled) type. Dezful's watermills are composed of the following parts:

1. Steel shaft
2. Wooden horizontal shaft
3. Wheel paddle
4. *Gorgor*
5. Gorgor cogs
6. Roller bearing
7. Dule
8. Upright shaft
9. bedstone
10. runner stone

Water enters the reservoir, in which wheel paddles and *gorgor* as well as other elements are located, via the sluice gate. Note that the place where the wheel is stored is called *slope* and where *gorgor* is kept is called reservoir. Water level should be about 70 to 80 meters (with the volume of 220 cubic meters) so that water can move the wheel (Figure 21).

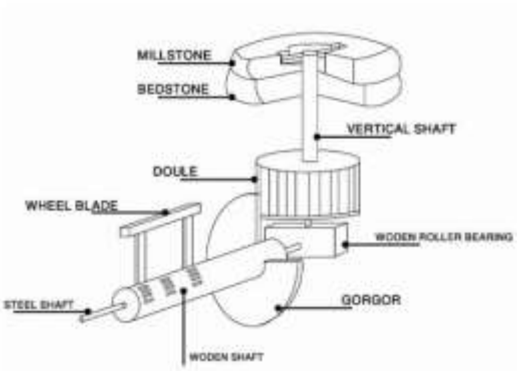

Figure 21. Details of the mechanical system of watermill
Source: author.

Watermill Wheel

The wheel is positioned in the opening of the reservoir, which is called *slope*. Water, when passes the sluice, hits the wheel with high pressure. As a result, it moves the wheel and, then, enters the reservoir. The movement of the wheel causes the rotation of other elements of the watermill. The wheel is made of lotus wood and has 16 paddles, which are pinned to each other by katal as well as ashkan, and are arranged in three rows. The length and width of the paddles is usually 90 and 80 centimeters. In the middle of the wheel, a horizontal shaft which is usually made of lotus or berry wood and is 45 centimeters thick is fixed up. The wood should be supplied from a lotus tree which is at least 80 to 90 years and 60 to 70 centimeters thick. The rationale for using lotus wood for the wheel and other elements of the watermill is its oldness and nativeness. The watermill wheel is built in a way that its surface area is changeable in size. That is, in summer (or at the time of water shortage), the vacant distance between the paddles is filled by another paddle. Depending on the wheel speed and water pressure, the vacant space between every other paddle or every two paddles is filled with some additional paddles so that the paddle surface area increases. As a result, the wheel is rotated with higher speed by the pressure of the water. When the water pressure was high, the additional paddles were not used. When the water pressure exceeded the allowable limit, two or three lumbers were placed in opening of the reservoir (or the slope) so that the pressure decreased and prevented the paddles to be damaged. Usually, the paddle surface area of the watermills inside Dezful city was less than that of outside the city, as the later included the paddle surface area of flutes Norse watermills. This was because water pressure for the watermills outside the city, which operated with the flute or well water, was very low. The surface area of the paddles of Dezful watermills was two palms but for that of outside the city was four palms. Hence, when the discharge of water decreased, the surface area of the paddle, by increasing the number of paddles, was increased so that the wheel could rotate with higher speed and could mill more wheat (Figure 22, 23).

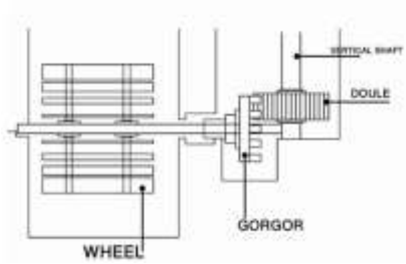

Figure 22. Detail of connection between main components of watermill, a profil of the instalation.
Source: author

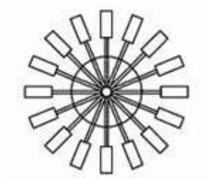

Figure 23. Façade of the wheel
Source: author.

GORGOR

Following the movement of the wheel, *gorgor* (Figure 21, 22) is moved by the rotation energy provided by the horizontal shaft, which is common between the wheel and *gorgor*. *Gorgor* is a type of wheel divided into four parts with 36 cogs on it. On each part, there are 9 cogs, which are made of apricot tree wood. All the four parts are connected, by four supports, to the horizontal shaft. To make the structure firmer, two wedges, which are connected to the horizontal shaft, are located on two sides of the supports. The diameter of each *gorgor* is 2.5 to 1.30 meters. The other side of *gorgor* is also cogged and a strip of wood, which was called *Pajar*, was inserted in between the cogs. *Pajar* is about 5 to 6 centimeters plank, which adds to the firmness of the cogs. On *gorgor*, a number of arches are located to strengthen its resistance.

When the wheel rotates by the water pressure and gorogr starts moving, the *gorgor* cogs (Figure 24) hit the dule rods and moves them. The reason why *gorgor* cogs (Figure 25) are made of apricot tree wood is that apricot wood, when is rubbed against any surface, spatters oil. That is, when the *gorgor* cogs which are made of apricot wood are rubbed against dule rods, they spatter oil. By the pass of time, not only the movement is not slowed down but also it becomes faster to hit the dule and rotate it.

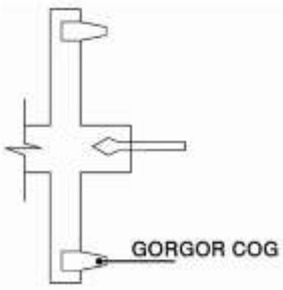

Figure 24.THE PROFILE OF GORGOR COG

Source: author.

Dule

Dule (Figure 21, 22) and its rods are made of wood. Each watermill system has a spare dule, as dule is broken after working for one or two weeks. Dule had six rods and a cylindrical spindle, which is called upright shaft, passes through it. One end of the upright shaft is connected to the bedstone and moves it and another end of it is connected to a prop and prop is attached to pushin and roller bearing.

In the place that upright shaft of dule is attached to pushin and roller bearing, or in other words on the top and bottom of prop, two wedges are placed. When coarser flour was intended to be used, a wedge was set on the top of the roller bearing or the same two wedges were hammered. They were hammered to raise the dule and to distance the bedstone from runner stone and, as a result, produce coarser flour. But if producing some finer flour was intended, the wedges below the roller bearing were lowered down so that the bedstone took nearer to the runner stone and, as a result, finer flour was produced. The miller should go to the lower floor to raise or move down the wedge and fix it.

The system of these watermills was used in different works and in various forms, from among which the primary models of transferring water system (such as *gavgard* and *shotor galu*) can be pointed out as a primary model and mechanical gearbox in the industrial machines as a modern model.

Millstone

Bearing in mind that big and firm stones were scarcely found in the region, people had to arrange small pieces of big stones near each other to build the millstone and put a metal belt around them. Then, the belt was fastened with two bolts. Another way to make a millstone was that a strap was filled with stone and mortar and, then, the surface of inside stones was rubbed so that they turned to a smooth and uniformed millstone.
With one turn of the water wheel, the millstone rotates for six times. The millstones were two stones, one on the other in an ardoun (a place where the flour, the result of milling the wheat, was poured firstly). The bedstone is fixed and covered by lime and clay. It is moved by an upright shaft, which was connected to the dule. The ardoun on which the stone is placed was made of wood, whose pores were filled with stone and lime. To prepare the millstone, a monolithic stone or some pieces of stones were circumscribed by an arch to make it firm. A hole was dug in the middle of the runner stone to take the wheat to the space between the two stones. The result of rubbing the two stones was the production of flour.

Wheat container and its board

Seven centimeters above the stone, there is a wheat container and its board. The board is located on a support, which is called *gachshen* and surrounds the stones in a semi-circle shape. First, the wheat is poured in the wheat container. The wheat container has a hole, from which the wheat passes and is directed toward hopper and, thence, to an eye. The eye is connected to the wheat container board by a cord. From the eye, the wheat pours into the stone hole. With the rotation of the stone, the wheat is ground to the flour. To regulate the wheat entrance to the stone hole, the shoe, which is connected to the cord, increased or decreased the eye slope. In this way, the amount of wheat which enters the eye is regulated. In dry seasons, some temporary dykes were built with a number of big wooden wheat containers, called *Chusala*. Then, they were filled with stones so that they could stop the flow of water and direct it to the watermills. When the river flow was decreased in the river bed, a sluice was created to direct river water into the river bed so that more water could flow in the watermills.

To heighten water level of the river, some wooden-made dykes, branches of the trees, or stone-made and basket-like dykes were put, like a wall, in sluice gate. Also, a conduit was extended from inside the river to upstream so that the river flow was deviated toward the watermills. Then, the dykes (or wheat containers) were filled with river bed pebble and fitted in a specific place. Every year, these temporary deviator dykes were ruined by the flood and the next year were built again in the seasons with water shortage. In fact, the wheat container was composed of three or four lumbers (with about two meters length), which were fastened together and filled with river bed pebbles so that it became heavy and went down on the river bed. Wheat container wood was usually obtained from lotus trees, as this type of tree is one of the oldest and native ones in Khuzestan. In winter, the inside watermills went down under river water and the miller had to leave these watermills and go to the river side watermills. Except for the wheel and *gorgor*, the miller carries other light tools of the watermills with him to the river side watermills and, then, he started to work in the new mills. In winter or any time that the inside river watermills were not operated, three lumbers were mounted vertically on a horizontal board, to act as a watermill sluice gate, so that the reservoir opening was closed. Sometimes, matting was used instead of those three lumbers and it did what the lumber could do. Despite all these facilities, sometimes the water flow broke the lumbers and damaged the wheel severely. That is, when level of river water raised and the watermills were not operated, the wheel and *gorgor* were, by a string of rope, lifted to 70 to 80 centimeters above ground so that they could stay away from the water pressure and being damaged. However, this practice was not commonly applied to the wheel and *gorgor*. In past, to raise the water level and redirect it toward the watermills in the dry seasons, some matting baskets were put on each other. These baskets were filled with stones and formed a deviator dyke, called *chusale*.

Example of watermill

Ra'na watermill

Next to Golegole watermills and near the place that is today called concrete New Bridge in Dezful, a row of numerous Roman arches as well as stone and mortar walls with 1.30 to 1.70 meters thickness, small and big mouths, and half-ruined rooms is observed. They are built in the river width and a wall with 150 meters circumference is built round the north side of the river. This wall is attached to another wall with 15 small bridges inside from the left end and is dived into four separate parts from the right end. These four parts are 3 meters far from each other. The north view of the foundation is like a ship prow and some rooms and sluice gates can be seen on it. Each room has two sluices, each connected to a hole, with narrow and wide parts in its inside.

The outer view of the foundation is caulked with gypsum and mortar and filled with mortar. Some holes and stairways are seen on it. The rooms are four meters above the river bed and some divisions in the form of stairway and symmetric vertical and horizontal holes can be seen in them. It indicates that these four parts and two other parts, which were connected to that four, are completely destroyed on one side of the whole structure. The same layout is built on the other side of the structure and occupied the width of the river. This type of structure building was transmitted to China in fourth century AD and the transmission seems to be done by Iranians or Greeks in Occident.

From the remnants of the ruined foundation and walls, it seems that the old installation, reservoirs, and sluices were used to upraise the water level, control water pressure, regulate the volume of needed water, directing water to the east or west side of the river, and water the farms. In the middle of the two arms (two sides of the structure), some parts of thick and arched dykes are remained. At the back of these two arms and next to a circumscribed area that is similar to a big pool and occupies about 35 meters of the width of the river, a big lake is formed. In the north side of the river, this lake categorized the river into four sections. In each section, a big pool is built and water pours into the pool from each section, which had six openings. In each arm 24 openings and, thus, in the two arms 48 openings were built. Therefore, there were 64 openings to direct water to the pools of north and south sides of the installation. At the back of the north side of the structure, three separate parts of the rooms are partly destroyed, which are like those found in the upstream of the river. The roof of these three rooms, which are like the ship roof, can be yet seen. From inside the rooms to the river bed, there are remnants of the structures of controlling water and the gates, which are like those found in the upstream of the river.

Different parts of the north and south dykes, which circumscribe the middle reservoir, are arranged in a way that the rejuvenated water flow can easily pass different surfaces and enter the sluices without any damage to the set-back and indentations of the sluice and without changing the angle. Then, it can simply contact with the body of south dyke and get out of there. Therefore, from the frequent and calculated angle changing, which is made in the path of water entrance to and exit from the sluice gate, we came to a conclusion that the pressure and volume of water were calculated by and were known to the builder of these structures and, in this way, the walls and dykes were protected against damaging. In the middle of north side, which is on the gate, a giant structure is remained which is curved and porch-like with Sasanid style. Remembering that these structures are located in the middle of the river and next to a lake, the Sasanid emperors were interested in the places near rivers and lakes to dwell, and some of them were buried near such places, and they carved their images on the stones near lake, we might say that these remained structures near lake are left from a small palace where an emperor stayed for a while or passed a few time in. In fact, it seems that on the middle of this watermill wide surface, which has view to north and south and has no path to be accessed but the dyke, there was a palace in which a general or a member of royal family lived. On the east and west sides of this giant structure and to about 400 meters away, which is next to Metal Bridge of Dezful, some old buildings can be seen. It seems that the function of these buildings were to stop the sudden fall in the height of water level and its flow out of pool. A number of devices were built on this part so that the deep pool and its warm water flow can be a place for jaunting and amusing, shipping, etc.

The water level in this pool came up in a way that building another set of installation to divide water path branches and to direct the conduits in order to control water pressure and volume in about seven hundred meters away from the south of that structure was deemed necessary. Therefore, such installation was built and its remnants from that era can be observed in the neighborhood of Metal Bridge of Dezful. Foundation and some parts of openings which are built on Ra'na watermills indicate that a bridge was built for people to pass and there were some guards who had houses to live in these sections of the watermill. The ruined remnants of this structure are seen on the east, near Metal Bridge.

From the whole system, with all its innovations in pressure breaking, opening, dam crowns, arches, rooms, dykes, and diagonal lines for inhibiting the tidal flow, some ruined parts are remained which occupies the width of the river. It has some conduits, which branched from east and west of the river to water Dezful city and the farms all around the city. Doubtless, milling the wheat was not the only usage of watermills. In fact, the set of watermills act like a dyke, which by the pass of time has been decayed. Over time, new watermills were built on the ruined parts of the old watermills. In other words, the foundation, walls, holes, and sluices of the ruined watermills were used for the new watermills. By investigating the watermills which were built by men and the repairs which were made on them, we might say that the last repairs were made on Safavid period. The reason for claiming this point is that the size of the watermill bricks is the same size of brick which was used in Safivid period, 18.5×18.5×3.5 centimeters.

Figure 25. Ra'na watermills.

Source: author.

Koli watermills

Today, Ali Koli brook, on which the watermills were built, is dry. Interior buildings of the structure of watermill indicate the elegancy and delicacy in their construction, room designing, and earrings-like style of the structure. There is no building or wall surrounding the structure. The sizes of structure bricks, which are very old, are 17×17×3.5 centimeters. In some parts of the structure, ionized bricks are used. Interior parts and rooms include two or three floors, which are made of adobe and are covered by thatch and the whole structure is 6.10 meters wide and 13.7 meters long. There is a sluice, made of brick and mortar, in northwest of the structure.

Golagole watermills of upstream and downstream, located in the north of the upstream river (called Alikale), are the oldest watermills of the city. The bases of these watermills are made of the arrangement of gypsum, ash, and three rows of brick, while some parts of it are made of stones. The walls are made of river bed pebbles and brick and, in some places, mortar.

Abas Abad watermills

This brick-made and rectangular-form structure is constructed in a good and organized style. Inside the structure, a building is made of clay and adobe, from which some parts of arches, rooms, and walls are remained. On the west side of the structure, a tableau of brick and mortar is built that direct water into the watermill. The bigness of the structure and its organized façade as well as its uniformity are the signs of a great culture. Such an excellent cultural heritage is a prerequisite for building any unique structure. These structures, with 15×9 meters width and length, satisfied one of the daily demands of the people of that era. On the east side of the structure, there is a brick baking forge, with a curved arch made of brick and adobe, which has some similarities with the ruined watermill. It may be stated that the forge was exclusively established to bake the brick, which was necessary to build the watermill.

Shams Abad watermills

This watermill is made of brick, like Ali Koli and Abbas Abad. It has two or three floors, some rooms, and a tableau of water is on the west side of the structure. On this watermill, some repairs, with brick and clay, are made. Most part of bricking of the outer view of the structure is now destroyed. The sizes of the old bricks on the south view are 30×30×6.5 centimeters and those of the new bricks are 17×17×2.5 centimeters. The older brick are red and yellowish white, like the famous *khotaei* bricks. On the south side of the structure, an arcade sluice is constructed to pass additional water. The arch curvedness was less convex and more concaved, in comparison with Ali Koli and Abbas Abad watermills. The outside dimensions of the structure are 16×7 meters.

Conclusion

Theory 1: these mills were built with the purpose of milling from about 1700 years ago, but with the pass of time they broke down. Some of them were reconstructed and some other left untouched until 1968 and became completely idle.

Theory 2: the structures that we call watermill did not function as watermill from the beginning. From the archaeological point of view, when they were exploited at about 1400 to 1500 years ago, they were not only dykes which connected the two sides of the river but also regulator dams that could impound water to be later used to water the farms. However, as their structures were suitable to mill, the theory of using them as the mills cannot be easily rejected. In archaeologists' ideas, these structures were rebuilt in Safavid period and operated as watermill. In other words, they were gigantic dykes which, after making a few changes, turned to mills. Over time, some changes were made on them by the floods and other environmental factors. Their last changes are considered to be made in Safavid period, with the evolution of brick. At that time, the dimensions of their bricks turned to be 18.5×18.5×3.5 centimeters.

These sets of installation, with their complex and well-aimed design, breakwater, large walls, openings, and depressurizing tools, were constructed on the river and took river water to the surrounding pastures and farms. They could not be some simple mills, which only milled the wheat. It might be discussed that they were the structures with some special purposes whose functions were changed to milling. We might even claim that, a few years later, the mills were built on the foundation of these structures.

Regarding the two theories and according to the conducted studies, we might discuss about the multipurpose design of this installation. That is, this set of installation was used to both direct the river and function as a dyke and mill, in Sasanid period. Additionally, it was used a as playground and stay place for Sasanid commanders, as the number of milldams and the pressure of the river flow could be controlled and people could swim or boat in the river. On the other hand, two capitals of the Sasanid dynasty were Fars and Tisfoun. The link between these two capitals was established through Kohgiluye, Bakhtiari, Ranhiroz, Shoushtar, and Dezful towns, Karkhe River, and most probably Dezful dyke. It might be claimed that the whole set was a dyke, which was built with much care and delicacy to increase the level of water behind the dyke, help the pass of the missions, water the farms, and serve as a stay and entertaining place for the commanders. In other words, it was a military path, which was also used as a place for taking rest and relaxing. We can even say that the whole set and the rotation of the mill wheels was a part of facilities for the Sasanid troops. In the openings, there are traces of a magnificent arch. Remembering the Sasanid kings' interests in this type of structure, we conjecture that it was a living place for a commander or a great man of that era.

Dispensed with the function of such structure, about which the technology of building by people of that time with that limited knowledge is questionable, what is significant is great resistance of these watermills against the flow of one of the biggest rivers in the country. To sum up, it is evident that this structure, dating back to 1400 years ago, is still firm. Its imperishability can be attributed to the engineering powerful theories of the builders of that era. They used nose-like structures in front of the whole structure so that it can act like a ship prow to cut water flow and prevent it from destroying the structure. The other cogitative technique was the use of mortar, as one of the toughest building material, to build the structure. Also, mortar, in comparison with concrete, could better increase the resistance of these structures against water flow.

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