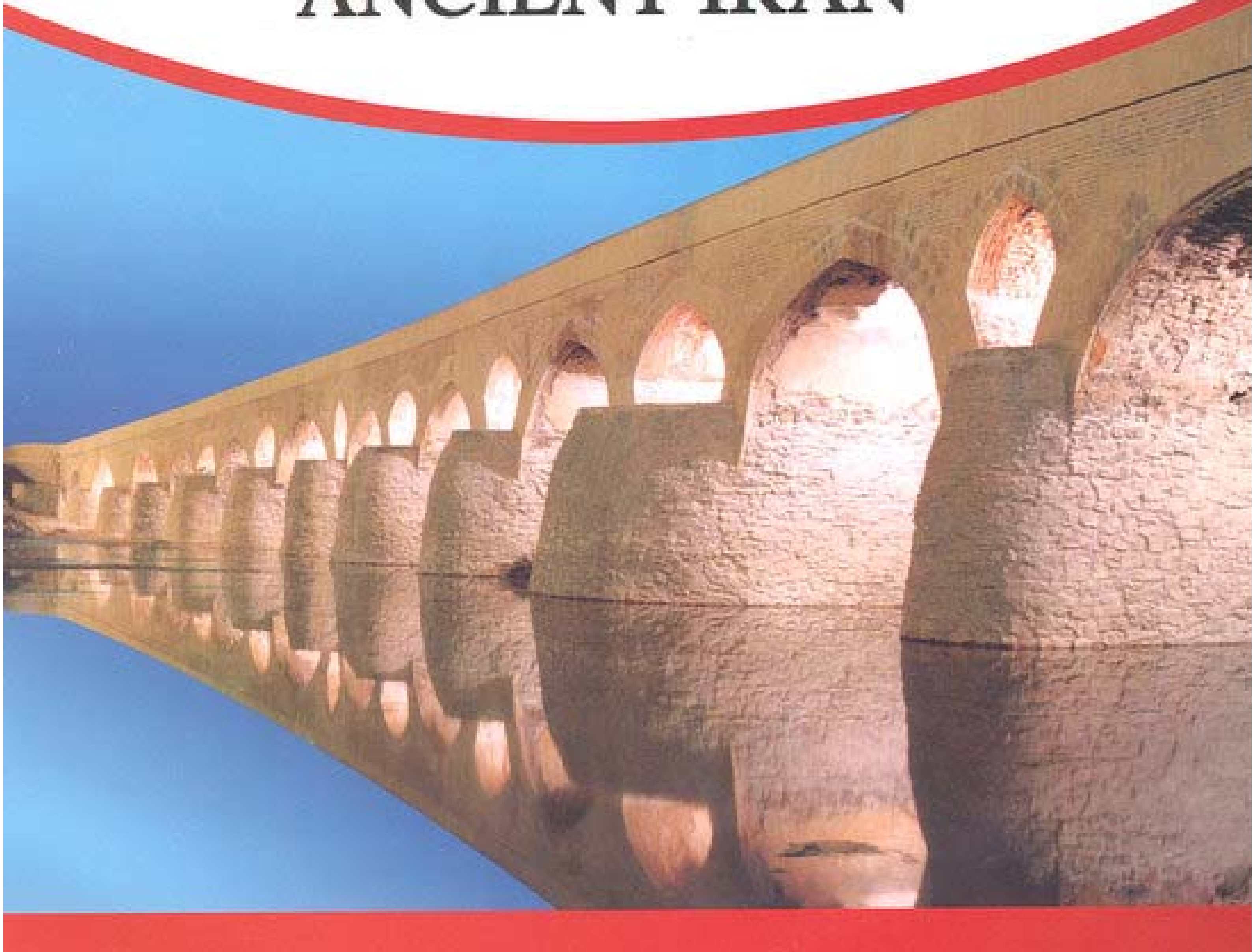
WATER AND IRRIGATION TECHNIQUES IN ANCIENT IRAN



IRANIAN NATIONAL COMMITTEE ON IRRIGATION AND DRAINAGE (IRNCID)

May 2007

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IN

ANCIENT IRAN

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WATER AND IRRIGATION TECHNIQUES
IN
ANCIENT IRAN

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PREAMBLE

Water scarcity, as well as, insufficient precipitation in our country has made the responsible Iranians challenge the technical, institutional, environmental, and social issues to establish sustainable water and Irrigation development and management in arid and semi-arid regions of Iran.

Indeed, the history of water supply, Irrigation, and drainage in Iran reveals how the relevant structures have played their important roles in forming, flourishing and development of civilizations.

There are over 30,000 ancient, Qanats, as well as, thousands of water structures such as weirs, benchings, bed groins, water reservoirs, water-mills, traditional baths, etc many of which are still under operation.

Water and Irrigation Techniques of Iranian in ancient time and the relevant services to the nation are admirable. Analyzing their experiences,we realize how the civilization of Ancient Iran affected on the civilization of the other nations and on the modern sciences & technologies.

Of course, we shouldn’t expect the old and new ideas to be the same, as the basis of modern sciences and technology lies on broad and extensive investigations and experiences of all the developed nations during the recent centuries. Comparing the old sciences with the new ones, we respect and are proud of our ancestors, because they solved their difficulties without having the present facilities and equipment.

I really appreciate Mr. Mahmoud Meschi & Mr. Majid Labbaf Khaneiki for the translation, as well as, I am thankful to Mr. Mehrzad Ehsani & Mr. Enayat Sabeti for the arrangement and publication of this priceless work.

Dr. R. Zargar
Deputy Minister for Water Affairs, and
Seminar Organizing Committee, Chairman

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CHAPTER ONE

THE STRATEGIC STRUCTURES

In the era of Achaemenian, the Imperial Government of Iran extended from Black sea and Mediterranean to Persian Gulf, Indus Rivers and Caspian Sea. And the people of those lands were the sovereignty of Iranian government.

Obviously, in such an extensive territory there were many military expeditions in order to suppress opponents and rebels. Those events have been written down in the texts of civilization history of middle and Near East. Besides the roads and bridges, which aren't mentioned here in order to summarize the words, some of the Iranian military expeditions had some marine strategy aspects, which are mentioned in brief as the following:

1-1- BABYLONIA FALL, CAUSED BY AN STRATEGIC WATER STRUCTURE

Cyrus The Great was the founder of Iran extensive imperial and the progenitor of Achaemenian. During Cyrus monarchy, Iranian civil and military affairs were unique and the army was the strongest one in those days.

The Kings of Babylonia, Syria and Egypt were trying to stop the progression of young Iranian imperium, and united against Cyrus. But the Iranian army defeated them at last. Occupying Syria and Asia Minor, Cyrus moved toward his major enemy, the Government of Babylonia and surrounded their city, which had very strong towers and seemed unconquerable. The city was located near the Euphrates River and Bagdad.

After surrounding, Iranian army's engineers excavated a diversion canal to divert the river. The Babylonia's guards watched the Iranian and made fun of them. One night when the people of Babylonia celebrated one of their religious festivals and were drunk and dancing in the streets, the army diverted the river through the new pass. Consequently, the water level in the Euphrates dropped and soldiers crossed the river and occupied the city. And Babylonia Government was over-thrown.

It has been stated in old testament during that night, Belsazar, the king of Babylonia and his guests were drinking wine in golden holy cups which they had stolen from Jerusalem temple.

Suddenly they saw some beam of lights on the walls of the hall, nobody could read the writings, but Belsazar was killed that night.

Heinrich Heine, the famous German poet described the celebration in a satirical poem. So the fall of Babylonia which was impossible by land; the victory came true by the engineers and experts thought and genius.

The victory caused that Cyrus The Great issued the famous charter of Jews' freedom and since then the name of the Imperial Majesty was recorded as a philanthropist in the history.

1-2- WATERWAY BETWEEN RED SEA AND MEDITERRANEAN SEA

After Cyrus The Great, his successors were his son Cambyses (529 to 522 BC), Usurper Gaumata and finally Darius The Great (523 to 486 BC) who ruled in Iran Empire. Darius The Great ordered to connect the Red Sea to Mediterranean Sea by a canal. He decided to complete the project by the year of 517 BC. Unfortunately, he was compelled to leave Egypt in order to vanquish the rebels, so he couldn't succeed in this huge historical project. As mentioned before, the reason why he couldn't complete the project wasn't the lack of technical ability. In fact, there were many other duties in the country, which caused him not to follow the aim.

But it should be remarked that the idea of excavation the Suez Canal was taken from his thought. When Cape of Good Hope was discovered as a waterway from Europe to India in 1498 AD, the thought of the Suez Canal between Red Sea and Mediterranean Sea came to a new and serious era. The excavation of the project got more serious by German philosopher Leibnity, Napoleon The Great and Meternikh the famous commander (1848 AD). Finally, this great project was designed and executed by Negrellis and supervising of F. Lessep during the years of 1859 to 1869 AD. It was inaugurated on Nov. 17th. 1869.

1-3-XERXES' SHIPPING CANAL IN AKTE PENINSULA

After Darius The Great, his son Xerxes became the king. In the early years of his ruling, he had to suppress those rebels who stood against his father just before his death. Then he made himself ready to fight against Greeks. Xerxes arranged a huge army and crossed Hellespont Strait. Many warships escorted the King.

Xerxes military attack to Greece was quite technical and well prepared. There were two important technical points which should be mentioned. One of them was the excavation of Xerxes' canal in order to pass the warships which was done as follow, First of all, it is necessary to give a brief explanation about Chaldikiki Peninsulas. Chaldikiki Peninsulas formed from three large peninsulas which were projected out into Aegean Sea and connected with the mainland of Greece. The most eastern ones were Akte Peninsula and Athos Peninsula were located at the lowest part of it (fig.1)

After crossing the Hellespont Strait, Xerxes had to pass from marginal part of Athos Peninsula. As the Aegean's storms were very strong, Xerxexs' warships became entangled in passing through. So the technical consultants suggested to excavate a canal at the lowest part of Athos Peninsula, so that the ships could pass through, instead of going through dangerous Aegean Sea.

The detail of this Iranian huge technical activity in Greece will be mentioned as follow:

It is better to remark the historical narrative at first. Herodotus declared"… Iranian drew a straight line on the ground near Sane and each end was given to a tribe to excavate. Some bodies were standing at the bottom and digging the ground. Some other people, handed the dug soil to some other groups.

Those people who were standing at the top of the ladders picked the soil and transferred it to the workers who were standing on the ground and spreading around the canal.

Except Phoenician tribes, other groups had to work twice in excavating because the edge of the canal they were digging would collapse all the time.

The reason was, that they chose the width at the top as wide as the bottom. Phoenician showed their skill here as well. They chose the width of canal twice at the top in respect to the bottom, As they dug down reducing the width, they reached the bed of the canal, it had the same width as the other parts of canal had."

Fallmerayer mentioned in his incomplete works about East, referring to some other historians' mote and put some doubts about Herodotus' statements about Xerxes' canal, because there was not any sign of the canal at that time. They thought it was not possible to execute such a huge work with those primitive tools at that time. However, it is not right to neglect the Xerxes' canal and eliminate it from pages of history.

Besides the Herodotus' report, there was another historian named Thukydides (460 BC) who described the Ploponz Battles. He brought out the following report in his history book, volume 4,"… during that winter, Magerer conquered their own ling walls which were defeated by Athenian before. After occupying Amphibolis by Brasidas, he moved toward Akte in company with his allies. Akte was the land beyond the Iranian's canal located near tall mount Athos, which was projected out into the sea. Sane was one of the cities belonged to Andries, near the canal.

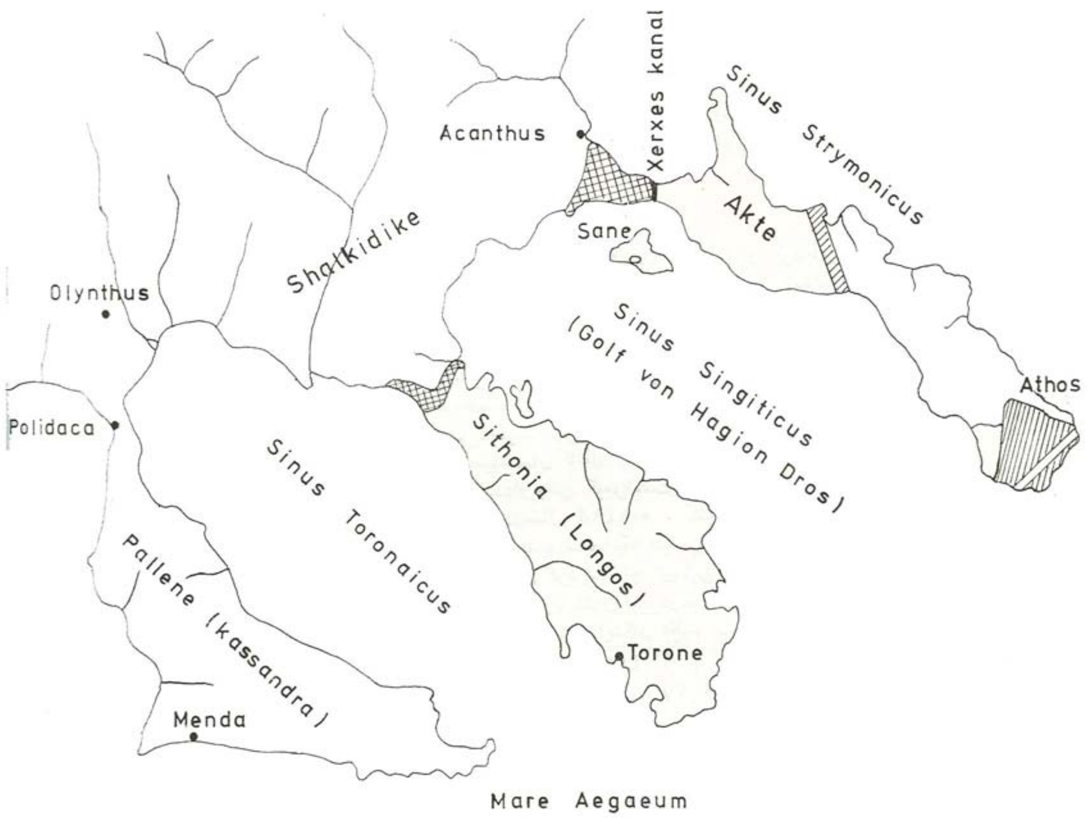


Fig 1, Athos Peninsula and the Situation of Xerxes' canal in Greece

It should be notified that Thukydides born in 460 BC, 20 years after Xerxes military expedition. He died in 400 BC. So during his life the memory of Iran and Greece battles were still alive and people remembered them.

Thus, those ideas mentioned about lack of technical ability can't be right, because there are many documents about the Iranian ability in irrigation and water structures services in the past.

In fig. 2 the imaginary dimensions of Xerxes' canal brought out according to the historical reports and the history of ship manufacturing in the past. It is not necessary to go through the detail of canals cross-section drawings, because the details were mentioned in an article by A. Birk.

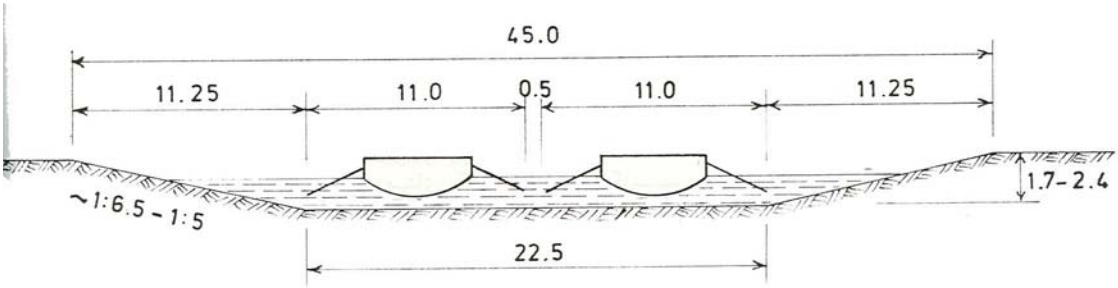


Fig 2. The cross-section of Xerxes' canal in Greece with 2 rows of warships

1-4- BRIDGE OVER HELLESPONT STRAIT

the second important technical work of Xerxes' experts, for military purposes was a bridge constructed over the Hellespont strait.

In fact, Hellespont is the Greece name of Bosphorus or Dardanelles Strait. As there was a state by the same name in the past, Herodotus explained in detail about the construction of a bridge over Hellespont Strait in his history book. The highlights mentioned below, had taken from his explanation. According to Herodotus' opinion, doing such an important technical affair was very great and considerable.

There were about 700 ships in 3 to 50 rows, which stood beside each other. 380 ships on the Euxenos side and 340 ones on the other side. The ships were fixed by anchors and tied up with thick and strong ropes to one another.

They covered the ships with lumbers and spreaded earth on them. Some of the historians believed it had been exaggerated about the number of the ships. On the other hand, the strait between Sestos and Abydos Cities had the least width about 1200 meters. If the average width of each ship assumed 3 to 5 meters, the figures show the number of ships at the narrowest section of the strait would be 340 in one row and 700 in two rows.

The schedule for bridge construction over Hellsport Strait and Xerxes' canal excavation had been studied by Iranian for many years and they had done all the measurements and provided all the necessary facilities for ship manufacturing, ropes etc… (fig 3).

As it was mentioned about the canal excavation, these kinds of activities were handed to different tribes that were living under sovereignty of Iran.

According to some narratives, the bridge construction over Hellesport was handed to Harpalos, who was from Ironi. He was known as an expert by historian. Besides there were some Iranian engineers like Bubares, the son of Magabusus and Artachaes the son of Artaus who worked on the bridge.

Unfortunately, all the references about Iranian services in the past were taken from Greece sources, because most of the Iranian documents went to fire many times and were destroyed.

So, it is possible that the Greece historians brought out the events spitefully and didn't tell the truth.

As the ideas and thought of Darius The Great about a canal between Mediterranean Sea and Red Sea (Suez Canal), the construction of a bridge over Dardanells strait had been started, it didn't take long this great historical thought of Iranian came to reality as well and went under operation.

MOAT EXCAVATION AS A STRATEGIC EFFORT

The old people remember the moats, which were excavated around Tehran. Moat means a wide ditch, which is excavated around a city or a castle in order to prevent enemies entry, or flood damages.

Defensive moats were designed and constructed by Salmaan Farsi, an Iranian companion of Islam prophet, for the first time. He was the first Iranian who accepted Islam and he became one of the trusted close companions of Mohammad…

According to records which were mentioned before, Iranian had used water structures and canals for military purposes. And there is no doubt Salmaan who lived 1390 years ago, knew the history of his country and the technical facilities which had been used before for military expeditions much better than us.

One of the important battles, which made clear the fate of universal movement of Islam was the battle of Moat. As you know in the year 3 A. H. The Ohod battle took place, because the Ghoraish tribe wanted to recover the defeat of Badr battle and took revenge from Moslems. The Ghoraish tribes were three thousands and Mohammad companions were seven hundreds who participated in Badr battle, the result of this battle, the companions were defeated.

After the Badr battle some Moslems apostatized and joined the Ghoraish tribe. In the year 4 A.H. Moslems were informed that the Ghoraish army intended to attack Medina once more.

They got worried because they were few and didn't have enough weapons. So Mohammad and his companions got benefit from Salmaan's thought and knowledge and agreed to dig a moat around Medina. They finished the job in 14 days. So Ghoraish couldn't cross the moat and their slings were useless. They decided to duel. Finally Abosofian and his followers had to return.

Perhaps moat construction around castles and cities in Iran and Europe were imitated from Salmaan's thoughts during Middle Ages.

If there was enough water, they would fill it up with water and install a bridge in front of the gate. During the night and dangers, they pulled up the bridge and cut the route.

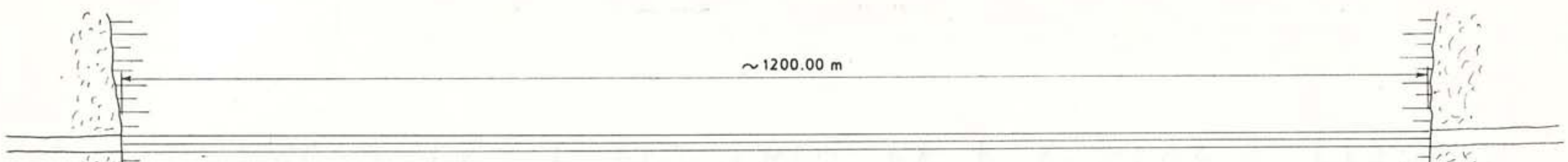
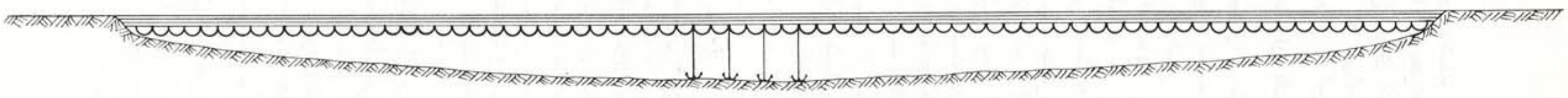
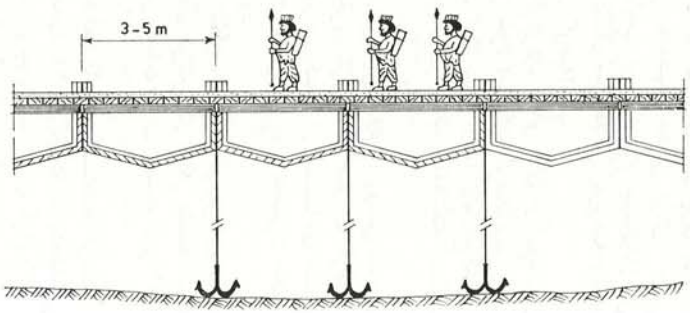


Fig 3, Xerxes' Bridge over Bosphoraus strait (Hillespont) according to Herodotus about military expedition of xerxes to Greece



Longitudinal profile of Bridge and the arrangement of Iranian warships



The detail of substructure of the Bridge made of warships and the arrangement of Lumbers

CHAPTER TWO

SMALL AND LARGE WATER STORAGE TANKS IN ANCIENT IRAN

Most of the rivers in Iran are seasonal because of irregularity and lack of rainfall. In most places, there aren't even any rivers and seldom does it rain there.

Our ancestors faced this natural phenomenon and tried to find a way out, called "Economic water storage."

There were two types of Economic water storages in our country:

2-1- DOMESTIC WATER STORAGE TANKS

Before establishing pipeline water distribution system, there were two separate water tanks in every house, one for drinking water and the other one for gardening. There are many people who still remember those and perhaps some types exist so far.

Drinking water storage tanks were generally sealed and they were very careful during construction and made them water tight with concrete. They took water by a tap, which installed some how above the tank floor.

Supplying water for storage it was a decorative structure.

Domestic storage tanks were recharged with water from rivers, infiltration galleries, springs and sometimes rain during the weeks. This type of water supply is still common in some villages, which have no pipeline water distribution system yet.

2-2- LARGE WATER STORAGE TANKS IN DESERT OR VILLAGES.

There were some covered tanks with considerable capacity for caravans, villages or old palaces in desert, dry plains, hot and dry regions in the south of the country. Most of these tanks have been destroyed but some of them are still usable. The structures of these tanks are very interesting for the passengers.

These tanks are cylindrical and buried under ground. At the top of the tanks, there is conical ceiling with ventilator at the center. Sometimes they installed a number of ventilators around the top as air traps.

For taking water, there were stairs extended as far as the floor of the tank. The taps installed just above the floor. The width of stairs was somehow the people with pail, bucket, jar or water skin could pass each other very conveniently.

They usually installed 2 or 3 taps for taking water. It is not necessary to describe the structure of air- traps, which could be seen in the central cities, especially in Kashan and Yazd. But it should be mentioned that the operation of these air- traps were somehow that those large water storage tanks were ventilated well and water got cool enough even in the hot days of the summer.

There were many of those water storages at the edge of desert and caravan roads. Some of those small desert tanks didn't have any taps. The structure of those tanks as mentioned above, are very interesting. The lower section had a cylindrical shell and the top had a conical one (fig 4).

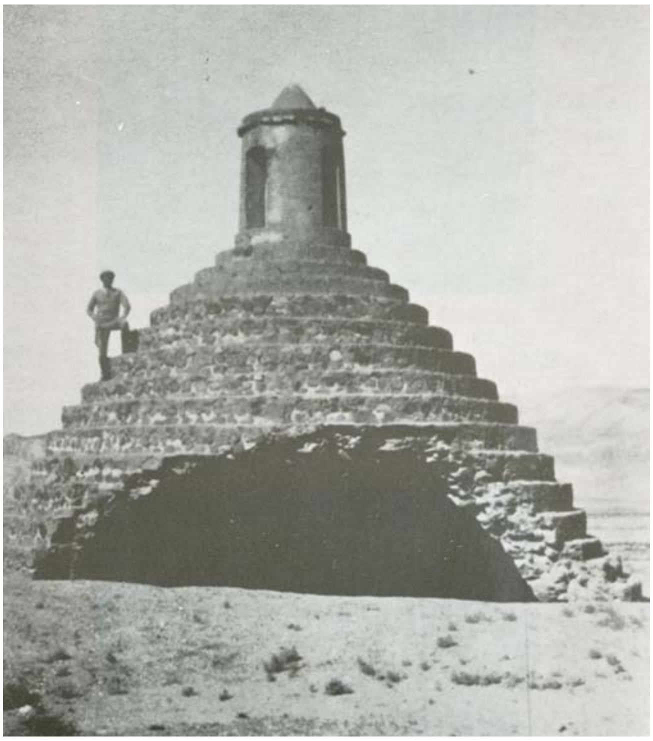


Fig 4, Ruined water storage tank in desert with air – traps at the center of conical ceiling

The capacity of this kind of water tanks could be about 300 to 3000 M^3 (the diameter of cylinder could be up to 20 meters. If the depth assumed 10 meters, the max. capacity would be 3000 M^3).

In some regions the water tanks had higher capacity up to 100000 M^3.The construction of these kinds of cylindrical water tanks without pillars were impossible. So they had to construct the middle pillars in one or more rows to support dome and the barrel shaped ceiling (fig 5,6).

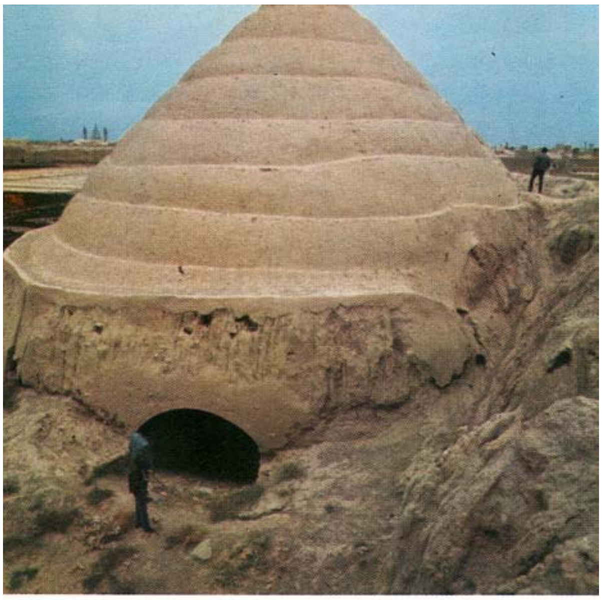
There are many - ruined store in the country, which look like conical water storage tanks, used for ice storage. They called them "ice – house". They supplied ice for the residents of the cities and villages nearby in hot days of summer in the past.

The procedure for ice making was very interesting. Beyond tall walls, they leveled a piece of land and let the water cover the whole land to a certain depth during the cold nights of winter to freeze. The purpose of tall walls was to protect the ice land from sunshine during the day. Then they added water every night, but the depth of water should not be more than a few centimeters each night. So icemakers had to level the ice land very carefully. When the thickness of ice became to 30 to 40 cm. Then they broke the ice to pieces and stored them in the cylindrical storages.

They dug some wells in the floor of store to drain water during the hot season. They scattered straw over the ice pieces to prevent them from sticking to each other. This type of ice store had two passageways for storing and evacuating (fig 7,8).

Fig 5, A caravanserai and two dome shaped water tanks which were supplied by Konar Dam

Fig 6, A large water storage tank with air traps near desert. The tap is on the left side



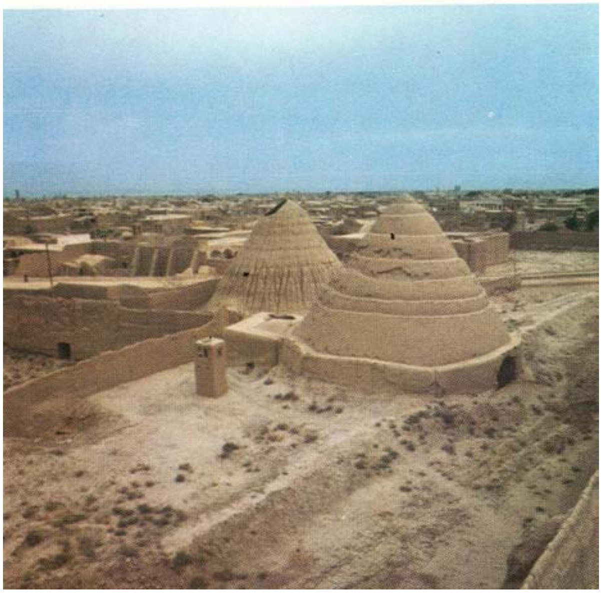


Fig 7 & 8, Old ice houses, made of
sun – dried bricks in Kashan

CHAPTER THREE

RIVER CONTROLLING AND THE METHOD OF DISTRIBUTING AND USING WATER POWER IN ANCIENT IRAN

3-1- RIVER CONTROLLING AND CANALS CONSTRUCTING IN ANCIENT IRAN

3-1-1- KHOZESTAN PROVINCE

As the historians wrote down, the civilization of ancient Iran were mostly located in the south (Fars province) and south west (Khozestan province). There were a number of dams in the south of Iran which are still existed. There is no doubt about their roles in the development of the south. While the rivers in the south have moderate discharges, Karoon River has been the largest one in Iran. There are many remains of ancient Iran civilization around this river.

Khozestan had been the store of grain and the land of sugar cane and it was very famous in the world. Although the execution of new dams, land leveling and providing modern irrigation networks cause some of those old water structures to be ruined, there are still many old canals, which show the greatness and importance of Khozestan province in the past. Even now, some of them are under operation.

Fortunately, G.V. Roggen had done too much study about water structure in Khozestan, which are our base lines for our explanation.

1- THE BOUNDARY OF SOUTHERN RIVERS

Khozestan extends from Lorestan mountains (Poshte Kooh) to Bakhtiari mountains in the east and Persian Gulf in the south.

The most important rivers in Khoseztan are: Karoon, Dez and Karkheh. There are many small rivers in this great plain as well. (Fig. 9) shows the rivers, old and new shores of Persian Gulf. The sign of projection of shore into the sea called river sedimentation. There are many canals between Karkheh and Dez, which belonged to the old era.

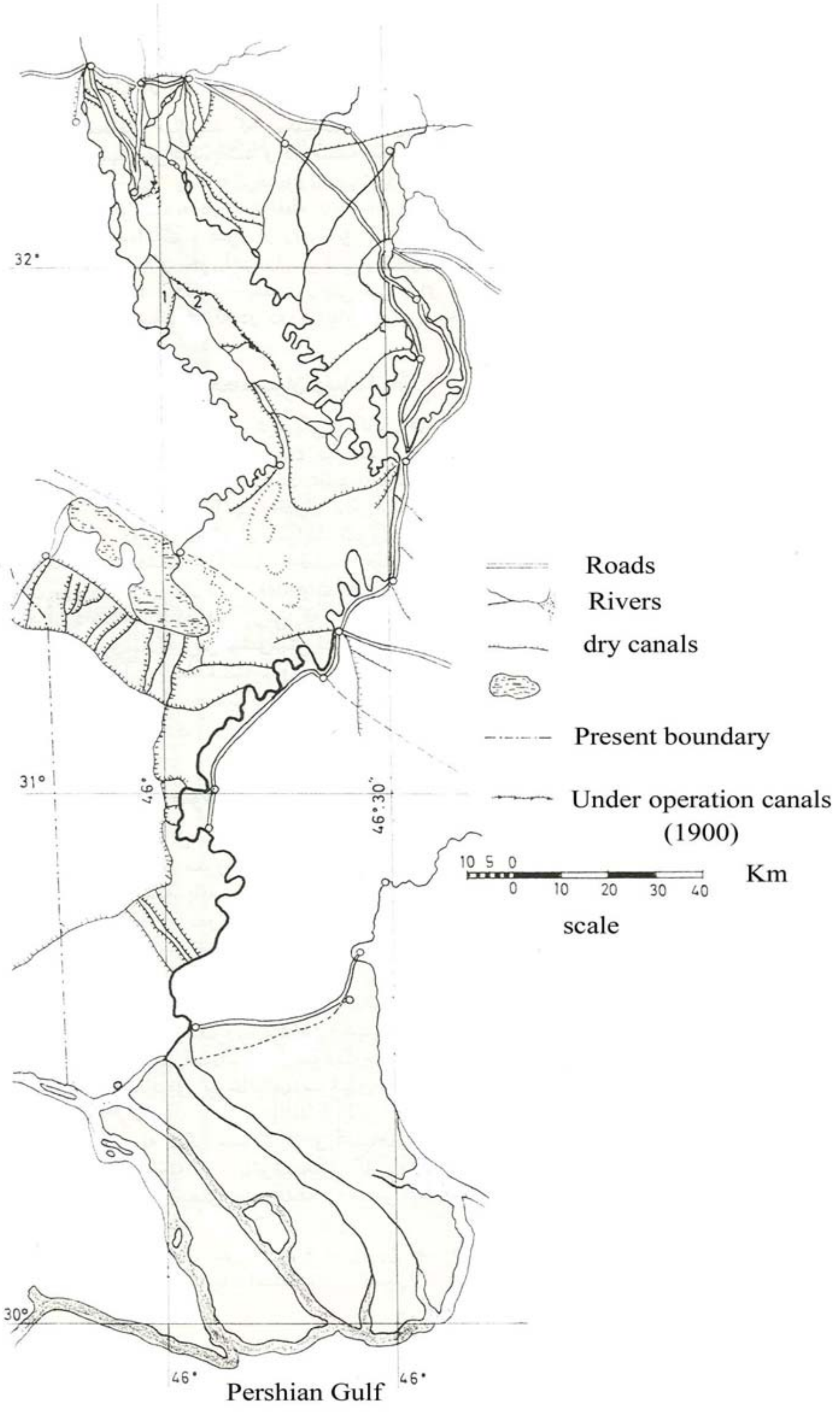


Fig 9, The map of some parts of Khozestan Plain with rivers and irrigation canals

2- THE TRACE OF ELAMITES' IRRIGATION CANALS

Investigators believe some of these irrigation canals in this large plain had been excavated during Elamites, as it was written on old inscriptions. It shows practically that they were crossing the Karkheh River without bridges, but there is no sign how the people were crossing the river. It is clear that they were crossing the Karoon River by boat or water – skin, but its location isn't clear. There are different crossing points on Dez. Perhaps they used bridges but G.V. Roggen believed, they mustn't have constructed any bridges in the region in Elamites era.

3- THE TRACE OF ACHAEMENIAN AND SASSANIDS

As it will be discussed later on, one of the important canals in Shoshtar is Darian. It is believed; Darian was excavated during Darius The Great. Besides that, there were many water and irrigation structures, which belonged to Achaemenian era in this great plain. Unfortunately there are not many traces of them, but there were some people believed they would belong to some other eras.

There was a serious need to construct some bridges over three important rivers in Khozestan region during Sassanids era. As you know one of the governmental centers was in Passargade and the other one in Teisphon. The main road, which connected these two centers passed through Bakhtiare, Ramhormoz, Shoshtar, Dezfool and Paipol. After crossing Hamerin Mount near Baiat, it was continued in a straight line towards the Tigris River.

Shapour the First decided to construct a bridge over Karoon in Shoshtar, one over Dez in Dezfool and the other one over Karkheh near Paipol in order to complete the great main road.

A – THE SPECIFICATION OF SASSANIDS' BRIDGES (MULTIPURPOSE STRUCTURES)

Shapour the First had two major objectives for these bridges:

His army could easily cross the rivers any time, which was necessary.

The piles of constructed bridges were some how used as dams to raise water level and divert it to left and right irrigation canals.

There were even structures with triple objectives in Iran. One of the best samples is Band-e-Amir in Fars. Irrespective of connecting both river banks, it acted as dam and raised water level to divert to the canals in both sides, and finally they used the water power of this great historical structure to rotate the millstones.

Another sample is Gargar Weir and the water mills around it, which were constructed during Sassanids era. Those explanation of multipurpose structures belonged to the most recent era.

When Shapour The First defeated Valerian the Roman Emperor in Epuda battle (260AD), he got benefit from Roman captives to carry out his construction plan. After Shapour his successor, Khosrov Parviz who was very interested in development and improvement of the country started the construction of Qasr-e-Shirin and Tape Bostan.

B- GENERAL INFORMATION ABOUT LARGE TRIPLE-PURPOSED ANCIENT BRIDGES IN KHOZESTAN

Shoshtar Bridge had been constructed with bricks and it had various arches laid on different piles. When the bridge was visited by Roggen it didn't have 5 gates. Some of the piles of Dezfool Bridge had been ruined and new piles were reconstructed. At present, except for some original parts, the rest have been destroyed (fig 10).

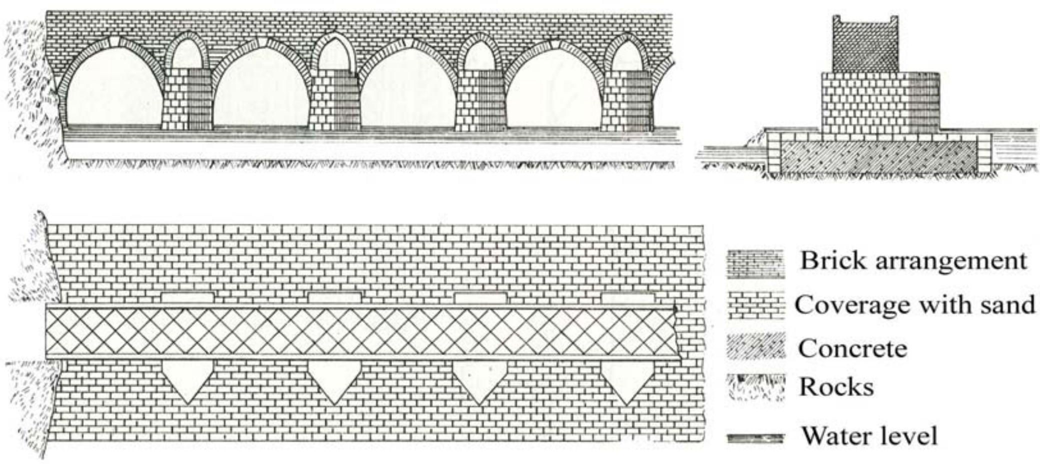


Fig 10. Details of a bridge dam in Sassanids era

Shoshtar Weir Bridge was made of carved cubic sandstones and the main road with the same materials with the thickness of about one meter. The piles and weir of Dezfool Bridge had two external walls made of carved stones, which were filled with concrete, and the stones were connected to each other by metal braces (fig 11 and 12).

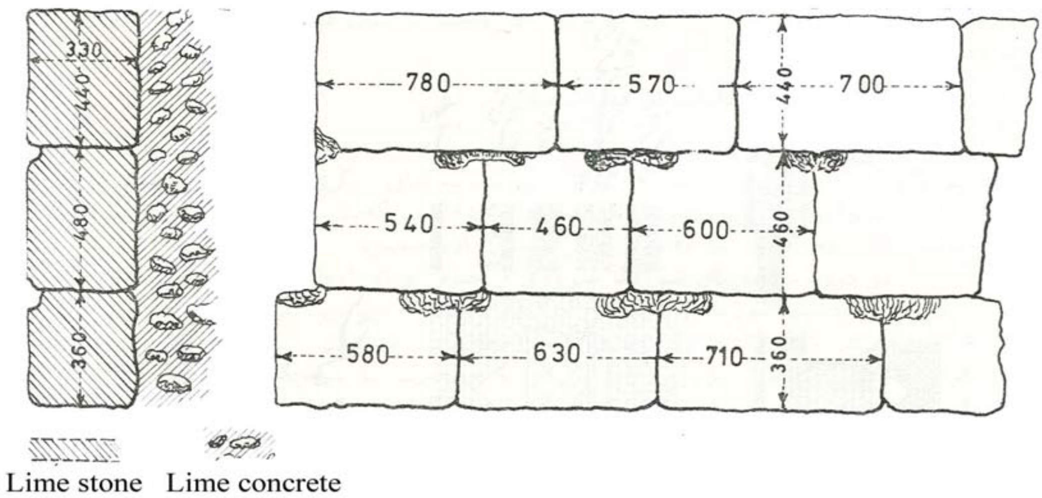


Fig 11, Metal braces between carved stones

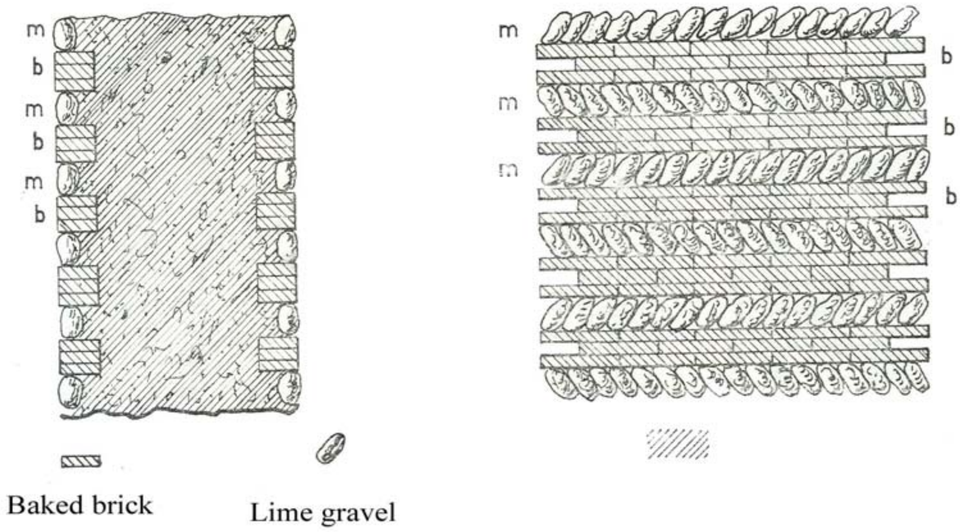


Fig 12, Details of brick arrangement in Dezfool and Paipol

Roggen saw a part of piles, made of rubble stones, bricks and concrete. The width of weir of the bridge with a height of 3 to 4 meters above water level in dry season was a little more than the width of piles. The weir, which extended throughout the cross section of the river besides raising water level, fastening the piles together.

There were different arches over the bridge in order to increase the capacity of the river cross section during overflowing (fig 13).

The materials used had high quality and the places they had extracted the sandstone is still visible and can be seen the marks of peck stroke. The natural riverbed in Shoshtar is covered with slate and Dezfool Paipol with conglomerate. These materials decompose by exposing to the air but if it is submerged in water its quality saves.

C- SHAPE OF PILES AND THEIR DIMENSIONS

All the piles of old bridges had rectangular cross section with a sharp edge opposite to the river water current. At first it looks like the dimensions of piles, are over design, but if we realize the pressure and water strokes during overflowing, we can understand the importance of this kind of design. The thickness of piles is between 5 to 6.40 meters and the length is a little more than the width of the road and some how less than the width of the weir bridge.

There were some small arches on the spaces between piles and the main arches (as mentioned before) in order to increase the capacity of river cross section during overflowing.

The distance between center to center of two piles were about 13 to 14 meters so the internal diameter of large arches were two times the width of their piles.

The width of the weir bridge was one or two meters longer than the length of the piles and it was 8 to 12 meters. (Fig 14)

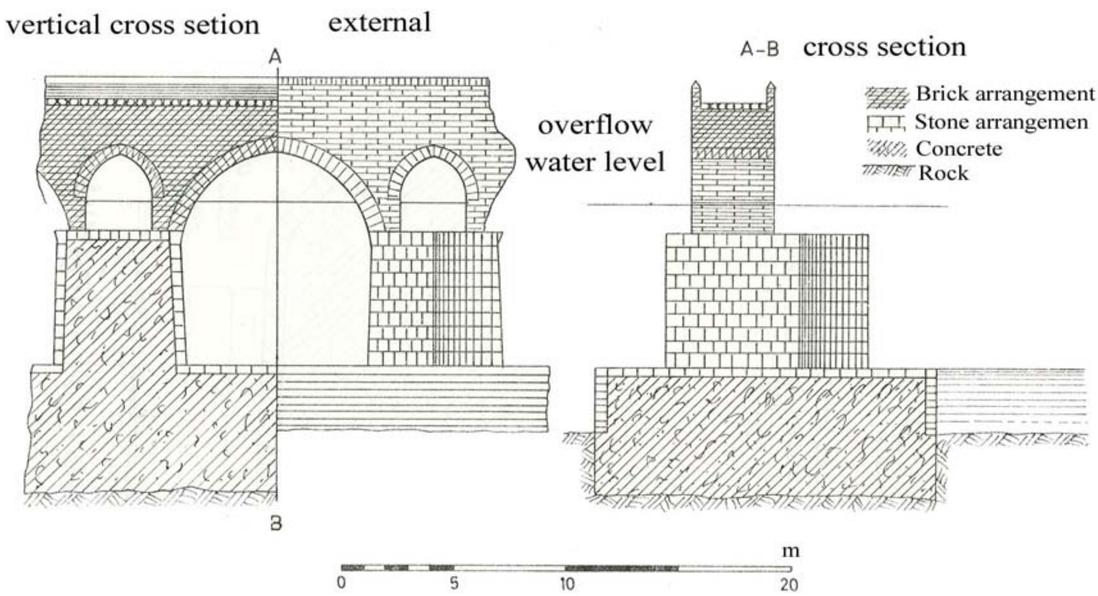


Fig 13, Instanlling Small Arches for Evacuation

of Excess Water During Overflow in the Middle of The River

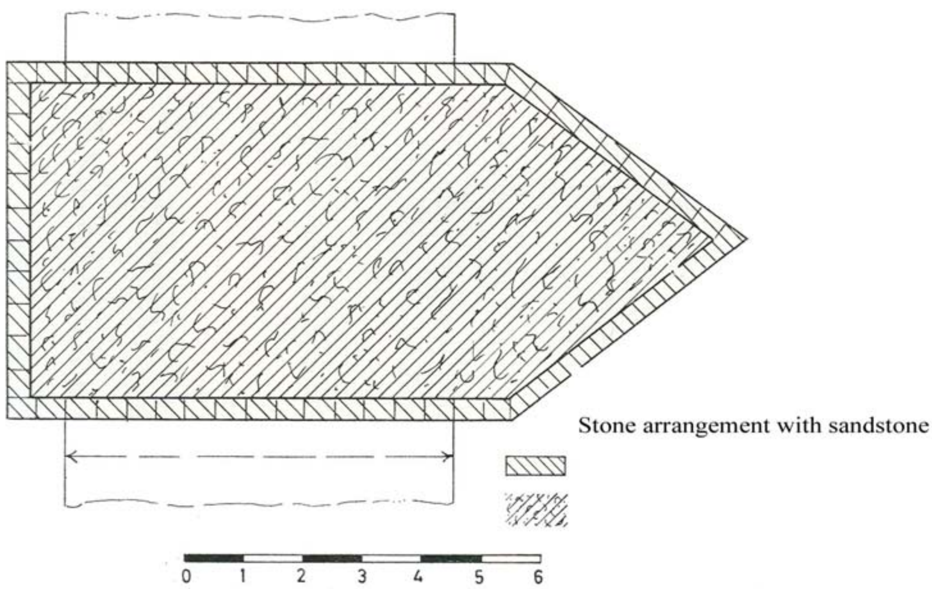


Fig 14, The cross-section of a pile of Sassanids' bridges

D- A SUMMARY ABOUT OLD WATER STRUCTURES IN SHOSHTAR (FIG 15 TO 20)

The advantage of Shoshtar Weir Bridge respect to two other important bridges in Khozestan was its longitudinal axis, which was not in a straight line. Roggen guessed the builder tried to put the piles of the bridge on natural rocks, so the axes of bridge got out of line. The original Shoshtar Weir Bridge had 40 gates and it was about 500 meters long.

The Karoon River was divided into 2 branches at the north of Shoshtar. The eastern branch called, Gargar River and the Western one Shatit. These two branches joined together in Gheer Dam site again. That is why Shoshtar and the land between these two rivers became as a peninsula.

There were two tunnels under Salasel Castle about 300 meters upstream of Shoshtar Weir Bridge which joined together, 100 meters downstream and formed Darian Canal. The other name of this canal was Mino-Ab or Darabian. It was said, this canal had been excavated by the order of Darius The Great. The width of both tunnels was 3 to 405 meters and on one side there was a passageway. They are all destroyed by now. By the way, the water intake bed of the tunnels was constructed as a weir. The height of the crest was about water level during dry season.

Darian Canal was divided into two branches in Band-e-Khak. The main branch went towards south, after 33 km, it joined to Shatit River in Arab Hassan Weir. The topography between Shatit and Gargar Rivers were some how that Darian Canal passed through ridges of the hills. So it was very easy to irrigate the land between these two rivers. There were many other irrigation canals passed through high lands. The second branch of Darian Canal after passing through Lashgar Bridge poured into Gargar River.

There was a dam in Band-e-Khak which store main portion of Darian Canal water discharge in original branch, because the eastern branch of Darian had 15 meters head. Apparently they had constructed 3 more weirs to reduce the velocity of water. Roggen emphased that Darian Canal had been older than the other water structures which were constructed during Shapour The First, because the max. height of weir in Darian was the same as water level during dry season. Roggen concluded that there must have been a dam for taking water before constructing the Shapour Weir Bridge and perhaps Shapour The First repaired the weir or he had completely changed it.

Between Darian Canal and Shatit River one can observe bank protection in order to protect the canal against Shatit River overflow. Roggen stated, they had constructed a wall to repair the ruined section of the weir, but it was destroyed at the time Roggen had a visit there. Consequently, it caused the Darian Canal got full of sediment.

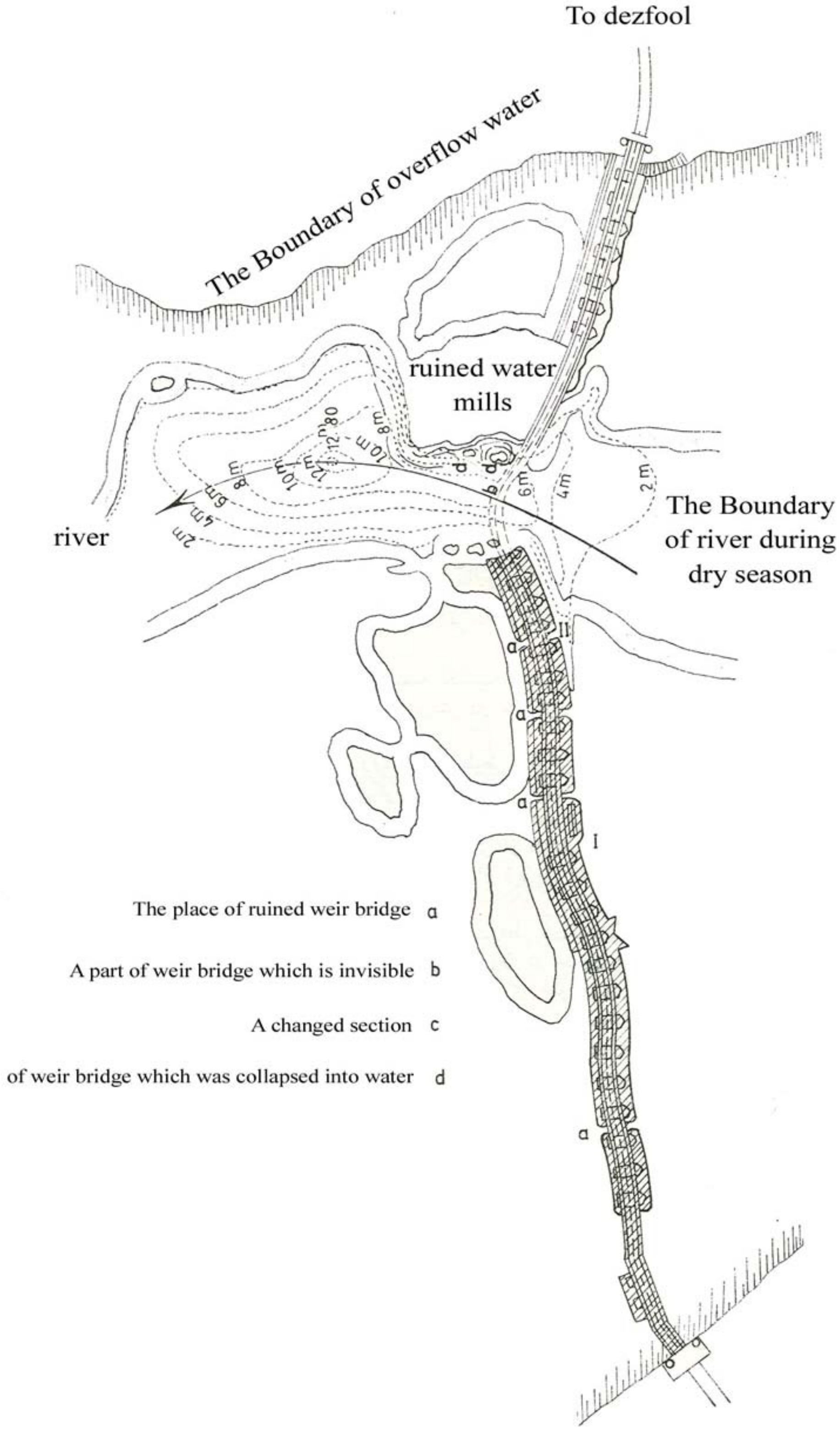


Fig 15, Shapour The First Weir Bridge in Shoshtar

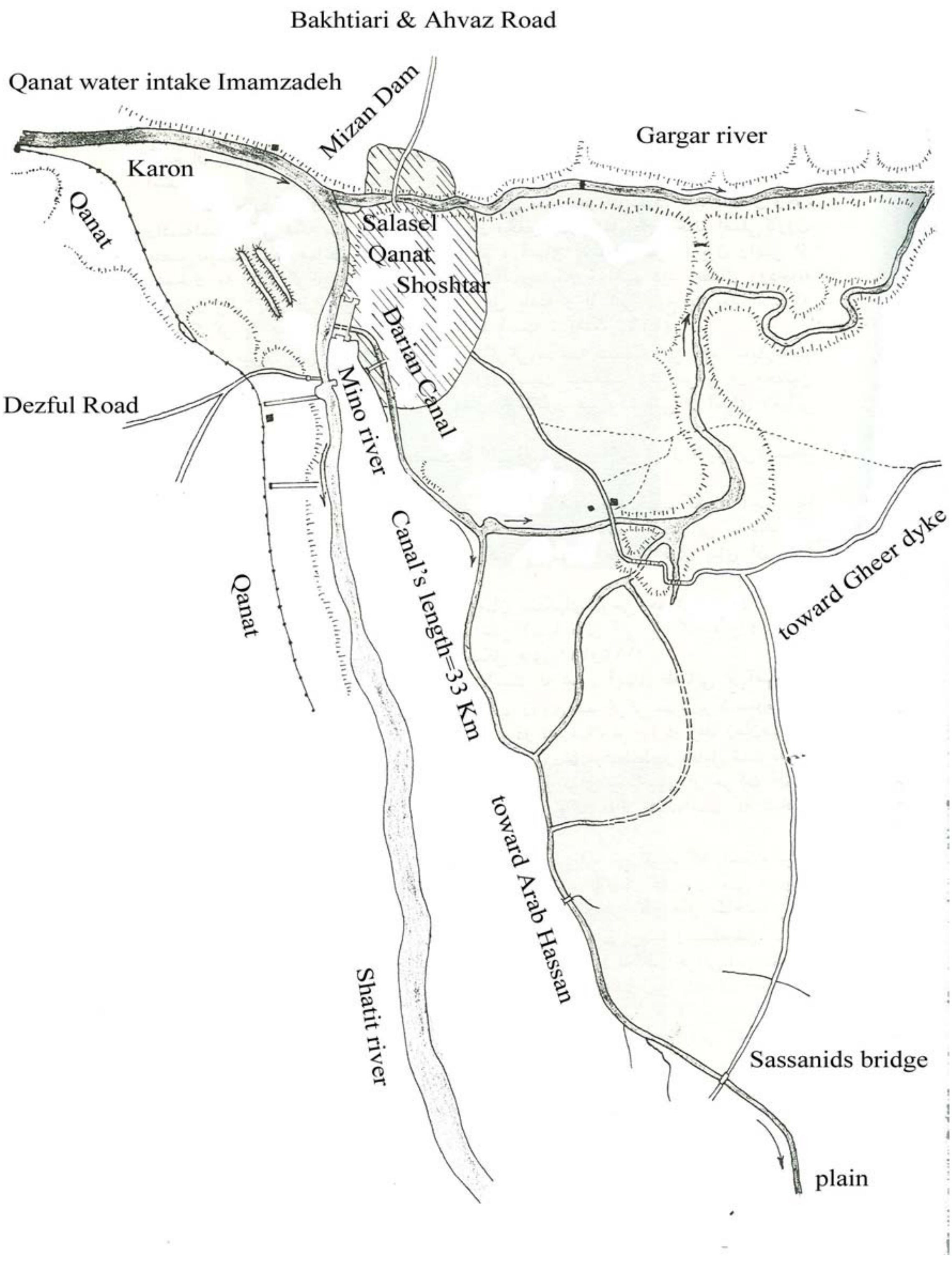


Fig 16, Karoon Riverbed along the old canals and weirs around Shoshtar City

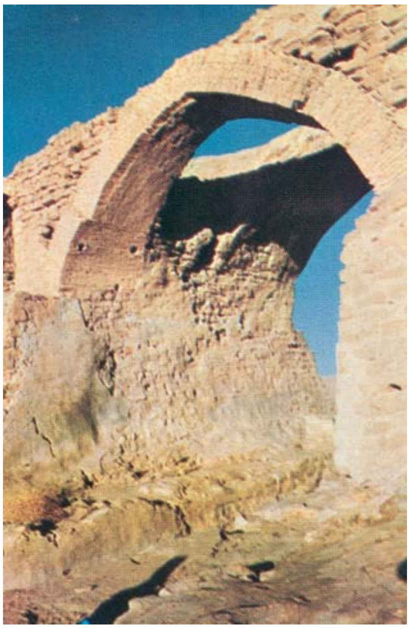


Fig 17, One of the ruined arches of Shoshtar Weir Bridge (1700 years old)

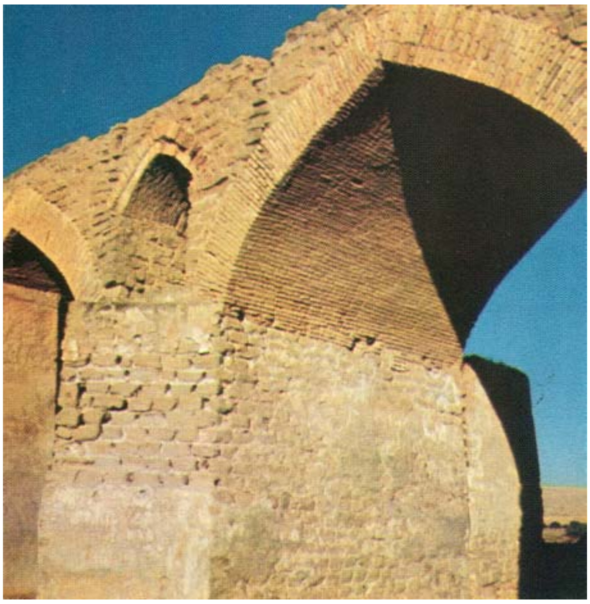


Fig 18, Two gates of Shoshtar Weir Bridge from upstream (1700years old)

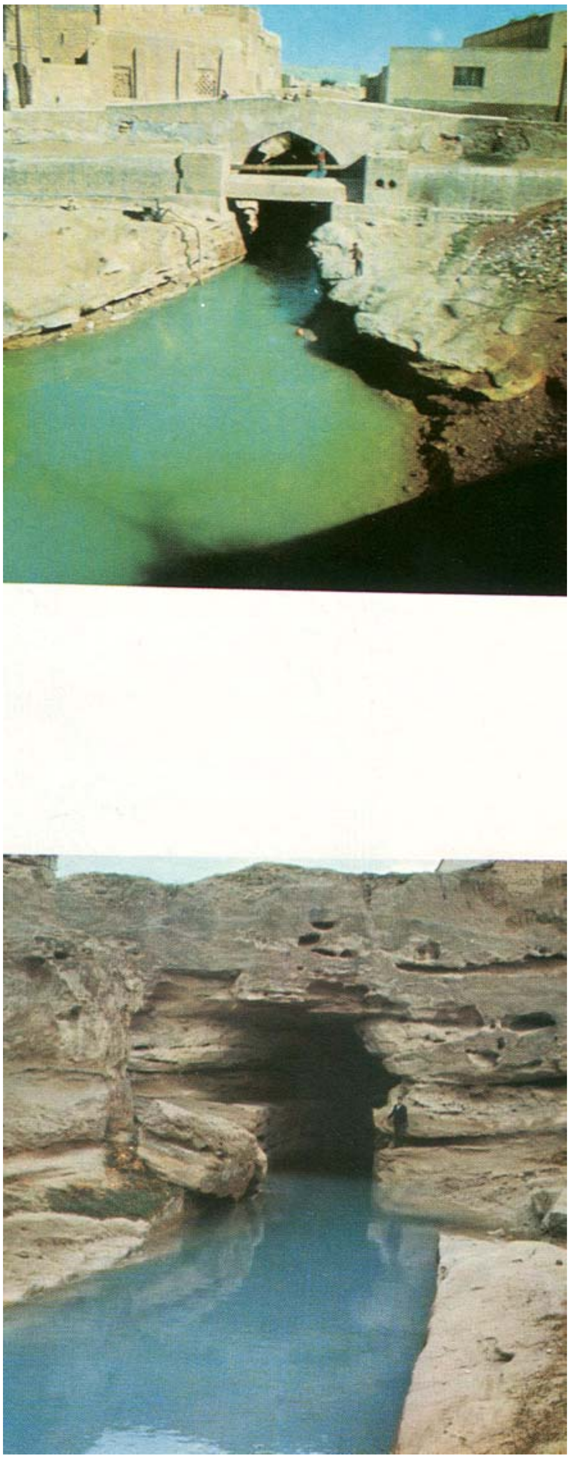


Fig 19 &20, Darian Canal entry behind Salasal Castle in Shoshtar (more than 2000 years old)

There was a strait where the Gargar River flows in the eastern part of the city at the present time. According to the opinion of investigators, this strait hadn't any connection with Karoon River. As it was mentioned, the excess water of Darian Canal was diverted to Gargar Strait at the downstream of Band-e-Khak. After excavation of intake canal the connection between Karoon and Gargar came true. Since then the Gargar Strait called Gargar River (fig 21).

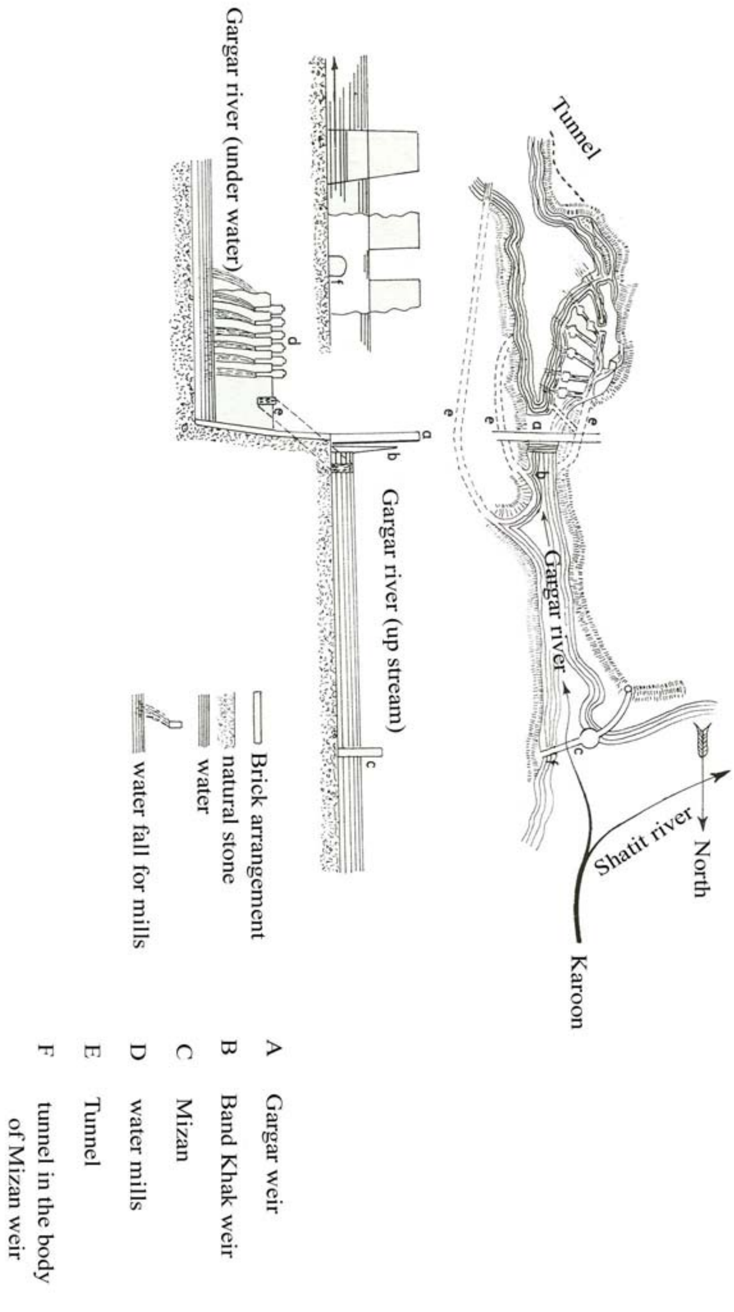


Fig 21, Some weirs in the eastern part of Shoshtar

Mizan Weir was constructed between Karoon and Gargar Rivers.

This weir was very strong and well erected and it is related to Shapour The First. But some of the investigators believed Mizan Weir, which was constructed for controlling the Karoon overflow in later years.

Mizan Weir had 9 gates; their bottoms were a little lower than the min. water level in the river.

There was a weir about 500 meters downstream of Mizan Weir, which was constructed with bricks. It might have been built on later eras.

There was an earthfill dam in upstream. As far as its structure showed, it was very simple and might be a temporary structure.

There were three tunnels, which were excavated in slates in upstream of Gargar Weir. One of them was for water supply of those water mills located in the right bank (fig 22 and 23).

The cross-section of above tunnels was large enough to let the overflow water pass without making any damages. Otherwise, water could overtop Gargar Weir and destroyed it. Roggen believed these two weirs and those three tunnels had been constructed at the same time.

Some of those investigators claimed that Shatit Riverbed was covered with large pieces of rock near the old city and they used metal braces to prevent them from moving. But Roggen couldn't prove it personally.

Schindler[1] stated "raising water level in Karoon they had to pave riverbed with stone and it caused water to flow in Darian Canal even in dry season." So those structures, which related to Shapour The First, could be weir bridge and paved Shatit Riverbed. Roggen said, "We must accept that these huge activities couldn't be done without drying the riverbed". On the other hand we should keep in mind, the width of Karoon River is about 300 meters and the depth about 3 to 4 meters.

Roggen explained how the execution was done in two phases as the fallowing.

Phase I, they excavated a temporary canal on right bank of the river. The walls of this canal were made of earth which was obtained from canal cross section. Those walls are still visible around the canal. Then they constructed a temporary dam at the joint section of Karoon and the canal. Diverting water through the canal, and the main Karoon Riverbed was dried down. The old weir, which was related to Darius The Great caused not to let water enters the site. According to Roggen statements the connection between Gargar Strait and Karoon River and construction of Mizan Weir were executed at the same time.

1 - Reisan im sudlichen Persian 1879, z, Ges. Erdk., Belrin 1881

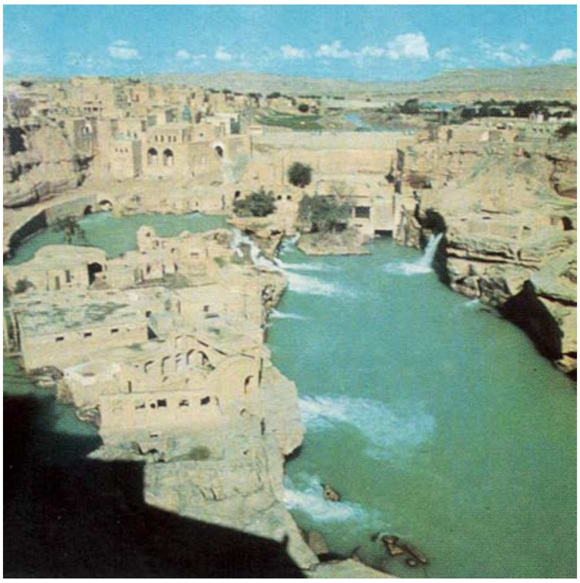


Fig 22, Gargar Weir Bridge (1700 years old)

Fig 23, The Canal below Gargar Mills (1700 years old)

Cargar Weir and the excavated canals at upstream, diverted seepage water collected in the dried bed of Karoon. The excavation of intake gates of two tunnels under Salasel Castle was done at this time. It was obvious that at this astage of construction the Darion Canal was dried and this was the only disadvantage of the above project (fig 24)

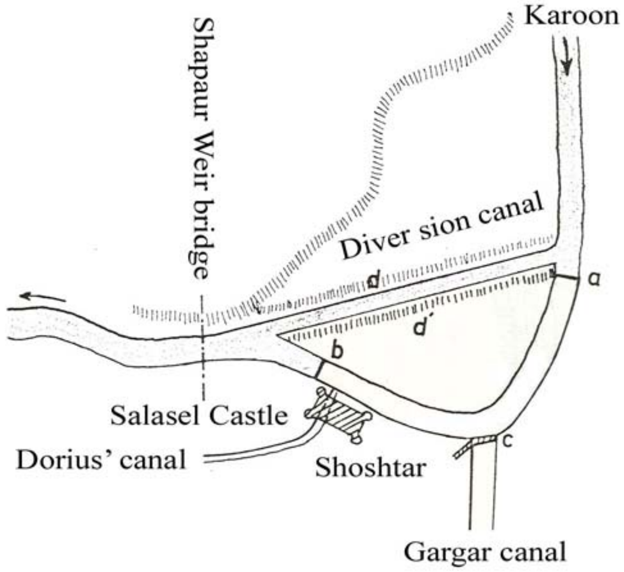


Fig 24, The phase I of construction was for drying down Karoon Riverbed.

Phase II, during this phase the former temporary weir (a) was washed out but the old one (b) was saved. So Karoon River ran through rehabilitated river course and from the gates of Mizan Weir, water flow into Gargar Strait and a portion of Karoon water discharge supplied Darian Canal.

It seemed a section of temporary weir (a) was ruined by hand and the rest was washed out (fig 25).

Drying Shatit Riverbed they blocked the temporary weir (e) to prevent from Karoon water entry to the site of the second phase of construction. By these arrangements they could erect Shapour Weir Bridge. As far as Gargar River made it possible to flow the whole Karoon discharge in regular and Flooded periods during the construction of the bridge. However there must have been some traces in the river course. That was the reason why, Roggen decided to investigate the Gargar Riverbed. He found out near Shelbi there was a place where the river was 1500 to 2000 meters wide during flood seasons, although it isn't more than 30 to 40 meters at the present time. After the implemontation of Shapour The First Weir Bridge they ruined the temporary dam (b) as well and the situation became as we can see to day.

Had they wanted to build Mizan Weir in some other time, the whole work would have been done under water and it was impossible to do such a huge and difficult job even at the present time which is not economical either. The source of Safteh Qanat, which is illustrated on fig. 18, was Karoon River, this qanat extended rather parallel with Shatit River. The excavation of this qanat might have been done in Sassanids era.

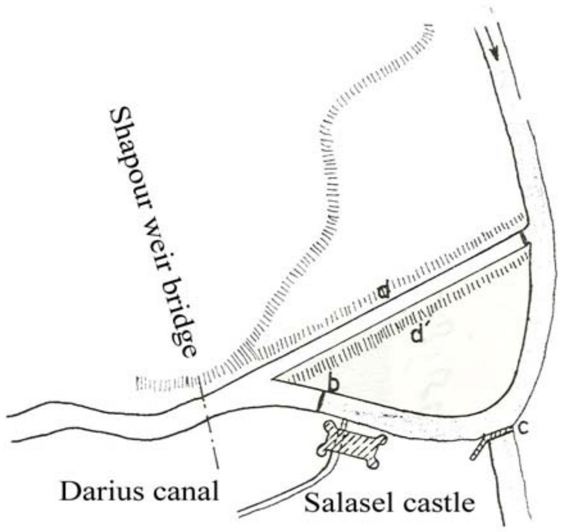


Fig 25, The Second Phase of Drying Karoon Riverbed for Construction of Shapour Weir Bridge.

E- A SUMMARY ABOUT CENTERS OF OLD WATER STRUCTURES IN DEZFOOL (FIG 26- 28).

Dezfool Weir Bridge was much stronger than Shoshtar's. This weir bridge had 22 spans. Some of the pillars belonged to more recent eras. Roggen stated that the flood in 1903 destroyed one of the pillars. This weir bridge was straight except for some declinations in both ends. It seemed some parts of the bridge had been repaired when Roggen had a visit there. As he could recognized the old and renovated sections easily. Except for some small parts of Dezfool Weir Bridge nothing was left. Consequently all the conglomerate exposed to erosion. This point was mentioned before. The height of crest from water level during water shortage was about 3 meters and there were a number of irrigation canals in both right and left banks. The first part of these canals excavated as tunnels. The height of weir from water level during dry seasons was about 3 meters and it supplied water the, on the left bank canal, which was excavated as a tunnel. This tunnel after extending about 100 meters became an open canal (canal c). Intake canal (d) was parallel with the former one. The riverbed was very high and Roggen couldn't find the location of water intake. The location of another branch of canal b was about 300 meters upstream of the weir. The structure of water intake was made of brick and it had a good quality.

There were two more tunnels near canal water intake, apparently the city waste water drained to the river by these tunnels. There was a wall along the river path, which protected the city of Dezfool during war and peace.

There were some irrigation canals on the left side, which appeared as open channels.

There was canal (e) on the right side of Dez River, which diverted from the river about 400 meters above weir bridge at the point (k). This canal was extended to the southeast and disappeared in the plain. Without any doubt it was the main irrigation canal, which drained to Dez River again after extending to the south. This canal at the point (f) diverted and its lateral branch, which was almost perpendicular to main canal after passing through a number of tunnels, diverted to the south and drained to main branch again. After collapsing a part of main canal, perhaps this branch had been excavated to repair the ruined section of the main canal. This type of job has been frequently observed in qanats.

The depth of sediment in the canals is about 10 meters and the width almost 15 meters. But the tunnels are 3 meters wide.

During the operation the width of tunnels were less but gradually they got wider and wider by erosion. Certainly, changing the smaller cross-section to the larger one, the velocity of water reduced and a lot of sediment settled down.

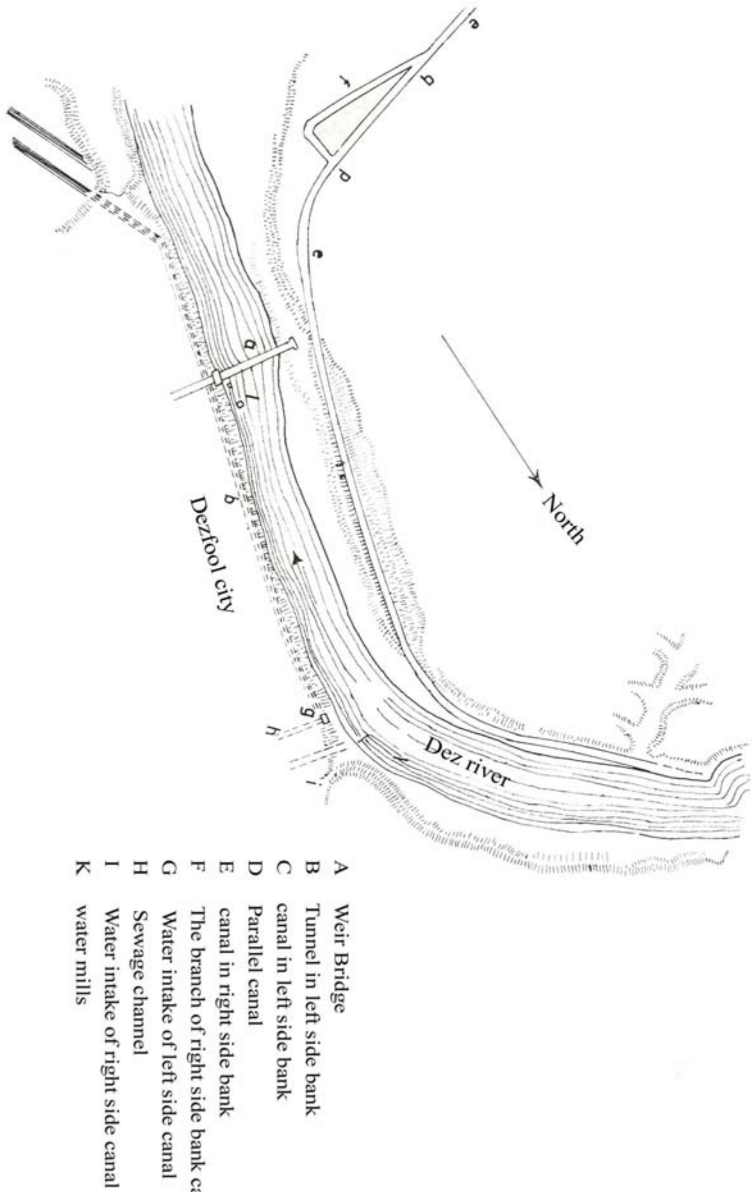


Fig 26, Shapour The First Water Structures in Dezfool

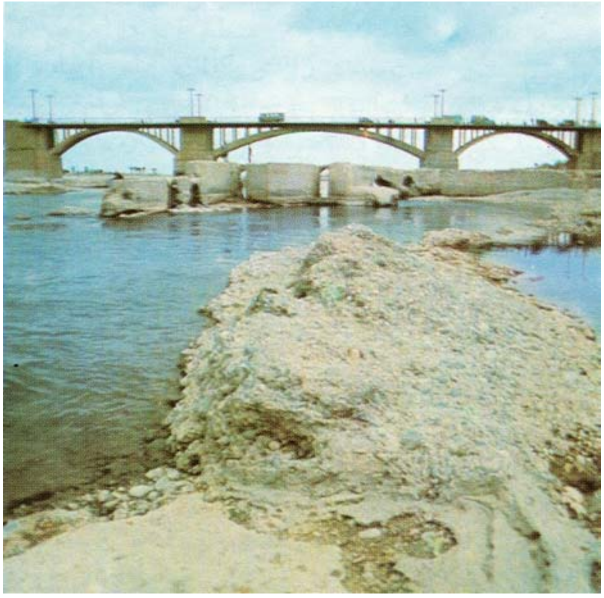


Fig 27, The ruined Dezfool Weir Bridge (1700 years old)

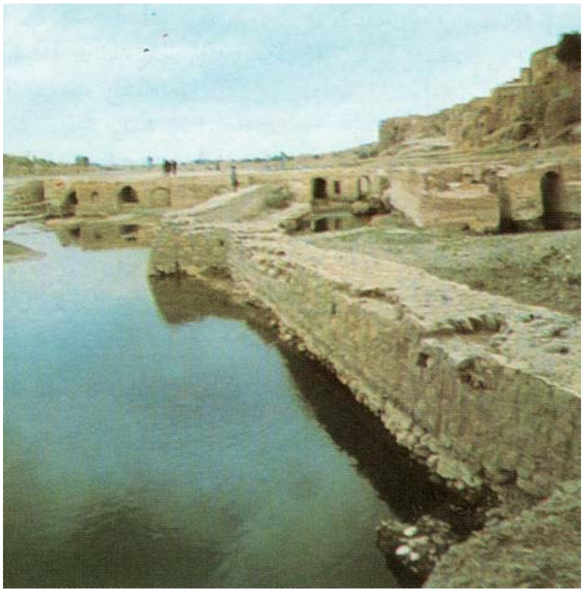


Fig 28, Some parts of old mills which looked like large boats halted in the port (1700 years old)

F- A SUMMARY ABOUT OLD WATER STRUCTURES IN PAIPOL (FIG 29)

There is the trace of a ruined Sassanids' weir bridge where the Karkheh River enters Shosh plain in the Northwest. Roggen saw 16 spans of that weir bridge. He estimated the height of pillars about 80 cm to 3 meters on the left bank. He said, there had been the trace of two more pillars on the right bank, which extended up to the arches' supports.

At the present time the weir bridge, which was 4 meters above minimum river water level is completely destroyed, but some parts on the left bank between the support and the first pillar is still remained. The width of river in this place is about 60 meters.

There is a tunnel on the right bank, down the weir bridge water intake, which extends along Karkheh to the old city of Sassanids called "Eivan Karkheh".

Fig 29 shows those canals, which took water from left bank and generally intercepted each other. So they had been constructed in different levels. As far as the details of their construction and whether they used siphon to cross each other isn't clear, so we just mention that Roggen estimated the age of one of these canals about 3400 years. On the other hand, he determined, one of the canals, which belonged to Shapour The First era had been filled with sediment up to the top of the weir, by the year of 1060 AD and it got out of order.

G- A SUMMARY ABOUT WATER STRUCTURES BETWEEN KARKHEH AND AHVAZ (FIG 30 AND 31)

Roggen visited and carefully investigated all the territories located between Karkheh and Shavor Rivers, and those lands between Karkheh and Karoon from Shoosh to Ahvaz. He saw many canals, which belonged to ancient time, but unfortunately he couldn't estimate the age because of lack of records. But according to narratives and traditions, which was heard from Khairabad residents, he guessed the excavation of one of those canals, which was located at the hills between Shavor and Karkheh belonged to Shapour The First. But there is no evidence to prove it.

The depth of the first excavated canal, which goes to Karkheh from the top of the hill is about 25 meters and from this place one can clearly follow the path of canal towards Shavor River. It is completely filled with earth came from the walls along.

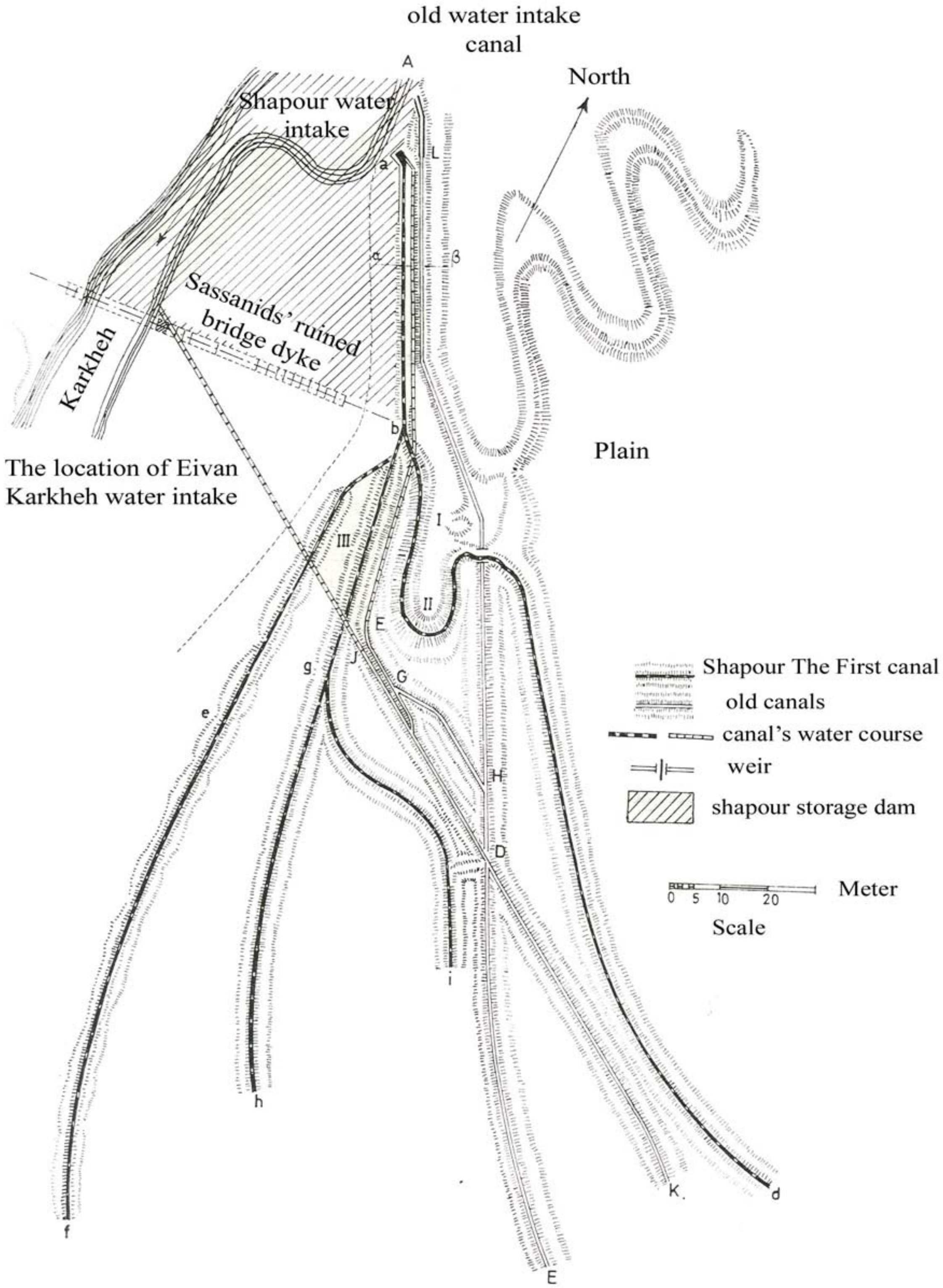


Fig 29, Old canals in Paipol

The cross-section of this canal where drained to Karkheh is about 50 meters wide. This size of canal brought out some doubts for investigators whether Shavor River was able to discharge these huge canals or not. Then Roggen came to a conclusion that the discharge of Shavor River must have been much higher than to day. This assumption makes clear the irrigation system in the region, and shows Shavor River happened when the second excavated canal was located a few kilometers far from the first one and it seems it was acted as a diversion canal for Shavor River.

According to the above investigation, Roggen concluded there must have been a dam on Karkheh, which diverted water to Shavor River and after it was destroyed the discharge of Shavor River reduced as well.

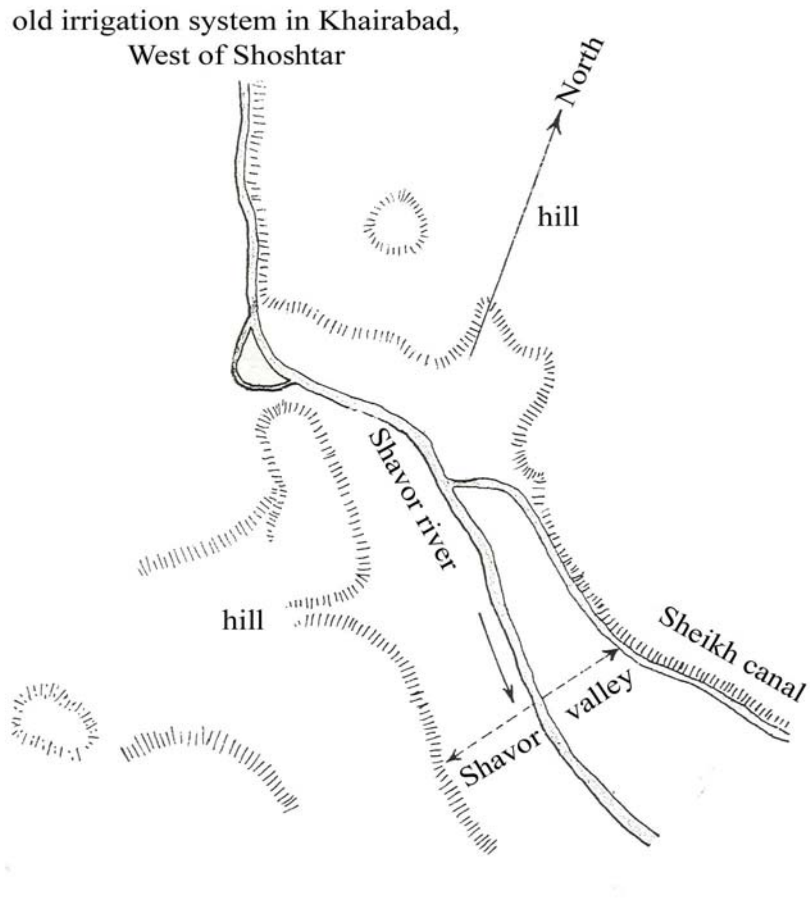


Fig 30, Old water distribution system in Khairabad, west of Shoshtar

Fig 31, Shavor River in Shoosh

H- A SUMMARY ABOUT OLD WATER STRUCTURES IN AHVAZ (FIG 32 TO 34)

There is a trace of an old weir in Karoon bedrocks in Ahvaz, which was built from carved sandstones. Its length was about 900 meters and the height about 3 meters above water level during dry season. There were two irrigation canals in each side. The one on the right bank delivered water to the plain between Khoramshahr and Hoveizeh. Unfortunately, the trace of this canal was completely demolished, but its considerable dimensions of water intake indicate the glory of the past.

The left bank canal extended from the north of Ahvaz. It was about 7 meters wide near water intake structure and the canal bed was about 5 meters higher than the riverbed. It is not possible to determine the age of Ahwaz Weir. But this weir should belong to Sassanids' era because of its solidity and style.

3-1-2 ESFAHAN PROVINCE

Zaindehrood is one of the most important and historical river in Iran. As far as agriculture is extremely important in Esfahan region, so Zaindehrood flows through different canals from the source to estuary to supply water demand.

The number of these canals, which call "Maadi" are about 125. Each one supplies water needs for one or more villages.

Zaindehrood water distribution system was very difficult and most often caused a lot of conflicts among farmers. So Sheikh Bahaie the most famous Iranian mathematician and scientist provided a scroll in order to solve this problem in 923 A.H. (1452 AD) and it is still valid. Studying his scroll is beyond the objectives of this publication. We hope there will be an opportunity to discuss about it later on.

Those canals, which were discharged by Zaindehrood were very old and it takes much time to discuss about all of them. According to the historical reports, there had been a number of diversion dams on Zainderood but they have been practically ruined.

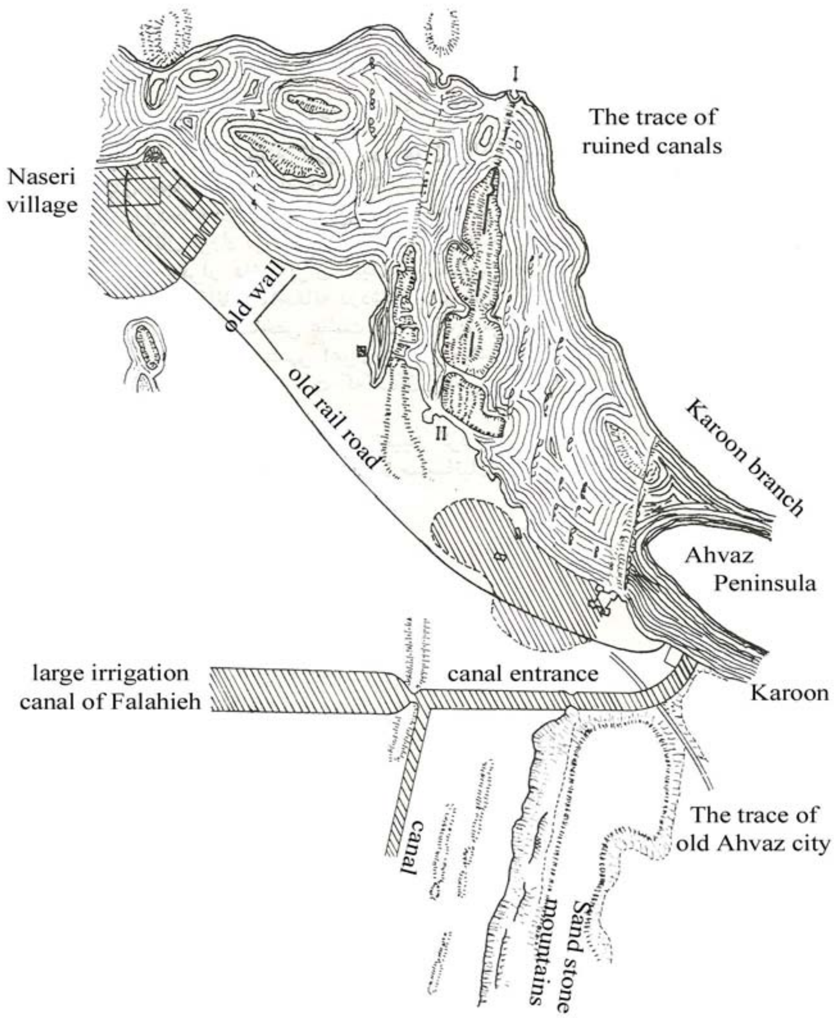


Fig 32, Map of Ahvaz water-fall

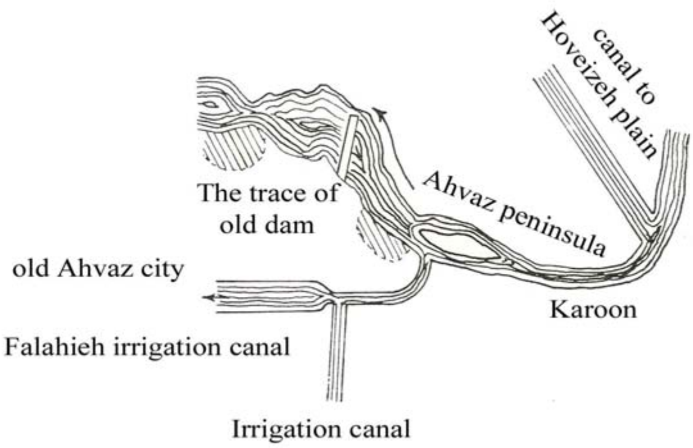


Fig 33, The location of Ahvaz old dam

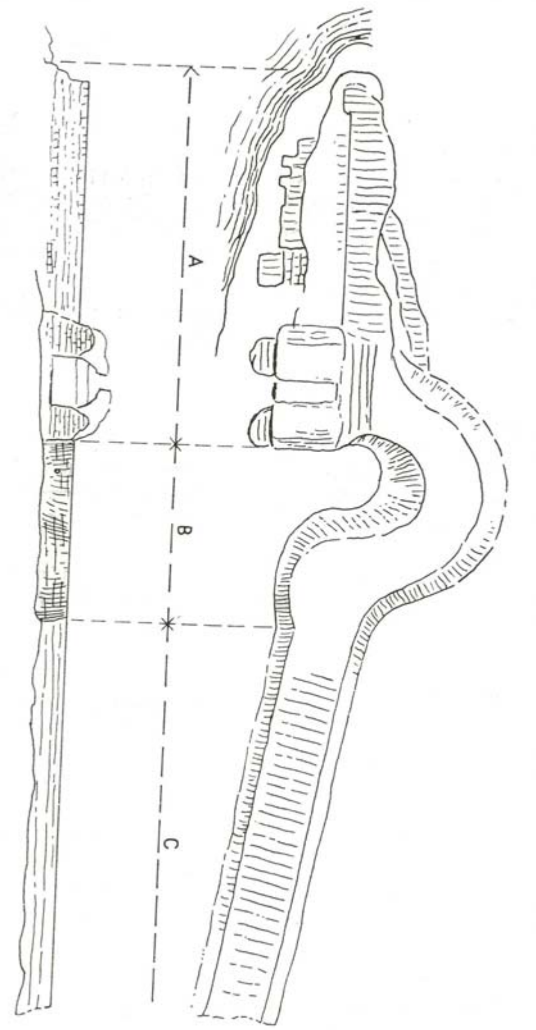


Fig 34, The remains of old Ahvaz Dam

3-1-3 FARS PROVINCE

Fig. 35 shows the location of weirs which were erected on Kor River and their traces have already remained. There were many canals at the upstream, which diverted water for irrigation. One of those canals was Darius Canal which extended from Darius Weir Bridge and it was located at the present site of Cyrus the Great Weir (Dorodzan) and supplied Estakhr water needs.

There are many traces of water mills around the weirs and canals. They are the sign of agricultural activities and cultivated lands.

3-1-4 OTHER PROVINCES

There are many old canals in other provinces and their water – rights determined according to scrolls and old regulations, which stated by local trustees and experts. Petroshfeski mentioned about agriculture and land suitabilities in his book during Mogul era in Iran. There was a chart about the cities and the type of irrigation. This table arranged by obtaining information from Hamdolah Mostoufy publication. It is necessary to mention, there isn't any other source to have such complete information, if there is some we don't know yet.

3-2- TYPES OF DITCHES AND WATER DISTRIBUTION SYSTEM IN ANCIENT IRAN.

3-2-1- WATER DELIVERY, DITCHES AND CANALS CONSTRUCTION

Construction of ditches was very important in ancient Iran. There were two categories of ditches, the large and small ones. Instead of calling large ditches, it is better to use the international term "Canal" in literature.

So here we discuss about ditches first then about canals.

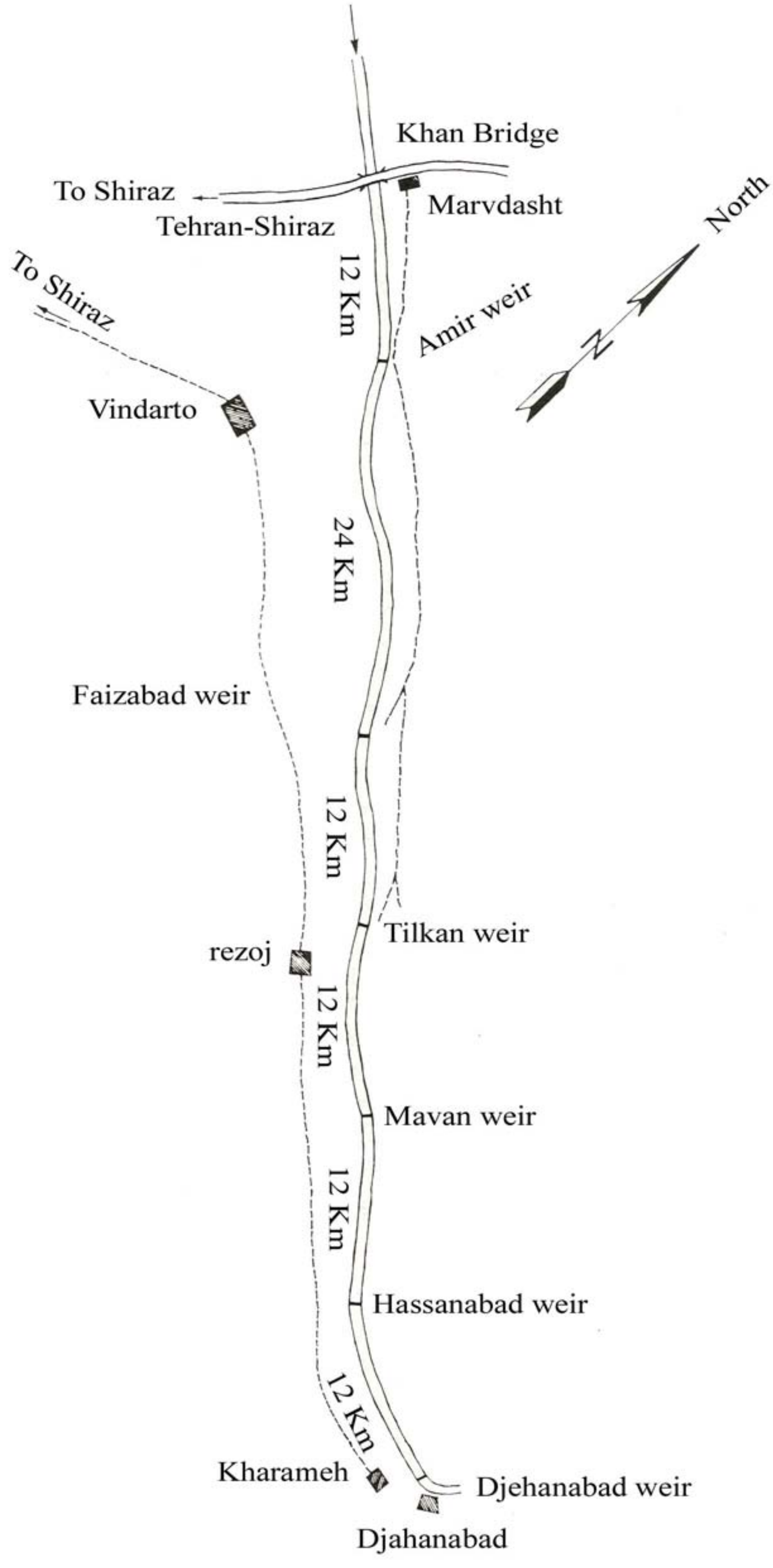


Fig 35, Location of weirs on Kor River

1- DITCH LINING

one is very curious about the construction of ditches in the past in respect to what it is done these days. Here are some points from Karaji book to prove the case. Then his statements will be discussed and described.

"If waterway is loose and permeable, the bed should be covered with large bricks and dark lime… or they have to dig the bed about a meter down, and then refill it with clay and compact it by beetle as the bed ditch stands at the same level. Both sides of the ditch should he inclined and built with the same material. Adding some water to clay makes the ditch more efficient. But the water shouldn't be cut so that its original moisture remains. Lining the ditch with compacted mixture of clay, sand and loam increase its firmness. Our ancestors said, "let the quadrupeds go through ditches to trample". Lining the ditches with compacted mixture of slaked lime, sand and clay with original moisture became very stiff after a while. Sometimes the bed of canals became so stiff that well sinkers are not able to dig it. Many times those loose lands are covered with rocks and their porous filled with the mixture of clay, lime and sand."

Here are the results about Karaji description, concerning modern science.

a- considering small ditches, they covered the bed with bricks and concrete lime.

b- In other cases when the land is permeable and it is not possible to cover with bricks, Karaji suggested to cover the bed with a layer of clay, the ditch walls should be somehow diagonal in order not to collapse.

Using clay to seal ditches is the same idea, which applies in dams, ditches and pools construction today. For instance puddled core of Cyrus The Great's dam is an impermeable diaphragm.

The information given about the moisture of clay by Karaji clears many things about soil. These experiments for determination of moisture intensity in clay called "proctor", which applied in dam and road construction. In order to eliminate the cracks on dry surfaces, they mixed clay with sand.

c- Karaji quoted from ancestors as they used quadrupeds to compact the bed of ditches. This method had been practiced before manufacturing special rollers, which called "Schaffusswalze".

d- Those explanations of Karaji about applying mixed clay, lime and sand, he meant lime concrete which mentioned before and it is used in modern road construction.

e- What Karaji knew about qanat sediment which was stiff and hard, actually it was lime layer which deposited by hard water.

Concerning the above statements we come to conclusion that the old and new thoughts are very close to each other. Besides, our ancestors were very careful with sealing the irrigation ditches and they knew how valuable water was.

2- SEALING OF WATERWAYS WITH CLAY PIPES. (FIG 36)

The statements of Karaji about the sealing comes first, "… they applied clay pipes for two reasons, eliminating infiltration rate in waterways and controlling water pollution when water flew through galleries with shallow depth in the villages. First of all we explain the technique and shape of the pipes.

The pipes were made with different diameters at the ends, during the installation the smaller end went 2 or 3 inches inside the larger end and got tight. The length of clay pipes were almost four times the diameter of larger end. Of course if the pipes were longer, that was the sign of better quality of clay and would be more durable.

The thickness of smaller end should be less than the larger end. Clay pipe made of pure clay without sand to be cooked well. The purer the clay the more durable it is.

Before installation, the bed was made almost level with a moderate slope as water flew by gravity. The first clay pipe installed some-how the water flew from larger end towards the smaller one. The smaller end mixed with lime paste some inches then the large end of the second pipe fitted and covered it with the same paste and let it dry. They installed an air valve to eliminate air condensation every 50 meters. Otherwise it might burst the pipes.

After installation, they left the site for 3 or more days. Then they gently flew water through.

Coating the inner surface of the pipes with melted fat or oil caused to increase the durability of pipes in water delivery. After finishing the job, they had to fill up all around pipe with clay so there wouldn't be any gap underneath.

Now we discuss about technical points which Karaji stated about clay pipe installation.

a- Old pipes made of tile. Karaje suggested, the inside diameter in respect to the length of pipe might be 1:4. it meant when the diameter was 20 cm. The length was 80.

b- B- Fig 36 shows pipe installation technique. Bed leveling and installation techniques were completely logical.

c- Applying air valves 50 meters apart was a technique used to prevent pipe bursting caused by water hammer.

Leaving air in the pipe, without providing air valve at higher elevations causes air compression when water flows through the system and burst the pipe.

d- As Karaji suggested, in order to eliminate water seepage through clay pipe, they coated inside the pipe with melted fat or oil. This is what it is done with tar or a layer of cement to prevent rusting today.

3- LARGE IRRIGATION CANALS (FIG. 37)

It was very difficult and expensive to seal large canals, because of their dimensions. Although Karaji's method for sealing with clay was practical here and passage of quadrupeds through large canals became very reliable, there were some factors which apparently caused the walls of canals to collapse, as they had to clear off and repair the canals every year. Another reason for heavy bed load in canals was concentration of suspended particles in water and sediments where the cross-section changed. Roggen remarked to this situation too.

It is clear, the operation and maintenance of large canals were very costly and difficult.

If there were negligent or lack of investigation especially during critical moments when the neighbor tribes attacked the country, many canals would be destroyed.

These days, the beds and walls of canals protected by concrete lining to eliminate water penetration.

3-2-2- SCALE FOR WATER MEASUREMENT

They applied time unit in order to measure water quantity. According to metric system measuring unit is one liter per second. This system is used for technical matters to day in Iran. But the old units are still very common in villages and even in some old cities.

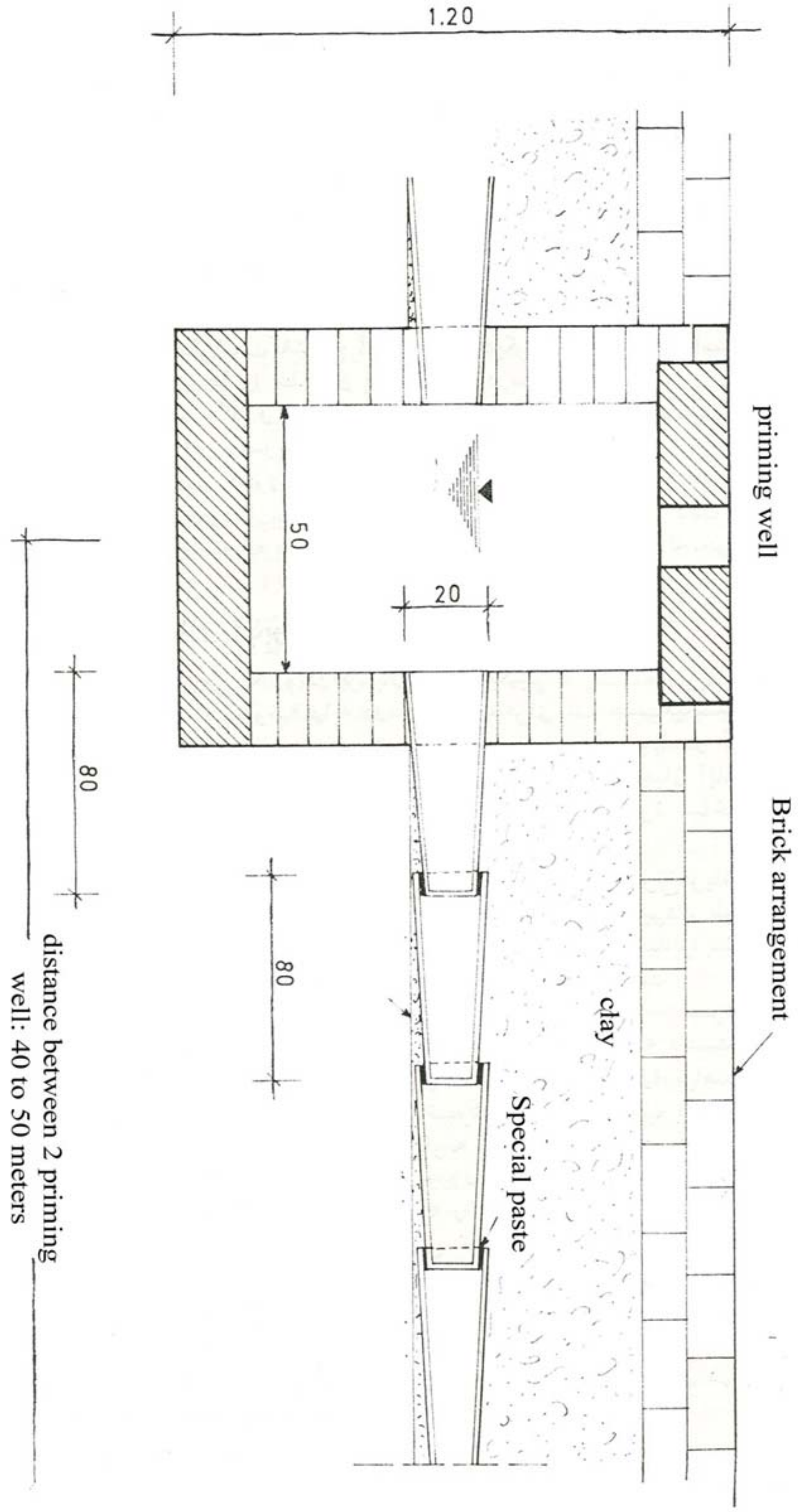


Fig 36, Tile pipe installation in ancient Iran

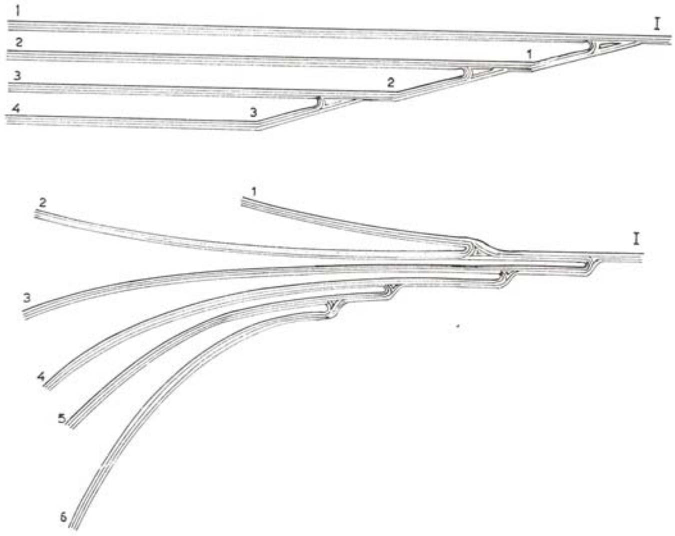


Fig 37, I. Main canal with 4 laterals, II, Main canal with 8 laterals.

CUP

It was noticed by Fengal that the water resource and its quantity varied in different parts of the country. The less quantity of water, the more curious they were about it. One of these systems, which has been very common since 1000 years ago called "peymaneh kardan" as a measuring system.

In this system "Time measure" which was a pan full of and it was laid beside the stream and water distributed between villages and farmers according to their shares relevant to "time measure".

The whole discharge of qanats, streams and springs distributed by this system.

There are all the old water terms in Kharazmi book, chapter 7. three of those measuring units mentioned here as follow:

Bast: This is a measure, which was used by Marv residents. It was a pot with a hole as big as a Barely grain for water entry.

Fengal: It was a cup with the capacity of 10 Bast.

Sorfeh: It was equal to 1/60 of river discharge per 24 hours, according to the regulations, set up by the elder people. However, it could be changed.

It is clear that Bast was 1/10 of Fengal and it was called time measure. For example, if the share of a village or a farmer was 10 Bast, the whole discharge of the qanat, spring or stream lift to the individual for the limited time, which was necessary to fill the measure and it was a fixed factor for water consumption.

Qasem ebn Yosef abs Nasri Heravi, who lived about 470 years age had some statements about water distribution by the scale "Bast" and "Fengal" in his book. Besides "the units mentioned above", there was another scale, which was called "Sang" and it is still common and practical.

The term “Sang” is very close to those units use today. According to Moein Encyclopedia “Sang” defines as follow

“Sang” is a unit for water measurement equal to some liters per second.

In Tehran one “Sang” is the flow of water through a notch of 0.2 m^2 (2.1528 ft^2) with a velocity of one meter per 3 seconds. In Kerman it is equal to sufficient water to irrigate 2 Hectares in 24 hours. In Esfehan, it is equal to adequate water to irrigate one “jerib” (1.2 Hectares) In shiraz they called it “Divani Sang”, it is the flow of water through a notch of 20 cm×80 cm with a velocity of one meter per second. In Hamedan it is equal to an Araki Divani Sang. Divani Sang is a unit for water measurement, which was divided into “Charkh” and every 5 Divanis Sang was equal to one “Millstone Rotating Sang”. In Arak one Divani Sang is equal to water flow through a gate made of four bricks (0.02 m×0.2m).

As it was mentioned above, the quantity of “Sang” varied in different parts of the country. The above Scales and measures could be changed to new scale of liter per second as follow:

Tehran Sang = 20 l/sec

Kerman Sang = Unchangeable to liter

Esfehan Sang = Unchangeable to liter

Shiraz Sang = 16 l/sec

Arak Sang = Unchangeable to liter

The amount of water is too high for Tehran Sang in Moein Encyclopedia. It should be about 13 to 15 l/sec (writer and et al.)

Here is the definition of “Sang” in Persian Encyclopedia page 1351 edited by Mosahab. “Sang” is a scale, which has different kinds (“Divani Sang”, “Mill Sang”, and “Cultivation Sang”) for water current measurement, applied in some parts of Iran. The quantity of Sang has been varied in different locations. Although it is a measure for river water discharges, it doesn’t have a clear concept about time factor (according to the official references). As it was mentioned in the scroll of water distribution system of Karaj River, written by Mirza Aqakhan, the prime minister, and the seal of Mirza Taqikhan Amirkabir:

“Sunday, 1267 H.A. (1846 AD). According to the decree of government, Karaj River water distribution is fixed and unchangeable and nobody can interfere. One sang is equal to 1 charak ×1 charak and the water flow river was divided to 84 Sangs. The schedule for water distribution started 40 days after the Spring.”

According to Zarrinehrood and Siminehrood regulations for water distribution, approved by council of ministers on May 7th. 1938, Divani Sang was determined as (10 cm×10 cm). As far as municipal and agricultural water consumptions have been highly concerned since 1941, the engineers estimated one sang equal to 13.3 l/sec. So one cubic meter per second is almost equal to 75 Sangs. Sometimes it is estimated 15 l/sec.

As far as they haven’t remarked on velocity, it is necessary to explain the consisting factors in brief.

If we assume the cross-section to be fixed, the discharge will directly be related to velocity of water. According to Darcy and modern science, the velocity is related to the quality of canal structure, cross-section, wet area and finally the slope. So by reducing the height of the cross-section, the width will be increased and vice versa. Consequently, the wet area will extremely be increased. If we assume the width is zero, the height goes towards infinitive and vice versa. In both cases the velocity of water will be zero. When the velocity becomes zero the discharge declines and goes towards zero.

If we consider the sources of water supply were qanats, springs and small rivers in rural areas, we would understand how our ancestors solved and determined the dimensions of canals and the velocity of water. It is clear that the determination of canals' dimensions depends on special condition. Our ancestors found out a very simple solution for this issue. As they store water in pool or reservoir at first. Then by removing more water from reservoir, they regulated the velocity. This method is still practiced in some parts of the country.

3-3-2- DIVIDERS

If the discharge of water sources were too high to determine the share of villages and cities and caused some problems to pass through the regular canals, our ancestors used dividers for qanats, springs and rivers.

Figures 38 and 39 show two dividers. One of them belongs to Feen Spring in Kashan and the other one belongs to Sheshtaraz River in Kashmar. Kashmar Divider delivers water to different villages by separate canals. The structure established on riverbed with a gentle slope. It consisted of different walls with sharp edges, which was installed on riverbed with definite distances from each other. Feen Spring Divider is illustrated on fig. 39. It was repaired a few years ago. But Kashmar Divider has preserved its simplicity and old structure.

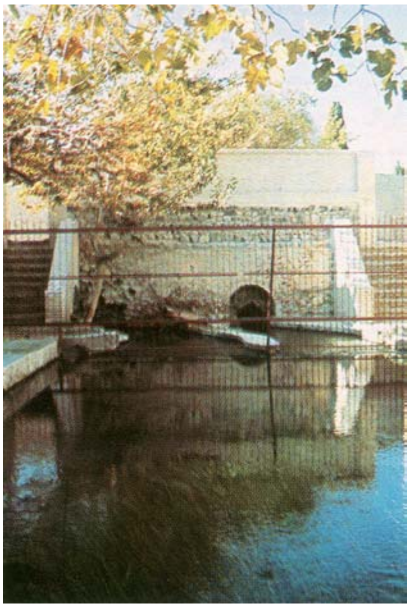


Fig 39, Feen Spring Divider in Kashan

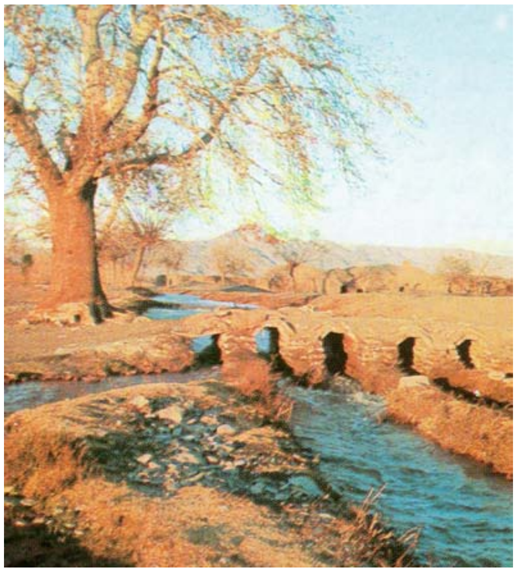


Fig 38, Kashmar River Divider in Khorasan

Wooden weir divider is another solution, which is technically valuable. This type has been common in the south part of the country and we encountered in Alle Benjeir's book. It was mentioned by Jlaledin Mohammad Benjeiri who was the son of Benjeiri the second, who passed away in the seventh century. He wrote two books about water distribution. He was the one who established wooden weir divider rule for qanat distribution in Shiraz suburbs. Wooden weir divider was a board, which installed in the middle of the canal and sticking some boards to it in order to divide and deliver water.

Wooden weir as mentioned was a measuring Weir. The difference between wooden weir divider and other types mentioned above (figures 40 and 41), concerning modern Hydraulic rules, the factors of Hydraulic friction and slope have no effect on water quantity so it was only related to the amount of water passed over the weir.

Rehbock and Thomson figured out some formula, but it isn't necessary to mention here.

The statements in Alle Benjeir's book indicated that there had been some other publications about water and irrigation as Jlaledin Mohammad Benjeiri who wrote two books about water distribution. He lived 3 centuries after Karaji and this situation showed, water and irrigation research never stopped after Karaji death.

As the investigators stated, there were some problems with dividers, like those installed in Khomain, they were similar to millstones and were completely rounded with hole in the middle.

3-3- USE OF WATERPOWER IN ANCIENT IRAN (FIGURES 42 AND 43)

As you know, water has energy, no matter where it is. When a part of energy changes into kinetic energy, it causes water movement through its path and the rest of energy stores in water.

The remained energy called potential energy. It exists in all materials. When something falls from an upper level, the potential energy changes into kinetic energy.

As a matter of fact water movement differs from free falling substances, because through water movement just a part of potential energy, which is stored in water changes into kinetic energy and the rest stores and can be used somewhere else while this is not true in free falling.

Our ancestors were quite aware of water energy and gradient and they got much benefit of it. The best evidences are the old water mills, which are under operation yet in different parts of the country.

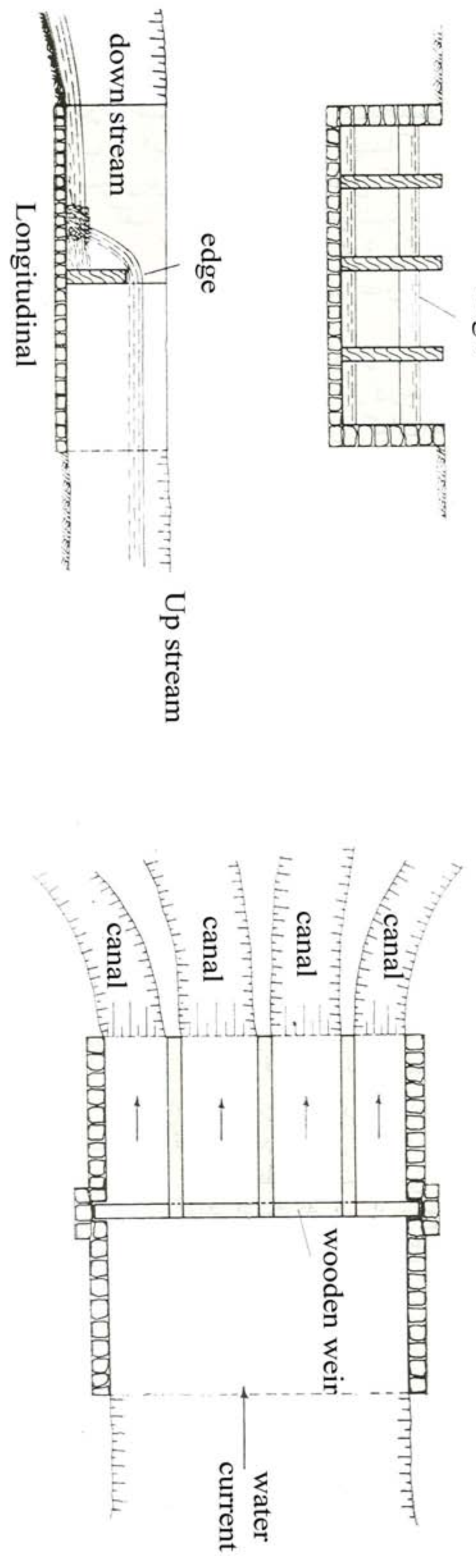


Fig 40, Wooden weir divider

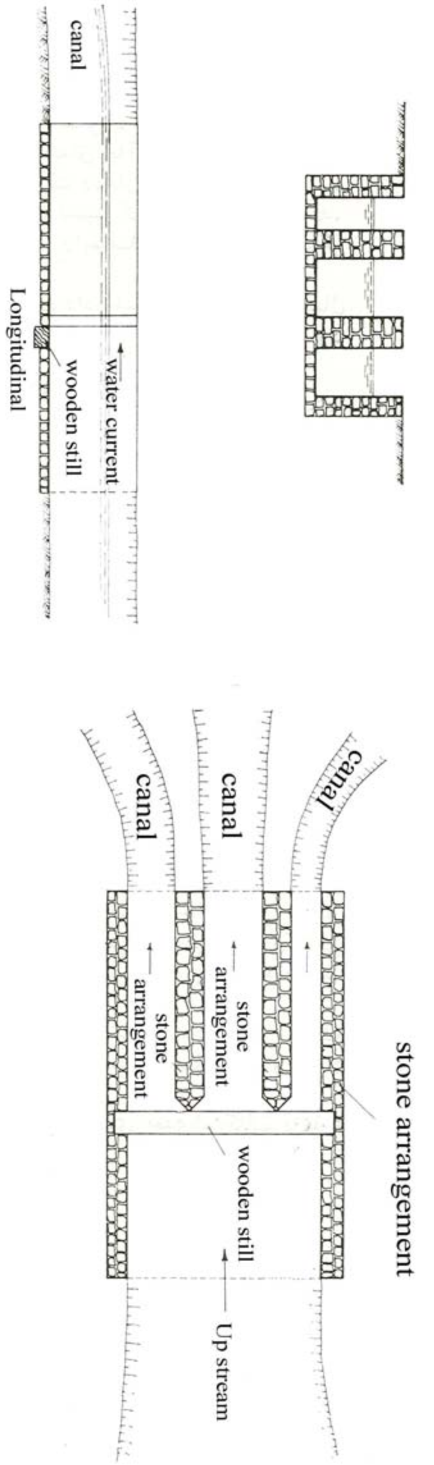


Fig 41, Divider with different canals, made of building materials

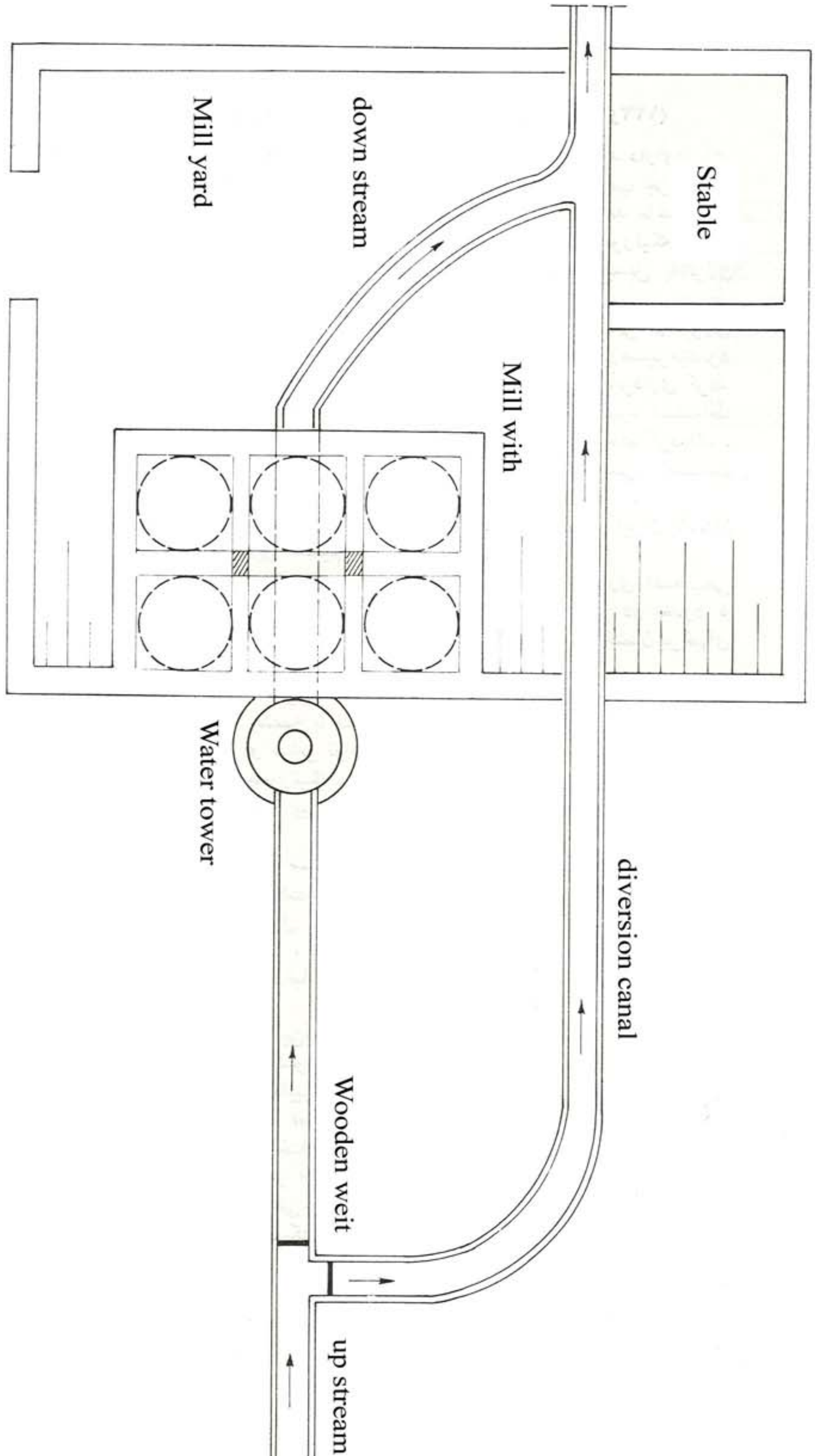


Fig 42, A brief map of water-mill in ancient Iran

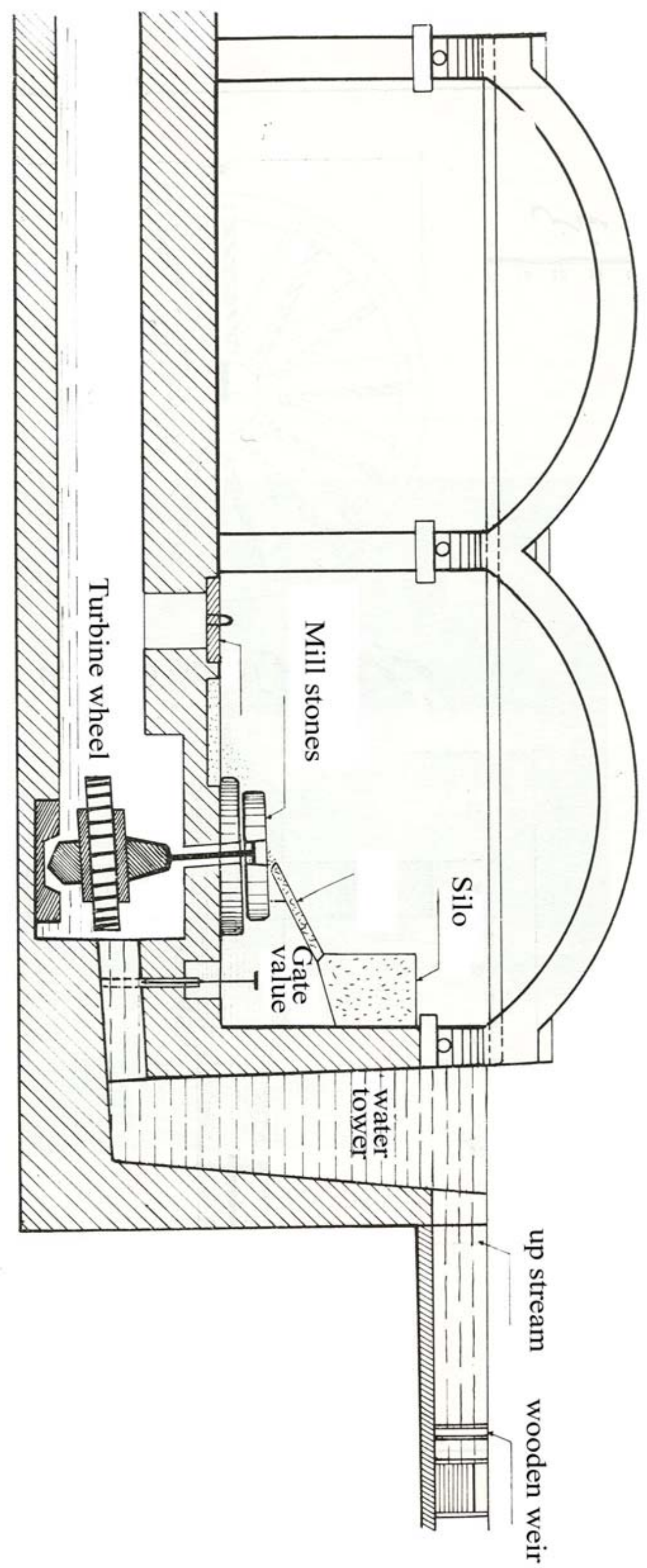


Fig 43, Longitudinal of a water-mill in ancient Iran

The water-mill system in ancient Iran consists of the following parts. It is necessary to bring out this point that, the location of water mills selected somehow to have 5 to 6 meters head between upstreams and down streams.

Apparently higher pressure caused problem for turbine's wheel and wouldn't let it work properly.

A- WATER RESOURCES

The resources, which were generally used to operating the mills, were rivers, springs and qanats. And they got much benefit from these resources in Gargar and Amir weirs and many other places. But the case was different in Feen Garden, as a part of river discharge supplies water for operating almost 75 mills located between Feen and Kashan and the villages in nearby.

B- UPSTREAM CANAL

This canal directly related to water resources. It was often covered with bricks and lime concrete. Besides the main channel, there was a diversion one or a wooden weir before water entered the tower. This diversion channel was connected to downstream channel and it diverted water while the mill was at rest. It was possible some mills operated just by one canal.

C- WOODEN TURBINE

This canal directly related to water resources. It was often covered with bricks and lime concrete. Besides the main channel, there was a diversion one or a wooden weir before water entered the tower. This diversion channel was connected to downstream channel and it diverted water while the mill was at rest. It was possible some mills operated just by one canal.

C- WOODEN TURBINE

Figure 44 shows a wooden turbine. It consisted of a wooden axle with a diameter, which gradually increased as it went down. The two ends of this axle are generally made of iron.

The lower end of the axle was fixed to a stone, which was the support of the turbine. The upper end tightened to the upper millstone, rotated when the turbine was under operation. The lower end of the axle had some grooves with blades, made of wood. These blades were 40 to 60 cm. long and their free ends were connected to each other. The blades respect to main axle had a moderate slope.

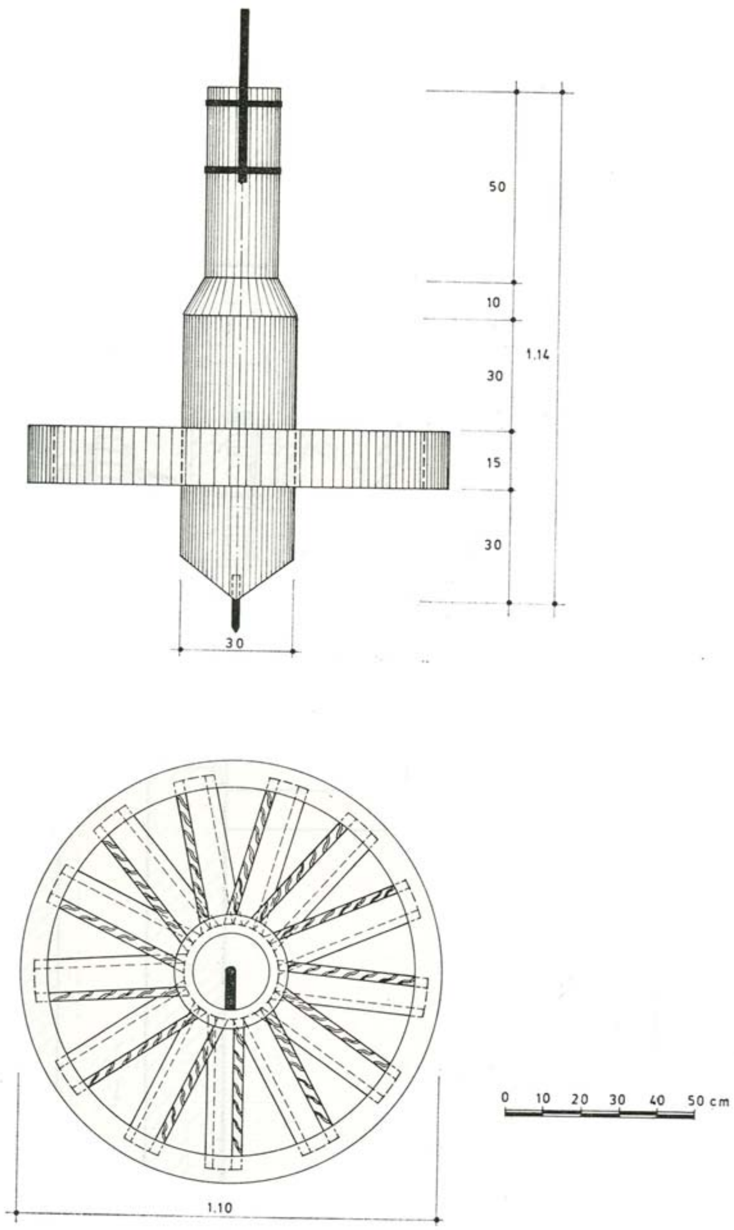


Fig 44, The map of turbine wheel of a water-mill in Iran

D- WATER TOWER

This tower was similar to an incomplete cone, and the cross-section decreased as it went down. In one of those towers in Kashan, the diameter was 2.5 meters at the top and 1.2 meters at the bottom. This tower led to a narrow channel with a wooden weir, which could be maneuvered from inside the mill in order to open and close. As it was mentioned, the difference between water level in upstream canal and the exit channel was about 5 to 6 meters.

When the mill was at rest, the tower was evacuated and water was diverted from behind of the mill (fig 45).

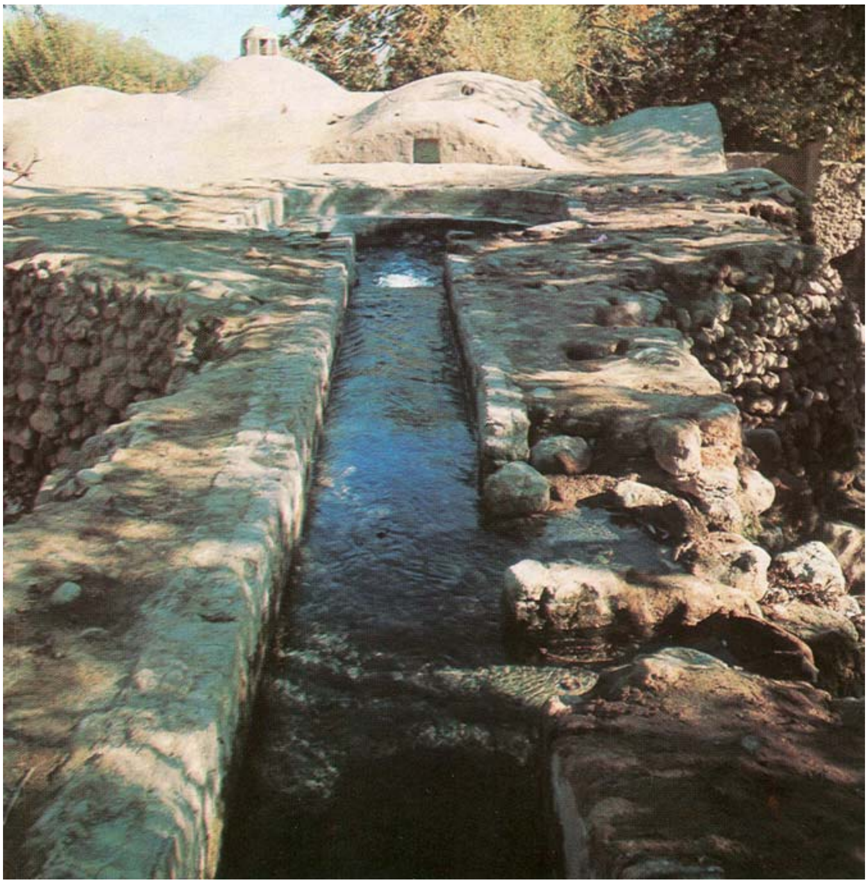


Fig 45, Here is Sohrab Canal which belongs to one of the mills in

Feen Gardan in Kashan. The spillway and diverting channel are shown in the right side and the roof of the mill in the rear.

E- MILLSTONES

The diameter of stones depended on water quantity and water head. For instance, the millstones of Feen Spring and Gargar Weir had a diameter of 1.6 meters and Amir Weir about 1.3 meters.

The lower millstone was very strong and unmovable, but the upper one, which was tightened to the axle of turbine, could rotate and it was generally lighter than the lower one.

In the middle of upper stone, around the axle there was a hole, which led the grain to the space between two stones.

The two stones were not completely horizontal; in fact they had a moderate slope. This simple technique caused flour jumped out from the highest point according to centrifugal force and collected in a shallow hole. Then the miller collected the flour in bags and delivered to the owners.

F- GRAIN STORAGE AND WOODEN HOPPER (FIG 46)

Grain was stored in a small room just above the millstone. And from the bottom of the room there was a wooden hopper, which led the grain to the sole in the middle of the upper stone of the mill. When the mill was under operation, caused vibration, its vibration reflected to the hopper and made grain move towards the hole in the middle of the upper stone.

G- DOWNSTREAM CANAL

When water passed through turbine, entered downstream canal and led to the river.

Fig 46, Upper millstone, hopper and flour site

CHAPTER FOUR

OLD DAMS IN ANCIENT IRAN

On the contrary to industry or qanat technology, the thought and design of small and large dams in proper places, down the valleys did not just belong to Iranian. As a matter of fact, some other developed countries must have implemented these types of water structures before us. However, Iran is historically considered at the top of the past dam builders.

Agriculture, industry and civilization are partially dependent on dam construction, so it is necessary to indicate the background of dam construction briefly in the world.

4-1- IRAN AND THE HISTORY OF DAM CONSTRUCTION IN THE WORLD

Fig. 47 shows all the old dams which had been constructed in Iran since 5000 years ago up to 1800.

Here is a brief about their specification and the history of dam construction in Iran and the world.

ANCIENT ERA:

About 2900 BC M. Menes the founder of the first Egyptian dynasty of kings constructed a dam to control the Nile River in Koshish in order to erect his capital city Memphis 20 km. downstream of the dam. The height and width of the dam were 15 & 450 meters respectively. Koshish Dam was a rock-fill dam.

There was another dam 30 km. South of Cairo near Qaravi village (2650-2465 BC).

The reservoir named Moeris it was very extensive, located in Fayum district and its upstream canal was about 400 km. This reservoir could control the Nile flood. It had two moveable gates and an earth-fill diversion dam, which delivered water to the farms on the west part of the riverbank. The area of the reservoir was about 2000 square kilometer with the capacity of 12×10q M3.

There were some old dams constructed on Tigris River about 600 to 700 BC. Here is a historical report about the subject. When Cyrus The Great defeated Babylonia, he ordered to construct some new water structures in this region. Herodotus stated that Cyrus The Great built a dam on Gyndes River which was one of the Tigris branches and diverted water to 60 canals.

In the new era of Babylonia, when Nebuchadnezzar II (605 – 562 BC) heard Darius The Great had ordered to construct 3 dams on Kor River to supply his Capital City Persepolis, he started to build a dam on Abo Habeh in south of Bagdad in order to competitive with the Persian king. Any way dam construction technology flourished by Sassanid kings especially during Shapour The First monarchy.

MIDDLE AGES:

It is not so easy to explain the details of dam construction technique in the other countries during the middle ages. Their names are listed on fig. 48 and the date of construction. According to the statements of historians and foreign scientists, dam construction technique flourished during the end of middle ages. As the first arch dam was Kobar constructed in 14 th. century between Qom and Kashan.

4-2- DAM CONSTRUCTION CONCEPTS IN ANCIENT IRAN AND THEIR ADAPTATION TO MODERN TERMS.

First of all, it is necessary to indicate the technical matter related to dam construction.

As it was already mentioned, dam construction technique started in ancient era.

The Persian term of weir is “Band”. The purpose of “Band” is to raise water level in order to divert water to the left and the right riverbanks. The foreigners call it “weir”, “wehr” and “deversoir”.

The old term for weir in ancient Iran was “Shadrarvan”.

4-3-1- WEIRS IN ANCIENT IRAN

As far as the irrigation development is directly related to improvement and progression of nations, it would be very interesting to determine date of construction of various weirs in ancient Iran, which have been remained so far. Although it is very difficult, by studying the history books, testing the materials, comparing their kinds and qualities we can approach to the aim. As a whole, we try to classify the dams according to their ages. As it was indicated, the age of dams in Iran can’t be accurate unless the future investigation approve it.

Fig 47, Map of Iran

1. Kosheish (about 2900 B.C.) and Sadd-el-Kafara (around 2500 B.C.)
2. Mashkai and Lakorian (around 2000 B.C.)
3. Homs (about 1300 B.C.)
4. Sudd-al-Arim (about 750 B.C.)
5. Ajilah, Qayin and Bavian (about 700 B.C.)
6. Basawakkulam (about 430 B.C.) and later Sinhalese dams
7. Sudarsana (about 300 B.C.)
8. Gukow (about 240 B.C.)
9. Siq and Kurnub (around Christ)
10. Cornalbo, Proserpina and Esparragalejo (1st. century)
11. Dams near Homs (Roman)
12. Orükaya (Roman)
13. Cavdarhisar (Roman)
14. Al-Harbaqa (Roman)
15. Kaerumataike (162) and Daimonike (1128)
16. Shadhorvan (about 270)
17. Dara (about 550)
18. Moti Talav (10th century)
19. Bhojpur (11th century)
20. Almonacid (11th century)
21. Kebar and Saveh (14th century)
22. Cento (1450)
23. Spiegelfreudersee (1460)
24. Tibi (1589) and Elche (1590)
25. Ming (16/17th century)
26. Ikinci (1651)
27. St. Ferreol (1675)
28. Oderteich (1721)
29. Pabellon, Los Arcos and San Jose de Guadalupe (18th century)
30. San Diego and Los Angeles (18th century)

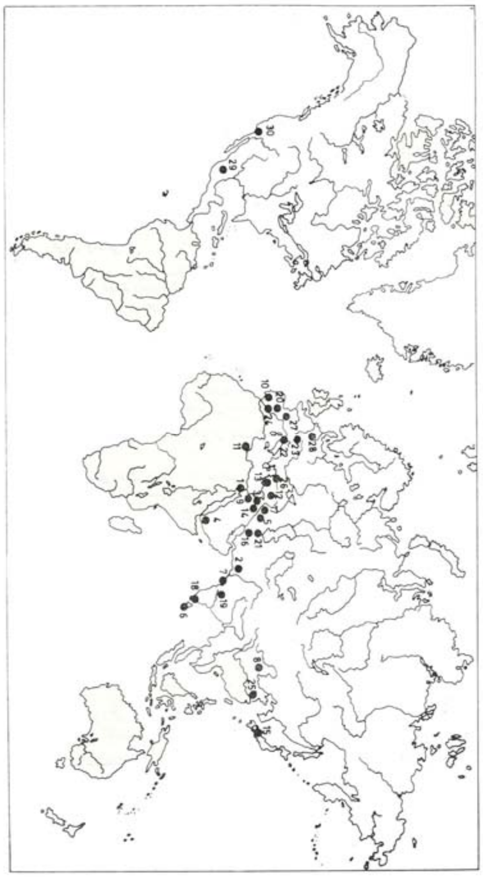


Fig 48, Shows the location of a number of historical dams in the world according to their date of establishment up to the 18 th century.

ACHAEMENIAN ERA (AGE BETWEEN 2000 TO 2500 YEARS, FIGURES 49 AND 50)

1- Cyrus The Great Weir: This dam was located at the source of Tigris River in Syria, apparently this dam erected in Gyndes.

2- There were 3 weirs on Kor River constructed by the order of Darius The Great. The trace of one of them is still remained. This weir was located just below the new Cyrus The Great Dam (Dorodzan dam). The large Darius The Great Canal took water from this weir and poured to a pool. It is decided to get benefit form this canal again after making necessary changes.

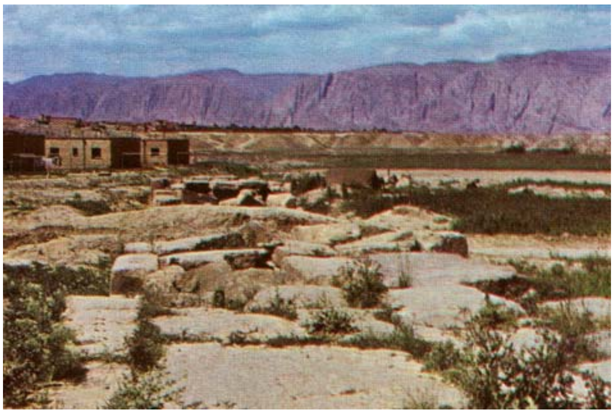


Fig 49, The remains of Darius The Great Weir on Kor River (age about 2500 years)

Fig 50, The remains of water intake from Darius The Great Weir on Kor River

3- Bahman Weir in Fars: This dam might be constructed during Achaemenian era and it is still remained. Without any doubt, there were many dams constructed during Achamenian era in different parts of Iran (like Khozestan). They might be ruined or repaired by Sassanids kings and recorded under their names in history (fig 51).

4- Darius The Great Weir (Ramjerd Dam): This dam sometimes called Ramjerd Dam too.

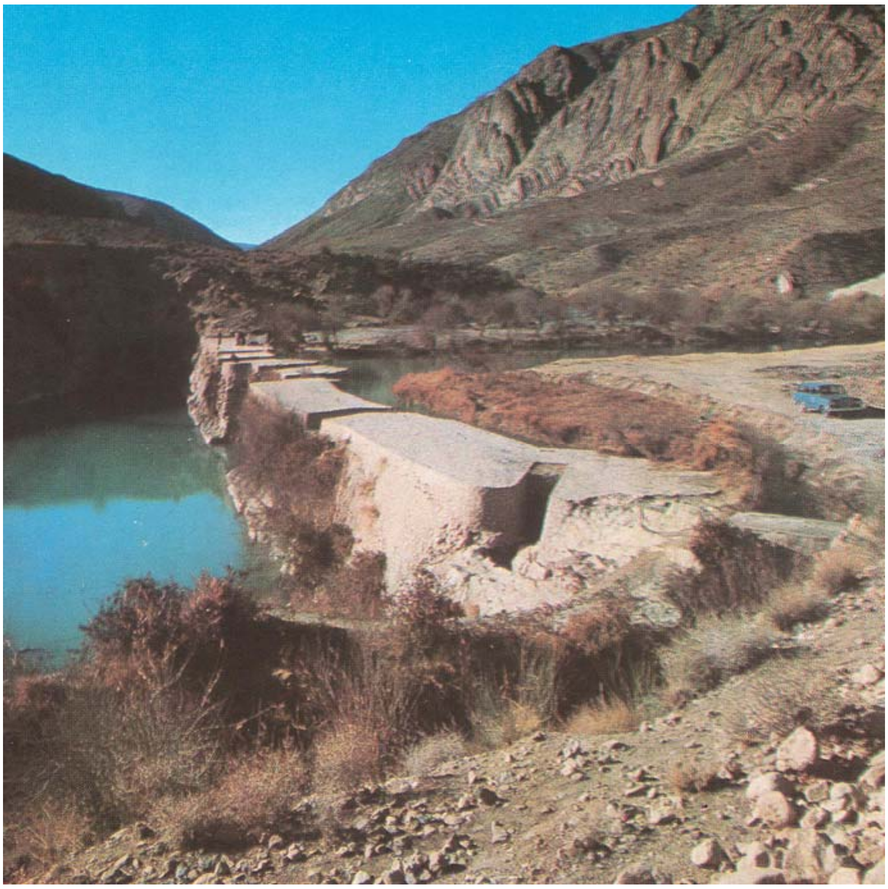


Fig 51, Bahman Weir in Shiraz (age about 2000 years).

SASSANID ERA (AGE OF DAMS BETWEEN 1300 TO 1700 YEARS)

5- Aqili Weir: It was located in north of Shoshtar on Karoon River, but its remains were completely destroyed by flood in 1968.

6- Dokhtar Weir: There are still remains of many huge canals which can be seen around this weir on Karoon River.

7- Mizan Weir: It was the first weir which was constructed at the beginning of Gargar Canal which was discussed in chapter 3 and it is still under operation (figures 52 & 53)

8- Gargar Weir Bridge: It was constructed on Gargar River after Mizan Weir in Shoshtar. The upstream canals and Gargar Water Mills were feeded by this dam. It is still under operation (fig 54).

9- Aiar Weir: It was constructed on Gargar River, very few remains of it still exist.

10- Khodaafarin Weir: It was constructed on Gargar River; very few remains of it still exist.

11- Dara and Qeer Weirs: It was just heard about those two weirs, but there are no sign of them anywhere.

12- Lashgar Weir Bridge: It was constructed on the eastern branch of Darian River; its remains are still existed (figures 55 & 56).

13- Shah Ali Weir Bridge: It was located below Lashkar Weir Bridge on the eastern branch of Darian Canal.

14- Shoshtar Weir Bridge: It had 40 gates and 500 meters long, it was described in chapter 3. This weir bridge is out of order now (figures 57 & 58).

15- Dezfool Weir Bridge: It is located in Dezfool City and very few remains of it, still exist.

16- Paipol Weir Bridge: It is located in Paipol. It was described in chapter 3.

17- Karkheh Weir: Its location is not specified, but it might be located between Shoshtar and Paipol. Shavoor River and many other streams were discharged by this dam. Unfortunately there is no remains of it.

18- Khak Weir: It is located in the path of Darian River. There are few remains of it at the present time.

19- Large khodaafarin Weir Bridge: There is still some remains of it on the rocks in Karoon Riverbed (figures 59 & 60).

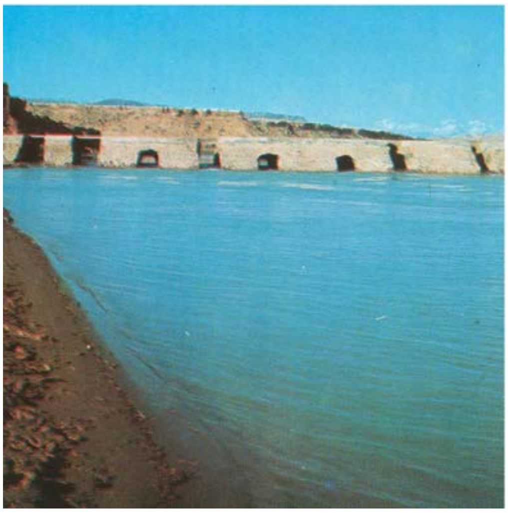
20- Ardekan Weir: It is located on Maroon River, 175 km. East south of Ahvaz.

21- Shahreloot Weir: It is located 285 km. East south of Ahvaz on one of the branches of Karoon, which passed through Tuo Village. There is still some remains of it.

22- Darvazeh Weir: It is located 150 km. East south of Shiraz, near Gabra Peak.

23- There were various barriers in Persian Gulf peninsulas like Qeshm etc. (figures 61 & 62).

24- Mond Weir: The remains of the dam had been destroyed but there was a report from British councilor who saw the remains of the dam himself about 70 years ago.



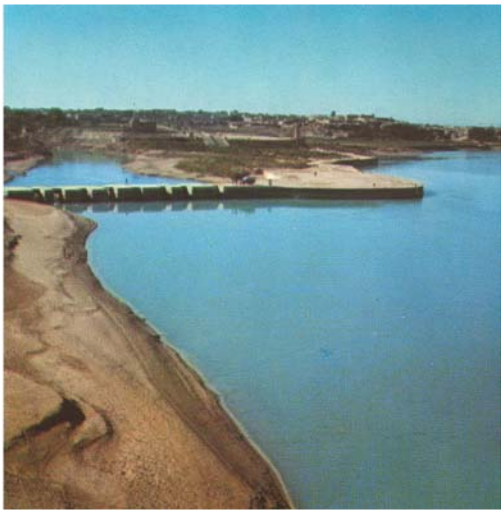
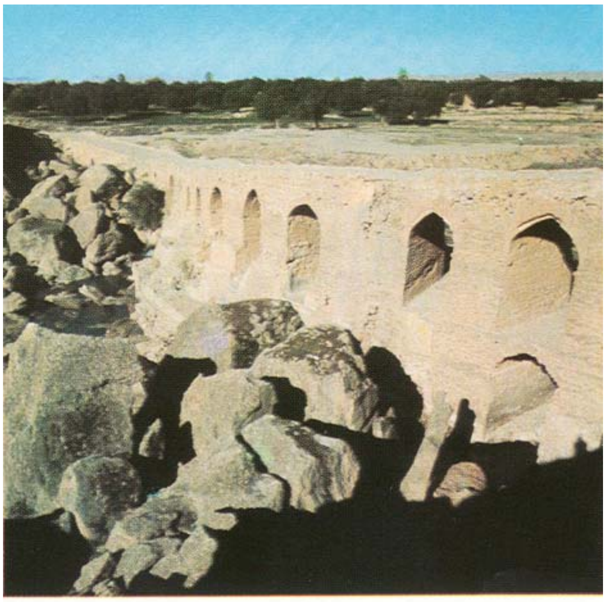


Fig 52, 53, Mizan Weir in Shoshtar, the pictures were taken from upstream, although it is 1700 years old, it is still under operation

Fig 54, Gargar Weir in Shoshtar (age about 1700 years). It is still under operation



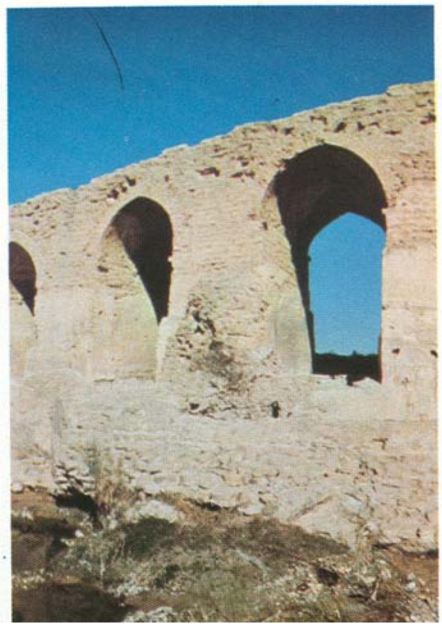
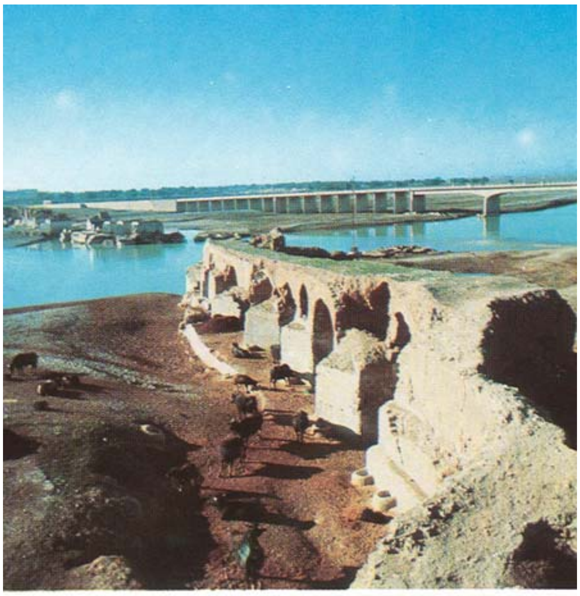


Fig 55, 56, Lashgar Weir (age about 1700 years)



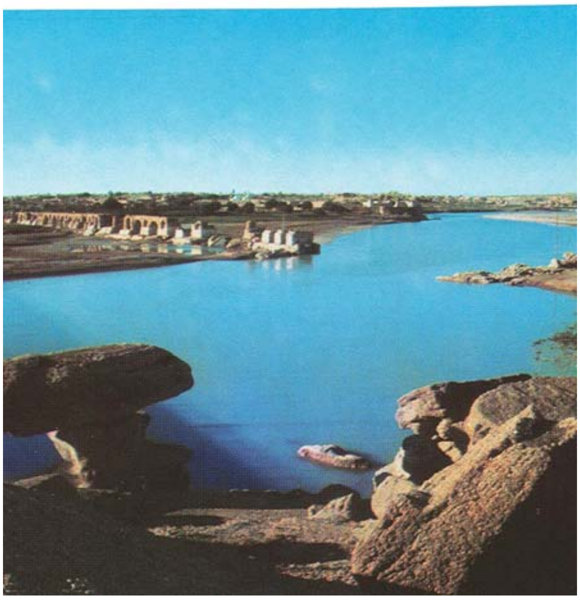
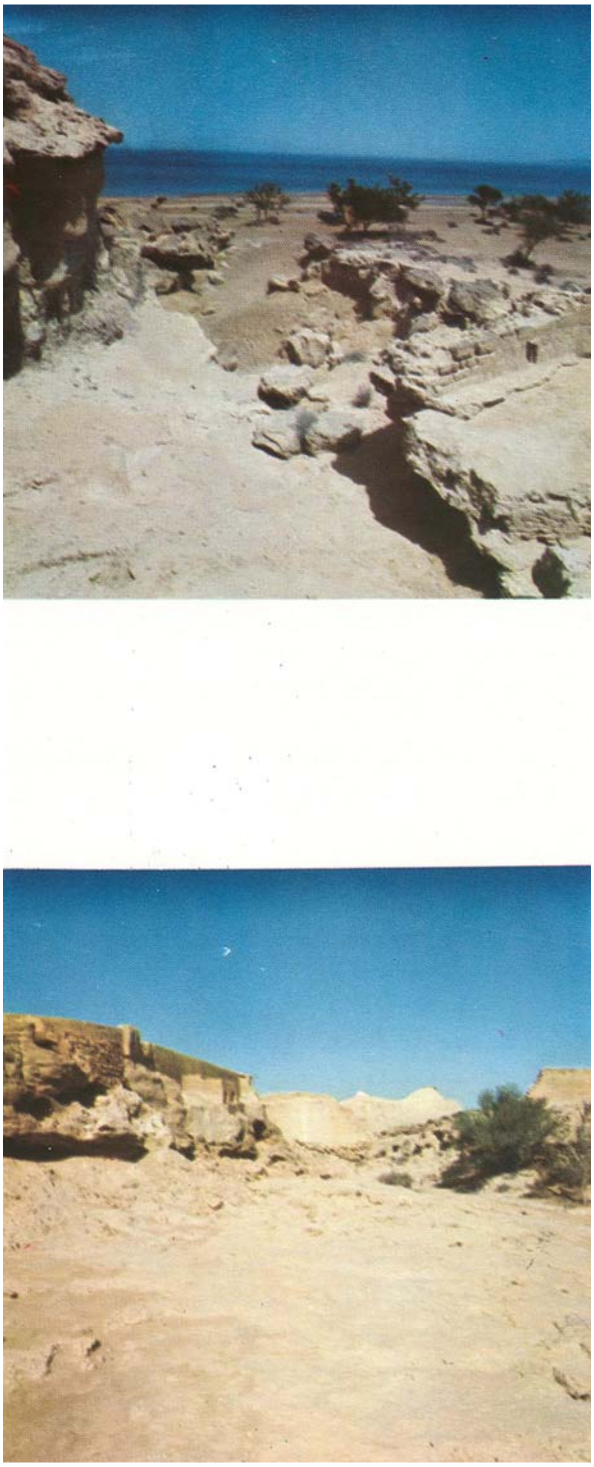


Fig 57, 58, Shapour The First Weir on Karoon River in Shoshtar. (age 1700 years)

Fig 59, The ruined structure of Argan Weir on Maroon River.

Fig 60, Water intake at the upstream of Argan Weir. It was constructed like qanat.



Figures 61 & 62, The remains of two old weirs in Qeshm Peninsula, age about 1500 to 1700 years.

ALE BOYEH ERA (AGE OF DAMS ABOUT 1000 YEARS).

25- Amir Weir: It was erected on Kor River, 35 km. North of Shiraz. The builder was Azadaddavleh Deylami. It is still under operation (figures 63 & 64).

26- Feizabad Weir: It was constructed on Kor River, about 222 meters long, 5 to 12 meters wide at the crest and 3 to 4 meters high. It was a rock-fill with lime concrete dam. There were about 22 water mills around the dam, but they are out of order except two of them. Apparently, the original dam was ruined, but it was repaired later on (figures 65 and 66).

27- Tilkan Weir: It was about 162 meters long, 7.5 meters wide at the crest, 16 meters at the bottom and 6 meters high. It was a rock-fill and lime concrete dam, but some sections were constructed with bricks and lime concert. There were some water-mills around the dam, but all of them were ruined except 8 units, which their remains can still be seen. The original weir was ruined, but it was repaired later on (figures 67 & 68).

28- Moan Weir: It was about 66 meters long, 8 meters wide and 6 meters high. It was constructed with stone, bricks and lime concert. The original dam was destroyed but it was repaired later on.

29- Hassanabad Weir: The original dam was completely destroyed and a new one was replaced.

30- Jahanabad Weir: It was about 50 meters long, 12 meters wide and 4 to 6 meters high. It was a rock-fill dam with lime concrete, the original dam was ruined, but a part of it is still remained.

31- Darvazeh Qoran Weir: It is located in Shiraz, but it is full of sediment.

32- Dokhtar Earth-fill Dam: It was located in the north of Bakhtegan Sea. It was 855 meters long, 15 meters at the crest, 23 meters at the bottom and 6 to 7 meters high. The water resource was a spring with discharge of 2 m^3/sec in spring. It is out of order at the present time (figures 69 and 70).

QAZNAVIAN ERA (AGE OF DAMS ABOUT 900 YEARS)

33- Toos Weir Bridge: It was located in Toos City. According to the historical reports, the daughter of Ferdowsi the great poet constructed it and endowed. Unfortunately, this historical structure was destroyed during the implementation of new projects in the region.

34- Sheshtaraz Weir: It seems the Sheshtaraz Dam was constructed in this era, because the structure is different from the other weirs in outlet system (figures 71 and 72). The diaphragm was washed out and it is not sealed any more.

EILKHANIAN ERA (AGE OF DAMS ABOUT 700 YEARS)

35- Saveh Weir: It was said; Saveh Weir had been constructed by the order of Shamsedin, the prime minister of Eilkhanian. It is located about 150 km. southwest of Tehran. The diaphragm underneath of the foundation was washed out, caused leakage through it and made the dam unusable, (figures 73 & 74).

36- Kobar Weir: This dam is located 170 km. southwest of Tehran. It is an arch dam. It is possible to put it under operation again (figures 75 & 76).

37- Tabas Weir: It is an arch dam and located 400 km. southwest of Meshad. It was constructed in a very narrow valley. The foundation was strengthened with bricks during Safavieh era. It is full of sediment.

SAFAVIEH ERA (AGE OF DAMS ABOUT 300 TO 400 YEARS)

38- Qohrod Weir: It was constructed by the order of Shah Abbas The First. It is located about 30 km. Southwest of Kashan. It is full of sediment (figures 77 & 78).

39- Qamsar Weir: The structure is similar to Qohrod Weir and it is located about 30 km south of Kashan. It is full of sediment (figures 79 &80).

40- Akhelmad Weir: It was constructed during Shah Abbas The Second. It is located 60 km. southeast of Meshad. It is out of order, but it is possible to rehabilitate it (figures 81 & 82).

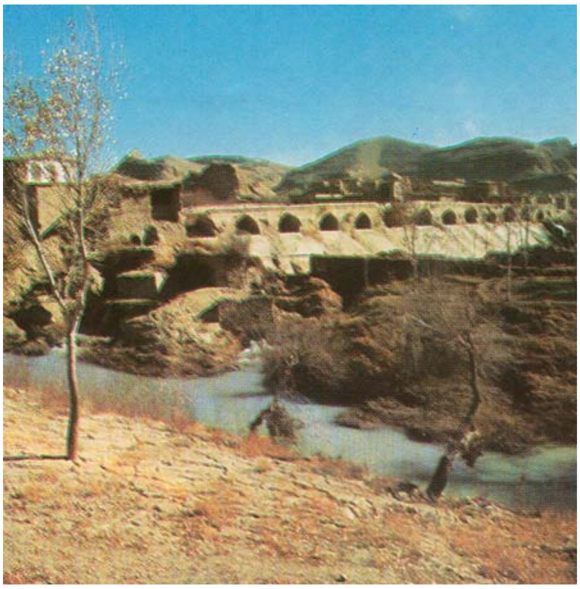


Fig 63, Amir Weir Bridge was one of the important triple-purpose structure in ancient Iran (age about 1000 years)

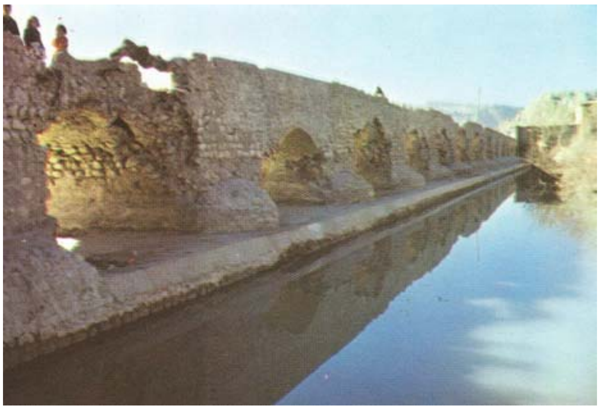


Fig 64, Amir Weir Bridge, view from upstream

Fig 65, Feizabad Weir on Kor River (age about 1000 years)

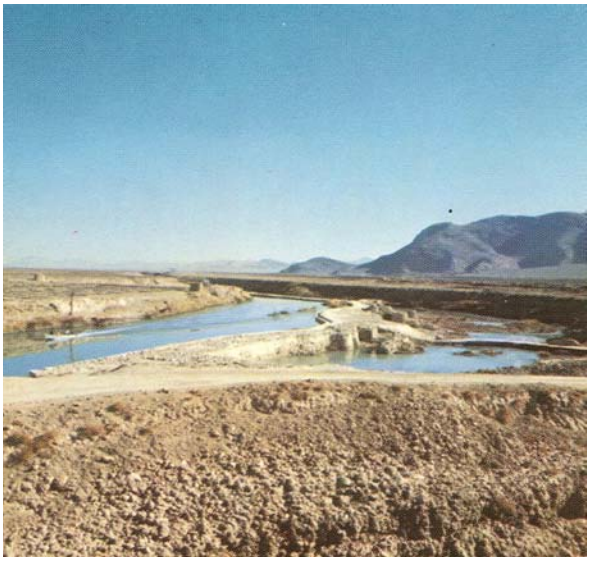


Fig 66, Feizabad Weir which was constructed as bank protection of the river

Fig 67, Tilikan Weir Bridge on Kor River. Water-mills are in the picture.
(age about 1000 years)

Fig 68, Tilikan Weir Bridge on Kor River (water mills)

Fig 69, Dokhtar Earth-fill Dam, in the north of Bakhtegan Sea, Fars
(age about 1000 years)

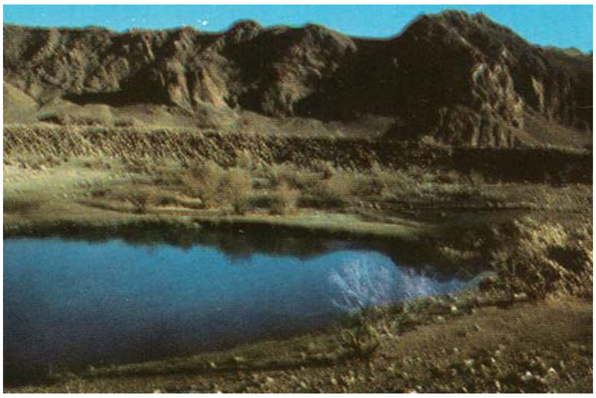


Fig 70, Dokhtar Earth-fill Dam, the crest and Bakhtegan Sea can be seen in the rear

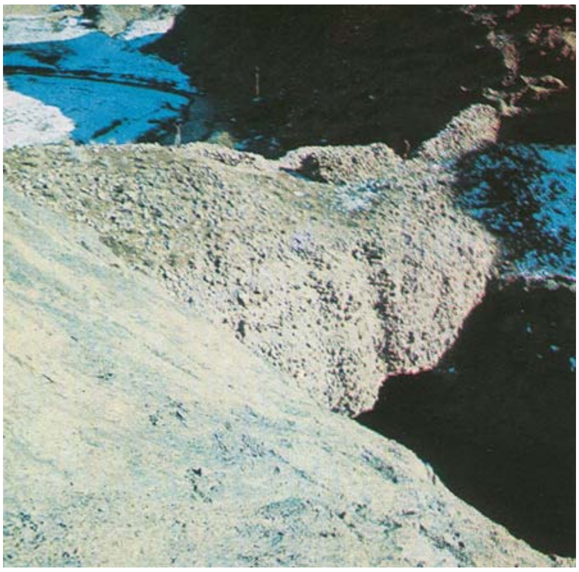


Fig 71, Sheshtaraz Weir in Kashmar
(age about 900 years)

Fig 72, Sheshtaraz Weir in Kashmar
(view from downstream)

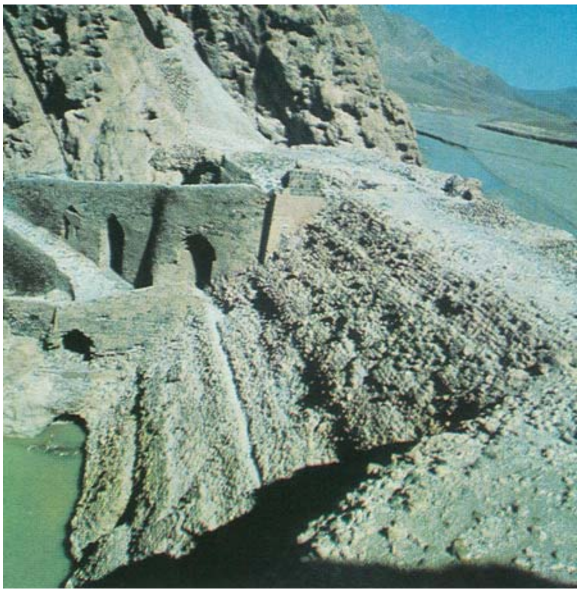


Fig 73, Saveh Weir, view from upstream
(age about 700 years)

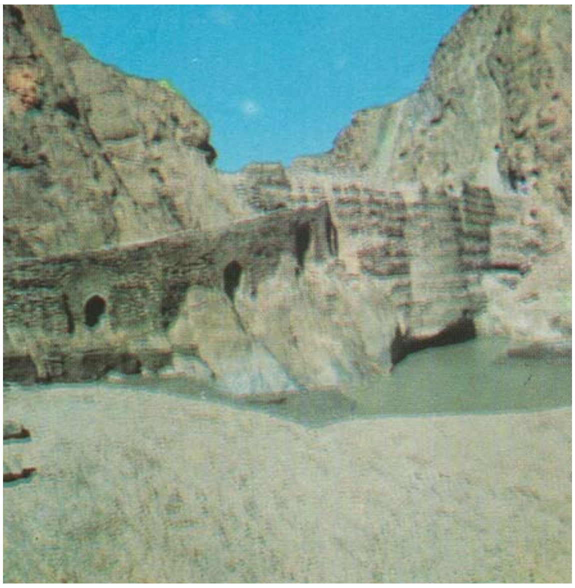


Fig 74, Saveh Weir, view from downstream, with the reservoir and sediment as shown in the picture

Fig 75, Kobar Arch Dam in Qom, view from downstream (age about 700 years)

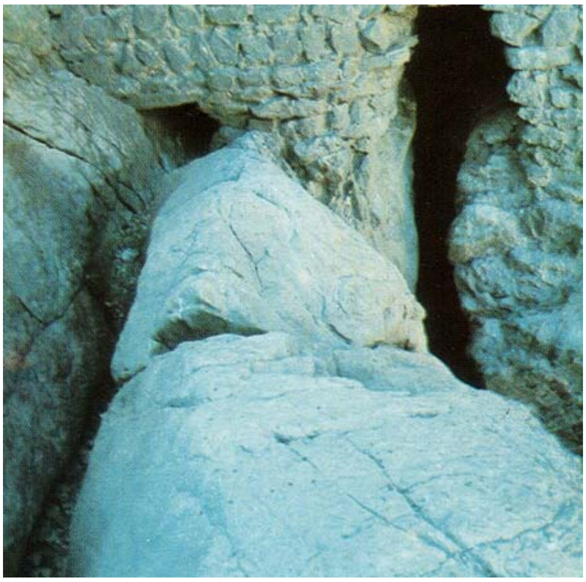


Fig 76, It shows kobar water outlet and the tunnel which Supplied water for Carvanserai located 3 km. far from the weir

Fig 77, Qohrod Weir in Kashan (age about 400 years)

view from downstream

Fig 79, Qamsar Weir, the reservoir is full of the sediment
(age about 400 years)

Fig 78, Qohrod Weir in Kashan, view from upstream.
The reservoir is full of sediment.
Water tower can be seen in front

Fig 80, Qamser Weir, view from downstream. It is possible to see the lime concrete of the body in the middle. There are the remains of one of the water towers.

Fig 81 & 82, Akhelmad Weir in Khorasan
(age about 300 years)

41- Khajoo Weir Bridge: It was constructed during Shah Abbas The Second, in Esfahan (Fig 83).

42- Fariman Weir: It is located 60 km. southeast of Meshad. It was constructed by Shah Abbas The Second. This dam is still under operation (figures 84 and 85).

43- Kalat Weir: It is located 90 km north of Meshad.

44- Korit Dam: It is located 400 km southwest of Meshad, it was an arch dam with the height of almost 100 meters. The reservoir is full of sediment (fig 86).

45- Salami Weir: It is located 200 km. south of Meshad near Khaf, it is still under operation (figures 87 and 88).

46- Golestan Weir: It is located 30 km. north of Meshad, the reservoir has been filled with sediment (figures 89 &90).

47- Toroq Weir: It is located 15 km. far from Meshad, The reservoir has almost been filled with sediment, but it is still under operation (figures 91 & 92).

48- Ashraf Weir: It is also called Abbasi Weir. It is located 5 km. south of Behshahr. It was a strategic structure. There was a watch – tower near the reservoir. There are also the remains of an old palace in the middle of it. This dam is still under operation (figures 93 & 94).

49- Qazveen Weir, It is located 160 km. northwest of Tehran.

Fig 83, Khajoo Weir Bridge, constructed during Safavieh era.

Fig 85, Fariman Weir, view from downstream

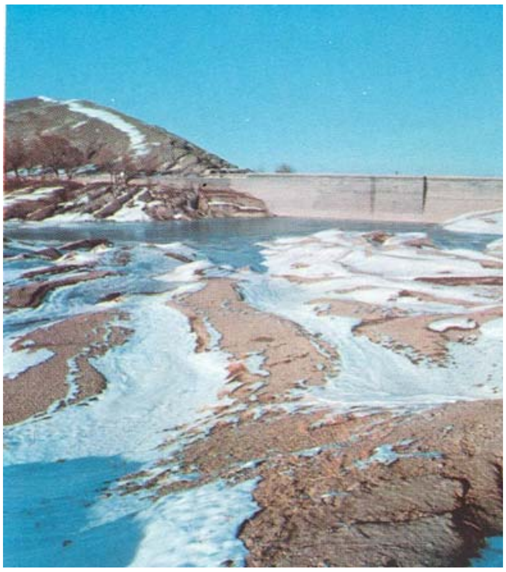


Fig 84, Fariman Weir, view from upstream
(age about 300 years)

Fig 86, Koreit Dam in Tabas, it is an arch dam, the height is more than 100 meters. The reservoir is full of sediment
(age about 400 years)

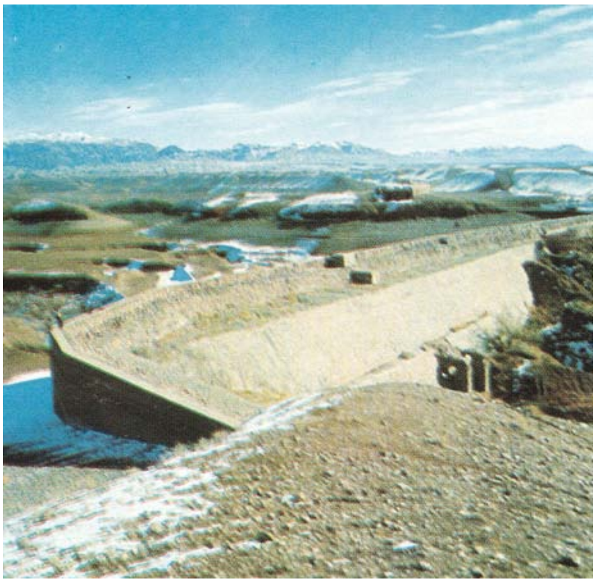


Fig 87, Salami Weir in Meshad (age about 300 years)

Fig 88, Salami Weir, view from upstream

Fig 89, Golestan Weir in north of Meshad, the reservoir is full of sediment (age about 300 years)

Fig 90, Golestan Weir, view from downstream

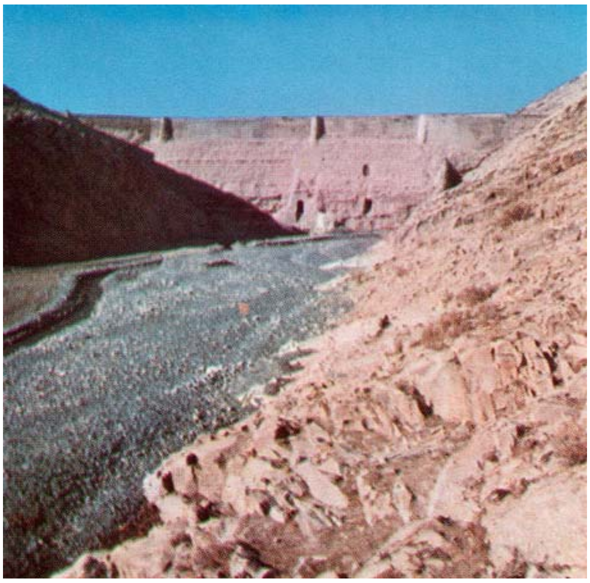


Fig 91, Toroq Weir in Meshad (age about 400 years)
view from downstream

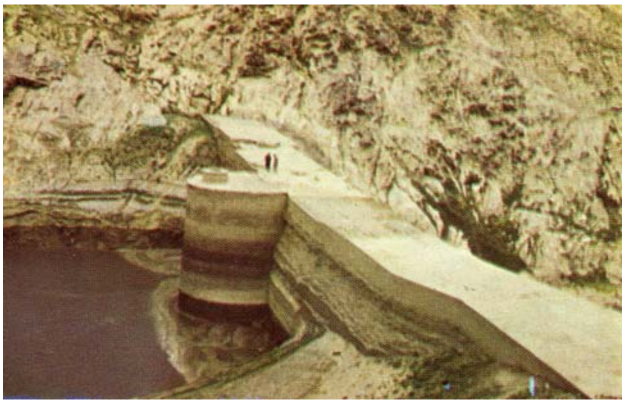


Fig 92, Toroq Weir, view from upstream with water tower

Fig 93, Ashraf Weir in Behshahr, view from downstream
(age about 300 years)

Fig 94, Ashraf Weir, the crest and reservoir

RECENT ERA (AGE OF DAM ABOUT 100 TO 200 YEARS).

50- Dareh Weir. It is 6 km. far from Birjand, it has been related to Shokat Almolk Alam (figures 95 & 96).

51- Omar Shah Weir: It is located in Birjand, perhaps it is as old as Dareh Weir. But it has been repaired in more recent years. Omar Shah Weir is an arch dam and it has two columns in the middle to make it stronger against water pressure (figures 97 and 98).

52- These dams under No 50 and 51 need to repair, in this case they can be put under operation.

The name of those dams, mentioned here have been collected according to the records, historical documents and the reports of investigators and tourists during many years.

Undoubtedly there would be many other dams in northwest and west parts of Iran, which have been unknown to us so far (fig 99).

4-3-2- TECHNICAL SPECIFICATIONS OF WEIRS IN IRAN

1- MATERIALS (FIG 100)

It is obvious that they tried to use local materials as: stone, brick and lime concrete. Perhaps, by the shape and the dimensions of bricks which used in dam construction and compare them with other dams can determine the real age of dams.

As a whole, bricks and stones with lime concrete make the dams resistible against lateral pressures. It should be mentioned that dam builders were very enthusiastic about the quality of materials in ancient Iran.

2- THE SHAPE OF DAMS AND TRANSFERRING THE LATERAL PRESSURES,

There are two main forces in dam construction, the weight of body and the lateral forces.

(a) Gravity dams,

Transferring the vertical force, which is the weight of body makes no difficulty, but the water pressure against dam makes difficulty to transfer the forces to the ground. Resisting against horizontal forces (water pressure) they had to increase the dimension of the body as large as the result of vertical and horizontal forces pass through equilibrium point and all the forces reflect to the foundation. It is obvious if the dimensions of walls of pools and ponds are not sufficient, the horizontal water pressure will ruin the walls. The experience leads us to make the walls thicker and heavier to resist against horizontal force.

In dam construction technology, when they increase the dimension of dam to resist against horizontal pressure, they call it gravity dam. Most of dams in Iran are gravity ones.

(b) Arch dams,

As it is possible to transfer the vertical forces to the foundation by arch, the same technique is used in dam construction and transfers the lateral pressures to the ends of the body. This type of dam call “Arch dam”. Perhaps it is necessary to mention this point that western countries have believed that the detection and usage of arch in structures belong to Romans and Atroskians. But Dr. Negahban proved that Iranian had used “Arch” in their structures before Romans by his excavation in Haftapeh.

Iranian used many initiatives and discoveries in dome of masques, which are not necessary to mention here.

Anyway the Iranian dam builders had known much about arch characteristics and transferring the load by making the dams arch form. So it must have been related this technique to Iranians. There were three arch dams in Iran, which were mentioned before (fig 101).

(c) Buttress dams,

The body of those dams are rather thin, but there are some triangular pillars which strengthen the dam against water pressure. The pillars in Akhelmed Dam were cylindrical form. But there are two pillars almost at the middle section of Omar Weir. There are a large pyramid as a pillar in the middle of Fariman Dam which strengthen the body. Probably they added this section later on.

(d) Dam site

All the dam sites, which were chosen, had suitable conditions, such as narrow valleys and geological situation. They were mostly located in mountainous region, which were very difficult to reach the sites. So we should accept that the old experts and dam builders found these locations by investigation and searching.

Fig 95, Dareh Weir, a part of reservoir is filled with sediment

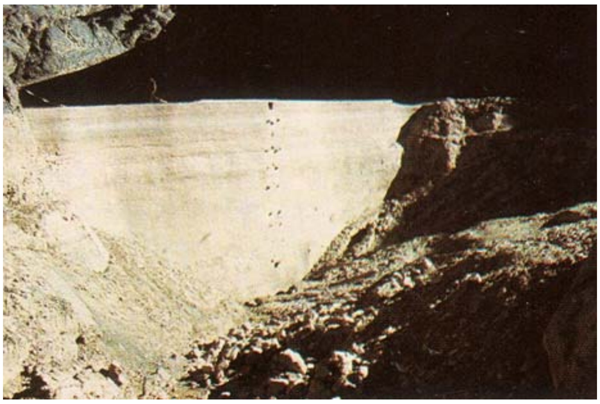


Fig 96, Dareh Weir, a part of reservoir is filled with sediment.

Fig 97, Omarshah Weir in Birjand, (age about 200 years)

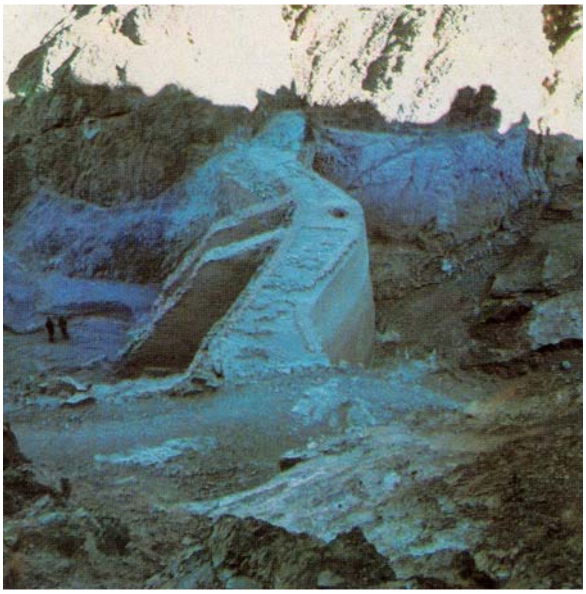


Fig 98, Omarshah Weir in Birjand, it is an arch dam with two pillars in the middle

Fig 100, Qamsar Weir, the reservoir is filled with sediment and the body was ruined. The picture shows the quality of lime concrete, there is water tower in the middle with stairs made of bricks.

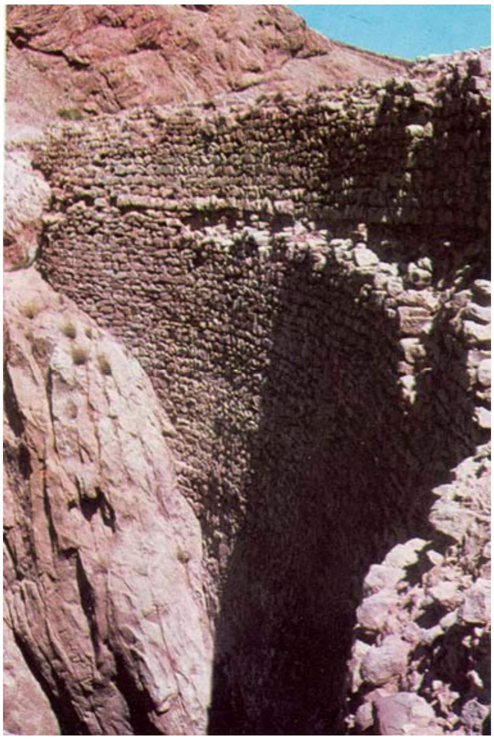


Fig 101, Kobar Arch Dam in Qom

(e) Dam foundation

The conditions of dam foundations are quite different. In some places where bedrocks located on the riverbeds, the foundations have still remained without any deformation after centuries, although the reservoirs are full of sediment. (fig 102)

But in many cases they were not able to excavate the foundation to reach the bedrock, so they established the dam on alluvial soil. It is obvious that these dams couldn’t be stable through the years. For instance: Saveh Dam and Sheshtaraz Dam in Kashmar and so on…

(f) Water towers

Most of the storage dams in Iran were 15 to 40 meters high. So it was obvious when they wanted to open the intake valve, the pressure of water made some problems for dam builders and operators during early stages. Finally, Iranians found out an interesting solution for in ancient time. It was the establishment of water tower with several holes in different elevations at the upstream beside the body of dam, which extended up to the crest.

Establishing stairs around the tower from the crest to the lowest intake hole, the guards could go down to open or close the holes.

This technical device could be seen in all dams for taking water. In some dams there were even two water towers (Qamsar Dam) with a considerable distance from each other. In Sheshtaraz Dam there were two water towers close to each other. This type of structure didn’t exist in other dams.

In most water towers, there could be found many laminated limestone, as water dropped down. Investigators try to find out how long those dams had been under operation by studying these sheets of limestone (figures 103 & 104).

(g) Delivery canals

The structure of water towers clearly shows, how water enters the tower and leads to the stilling basin and then to the riverbed to supply irrigation needs. But in Kobar Dam, water diverted to a canal along the right bank of the river about 20 to 25 meters above riverbed. The details come later on.

(h) Flood release system

It was necessary to establish a flood release system for all dams to evacuate the excess water to save the dams during flood events.

The simplest way for evacuating flood in the past was over topping (Saveh and Amir Weirs). Of course this system would be very dangerous for the structure of the dam, because the drop of water over the body and the foundation started to erode the foundation and destroy the whole structure.

This situation happened for many dams in Iran (Sheshtaraz, Saveh and Qamsar Dams). Because after over-topping, the foundation washed out and caused some holes at the bottom of the dams.

In order to eliminate the above dangers, they had to find a passage without involving the body and original sections of dam to evacuate the flood. In some dams they lowered a part of the crest for evacuation. It was possible to lower down both sides of dam for flood to pass through. Generally leads water to pour over natural rocks of mountains to lose its energy.

The later solution caused the builders could save the dams and foundations without any harm.

It should be concerned that the age of some dams in Iran are between 2500 to 3000 years, and for sure there have been many catastrophic floods during this long period of time. Without any doubts there were some other events like earthquake, which made some effects on dams (figures 105 and 106).

Operation and present condition of dams:

A number of dams in Iran like Amir, Fariman, and some dams in Shoshtar have survived and are under operation now. But the reservoir of many other old dams have been filled with sediment. Some of them got out of order after a period of operation.

During flood events, over-topping destroyed many dams in Iran. As it was already mentioned, there were some cases that water dropping over the body and the foundation of dam damaged the body and destroyed the foundation. Finally, the whole structure collapsed.

As the foundation of Amir Weir was well done, the stilling basin has naturally been sustainable and the dam has been quite resistible against water energy, consequently the structure has remained without any damage up to now.

In Esfahan, the foundation of Alahverdikhan Weir Bridge in downstream was paved with stone in order to protect it from destruction. Beyond the stone pavement there was a natural stilling basin to restore equilibrium between Hydraulics situation and water energy. That is why the structure has been remained without any harm (fig 107).

Another reason why it can’t be used Iran old dams is sediment, which has filled the reservoirs. This is a problem without a decisive solution even at the present time. So the useful life of all dams are limited, depending on the amount of sediment which carries by the river.

As it was mentioned before, there are some old dams in Iran, which are under operation yet. Because it is possible to evacuate and wash out the small dams’ reservoirs every year. This technique uses for Fariman Dam. As this dam is still under operation after 300 to 350 years. It can be an important subject for water economy, which should be studied about in future.

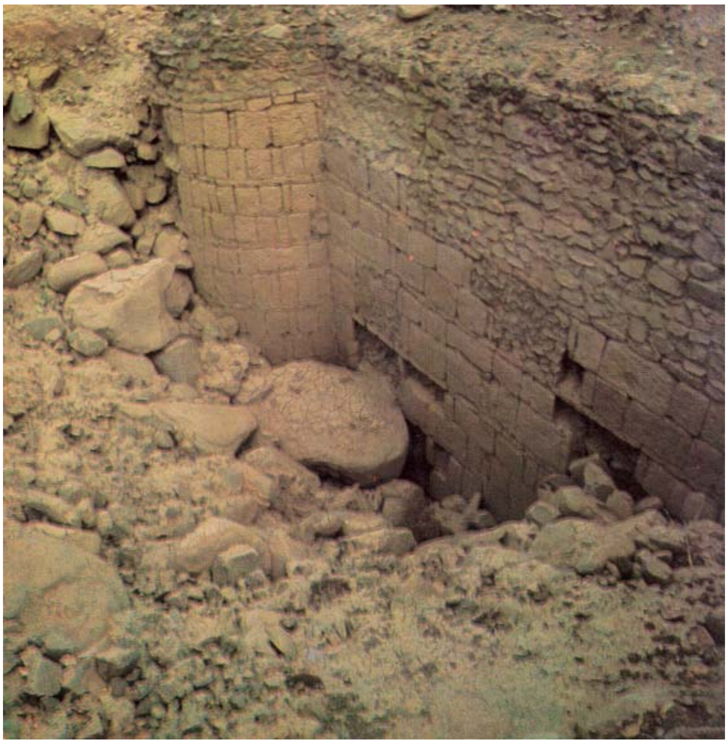


Fig 102, The foundation of ruined Qamsar Weir

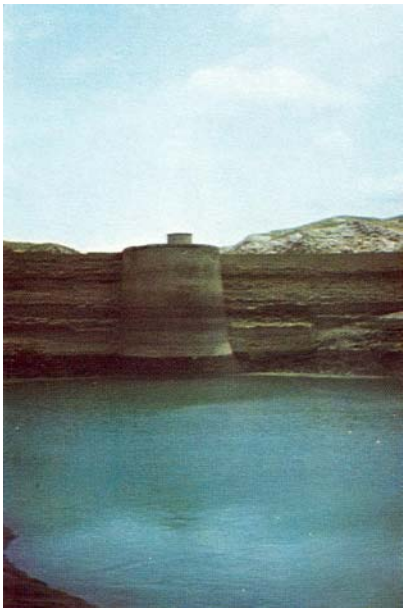


Fig 103, Toroq water tower in Meshad

Fig 104, Golestan water tower with spiral stairs

Fig 105, Fariman spillway located at the left bank

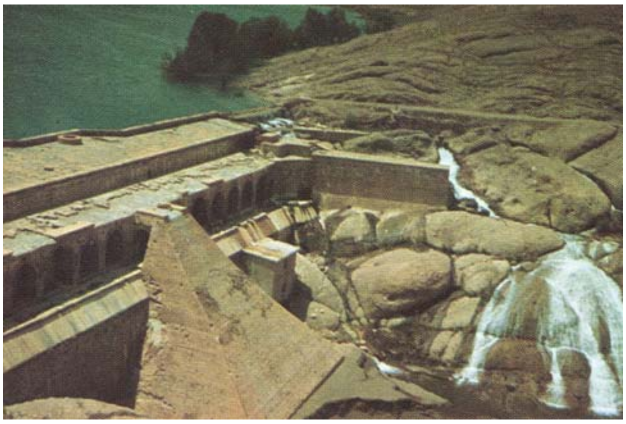


Fig 106, Fariman Weir and its lowered section for flood to pass through without touching the body of dam

Fig 107, Natural stilling basin of Amir Weir

4-3-3- DETAIL STUDY ABOUT SOME OF THE IRANIAN DAMS

1- SAVEH DAM (FIGURES 108 TO 112)

Saveh Dam was located 157 km. southwest of Tehran and 37 km. far from the historical city of Saveh. The crest was 65 meters long with 18 meters thick at the top and 35 meters at the bottom.

The water tower and spiral stairs were 7 to 8 meters from the outer edge of the dam. This dam was 30 to 35 meters high from the riverbed.

The materials were limestone and lime concrete, which were very resistible to water.

The core wall was 7 meters from the outer edge of the dam at the bottom, made of brick and lime concrete.

On the left bank, there was a path, which crossed the dam crest and extended to the right bank through mountainous side.

It looks like they evacuated flood through the mountains at the right bank at first. Later on they established a water outlet at the middle of the dam body.

There was a tunnel on the left bank side, which was constructed, in later eras. At the present time a portion of river discharge passes through this tunnel to irrigate Saveh plane. About 20 years ago it was excavated another tunnel on the right bank in order to repair the dam. This tunnel has been filled with sediment since then.

However, this dam has been studied many times to get repaired and put it under operation. First time it was studied by Bongah Mostaqel Abiari and Engineer Nater. Then A. Ludind, F. Tolke and the author of this section of the book suggested a new dam in order to use both the old and the new dams in 1954.

HISTORY OF SAVEH OLD DAM

The people called this dam “Abbasi Weir”. But this dam is too old to be called by this name. In petroshfeski’s book, volume one, page 209, quoted from Hamdolah Mostofi “Gamasa Rood was very important for Saveh district as Zayendeh Rood for Esfahan. The Minister Shamsedin Mohammad, the author of Joveini poetical works (he was executed in 1284) constructed a dam on this river to irrigate the Aveh and Saveh farms. But the excess water wasted in the desert.”

According to this historical document, the age of this dam should be around 700 years and for sure it was constructed before Safaveih era. However, it must have been repaired during Shah Abbas The Great. Perhaps those new walls in the middle of the dam body were constructed for flood control during Safaveih era. This can be the reason why it was called “Abbasi Weir”

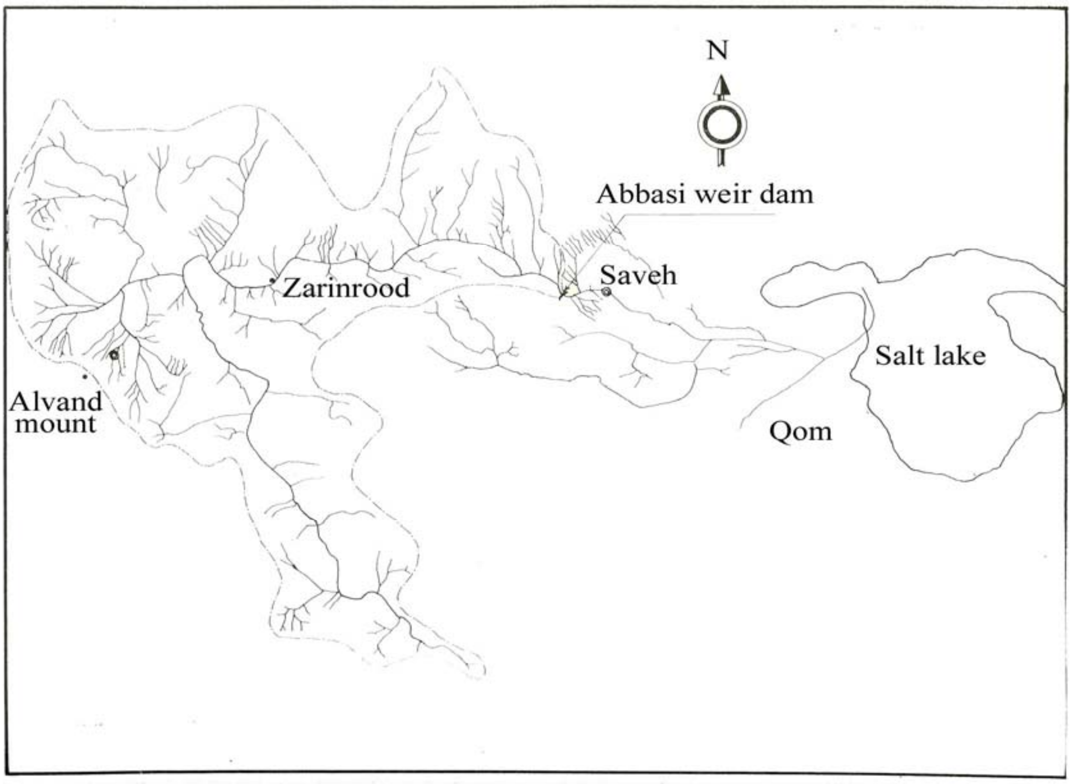


Fig 108, Qarachay Watershed & Abbasi Weir

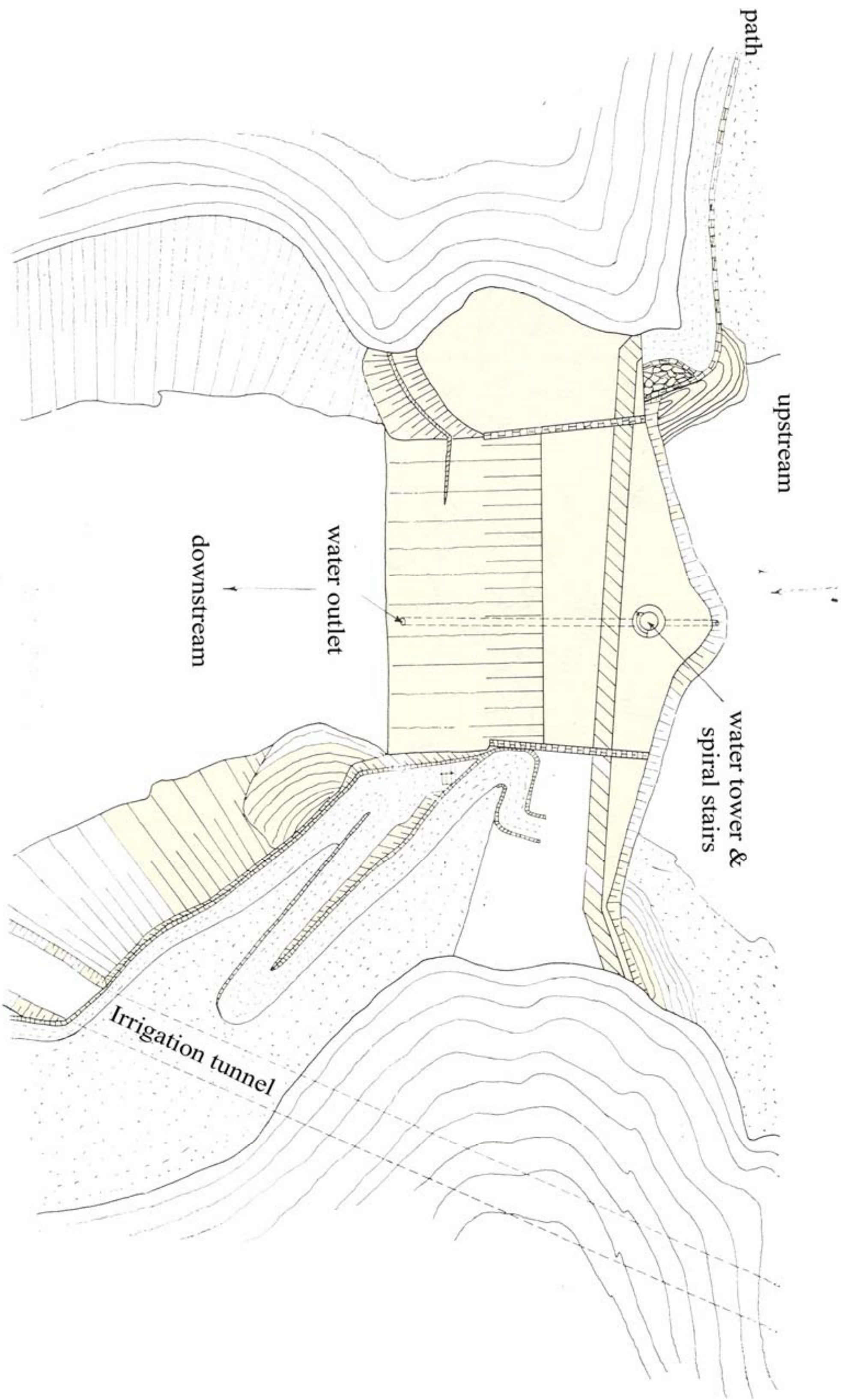


Fig 109, Saveh Dam General View

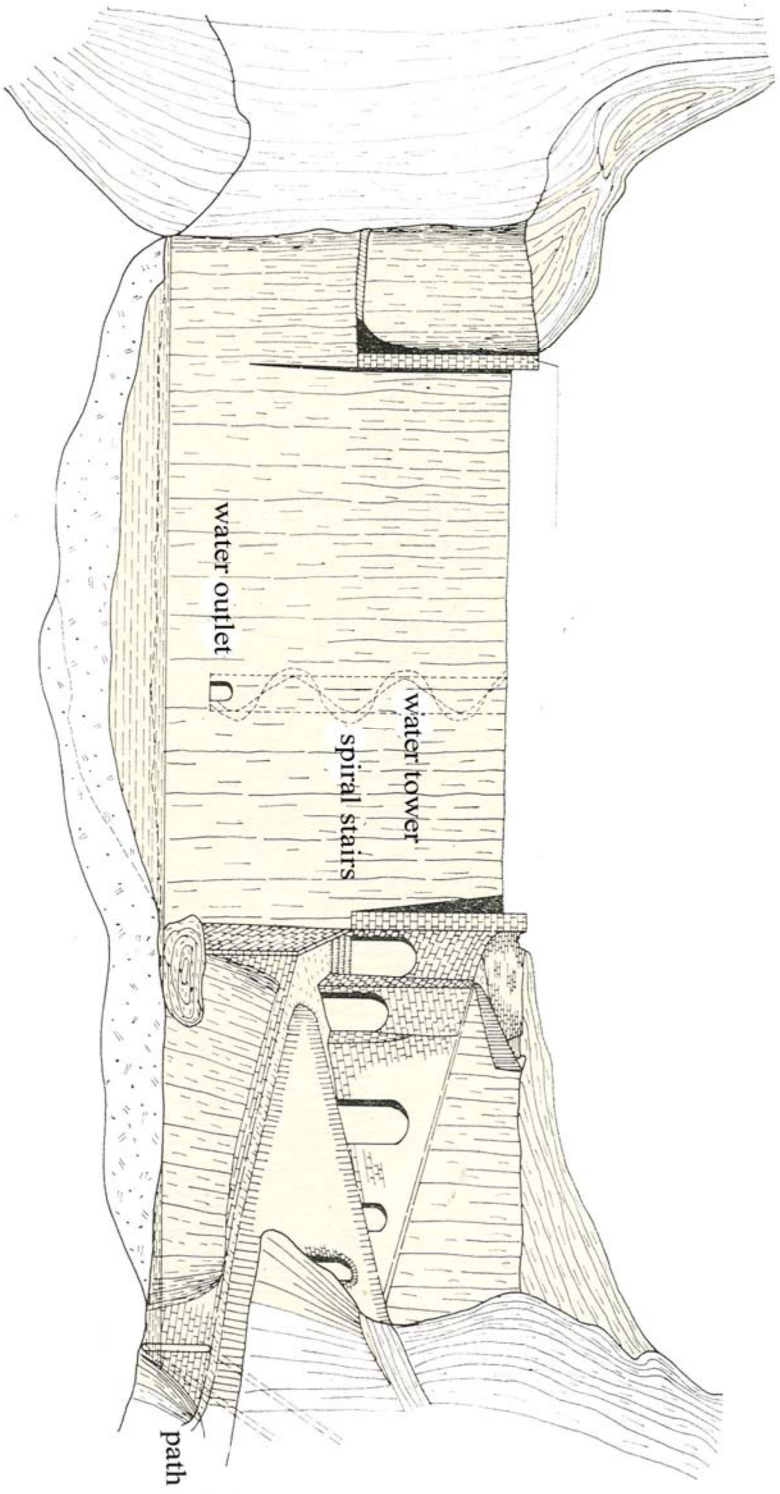


Fig 110, Saveh Dam, view from upstream

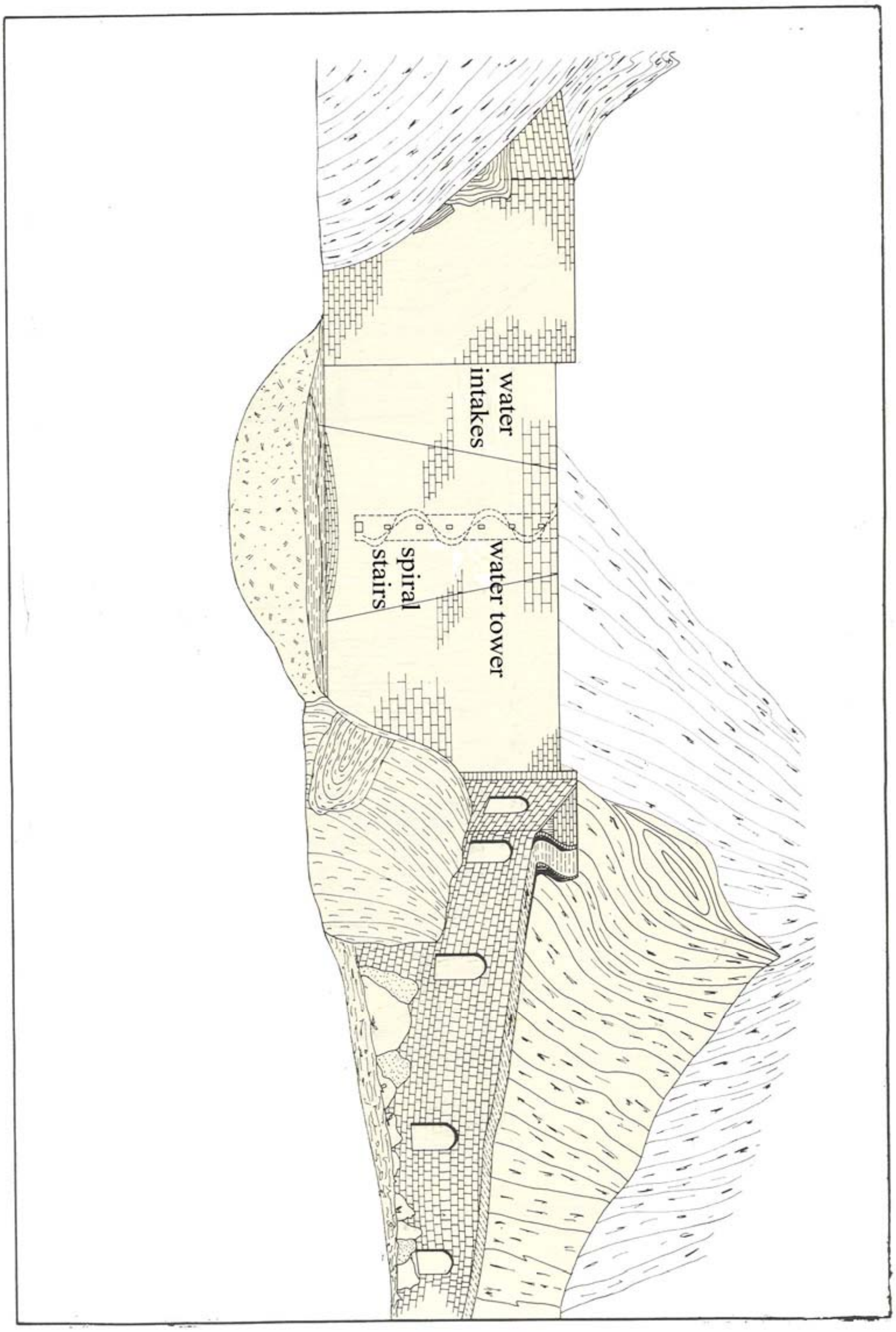


Fig 111, Saveh Dam, view from upstream

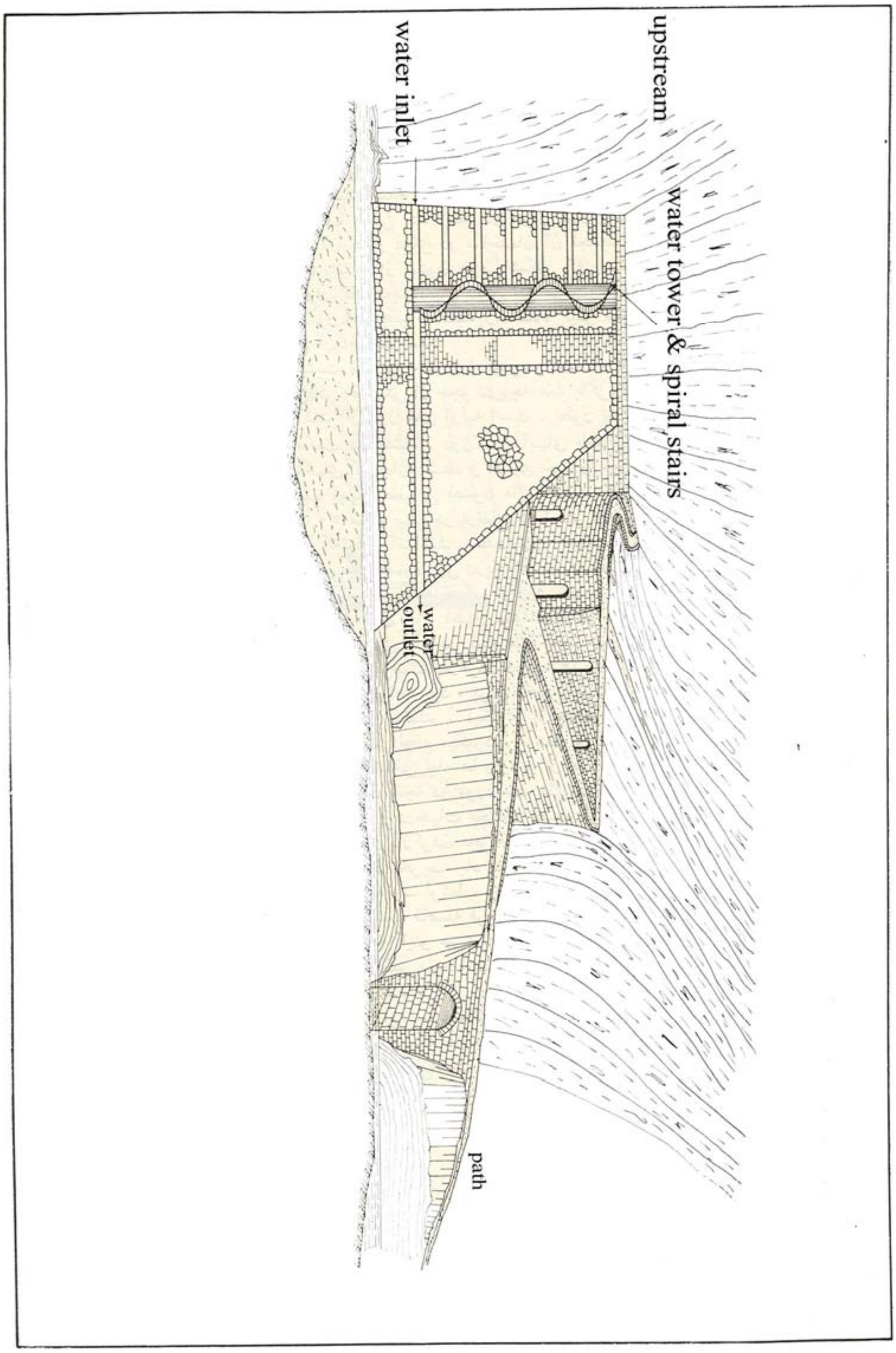


Fig 112, Saveh Dam cross-section

2- FARIMAN DAM (FIGURES 103 TO 117)

Fariman Weir is located 90 km. far from Meshad and 12 km. from Fariman City. It was constructed on Fariman River. But the date of construction is almost unknown. As the residents around declared, this dam should be constructed about 1000 years ago with a height of 4 meters. Later on there were some changes in the structure and it was raised to 20 meters. The buttress in the middle of the dam shows that it was repaired and strengthened during the later eras. About 50 years ago, it was repaired for the third time by the order of Reza Shah and raised the height somehow.

The reservoir is about 2 km. long and its average width is about 500 meters. A part of the reservoir has been filled with sediment, so the storage capacity has been decreased to 1000000 M^3. The excess water during flood events evacuated from both sides without making any harm to the dam body. During the last renovation (50 years ago), there were installed 6 gates with the height of 1.5 meters on the crest. Generally they are closed, but during the flood events, they are opened to evacuate the flood without over topping the body of dam. As the residents declared there was a huge flood in 1962 and the guards didn't get a chance to open the gates, so the flood over topped the dam. However if this situation repeated continually, the whole structure would collapse for sure. For flood evacuations gates should be left open all the time.

Water taking is done by two water towers, which operate independently. Water passes through the gates, installed in different elevations on the tower into the well and releases from the bottom. In order to open and close the gates, there were installed some timbers to use as energy dissipater as well. Otherwise, the water energy might destroy the tower.

This dam supplies water demand for 4 villages (Taqi Abad, Qaleh Now, Loshab and Havas), Fariman Sugar Factory and Fariman City. Fariman City and Qaleh Now are 12 km. far from the dam site but the other villages are 3 km. far from it.

The simple structure of water towers shows the dam belongs to some eras before Safavieh.

On the right bank of the storage dam, there is an irrigation canal, which takes water directly from the reservoir. Such a case wasn't observed in other dams. The high lands are irrigated by this canal.

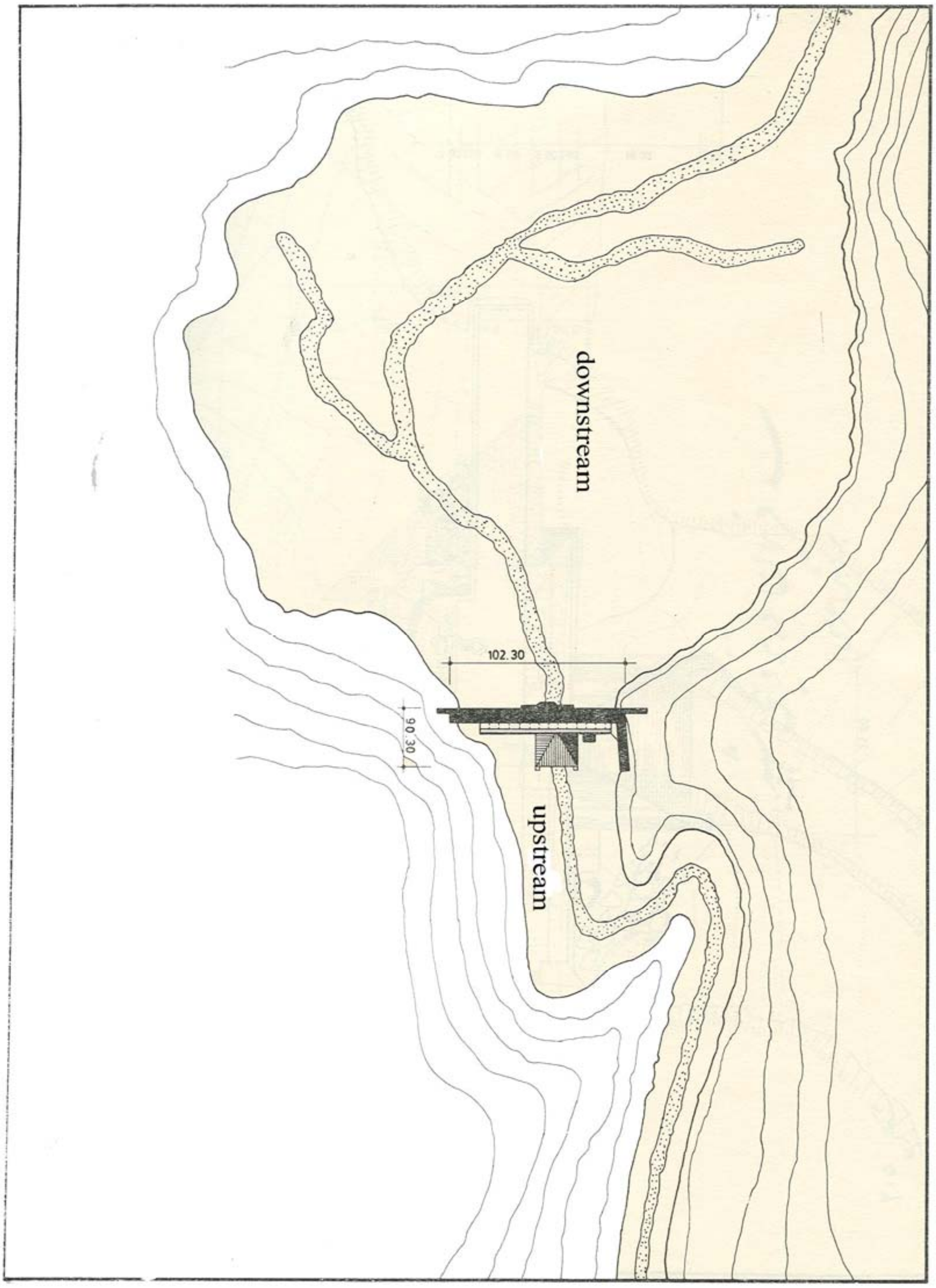


Fig 113, Fariman Dam near Meshad

(General view)

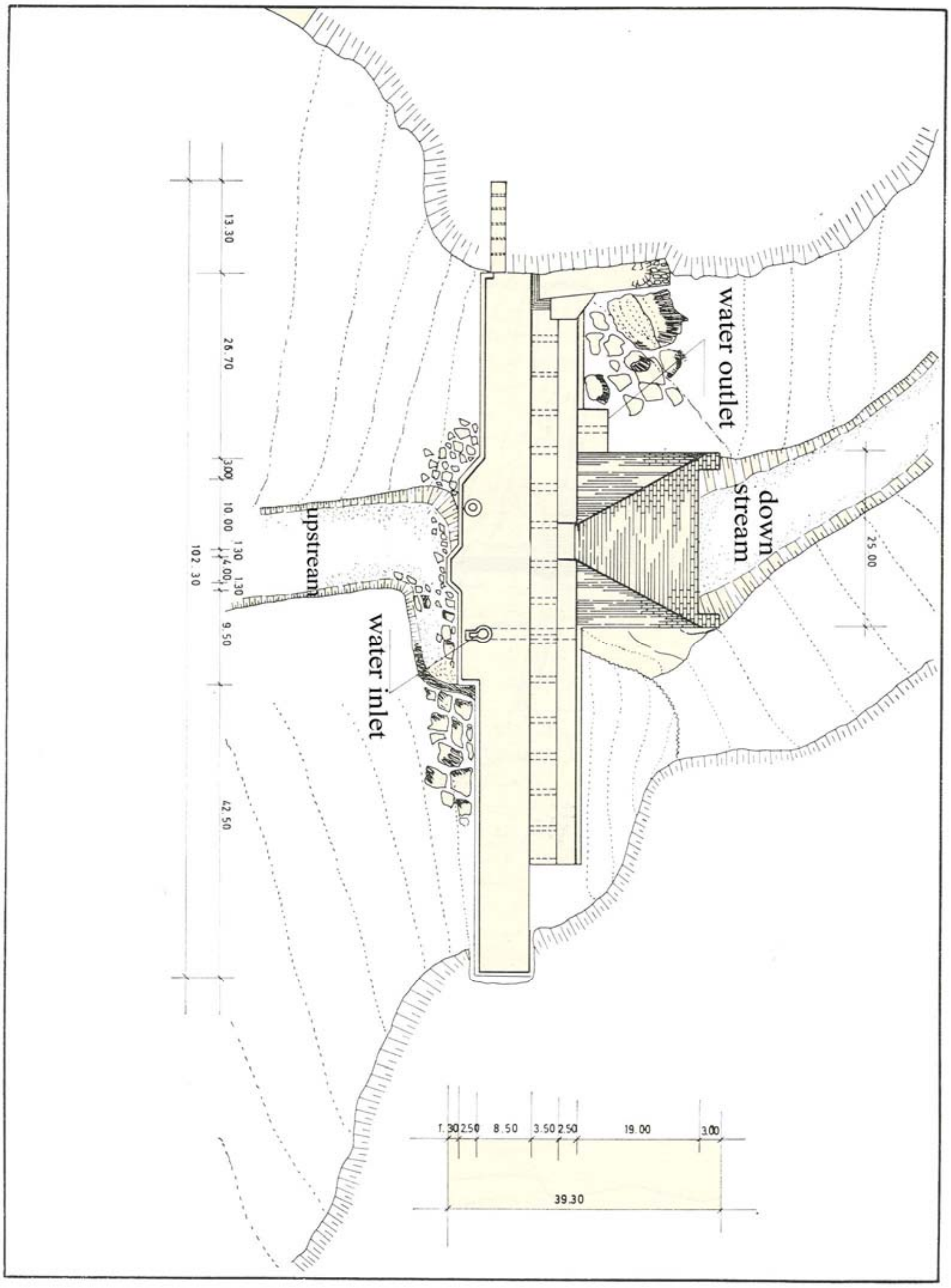


Fig 114, Fariman Dam near Meshad

(General view)

Fig 115, Cross-section of Fariman Dam near Meshad

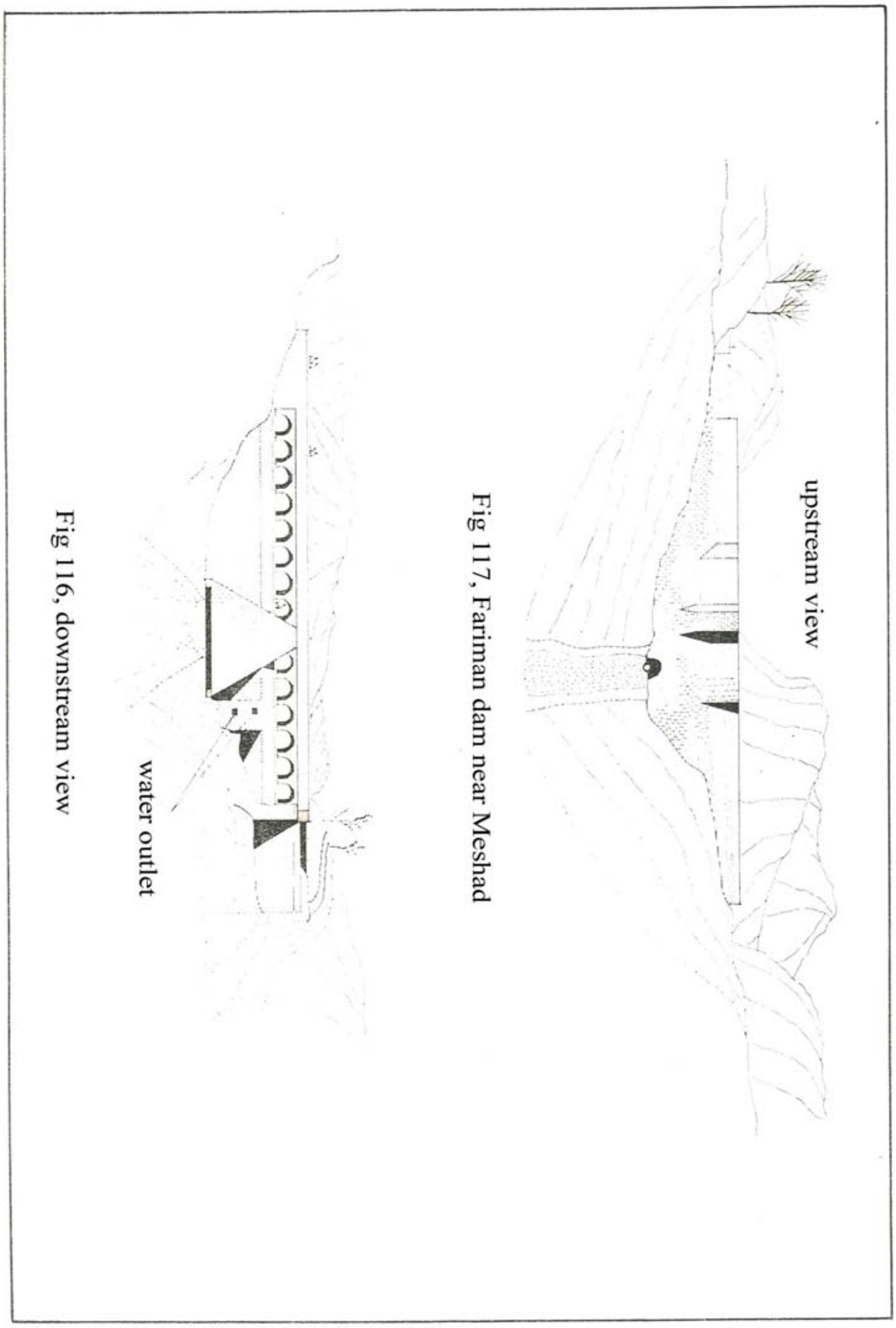


Fig 117, Fariman dam near Meshad

Fig 116, downstream view

3- AKHLEMAD WEIR (FIGURES 118 TO 122)

Akhlemad Weir was erected on Akhlemad River, 82 km. from Meshad. This dam belongs to Safavieh era. As far as it concerns, there has not been done any repairs since now. This dam isn’t usable at the present time.

The materials used in the body of dam were rocks and lime concrete. The water towers made of bricks and lime concrete. The dam is 220 meters long, 11 meters wide and 12 meters high. Along the crest there are a number of half cylindrical buttresses to strengthen the dam. It looks like, some of them acted as water towers. This dam could be a good example of buttress dam in ancient Iran.

The reservoir is about 1500 meters long and 500 meters wide. The height of sediment near the dam is about 6 meters and the storage capacity is approximately 3000000 M^3.

As they didn’t predict any spillway for the dam, therefore water over topped during flood events in the past and caused many damages to the body and the foundation.

There were 4 water towers with 3 gates each at different elevations for water use.

There were also some timbers installed inside the towers as stairs. Of course, those timbers are not there any more.

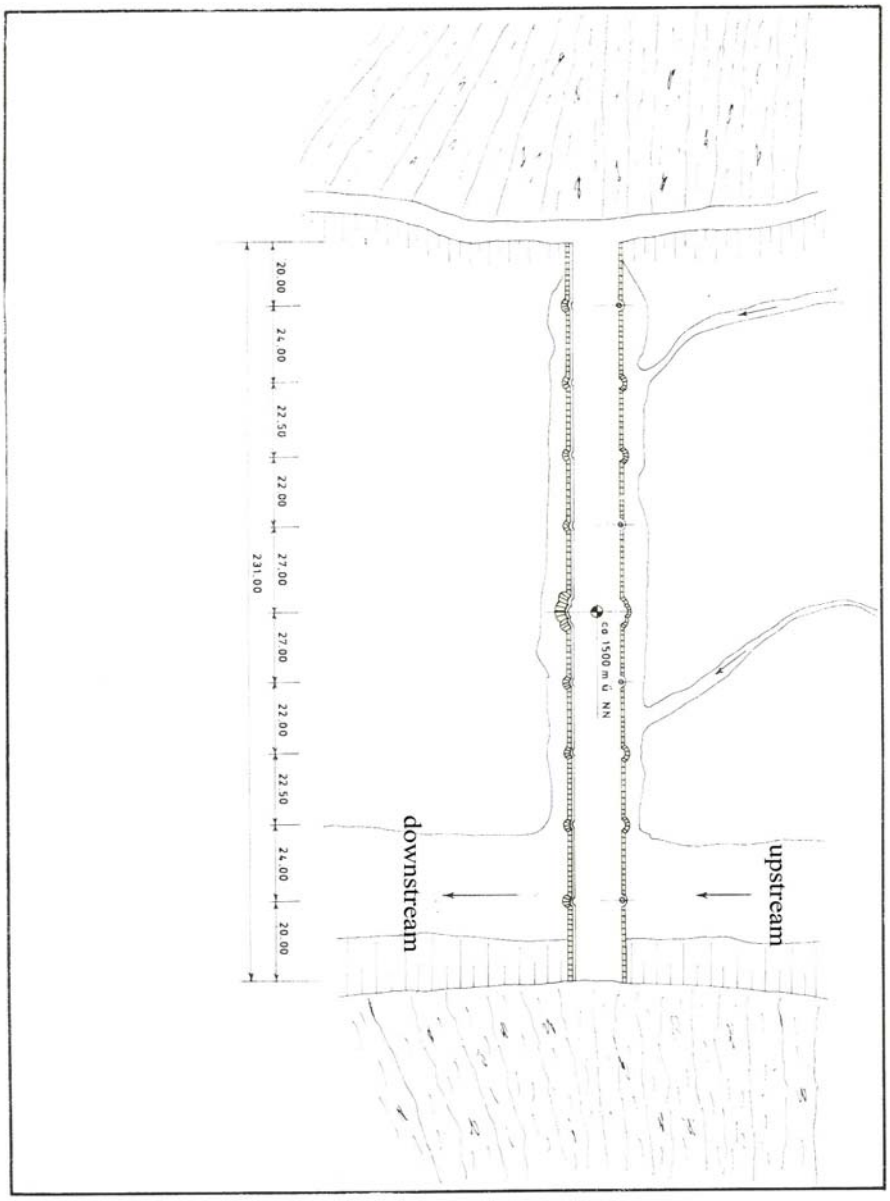


Fig 118, Akhlemad Weir near Meshad

(General view)

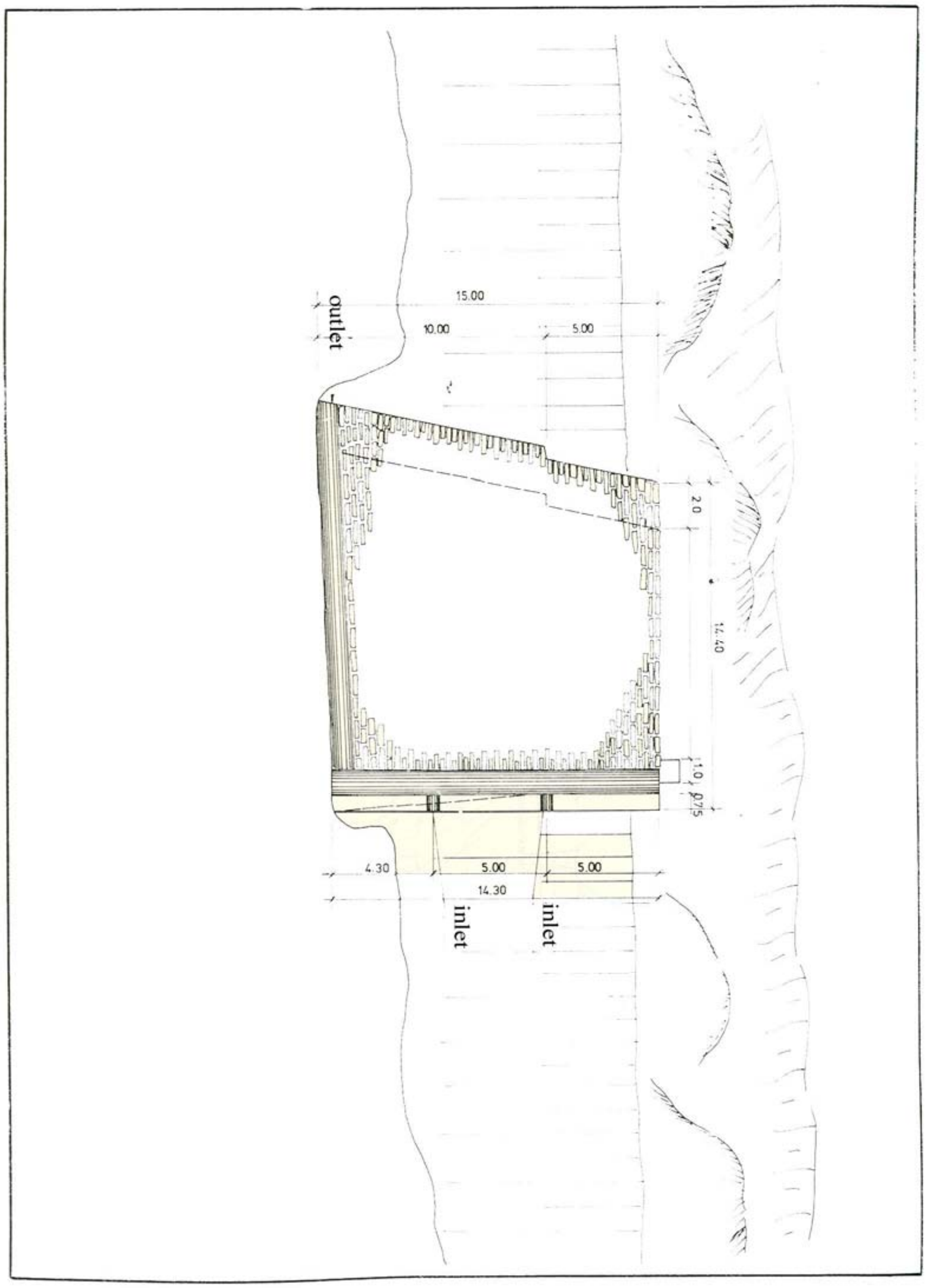


Fig 119, Cross-section of Akhlemad Weir near Meshad

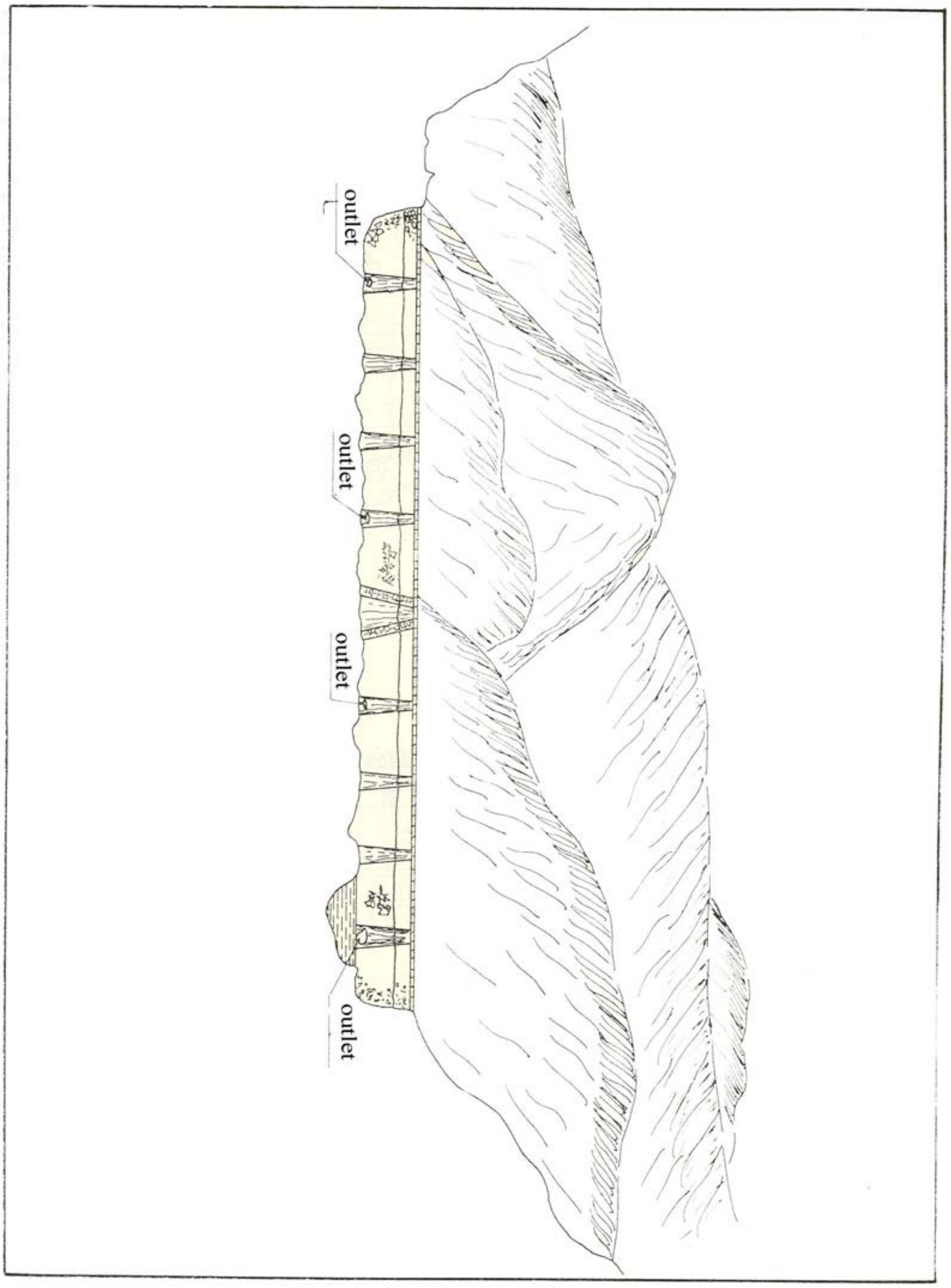


Fig 120, Akhlemad Weir near Meshad

(Downstream view)

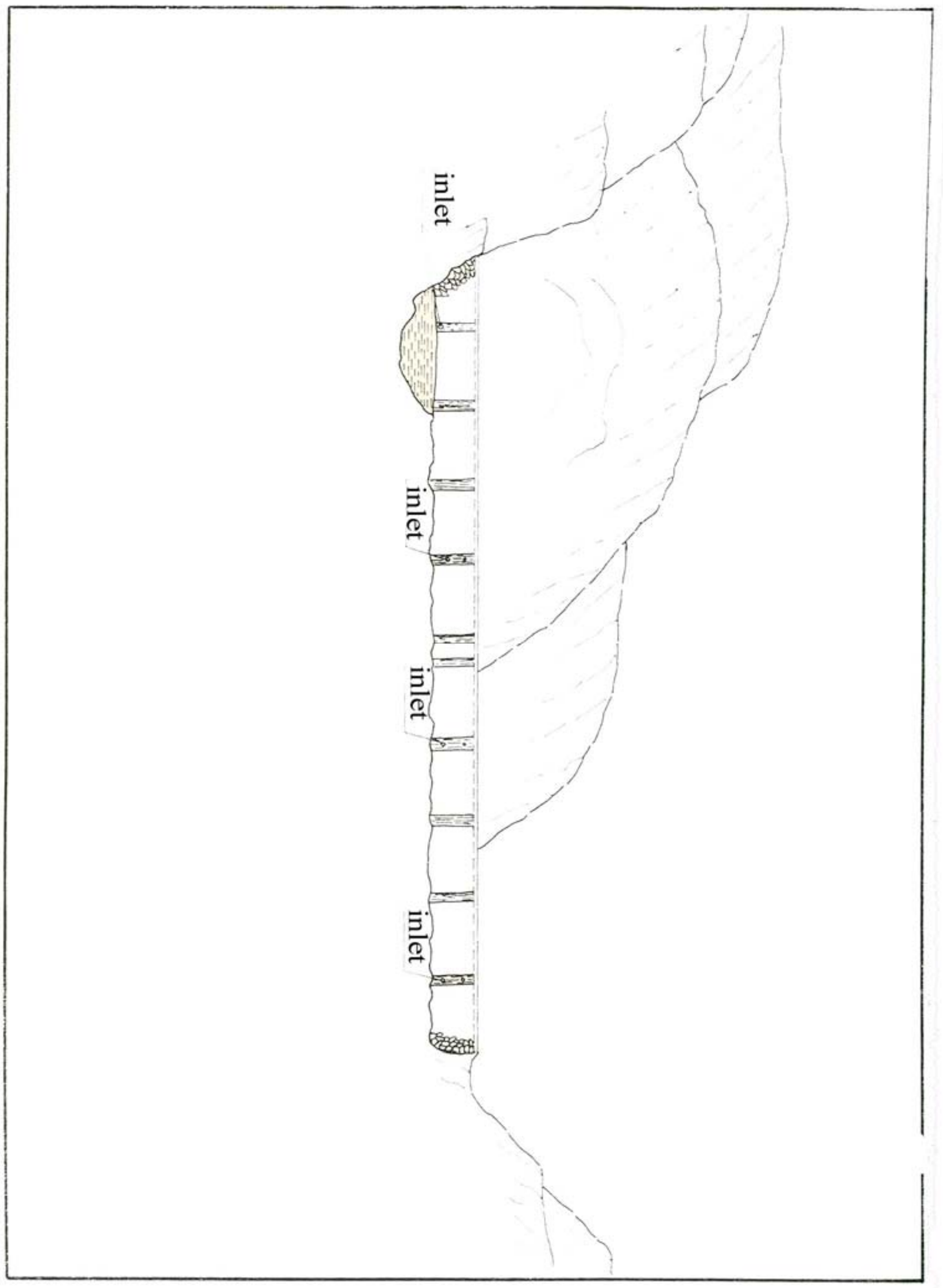


Fig 121, Akhlemad Weir near Meshad

(Upstream view)

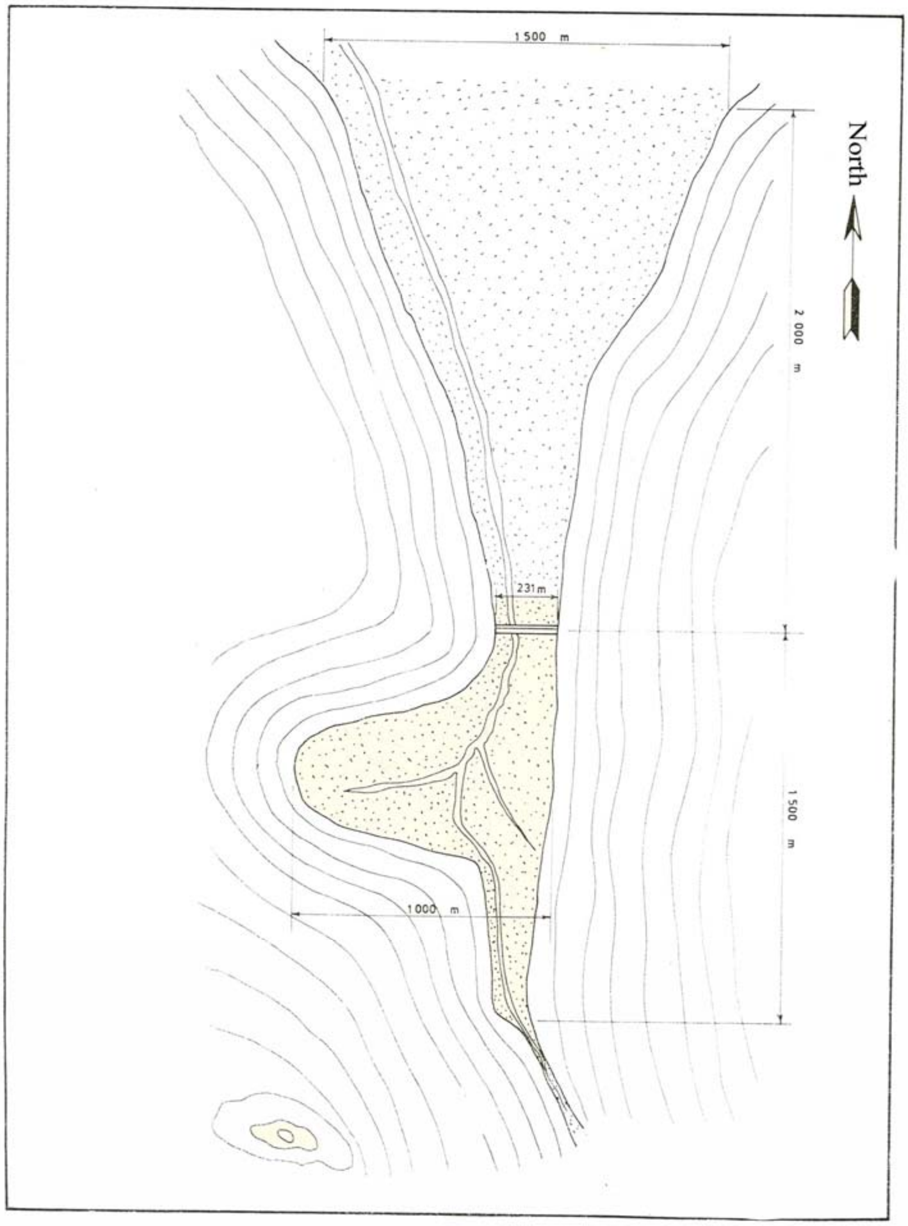


Fig 122, Akhlemad Weir near Meshad

(General view)

4- DAREH WEIR (FIGURES 123 TO 127)

Dareh Weir is about 11 km. from Beirjand in the northern mountainous area of the city. According to a narrative, this dam was constructed about 50 years ago by the order of late Shokat Almolk Aalam. This dam is under operation at the present time. But some of the residents believe this dam is much older.

This dam is about 35 meters high, 3 to 4 meters wide at the crest, 15 meters high and 150 meters wide at the bottom. The storage capacity is approximately 150000 M^3, which is very limited.

The spillway was established on the body of the dam, which was 4 meters wide and 50 cm. deep.

Water taking is done by a water tower, which is 4 gates at different elevations. The procedure of water taking is the same as the other old dams e.g. Saveh Dam.

The bottom outlet was established to release sediment by flushing method.

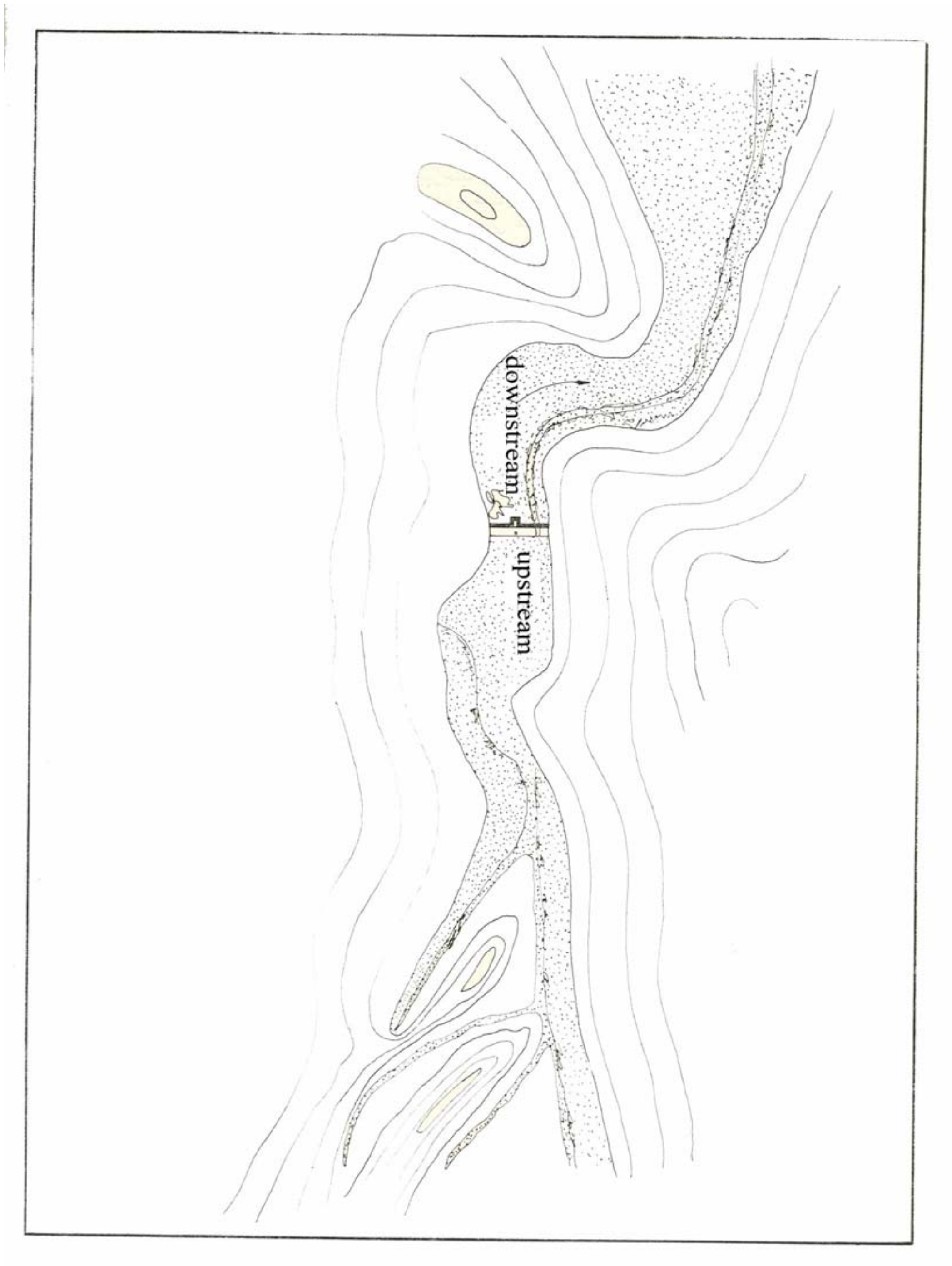


Fig 123, Dareh Weir near Beirjand

(General view)

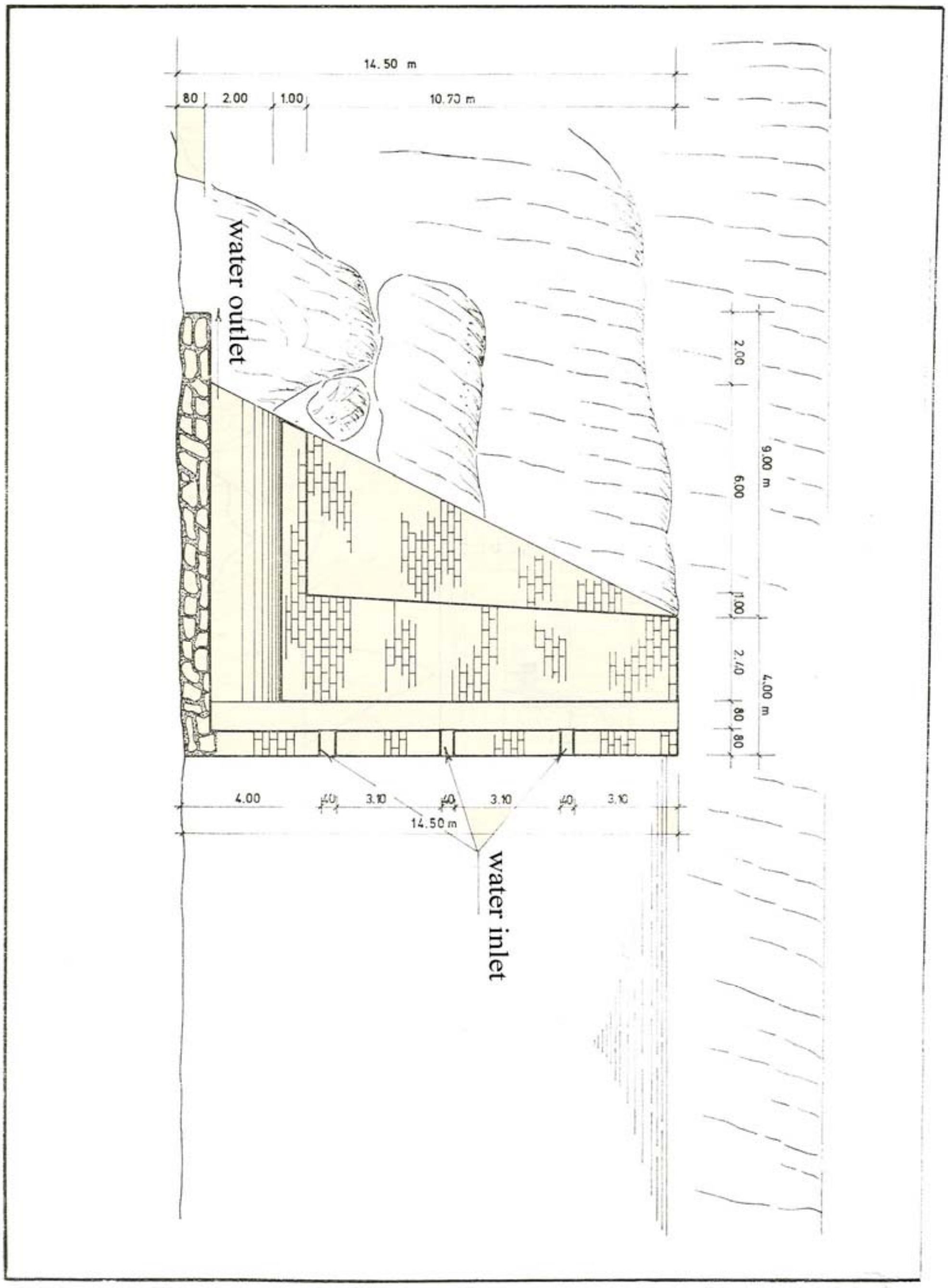


Fig 124, Dareh Weir near Beirjand

(Cross-section)

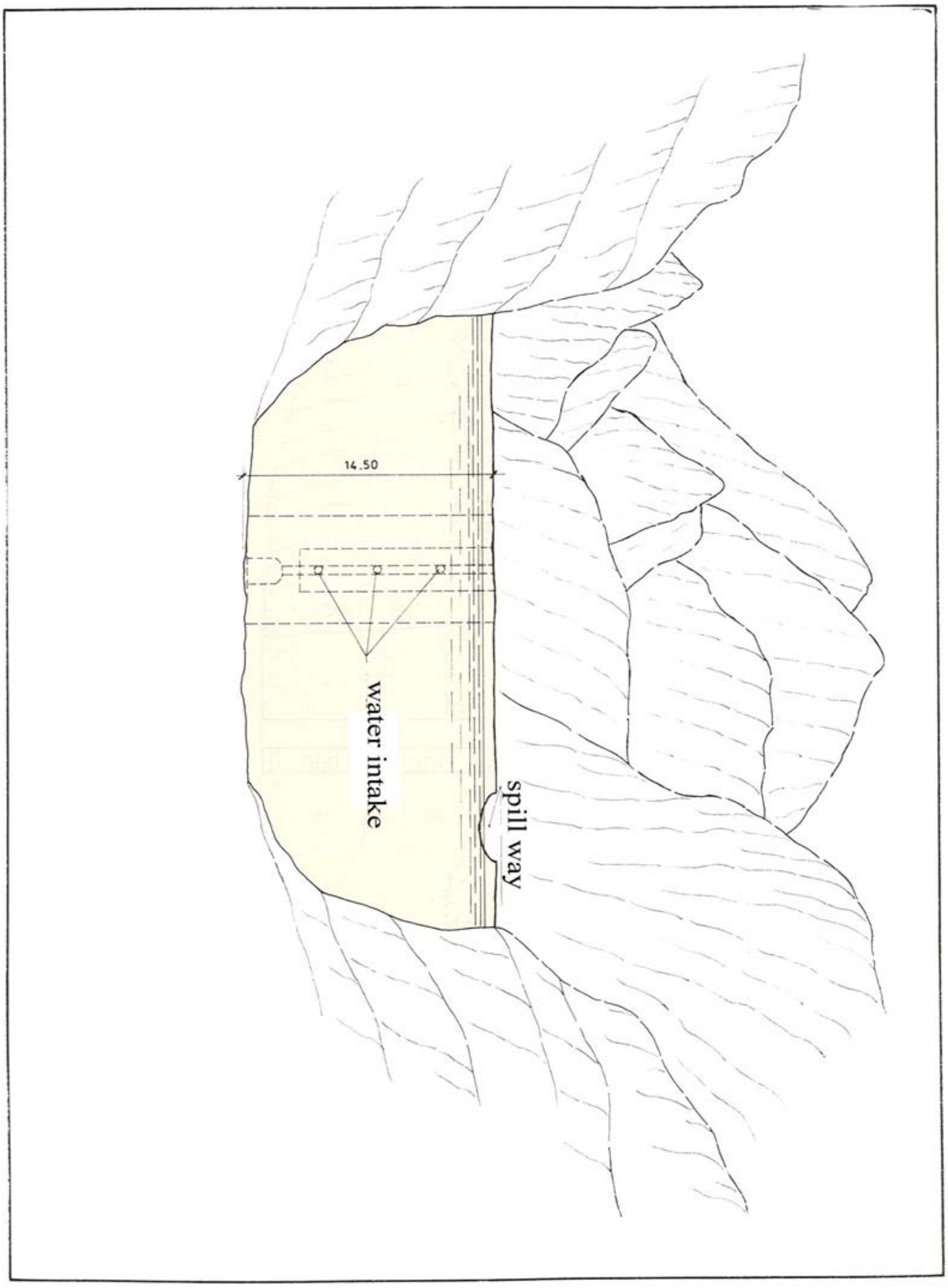


Fig 125, Dareh Weir near Beirjand

(Upstream view)

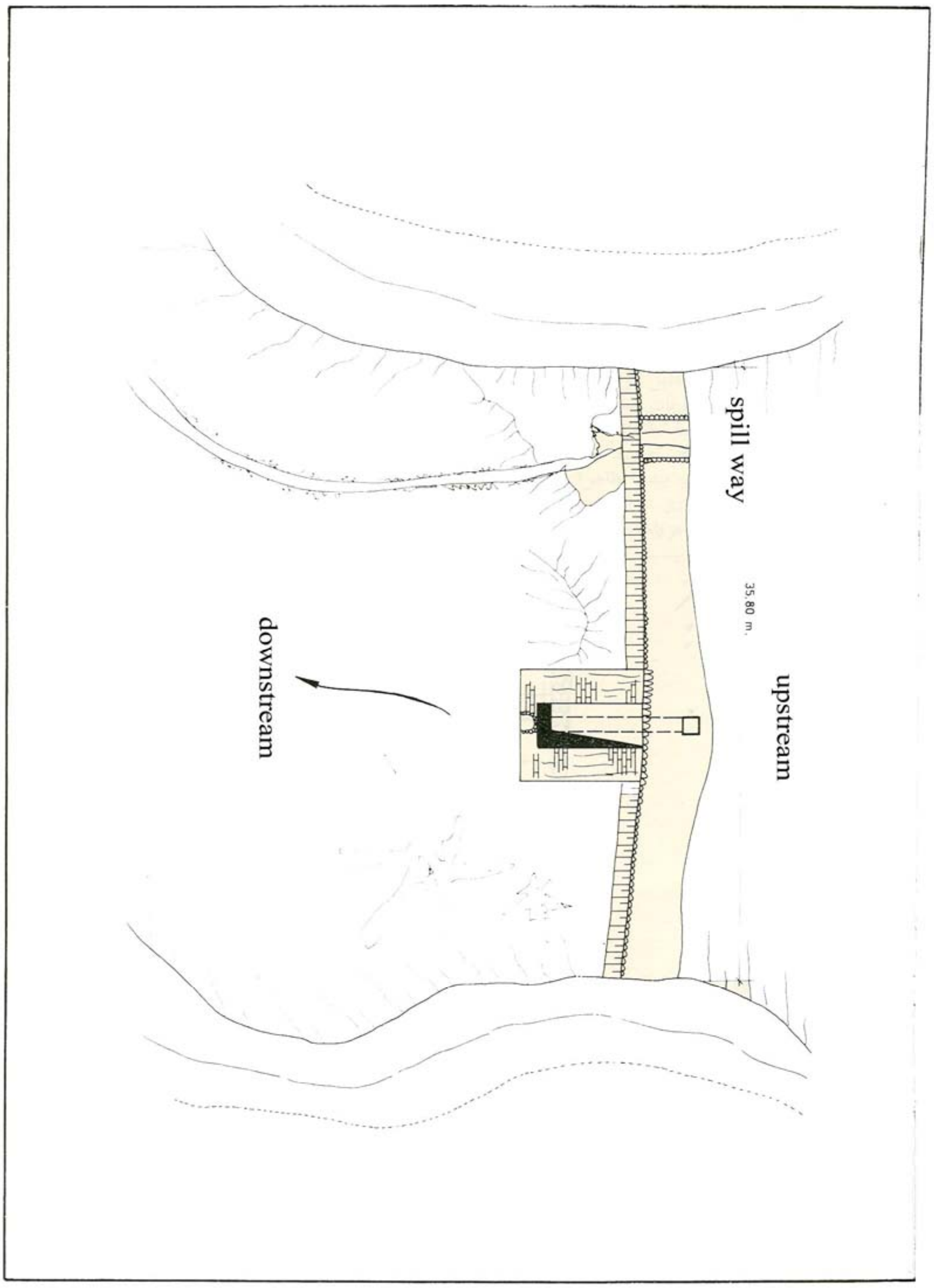


Fig 126, Dareh Weir near Beirjand

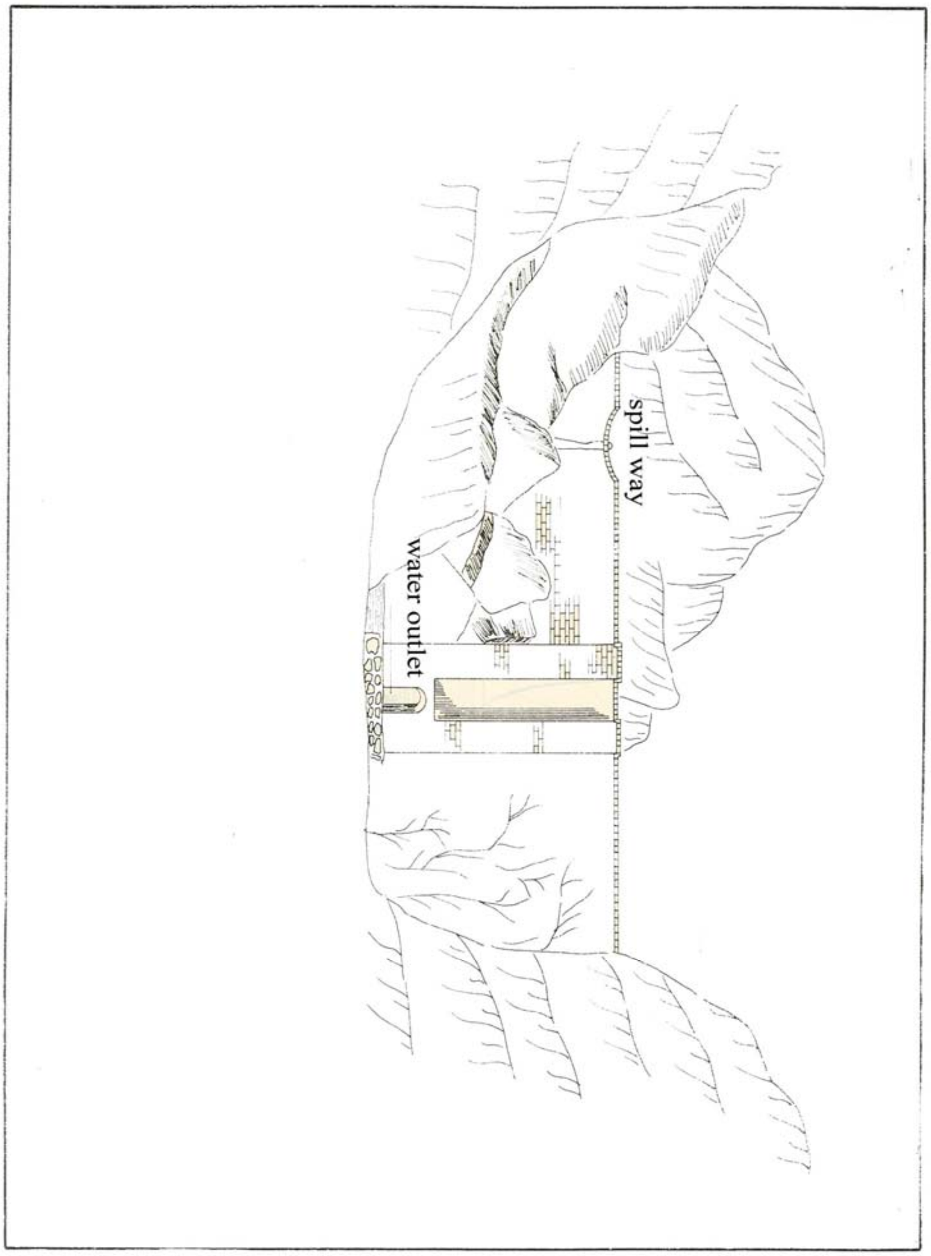


Fig 127, Dareh Weir near Beirjand

(Downstream view)

5- GOLESTAN WEIR (FIGURES 128 TO 132)

Golestan Weir is about 30 km. north of Meshad, which was constructed on Torqabeh River. Perhaps this dam was built at the same time as Goharshad Mosque. The outer surfaces of the dam were covered with bricks and mid-section filled with rocks and lime concrete. The Thickness is about 15 meters at the crest and 22 meters at the bottom. The bottom outlet was established to release the sediment. The water tower has 4 gates at different elevations and it is connected to the body of the dam, the same as the other old dams. The spiral stairs are inside the tower to reach the gates.

The Iranian dam constructors advised to release the sediment by flushing method every year. But it has not been done and the reservoir has been filled with sediment.

The spillway didn’t have the capacity to release the water during the flood events, so water over topped many times and washed out a part of outer surface bricks.

This dam belongs to Astan Qoods Razavei but the river discharge doesn’t. So the means of this dam was only limited to flood events.

Releasing the sediment and increasing the storage capacity is something, which should be concerned.

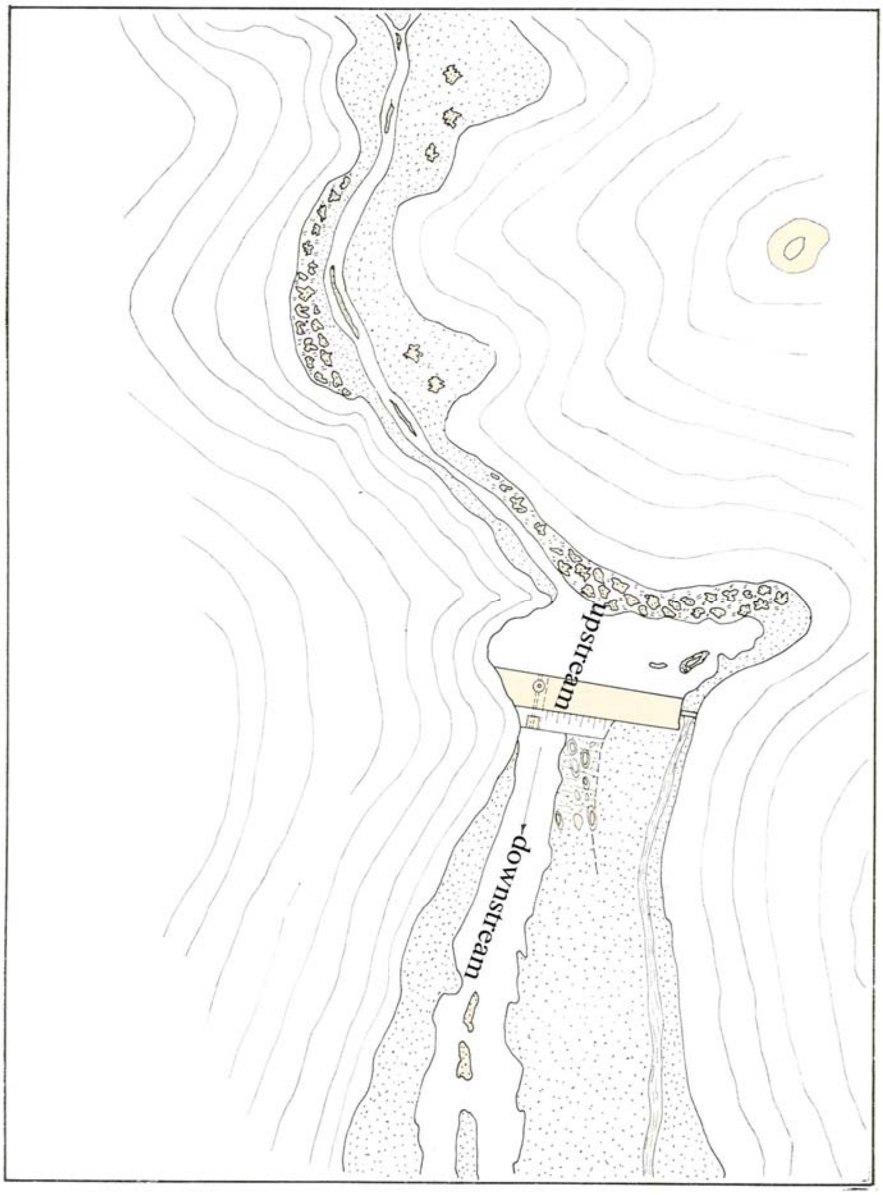


Fig 128, Golestan Weir general view near Meshad

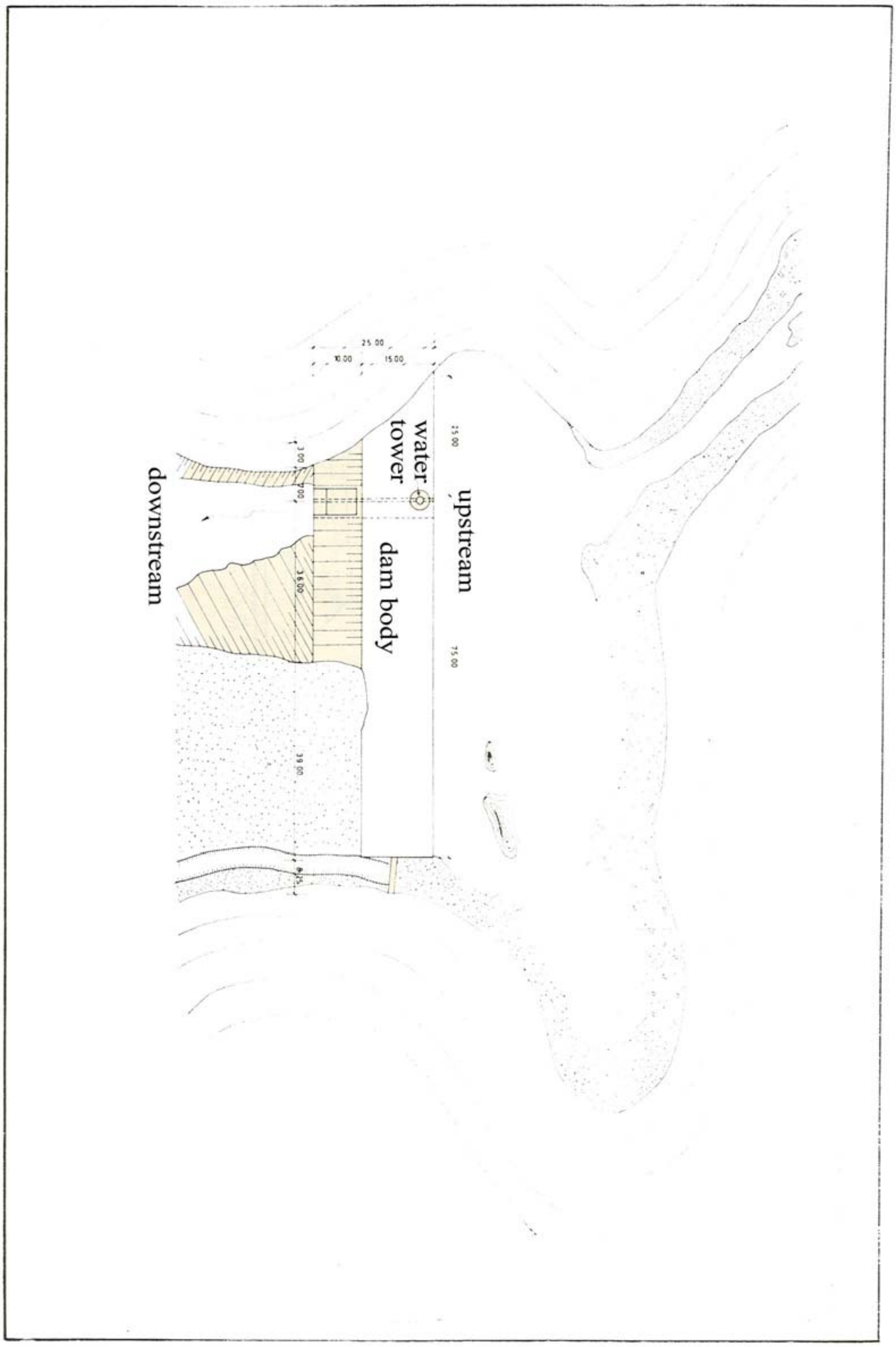


Fig 129, Golestan Weir general view near Meshad

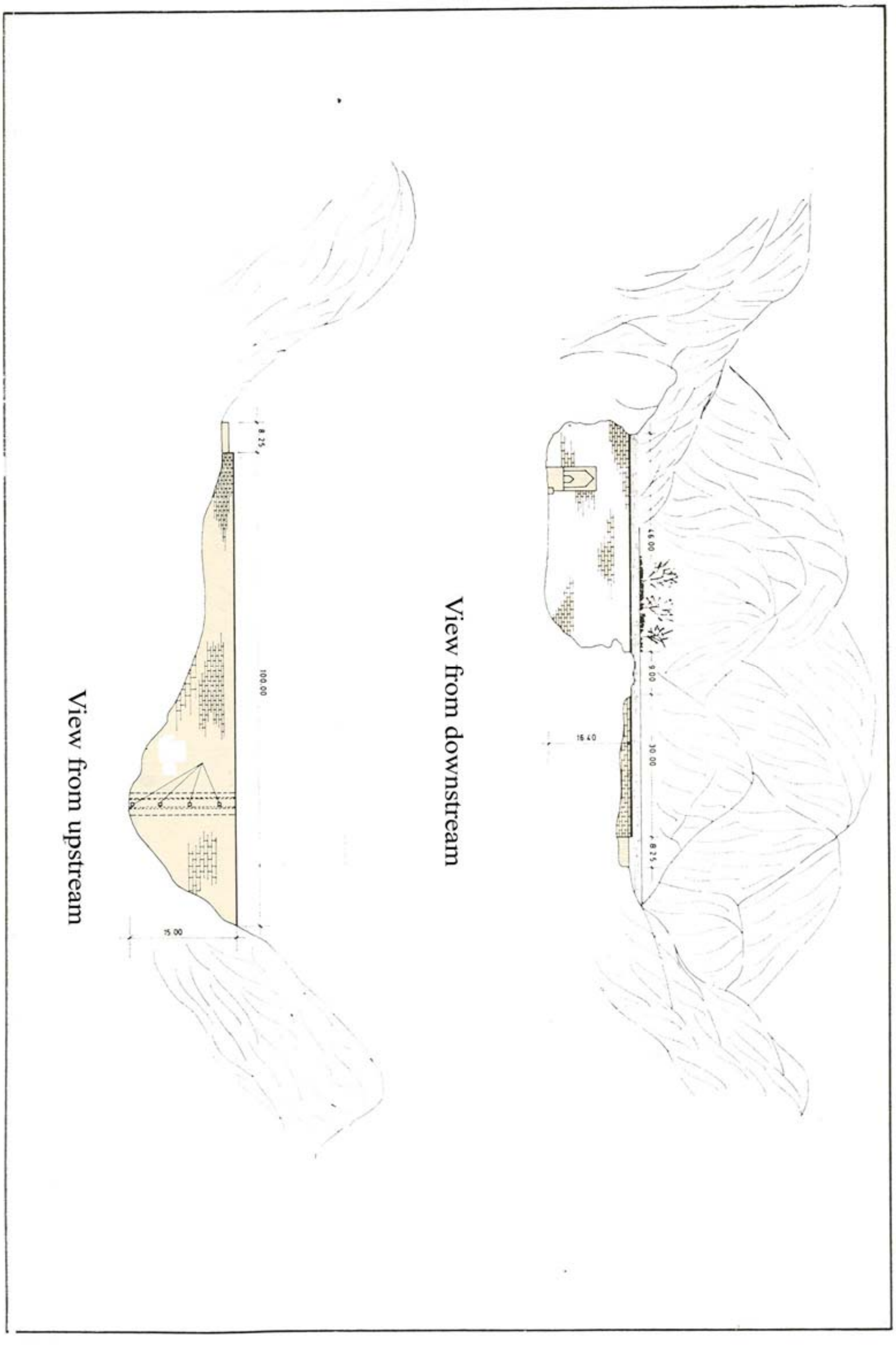


Fig 130 & 131, Golestan Weir near Meshad

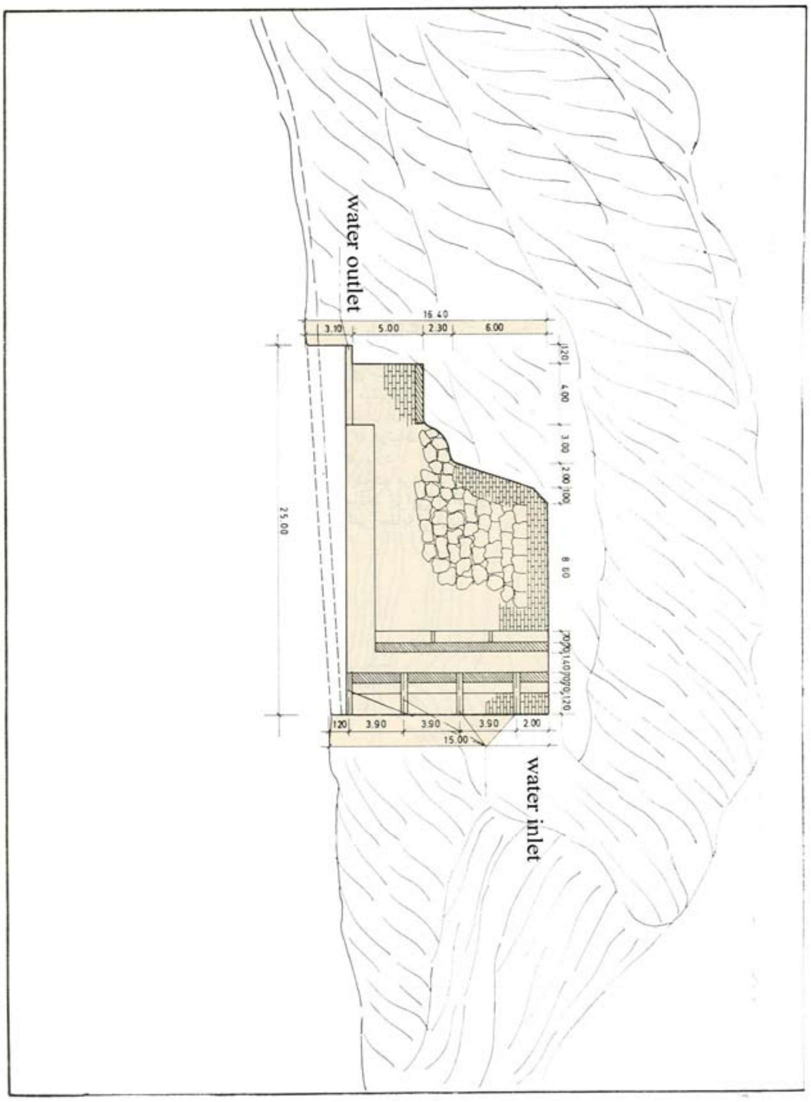


Fig 132, Golestan Weir near Meshad

(Dam and water tower cross-section)

6- SHESHTARAZ KASHMAR WEIR (FIGURES 133 & 134)

Kashmar Weir is about 25 km. west of Kashmar and 5 km. far from main road.

As the residents of the nearby villages declared, this dam was constructed about 1000 to 1200 years ago. It is a rock- fill dam with lime concrete. One of those old residents declared according to a narrative, its concrete was mixed with milk, so the inner section is very hard although the outer surface has been eroded and decayed.

Water taking system in this dam is different from the other old dams. There are two water towers beside each other on the upstream attached to the body of dam. Water enters from the lower section of one of those towers and passes through some horizontal holes to the other one. This type of water taking is still under investigation and the result will be published later on. But it should be mentioned, this is an old system in respect to the other dams.

Apparently, during flood events water over-topped the body of dam.

The storage capacity was about 2 MM^3. The reservoir has been filled with sediment but it is possible to put this dam under operation in case of repairing and renewing.

The water divider of the dam, which was located 5 km. south of the dam, was very interesting (fig 133).

This dam supplied 5 villages water demand (Mazdeh, Hoosain Abad, Kondor, Arqa and Jagos).

During wet years Sheshtaraz River discharge divided into 6 channels yet and Kondor village has water rights from two channels.

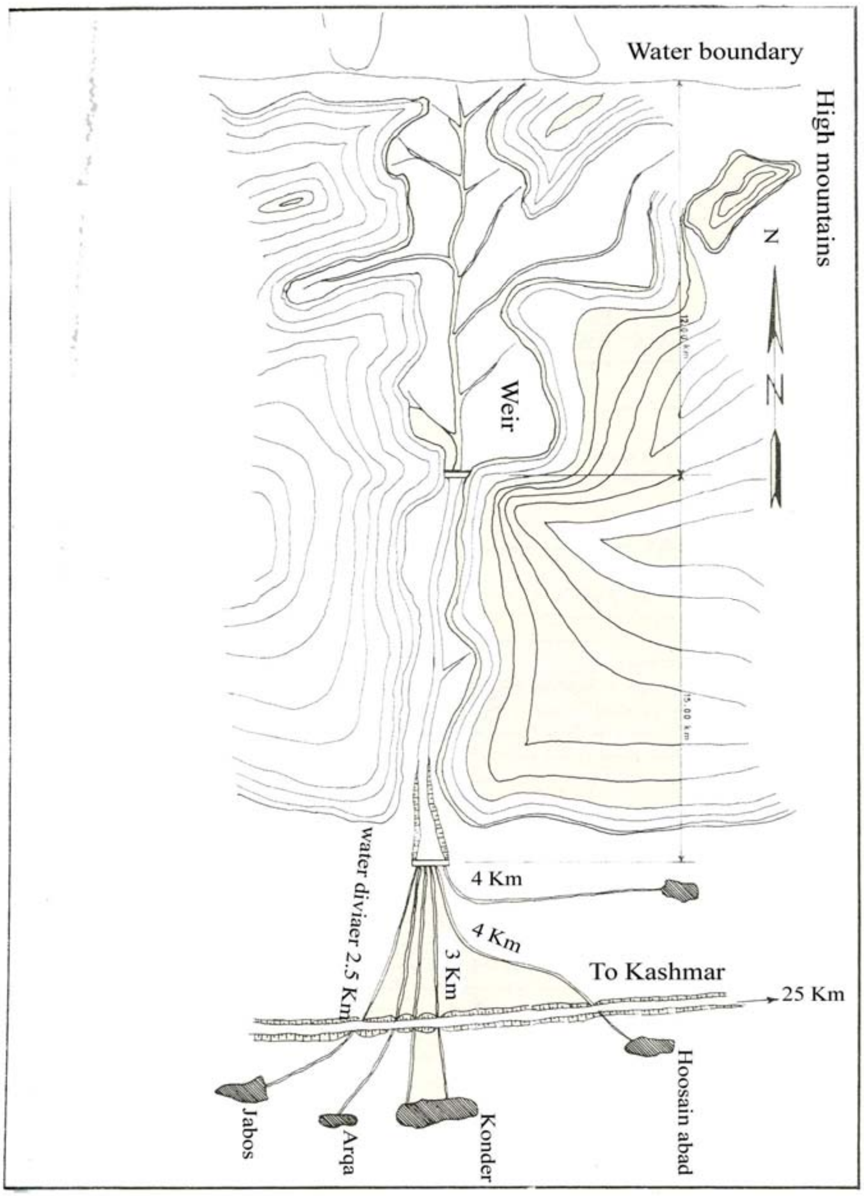


Fig 133, Old Sheshtaraz Weir near Kashmar

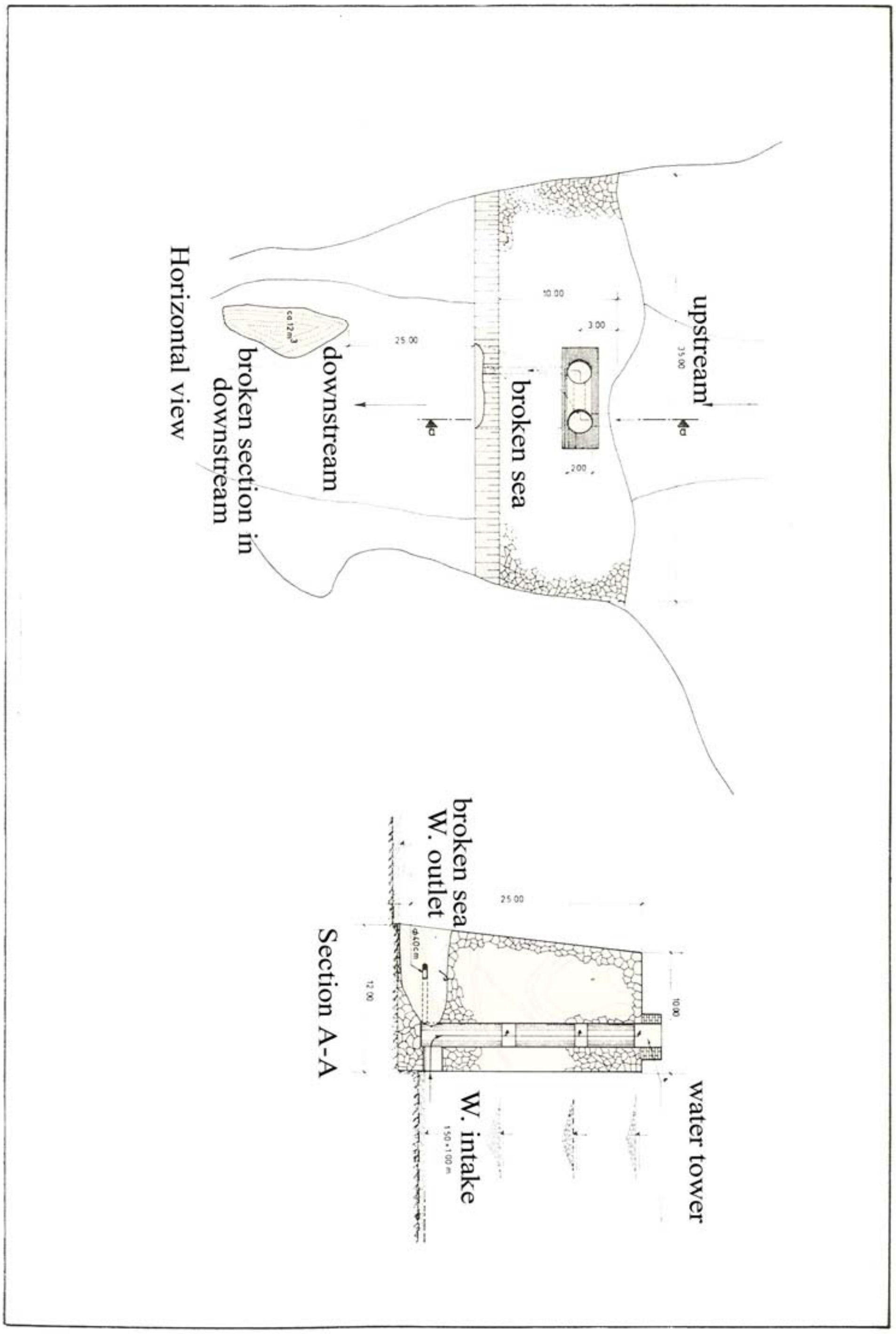


Fig 134, Old Sheshtaraz Weir near Kashmar

7- AMIR WEIR (FIGURES 135 TO 137)

Amir Weir is one of the most important dams in ancient Iran, which is still under operation. It is about 37 km. northeast of Shiraz, which is erected on the Kor River.

Here is the report of Ebnolbalkhi about Amir Weir in Farsnameh (pages 151 and 152).

"… Azodi Weir is the one, which is unique in the world. Before constructing the dam, Korbal region was a desert without water, so Azedaddoleh decided to construct a dam and diverted water to this huge desert. Then he called the experts and allocated the budget to establish the left and right bank canals.

The materials used in this dam were rocks, sands and lime concrete.

There were many canals, which supplied all Korbal lands with water…)

Here are some of the technical specifications of the dam at the present time.

This dam is about 103 meters long, 7.5 meters wide at the crest and 20 meters wide at the bottom. It was constructed with rocks and lime concrete. The lower section of the dam, which was under water, covered with calcareous sediment, looks like white cement. The height of the dam is about 15 meters. There was a bridge with 13 gates on the crest for pedestrians. Unfortunately some of them were collapsed. It is necessary to repair them as soon as possible. The height of bridge from the crest is about 10 to 12 meters.

During flood events water passes through the gates and overtops the dam, so the edge of pillars were sharpened and made of concrete. Of course, these kinds of arrangements belonged to some later eras.

There were some irrigation canals on both sides of the dam at the upstream. Near the dam on the right bank there were two short water towers, which supplied water-to-water mills.

The operation system was mentioned before. But many of those mills were ruined; perhaps one or two units are still under operation.

The outlet canal of the mills drained to a valley and finally evacuated to the main river.

The Gavshiri Canal was an important part of this structure, which branched from the upstream of the reservoir. It had some gates with wooden blocks. As a matter of fact it was a diversion canal and which regulated the water level on the reservoir.

According to the residents, during the flood events, the whole part of Gavshiri Canal goes under water and the residential area is flooded without having any reach to their neighbors.

Amir Weir is a triple-purpose weir and it is one of the most valuable structures in dam construction technique in ancient Iran. It should be repaired before the whole structure collapses. This dam can be very interesting for travelers and tourists. One of the most urgent steps is to save this ancient remain.

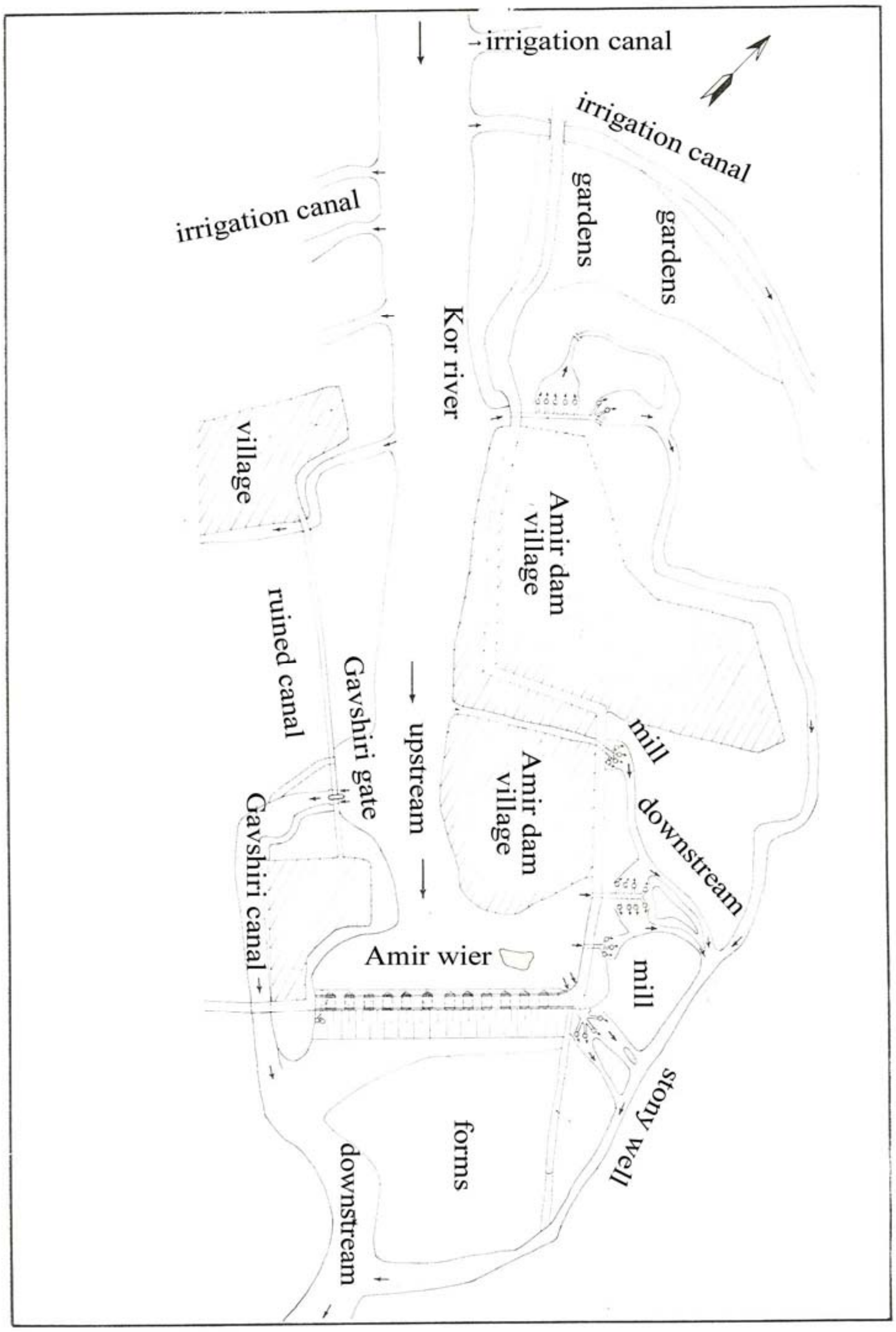


Fig 135, Amir Weir in Fars

(General view)

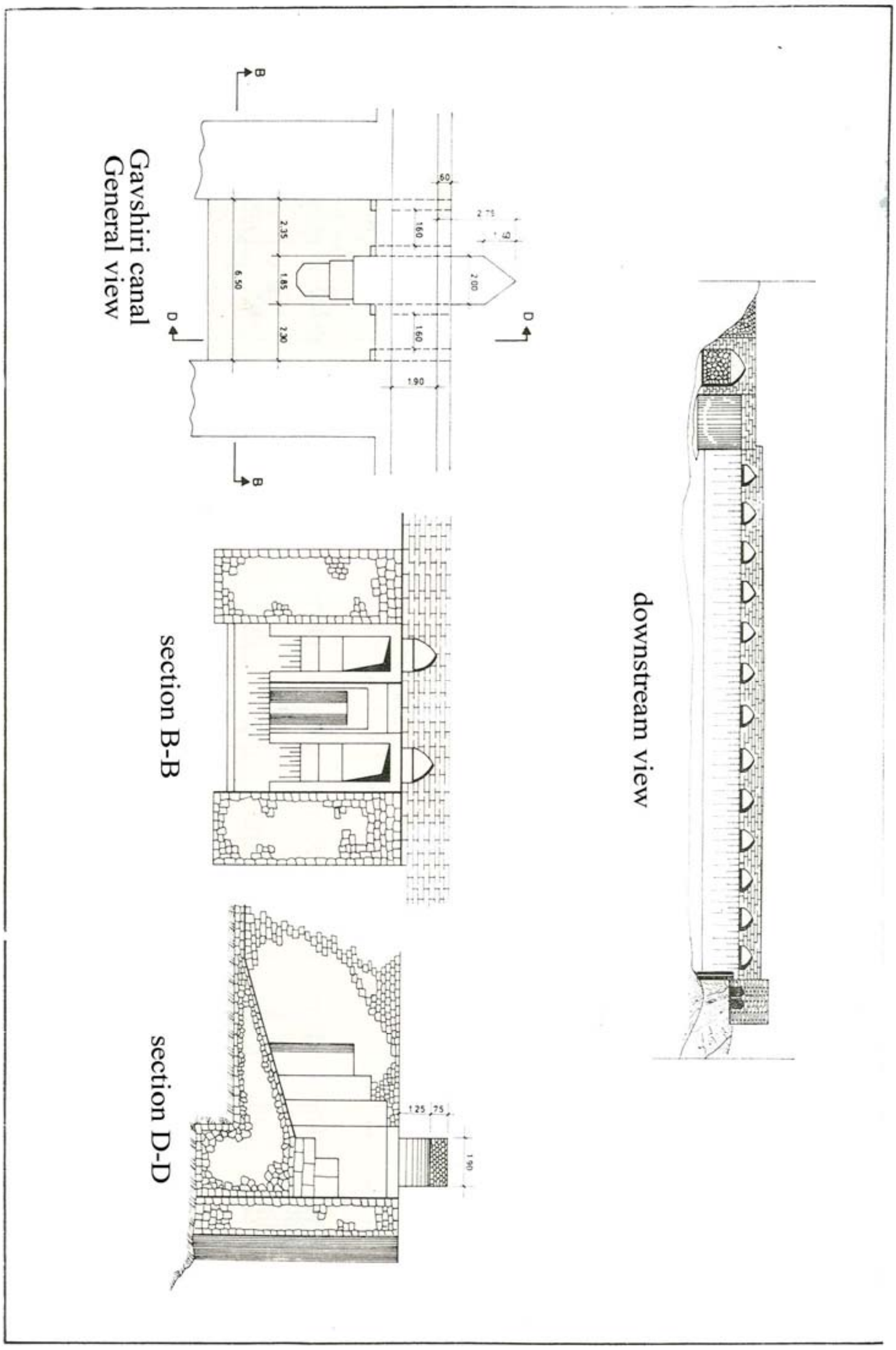


Fig 136, Amir Weir in Fars

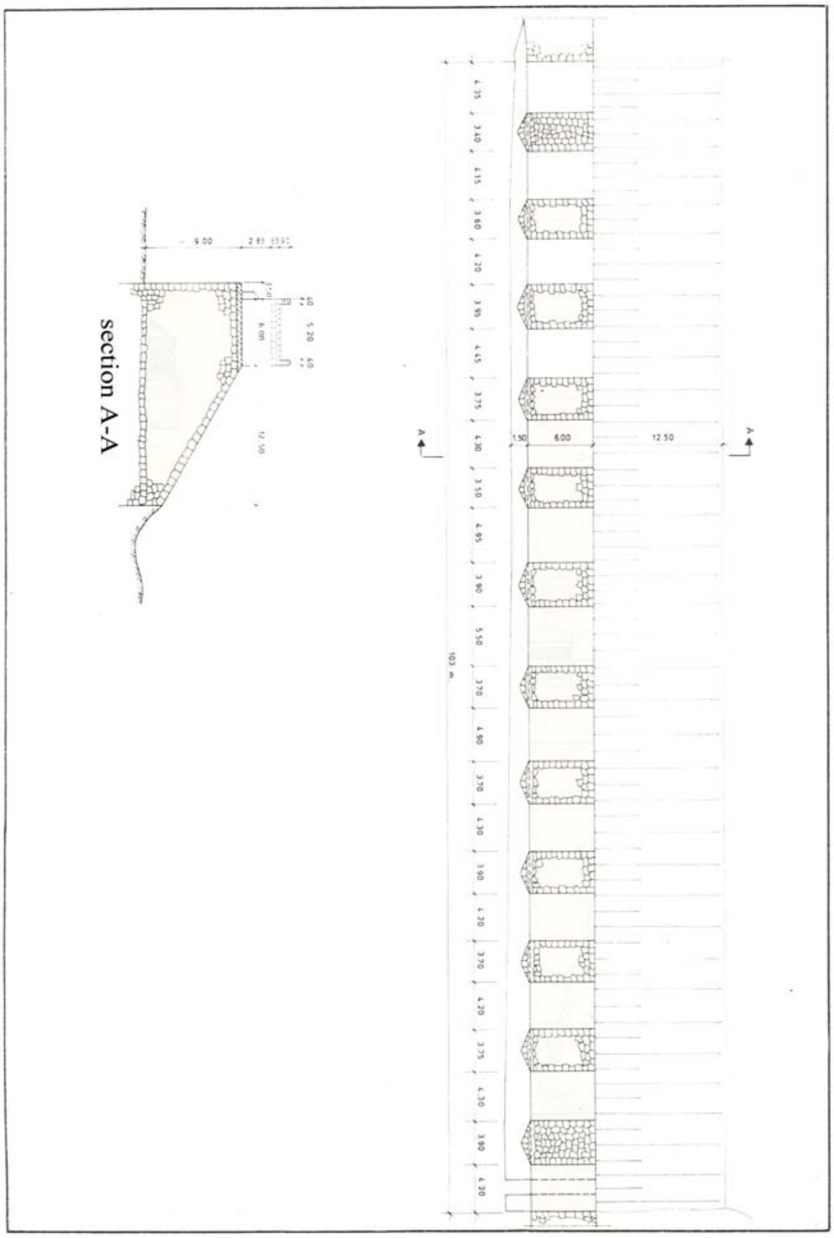


Fig 137, Amir Weir in Fars

(Plan and cross-section)

8- KOBAR WEIR IN QOM (FIGURES 138 AND 139)

Kobar Weir is one of the arch dams in Iran. Figures 138 and 139 show the general view of the dam. The reservoir is almost filled with sediment. But it does still regulate some water, which passes through the water tower and drains to the river in downstream. Near the existing outlet there is a small canal, which could deliver water to the high lands. There was a karvanserai, 3 km. Far from the dam with two water storage tanks, which must have been supplied by the dam. The dam and karvanserai need more investigation to find out about their ages.

By our opinions Kobar Weir is an important historical structure, which should be rehabilitated. This dam is located near the main road between Qom and Kashan cities and it is very easy for tourists to reach the site by car.

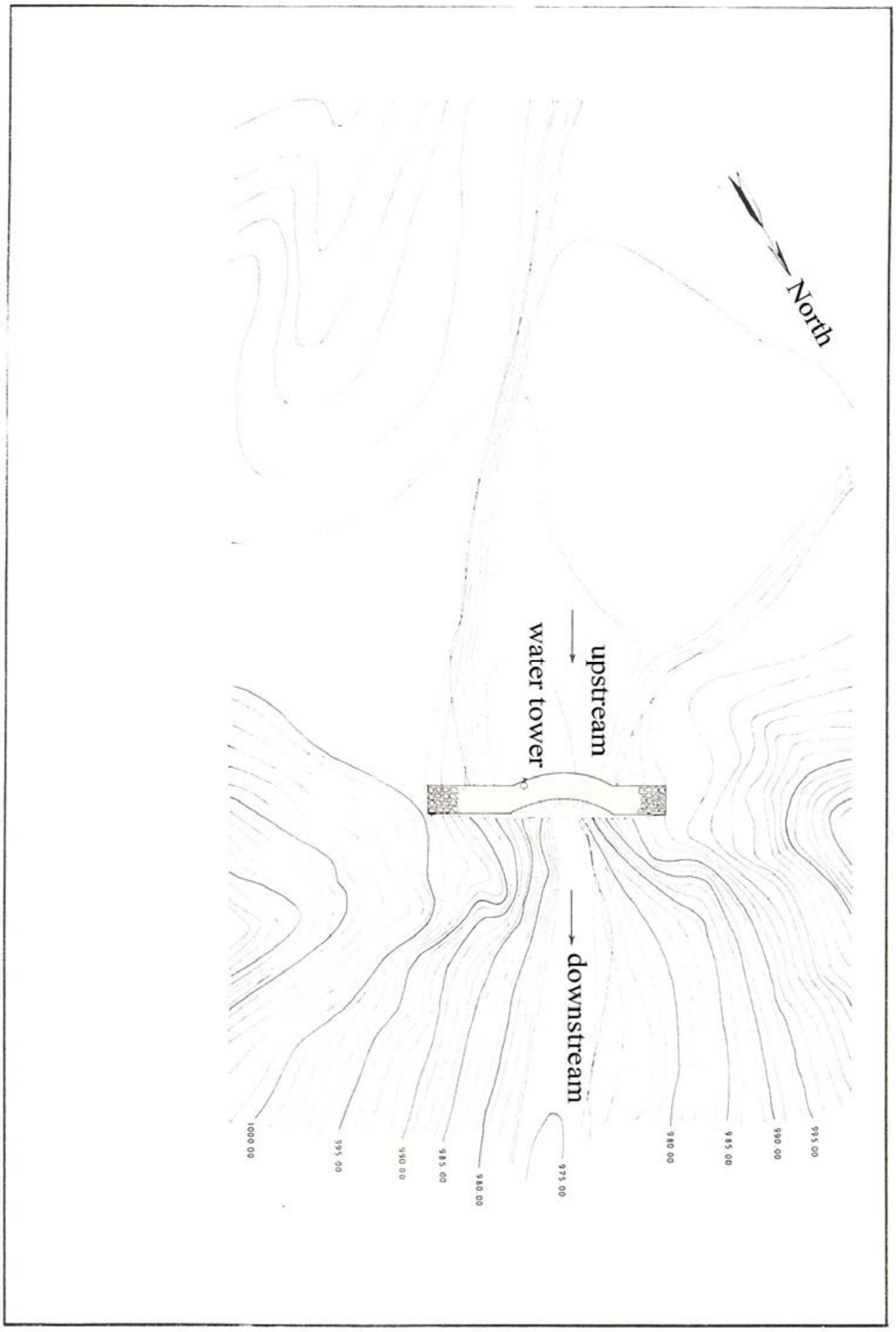


Fig 138, Kobar Arch Dam

(General view)

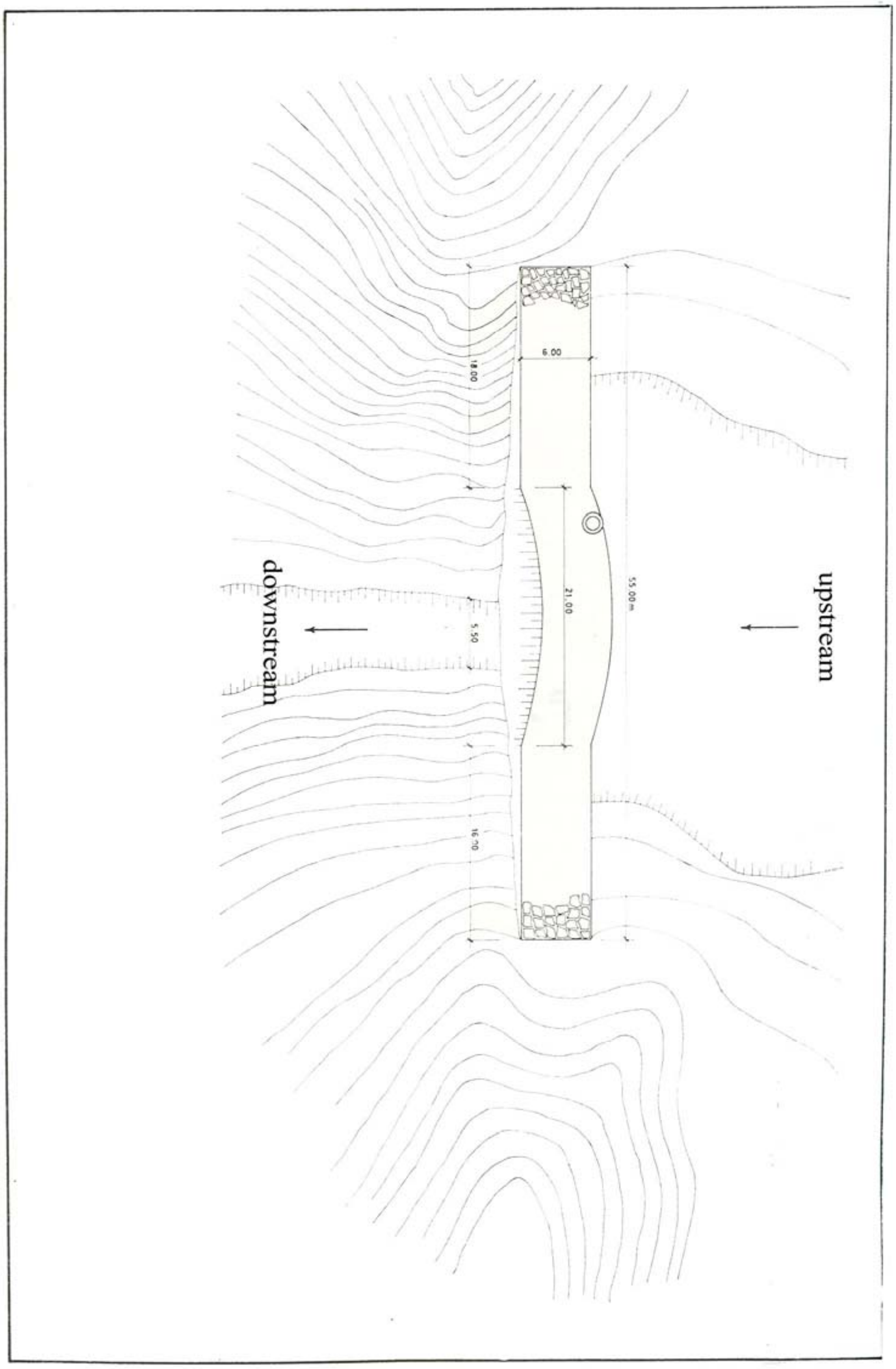


Fig 139, Kobar Arch Dam

CHAPTER FIVE

A REVIEW ON THE FOREFATHER'S KNOWLEDGE ON WATER AND IRRIGATION

The word knowledge has been defined as a collection of some logical and experimental information in a particular field. The different branches of science do not originate from a unique system, but there may be some close links or relationships between them such as chemistry and physics. No doubt, earth sciences, astronomy and medical sciences are the oldest kind of human sciences. Our forefathers sometimes believed that here are some connections between the different branches of science, for example they assumed that the human's fate or future had something to do with the position of the stars which was studied in astronomy, though nowadays according to the scientific findings that theory no longer carries any validity. Their attempts in the field of astronomy emanated from their curiosity about their environment and their desire to track down the secrets of nature, but their involvement in the earth sciences derived from their need to overcome the natural problems and harmonize with nature. In the face of all their scientific efforts, if they failed to discover the real cause of a natural process, they resorted to some superstitions which are still remaining among some nations.

The history of science in Iran is so long that it deserves to be studied for many years. Iran can be considered not only as the cradle of science, but also it acts as a junction between east and west. Richard Frye writes: "Iran has been the territory of the important scientific interactions in Middle east. Egyptians, Babylonians and Indians who were once included in the Iranian territory took advantage of each other's knowledge, and in this regard one can say that Iran played an important role in the development of the ancient sciences."

Some historians refer to the fact that even Achaemenian kings were so concerned about scientific activities. For example Ibn Nadin writes: "After Alexander occupied the Persian capital, he gave the order to translate whatever he found in the royal libraries into Greek, and after he withdrew the Persian sciences on medicine, astronomy, etc he set fire to the books." Ibn Nadim adds: "the Persians had already made some copies of their books and sent them to India and China for a rainy day, because Zoroaster had anticipated such an invasion. Later Ardeshir Babakan sent out some officials to those countries to get the books back to Iran."[1] In the course of the Iranian history, many scientific records vanished during the bloody conflicts and invasions.

There are also some scholars who refute the fact that there was such a scientific development in Iran before the advent of Islam. I hope the publishing of some ancient scientific records could shed light on the magnificent history of science in Iran and make it possible for the scholars to get access to these documents such as the two books written by Karaji and Kharazmi discussed here.

Taking into account that science and art are usually considered interwoven whenever there is a discussion about the historical civilizations, so here I brief some principal concepts of art. Art means some acquired abilities and inborn talents which are manifest

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1- Ibn Nadim, Al-Fehrest, translated into Persian by Tajaddod R, p.436

in the creating of artistic materials with the aid of human mind and emotion. If we can name the mental powers as the spiritual powers, so Art emanates from the artist's spiritual inspirations which may take various shapes such as painting, music, dance, poetry, etc. There are some relationships between the different branches of art as Goethe[1] believed that architecture is associated with music and likened architecture to a "solid music". In Persian language, the word art is sometimes a synonym for the word technique. For example, it is usual to say such term as the art of irrigation, perhaps due to the fact that a technique like irrigation is rooted in the human mind and emotion just the way an art is. Even in ancient Egypt, irrigation was called the art of kings, and the Iranians used to place a high value on irrigation, before & after Islam.

Now, we want to step in the world of ancient sciences and see what Iranians could discover in terms of water and irrigation. During this scientific journey, our guide is the books written by Karaji and Estakhri which would be explained and interpreted in some cases. Meanwhile, we would try to compare our ancestor's ideas with the new scientific findings. If their ideas would match up with the new findings, it would bring Iranians a higher position among other ancient civilizations of the world, and in case their ideas would contradict the new scientific facts, we should not belittle their efforts bearing in mind the scientific atmosphere of that time.

5-1- SOME NOTES ON THE EARTH SCIENCES

5-1-1- THE SHAPE OF EARTH:

Karaji in his book defines the shape of Earth as follows: "The Earth with all the mountains and plains on it has a spherical shape. The earth is doomed to spin all the time. God created this universe brimful, with no vacuum in it, and designated the positions of the stars as well as the elements such as fire, air, water and soil[2]. In case an element would be separated from its original position archetypally determined, it would tend to get back. That is why such elements as water and soil have a strong tendency to go downer and downer."[3]

One can deduce from Karaji's explanations that at that time they took the sphericity of the Earth for granted. The Earth not only spins, but also moves around the Sun, so it is not true that the Earth has been fixed immobile just spinning.

Note that one of the Greek philosophers named as Aristarchus believed that the earth is not immobile but it orbits the sun (91). His theory was refuted by Claudius Ptolemaeus. Eventually in the 16th century Copernicus brought up the theory of the movement of Earth around the Sun which has been discussed in his famous book entitled "Orbital Movement of Stars" published after his death.

5-1-2- TENDENCY TO THE CENTER (THE EARTH GRAVITY)

The tendency to the center or the Earth gravity is a key concept in the Karaji's works. He believed that the Earth enjoys a kind of force that makes every things tend to move toward the center of the earth. This is very similar to what Isaac Newton told about

1 - Johann Wolfgang Von Goethe (1749-1832)

2- Many ancient philosophies used a set of archetypal classical elements to explain patterns in nature.

3- Hidden Water,p.3

gravitation in 1727. It is said that an apple falling down sparked the idea of gravitation in Newton's mind for the first time, but he did not know that about 1000 years ago a Persian scientist had stipulated: "Every element on the earth is being drawn toward the center of the earth…."

He also writes in his book: "whatever higher than the Earth surface such as a building may fall down, and it is attributable to the same attracting force inherent in the Earth and its sphericity." In sum, one can say that gravitation is one of the greatest discoveries making up the basis of our new sciences.

Note that in some cases, human imaginations and emotions about a natural phenomenon match up with the reality, though he or she is not aware of the physical principles of that particular phenomenon. For example, if you give somebody two objects one heavier than another, and ask him which one is heavier, he would start weighing them by slightly moving his both hands to examine their weights. Doing so, he can recognize the heavier object after a while. How can you explain this recognition according to the modern scientific principles? His muscles moving in a steady direction, and acted on by a constant force parallel to that direction result in work which can be calculated by the following formula:

$W=F\times D$

Where F is the portion of the force acting in the same direction as the motion, and D is the distance traveled by the object. The heavier the object, the more Force is needed to do a particular work, the more his muscles would be exhausted. That is why he can find out which object is heavier without knowing the above explanations. In this manner, Karaji succeeded in Knowing that the earth has a force he named "*the tendency to the center*". This is the same that Newton called gravitation but he could formulate this concept with the aid of the new progresses in mathematics and physics.

5-1-3- THE BALANCE BETWEEN THE OBJECTS ON THE EARTH

Karaji writes that the Earth is not a perfect sphere, but it enjoys many mountains and valleys which disturb the sphericity of the Earth; otherwise, the oceans would cover all over the earth and there would be no room for humans and other animals to live. Also if the whole waters would be located underground, it would not be that easy for the civilizations to emerge and flourish.

In terms of the tendency to the center, he mentions an interesting fact. According to his writings it is gravity that draws the water bodies to the lowest lands and leaves the elevations dry. All the spots on the crust of the Earth are in balance and their weights are evenly distributed in all over the Earth. Imagine that in a particular place the water level would go up, what would happen then? He answers that this incident would throw the Earth off balance and the Earth would shake until the uneven objects would be distributed again and the Earth would reach a new balance, and all this is impossible unless there would be the force of gravity. The Karaji's theory reminds us of what professor Rothee, the manager of the International Association on Seismology, has said about the effects of the changes in the Earth's crust on the occurrence of earthquake. He believes that the volume of water accumulated behind a large dam may impose an excess burden on the earth's crust losing its natural shape and balance. So this situation may cause an earthquake which in fact is a backlash of the construction of the large dams. Rothee gives several examples from India, South Africa, the United States and France to show the role of the big dams in the occurrence of earthquake. Perhaps the 1962 earthquake which hit Bouyin Zahra in Iran had something to do with the dam of Sefidrood constructed just before that disaster.

5-2- SOME NOTES ON OUR FOREFATHERS' HYDROLOGY

5-2-1- THE CAUSES OF PRECIPITATION AND WATER CYCLE

Karaji writes in his book: "The Sun takes the most delicate parts of water and turns them into air (vapor)". He adds: "The transformation of water into air in the hot regions and air into water in the cold regions creates a constant cycle which guarantees the prosperity of the lands".[1] "God has created water to fill up the gaps and cracks of the earth, and the rest of water spill into the oceans. So the whole water has originated from the cycle of transformation of water into air and air into water."

What Karaji tells about the causes of precipitation is called water cycle in the science of water economy.

All the water resources of the Earth consist of saline water oceans, vapor in atmosphere, ice in the poles, groundwater in aquifers, surface streams in rivers. According to the Raymond's estimates, the total water of the earth amounts to 1/336/801/903 cubic kilometers out of which 1/300/000/000 cubic kilometers make up the free oceans and seas. The amount of water existing in the rivers and shallow aquifers is 66/230 million cubic meters which is 0.0495 percent of the total water resources of the Earth (Figure 31). Total water neither increases nor decreases, but it is always a constant amount. In fact, the sunshine heats the water in the oceans and turns it into vapor ascending and then moving to the lands where a decline in temperature gets it condensed as rain or snow. This rainfall partly turns into vapor again as soon as it touches the ground, partly seeps into the earth forming the underground streams, and partly flows on the surface toward the free oceans or seas. The travel of water from oceans to lands and vice versa is called water cycle which is out of human control. In addition to this water cycle, there is another process named as small water cycle which refers to some limited precipitation associated with some evaporations and condensations on a local scale. Note that this process does not add anything to water cycle, but it is a part of water cycle.

5-2-2- THE CAUSE OF WATER FLOW

We know that gravitation multiplied by the difference between two particular levels is potential energy which can be transformed to other types of energy such as temporal or electric energy. A water flow from a high to a low spot is attributable to this potential energy which makes water run down a river or a pipe. Karaji's explanation shows that our forefathers considered the gravity and the difference between two particular levels as the cause of water flow. Karaji assumed the center of the Earth as a criterion to which the level of every spot could be compare, though today the difference between two particular levels should be compared just to each other. In terms of water flows, another factor is the friction between the liquid and the inner side of a pipe or a river bed. Our forefathers made use of this concept in making "The wonderful containers" to be

1- Hidden Waters,p.16

explained later. The first scientist who examined the water flow and its causes based on the modern mathematics and physic, was H. Darcy. He succeeded in calculating the coefficient of friction between a liquid and its pipe for the first time in 1857. It should be noted here that no branch of science can make any progress without using experiment. In fact, experiment guided Darcy to discover the coefficient of friction. There is an interesting story about the importance of experiment. It is said Euler who lived in 1770, contemporary to Fredrick II, wanted to build a water spout throwing water 500 meters up. Euler was a famous mathematician whose formulas about the resistance of columns against pressure are still being used by the civil engineers. Fredrick II ordered Euler to do his best to calculate such a water spout which could be unique in the world at that time. Euler specified the elevation at which a water tank should have been placed as well as the condition of the pipes etc. whereas the result did not meet his expectation, and the water spout was so lower than what Fredrik wanted to be. The reason of Euler's failure was to ignore the role of the friction between water and pipe which was calculated later by Darcy. According to Karaji, water is also affected by the force of gravity like every object on the earth.

5-2-3- HOW TO FIND GROUNDWATER

Ancient Theories

1- Effect of Water Seepage:

In terms of the effect of water seepage, Karaji writes: "… There are some reservoirs under ground whether soft or hard, water can penetrate these reservoirs through the gaps and cracks of the earth. This water replenishes the underground reservoirs which are always being discharged by the springs. In fact, the water keeps seeping down until it is stopped by an impermeable layer lying at a lower depth. If a conduit is made through this water, it would immediately flow along the conduit according to the pressure which is on the water."[1]

2- Effect of Air Penetration into the Earth:

Another theory about the existence of water underground was the distillation theory according to which when the moisture of air penetrates the porous formations of the ground, it starts to distillate and form lots of small drops filling up the ground hollows. In this regard Karaji says: "The very cold air can change into water under ground and provide the Qanats with a permanent supply of water".[2]

3- Effect of Deep Waters:

According to Karaji, the main supply of water is located somewhere very deep under ground which does not correlate with the fluctuations of rainfall. This deep water makes up most of the Earth's mass, and does not change over time. Sometimes the water goes up and gets available to the humans.[3]

1- Hidden Water, p.10
2- Ibid,p.9
3 -Hidden Water,p.25

New Theory

In the modern hydrology there are two main theories on how groundwater comes into existence. According to the first theory, the water resulting from precipitations seeps into the ground and fills up the porous layers, and then slowly moves toward the free oceans. An increase in the discharge of the springs, wells and Qanats after a rainfall, proves that the groundwater supply is tied with the amount of precipitation. According to the second theory, the water vapor existing in the air can penetrate the ground where it would distillate and produce the groundwater reserves. This is originated in the melted materials existing below the Earth's crust. The hot vapors go up and eventually condense into water which may show up on the surface as mineral springs. Suess calls the groundwater that originates in a very deep reserve as juvenile, and the groundwater produced by magma as vados.

5-2-4- HOW A SPRING APPEARS AND WHAT IS THE EFFECT OF EARTHQUAKE ON IT

Karaji says: "There is no spring whether oozing or spouting on the earth surface, unless its reserve lies somewhere farther away than the mouth of spring from the center of the Earth. That is why a spring can appear on the surface."[1] He adds: "I was told that there are some fresh water springs on many islands. No doubt these springs have nothing to do with sea water, because the sea level is lower than the islands, and the sea water is salty whereas these springs drain out fresh water. The answer is that the water supply of these springs are linked to it somewhere more elevated than where the springs appear. In fact, the rainfall seeping into the hills turns up downstream as spring."[2]

In terms of the springs on the top of mountains, he says: "inside such mountains may be a large cavity full of vapor which ascends and gets cold and condenses into water coming out from the springs on the top of the mountain."

Another important subject that Karaji takes up in his book is the effect of earthquake on a spring appearing or drying. He says: "In the wake of an earthquake, some springs may appear and some may dry up or move to elsewhere. Because, there are some extensive cracks under ground through which water can move from a groundwater supply to the surface. These cracks are wrapped by some impermeable formations through which water can never escape. The accumulation of a large quantity of vapor under a high pressure may make an explosion leading to an earthquake on the surface. Now this earthquake may disturb the order of the layers and cause cracks in that impermeable formations. Water would go down the crack which is closer to the center of the earth than the others. That is why an earthquake may change the locations of the springs. Perhaps the explosion of the vapor causes a long crack through which a groundwater supply finds a way to the surface for the first time."[3] He writes about artesian spring: "There is an artesian well at the base of a hill from which a sound like the howl of wind is heard every once in a while, and then there is a spout of water flowing down the hill and irrigating the farm lands. This happens several times a day."[4]

1- Hidden Water,p.7
2- Ibid
3- Hidden Water,p.37
4- Ibid,p.21

According to the new theory, the springs are related to groundwater resources which appear on the earth surface and flow. In terms of the structure of the mouth of spring, all the springs have been classified into four categories as follows: layered springs, storage springs, sliding springs and cracked springs. (figure 32)

Through a layered spring, water flows out just according to the force of gravity, whereas water may spout from the other tree types of springs, for water is under pressure. As Karaji mentions in his book, an underground crack stretching out from somewhere elevated to the top of a hill, may direct groundwater to an exit (as a spring) appearing on the top of that hill. Karaji's idea about such springs matches up with the modern findings in this regard.

Also, what Karaji says about the boiling springs frequently spouting is in keeping with the knowledge we now have on this issue. J. Stiny believes that from a boiling spring, water and vapor usually spout respectively at regular intervals. Such springs have a period of calmness which varies from a few minutes to several hours between two eruptions. There are many springs of this type in North America, New Zealand, Japan and Iceland, and called as Geisyre or Geiser.

The effect of earthquake on the status of the springs is an important issue in Karaji's works. It is likely that the springs which existed in the Iranian plateau vanished or turned up elsewhere due to the earthquakes.

5-2-5- SEARCHING FOR WATER

1- Searching for Water by Means of Experiment

Karaji says: "If any moisture is found in the earth surface, it implies that there is a water supply under ground." To know if there is groundwater, he suggests the following experiment: "Take a ceramic or copper bowl and stick a piece of wool to the bottom of the bowl by means of wax. Now dig up a 100 cm deep hole and place the bowl in it upside down. Put a green leaf on the bowl (no matter which plant the leaf belongs to), and fill up the hole. Wait until sunset and then empty the hole and bring up the bowl to see if the wool could have absorbed any moisture. In case the wool would be soaked in water, it means that there is a good supply of water underground".

To find groundwater reserves there have been several methods some of which were practiced by the ancient Romans as well. For example in 97 AD, Nero appointed Frontinus as the water manager of Rome. He was in charge of supplying water to that ancient city. Prior to him another expert lived named Vitruv who utilized some methods mentioned later by Karaji. Vitruv says: "It is easy to find water where there is any natural spring, but if water does not come onto the earth surface automatically, it is up to you to find the concentration of water under ground. To do so, you should do this experiment: just before sunrise, where you want to find groundwater, you should lie down and put your chin on the ground to prevent any shaking in your head. Now stare at a distant point, if you notice any vapor being emitted, this spot enjoys a good supply of groundwater". In this regard Karaji says:" At the time of sunrise, if there would be a lot of vapor, fog or dew on the earth surface, it shows that there would be ground water."[1]

1- Hidden Water,p.21

2- Searching for Water by Digging Trail Well

The Iranian people who invented the system of Qanat used to measure the volume of groundwater by digging trail wells. They sank a trail well where they already guessed there may be ground water. They constantly hauled the water infiltrating into the bottom of the well to the surface. The quicker the trial well was refilled, the more the amount of the groundwater. This procedure is still practiced when a Qanat is to be constructed. The only difference between this manner and the modern one is that nowadays digging and pumping is done with the aid of machines.

3- Searching for Water by Means of Vegetation

Karaji explains that there are several plants which are a good indication of the existence of groundwater. To avoid padding this book out, I refrain to quote Karaji on his long list of such plants.

4- Searching for Water with the Help of Geology

Nowadays such studies are called hydrogeology conducted before drilling a trail well. In this regard Karaji says:" the higher the ratio of the amount of stone to the amount of soil in a particular mountain, the less the chance to find a supply of groundwater. There is no groundwater in the small and separated mountains especially those which have hard rocks, because no snow can last long on their tops. In case there would be a chain of mountains covering a vast area, it is more likely to find a good supply of groundwater, because such mountains enjoy many valleys that can hold ice and snow until summer. If a mountain has a flat top with thick vegetation casting shadow on the ground and protecting the soil moisture from sun, there would be a better chance to come across an aquifer.

He adds: "all the lands linked to the aforementioned mountains contain a good supply of groundwater, especially the land which is the lowest as well as the closest to the Earth's core…." In fact, Karaji believes that the more extensive the mountains overlooking a particular plain would be, and the more porous the soil texture of the plain, the more groundwater we can expect to find there. To confirm the Karaji's idea it is enough to take a look at the situation of groundwater in Tehran. There is a vast mountainous area surrounding the north of this city. These elevations receive a considerable deal of snow every winter which recharges the aquifer. The farther we get from the base of the mountains, the shallower the groundwater would be. That is why in Tehran water table is 120 meters deep, whereas one can find groundwater at a depth of 14 meters in Shahr-e Ray a nearby town which is less elevated than Tehran.

5-2-6- HYDROLOGY

Our forefathers used to take the quality of water into consideration. To distinguish a good water from a bad one, there were some methods described by Karaji in his precious book as follow:

1- Physical Characteristics:

“Whenever you see that water has an abnormal color, take it for granted that this water is not safe. In case water is giving off a bad smell, or it has a bad taste, the water is certainly rotten and unsafe.”[1]

Our modern knowledge about water sanitation confirms what Karaji has said at that time. We know that drinking water should not have any color, odor or taste. All yellow or brown waters are laden with the organic materials, and the dark waters are no doubt polluted. The organic materials in water decompose and as a result produce a bad smell and taste in water. The existence of H_2S can add a smell like that of a rotten egg to drinking water.(67)

2- Chemical Characteristics

In terms of the chemical characteristics of water, Karaji says[2] : “The most refreshing water is what is coming from rain or snow directly. After that the waters flowing on sand, gravels and rocks can keep their freshness, but the waters running through the minerals and saline soils along the ditches flanked by lots of algae and moss can easily lose their purity.

Such waters are salty, bitter, sour or sweet because of sulphur, orpiment, salt, mercury, tar, oil, alum, etc dissolved in water.”

All the streams whether underground or surface would dissolve the minerals of the soil. Nowadays it is so easy to determine the minerals dissolved in water by means of some chemical examinations, and Iranian scientists living 1000 years ago was aware of this fact a he says:” If you have two sources of water whose characteristics were the same, and you want to know which one is more refreshing, you should take two particular amounts of the water and weigh them to see which one is heavier. The lighter water contains less mineral and is more refreshing…”[3]

Even today, people are used to use the words heavy and light when they talk about the quality of water. I believe that attributing the words heavy and light to water has emanated from this Karaji’s experiments in terms of water quality.

We know that the specific weight of the ocean water is about 1.04 kilograms per liter, so how Karaji could compare the waters by weighing them. He should have had a very accurate weighing device, otherwise he could not recognize the little difference between the weights. One can deduce from Karaji’s experiment that the Iranians might succeed in inventing such an accurate device being able to weigh a very little mass though there is no relic of that left.

Even today, in remote villages it is common to say that a particular water contains mercury, but the villagers mean there is too much calcium carbonate in water by that. Therefore Karaji addresses calcium carbonate, whenever he talks about the existence of mercury in water because the specific weight of mercury is about 13 and can not float on water. Karaji says a water laden with mercury would leave a layer of a white residue

1- Hidden water,p.28
2- Hidden water,p.27
3- Hidden Water, p.28

on the inner side of a container after boiling, so he gives the name of mercury to this combination. Perhaps, the reason of why those people used to name "calcium carbonate" mercury was the fact that calcium carbonate could be harmful to human body when eaten in large quantity. For example, a company named Dow Chemical spilled its sewage containing mercury into the lake of St. Clair for about 40 years. As a result, fishing in this lake was banned, because 45 people died of eating the fish contaminated by mercury and 116 people got cripple for their whole life. The examinations showed that those people had poisoned by mercury stored in the fish's body.

5-2-7- TREATMENT OF WATER

Karaji suggests some ways to purify water out of which some are considerable. He writes: "To make salty and heavy water suitable for drinking, put the water in a new pottery through which water can leak out. Doing so, the water would be purer"[1].

Nowadays, to treat water physically and bacteriologically, the water is pumped through some specific porous filters and screens made of ceramic. As mentioned, Karaji believes that if water flows through sand and gravels, it would be purified in the way that water is treated at modern water treatment plants. Nowadays we pass the water through some layers of sand named sand screen. This method is practiced in cities like Tehran and Ahvaz whose water is supplied by the rivers. A special chemical is added to water to make the dissolved materials clot and deposit, and then water is passed through the layers of sand to separate the materials from water.

1- Hidden Water, p.30

CHAPTER SIX

PERFORMING TRICKS WITH WATER

According to our forefathers' opinion, all the living things in all over the world need the four principle elements; water, soil, fire and air to survive. That is why the ancient Persians considered these four phenomena as sacred elements.

Note that no other elements can substitute for these four elements which are necessary for life to continue.

So from the dawn of history, humankind has been dominated by water whose lack could wipe away all kinds of life, and at the same time could wash away and destroy everything if it would overflow.

Humans had no option but trying to discover the characteristics and nature of water to take control over it and safe themselves from its threats.

In the last chapters, we talked about the relationship between water and air. Our forefathers were aware of the existence of air in every little gap and hollow underground, though they had no idea that the pressure of air on sea level is equal to that of a 760 millimeter column of mercury. They just did some amazing experiments like performing tricks by means of using the natural behavior of water, vacuum and the friction between a liquid and its container. In the ancestors' view, such experiments were somehow mystical, as Kharazmi has mentioned in his book "Mafatih al-oloom"(the doors of sciences) that all these experiments are "the industry of tricks" also mentioned in other historical records. For example Hafiz, the popular Persian poet, says:

"Thou cup-bearer, spill your wine into the cup of Adl, so wicked people would not raise a fuss and mess up the whole world"

The cup of Adl was a special container that worked based on some physical processes. Later we will get back to the subject of the cup of Adl. The abovementioned poem shows that hafiz was aware of the mechanism of the cup of Adl.

The purpose of this book is to introduce the knowledge our ancestors had about water, so I would take up the most important devices they had invented to make use of water in performing tricks. Even I used my imagination to sketch some of these devices based on the explanation found in the historical records.

Kharazmi, in his book, examines the movements caused by water, and he attributes these movements to the nature of water. Now, I would like to draw the readers' attention to such devices as follows:

6-1- THE BOWL OF TIME

According to Kharazmi, if a metallic bowl with a tiny hole at its bottom was put on the surface of water, the bowl would be filled and sink in the water after a while. You can tie some threads to the bowl in order to transfer its movement to elsewhere to move another object. If you want to move an object after a particular time, you can use this device.

No doubt, this device was used to calculate time even before Kharazi's time (about 1100 years ago), and also it was operated later, as Shardon describes: "To divide the water of a spring or river among the farmers, a round thin bowl made of copper was placed on the surface of water. Water starts entering the bowl through a tiny hole at its bottom until the bowl sinks in water. The farmers do that again and again over to see how long each one has the right to direct the flow to his land." Petrushevsky in his book, quotes Sharden as saying, and then adds that there is a sample of such a bowl in the ethnological museum of the sciences academy of the Soviet Union. In Persian, this bowl is also called Keyl or Tong.

A scholar named Anjari Shirazi who has gathered all the water related legends from all over the country, let me know that the bowl of time is still being used in the rural regions of Kashan and Yazd. Usually someone reliable and honest is in charge of operating the bowl, repeatedly putting the bowl on the water in a larger bowl.

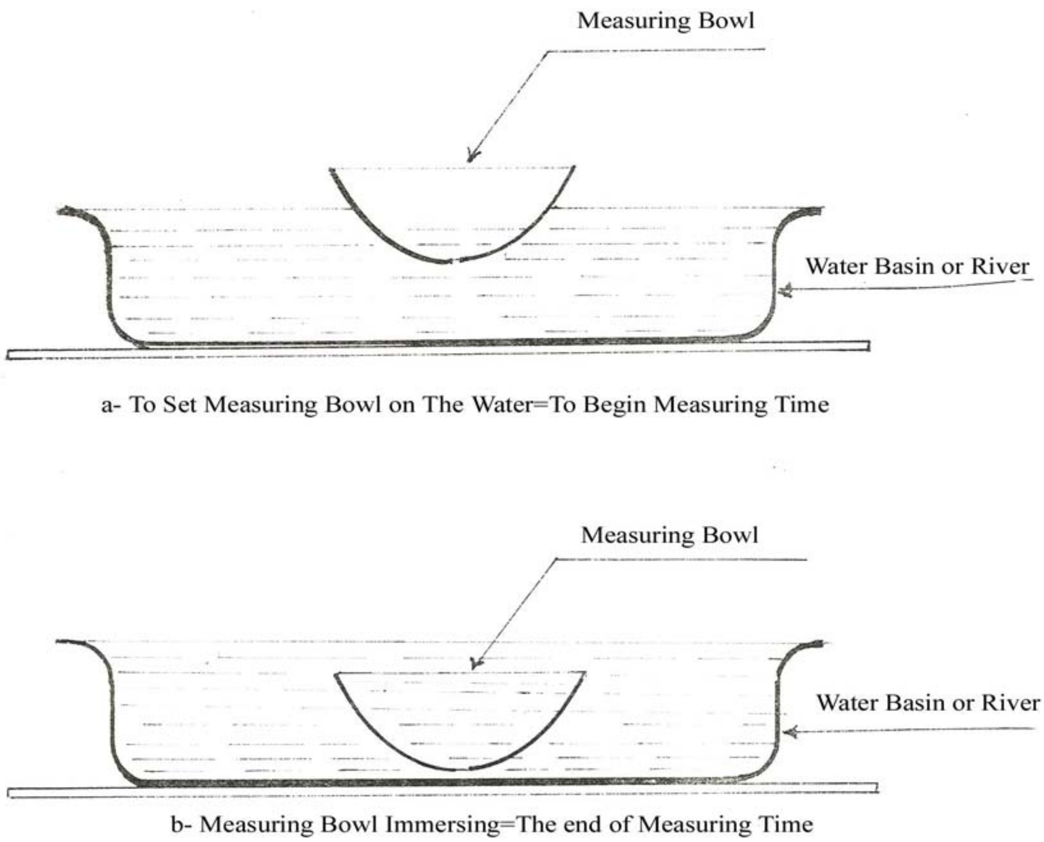

Figure 140, The time since the bowl floats on the surface of water until it sinks was considered as a unit of time named Bast according to which water was divided and transacted. In ancient Iran, a water county defined the water shares based on the number of Bast the shareholders were entitled to.

In Yazd, the bowl of time is called Saboo which measures a unit of time named Jore equal to 15 minutes.

Petrushevsky gives the name of clepsydra to the bowl of time, but I believe that clepsydra is something else.

6-2- THE FLOATING BALL

Kharazmi explains the floating ball as follows: “to build a floating ball, you should attach a short pole to a ball, and then float the ball on the water in a bucket and put a cover with a hole in its middle on the bucket, so that the pole sticks out through the hole of the cover. The more you put water in the bucket, the upper the pole would come.”

In fact it is what is used in the flash tanks to automatically stem the flow of water, whenever the tank is nearly full of water.

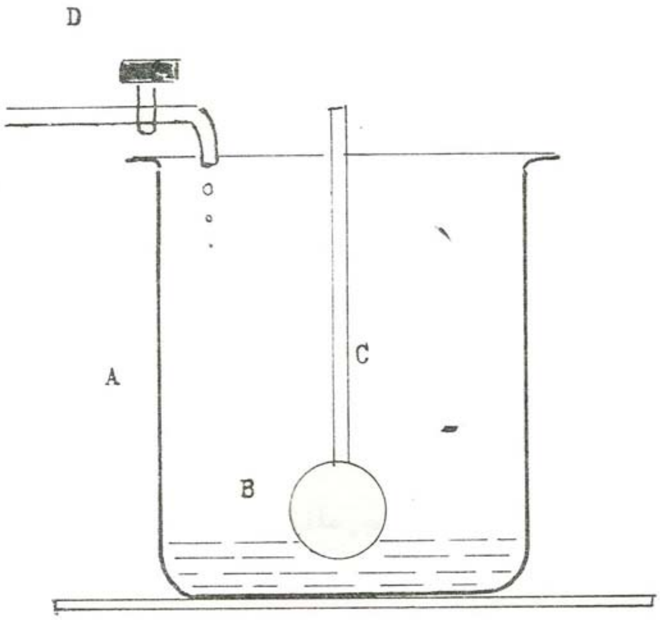

Figure 141, the floating ball or Dabbeh. The empty ball in the container A would ascend along with the water level coming up. The pole C attached to the ball B would ascend too.

6-3- WATER CLOCK

In the historical records, I could not find any note or explanation about water clock, but it is very likely that the ancestors made use of the floating ball in inventing water clock. The second chapter of Kharazmi’s book offers hints on the different types of clock used at that time.

“To measure time, there are many devices such as Tey Jahara , Sandoq Al-sa’at, dabbat Al-sa’at, Rekhama, Makhala and Lown”.(figure 35)

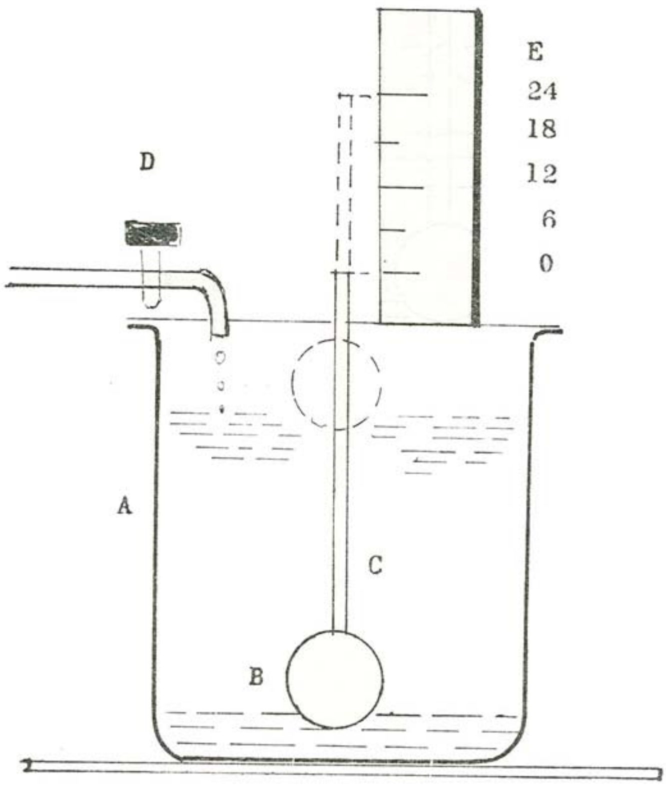

Figure 142, water clock in ancient Persia. A kind of water clock named Dabbat Al_sa’at: a sign was attached to the pole c moving during a day and showing time on the scaled tablet E.

Perhaps, Kharazmi means sand clock by the word Makhala, and the word Lowh probably addresses sun clock.

Taking the structure of the floating ball into account, we can describe how a water clock has worked. There was a ball floating on water in a container with a holed cover on it, as explained in terms of the floating ball. Here the pole attached to the ball was linked to another pole by means of a hinge. There was a constant flow into the container making the water level come up. The ball would ascend and make the poles move along a scaled plate. (figure 36)

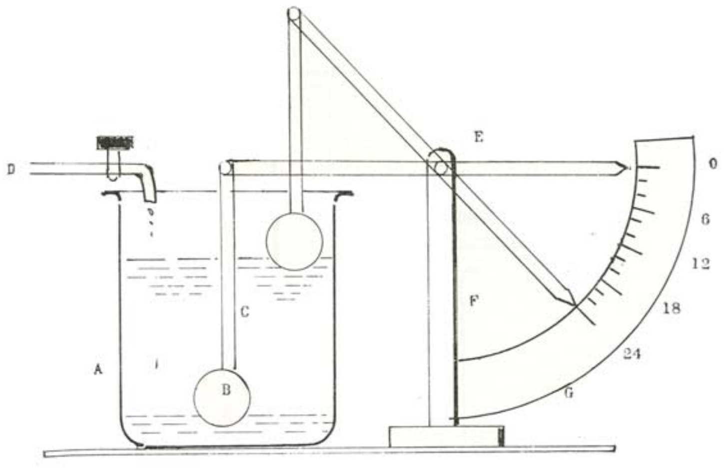

Figure 143, Water clock in ancient Persia

6-4- SIPHON (AB DOZDAK)

Kharazmi calls siphon Ab dozdak or sareqat al-ma' which means thief of water[1]. "This device is a bent tube made of glass or something else. One end of the tube should be put in a container full of liquid and the other end should be sucked until the liquid flows in the tube. In case the container is placed somewhere higher than the other end being sucked, the flow in the tube would not cease.

Due to the difference between the levels of water in the container and in the exit of the tube, water can flow down the tube. The pressure of air on the exit of the tube and on the water surface in the container is the same. After the air existing in the tube is sucked out, there would be a vacuum in the tube, so the pressure of air on the container would push the water into the tube.

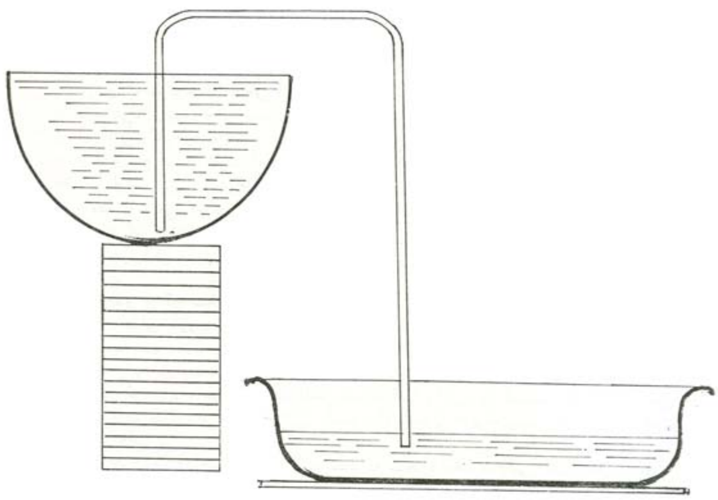

Figure 144, Ab dozdak: when the bent tube is sucked, the water starts flowing from the upper container down. In the past, this matter was used for irrigating.

1- The Greeks called water clocks klepsdra, which means "thief of water" in their language. (translator)

6-5- JAM-E ADL (THE CUP OF ADL)

According to Kharazmi:" Jame Adl is a special container in which there are two tubes attached together. There is a hole at the bottom of the container, so if the level of the liquid would be lower than the lower tube, then the liquid would remain in the container, otherwise the liquid would spill through the hole."

The figure 38 has been sketched based on Kharazmi's explanation on the cup of Adl. According to this figure, if you fill the container with water so much that the water level would pass the bent tube, the pressure of water would push water into the tube until the container would get empty.

Kharazmi mentions some terms about the components of the cup of Adl. He calls the two tubes used in the cup of Adl, Bathion. "The tube installed in the hole of the container is Madeh (female) and the other tube which is driven into Madeh is Nar (male). In general, every tube into which another tube is put named Madeh (female) and the other is Nar (male).

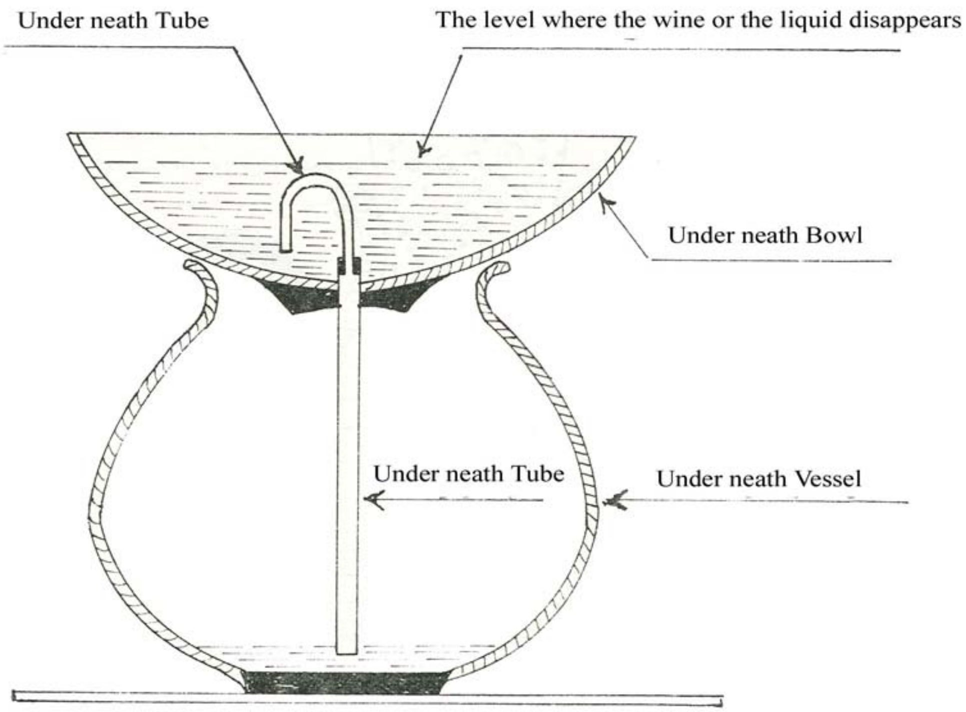

Figure 145, Imaginative of Jam-e Adl (The Cup of Adl)

6-6- THE HOLED POTTERY

Kharazmi names this kind of jug Sahara on which he writes:" Sahara is a jug with a narrow opening and some holes at its bottom. When this jug is full of water and its mouth is closed, no water can spill through the holes. The figure 39 shows this special jug.

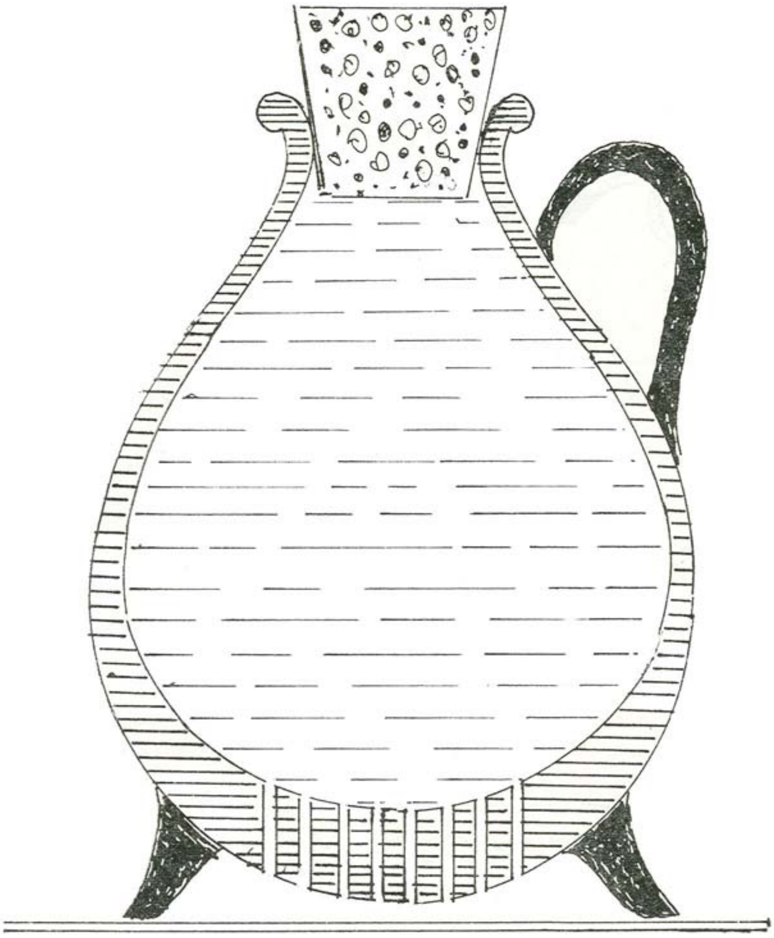

Figure 146, The holed pottery named Sahara was filled by water and its opening was closed not to allow water to come out.

The fact that water can not spill through the holes is attributable to the friction between the holes and water as well as to the air pressure applied from outside toward inside stopping water from flowing. The width and the length of the holes are very important to design such a jug which indicates how much our ancestors were aware of the physical behavior of water. (figure 39)

6-7- THIEF OF WINE (MEY DOZD)

Mey Dozd is an amazing container described by Kharazmi as follows:

“In Persian the word Mey Dozd means thief of wine. This container is filled with wine and then turned upside down without any wine spills out, so you may assume that you have already drunk up all the wine”.

The figures 40 and 41 show how this container works.

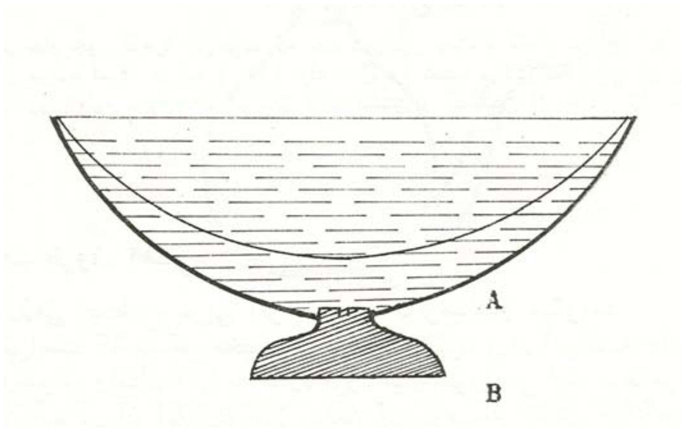

Figure 147, Jam-e Joor or Mey Dozd is a two layered cup made of glass. No one could drink just a drop of wine from this cup. There was a hole (A) at the bottom of the cup which was obstructed by a stand (B). First, the cup was turned upside down so that it could be filled through the hole which got blocked by a stand not to let the wine out. According to Kharazmi, Jam-e Joor is opposite to Jame Adl.

Another name for Mey Dozd is Jam-e Joor which has been defined by Kharazmi as follows: "Mey Dozd is quite opposite to Jame Adl, for all the liquid in a Jame Adl would spill out, in case the liquid was dropped in it more than a given amount."

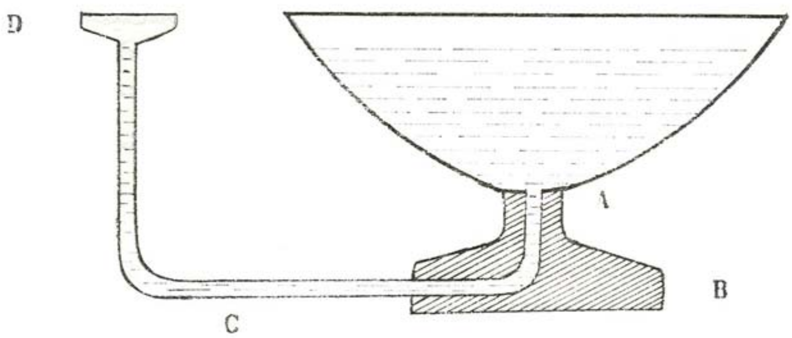

Figure 148, This is another type of Jame Joor with a bent tube attached to its bottom.

6-8- MUSICAL CONTAINERS:

According to Kharazmi "these are several containers in which there are given amounts of water. The vibration of the containers can produce a series of sounds making up a particular melody."

6-9- PERFUME SPRAYER

In the past, people used this device to spray perfume on the face of their guests. This container was made in several shapes. The mechanism of a perfume sprayer was the same as that of the sprayer we use now, except for how to send air into the container. In terms of the old sprayers, air was sent by blowing as shown in the figure 43.

We can deduce from these explanations that our ancestors were aware of the air pressure and its effects, because they could use this fact for making such amazing devices. To prove so, we can refer to other parts of Kharazmi's book which take up the subject of air pressure on different cups of water the way the modern physics describe.

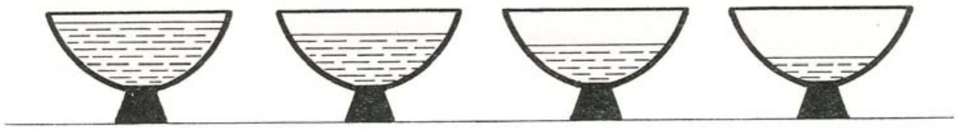

Figure 149, musical containers. If you put different amounts of water in some thin cups which are of the same size, and then wet your finger tip and touch the rims of the cups all the way, you can make different sounds. Every body can do this experiment with their wine glasses.

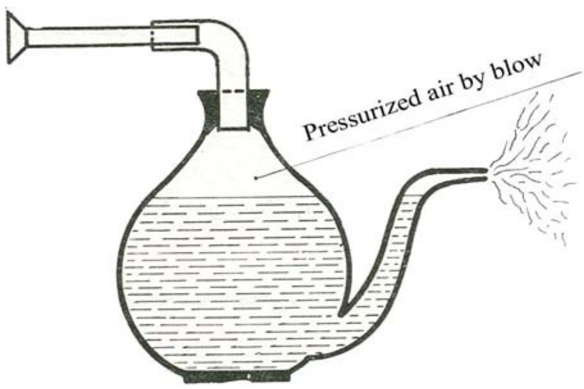

Figure 150, This figure shows how a perfume sprayer - which has been named Nazahat by Kharazmi - works. They put their mouth on the bent tube above the container to blow into it. Blowing could increase the air pressure in the container so much that the perfume was sprayed through the other tube.

CHAPTER SEVEN

QANAT (KARIZ)

The exiting water resources such as normal wells and springs no longer sufficed to supply water to the ancient communities in the wake of the growing development of the Iranian civilizations, so those people resorted to using a new technique to drain groundwater out by the force of gravity. This invention is unique in the world, for it can bring groundwater onto the earth surface all the time the way a natural spring does.

The residents of many parts of Iran are still supplying water to their farm lands and homes through this system, though it has long been invented. It is likely that the ancient Iranians were inspired by the natural springs which were their immediate water resource to dig Qanats,

Needless to say, the first step to dig a Qanat was to figure out whether there was any underground water supply. About 2000 years ago, Karaji has studied all the principles of the groundwater flow, and as mentioned our new findings confirm many of his theories. Karaji explains the causes of groundwater flow as the force of gravity along with the earth gradient which can be ranked among his most important discoveries.

I believe that behind the technique of Qanat there has been a deep knowledge on the existence of groundwater and its behavior. Our ancestors came to figure out how to get access to this groundwater supply through a horizontal canal instead of a vertical shaft in order to get rid of spending too much labor and time to obtain groundwater. Eventually, Iranian workers got started on the first Qanat, and their dream came true. It is very likely that they were completely aware of the existence of groundwater and they used it for irrigation and drinking, even before the idea of constructing a Qanat came to their mind. This invention which is now well known was introduced to other continents and other nations started using it. I can claim that qanat is the first invention in the field of irrigation which is still being used the way it was used thousands of years ago, and this system is still a basis for agriculture in the central plateau of Iran.

What I would write about Qanat in this book, all come from the methods being practical today, and I would also mention some facts found in the old records if necessary. As an introduction, I would like to draw the readers' attention to the fact that there exist about 50000 Qanats in all over Iran.

Figure 151, This photograph shows the piles of dirt around the mouth of shafts, taken from the air. These piles form a perspective showing the direction of

a Qanat on the surface.

7-1- A BRIEF ON QANAT AND ITS MECHANISM

In almost all the existing languages of the world, there are some records about Qanat, and many tourists have come to Iran to visit this hydraulic structure. When you look from a plane down, you may spot a row of many small hills ending up in a nearby village (figure 65). The exit point of a Qanat is usually located close to a village to provide the villagers with drinking water, and then to irrigate their farm lands. In both old and new books, some explanations on Qanat have been presented in detail (refer to Karaji's book, Nozhat al-Qoloob written by Hamd al_Allah Mostoofi, etc).

Contrary to the explanations offered so far, as mentioned in the last pages a Qanat can be considered as a horizontal well. The figure 66 shows a vertical shaft and the figure 67 shows a horizontal well.

The main conditions which make it possible to dig a qanat are an appropriate gradient and the existence of a permanent supply of groundwater which should be more elevated than the exit point of the Qanat in order to guarantee a constant output. The easiest way to construct a Qanat is to dig up an almost horizontal tunnel from the earth surface to the aquifer in order to drain the groundwater out. To do so, a gentle slope (about 1:1000) should be envisaged to let the gravity bring the groundwater to the surface. Even the shortest Qanat is about one kilometer, and the longest one that lies in Gonabad is about 70 kilometers. In fact, it is impossible to construct even a one kilometer long Qanat without digging some vertical shafts which are necessary to ventilate the tunnel as well as to provide a way through which the debris can be hauled to the surface and the workers can get access to the tunnel. These shafts also help the workers find the right direction under ground. The ancient Iranians could settle the problem of digging a long horizontal tunnel by sinking a row of vertical shafts making it possible to haul the excavated materials without traveling a long distance in the tunnel.

Such shafts also let the fresh air circulate in the tunnel and later workers can climb down them to repair the gallery if necessary. Round each shaft a ring of soil accumulates and from the air the qanat has the appearance of a line of small craters. The excavated materials put around the mouth of shaft can prevent the surface seasonal runoffs from rushing into the gallery and destroying the Qanat.

Qanat can be compared to the water bearing bridges (weirs) built by the ancient Greeks and Romans. Imagine such a bridge and get it upside down, and then replaced the columns of the bridge with the gallery of the Qanat. The height of columns varies with the ups and downs of the surface in the way that the depth of shafts follows the topographical situation. (figure 68)

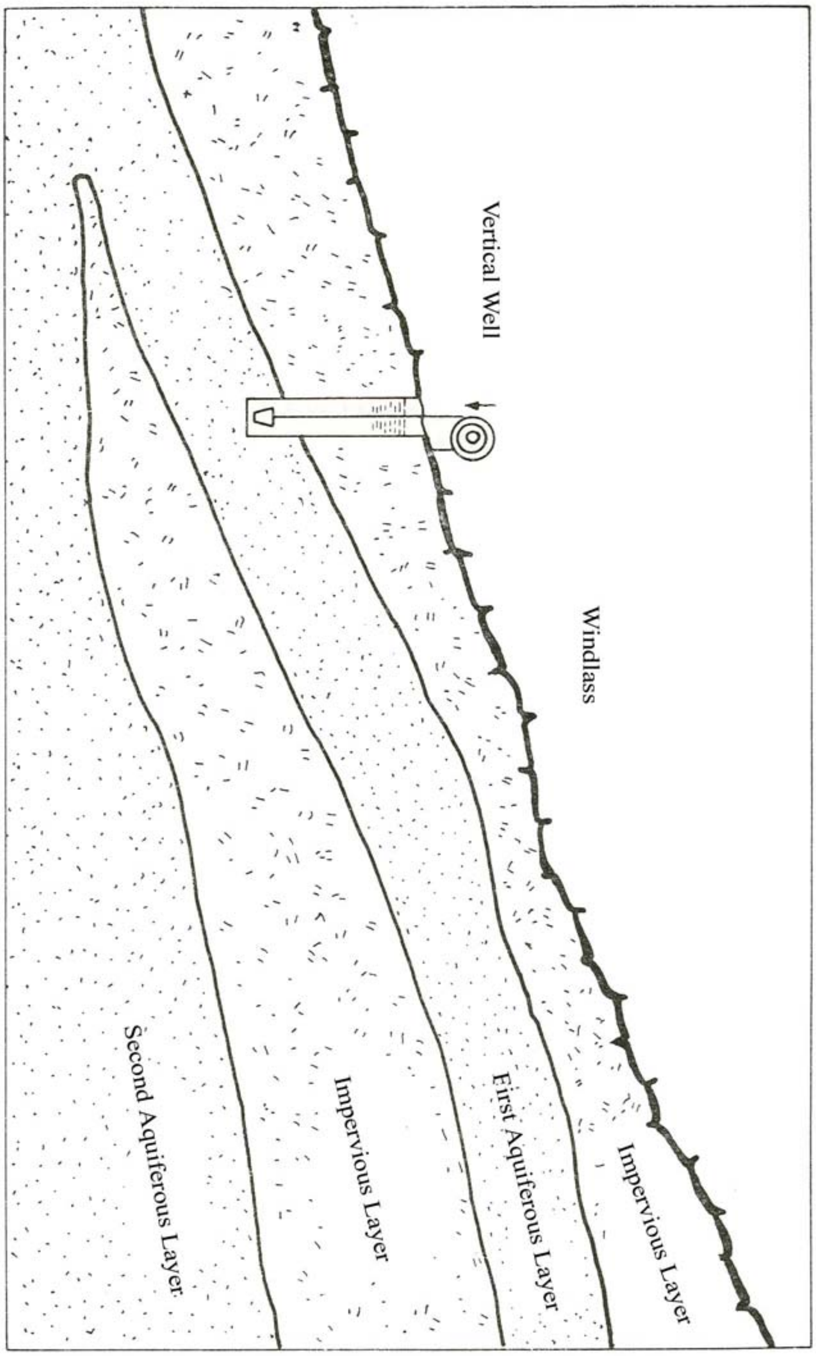

Figure 152, The first and easiest way through which human could obtain groundwater was to sink simple wells.

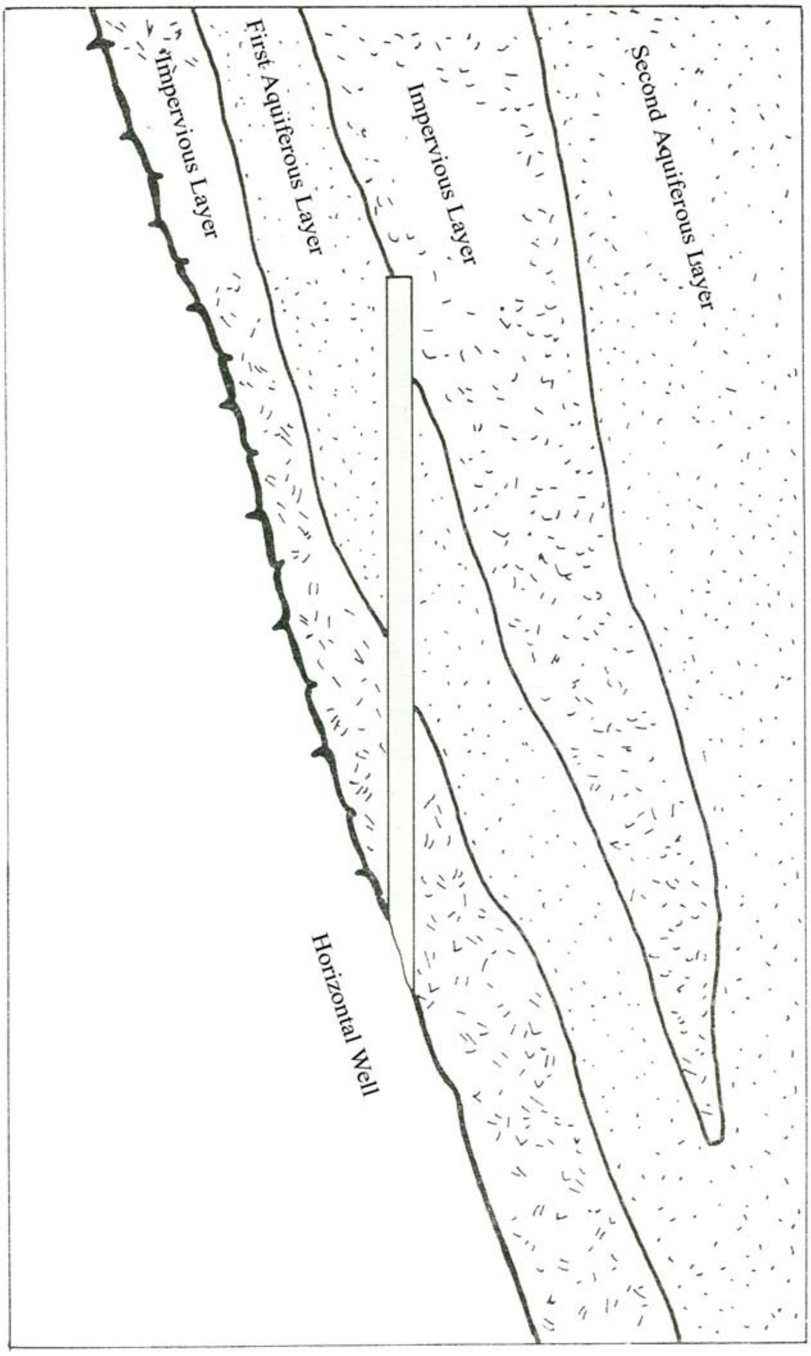

Figure 153, Digging a horizontal canal to get access to a groundwater supply. It was the ancient Iranians' idea which became a reality 3000 years ago through digging Qanat.

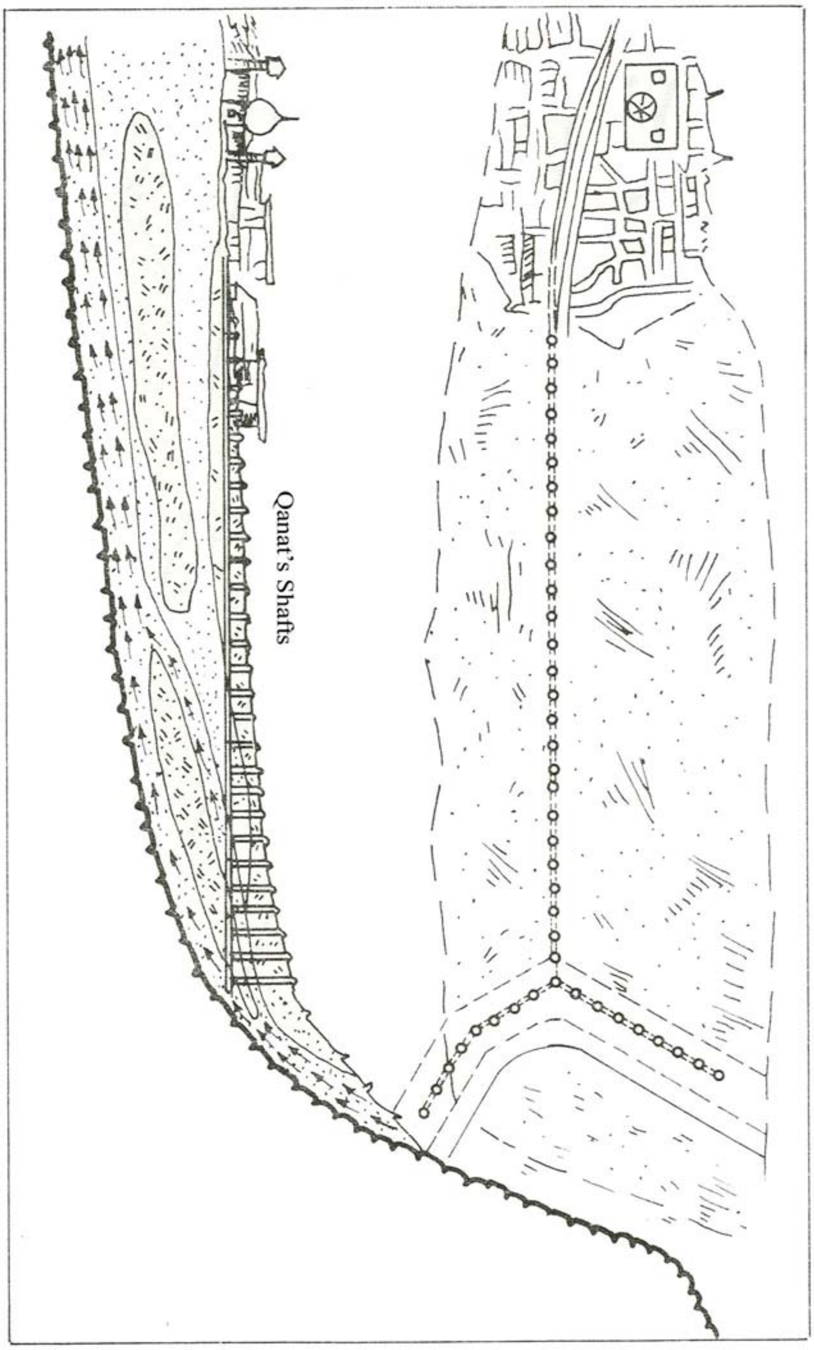

Figure 154, The top shows the situation of a Qanat on the earth surface, and the bottom is a cross section of a typical Qanat.

Figure 155, This is a cross section of a Qanat's gallery in the town of Sabzevar. The Qanat is being used for the modern domestic water network by putting pipes in it.

7-2- THE DISTANCE BETWEEN TWO SHAFTS AND THEIR MAXIMUM DEPTH

In a typical Qanat, the depth of the vertical shafts varies from zero at the exit point of the Qanat to a maximum at the end of the tunnel. The deepest well which is sunk in the saturated layers is called mother well (in Persian: madar chah). According to some folkloric legends, the deepest Qanat is about 400 meters. Hamdo al-Allah Mostowfi reports that around the town of Gonabad there are some deep Qanats out of which a Qanat is about 400 meters deep[1].

Also, Naser Khosrow (the 11 century poet and explorer) writes in his travel account: "while departing from the town of Tun, a man who was from the province of Gilan told me that when he was traveling from Tun to Gonabad, a gang of thieves showed up and plundered them. Some of the travelers jumped in a Qanat's well out of fear. There was a boy among them who had jumped in the well. After the thieves ran away, the boy's father hired a Qanat worker to climb down the well and bring up his son. Whatever ropes everybody had, the worker tied to each other in order to reach to the bottom of the well. Eventually the worker came up with a 400 meter long rope being able to reach the bottom. By this means, the worker could bring up the boy, though he was already dead. This deep well belongs to a Qanat which is 27 kilometers long"(5).

In most cases, the shafts are 15-20 meters away from each other, though sometimes the distance between them exceeds 200 meters when the gallery runs across a river or a hill. For example, In Mr. Ziya al-din Tabatabayi's farm in Sa'adat Abad (Tehran), there are two shafts so far away from each other.

1- Nozhat al-gholoob,p.144

7-3- DIMENSION OF GALLERY AND SHAFT

The dimension of a typical gallery is about 60 by 120 centimeters, and a shaft is about 80 to 90 centimeters in diameter. The Qanat practitioners usually try to envisage a tunnel as small as possible. The narrower the gallery, the less debris the workers would have to haul (figure 69). In sum, the amount of debris the workers should haul to the surface is considerable. According to the studies Gorji Mamlo has done on the Qanats in the eastern Turkistan, “We would be stunned, if we know how much labor these people have spent on the construction and maintenance of this hydraulic system which has being guaranteed their lives. Suffice to say, to irrigate a 8.7 hectare farm land, a 3 kilometer long Qanat is needed. The mother well of this Qanat should be at least 90 meters deep, and about 300 to 360 shafts should be sunk along the Qanat. In terms of the shafts, the average depth is 45 meters, and the area of the section of a shaft is 0.50 square meters. As a result, the digging of all shafts needs to move at least 57000 cubic meters soil and sand which should be added to the amount of debris coming from the gallery. So these people have to excavate 85000 cubic meters soil and sand in order to have such a Qanat.”

Zimbalenko has conducted some researches on 12 Qanats in Turkistan from ecological point of view, but here I have to skip this valuable work to avoid padding out this book.

Figure 156, Some ceramic rings for lining the gallery in crumbling soft lands.

Figure 157, The equipments of a Qanat practitioner which are oil lamp, pick axe, leather bucket and shovel.

7-4- THE LINING OF GALLERY

In many parts of the central plateau of Iran, there is no need to do lining because of some characteristics the geological formations have. In the gallery, the flowing water can deposit so much sediment that an impermeable layer would form and stop the water from seeping into the ground. The Qanat practitioners refrain to remove this layer completely when they want to clean the gallery.

In case a Qanat cuts through a crumbling soft formation which is called Shoolati in the local language, the workers use a kind of ceramic ring to line the tunnel. Some of the shafts are sometimes blocked and lined all the way with brick, stone and lime.(figure 70)

In the past, the Qanats were well maintained, as Schinder the famous explorer who came to Iran in 19 century reports about eight long Qanats running by the town of Damghan (73). He writes these Qanats date back to thousands of years ago as their relics show. The gallery had been lined with bricks which were withdrawn by people to be used for building their homes. The reason that our ancestors did their best to safeguard their Qanats was sometimes to go through some military crises. When the enemy laid siege to their town, the only means which could bring water to them out of the enemy's sight was Qanat. So they tried to maintain their Qanats as well as they could, because if the invaders could destroy the Qanats, the fall of their town was inevitable.

7-5- THE LENGTH OF QANAT

The length of Qanat varies with some environmental conditions such as the earth gradient and the depth of mother well. It is said that there is a Qanat in Gonabad in the province of Khorasan which is 70 kilometers long.

7-6- THE NUMBER OF THE QANATS IN ALL OVER IRAN

An estimated the total number of the Qanats amounts to 50000 out of which some are out of action due to the advent of the pumped wells. In the face of such a decrease in the number of Qanats, there are still many Qanats being used to supply water to the regions which lack any surface streams. No doubt, the number of Qanats in Iran was once much more than the present number, as Petrushevsky writes[1]: "According to Shardon's reports, the number of Qanat in many regions - for example in Kerman- was once considerable. Mostowfi says that the city of Tabriz utilized 900 Qanats as well as many wells and the branches of the river of Mehran Rood. We have no idea about the exact number of the Qanat in 13 and 14 centuries, but we can deduce from a story written by shardon that there were tens of thousands of Qanats running at that time. "In Isfahan one of my neighbors who is the son of the minister of Khorasan repeatedly told me that his father has seen in the proofs and documents that once there has been 42000 Qanats in that province".

7-7- THE TOTAL DISCHARGE OF THE ACTIVE QANAT IN IRAN

An estimate, the total discharge of the active Qanats amounts to 750-1000 cubic meters per second. This volume of water is distributed in all over the regions where the farm lands live off groundwater resources.

7-8- HOW TO DIG A QANAT

In comparison with the methods practiced in the past, the technique of Qanat has not changed too much (figure 71). To construct a Qanat, first of all the practitioners sink a trial well where they guess there may be a good supply of groundwater, sometimes they dig three trial wells to determine how much water this Qanat would be able to drain out. After making sure, the workers start to determine the gradient and the distance between the wells by means of some special measuring tools which have been abolished nowadays. The experiences passed from generation to generation have taught the workers how to dig many shafts and several kilometers of tunnel with no error.

In general, the workers start constructing a Qanat from its exit point to its mother well. To do so, they sink two nearby wells whose bottoms are linked by an underground tunnel. This procedure continues until the tunnel enters the saturated layers. Note that from the exit point to where the water bearing zone appears is called water transport section (Khoshke Kar) and from this spot to the mother well is called water production section (Tareh Kar). As soon as the workers dig through the water bearing zone, the water starts dripping and even pouring into the tunnel and then flowing down. To make it possible to dig through the water bearing zone, the workers should be able to estimate where the tunnel would intersect the surface (the exit point) in order to prepare the water transport section draining out the seeping water. Otherwise the accumulation of water does not let the workers keep digging through aquifer. After a while, the water table would drop so that the workers can sink the vertical shafts joining the tunnel. (figure 73 and 72)

1- Volume 1,p.216

In case, the water table is still above the tunnel, there is no way but to dig the shafts from down to up. This procedure which is called Devil is a solution for the problem of sinking well in aquifer. To do this dangerous job, the workers are used to wear a metallic hat and a waterproof cloth. On the two opposite sides of the well, they gouge two holes into which they can put their feet in order to stand and dig overhead, while water and mud are pouring on them (figure 74).

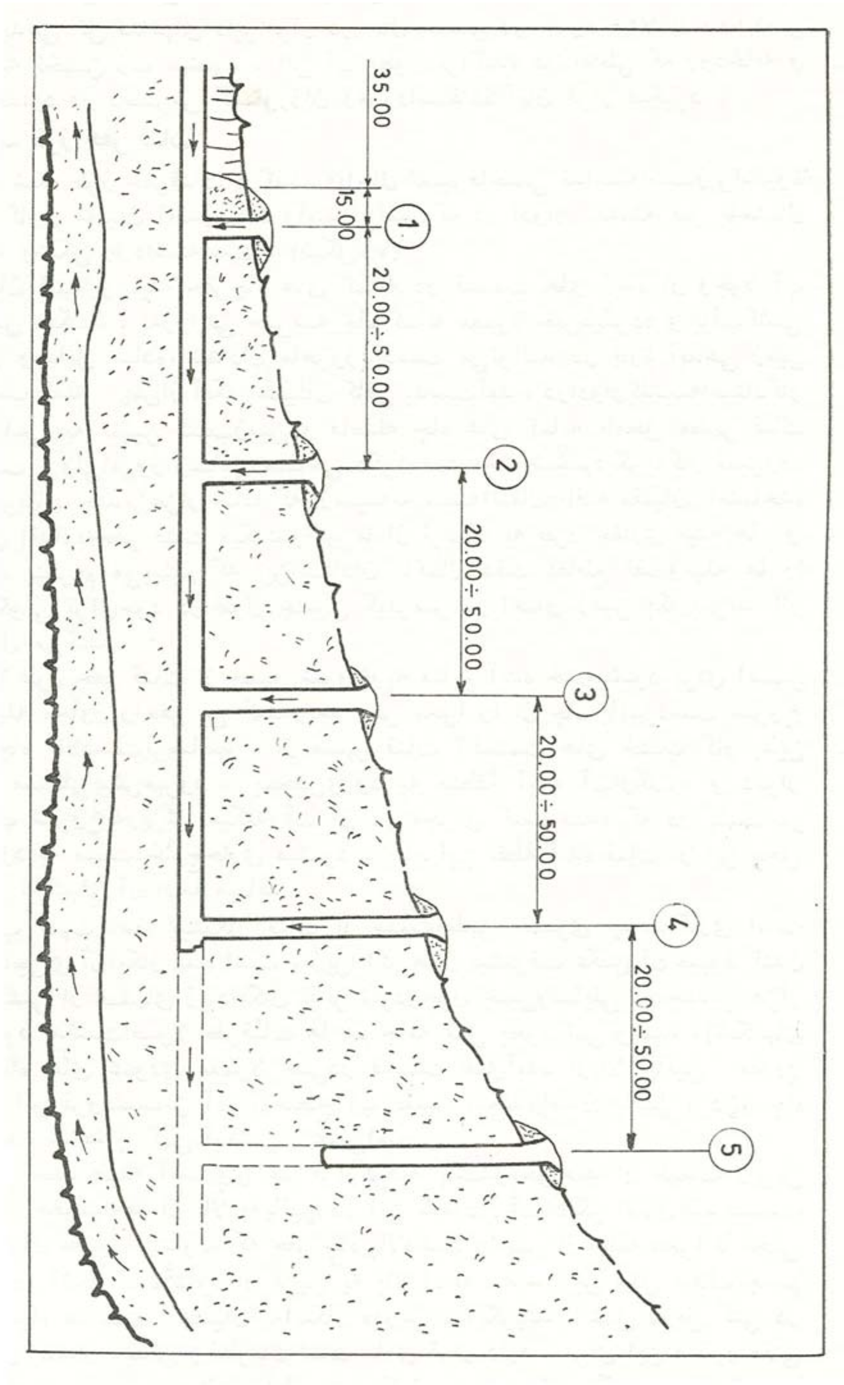

Figure 158, The digging of shafts and tunnel in the water transport section

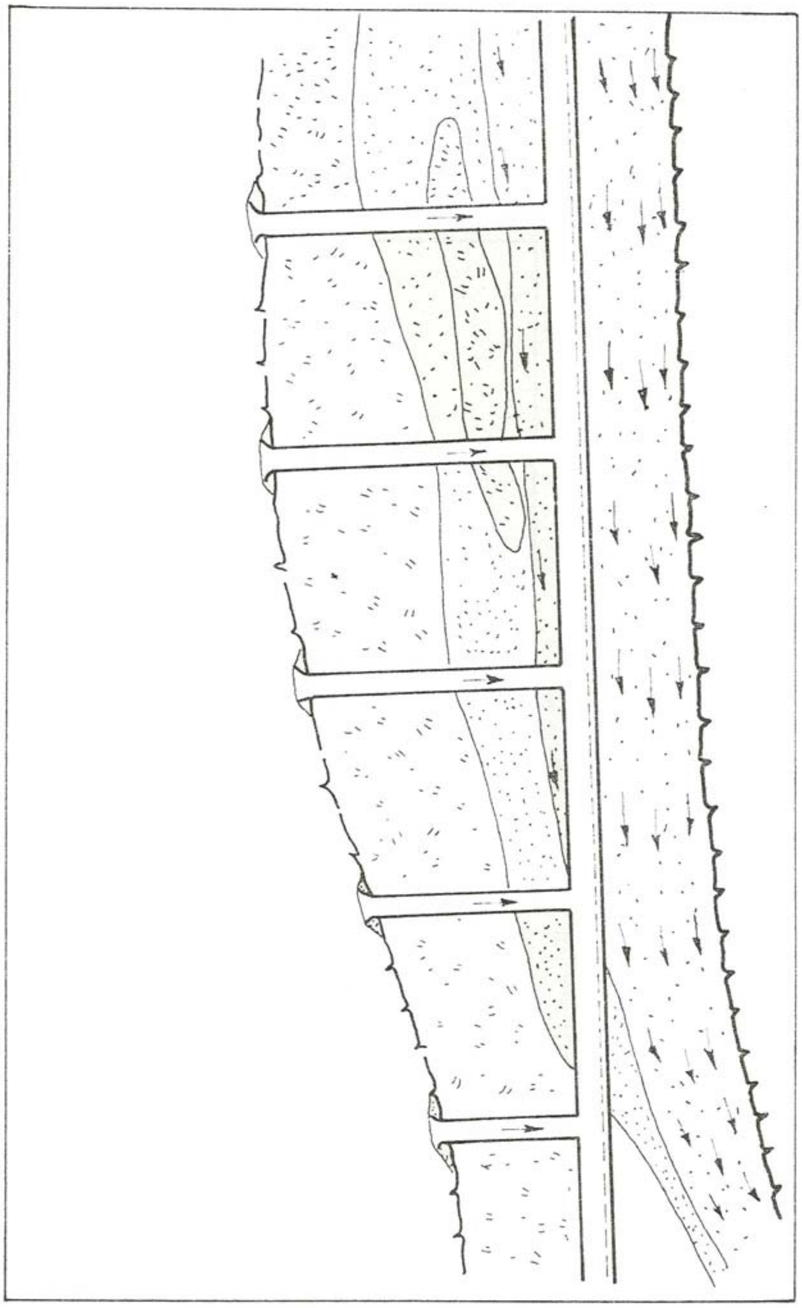

Figure 159, The digging of shafts from up to down when the seepage is not too much.

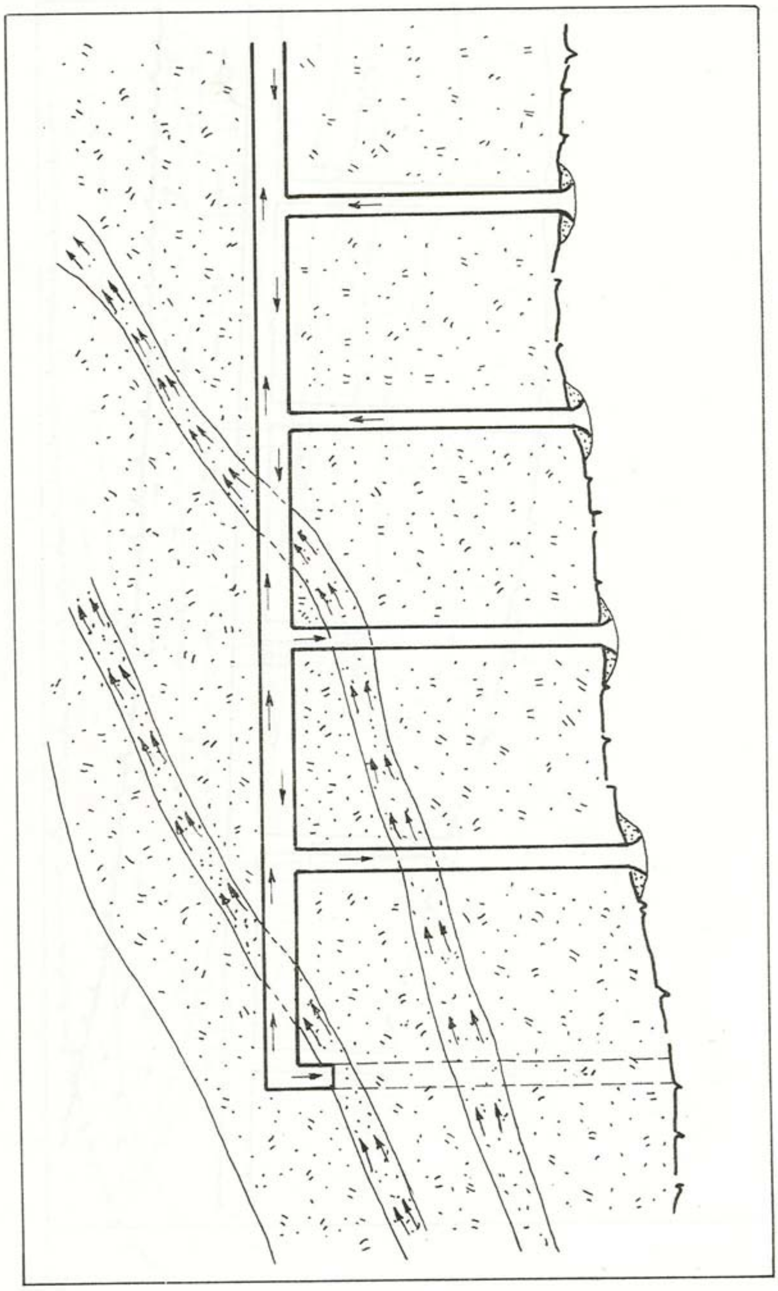

Figure 160, The digging of shafts from down to up (devil) when the seepage is too much. Note that other shafts in water transport section are sunk in a normal way (up to down)

Figure 161, A windlass for sending up and down the workers and debris.

7-9- THE EQUIPMENT OF QANAT CONSTRUCTION

One of the equipments the workers use to construct a Qanat is windlass which had two wooden stand fixed in the ground. The main part of a windlass which is placed on the two stands above the mouth of well is a wooden wheel over which a rope is pulled in order to lift or lower objects. To haul the excavated materials to the surface, the workers put them in a bucket hooked to the rope being pulled. To go down a well, the worker puts his foot into a ring hooked to the rope, and then takes hold of the rope. Two other workers start operating the windlass to lower that worker, until he reaches the bottom of the well. (figures 75 and 76).

The digging tools are shovel, hoe, oil lamp, bucket, and sometimes compass. As mentioned in chapter six, the workers have had some special methods to navigate the tunnel and find the right direction under ground, for compass in its present shape had not been invented yet. (figure 77)

7-10- QANAT PRACTITIONERS' CLOTHING

In the past, the workers were more careful than now to use some devices to avoid some harmful factors in Qanat. Nowadays the workers content themselves with a kind of cheap and simple cloth, whereas in the past the workers used to wear a very protective cloth as Karaji reports[1]: "In case the amount of water dripping off the tunnel ceiling is so much that the worker is no longer able to go on, the worker should wear a coat made of cow leather smeared with cow fat. He should also wear a leather hat whose rim is so long that it covers his collar all the way".

7-11- THE PROBLEMS OF QANAT CONSTRUCTION

The workers may face many problems some of which would be described here.

7-11-1- ENCOUNTERING BIG ROCKS

While digging a tunnel or a shaft, if the workers come across a big rock which can not be hauled as a whole to the surface, they may do one of the following jobs:

They may shatter the rock into small pieces. In the past, the workers used to make a hole in the rock, and then they hammered a wedge into the hole to split the rock.

The second way is to deviate from the main direction in order to bypass the rock. Sometimes the workers have to deviate from the direction several times so that they may lose their way underground. In this case, they use a special polygon tool to find their way as described before in chapter 6.

The third method which is practiced nowadays is to use explosives or compressor drills. I have witnessed such a procedure in northwest of Tehran in person. The workers wanted to sink a well at the foot of a mountain. That was why they repeatedly came across the big rocks bringing the work to a standstill. Eventually the workers decided to blow up the rocks. To do so, they made a hole in the rock and put some explosive in it with a wreck. They set fire to the wreck and escaped from the well immediately. When the explosive went off, the workers were out of the well. The workers' courage to do so was really wonderful.

7-11-2- VENTILATION OF THE SHAFTS

In case a well is too deep or contain harmful gases, it is would be a problem how to get fresh air to the bottom. To ventilate such a well, the workers may double the number of the shafts or use a kind of bellows which resembles the one the blacksmiths use. This bellows can send fresh air to the bottom through a leather long hose. On the other hand, a burning lamp itself may produce some gas, so our forefathers have studied several

1- Hidden Water, p.59

kinds of fuel[1] to see which one is more appropriate. In this regard Karaji writes: "if the existence of gas in the well makes it impossible to go on working, first you should find out where the gas originates from. The causes of gas in the well are as follows:

1- The well may be too deep
2- The tunnel may be too long without vertical shafts
3- The soil may has rotted
4- The mouths of some wells have been constructed not letting the fresh air in.

When there are such materials as sulphur, oil and tar in the soil, it is said that the soil is rotten and gives off a harmful gas or vapor. If your lamp goes out, you should know that this tunnel is full of gas whose deal reaches a peak in the middle of day. The lamps that work with the fat of pig, cow, or sheep and wax are more resistant against the existence of gas in the tunnel. Also, olive oil and other vegetable oils can be used for these lamps, but petroleum is not recommended because it can produce too much gas.

I have read in some old books that the better oil for burning in a tunnel full of gas and vapor is olive oil and after that wax is appropriate. If the worker notices that there is some gas in the tunnel and if the gas would be temporary, the worker should put some vinegar and some watermelon beside himself to decrease the amount of gas. If this method does not work, the other workers should operate a bellows on the surface to send fresh air to where the worker is digging up. To do so, a long hose made of leather should be attached to the bellows, while the other end of the hose is in the well or tunnel. Note that a sweet smelling soil never gives off harmful gases.[2] I was told that the animals' dung which had built up at their stable could kill them, because of the accumulation of gas. If there is no smelling material in the ground, there would be no gas even though the qanat is too deep and long. In case a Qanat whose shafts are blocked is to be cleaned, the shafts should be opened for several days before getting started. The worker who wants to work in a tunnel emitting gas should eat a watery food like soup and refrain to eat smelling vegetables like onion or garlic."

The above mentioned instructions show how developed the technique of Qanat construction has been in ancient Persia, and how important it has been to protect the workers against the likely dangers.

7-11-3- ENCOUNTER WITH CRUMBLING GROUNDS

Digging through a soft sandy or a very crumbling formation may spell a serious problem which can be solved by several methods as follows

1- Sinking a Well in Sand

It is very difficult to sink a well in sand, because whatever you remove from the well, sand would rush into the well again, and the mouth of well would get wider and wider.

1- Hidden Water, p.5
2- Here Karaji uses the Arabic word Tarbi' which has two meanings. Tarbi' means fashioning something into a rectangular object, also means watering an object once every four days. He says that one should do Tarbi' in order to decrease the amount of gas, but I do not know for sure what Karaji means by that.

To solve this problem it was common to use a round wooden frame which was later replaced by a ceramic one, because the wooden frame rotted away soon. Nowadays these frames are made of concrete. They put a frame which is 70 centimeters in diameter into the well and dig below the frame so that it can slide down. Now they place another frame on top of the one before and so on. The less the friction between the frames and sand, the easier the frames would slide down.

2- Digging a Tunnel through a Crumbling Formation

It is more difficult to prevent a tunnel from collapsing than a well. Karaji suggests to use some wooden frames in which a lining wall is built, but we should factor in the cost of this job.

"In case the tunnel is deep, you should use some rectangular frames having the same height as that of the tunnel. If the tunnel is worth enduring such a labor, now you should build a wall inside the frames all the way to reinforce the crumbling tunnel."[1] Karaji says that in Isfahan in the tunnels which are prone to cave in, it is common to use some round ceramic rings which are 1/20 meters high and 75 centimeters wide. In terms of a tunnel whose collapse is intensive, Karaji recommends to use some timbers to get an opportunity to install the rings. Another method to reinforce the tunnel cutting through the soft formation is to build two parallel walls flanking the tunnel. Now some rocks are put on the walls to cover the tunnel. This method is still practiced In Tabriz (figures 78 and 79).

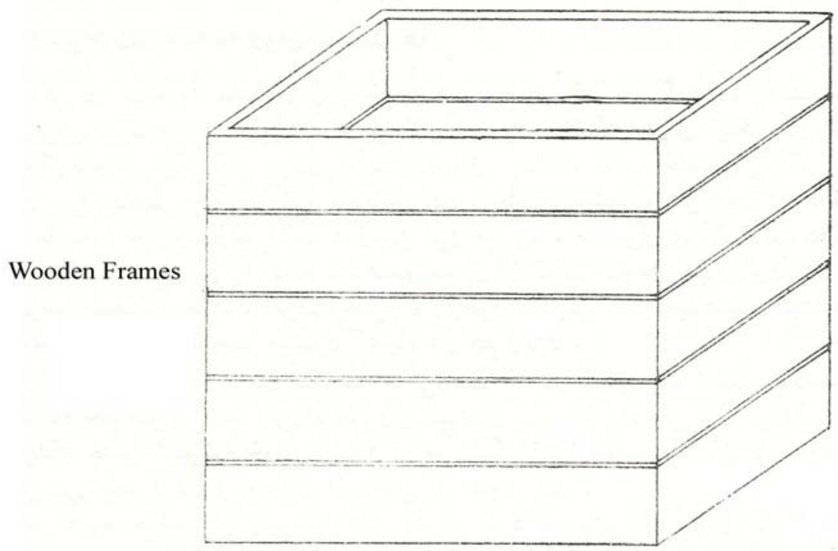

Figure 164, The wooden frames used for sinking well in sand, according to Karaji's explanation

1- Hidden Waters, p.55

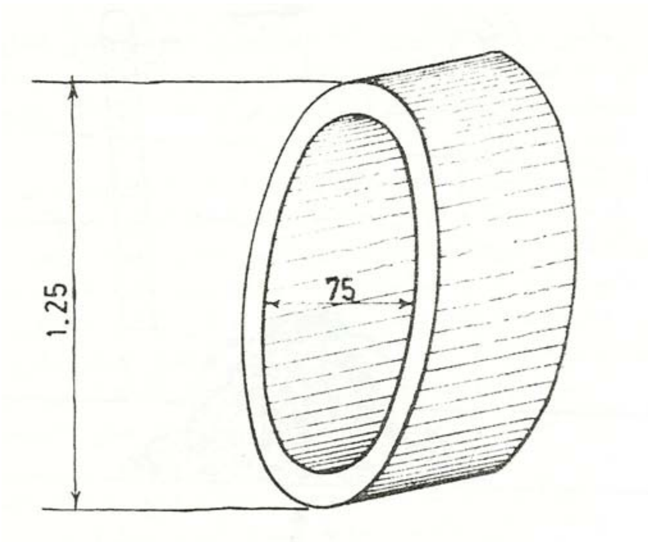

Figure 165, A ceramic ring which is called Kaval in Persian for reinforcing a crumbling tunnel, according to Karaji's explanation

7-12- THE DREDGING AND REPAIRING OF QANAT

In most cases, there is no lining in the tunnel, so the sides and ceiling of the tunnel usually crumble and make the floor uneven. As a result the tunnel may be obstructed, especially in case a collapse would totally block the tunnel and make the water build up and flow out from the mouth of a well[1].

Needless to say in such a case the Qanat would incur a serious damage which could not be fixed so easily.

When a worker wants to remove the obstruction, he has to make a bypass through which the water would be directed to the main tunnel down slope from the blockage. If the worker manages to dig through the obstruction directly from the main tunnel, he would be washed away by the fury of water. So the worker should make several bypasses to empty the water behind the obstruction little by little. After that, if the main tunnel still works, the worker lets go of the bypass, otherwise the bypass would substitute for that part of the main tunnel which is damaged. (figure 80 and 81)

It is necessary to clean Qanat every year, otherwise Qanat may fall into decay. In case a Qanat runs across a home, the owner of the home is obligated to allow the workers to work in the wells sunk at his home, whenever the Qanat needs to be cleaned.

1- In case of an obstruction, water can not go up so much that water can flow out of a well. Water would ascend in a well just until the level of groundwater (water table). (translator)

It was strictly forbidden to withdraw water from somewhere in the tunnel of Qanat upslope from its exit point. It was a criminal act to steal water from a Qanat and was subject to punishment.

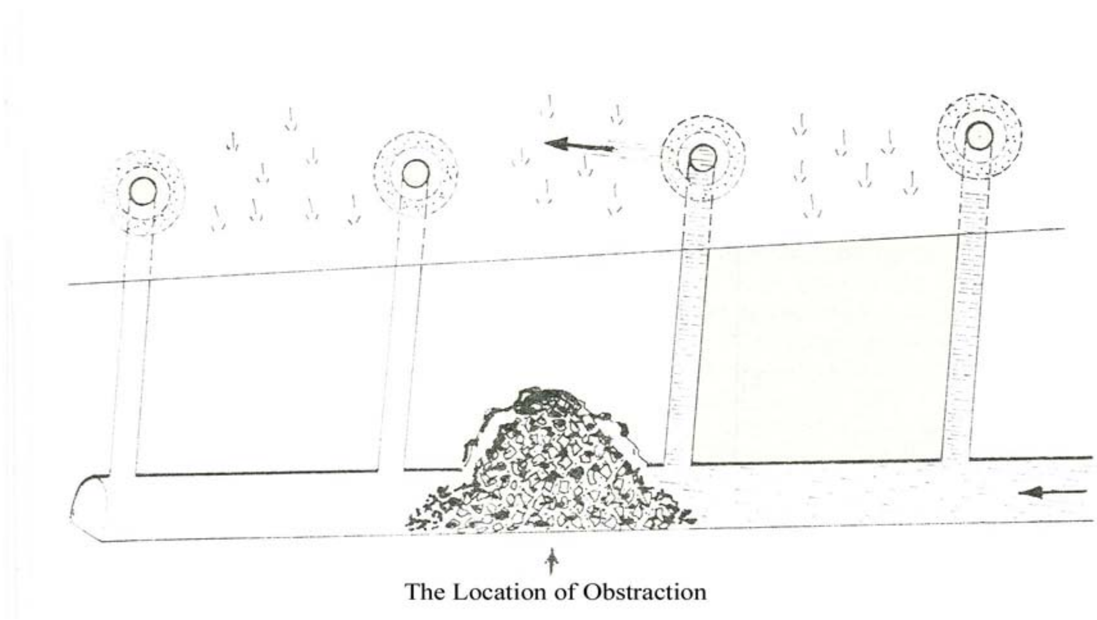

Figure 166, Obstruction of a tunnel that leads to water flowing out from a shaft

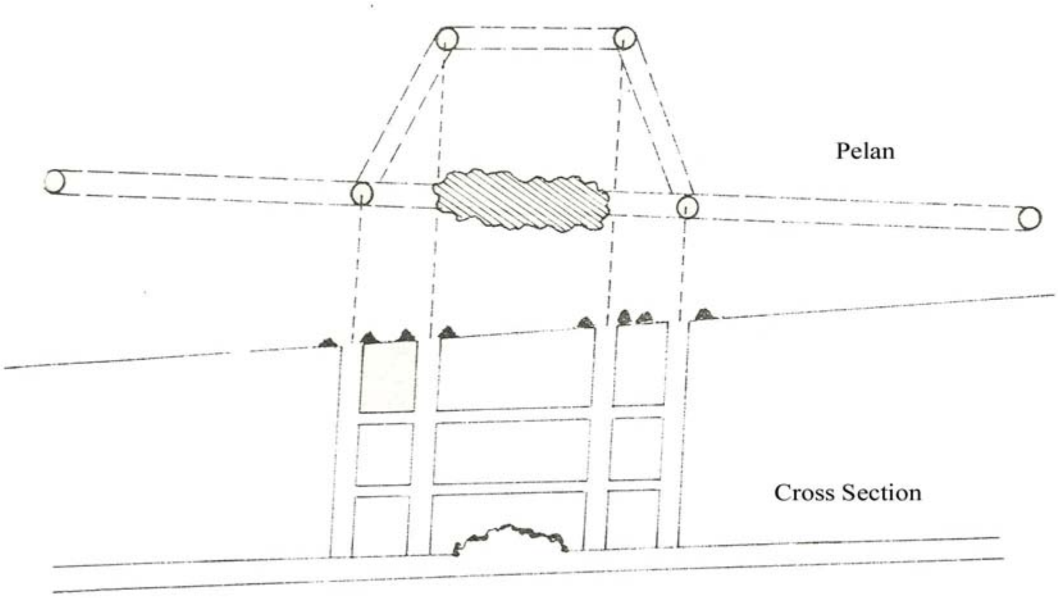

Figure 167, Method of removing an obstruction, when water has built up in tunnel and some shafts

7-13- INCREASING THE QANAT DISCHARGE

In some parts of country where the water table is considerably deep, the Qanat are dug stepwise, so there are several waterfalls along their tunnels. Doing so, the tunnel floor can be lowered if the water table goes down.

In the town of Sabzevar, there is an extensive water bearing zone feeding some Qanats with stepwise tunnels. In this region, the surface slope is too steep, so the mother well would be very deep, if the tunnel would be completely horizontal and straight. On the other hand, it is very hard and dangerous to dig the wells from down to up (Devil). The owners of the Qanat know that the deepening of a Qanat may lead to the depletion of aquifer having a navigate impact on the surrounding Qanats. So if a Qanat is deepened, the other Qanats should be deepened too in order to keep their discharge steady.

In many parts of the country, for example in Yazd, Mashhad, Tabriz, Qazvin, etc, the groundwater level has declined due to the pumped wells and over exploitation of aquifer, so the artificial recharge projects can be a remedy for the crisis of groundwater depletion which sounds the alarm about the annihilation of Qanats.

The frame of this book does not let me take up the modern methods of artificial recharge in detail, but suffice to say the ancient Iranians were aware of these methods and used them in the past. They used to construct some dams with soil and stone around the Qanat to harvest the seasonal runoffs and make the surface streams seep into the ground. In the town of Yazd such dams are called "Ab Goor"[1]. Taking into account that groundwater moves very slowly, so "Ab Goor" could work to the advantage of the Qanat by recharging the aquifer.

7-14- THE BOUND OF QANAT OR WELL

Every Qanat or well has a restricted bound or vicinity as shown in the figures 82 and 83. If a well or Qanat would be dug in the bound of another Qanat or well, it may have a negative impact on the discharge of the first well or Qanat. Our forefathers knew the interactions between the Qanats and wells, so they envisaged a special vicinity for every Qanat or well, in which no one had the right to dig a well or Qanat. Before going through the new theories about the bound of Qanat, I would like to draw the readers' attention to the ancestors' view.

7-14-1- THE OLD THEORIES

Karaji examines the issue of the bound of Qanat in his book in detail from two different perspectives as follows:

1- The bound of Qanat and well based on the religious rules:

Karaji writes that Mohammad Ibn al-Hassan has quoted Aboo Hanife as saying: "the bound of a well is 20 meters in diameter and the bound of Qanat is 250 meters from the tunnel to both sides". According to karaji, there has been a difference between the wells sunk with Imam's permission and the wells without Imam's permission, but this matter did not apply to the bound of Qanat which was 250 meters. If someone manages to sink

1- In fact, this structure is called "Goorab" in the town of Yazd (translator) a well in another person's land without his permission, the first person is obligated to compensate the second person for inflicting damage on the second person's well, unless Imam would allow the first person to dig a well in the second person's land even though it would lead to the depletion of groundwater.

I deduce from Karaji's explanations that the bound of a well is 20 meters in diameters when the well is just 20 meters deep. In case the depth of well exceeds 20 meters, the bound would increase to the same as the depth of well. According to the religious rules, whoever manages to cultivate a deserted land would be entitled to the some land. Also, sewage well should be at least 3.5 meters away from drinking water well to prevent any contamination.

2- Qanat boundary of according to Karaji

After Karaji mentions the religious rules, he continues bringing up his own ideas about Qanat boundary. He believes that Qanat boundary can be classified into two types based on the ground quality: 1- The grounds which are evenly porous and recharged by rain and rivers such as the bank of the river of Dejleh.

3- The grounds which are so soft and porous and surrounded by mountains covered with snow.

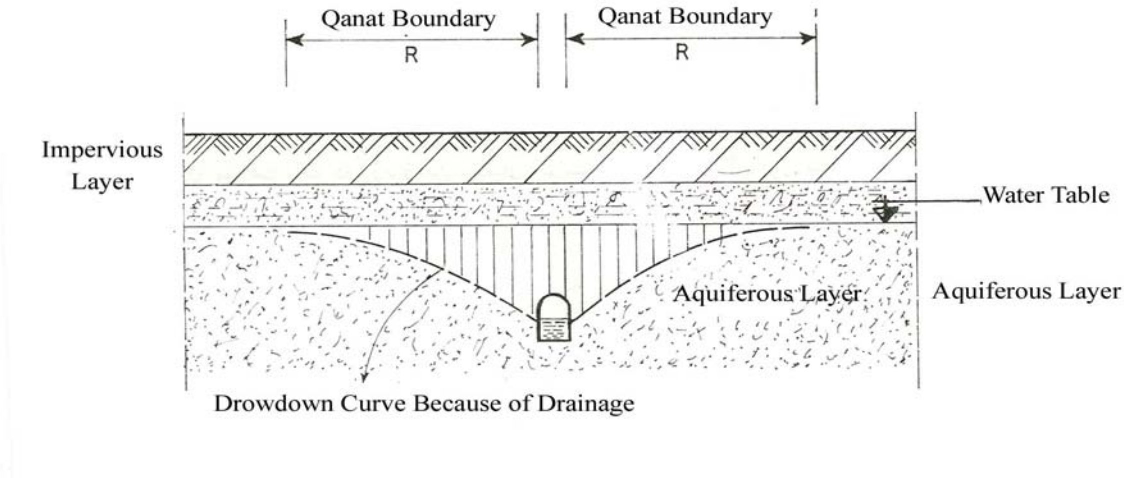

Figure 168, Qanat Boundary of lies between the normal water level and the bottom of the hydraulic curved line. The amount of R correlates with the type of ground as well as the volume of water extracted.

Nowadays such grounds are known as high capacity grounds with a high discharge. According to Karaji, the bound of the Qanats cutting through such grounds should be considered to be 250 meters which is still up to discussion in case a dispute would break out between the owners. He adds that any judgment should be on the basis of some trail wells sunk in given spots to study the level of water in them. In this case, Karaji's view is very important and deserves to be more discussed in an independent research.

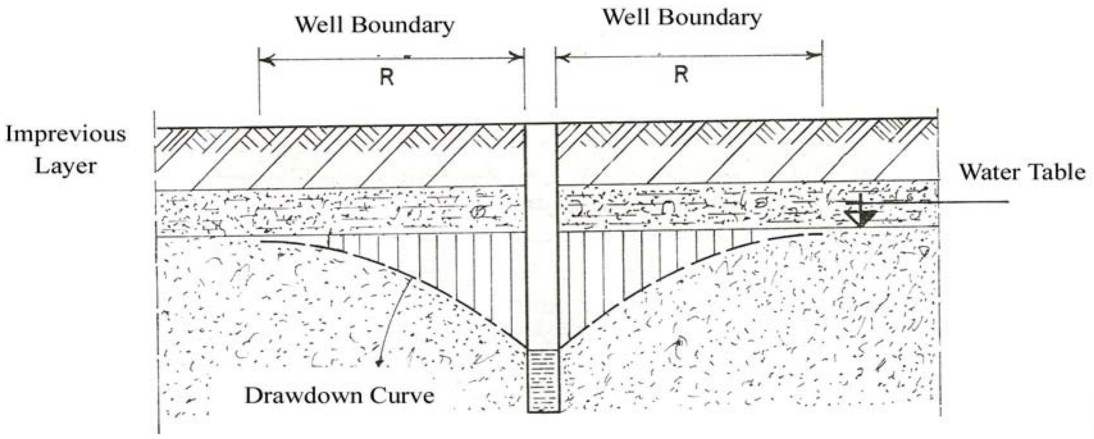

Figure 169, The boundary of well lies between the normal water level and the bottom of the hydraulic curved line. The amount of R correlates with the type of ground as well as the volume of water extracted.

7-14-2- THE MODERN THEORIES

According to the science of hydrology, the amount of the bound of well or Qanat is shown with the letter R which correlates with the type of ground, the amount of seepage and a steady coefficient. So Karaji proves that he knows the principles of the defining of bound by writing about the role of depth, seepage and ground in designating a bound.

7-15-THE QANAT PRACTITIONERS' MORAL CHARACTERS

Bearing in mind the aforementioned topics, our ancient civilization is deeply indebted to the Qanat practitioners and irrigational experts whose efforts brought prosperity to the regions that lacked any surface stream.

In general the Qanat practitioners are modest, patient, content and brave. Even nowadays the Qanat practitioners do their duty which is often dangerous properly and without any sham. They keep alive all the Qanats whose total length amounts to 350000 kilometers equal to the distance between the Earth and moon (figure 84).

In the past, people had a great respect for the Qanat practitioners and every one contributed to hold funeral ceremonies for those who fell victim to a collapse in Qanat. Therefore, the Qanat practitioners deserve to be considered as the devoted faithful workers of our society.

7-16- QANAT AS A CONDUIT

G.V. Roggen reports that in west of Shooshtar there is a ditch derived from the river of Karoon and running parallel to the river of Shatit. A part of this ditch runs across a hill underground through a subterranean canal like Qanat. This kind of Qanat was constructed when a surface stream was to be conveyed from one side of a hill to the other. Contrary to a normal Qanat, these Qanats do not drain a groundwater resource, but tap a river or a surface stream.

Petrushevsky writes that in the past there was a kind of Qanat which was dug to direct a surface stream from somewhere to somewhere else with an elevated area between them, despite the normal Qanats which were directly connected to an aquifer. Jozana Baryard, the Italian ambassador, writes about such a Qanat he has seen in the south of Iran in 1740: “throughout this part of Iran we traveled to was arid, uncultivated and short of water. Wherever there has been water, people have not hesitated to set up a town which is almost in ruins…Farms and orchards are irrigated by the water of Qanat. Wherever lacks water, it is so hard to live. That is why the Iranians try to transfer water from a river to everywhere they want through the following method:

Somewhere near a river, they sink a well, and then dig a tunnel from the bottom of the well toward the desired direction. While digging up the tunnel, they sink other wells one after another every 20 meters until the water reaches where they want” (Baryard, p.70). In the town of Dezfool and Shooshtar the remaining of such Qanats can be easily found, and I would get back to this issue later.

7-17- THE NAME OF QANAT

Qanat is an Iranian original innovation which is completely in line with the climatic and natural conditions of this country. This technique which has been introduced to the four continents of the world is still in use. I do not want to investigate why this technique is so called Qanat, but I would like to emphasis that in spite of the various names this technique has in different parts of the world, its mechanism and structure is the same.

Professor Terel (88) has done a comprehensive research on this issue. In eastern Iran, Afghanistan, Turkey and Turkistan, this technique is called Kahriz which is another pronunciation of the Persian word Kooh-Riz. Kooh means mountain and Riz means spilling, so Kahriz or Koohriz means a water spilling out of a mountain, which is quite relevant to the structure of Qanat. According to Goblot, in Syria Qanat is called Kenayat which probably comes from the Persian word Kandan that means digging. Cressey (1958) has come across the names of Aflaj in Oman and Falladj in Yemen for this technique. Colin (1932) reports that in the countries Yemen and Syria the word Sahrig has been used for Qanat in their literature. In the old Arabic books, Qanat has been named as Faghir which in fact means digging and making water flow. In North Africa Qanat is called Foggara which comes from the Arabic word Faghir. In this region the word Kizama is also used which means keeping something hidden inside. In the central Europe, Qanat is called Wasserstollen which means hydraulic tunnel. Also, in the north and south of America, people have given the name Galeria Filtrante to this system, and the vertical shaft is called Lumbreras which means chimney.

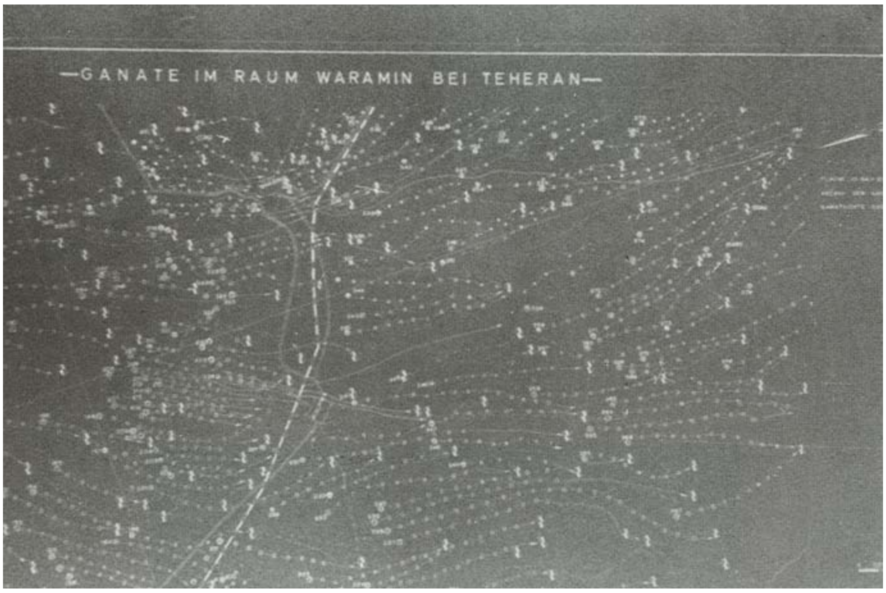

Figure 170, The active Qanat running in an area of 10 by 20 kilometers in Tehran

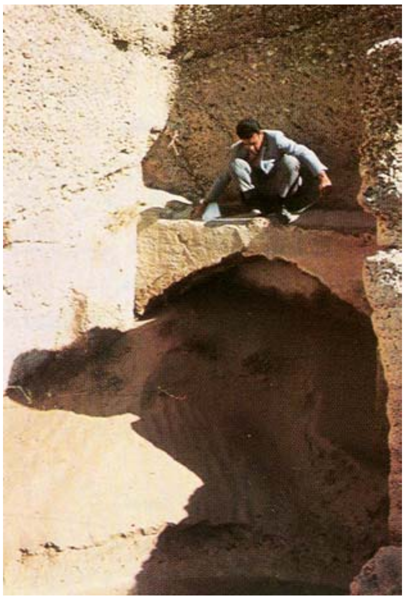

Figure 171, The Qanat of Galoogard in the north of Shooshtar. This Qanat was used just for transfer of water.

Fiqure 172, The shafts of the Qanat of Galloogard with round protective walls against the flash floods.

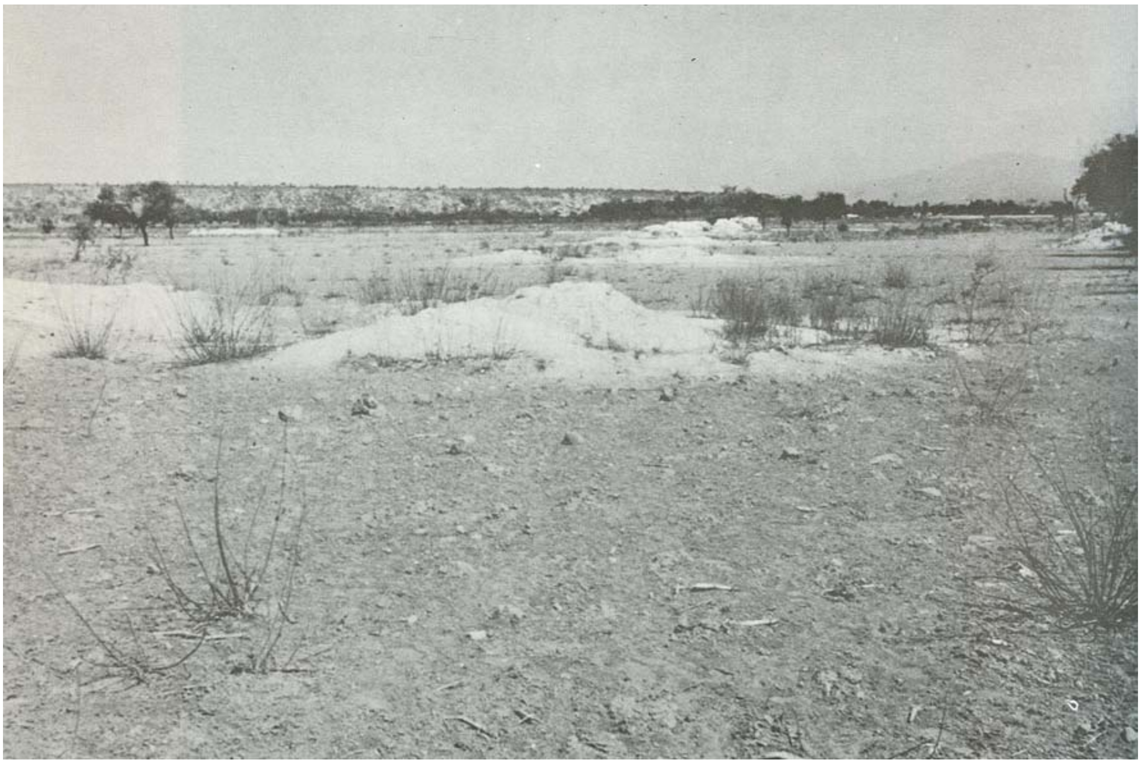

Figure 173, The exit point of a Qanat in Mexico. In Mexico, there are other Qanats still unknown.

Figure 174, The shafts of a Qanat in Mexico. The Mexican natives call the shafts Lumbreras which means chimney. They also call the tunnel Galeria Filtrante which means infiltrated gallery.

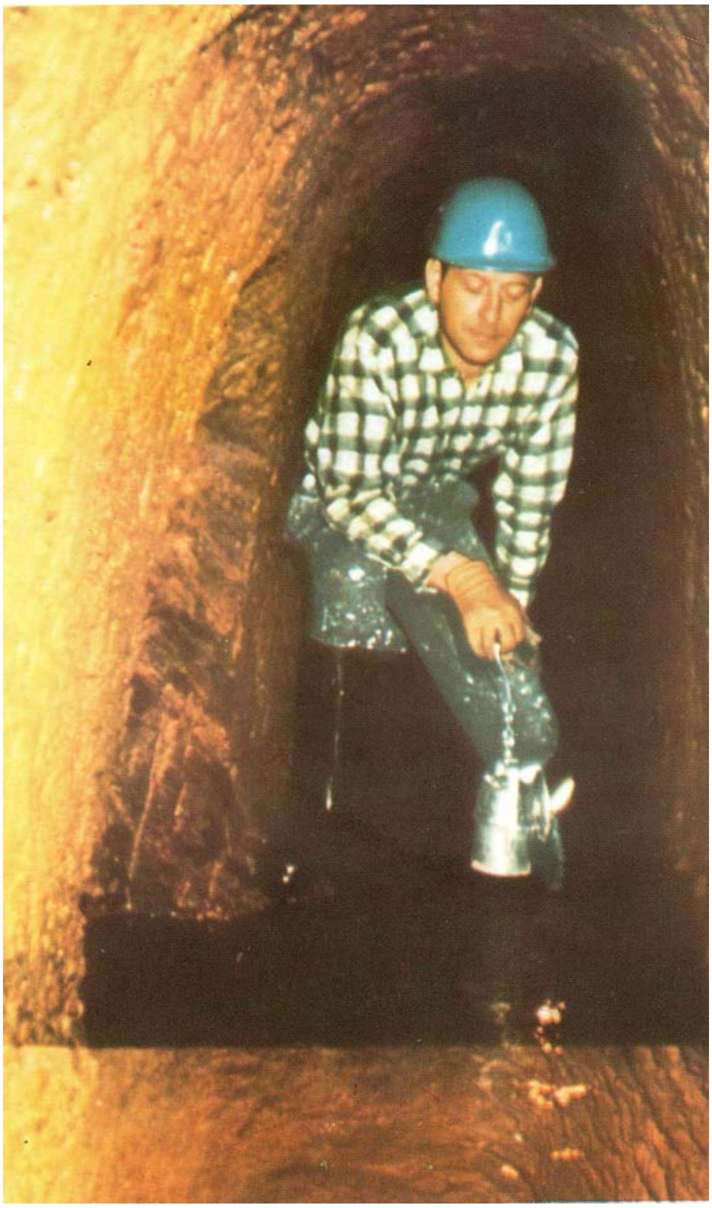

Figure 175, The gallery of a Qanat discovered in western Germany.

7-18- QANAT IS AN IRANIAN ORIGINAL INVENTION

Many researches have been conducted about the origin of this hydraulic structure. Almost all the researches stipulate that Qanat has originated In Iran. Some of the historical facts that confirm this claim are as follows:

1- It is said that Cyaxares the Median king and the founder of the city of Ecbatana (624-584 BC) could occupy Armenia and some other neighboring territories and established a powerful state, so that Nebuchadrezzar[1] the king of Babylon recognized his government by marrying his daughter Nitokis. This marriage had something to do with the advent of a new method of irrigation in Babylon. According to Benassos, the king of Babylon had a Qanat constructed in an Iranian way in order to create an Iranian vista which could please his wife. In this manner Qanat was introduced to Iraq. The famous archeologist, Koldway, during his excavations in Babylon, found a Qanat which was unique whether in Babylon or in the other parts of Iraq. This system had been constructed to collect and drain groundwater in order to irrigate the orchards of the royal palace.

2- Y. Walter (1912) and G. Cressey (1958) found the remaining of a Qanat in the oasis of Kharga in Egypt on the basis of H.J. Beadnell's studies (1909). In the above mentioned oasis, under the sand stones there was an impermeable layer which made it possible for some natural springs to appear. When the Persian army commanded by Darius the Great[2] occupied Egypt in 500 BC, the natural springs started to dry up, so Darius gave the order to dig some Qanats through the sand stones. Goblot (1963) acknowledges that the first Qanat in Egypt was constructed by Darius's order. In my opinion the invention of Qanat can be traced back to the Median dynasty long before Darius and Achaemenid dynasty. This irrigational system might be invented 3000 or 4000 years ago.

3- Another fact that confirms the Iranian origin of Qanat is the lack of any remaining of Qanat in Greece and Rome, except for a system whose function was quite different with a typical Qanat.

As you know, in Greece and Rome the common way to convey water was to construct some water transferring bridges or weirs. The ancient Greeks even knew how to use the pressured pipes to convey water, but their geographical conditions did not let them dig any Qanat.

Professor Sheldon Judson from Princeton University has done some researches on the history of Qanat in which he mentioned a system similar to Qanat called Cuniculi. This system was used in Monti Sabatini (north of Rome) and Monti Albani.

A Cuniculi consists of an almost horizontal tunnel with a gentle slope and some vertical shafts to ease ventilation and removing the excavated materials. In spite of the similarity between Cuniculi and Qanat, their functions are different. Cuniculi was dug to build a water spout or to drain the wetlands. A Cuniculi might run along a valley even stretching to the other nearby valleys. In sum, the application of this system was to drain the wetlands in order to turn them into cultivated lands, unlike a Qanat whose application is to extract groundwater for irrigation. In some cases, Cuniculi was used to lower the water level of a lake, as Livitus reports that some of the water of Lagodi Albano Lake was drained out by means of a Cuniculi in 4th century BC. Also, in Middle Ages (1152-1184) the water level of Maria Laach Lake was lowered through a Cuniculi.

The history of Cuniculi can be traced back to the city of Veii in Monto Sabatini where this system was constructed only for drainage. It is very likely that Cuniculi dates back

1- Bokht al-Nasr
2- 549 BC– 486/485 BC (translator)

to about 400 BC when this city and its surroundings were an integrated political unit ruled by Etruscans[1], because in 396 BC Romans occupied this city.

The systems of Cuniculi running in the western mountains of Albania are known in antiquity, so these systems have been introduced from the city of Veii. Such discoveries made some scholars doubt the Iranian origin of Qanat, but professor Terel writes as conclusion that the existing evidences and records still convince us to accept that the technique of Qanat came into existence for the first time in Iran. Bearing in mind that some scholars have attributed the technique of Qanat to Etruscans, it is necessary to say a brief about this ancient nation. According to the German encyclopedia, Brockhaus, this people had immigrated from east to the central Italy, so they were familiar with the eastern techniques of irrigation such as Qanat which later they used to cultivate the wetlands. On the other hand, at the dawn of the history of civilization, humans did not go around cultivating the lands which were not so suitable for agriculture such as wetlands which should have first been drained costing them too much time and energy. Even nowadays, modification of wetlands having many difficulties does not make economic sense in most cases. The ancient people naturally preferred to cultivate the lands which were already fertile and ready.

7-19- QANAT IN THE OTHER CONTINENTS

7-19-1- QANAT IN ASIA

Cressy points out that this irrigational system exists in Syria, Jordan and Cyprus (34). The first person who mentioned the existence of Qanat in Cyprus was Sir S. Baker (18). Also, Goblot acknowledges the existence of Qanat in Cyprus on the basis of a report issued by the officials of that island (44).

The valley of Damascus in Syria and Yarmuk in eastern Jordan also enjoy the system of Qanat. E. Sachau has spotted some subterranean conduits along with some vertical shafts in the historical town of Palmyra, and then he has concluded that these conduits are nothing but Qanat (72). His idea was later confirmed by Merckel (64).

Also, there are relics of many old Qanats in Riyad (Saudi Arabia) (70), Qatif (on the coast of Persian Gulf), Oman (92) and Yemen. In Qatif, each vertical shaft has been surrounded by a round concrete wall to prevent the moving dune from rushing into the Qanat.

According to R. Furon, Qeysaria in Turkey also enjoys some Qanats. As mentioned, Afghanistan and Turkistan house many Qanats like Iran.

7-19-2- QANAT IN AFRICA

As mentioned, the system of Qanat can be found in the valley of Kharga in Egypt. North Africa can be ranked among the regions that enjoy most of the Qanats, but after

1- The Etruscan civilization is the name given today to the culture and way of life of people of ancient Italy whom ancient Romans called Etrusci or Tusci. The ancient Greeks' word for them was Tyrrhenoi, or Tyrrsenoi. The Etruscans themselves used the term Rasenna, which was syncopated to Rasna or Raśna. (translator)

Iran. Bernard, Schiffers and Capot-Ray published a map showing the locations of the most important Qanat in Africa. Here, I would like to quote them on some important reports in this term:

In the valley of Touat, the total length of the system of Qanat amounts to 2500 kilometers. K. Suter (82) traveled twice to the desert of Africa to observe these Qanats. As a result, he could publish some essays on the hydrological principles of the Qantas (on the basis of Sarovonin's studies), water division system and the method of Qanat construction and maintenance. K. Suter also took up the issue of water division which was very developed and complicated.

Terel writes that the system of Qanat was introduced to the deserts of North Africa in medieval period by the Iranian dynasty Barmakids who were succeeded by Boramits. Iranians again came to this territory along with the Arab invaders in 984 and then in 1980 and did their best to bring prosperity to these lands (Touat).

Needless to say all the Qanats of this desert were not constructed at the same time, but it took the Qanats several centuries to develop. According to some historical records, these Qanat were dug by the young black slaves who belonged to a marginal cast in the African society. Whereas In Iran, people placed a high value on the job the Qanat practitioners did. That was why the freedom of slaves in Africa caused the Qanat construction to come to a standstill due to the lack of manpower (32).

In the historical town of Sadrata in Algeria, some remainings of a Qanat turned up during an archeological excavation (20). This city was in its heyday in 11^{th} and 12^{th} centuries, but in 13^{th} century the movement of dune wiped the city away. All the prosperity and production that the historical records attribute to this city depended on the water coming through the Qanats. (16)

J.Bruhnes (31) mentions some Qanats running around Alqolle between Algeria and Morocco.

In Libya, Qanat is rarely found, but Capot-Rey claims that there are some Qanats in Fezzan.

In the region of Schatt-el-djerid there are some interesting Qanats which have been studied by the geographical institute of Monick university under Suter's supervision (82). They have reported 59 short Qanats so called Khariga which drain a water bearing zone in Djebel Tebaga.

According to Solignac, in the north and central parts of Tunisia, at the time of Almohaden and Hafsiden, there were some extensive irrigational systems profiting from the technique of Qanat. He mentions one of these systems dating back to the period of Romans' occupation. He has also visited some Qanats which were in use in 7^{th} and 9^{th} centuries. One of these Qanats ran in Bir-Al-Adin 36 kilometers west of the town. According to Solignac (79) these systems were set up at the reign of Caliph Abu Amir Utman, and the water transferring bridges of the region were renovated in 13^{th} century. It seems that the technique of Qanat and water transferring bridge were exploited together in this area.

No doubt that Arabs played an important role in developing the system of Qanat in North Africa, but it is also likely that Romans learnt the method of Qanat construction from near east and then made use of it in Africa During their reign.

In a part of the desert belonging to Morocco, some valleys enjoy Qanat. According to N. Mensching (63) the situation of groundwater resources in this region is suitable for constructing Qanat. At the southern base of the Atlas Mountains which are covered with snow in winters, some Qanats have been found. The city of Morocco closely resembles Tehran from natural and geographical point of view. Morocco is located in the middle of an elevated plateau called El Haouz. The Atlas Mountains and the central elevations of this region are covered with snow until the beginning of summer. These elevations are about 465 meters above sea level and their average annual precipitation amounts to 235 millimeters. Needless to say, the artificial irrigation is inevitable due to the shortage of precipitation. In winters, the weather may become freezing cold. This plain contains some alluvial fans with layers of sand and clay deposited on the layers of the third geological period.

Most of the plain of El Houz is irrigated by Qanats which were recorded on a map that Th. Fischer prepared when he traveled to Morocco (36). Also, some other scholars have done some researches as listed in the bibliography of this book.

In this region, there are 600 Qanats with lots of vertical shafts out of which the deepest one is 70 meters. All these qanats can be classified into two separate types: At the base of Atlas Mountains lying south of the city, the qanats are about 4 or 5 kilometers long such as the Qanat of Ain-el-kobba and Ain-el-Barraka which supply water to the city of Morocco. In the north of the city, aquifer is shallower. The water temperature is almost steady between 16 and 18 centigrade which feels warm in winter and cold in summer.

In Morocco, just a little portion of the water of Qanats goes to domestic sector, and is almost consumed to irrigate the farm lands. According to J. M. Pourpart, the first Qanats in Morocco were constructed by Sultan Yaqoob Al-Mansoor’s order at the time of Almohoden Berbers. In fact, the Christian prisoners who were captured in the war between E-Arcos and Alfons (1195) labored to dig these qanats, but I think these qanats already existed and the prisoners were forced just to rehabilitate or develop them as the Arab historian Edrisi (1166) confirms this fact. G.C. Colin believes that a Jew named as Abdo-Allah ibn Yunus al-muhandi was responsible for the construction of Qanats in the region. Almohoden summoned him, and he obeyed the order to take on this project.

Even until 1930, the only water source of the city of Morocco was Qanat. In Morocco like Iran, the Qanat practitioners (moqanni) are in charge of Qanat construction, and this technique is passed from generation to generation. In 1912, 40 Qanats with 8000 shafts provided water to the city of Morocco, and the kings had two big pools to irrigate their orchards.

7-19-3- QANAT IN SOUTH AMERICA

The existence of Qanat in North and South America raises the question whether this technique was introduced to this continent by the Spanish immigrants or it was already known and used by the American natives. No doubt, the American natives were quite familiar with artificial irrigation in arid regions, but the issue of Qanat in this continent still remains controversial.

For the first time, K. Kaerger (53) examined the issue of Qanat in his book on irrigation in the state of Tarapaca. The farm lands of Matilla in the north of Chile are irrigated by some rivers, but the valley of Pica lives off a kind of irrigational system called Socabones that closely resembles Qanat. Like a typical Iranian Qanat, Socabones enjoys a tunnel with some vertical shafts so called Lumbreras which means chimney, according to David H. K. Amiran. Bowmonn who visited the valley of Pica in 1924 found 25 Qanats which all cut through hard sand stones, so their galleries are never subject to collapse, and there is no need for lining or reinforcing the tunnel. The total length of these Qanats is 13000 meters and the longest gallery is 2350 meters. Their total discharge amounts to 34.5 liters per second. According to H. Kinzl (55) and on the basis of a paper written by M. F. Gonzales (45) there are some Qanats running in the area of Nazca in Pero. The distance between the shafts of these Qanats which are still in use varies from 5 to 50 meters. At the moment, it is not possible to climb down the shafts which are firmly blocked. The mother well is located near a dry river. Like Iran, water is harvested in an irrigational pool after it appears at the exit point of the Qanat.

A Japanese team was dispatched to Ande Mountains to investigate the irrigational system. I. Kobori (56) published the result of this research according to which in this region Qanat is called Puquio which means a natural spring in an arid land. Gonzales believes that according to some evidences, the irrigational canals exited even before the Spanish seafarers occupied America, and Kinzl confirms this issue too.

7-19-4- DISCOVERY OF QANAT IN MEXICO

Terel and H.V. Kuegelgen reported some irrigational systems similar to the Iranian Qanat in the dry valley of Tehvacar in the southeast of Puebla, when they passed across Mexico (figure 87). I have to give up the details of Terel's report to avoid padding this book out. The village of Coapan lies at a given distance from a mountain. Upslope from the village, there is a row of white conic walls which represent the shafts of a Qanat. These shafts are called Lumbreras which means chimney. The color of the excavated dirt shows that this Qanat has recently been dug or repaired. At the exit point of the Qanat there is a 3.5 meter deep open canal called Sanja which directs water to some ditches and side branches bringing water to the farm lands. The residents of this village have set up an irrigational cooperative company named Socicdad de Aguas headed by a selected chief. It is said that Chilac also enjoys Qanat.

7-19-5- QANAT IN EUROPE

In 1965, in the town of Selb in Germany a research institute on Qanat was established. In 1965, H. Klaubert contacted me to get further information about the history of Qanat in Germany.

The story of the discovery of Qanat in Germany is that one day in the yard of the ceramic manufacturing company of Rosental in the town of Selb, the ground started to subside. They managed to find out why the ground has collapsed, so they came across a subterranean conduit of water. Immediately the research team of Qanat-Selb was organized to study this conduit. The residents of the region were aware of the existence of this conduit, and they assumed that it was a secret way through which people could escape from their likely enemies in the past. But, further evidences showed this conduit had nothing to do with a secret way, but it was a Qanat (figure 89). The construction of Qanat in Germany can be attributed to the persons who participated in the Crusades. According to the studies of the research institute of Selb, it is certain that there are some Qanats in southern Germany, Check, and eastern Germany. One of the residents of the town of Dansik told me that the region enjoys the system of Qanat which even called by the name of Qanat. It was also proved that the island of Cyprus, Italy, and Spain enjoy this hydraulic structure. A. Desio discovered the system of Qanat on the island of Sisil, and he believed that the existence of Qanat on the island is associated with the presence of Arabs.

In closing, I would like to conclude that Qanat is an Iranian invention dating back to 3 or 4 years ago. This method of irrigation originated in Iran and then was introduced to the other parts of the world. Many of the ancient irrigational systems such as water transferring bridges or weirs have been deserted nowadays, but the system of Qanat is still in use in Iran as well as in some other countries, and the artificial irrigation in Iran is still indebted to this ancient hydraulic system. It seems necessary to establish a research center in Iran to track down the historical roots of this ancient technique in order to shed light on the unknown aspects of Qanat.[1] (figure 90)

Unfortunately, the growing pumped wells in Iran are paring down the number of Qanats. The full exploitation of groundwater has led to the annihilation of many Qanats in Iran. Fortunately, The Ministry of Water and Power restricted the pumped wells to safeguard the existing Qanats. It was forbidden to drill a new pumped well, without having an official permit. This legislation worked to the advantage of Qanats. From technical point of view, there are some solutions to increase the discharge of a Qanat or revive a dry Qanat. As for as I know, the French engineers could construct a new qanat with an output of one cubic meter per second with the aid of the modern technology. Needless to say, the technical ability of Iran completely suffices to construct such a Qanat with the application of modern devices.

1- In 2001, UNESCO and the Iranian ministry of energy signed an agreement to set up a research center on Qanat. This center named International Center on Qanat and Historic Hydraulic Structure was eventually inaugurated in Yazd in 2006.(translator)

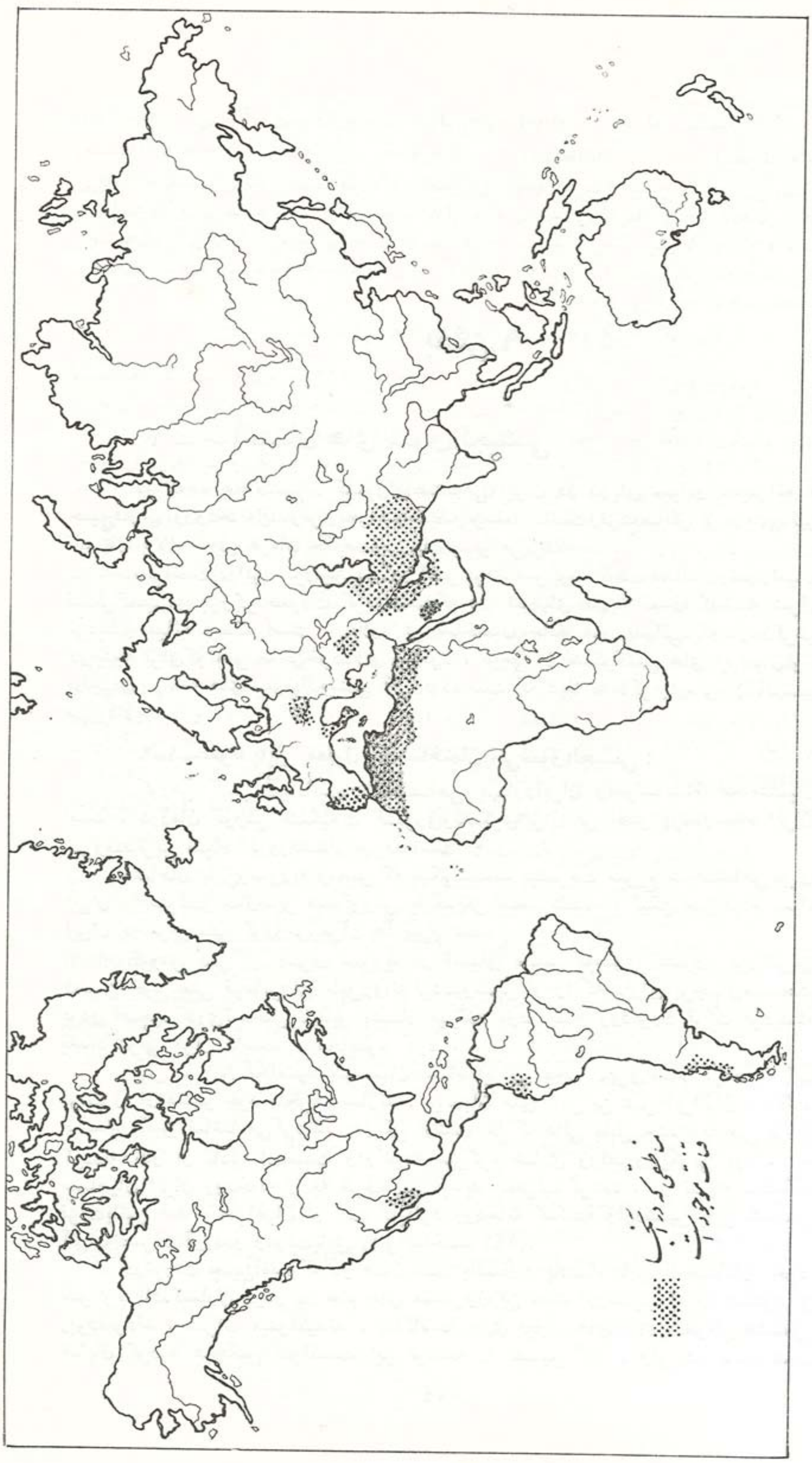

Figure 176, The map where the Qanat technology of Iranian has been extended

CHAPTER EIGHT

TRADITIONAL WATER MANAGEMENT SYSTEMS IN IRAN

8-1- HISTORY OF TRADITIONAL WATER MANAGEMENT SYSTEMS

In the course of history throughout Iran wherever farms required irrigating, there were water management and division systems. In terms of major water resources such as rivers, the central governments used to take control over water management systems, whereas the management of minor resources such as qanats had nothing to do with the state and were managed by the public or sometimes by local land-lords. Water management systems have always played important roles in the Iranian civilizations, and according to some thinkers many economical and political structures in Iran have historical roots in water management systems. For example, Karl Vitfogel has a theory on the relationship between water management systems and creation of ancient governments according to which throughout a vast area from northern Africa to Saudi Arabia, Iran, India, and central Asia, the agricultural activities have been dependent on irrigation, so watering and water division have underlain the livelihood of the residents of this area. It was impossible to distribute water fairly and avoid conflicts over water without water management and water division systems, Gradually, a new social class emerged and took responsibility for water division. According to their authority and control over water, they could establish a kind of political system. According to Vitfogel, totalitarianism and despotism could not exist and flourish in western territories where water is so abundant that people did not have to gather around a limited water resource and be submissive to those who had control over the water resource. That's why there was a better potential in Europe for democracy to turn up[1].

The issue of water management has always been one of the challenges of the Iranian governments. For instance, during the Sasanid era, the government had an irrigation department to supervise all water related affairs such as water ownership and distribution. Later in the 9th century, the same department was reconstructed. One of the main missions of this department was to calculate and record the taxes that the owners of water were to pay. Also when some shares of a water resource were sold or bought, this department should have been informed. Some experts named as Qayyas or Hassab at the time of Abbasid were in charge of water division.[2] Taking into account the fact that any political power was economically dependent on the taxes coming from the agricultural sector, be did his best to regulate this sector[3]. Water management systems were so important to the government that in most cases the amount of taxes was

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1- Naghib zadeh A. 2000. An Introduction to Sociology. Samt Publication. Tehran. P; 64-65

2- Papoli Yazdi M. and Labbaf Khaneiki M. 1998. Division of Water in Traditional Irrigation Systems. Geographical Researches Journal. Vol. 49&50. Mashhad. P; 49

3- In this regard see: Bartold. History of Irrigation in Central Asia (Russian). 1970. Moscov, Nauka.

A good example of making legislation on water was what King Moez al-din Hossein did about 680 years ago. He belonged to the dynasty of Ale Kart who ruled the city of Harat for 148 years. Harat that is located in today Afghanistan was irrigated by the river of Harirood. In the wake of a dispute broken out between some residents of Harat, King Moez al-din Hossein decided to send one of his officials to a scientist named as Nezam al-din Abdolrahman Khafi who was famous for his knowledge on geometry. Upon the king's recommendation, Nezam al-din Abdolrahman Khafi managed to compile a book containing all legislations and laws on water related affairs to which every one used to make reference in case of a legal debate on water.

See: Amiri H., Resaleye Tarigh Ghesmat-e Ab-e Ghalb (Persian), the book of history and geography, No. 44 & 45, 2001, pp. 82-85 calculated just based on the amount of available water[1]. Needless to say if there is no regulation or legislation on water related affairs, many conflicts and disputes will break out between the farmers and too much time and energy will be needed to settle such problems leading to annihilation of agriculture. So the governments tended to intervene in water related affairs in order to prevent such problems which could eventually inflict damage on the state in addition to the peasants. One of the good examples of the Persian rulers' concern about water management is the ancient dam in Damghan as Aboodalaf reports. This fascinating dam was constructed by Sasanid kings in order to divide water into 120 shares each of which belonged to a village. Aboodalaf admits: "He has never seen before such a clever and accurate technique to manage water"[2].

Note that water management systems were always subject to change. Some factors such as rate of population growth, changes in cropping area, and immigration could cause a water management system to change. For example, the immigration of a population of Arabs to the town of Qom and then a change in their economical background from nomadism to agriculture brought about many conflicts between them and the native residents of Qom. After a long dispute over water, the natives had to change their water management system so that the Arabs can be included in it. The whole story of how the water management system changed has been detailed in the book "History of Qom" written in the year 957[3].

Also, what Maqdasi, an Arab geographer, reports on the Marv dam, in fact shows how much the Iranian governments were concerned about the irrigation systems and water management. According to Maqdasi's report the Marv dam was run by a staff of ten thousand persons who were hired to protect the dam or be in charge of its water management. To measure the amount of water, the dam had a special tablet in a standing posture with some horizontal lines cut into it. Should the level of dam water reach the sixtieth line, it would imply that the coming year would be so wet and fruitful that the staff of dam no longer needed to be quite strict about the water division. But, it could be a bad omen predicting an upcoming drought, if the level of water could not exceed the sixth line. There were some main outlets in the dam each of which belonged to a separate village to distribute water among them as fairly as possible, and then there were other outlets in every village to divide water among the quarters, and more outlets in every quarter, so on. If the dam would become short of water, the staff would do their best to decrease all the shares alike[4].

The way how to divide water among the farmers was often checked by the king or his minister. For example, the water division plan of Karaj river should have been reviewed and then signed only by Amirkabir the famous minister of Naser al-din Shah[5].

1- Khosravi Khosrow. 1969. Irrigation and the Rural Society in Iran. Social Sciences Journal. Vol. 3. Tehran. P; 49

2- Aboodalaf, 1975. Aboodalaf's Travel Account. Translated by Tabatabyi A. Zavar Publication. Tehran. P; 81-82

3- Qomi, Hassan ib al-Mohammad, History of Qom, translated into Persian by Hassan ib al-Ali Qomi, edited by Jalal al-din Tehrani, pp. 47-49

4- Meftah Elhame. 1992. Historical Geography of Marghab/Marv/Marry. Historical Researches Journal. Vol. 6&7. Tehran. P; 71-132

5- Enayatollah R. and others. 1971. Water and Irrigation Techniques in Ancient Iran. Ministry of Energy. Tehran. P; 214

If any problem disordered water division systems, the government was in charge of solving it, as king Tahir did about 1000 years ago. A terrible earthquake struck Khorasan province and destroyed many qanats so that their flow completely ceased. After renovation of the qanats, some serious disputes broke out between the owners of the qanats for more shares of water. Finally, king Tahir mediated between the owners and settled the problem by means of calling in all the clergymen and lawyers from all over Khorasan to compile a book on the water division and water related laws[1]. But later Tahir's actions in terms of qanats turned into a fabulous matter. For example, villagers believe that Tahir has a metaphysical talent for building qanats, and he was able to find groundwater sources just by a glance at the earth surface[2].

8-2- WATER OWNERSHIP AND LEGISLATION IN IRAN

There are many rulings on water ownership in both Sunni and Shiite religious texts. In the past, these rulings were the focal point of the Iranian civil laws. For instance, Imam Sadiq and Imam Musa bin Ja'far have considered the sale of water whether in cash or in kind as a permissible act[3]. According to the civil law, ownership is sacred, however, all the water bodies and natural streams are common properties to which the government is entitled to allocate them to the public fairly[4].

There are also some legislation about the ownership and water management of qanats that are of great importance in Iran. For example, the law passed on August 28, 1930 takes up the matter of qanat in order to encourage people to develop this hydraulic structure[5]. In the year 1942, the parliament passed a law that gave the government more power to regulate water-related affairs whether governmental or private. This law let the ministry of agriculture set up the Foundation of Irrigation[6]. Before water resources nationalization, following the rules, everybody could take ownership of a water resource. This sort of property was called Mobah that means something lying within the Islamic territories and not belonging to any particular person. The new legislators adopted the term Mobah and enacted some laws about the water resources which were Mobah. According to the civil law article 160, a well or a qanat dug in a Mobah land is itself Mobah and can be owned by the same person who has dug that well or qanat[7]. But after the enactment of water nationalization law in 1968, water resources were excluded from the properties considered as Mobah to which everybody could hold title under any condition. This law considered all water resources as public properties and according to its first article, the Ministry of Water and Electricity was responsible for the preservation and exploitation of this national property[8]. According to the articles 23 and 25 of this la, any kind of exploitation of groundwater resources should be just with the

1- Salimi M. S. 2000. The Legend on Creation of Qanat in Shahdad District. The Book of International Conference on Qanat. Yazd Regional Water Authority. Vol. 1. Tehran. P; 158-159

2- Ibid

3- Naser Faruqui, Asit K. Biswas, Water Management in Islam, United Nations University Press, 2001, P. 105

4- Ghorbani, F., Comprehensive Collection of the Legislations, Ferdowsi Pub., Tehran, 1990, p.15

5- Ibid, p.196

6- Lambton, Landlord and Peasant in Persia, translated into Persian by Amiri Manoochehr, Scientific & Cultural Publication, Tehran, 1983, p.405

7- Ghorbani, F., Comprehensive Collection of the Legislations, Ferdowsi Pub., Tehran, 1990, p. 196

8- Safayi, Hossein, Civil Laws, Vol. 1, Publication of High Accounting Institute, Tehran, 1969, pp.216-217 permission of the Ministry of Water and Electricity. Also on August 28, 1930 and then on September 9, 1930 in terms of qanats some articles were added to this law which became a basis for the law of water fair distribution enacted on March 7, 1983.

Nowadays, there are two types of ownership of water; the first is the ownership of water along with land, and the second is the ownership of water independent from land.

A) Ownership of water along with land: this type of ownership is mostly practiced in the regions which enjoy rivers and natural springs. In these regions, water and land were bought and sold together, and it is not possible to transact a farm without the share of water associated with the same farm. Therefore, the shares of water are usually measured based on the area of the land that is to be irrigated. Note that in qanats that belong to the large owners or land-lords, the ownership of water and land is not separate. In this case, the amount of water varies with the area of land which is irrigated until nowhere is left dry. This system of ownership is run by the owners themselves and is not as complicated as the ownership of water independent from land[1].

B) Ownership of water independent from land: This type of ownership is very common in the central plateau of Iran[2], and mostly practiced in case of small landownership. Regardless of how much land each one is entitled to, the water of qanat is divided to several shares which can be purchased by whoever can afford to pay for it. In some cases, a person possesses many shares of a qanat without having any farmland to be irrigated. For example, the qanat of Firooz-abad belongs to 302 shareholders some of which have no land. The separation of water and land paves the way for some individuals from outside of the region to acquire some shares of a qanat though they have no land. In the past, it was a trend in rural regions to invest money in water which was the most important production factor. According to this type of ownership, water is divided among the shareholders based on minute and second, so division of water is a very accurate job needing a special organization headed by a Mirab i.e. water-master who is a person in charge of distribution of water among the farmers. That is why the qanats run by this system of ownership are called Mirabi. Researches show that there is no proportion between the area of land and the amount of water a particular farmer may. In other words, some-one may have too much water which is out of proportion to his small farmland and vice versa, and this fact is attributable to their water division system. The independent water ownership leads to the policy of the unifying of farmlands failing. For example, in the qanat of Qasabe in Gonabad, the ownership of water has nothing to do with that of land, so water can be transacted regardless of land[3]. In fact two production factors which are complementary to each other are bought and sold separately. Needless to say the economic value of water is not on a par with that of land, the price of each may independently fluctuate under various conditions. For example, there would be a hike in water price in case of a drought whereas there would be no change in

1- Janeb Allahi, M.S., "Water Division System in Traditional Irrigation in Meybod", Geographical Researches Journal. Vol. 2. Mashhad. P; 57

2- Lambton, Landlord and Peasant in Persia, translated into Persian by Amiri Manoochehr, Scientific & Cultural Publication, Tehran, 1983, p.397

3- See: Alvandi, Minoo, "Crop Division Based on the Five Production Factors", Articles on the Problems of Peasants and lands, pp.401-407 land price. So if you want to integrate all the production factors and unify the separate farm lands to set up agricultural cooperatives, it would be very difficult to specify how much each farmer contribute and then how much they can share in the profit.

In any way in the course of the Iranian history water management and agricultural systems have been interwoven, and water management has always been under the influence of the agricultural systems. In terms of water management, one can refer to two types of agricultural systems as follows: 1- the system of Boneh 2- the system of small land ownership

8-3- SYSTEM OF BONEH AND WATER MANAGEMENT

In a nutshell, Boneh is an agricultural unit on which some farmers have the right to work cooperatively. Before the land reform program, the system of Boneh was commonly practiced in the central plateau of Iran. Accoding to this system, in a particular village all the farmlands belonged to a land-lord who divided his lands into some agricultural units named as Boneh on each of which a team of peasants worked. Each team usually consisted of four peasants out of whom one was Abyar (water-master), one was Dam Abyar (Abyar assistant), and two were Barzgar (in charge of plowing and cultivating). An Abyar had a higher position and supervised the other members of the group, and a Barzgar occupied the lowest position of this hierarchy. There was a person named as Mobasher who acted as an intermediary between the members of the Boneh and the land-lord.

The water divided among the agricultural units (Bonehs) was based on a particular rotation. For example, if a village enjoyed 8 agricultural units, each unit had the right to appropriate the water once every 8 days. In other words, the units should have taken turns being irrigated. But irrigating in this way was not that easy, because in some cases a Boneh was not concentrated on a unique location but consisted of different parts in different areas. Therefore, the formers had to distribute their right of 24 hours irrigation throughout the rotation period of 8 days. Because the parts of a Boneh were so far away from each other that they had to spend the whole 24 hours directing water from here to there rather than irrigate the lands. That was why they preferred to irrigate an area, no matter whose lands were being watered. In the system of Boneh, an Abyar was quite familiar with geographical distribution of lands and the way in which the Bonehs were irrigated. There was a very good social movement within the hierarchy of a Boneh. For example, a Barzgar could be promoted to Abyar and even Mobasher, if he could ensure his qualifications for a higher position. Also, the Abyars who headed the Bonehs did their best to compete with each other by optimizing irrigation. Doing so, they could increase their production which was of great importance to the lord. The better an Abyar could manage his team, the more he could produce, the more value he could gain in the sight of the lord. The Abyars had to make a lot of efforts to satisfy the lord's expectation otherwise, it was very likely for them to lose their position.

In the system of Boneh, the products were not distributed among the peasants and the lord very fairly. In case the lord would provide the peasants with land, water, plowing ox, and seed, he could appropriate one fifth of the crop for himself, and peasants had to content themselves with the rest. Besides, other people who gave services to the farmers during a year such as carpenter, mason, blacksmith, and barber also shared in the rest.

These are the flaws which made the system of Boneh unworkable and paved the way for the land reform program to appear. But this program did not come from a sufficient comprehensive study to be conducted on the complicated relationship between the rural societies, land-lords and government. The land reform program brought no profit to the rural society but turned the peasants into some small owners with no morale to cooperate with each other. If the former regime could properly weigh the advantages and disadvantages of the system of Boneh, we did not probably face the problems we are wrapped in even today. It was better for the government to purchase the lands and substitute the Bonehs with some cooperative companies run by the government, instead of granting the lands to the peasants who could not afford providing the primary production factors. Doing so, the government could improve the traditional Bonehs by distributing the profit among the farmers more fairly. If the system of Boneh was modified, the interaction between the members of the agricultural units would remain, and in the hope of a promotion the farmers would try to overtake each other in optimizing water. This interaction between the farmers in the system of Boneh was so efficient that there was some excess water left by which more land could be irrigated. In this manner, sometimes the farm lands of a village could be extended to 1.5 times[1]. But the land reform program uprooted the former lords and made them invest in the industrial and commercial sectors. In the rural regions, whoever had the right to work on the lord's land could profit from the land reform program by taking ownership of a part of the same land, and the rest of the villagers had no choice but immigrating to the principle cities and getting involved in some black jobs. In the rural regions, the water management lost its traditional function. In a system of Boneh, only an Abyar was capable of irrigating and the others were experienced in other jobs such as plowing, seeding, etc. Therefore, every one could not irrigate as well as an Abyar did, after the land reform law was enforced and the lords' lands were distributed among the farmers. This fact decreased the irrigation efficiency and caused more waste of water. Breaking down the farm lands, and distributing them led to a decline in irrigation efficiency and as a result searching for more water started. The pumped wells were drilled one after another and the many pumps got started on sucking up the ground water resources. In the villages, whoever was at a better financial level, did not hesitate to drill a deep well which in fact extracted the water many other people were entitled to. The drilling of pumped wells eventually sounded the alarm about the depletion of groundwater, and fell many qanats into decay. As a result some farmers fled to the cities, and some had no option but going over to the owners of pumped wells to rent or buy the water they were in need of. There was a boom in the numbers of the pumped wells and more qanats ceased function year by year, and the demand for the water extracted the pumped wells increased. In some cases, in dry seasons when there was an urgent need for water, the water became so expensive that it did not make economic sense to keep working on the farms, because the benefit could no longer cover the cost. Whereas in the system of Boneh, no agricultural unit was short of water, and the benefit and cost were always kept in balance. This system eventually vanished rather than evolving into a system to be more consistent with the new circumstances of the country. In fact, we wiped away the question rather than find an answer to it[2]. After the land reform, the irrigation

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1- Safinejad Javad. 1989. Traditional Irrigation Systems in Iran. Astan Qods Publication. Vol. 2- Mashhad. P; 244

2- Azkia M. 1994. Sociology of Development and the Lack of Development in Iranian Villages. Ettelaat Publication. Tehran. pp. 85-168 efficiency decreased for two reasons: 1- All the shareholders were not experienced in the techniques of irrigation except for the Abyars who were already in charge of watering. 2- In the wake of land reform, the competition for higher position in Boneh was over.

In the face of such a decrease in the irrigation efficiency, the farmers wanted to keep the level of production steady, so they had to supply more water to their lands in order to offset the shortage of water caused by the irrigation efficiency decreasing. The more demand for water fueled the problem of over exploitation of groundwater caused by the pumped wells. This condition got the farmers dependent on the owners of the pumped wells who played an important role in water crisis especially in the dry seasons. On the other hand, the changing of cropping pattern aggravated the problem. Taking into account the changes in people's consumption, the farmers tended to produce something which brings them more benefit in comparison to its cost, even though it consumes more water and fuels the water crisis. The only way to put this chaos in order and regulate water consumption in rural regions seems to be traditional water management systems which deserve to be reviewed. We should consider water management system as interacting with the other socio- economical issues. Needless to say, traditionalism no longer works and in most cases is not practical. Nowadays, the rural societies do not accept the system of Boneh with the same traditional shape, and no doubt we fail if we try to rehabilitate it. But it may be practical to montage the traditional and modern elements in a way that does not contradict the new conditions ruling our rural societies. To do so, on one hand we should be quite familiar with the traditional systems and the characteristics inherent in them, on the other hand we should know the new circumstances of the villages, and the influences of the modern world they may be under.

8-4-SMALL OWNERSHIP SYSTEM AND WATER DIVISION MANAGEMENT

In some areas in central plateau of Iran, water has been managed in the system of small ownership that has nothing to do with the system of Boneh. One may find two regions whose natural conditions are quite similar but the system of Boneh is practiced in one region and the small ownership system is practiced in the other. For example, in Sabzevar and Torbat- Heydariye, the system of Boneh has been common, but there was the small ownership system in Qayen and Birjand, though all these regions enjoy similar conditions. Apart from some mountainous regions whose topographical condition does not allow the system of Boneh to take place, there are many regions with small ownership system. I believe that in the central plateau of Iran, the widespread system having historical roots has been the system of Boneh which is more developed and functional than the small ownership system. The system of Boneh was supported and encouraged by the land-lords, because this system could fully exploit the production factors while reducing their waste to a minimum.

Needless to say in the system of Boneh, the higher the production efficiency, the more both lord and peasant could profit. In the regions now with the small ownership system, such as Birjand, Qayen and Gonabad, there probably exist the system of Boneh which has gradually been replaced with the small ownership system in the course of history. In fact, in such regions there was no possibility for the lords to exist, because the whole area was ruled by the local governors who were entitled to almost every property. These governors were the heads of some Arab nomads who had immigrated from Arabic peninsula to this area, and they had no knowledge of the agricultural production systems, for they used to live on animal husbandry common in their homeland. For example, the governors of Qayen and Birjand came from the tribe of Khozeyme who were forced to immigrate from Saudi Arabia to Khorasan by the Caliph Haroon Al-rashid. Also, Toun and Tabas were ruled by the Zangooyi Arabs who had been brought to Iran by Safavid kings[1]. These local rulers used to charge people a certain tax regardless of the climatic condition such as drought that directly affected the farmers' income. Whereas the land-lords shared in the crop which was independent on the climatic factors, the local rulers paved the way for the system of Boneh to be replaced by the small ownership system in which the tax was supposed to be paid to the ruler directly, contrary to the system of Boneh in which the land-lord acted as an intermediary between the peasants and the central government in terms of tax. In this manner, the small ownership system came into existence. This system lacked any Abyar who was in charge of irrigation, but an organization for water division emerged. A person called Mirab headed this organization which was responsible for water division, ownership and any transaction of water. A basic concept is irrigation cycle which should be defined to better understand the traditional water management.

8-5- MAIN CONCEPTS OF THE TRADITIONAL WATER MANAGEMENT

Iranians traditionally used to live in harmony with their environment, so their techniques to supply water did not end up in the annihilation of groundwater resources. They used qanats as a sustainable technique to extract groundwater, which was recharged in winters by some special dams constructed by the farmers. To prevent damaging aquifer, they designated the vicinity of qanat, which was the area defined surrounding the qanat and comprised between 1 and 3 km depending on the local conditions. The aforementioned dam is nothing but a pile of soil in upstream above the first and deepest well of qanat so that it can catch the floods in winter behind itself. The water accumulated behind the dam can gradually penetrate the earth and then seep into aquifer, so an increase in the discharge of qanat as well as the lack of erosion are two of the advantages of such dams. Nowadays, most of the dams are leveled and then cultivated with the help of pumping deep wells drilled in the vicinity of qanat. The fertile deposits of the dams tempted some farmers to change the dams into the farms at any cost, even though the qanat would dry up. As an instance, in Yazd a qanat named Chahok-e Nir was recharged by four dams which were located in the bound of another village named Pandar. The in habitants of Pandar had some shares from this qanat, so they not only put up with the presence of the dams in the middle of their lands, but also they helped the main owners of the qanat with renovating and protecting the four dams. After the Islamic revolution, the farmers of Pandar started selling their shares, and after a while they completely destroyed the dams and drilled some pumping wells in order to cultivate the whole area. The lack of those dams caused the qanat to drizzle. But fortunately such traditional dams could provide inspiration for the Yazd Regional Water Authority which is very concerned about improving the groundwater resources in Yazd province. Doing so, they recently implemented some great projects to help recharge aquifer such as building 18 mud dams being able to inject more than 17 million cubic meters seasonal flood into aquifer. This gives hope for the future, where we would be

1- Yate, Charles Edward, Khurasan and Sistan, translated into Persian by Rowshani Zaferanloo G., Rahbari M., Yazdan Publication, 1986, Tehran, p.64

equipped with both tradition and modernity to guarantee a sustainable agricultural system, though after the land reform program and the advent of modern devices, these traditional water management systems started to fade out.

Another aspect of the traditional water management addresses all the actions the local farmers take in order to regulate water division, irrigation related subjects and preservation of water resources. They have traditionally established some complicated systems in order to divide water among the farmers or the shareholders of a water resource. The following topic takes up the subject of irrigation right which is based on landownership or time shares within a certain period of rotation.

8-6- ROTATION PATTERN OF IRRIGATION WATER

Water irrigation is owned by shares. In fact the farmers take turns bringing water to their land. In terms of a particular shareholder, the interval between two irrigations means an irrigation cycle or rotation pattern of irrigation water which may take 6-21 days. For example, if a farmer has an irrigation right of 2 hours within a 6 day irrigation cycle, it means that he has the right to water his land just for 2 hours once every 6 days. The duration of irrigation cycle differs from 6 to 21 days in all over Iran, but the average is between 6 and 16 days in most of the country which has something to do with the cropping pattern. In terms of wheat and Barley which make up the most common cropping pattern in Iran, the best interval between two irrigations is 12 days that is equal to the most common irrigation cycle.

The duration of irrigation cycle varies from area to area with the prevailing cropping pattern, the number of shareholders, climatic condition, etc. For example the more the number of the shareholders, the longer the duration of irrigation cycle. Also, in case of the plants with short and horizontal roots which are more vulnerable to the shortage of water, the irrigation cycle tends to be shorter, because a long interval between the irrigations can do a great damage to the crop. The climatic and soil conditions may affect the duration of irrigation cycle too, through the fact that the porous and light soils have a low capacity to hold water leading to a short irrigation cycle and vice versa. The most essential concept in terms of traditional water management is irrigation cycle that specifies when each farmer is to irrigate as well as how many times each shareholder has the right to use the water during a year the way a calendar does. Note that an irrigation cycle in a particular region is not always constant, but it may vary for several reasons. For example, in the region of Taft (province of Yazd) there is a wide variety of irrigation cycle. Even in a small village each Qanat may enjoy a different irrigation cycle. This variety may be attributable to some economic, social and climatic factors which are sometimes interwoven. One of the most important causes of the change in the duration of an irrigation cycle is the fact that every Qanat needs to be repaired and cleaned every once in a while. A Qanat is a very long subterranean canal being up to 60 km long, so this system is subject to many natural phenomena which may cause it to flood, collapse, etc. that is why every year the shareholders have to collect a particular deal of money which goes to the maintenance and rehabilitation of their Qanat. In some cases if the damage inflicted on a Qanat is so severe that the shareholders no longer afford the cost of its repair, they would have to go around asking a rich person to invest in their Qanat and appropriate a day of the irrigation cycle for himself in return. In this case they increase the irrigation cycle for example from 12 to 13 days out of which a day belongs to some one who has financed the procedure. In this regard there is a story which shows how such a change in irrigation cycle may occur. In 1710 an earthquake struck the town of Gonabad and reduced many homes to rubble and destroyed an important Qanat named as the Qanat of Qasabeh. The obstructions in the Qanat were so extensive that the shareholders failed to cope with it, so they requested a rich man named as Mirza Ali Naqi Riabi to take part in the repair of the Qanat. He accepted to invest in the Qanat on the condition that two days would be added to the irrigation cycle and then given to him in return. At that time the governor of the region was an Arab named as Mir Hasan Khan whose claim for more taxes on the income of the Qanat touched off a riot, until Mirza Ali intervened and settled the problem by granting his own shares of the Qanat to the governor. The governor was touched by this sacrifice Mirza Ali made, so decided to devote these irrigation shares to the charity purposes. But after a while, one of the Mirza Ali's sons claimed that he already inherited these irrigation shares and now was entitled to them, so a dispute broke out between him and the elderly governor. Mirza Ali's son and the authorities of the great shrine of imam Reza in Mashhad agreed that the half of these irrigation shares would be included in the properties of the shrine as endowment, and in return the authorities would back him up until he would win the conflict. Since that time, the shareholders of the Qanat have learned from this experience that to be content with their own resources is better than to rely upon a stranger.

Sometimes for a religious or charity purpose, the irrigation cycle may be extended. In many regions, in the name of Imam Hossein who means a lot to the Iranian Muslims, the farmers add a day to their irrigation cycle and then rent it out in order to come up with the money they need to hold some religious ceremonies. This custom is called Miyoon or Farkhiz that can be performed with every body's consent. Another reason for changing an irrigation cycle is the fluctuation in the flow of a Qanat. In case the discharge of a qanat decreases due to a drought, the water shares would no longer suffice to irrigate the existing lands. For example if a farmer has a water share of 4 hours within a 6 day irrigation cycle, and the discharge of the Qanat would drop from 100 to 50 liters per second, he would not be able to water his land. To solve this problem he changes his cropping pattern to something more resistant against the dry condition, and then he receives a water share of 8 hours once every 12 days not 6 days. By this means, the existing water can cover his whole land, even though the Qanat drizzles.

8-7- WATER DIVISION UNITS

To measure the irrigation shares the farmers are entitled to, they have invented some units which vary from area to area with the local conditions and the volume of the water available. In sum, there are three types of water division units traditionally used by the Iranian farmers as follows:

1- Units based on the area of the farm;

2- Units based on the volume of flow;

3- Units based on time.

The first type, measures the irrigation share by the area of the field that is to be watered. For example, if some-one has a share of 1000 meters, it means that he is entitled to a volume of water which is able to fully irrigate a 1000 square meter land. This unit is practiced in the regions where there is no scarcity of water. The second type in more similar to the units used today than the others. This type measures the volume of water flow per a particular time. The third type just measures the time during which a shareholder has the right to irrigate regardless of either the land area or the volume of flow.

The latest unit is very common in the central plateau of Iran. To calculate the time of irrigation they have invented a special type of water clock or clepsydra. Their clepsydra consists of two bowls made of copper one of which is so small that could freely float on the surface of water in the large one. The floating bowl has a tiny hole at its bottom through which water can enter the bowl and gradually fill it up. After being filled which may take a certain time, the small bowl sinks in the water and bumps into the bottom of the large bowl. As soon as the bump would be heard, a unit of time would be over, so the time between the two bumps equals a certain unit of time. One can also find some marks cut into the inner side of the small bowl which divide the certain unit of time into the shorter fragments. The time it may take the small bowl to be filled and sink varies from area to area in the central plateau of Iran. I examined some different types of clepsydra in some areas and summarized all the results in the following table.

Location	Time (hour: minute: second)
Kol-e Birjand	00: 24: 00
Shahik-e Qayen	00: 22: 30
Khor-e Birjand	00: 17: 00
Kadekan	00: 15: 00
Sarbisheh, Zirkooh-e Qayen, Darmian-e Birjand	00: 12: 00
Yazd	00: 11: 15
Zoozan, Boshrooyeh	00: 10: 00
Fakhrabad-e Bajestan, Eshgh abad-e Tabas	00: 09: 00
Bilond-e Gonabad	00: 08: 30
Gonabad	00: 08: 24
Dihook-e Tabas	00: 08: 00
Khanik-e Gonabad	00: 07: 30
Abiz-e Qayen	00: 07: 00
Aboojafari-e Boshrooye, Kakhk	00: 06: 00
Khosro Jerd-e Sabzevar	00: 05: 00
Serend-e Ferdows	00: 04: 44
Bajestan	00: 04: 36
Tabas	00: 04: 00
Ferdows	00: 03: 00

Sometimes, in a certain area, the unit of time may vary with the season and the period of rotation within which the irrigation rights have been defined. For instance, In Bajestan area, the unit of time varies from 2.3 to 17.2 minutes between the months of March and February. In this area, there are three qanats named Mohammad-abad, Golbid, and Nowkariz. Bearing in mind the location of farms and the distance between the qanats and the farms, each farmer may use either one of the three qanats or two/three of them mixed together. The joint flow of the qanats of Golbid and Nowkariz is only considered as the standard flow to which all the official proofs refer. For example, if someone claims that he/she possesses ten shares of water, in fact he/she is entitled to irrigating his/her land for 46 minutes because every unit of time equals 4.6 minutes on condition that the flows of Golbid and Nowkariz are together. On the other hand, the rotation of irrigation rights may be based on 21, 14 or 10 days during a year. Within a period of rotation based on 21 days, every shareholder is allowed to irrigate only once every 21 days and so on.

Meanwhile, the length of the period rotation varies from season to season in order to adapt the available water to the existing climate condition. Therefore, there are 15 units of time all of which depend on the period of rotation and the source of water, as you can see in the following matrix. The gray part of this matrix shows 15 possibilities for unit of time from 2.3 to 17.2 minutes. As an example, the unit of time would equal 4.6 minutes, if the rotation of irrigation rights would be based on 14 days as well as both the qanats of Golbid, and Nowkariz would be taken into account.

10	14	21	period of rotation / source of water
2.3	3.2	4.8	Mohammad abad+Golbid+ Nowkariz
3.2	**4.6**	6.9	Golbid+ Nowkariz
8.2	11.5	17.2	Mohammad-abad
8.2	11.5	17.2	Golbid
5.5	7.8	11.7	Nowkariz

Due to the complexity of the water division, there are some professionals named mirabs i.e. water-masters who are in charge of distribution of water among the farms, and are paid a definite salary by all the shareholders. While giving water to a shareholder, mirab also has to consider the time it may take the qanat flow to get to a given farm. For example, if someone has a right of 46 minutes irrigation, and if it takes the flow of water 4 minutes to arrive in his/her farm, then he/she should be allowed to use the water for 50 minutes. Therefore, mirab does his best to distribute the water among the farms in a way that as less water as possible would be wasted in the ditches. Doing so, mirab should be quite familiar with the locations and characteristics of all the ditches leading water to the farms. Mirab has a notebook too, including all the irrigation rights in detail, so if the shareholders want to sell or buy any right they should let mirab know about any transaction. Unfortunately, nowadays this profession is fading but nothing is replacing it, so we witness some conflicts over water in rural areas these years.

8-8- WATER MANAGEMENT IN THE REALM OF MODERNITY

Among the package of the modern reformation of the former Shah in 1963, the redistribution of agricultural lands which sheared the traditional landed elites of much of their influence has the most significant effect on water management systems in Iran. As mentioned, before the land reform, most of the Iranian population resided in rural regions. Each village consisted of some agricultural units (boneh) cultivated by 8 to 12 farmers (share-croppers). The duty of each farmer was perfectly specialized, some were usually in charge of plowing and preparing the field, some were responsible only for irrigation, and some were involved in seeding, protecting and harvesting. Everybody worked and lived under the management and authority of a lord, who owned the whole village. According to the Law of Land Reform, the villages were purchased from the lords by the government one after another, and then were sold to a few farmers in the same village by installments.

The land reform law was finally carried out, without caring about the majority of the villagers who had no share in the agricultural units (boneh), not profiting from the land reform at all, and without caring about the complicated relationships between the production systems, environment and water management in Iran. So, the land reform law could lead to annihilation of many qanats which were only resources to supply water to central Iran, by means of a blind mechanization and confusing water management systems. Even if the motive for the land reform was making the lords' capitals move to the principal cities to be invested in the industrial section, the government should not have distributed the lands between the peasants. But, it was better for the government to retain the purchased lands and reconfigure the traditional management in a modern context by means of setting up some organizations in the rural regions being able to take the landlords' place.

In fact, the land reform removed the lord’s traditional position, because those agricultural systems carrying such a position were ruined, but anyone or any kind of organization did not exactly replace the lord’s role. Therefore, many qanats were abandoned for a while or even for ever. Because, within the agricultural system of boneh, the lord used to look after his qanat, and if a qanat needed repairing, the lord did not hesitate to call in the qanat practitioners and finance the whole project. After the land reform, the qanat practitioners could no longer work for any lord who used to finance the qanat and give them an opportunity to earn a living, so they were encouraged to immigrate to the cities or other regions. In central Iran, qanat practitioners were a professional community having no right to work on the lord’s lands as some official and permanent farmers. In the rural regions, the society was divided into two casts locally named Nasaqdar and Khoshneshin. Nasaqdar meant the groups who had the right to work for the lord as his farmers on his fields, so they had priority over the second cast (Khoshneshin) who had nothing to do with the agricultural activities, and their jobs would only satisfy the other needs of the rural community such as masonry, carpentry, handicrafts and qanat-related activities. According to the land reform law, the lord’s lands should have been distributed just among the Nasaqdars, the people who worked on the lord’s fields, so this program did not bring any profit to the qanat practitioners and made them go out of the agricultural areas.

On the other hand, the land reform raised a great demand for irrigation water because of bad management. Before the land reform, whoever worked in an agricultural unit (boneh) was responsible just for a particular job such as plowing, seeding, irrigating or harvesting, and the farmers rarely interfered with one another's job. Therefore, each farmer could not be so good at all jobs. so most of them were not capable of irrigating the fields. In a traditional manner, someone who was not expert at irrigation might waste some water in many ways, so after the redistribution of the lands the consumption of water increased, and the demand for water quickly surpassed the supply of qanats mostly due to misusing water. Therefore, the farmers had to drill some deep well to pump the aquifer to provide the required water, doing so lots of qanats fell into decay.

As mentioned, according to the Law of Land Reform, the lords were forced to sell their lands to the government. But mechanized farms were the exception, and having pump extraction was legally considered as a proof of it (Azkia M.. 1994), so some of the lords were encouraged to replace qanat with pump extraction in order to save their own lands. Actually they did not want government to destroy their traditional position in the rural communities by means of removing their economical roots. The lords hurried to dig the well with extractive pump to avoid being included in the land reform law, even if their lands needed no well. Doing so, the number of the deep wells dramatically began to increase. For instance, the first well with extractive pump, which took place in Neyshaboor region, was drilled in 1958. But the number of such wells reached 14 in 1960 just when the land reform law were approved and announced, and then amounted to 286 in 1970. Massive ground water extraction causes depletion of finite aquifer reserves, and it dramatically reduces the water table of the whole surrounding area. An estimated in Neyshaboor region, the water table goes down about 0.2 meters a year on average, because of the massive groundwater extraction (Velayati. 1999). Therefore, most qanats were drying one after another, due to the wells and their pumps, which took the water table away from the access of qanats. The comparison of qanat with well (extractive pump) can shed a light on the fact that such wells are not suitable for Iranian agricultural systems in many cases. Extractive pump empties the porous layers of water and cause some subsidence, which do lots of damages to the structure of soil and even buildings. If extractive pump empties karstic holes of water and destroy them, then a circular hollow appears within a radius of 100 meters on the surface of earth. But qanat never makes such a problem. The potential loss of fresh water, which makes salt water move towards up-stream, is attributable to extractive pumps, whereas qanats never change the quality of water. According to some information related to Iran, the wells with extractive pumps could not last more than 30 years unlike qanats which last more than 2000 years without any defect. After all, water flows out of qanat only because of the force of gravity that is free of charge, whereas the extractive pumps consume an enormous amount of fuel per year. For example, in Yazd area there are 4340 wells with extractive pumps, which totally consume 205854880 liters gas oil a year in order to obtain 926350000 cubic meters water. But in the same area there are 2948 qanats, which withdraw 329870000 cubic meters water a year without any fuel (Baqeri & Roozbeh. 1999).

This land reform was an example and a bad experience that taught us the fact that development is not a simple concept we can import from the modern world into our own country, without taking our cultural economical and ecological conditions into account. Although the Iranian authorities tried to belittle all the traditional production systems, while carrying out the land reform program, in order to pave the way for a modern model. They believed that our country could never achieve a developed stage, unless we completely let go of the traditional sections of the society that appropriate most of our resources. Therefore, most of the Iranian scholars and politicians tried to exaggerate the technical defects in qanat and traditional water management to justify their own hasty programs and convince farmers to use pump extraction instead of qanat. For instance, a report entitled “Economical Development of Soil and Water Resources” prepared in 1966 explains the amount of required water to irrigate an area equal to 10000 square meters or a hectare. Some parts of that report associated with modern techniques estimate the amount of required water for a hectare to be about 10000 cubic meters a year. But another part related to qanat and traditional irrigation makes contradictory statements, so that it estimates the amount of water needed for a hectare to be about 16400 cubic meters a year. In fact there is a thirty percent decrease in the required water in comparison with real estimate when the report explains modern irrigation, and a sixty percent increase when the report engages in qanat and traditional irrigation. Then the report concludes from such wrong estimates that qanat cannot supply the required water to irrigate our farms. Such exaggerating reports resulted in thousands qanats being destroyed. For instance, only in the plain of Yazd there are more than 70 dried-up qanats, which have caused many villages and about 2500 hectares rich lands to be abandoned (Labbaf Khaneiki M.. 1999). The main reason why qanats started drying is that many deep wells were drilled in lower slopes to extract water with pumps depleting aquifer.

The depletion of aquifer not only makes qanats dry, but also causes desertification especially in central Iran in which some plants such as Salsola Spp and Seidlitzia Sp usually grow depending on the water table (Ekhtesasi & Daneshvar. 1999). When I worked for Amirkabir institute in 1996, I came across an awful adventure explaining the role of pump extraction in some water and land management disasters as well as social – economical problems. There were some villages in southern Khorasan lying on the edge of central desert of Iran in which some peasants had settled and traditionally earned their living by camel husbandry. An organization had made a decision to help them start to cultivate their pastures in hopes that they could improve their economical situation. So the organization encouraged them to give up camel husbandry that was supposed to waste their time and energy. They started to drill many deep wells to pump water for the lands allocated to produce pistachio instead of camel husbandry. The extracted water contained some salt, and irrigation water that was not properly drained left a salt residue. The salt built up and finally led to a type of soil unusable for farming. According to the book Blue Gold, salinity has affected a fifth of the world’s agricultural land, and each year it forces farmers to abandon a million hectares of farmland (Barlow & Clarke. 2003). As a result, the aforementioned farmers had to stop planting the pistachio trees, because of the salty soil not letting pistachio grow. So they desired to return to the camel husbandry, but the environmental condition had changed so much that no animal could feed on such poor vegetation. In fact, the pumps caused depletion of aquifer as far as the roots of some plants such as Alhaji which was the main food to camels could not reach the water. Therefore, there is no enough plant in the field in which their camels were supposed to graze. Unfortunately, the farmers lost both agriculture and animal husbandry, and they had to immigrate to some principal cities as a community of poor suburbanites. I believe that after water management broke up in disorder and lost its traditional function, we faced some multidimensional problems which would remain unsolved unless we would modestly learn some lessons from tradition.

8-9- CONCLUSION

It is not wise to give up all modern technologies and revive tradition instead, but it is quite wise to adopt the sustainable relationship which has always existed between environment and the elements of the traditional production system. In the traditional agriculture, such an accurate water management perfectly met environmental conditions to make use of every drop of water in cultivating this arid region. Therefore, there are still many things we can learn from traditional water management to promote our new water affairs. Recently, in Iran some governmental centers' attention to traditional water management is tending upward. This gives glad tidings that future is not that disappointing if we learn how to have both tradition and modernity living side by side meeting a unique purpose, and it is the golden key of the sustainable water management.

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Iranian National Committee on Irrigation and Drainage (IRNCID)

Background:

In 1955 Iran became a member of ICID by the recommendation of the former Irrigation Institute, but practically it was not active due to disapproval of the parliament up to 1967 to establish the Irrigation and Drainage Committee. The constitution of Iranian National Committee on Irrigation and Drainage was approved by the parliament in 1968 and its regulations and organization were signed to the former Ministry of Water and Power.

It is necessary to mention that the most important activities of the committee before the Islamic Revolution Victory contained establishing working groups and holding 5 seminars at the national level.

After the Islamic Revolution Victory and the industrial and agricultural fulfillment, huge investment has been allocated to irrigation and drainage networks establishment since now. In this regard, it is necessary to be more concern on this issue.

The progression and development of irrigation and drainage are very considerable in the world, so there should be a kind of conformity in investigation, design and implementation of the networks with the world's new findings and standards.

In this extent, IRNCID started its new activities by the support and effort of the water industry authorities once again in 1993 in order to promote irrigation and drainage, soil and water management, flood control, water and environment conservation for sustainable development.

The Iranian National Committee is constituted of the High Council, Executive Board, Technical Working Groups, Regional Committees and the Secretariat. IRNCID has more than 100 main members and 2000 associate members selected from eminent experts, professors and students of water engineering all over the country.

Two periods vice presidency of the International Commission on Irrigation and Drainage, Chairmanship of the Working Group on "Irrigated Agriculture under Drought and Water Scarcity" and Vice Chairmanship of the Working Group on "Young Irrigation Professional Forum" and panel of experts of the 17th and 18th ICID International Congress are the Iranian National Committees honors.

Duties and Options:

Providing and formulating the regulations and criteria required to select qualified members among individuals, companies, organizations and institutes (including research and training centers).

Making connections and exchanging information with international and national committees on irrigation and drainage of other member countries.

Determining the programmes, policies and annual activities of IRNCID in the first session after every international conference and following up the procedure by the executive council.

Encouraging and supporting the irrigation and drainage researches, flood and sediment control, soil and water management to improve the irrigation and drainage affairs in the country, soil conservation, environmental protection and sustainable development related to soil and water and giving technical advice regarding to investigation and execution of the project.

Arranging seminars, symposiums and irrigation and drainage workshops, discussions and exchanging views.

Arranging technical committees and working groups as required; providing and formulating their instructions according to IRNCID objectives.

Selecting and introducing the IRNCID delegates to take part in IEC meetings, congresses and special international committees according to the regulations and constitution.

Purchasing, collecting and centralizing the information, technical documents, books, magazines and publications related to irrigation and drainage science.

ICID.CIID

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