AN ANCIENT AND TRADITIONAL WATER SUPPLY SYSTEM IN ARID AND SEMI-ARID REGIONS OF IRAN

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ABSTRACT

Dasht-e-Kawir in central Iran is a catchment, which includes saline, swampy areas and sandy land. The system of water supply in the margins of the Dasht-e-Kawir is limited by the amount of underground water which can be extracted by qanats and wells. Six kinds of qanats have been recognized in the region. A qanat is usually produced in six stages, of which measuring the gradient is the most crucial for the successful construction of a qanat. Thus the construction of 30 qanats in the margin of Dasht-e-Kawir has been studied to determine the logical relationship between (a) the gradient, (b) the depth of main well, (c) the length and (d) the discharge of the qanat. According to the information derived, planning for digging a qanat is divided into six stages as follows, 1- select a suitable field, 2- enough capital, 3- Search for under ground water, 4- digging of test wells, 5- measuring the slope, 6- determination of qanat direction and actual digging of the qanat.

INTRODUCTION

The interior of the Iranian highland encloses a central area of irregular shape consisting of a number basins. Dasht-e-kawir, Masileh and Dasht-e-Lut are a collection of these basins.

These regions are located inside a triangle which its corners are three cities. 1-Qum in the west, 2- Sabzewar in the north, 3- Iranshar in the south.

The precipitation in the most parts of these regions is less than 150 mm, the extent of this desert area in about 390,000 Km2 or 23% of the total of Iran.

The influence of men on the water supply pertains to artificial storage, surface or underground diversion, transport and the extraction of groundwater etc. But the influence of men in the Iranian triangle arid region area is limited to the extraction of ground water which is operated by the qanats, shallow the wells and deep wells, which the qanat system an ancient and traditional water supply system in arid and semi arid region of Iran is discussed as follow:

QANATS

This system of water supply is widely used for irrigation and domestic purposes in arid and semi-arid regions of Iran.

Qanat has been defined in several ways by research workers but most of them have not obtained a comprehensive definition of the qanat. Most researchers have not paid attention to the different sources of water and gradient of the tunnel and they believe that qanats always feed off the watertable and are constructed into an alluvial fan and have gently sloping tunnels. For example, English (1968)[1] observes:

> *"Qanats are gently sloping tunnels dug nearly horizontally into alluvial fan until the watertable is pierced".*

Beaumont (1971) believes[2]:

> *"The qanat is a method for developing and supplying ground water and consists of a gently sloping tunnel, cut through alluvial material which leads water by gravity flow from beneath the water table at its upper and to a group surface outlet and irrigation canal at its lower end.*

Chazi (1977)[3], Walton (1969)[4], Honary (1980)[5] and Kuros (1971)[6] and others have given similar definitions. However, the author believes that although most of the qanats feed off the watertable, this is not always the case because there are many qanats that feed off springs, rivers and seepage from dams (see Fig, 1). Qanats are not always constructed in the alluvial fan because the location of a qanat depends on the topographical condition of the area. Also, research workers paid little attention to the gradients of qanats, and this is an important point when considering the construction of a qanat and its study.

However, bearing in mind the above points, the author has tried to obtain a comprehensive definition of qanats as follows:

Qanat is a succession of vertical shafts, connected by a sloping tunnel. The slope of the tunnel depends on the length of the qanat and the different elevations between the depth of the main well and field. Qanats feed from the watertable, river or seepage form reservoirs. The water flows in the sloping tunnel from the water to the surface.

This system of water supply was widely used in the past and is still used at present for several reasons. First, qanats require no power source other than gravity to maintain flow. Secondly, water can be moved substantial distances in these subterranean conduits with minimal evaporation losses and little danger of pollution. Thirdly, the flow of water in the qanat is proportional to the available supply in the aquifer and, if properly maintained, these infiltration channels provide a dependable supply of water for centuries. Fourthly, a qanat is usually a sure, permanent source of water supply for settlements and irrigation in arid and semi-arid areas. Finally, the water of the qanats is usually more digestible than other water, especially in the Abuzaid-Abad area.

HISTORY OF QANAT IN IRAN

Qanats are extremely important in the history of irrigation and human settlement in the arid lands of Iran. A number of scholars have discussed the possibility of the existence of qanats in prehistoric times, such as Wulff (1968)[7] who said "it is still used after 3000 years". Bastani parizy (1975)[8] demonstrated that the qanat of Joopar[9] near Kerman was dug some 3000 years ago.

Some research workers have shown the spread of qanats from Iran to other parts of the world. English (1968)[10] said "Apparently originating in pre-Achaemenid persia, tunnel wells spread to Egypt, the Levant and Arabia, western China and on a more limited scale in the dry region of Latin America (550-331 B.C)" Honary (1980)[11] believes "... after the rise of Islam,qanats greatly spread through the world of Iran-from North Africa to Central Asia."

Classification of Qanats

As previously stated, although most qanats feed off the watertable, this is not always the case because there are many that feed off springs, rivers and seepage from dams (Fig. 1).

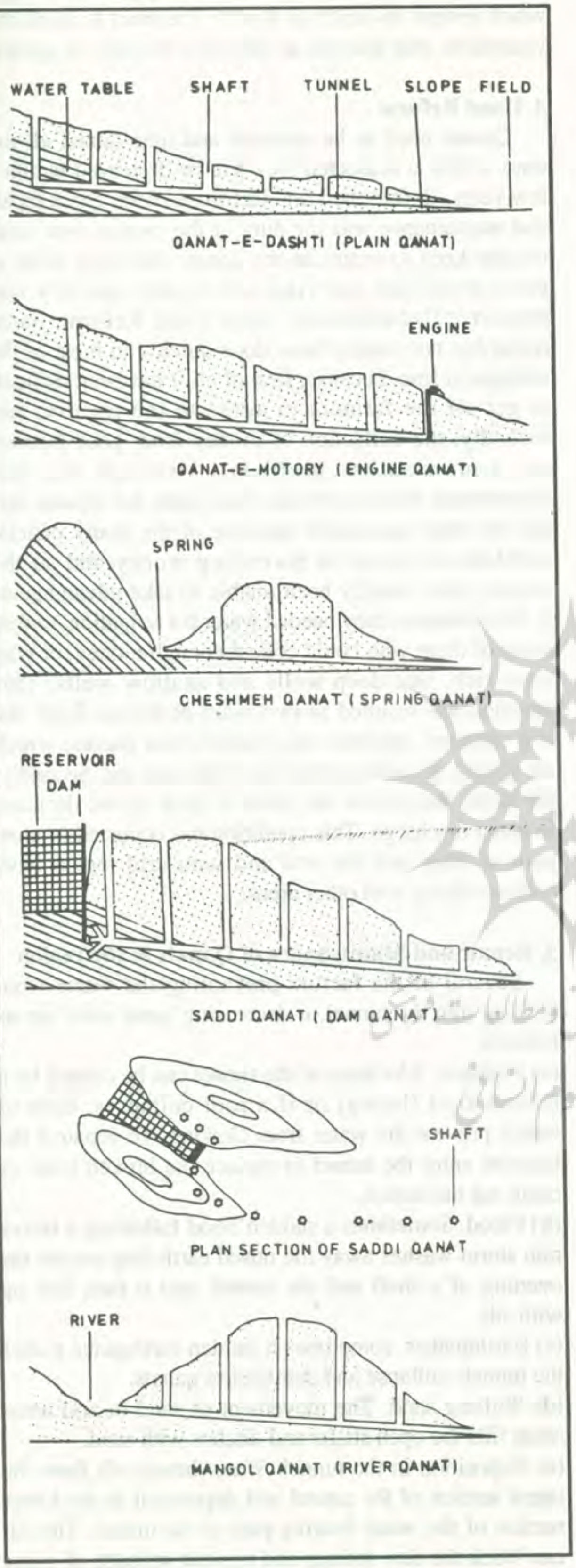
The first category of qanats is called *Qanat-e-Dashti* (Plain qanat). The source of water in the plain qanats comes from the watertable and has gently sloping tunnels dug nearly horizontally into alluvial material until the watertabel is pierced. Generally when the term qanat is mentioned, it is this kind which is considered.

The second category is called *Qanat-e-Motory* (the engine qanat). This kind of qanat has recently been constructed in some parts of Iran. It is rather like a qanat-e-dashti, but with this difference the water does not appear on the surface by gravity but must be pumped to the surface. This can result from incorrect digging or it may be dug to increase the water supply and reservation for a semi-deep well.

The third category is *Cheshmeh-qanat* (Spring qanat). This kind of qanat is an extension of a natural spring and it is dug in mountainous areas. The length of the tunnel is usually short (200-100m) and the depth of the main well does not exceed 10-30m. In this kind of qanat the rate of water flow is dependent on the rain fall.

The fourth category of qanats feeds off seepage from a dam and it is called, on the south edge of the *Dasht-e-Kawir* (the dam qanat). This kind of qanat is fed by the water which seeps from reservoirs behind the dams. Usually the dams which feed the qanats were constructed in flood passes, and flood water collected

Fig. 1 CROSS SECTION OF DIFFERENT TYPES OF QANATS



behind the dam, and water seeps into the qanats dug beneath the dam. This kind of qanat is found in Jandaq to the south of Dasht-e-Kawir.

The fifth category comprise qanats that are fed by a river. This kind of qanat is named *Mangol qanat*, and exists in Tehran area and Karaj[12] for example the *Ab-Mangol* in Tehran and mangol qanats of Shams-Abad and Mohammad-Abad villages. They flow from the Kordan river to the west of Karaj. This type of qanat is a ditch which is diverted from the river, and as the depth of the ditch increases because it may pass hills or mountains, it goes underground, and when a long tunnel is to be dug underground, shafts are required to remove the soil and to provide ventilation.

Type of Qanat in the Area

The *Moqanis* (qanat diggers) believe that qanats be divided into two sorts, as follows:

(a) *pust-Ab* (Which means the watertable is near the surface). There is limited layer of water relatively near the surface. The qanats using this sort of water are called *pust-ab-qanat*. In other words the *Moqanis* if the depth of the main well is less than 30 m. then the qanat is *pust-ab*.[13]

The specific water yield of *pust-ab* qanats change during the year. They have maximum discharge at the end of February, and minimum discharge at the end of September. Moreover, their total discharge directly depends on the annual rainfall.

(b) *Qarq-ab* (which is the deep rich permanent watertable). If the main well is dug to more than 30 m. depth in the region it will use the permanent watertable, and the annual discharge does not completely depend on precipitation; the discharge usually dose not change during the year.

One criticism of qanat can be made in that it wastes water during winter, or during times when cultivation does not need irrigation. On the surface this criticism appears valid, but in fact it is not exactly correct in that it is an external judgement of the qanat. Because, although a qanat is a permanent resource for water supply which discharges underground water throughout the year, it must be realized that during wet years when the rainfall saturates the watertable, surplus water flows along a qanat or from a temporary spring. Furthermore, usually in all villages in the arid areas of Iran qanat, water is used in the home and for animal husbandry throughout the year. Also, as stated earlier; during dry years the qanat is a source of water supply and is used for winter crop irrigation.

THE FACTORS CAUSING A REDUCTION IN THE DISCHARGE OF QANATS IN THE REGION

Qanat is a water supply system widely used throughout the country. Unfortunately, recently the specific yield of the most of qanats has decreased. There are many different causes of this decrease of qanat discharge in various regions depending on some factors relating to the geographical conditions. The most important causes in the area under investigation are as follows:

1. Drop in the water table

It is obvious that if the amount of water withdrawn from the ground water is more than the amount of water which seeps into the ground, the watertable will drop. In recent years this has been the case and as a result the level of the water tables have dropped in relation to ten years ago.

Qnats are fed by watertable in the region. The *Ab-Deh* (Water bearing) Section of tunnel is dug almost horizontally into the aquifer and water seeps into the tunnel. When the watertable drops, the proportion of *Ab-deh* decreases until the water dose not perfectly seep into the tunnel. This situation has occurred in most of qanats in the region. Of course, sometimes extending the tunnel can be a remedy, but in some circumstances it is difficult to reach the ground water horizontally, then the floor of the tunnel can be dug downward. This is called *pey-cani*. But some times the water can drop too much and in this situation the water which the qanat discharges as a result of the repair may not be useful for irrigation purposes because the level of the water has dropped, but the level of the farms has not changed.

2. Wells

According to the Ministry of Water Power records in 1964, the total discharge of 11 qanats in the margin of Dasht-e-Kawir (Abuzaid-Abad adjoining villages) was 2,958,980 m3/year and the total discharge. But according to estimations made by the author in 1988 the discharge of these qanats was 942,920 m3/ year (Four of qanats had dried up) and the rate of decrease is about 4,8% for each year. The total discharge of wells, most of which have been dug during the last twenty four years, is about 036,000 m5/ year. The total discharge of wells at the present time is 10 times the discharge of the qanats 24 years ago. On the other hand, precipitation, which is the main resource for stocking the ground water in the area has not changed during the last 24 years. There is no doubt that one of the main reasons for the drop in the watertable is the over-withdrawal of ground water by wells in the area.

3. Artificial Forests

During the last 8 years the Ministry of Natural Resources has made artificial forests to control the shifting sand problem and to prevent the spread of the desert. The trees planted in these forests usually have long vertical roots (most of these are Tamarix Sp.), which extend to depth of 8 m.[14] The trees feed off the watertable, this also has an effect on the yield of qanats.

4. Land Reform

Qanats need to be repaired and maintained all the time. If this is neglected they will be destroyed within a few years. Before the Land Reform in Iran, qanat repair and maintenance was the duty of the owners who were usually keen to maintain the qanats and keep them in good condition carrying out repairs quickly and property. Unfortunately, since Land Reform, qanat repair has not usually been done quickly in most of the villages in Iran, because, first of all it has been difficult to get all the farmers to agree to the repairs, and secondly, the collection of money from poor farmers has been another problem. Although the last government tried to provide some loans for repairs, this has not been successful because of the many official problems involved in borrowing money and so the farmers have usually been unable to take advantage of it. Nevertheless, they needed water for irrigation, and so some of them who could collect enough money, or who were rich, dug deep wells and shallow wells. This situation has resulted in two main problems: First, the rich farmers' attention has turned from qanats, which are public, to wells, which are often private. Secondly, the wells themselves are often a cause of the decrease in qanat discharge. This condition has occurred in most parts of Iran, and the arid and semi arid region have suffered along with other areas.

5. Repair and Maintenance of Qanats in the region

Several of the factors preventing the water from flowing into the tunnel or decreasing qanat yield are as follows:

(a) Collapse. Blockage of the tunnel can be caused by a broken kool (lining) or if a roof collapses, both of which prevent the water from flowing. To repair it the laborers enter the tunnel to replace the broken kool, or clean out the tunnel.

(b) Flood. Sometimes a sudden flood following a heavy rain storm washes away the raised earth ring around the opening of a shaft and the tunnel, and it then fills up with silt.

(c) Earthquakes. sometimes a sudden earthquake makes the tunnels collapse and demolishes qanats.

(d) Shifting sand. The movement of sand in arid areas often fills the open shafts and ditches with sand.

(e) Deposition in the tunnel. Water brings silt from the upper section of the tunnel and deposits it in the lower section of the water bearing part of the tunnel. The silt can block the tiny springs and prevent seepage of water

into the tunnel.
(f) Sedimentation. In some qanats the water itself carries sediment and deposits it on the bottom of the tunnel and the rate of water flow then decreases.

ACTUAL METHOD FOR CONSTRUCTION OF A QANAT

In this section the process of construction of a qanat is described in the way that it is actually achieved by Moqannis (a class of professional diggers). In order to be as accurate as possible, the information about this was obtained by interviewing some Moqannis and closely observing their work as much as possible, during my field studies in the region and other parts of Iran.

According to the information derived, planning for digging a qanat is divided into six stages as follows:

The first stage is to select a suitable field for agriculture (irrigated cultivation). In the second stage, the owner must acquire enough capital. The third stage is the search for underground water. The fourth stage involves the digging of test wells. Measuring the slope is the fifth stage and the sixth stage is the actual digging of the qanat.

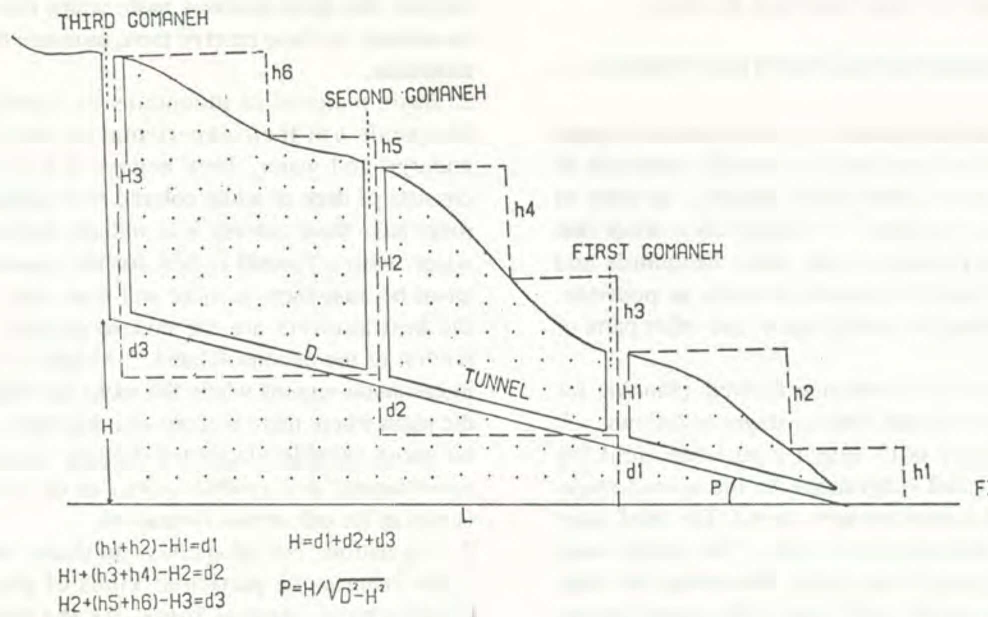
The owner, or owners come to a conclusion after the first and second stages, and based on this decision, the Moqannis are hired. The Moqannis, or the chief of the Moqannis (Memar) are responsible for the last four stages.
(a) Suitable field. The principal aim of digging a qanat is to provide water supply for irrigation which is needed to make the land suitable for agriculture. Sometimes even though the water supply is potentially adequate, either there are not enough for agriculture, or the land is not suitable. There is a good example of this situation in the Abuzaid-Abad area, east of Kashan, although in this case the example is a deep well (Mazreah-Zahraieh).
(b) Capital. There are many qanats in Iran which are not yet finished or have been finished by their second or third owners. This is a result of the original owner's incorrect estimation of the capital necessary for constructing a qanat, and so they lacked enough money for the digging of the qanats.
(c) Search for underground water. The search for underground water is based entirely on information supplied by Moqannis, although recently the opinion of natural scientists have been used in the construction and maintenance of qanats.

The majority of Moqannis take into account three factors, topography, basic material of foothill or mountains (area) and vegetation.
1. Topography. First of all, the qanat under construction must have the correct slope to bring the water to the field where it is required. Secondly, the best place for digging a qanat is in the foothills of ranges of mountains, not on the slopes of a single mountain. Thirdly, the width of the mountains is important because the qanat receives more water from the wider mountains, as these receive more moisture than a single mountain.
2. Basic material of mountains or foothill. Usually Moqannis use their experience in their search for underground water. They believe that if a mountain consists of dark or white colored rock (usually igneous rocks have these colors), it is unlikely that there will be water. Also a foothill is best for the construction of a qanat because there is more soil than rock. In general, the best aquifers are the coarse grained, saturated portion of the unconsolidated.[15] Moqannis believe that in mountain regions where the rocks are reddish, and in the plain where there is more soil than rock, are located the most suitable places for digging a qanat. (In the mountainous area reddish colour in the rocks usually occurs in the calcareous formation).
3. Vegetation. The Moqannis can detect underground water from some particular kinds of plants, which usually have vertical roots. As the result of the existence of underground water, these kinds of plants can survive in the hot and long dry summer.
4. Digging of test well. The Moqannis starts to dig the *Chah-e-Gomaneh* (experimental wells) to find out the level of the watertable and to understand the structure of the ground and availability of underground water. The location of the first experimental well is usually determined from the gradient of the area. The test wells are usually located at three points along the route of the qanats. The first *Gomaneh* is dug in the *Khosh-Kan* (dry section) of the qanat. The third *Gomaneh* is dug in the *Ab-deh* (water-bearing strata) and the second *gomaneh* is located between the first and third wells, and is called *Taran* (wetness). If the difference in elevation between the field and the mouth of the third *Gomaneh* is more than the depth of the well, it is successful, because the water table level is higher than the field, and water can flow to the field by gravity force. (Figure.2) shows the situation of *Chah-e-Gomaneh*.
5. Direction of qanat. to determine the direction of a qanat, the Moqani finds the direction of ground water. Glow from the test wells, and the tunnel of the qanat is dug along the route of the ground water flow in the water-bearing section. Its direction can be changed toward the field in the dry section.
6. Measuring the gradient.

(a) Traditional method for estimating the qanat gradient.

Measuring the gradient is crucial for the successful construction of a qanat. A mistake in measuring the

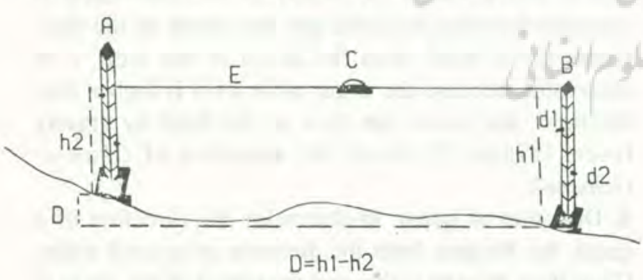
Fig. 2 MEASURING THE SLOP OF QANAT



slope can cause a major problem in the construction of a qanat because it affects the force of gravity to the determined field. Therefore, the Moqannis tries very carefully to carry out this job with accuracy, and failure is very rare. This not withstanding, unfortunately there is a badly measured qanat in the correct sloping will be discussed in the mathematical method for estimation of the qanat gradient.

The apparatus for measuring the gradient used by the Moqannis is simple (Figure.3). Its basis of levelling is surveying-the levelling goes from the field to the first

Fig. 3 MEASURING THE SLOP OF QANAT



A&B, two wooden poles are fixed on a flat wooden base (each 1.5 m long).
d1 and d2, two slots, a moving piece of wood suspended inside each slot, for keeping the poles vertical (if the poles are not exactly vertical these pieces of wood come out of the slots.)
C, spirit-level (is called "Traz")
E, a piece of string 20 m long
Difference of elevation between two poles is **$D = h_1 - h_2$**

experimental well, and from the first test well to the second, and from the second to the third.

Particular attention must be paid to the slope from the bottom of the experimental wells to the surface of the field which must have a particular gradient determined by the Memar (Moqanni).

In studies about qanats, research workers paid little attention to the gradient of qanats. Some researchers were not interested in the slope, or they satisfied themselves with a description of the quality of the slopes without noting of the quantity. Other groups have paid attention to this basic factor of qanat slope, but some of them have determined constant values for slopes of all qanats. Although these values may have been obtained by measuring one or more qanat gradients, they are not acceptable for all qanat gradients, for example:

"... The maximum gradient in a short qanat is approximately 1:1000 or 1:1500, in a long qanat the tunnel is nearly horizontal" (English 1968)[16]

"... and consists of a gently sloping tunnel. "(Beaumont 1971)[17]

"... This (slope) is normally 10-30 cm in 100 m, (1:1000 to 1:3000") (Honary 1980)[18]

"... The maximum gradient in a qanat is 1:1000" (Ministry of water and power of Iran 1971).

"... at a gradient of 1 in 2500 or 1 in 1500 in the direction of spring. "(Noel 1944).[19]

In fact the slope of a qanat depends on the length, topography and watertable level, and all these factors must be taken into consideration.

(b) Mathematical Method for estimating qanat gradient

As stated, the slope of a qanat is usually measured by the Moqanni using simple apparatus allied to experience and skill.

However, mathematically, the qanat gradient can be show by the following formula:

$$P = \frac{D}{L} .10000$$

Where P is the gradient of the tunnel in per thousand D, is the difference in elevation between the field and the bottom of the main well or D=[(altitude of mouth of main well-Altitude of field)-depth of main well] and L is the horizontal distance.

Although sometime the water bearing strata is too high in relation to the level of the field, the water amy come to the surface for a short distance. There are reasons, however, why it is better to continue underground. In this situation if the tunnel is dug too steep, the water rushing down the tunnel will erode the walls and soon destroy them, so the Moqanni makes a water fall in a suitable place. Qanat Mohammad-abad in the east of Kashan is a good example of this case (Fig.2,4,5).

The author has studied the construction of 30 qanats in Kashan region at various locations to determine a logical relation ship between the length of tunnel, depth of main well and H (difference in elevation between the field and the bottom of the main well).

The gradient of the 30 qanats have been measured in the field. Table 1 shows the specification of qanats. According to this calculation, 25 per cent of qanat gradients are less than 4 per thousand, 45 percent of them 4-8 per thousand, 25 per cent of qanat slopes are 8-12 per thousand and 5 per cent of the rest are 12-15 per thousand.

To establish a logical relationship between the length of qanat (L), its gradient (P), the depth of the main well (Z) and the difference between the field and the bottom of the main well (H), a coefficient of correlation has been calculated by computer between these factors two by two for the 30 qanats in the region (Table 1).

The coefficient of correlation between the slope and the length of a qanat is $r_{P,L}$= -0.54842. This negative figure shows that there is a negative correlation between the length and the gradient of a qanat.

The multiple regression equation has been calculated between the factors which have an impact on qanat gradient, and it is showed as follows:

1) P = 6.37-0.69 L-0,01 H-0.14 Z+0.14 HD
2) H = -3.81 +1.04 HD -0.90 Z-0.33L -0.47 P
3) HD = 1.81 +0.882+ 0.77 H+0.79 1 +0. 47P
4) Z = 0.38 + 1.04 HD -0.78 H- 0.78 L-0.56 P

As regression equation 1 suggests, the gradient decreases 0.69/1000, 0.01/1000 and 0.14/1000 per kilometer in length, per metre in different elevations at the bottom of the main well of the field and depth of the main well, respectively and increases 0.14/1000 per metre in different elevations to the mouth of the main well and field.

According to the above explanation we can analyze equations 2,3 and 4.

Digging Qanat

According to interviews with some *Memar* (technical expert in qanat construction) and from individual observations, this gomaneh.author asserts

Fig. 4 WATERFALL IN QANAT SYSTEM

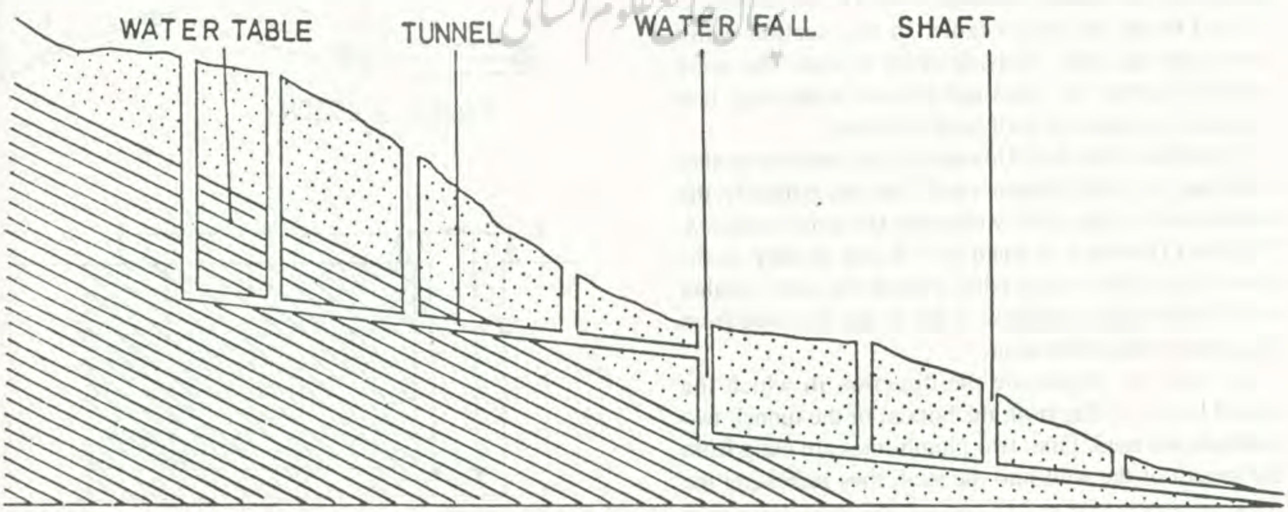
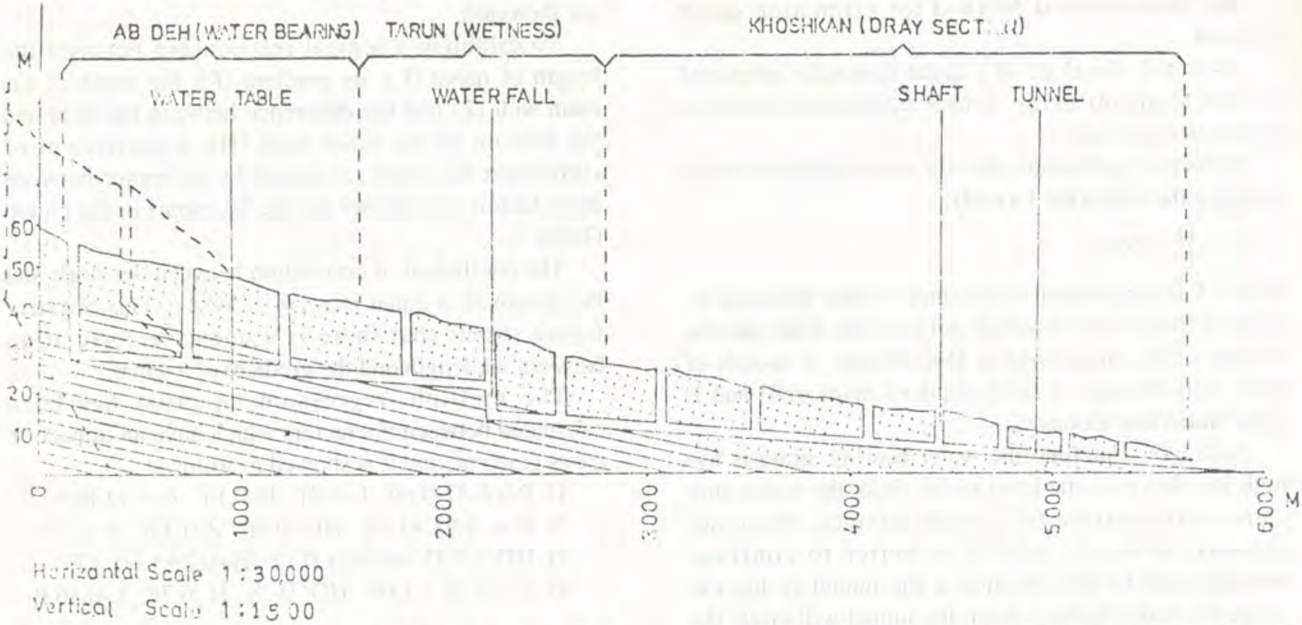


Fig. 5 CROSS SECTION OF THE QANAT OF MOHAMAD-ABAD



that digging starts at the first. The bottom of the first Gomaneh is the tunnel floor and from this point the tunnel is dug to the field and to the second Gomaneh.

From the first Gomaneh toward the field is the *khoshkan* (dry section) of the qanat. One group can dig the tunnel from the first Gomaneh to the field, while another group can dig the shaft connected to the tunnel, which provides ventilation and thorough which the soil is removed. Another group starts to dig from the field beginning with an open ditch, called "Joy" until it reaches a depth of some 2 to 3 meters.

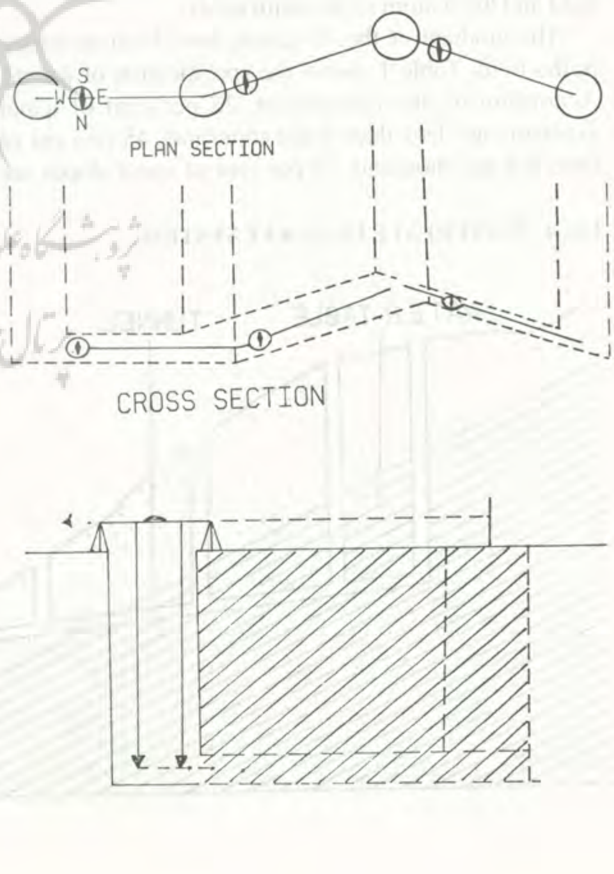
The next section of a qanat is called *Tarun* (wetness). This section is usually located between the first and second Gomaneh. To dig the tarun section, one group starts to dig the tunnel from the base of the first Gomaneh towards the second Gomaneh and another group digs the shafts. The last section of a tunnel is called *Ab-deh* (water bearing). The *Ab-deh* section is located inside the water-table. In this section water seeps from all sides. Thus, in order to make the water run gently down the sides and prevent it dripping, it is necessary to make the roof steeply ridged.

Sometimes the third Gomaneh is the main or mother well and is called *Madar-chah*, but occasionally the mother well is dug a few wells after the third *Gomaneh*. The third *Gomaneh* or main well is dug as deep as the upper layer of the water-table, though the term 'mother well' is misleading because water is not removed from the qanat at this point alone.

In order to determine the direction in which the tunnel has to be dug from the bottom of the tunnel, two methods are used. First, two plumb-lines are hung from the mouth of the well into the well, thus indicating the direction of the next well. Secondly, a compass is used at the top of the well. According to the Moqanni's plan, the compass direction of the next well is read, then the compass is taken to the tunnel and it is dug in the same direction until the next shaft (Fig 6).

A good deal of skill is required in the surveying,

Fig. 6 DETERMINATION OF QANAT DIRECTION



and all the available instruments are used in order to bring the water from the water bearing layer to the surface. But there are many difficulties and problems in qanat digging, the most important of which are as follows: levelling and measuring of the slope, determination of the direction of the well, lack of air at the bottom of a deep well, or in the tunnel, accumulation of natural gases, lack of light for working at the bottom of deep wells or in the tunnel, lack of sufficiently large space for digging, and digging a shaft or a tunnel through hard soil or rocks or unstable soil. Further more dealing with sand and stones which fall down the wells, and with the danger of a falling bucket or rock, descending and ascending the deep wells, sending messages from the group of workers outside the qanat to the workers inside, and vice versa, working on wet areas for a long time and other problems which occur in special conditions cause difficulties.

But the skillful Moqannis know how to solve many of the problems by simple but effective techniques.

Although the method of constructing qanats is the same in all parts of Iran, in principle, the geographical and social conditions vary and the skill of the Moqanni lies in adopting the basic methods to suit these conditions.

Recently, use has been made of machines for digging and removing the water, soil and mud, of hydrologists for determining the underground water and of surveyors for levelling and measuring the slope in the digging of some of the qanats. In spite of this, however, the Moqannis are still the main planners in the construction of qanats.

TABLE 1. REGRESSION EQUATION FOR SPECIFICATIONS OF QANATS

CASE-N	L	Z	HD	H	D
1	11.250	45.000	110.000	65.000	5.50
2	6.250	90.000	120.000	65.000	4.30
3	10.500	43.000	50.000	7.000	4.00
4	10.000	35.000	40.000	5.000	5.00
5	10.500	41.000	50.000	9.000	0.90
6	2.500	64.000	80.000	16.000	6.40
7	3.000	34.000	60.000	26.000	8.60
8	1.000	18.000	30.000	12.000	12.00
9	1.100	34.000	45.000	11.000	10.00
10	2.500	12.000	50.000	38.000	15.20
11	9.000	40.000	55.000	15.000	1.60
12.	9.500	22.000	40.000	18.000	1.80
13	12.000	35.000	75.000	40.000	3.30
14	6.250	16.000	30.000	14.000	2.20
15	3.000	20.000	45.000	25.000	8.30
16	7.000	34.000	55.000	11.000	2.90
17	12.000	38.000	90.000	52.000	4.30
18	8.000	80.000	95.000	15.000	1.30
19	2.000	50.000	60.000	10.000	4.90
20	11.250	40.000	95.000	55.000	4.80
21	6.500	45.000	75.000	30.000	6.90
22	7.000	40.000	50.000	10.000	1.30
23	3.000	80.000	100.000	20.000	6.60
24	1.300	10.000	25.000	15.000	10.00
25	2.750	12.000	50.000	38.000	13.80
26	2.000	22.000	40.000	18.000	9.00
27	6.000	20.000	65.000	45.000	4.10
28	2.000	55.000	70.000	15.000	7.50
29	6.000	44.000	75.000	31.000	5.10
30	5.500	30.000	55.000	15.000	4.50

L, LENGTH OF QANATS KM/
Z, DEPTH OF MAIN WELL/
HD, DIFF ELEVATION MONTH OF MAIN WELL&FIELD/
H, CIFF ELEVATION BOTTOM OF MAIN WELL& FIELD/
P, GRADIENT PER 1000/

VARIABLE	MEAN	STANDARD CEV
L	5.6453	3.8548
Z	35.9063	21.6860
HD	58.7500	28.1986
H	23.3125	17.8062
P	5.5187	3.8526

CORRELATION COEFFICIENTS

	L	Z	HD	H	P
L	1.00000	0.29180	0.47187	0.39616	-0.45036
Z	0.29180	1.00000	0.82589	0.25470	-0.15674
HD	0.47187	0.82589	1.00000	0.72035	0.02363
H	0.39616	0.25470	0.72035	1.00000	0.23366
P	-0.45036	-0.15674	0.02368	0.23366	1.00000

REGRESSION EQUATION

P=-0.7783693*L+0.06652174*H-0.07630286*Z+0.02167657* HD+10.48357

H=1.015412*HC-0.8164202*Z+0.5813057*P+0.2280683*L-12.29226

HD=0.8547449*Z+0.7950199*H+0.5079513*L+0.1483089*P+6.228682

Z=1.038077*HD-0.7763226*H-0.8392378*L-0.6340307*P+1.337767

L=-0.8087812*P+0.2711872*H-0.1494448*Z+0.07714201*HD+9.293492

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10. English, P.W. (1968) op. cit., P.173.
11. Honary, M. (1980) op. cit.
12. Karaj is a city in the west of Tehran, Iran (30 km from Tehran).
13. Personal interview with Moqannis and farmers.
14. The roots of these trees have been seen by the author at 8 m depth of a well in the Rijens qanat in 1978.
15. U.S. Department of the Interior, Bureau of Reclamation (1977), Ground Water Manual; Washington. P.7.
16. English, P.W (1968) op. cit.
17. Beaumont, p. (1971) op. cit.
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