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# THE HISTORIC KURIT DAM: AN ILLUSTRATIVE EXAMPLE OF WATER WISDOM†

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## ABSTRACT

The historic Kurit Dam near Tabas, Iran, has regulated the Kurit River for irrigation for 600 years and can be considered a symbol of sustainability. The arch-gravity dam is especially remarkable for its extraordinary height of 60 m. This was to remain a world record for any type of dam from 1350 until the early twentieth century. The former president of ICOLD referred to the Kurit Dam as one of the most astounding achievements in dam engineering in the Middle Ages. Despite the fact that the dam was built 650 years ago, it still serves as an illustrative example of creativity, harmony with floods, sustainable development and coping with uncertainties.

Unfortunately overlooking the valuable water wisdom of past generations, a modern dam was constructed just upstream of the historic dam. When, 6 years after impoundment, the new dam remained virtually empty due to error in estimating the river inflow, the canniness of the builders of the old dam became evident.

This paper seeks to reveal the engineering genius of Iranian history to provide an example of the intergenerational and multicultural collaboration demanded by the global climate challenges of today. 

KEY WORDS: historical dam; overtopping resistance; uncertainties; water wisdom

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## RÉSUMÉ

Le barrage historique de Kurit près de Tabas, l'Iran a régulé la rivière Kurit pour l'irrigation pendant 600 ans, et peut être considéré comme un symbole de la durabilité. Le barrage poids-voûte est particulièrement remarquable par sa hauteur extraordinaire de 60 m. Il reste un record du monde pour tout type de barrage datant de 1350 jusqu'au début du 20e siècle. L'ancien président de la CIGB a cité le barrage de Kurit comme l'une des réalisations les plus étonnantes de l'ingénierie des barrages dans le Moyen Age. Malgré le fait que le barrage ait été construit il y a 650 années, il sert encore comme un exemple illustrant la créativité, l'harmonie avec les inondations, le développement durable et les défis liés aux incertitudes.

Malheureusement sans se soucier de la sagesse qu'avaient les générations passées du bien précieux qu'est l'eau, un barrage moderne a été construit juste en amont du barrage historique. Lorsque, 6 ans après la mise en eau, le nouveau barrage est resté pratiquement vide dû à une erreur dans l'estimation du débit d'entrée de la rivière, les canines des bâtisseurs de l'ancien barrage devinrent apparentes.

Ce document vise à révéler le génie de l'ingénierie de l'histoire iranienne et à donner un exemple de la collaboration intergénérationnelle et multiculturelle exigée par les défis climatiques mondiaux d'aujourd'hui. 

MOTS CLÉS: barrage historique; résistance au débordement; incertitudes; la sagesse de l'eau

## INTRODUCTION

In view of the challenges of a water crisis in the twenty-first century, water engineers and scientists must accept the challenge of sustainable development to ensure that they meet the needs of the present without compromising future generations (Frederiksen, 1996; Veltrop, 1996). They should translate sustainable development into concepts for designing, operating and maintaining water resources and water projects (Loucks, 1995). Against this backdrop, the water wisdom of the past acquired over the course of centuries can be

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regarded as an irreplaceable gift from previous generations (Emami, 1998a).

## HISTORICAL ACHIEVEMENTS OF IRAN IN WATER ENGINEERING

The Persians of ancient times recognized the importance of irrigation to the sustenance of civilization. By excavating underground water tunnels and gallery systems (*qanats*) and by constructing many dams, they accomplished projects that rank among the greatest in history. In the ruins at Sialak, near Kashan, are to be seen traces of irrigation channels that are considered to be as much as 6000 years old, suggesting that irrigation was practised there from very early times, even before the arrival of the Aryans in the land now known as Iran (Jansen, 1983).

With an annual mean precipitation of less than 150 mm for most regions in the country, efficient water resource management has been vital to Iranian civilization. Throughout the history of the country, ancient Iranians had to introduce many innovations such as *qanat* systems to utilize the available resources. As Figure 1 clearly indicates, the most important characteristic of historic Iranian dams is their remarkable height. Twenty-one historic dams higher than 15 m have been identified in Iran, as shown in the figure. This is a world record in dam engineering. Spain ranks second with 10 historic dams and Slovakia ranks third with 9 (Schnitter, 1994). Of the historic Iranian dams, the most important and the highest is the 60 m high Kurit Dam. Nonetheless, because of difficult access to the site, the dam is not well known to the world or to the profession. Yet Dr Pircher, former president of the International Commission on Large Dams (ICOLD), has referred to the Kurit Dam as one of the most astounding achievements in dam engineering of the Middle Ages (Schnitter, 1994).

## RECORD HIGH KURIT DAM

The Kurit Dam was built in a very narrow canyon in a mountainous region 30 km from the great desert of Kavir-Namak around 1350 (Figure 2). The arch-gravity dam located 42 km south of Tabas, Iran, is especially remarkable for its extraordinary height of 60 m. This was to remain a world record for any type of dam for 550 years until the early twentieth century (Gobolt, 1973; Schnitter, 1994). In this respect, the second highest historic dam is the 48 m high Tibi Dam in Spain. The crest length of the Kurit Dam is only 80% of the height (50 m) and the crest thickness only 1.2 m (compared to a crest thickness of 21 m for the Tibi Dam). Unlike other gravity dams, the downstream face of the Kurit Dam is vertical while the upstream face is inclined, apparently due to difficulties of access downstream. The dam was built of limestone masonry laid in lime mortar (*saaro*j) containing cane fibres (for reinforcement) and ash from thorn bushes. These gave the lime hydraulic properties comparable to volcanic ash. The Iranians used *saaroj* in almost all the hydraulic structures they built.


Figure 1. The historical weirs, bridge-weirs and dams of Iran. This figure is available in colour online at wileyonlinelibrary.com/journal/ird

 

Figure 2. The Kurit Dam (May 1999)

Square bricks (37 cm) were used in the last stage of construction around 1850. The dam has regulated water for Kurit village, 26 km downstream of the dam site, for more than 650 years. The water flows for 5 km in a very narrow canyon and 21 km over a plain. Before a 13 km long access road was constructed in 1997, it took about 10 h of hiking and mountain climbing to reach the site from Kurit village. Accordingly, all the materials required for construction were prepared on site. An all-season spring 2 km upstream of the dam served as a reliable supply of water (100 l $s^{-1}$ in summer). The lime was manufactured on site and food prepared mostly by hunting. The site selection was perfect. The valley is very narrow especially in its lower half (width is only 2 m at the river bed). A very narrow and inaccessible canyon extends 5 km downstream of the dam and the valley widens substantially just upstream of the dam (the crest length of a 87 m high dam constructed 10 m upstream of the dam is 293 m compared to 50 m of the existing dam). It is evident that the builders had closely examined all feasible sites before the final selection. The geology of the site is satisfactory in relation to water tightness and stability as the experience of 650 years of operation clearly indicates. A recent study for construction of a new dam suggests that the old dam axis is the best alternative.

## LESSONS FROM THE KURIT DAM

### *General*

The Kurit River is the main water resource of Kurit village. In fact the village derived its name from the river. The village is located at the edge of the great Kavir-Namak desert and consequently water is highly valued. The construction of the dam is attributed to the Mongolian period (Hartung and Kuros, 1987; Schnitter, 1994). In fact the region is so remote that immigration as a result of the Mongolian invasion and their notorious massacres was likely to provide the necessity, expertise and strong motivation to build, with primitive tools, the greatest achievement in dam engineering in the Middle Ages. In this regard it should be noted that the Mongolians destroyed much in their onslaught, including hydraulic structures, and were far from envisaging such an extraordinary structure. Furthermore, ever since the dam was constructed, the residents of Kurit village have been exclusively responsible for rehabilitation, repair and operation of the dam. Because of the primitive technology of the thirteenth century, the visionary builders had to rely on their intuition and creativity to accomplish this astounding achievement in dam engineering. The lessons learned from the water wisdom of the builders of the Kurit Dam can be classified as follows:

- creativity is the key to sustainability (river diversion during construction) (Emami, 2005);
- the water schemes should be able to cope with uncertainties (overtopping resistance and stage construction);
- the main water structures should demonstrate resilience during extreme events (structural ductility and overtopping resistance);
- in the context of sustainability, the main focus should on operation rather than construction.

### *River diversion during construction*

To avoid the construction of a diversion tunnel that was not feasible at the time, the dam was built on a brick arch 10 m from the riverbed. The lower part of the dam was constructed in a dry season after the completion of the upper part. Consequently there was no need for river diversion during construction. The same technique was used for flood retention for the Abassi Dam 25 km to the north-east of Tabas, Iran 50 years later (Figure 3). The dam is 25 m high and has provided flood protection for Tabas for 600 years. The Abassi Dam is an illustrative example of a sustainable hydraulic structure because there has been very little

 

Figure 3. A 25-m high Abassi flood retention dam near Tabas, Iran, with similar bridge diversion system

sedimentation in the reservoir in the life cycle of the dam. The dam has resisted extreme events like the 1978 earthquake and substantial overtopping. Consequently the dam may perform its function for hundreds of years in the future. The same technique was used in the construction of the 142 m high Kowsar dam constructed in the south-east of Iran in 2003. The volume of the concrete arch dam is 265 000 $m^3$ and the innovation used has decreased construction time from 53 to 28 months.

## *Overtopping resistance*

The dam builders of 650 years ago could neither foresee the extreme floods probable during the life of the structure nor excavate a spillway in the rock. Accordingly they selected an arch configuration that is highly resistant to overtopping, considering the erosion resistance of the lime masonry. A recent study has given the following hydrological parameters for the Kurit basin:

- basin area: 171 $km^2$;
- annual precipitation: 203 mm;
- annual inflow: 8 MCM;
- length of the main channel: 22 km;
- slope of the main channel: 3.8%;
- PMF = 970 $m^3 s^{-1}$;
- peak of 1 in 5 year flood: 50 $m^3 s^{-1}$;
- peak of 1 in 50 year flood: 280 $m^3 s^{-1}$.

Evidently the dam must have been overtopped frequently as the reservoir volume was much lower than the mean annual flow of the river. Old residents of nearby Chirook village say they have seen years with more than 10 overtopping incidents, but never a year without overtopping. Accordingly it is estimated that the Kurit Dam could have been overtopped more than 1000 times in 650 years. This fact alone suggests that the Kurit Dam has set another world record for large dams.

Conventionally it is attempted to minimize the risk of occurrence of extreme events (such as overtopping) in the useful life of a dam. But it is difficult to estimate the frequencies of rare events and their consequences. The profession must admit that it is something like squaring the circle. Any direct way to assess the probability of failure due to a probable maximum flood (PMF) event must fail. It is fallacious to think otherwise. Another consideration is that tolerable uncertainty depends on the safety margin. If the safety margin is large, a wider scatter of the uncertainty can be tolerated (Kreuzer, 2000). In practice, large safety margins can be achieved by a very conservative approach that can be quite expensive. These margins can also be achieved by the inherent safety of the structures (overtopping resistance of an arch dam or piping resistance of a concrete-faced rockfill dam (CFRD)). The latter approach can be implemented at quite low cost in many projects. In other words, in view of the uncertainties and economic considerations, the structures should be designed to adapt to extreme events far larger than the design parameters to remain inherently safe.

- Starting in 1980, roller compacted concrete (RCC) has been used to hydraulically upgrade more than 60 existing embankment dams (to provide for overtopping). This method has proven to be both effective and economical (ASCE Task Committee, 1995; Hansen and Randall, 1999);
- There have been no reported failures by overtopping among the 1200 gravity dams higher than 30 m built in the last 100 years. However, there have been 22 failures out of the 3000 embankment dams higher than 30 m (Lemperiere, 1993);
- RCC protection could have prevented the failure of Marun and Karun-3 cofferdams in 1993 and 1998, respectively, in the south-west of Iran (Emami, 1998b). The current Karun-3 cofferdam is overtopping-resistant. This means a combination of an old strategy and a modern technique can be very effective and efficient (Emami, 2001; Emami et al., 2002).

Spillways could account for 30% or even more of a dam's cost. In view of climate change and inherent uncertainties associated with calculation of extreme floods, overtopping-resistant dams and cofferdams should be increasingly used in dam engineering to enhance safety, in addition to reducing costs and construction time.

### *Stage construction*

The Kurit Dam was constructed in four stages, as clearly indicated by different material used. In the final stage, the dam was heightened by 4 m around 1850. Another heightening dates back to around 1600 (Figure 4). The stage construction was crucial in increasing the useful life of the dam in view of sedimentation in the reservoir. On the other hand, stage construction was essential in view of structural, geological and hydrological uncertainties and technical and resource limitations. The Saveh gravity dam built in 1285 serves as an illustrative example. The river deposits on which the dam was founded washed out probably upon the first filling and rendered the 25-m high dam useless (Hartung and Kuros, 1987).

Dam heightening is a major task in dam engineering and has been discussed by ICOLD in Question 20 at the 6th Conference in 1958 and Question 48 at the 13th Conference in 1979. ICOLD Bulletin 64 in its historical survey regards the 14-m high Almansa Dam in Spain as the oldest dam built by stage construction. The dam was heightened by 7 m in 1586. As mentioned above, the 2500-year-old Amir Dam in Iran has greater claim to the title. Several centuries have elapsed since the heightening of the Amir Dam, yet the same principle used there has developed in the construction of huge projects that are the pride of our present-day civilization, including the Grand Dixence Dam (Switzerland) and the Guri Dam (Venezuela). Most instances of dam heightening have occurred as a result of design error. These include reinforcement, repairs, reappraisal of data, increase of spillway capacity, silting and increase of demand (ICOLD, 1988). Consequently stage construction would not only ensure flexibility and adaptability but also would benefit developing countries where limited funds are available and where dams are urgently needed. In addition, observing hydrosystem feedback before heightening can minimize adverse environmental damage.

Unfortunately Iranian dam engineers did not properly use the valuable experience of early dam builders in the country. Currently many large dams are completed in Iran while only a percentage of the planned irrigation area can actually be irrigated:

- The 165-m high Marun Dam, the second highest rockfill dam in the country, impounded in 1999 after 12 years of construction. Only 30% of the planned irrigation area can be irrigated now. A smaller reservoir would have had much less cost, construction time and greater benefits. The main purpose of the dam is regulating water for agriculture;
- The 5700 MCM Karkheh Reservoir, the largest reservoir in Iran, was impounded in 2000 while less than 25% of planned irrigation area was ready. The main purpose of the dam is regulating water for agriculture.

### *Sustainable development*

The Kurit River has small yearly and monthly variations (the minimum annual flow in 50 years is 50% of mean annual flow). On the other hand there are agricultural demands throughout the year with similar trends to monthly flows.

Figure 4. A view of the dam from downstream indicates the use of different materials in the stage construction (the hole near the abutment was intentionally made when the intake was blocked)

 

Consequently a small reservoir has a great regulating effect. This may be the main reason for the construction of the dam in the first place and the regulation of water for more than 600 years through sediment flushing and heightening. A 22-m high water intake located 16 m from the left abutment was used for reducing the exit flow velocity and sediment flushing. There are 11 holes (at 2 m) and two openings in the water intake. The holes were closed with tree logs before the flood season. Several logs were used for closure of the opening. In March, the holes were opened from the top respectively. There is access to the lowest part of the intake from the downstream face. The closing and opening of the gate and holes were dangerous tasks. In fact two people have been killed during the operation in last 50 years.

As the experience of sedimentation in the Kurit Reservoir clearly indicates, the sediment yield of the Kurit basin is exceptionally low. This is another major advantage of the selected site. Evidently sediment flushing had been very efficient in increasing the useful life of the reservoir. The villagers used to liquefy the sediment in order to flush it out of the reservoir through the intake. It appears that a considerable volume of the sediment inflow had been flushed out of the reservoir to ensure 'sustainable development'. For the last 40 years and especially after the calamitous earthquake of 1978 with a magnitude of 7.8, in which the Kurit village was totally destroyed and 50% of the population died, flushing has been abandoned. Consequently with the accumulation of more sediment in the reservoir, a dense forest has been formed in the reservoir, as shown in Figure 2. It appears that by utilizing present technologies and through soil conservation methods, check dams and flushing, the useful life of the dam can be extended for hundreds of years. This option had a clear economic advantage over the 87-m high concrete dam constructed a few metres upstream of the old dam. As the experience of the Kurit Dam evidently indicates, all generations should contribute to water resources management to ensure sustainable development.

## *Structural ductility*

The structural dimensions of the Kurit Dam are as follows:

- height: 60 m, crest length: 50 m, crest thickness: 1.2 m;
- central angle of the arch: 135 degrees (approximately), dam thickness at the riverbed: 10 m (Figure 5).

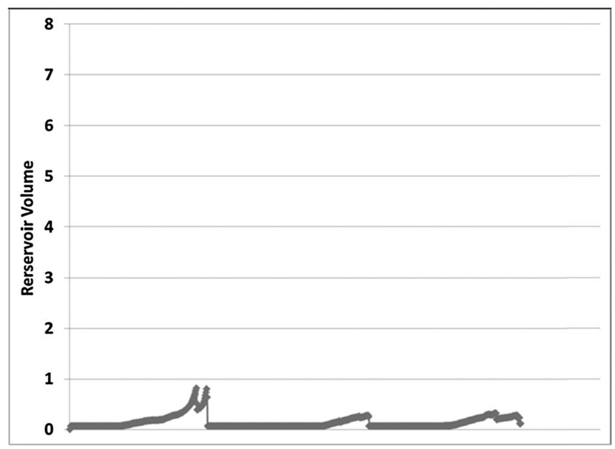


Figure 6. The reservoir of the new Kurit Dam in the 6 years after the first impoundment (the reservoir volume is 8 MCM at normal water level (NWL))

Figure 5. A view of the Kurit Dam showing the arch geometry, March 1998 (the top of the water intake is shown near the centre of the arch and the operating room can also be seen)

 

The dam consists of two different structural elements: (i) a gravity lower part, (ii) an arch upper part.

As previously mentioned, the dam was built in different stages and with different materials. Surprisingly, despite the fact that the arch section of the dam was not completely keyed into the abutments, the dam withstood extreme conditions such as earthquakes and numerous instances of overtopping without destruction. The Kurit Dam experienced the Tabas earthquake with a magnitude of 7.8 without even minor damage in 1978, and 25,000 people (50% of the population) were killed in the earthquake in the thinly populated region and the city of Tabas and many villages including Kurit were destroyed. As soon as the geometry of the dam is completely available, a dynamic analysis of the dam in the 1978 earthquake can provide greater insight into the structural safety of masonry dams.

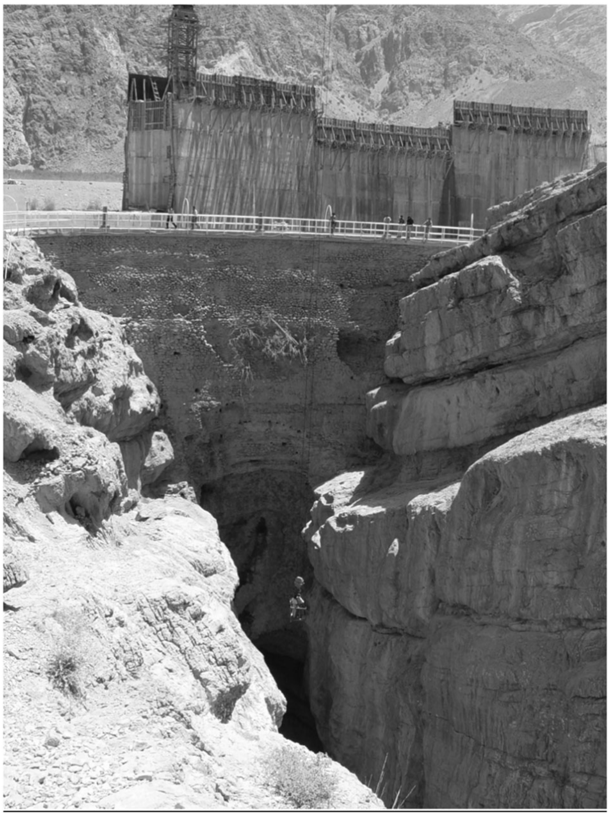

Figure 7. The old and new Kurit dams during construction (2004)

## THE NEW DAM VERSUS THE OLD ONE

In the early years of the first decade of the twenty-first century, construction of new Kurit Dam just upstream of the old one commenced. In 2005 the dam was impounded. The author of this paper, a dam engineer himself, opposed construction of the new dam years before it was begun. He argued that construction of a new dam in the vicinity the old one would not only undermine the heritage of the historical structure but would also endanger its stability and integrity. Furthermore, the basic function of the new dam could have been achieved by improving irrigation productivity at a much lower cost. The author also drew attention to the lack of reliable inflow data and the resulting uncertainties (Emami, 2013). He proposed an alternative based on rehabilitation of the old dam, improvement of irrigation productivity and making the dam a tourist attraction. Unfortunately these warnings were not heeded and

Figure 8. The old and new Kurit dams (2013)

the construction proceeded as scheduled. As shown in Figure 6, the reservoir of the new dam has been virtually empty for 8 years after the 2005 impoundment. Much valuable capital and time have been wasted, in addition to violating the heritage of a unique engineering structure (Figures 7 and 8). Furthermore, the enormous potential to present this historic dam as a tourist attraction cannot be materialized. In this context, the lack of foresight of modern designers stands in sharp contrast to the vision and wisdom of the builders of the historic dam. Perhaps the limited resources available to the builders of the old dam rendered them more creative and savvy.

## CONCLUSION

Because of the primitive technologies of the thirteenth century, the visionary builders of the Kurit Dam had to rely on their intuition, imagination, creativity, hard work and courage to accomplish this astounding achievement in dam engineering. Their accomplishment can inspire many water engineers who are faced with the most important challenges for mankind in the twenty-first century: the design and construction of safe, sustainable, cost-effective hydraulic structures with uncertain design parameters (Obasi, 1997). Their achievement stands in sharp contrast to the failure of the modern dam constructed just upstream of the historic dam. Hopefully this unfortunate experience will encourage the preservation of other historic hydraulic structures that are endangered by modern projects. In this context, removal of the modern dam would not only preserve the heritage of the historic dam but would also raise public awareness.

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