LEARNINGS FROM HERITAGE IRRIGATION STRUCTURES AND SYSTEMS IN CHINA

LI Yunpeng¹, ², LI Ruoxi¹, TAN Xuming¹, WAN Jinhong¹, CHEN Fangzhou³

ABSTRACT

During its long history, China has built numerous irrigation projects and systems that have laid foundation for the country’s development of agriculture, population, society and culture. The seven projects listed as ICID’s HIS from 2014 to 2015, including water storage irrigation structures, diversion irrigation structures with without dams, terraces with irrigation engineering system and shadoof irrigation system, are highly representative of the engineering level of irrigation in pre-modern China in terms of environment suitability, systemic and low impact planning, ingenious structure design, ecotype material and irrigational management. The empirical knowledge and engineering philosophy reflected in these heritages, such as adaptation to local conditions and advancing with the times, and especially management mechanism giving consideration to both upstream/downstream and left/right bank area, thorough annual repairs systems, and division of responsibilities between and cooperation of government and private sector, can serve as a valuable reference for contemporary irrigation construction and development.

Keywords: Heritage irrigation structure, management, China, learning.

1. INTRODUCTION

China is an agricultural country with long history of more than 8000 years, what had been confirmed by archaeological discovery in ruins of Pengtoushan Culture and Chengbeixi Culture in Changjiang Basin, Cishan site in ancient Yellow River Basin, etc (Yan 2000). With typical East Asian monsoon climate on the complex and various terrain in mainland China, diverse irrigation engineering are necessary for agriculture and human livelihood. Especially in eastern China areas, 60%~80% of annual precipitation is concentrated between Jun. and Sep., and the largest monthly rainfall tends to occupy 30%~50% of the total yearly precipitation (Tan 2005). In Chinese ancient society leading by agricultural economy, irrigation has showed important influence on politics, economy and human culture (Yao 1996). In nearly 3000 years of written Chinese history, countless and varied types of irrigation projects had been constructed and used for regional agriculture development, based on the different environments, with varied engineering and managerial types. According to nationwide investigation in China, more than 400 ancient irrigation projects are preserved up to now and most of them still irrigated fields (Wang et al. 2012). The empirical knowledge and engineering philosophy reflected in these heritages, such as systematic planning, ecotype structure design and practicable irrigation management, can serve as a valuable reference for contemporary irrigation development. The administration by both official and civilian organizations was general management mode in ancient China and had ensured continuous operation of the irrigation projects. Such an administrative mechanism combining both official and civilian resources arose on the basis of China’s traditional social structure and culture. The local government officials, offices normally held by scholar-bureaucrats, have the

¹ China Institute of Water Resources and Hydropower Research Beijing 100038, China
² Research Center on Flood and Drought Disaster Reduction Beijing 100038, China
³ The Qiantang River Administration of Zhejiang Province Hangzhou 310016, China
duty, awareness and tradition of building irrigation projects to benefit the local people. A public irrigation project turns the irrigation zone into a community and the rural esquire class organizes annual repairs and performs other common obligations to ensure fairness in water distribution. With the vicissitude of time, this administration mode will remain effective so long as the grassroots social organizational structure has remained basically the same in some irrigation heritages.

2. HERITAGE IRRIGATION STRUCTURES AND SYSTEMS IN CHINA

During 2014~2015 7 projects of China with different types had been enrolled in The World List of ICID Heritage Irrigation Structure, which are typical examples in respects of planning, structure, management, culture and comprehensive benefits. These heritages including water storage irrigation structures (such as Quebei Pond), diversion irrigation structures with dams (such as Tuoshan Weir, Tongjiyan Irrigation Structure and Mulanbei Irrigation Structure) or without dams (such as Dongfeng Weir), terraces with irrigation engineering system (such as Ziquejie Terraces) and shadoof irrigation system (such as Zhuji Shadoof irrigation system), are highly but not all representative of the engineering level of irrigation in pre-modern China.

Figure 1. Locations of 7 heritaeges irrigation structure in China.

2.1 Dongfeng Weir

Dongfeng Weir located at Jiajiang County in Sichuan Province and on the left bank of Qingyijiang River- the tier 3 tributary of Yangtze River, is project of diversion irrigation without dams. According to the historical book COUNTY ANNALS OF JIAJIANG (1813), Dongfeng Weir was constructed in 1662, the early time of Qing Dynasty, led by the county magistrate Wang Shikui. The weir was first named Pilu Weir since the diversion mouth was located outside Pilu Temple, and renamed Dongfeng Weir in 1967. In 1930, the diversion mouth was forced to move to upper stream of Qingyijiang River due to the difficulty of water diversion caused by riverbed sinking. In 1975, it was relocated to the even upper for the same reason. Dongfeng Weir’s main diversion canal is 12 km in length. Below it are two secondary canals that are 17.8km in length. Besides, the project has one tunnel under the cultural relic Qianfoyan.
Grotto, 11 aqueducts, 21 water-gates and other supporting facilities. Since the completion of Dongfeng Weir in 1662, its irrigated area has expanded by more than 10 times from 467 hectares to 5113 hectares, covering over 4 towns and 48 villages. The local multiple-cropping index has increased to 2.68, and the cultivated area to 13367 hectares. Nowadays it has a combined function of irrigation, drainage, urban flood control, and environmental water. Dongfeng Weir is managed both by the local government and the resident. The administrated offices charge of the maintenance of the general canals and branch canals, meanwhile the water user association, in the village as a unit, is responsible for the sub-lateral canals. Otherwise, during the peak of irrigation water, there exists another 4 water coordinating groups for coordinate water supply and water between the office and user, even among the users.

Figure 2. The Qianfoyan Gorotto on the top of the main canal of Dongfeng weir.

2.2 Mulanbei Irrigation Structure

Mulanbei project is situated at Mulan river in Putian of Fujian province in southeast of China. The structure was completed in 1083 (during the northern Song Dynasty) before twice transfer of structure site. The head works structures of Mulanbei water conservancy project included overflow weir, gravity dam, diversion dike, sluicing gate and diversion mouths at both banks. The gravity dam is 123.43 m long and 7.6 m high, in north bank of the river. In the south bank, the overflow dam is 95.7 m long, with 28 water release gates and one scouring sluicing gate distributed above it. The weir foundation adopted the “raft foundation” commonly seen in bridge foundation which could effectively alleviated pier pressure on unit area. Gate walls or piers were built on the weir while stone pillars which was called “general column” inserted through the walls or piers into the river-bed base rock, afterward, pig iron was melted to fill the gaps, the pier stones of the weir and the gates were linked with shoe-shaped iron ingots. As such, the weir/gate formed an integrated whole. Such structures integrating weir and gates were conducive to spill floods and dredge silts. Before the construction of Mulanbei project, no crops except cattail could grow in the salty soil of south and north plain on both sides of Mulan River. After construction, the project has been playing its role in ensuring water supply for agriculture, industry and domestic life in the irrigation area. It irrigated a farmland area of 10867 ha and benefited 133 villages with more than 500,000 people. As public construction, Mulanbei project was supervised under the government since Song dynasty. Special personnel took charge of annual repair outlay, labor expenditure, and construction supervision and so on. This kind of management mechanism continued until today. Currently, Mulan river
administrative office and the local administrative office of the south and north canals are responsible for floodwall management in the area.

2.3 Tongjiyan irrigation structure

Tongjiyan irrigation structure is located in Bihu plain in Lishui of the southwest Zhejiang Province, conveys water of the Xiekengshui River over the main canal into the Songyinxi River. Tongjiyan irrigation system is composed of dam, canal systems, water gates, aqueduct, and ponds. The Tongjiyan dam was firstly constructed in 505. It dammed up Songyinxi River 1.2 km upstream from the confluence of the Songyinxi River into Oujiang River, and allocated water by gates into the canal systems and fields in the Bihu plain. The earliest Tongjiyan dam was a weir built with rock-filled timber crib. It was destroyed easily during flood period of the Songyinxi River, and must be rebuilt in the next winter and spring seasons for the needs of field irrigation. After used for about 700 years the weir was substituted by a stone dam in 1205. A sand-flushing sluice and a ship lock were built subsequently on the dam. Since then the Tongjiyan dam has become a multi-functional project for water storage, water diversion, overflowing, sand flushing, shipping etc. Although it repaired later on, the location, structure, and construction materials of the dam have been remained unchanged to this day. The current images and measured data show that the completed Tongjiyan dam forms a low arch upstream of 120 degree. The length of dam is 275m. Its crest width and base width are 2.5m and 25m respectively. The main canal of the Tongjiyan irrigation system is often destroyed and silted by flood and sediment of the Xiekengshui River- a tributary of the Songyinxi River, flows across with the main canal at 300 m downstream from the Tongjiyan dam. A canal aqueduct was constructed in 1111, it is the earliest across-flows divided system in three dimensions in China (LI et al. 2015).
According to historical records the irrigation area of Tongjiyan irrigation structure has reached 2,000 ha by the 13th century. It accounts for one third of the Bihu plain. The scope of irrigation has not been changed much since then. The Tongjiyan irrigation structure was jointly managed by official and people. Local government was responsible for maintenance and repair of the irrigation structure. The non-government organization was responsible for water allocation for water users. These were recorded in the management regulation of the Tongjiyan irrigation structure and chiselled an inscription on a stone. History records that the earliest Tongjiyan management regulation was made in 1092. However the earliest of the extant Tongjiyan management regulation was made by Fan Chengda in 1169. It is now standing in the Zhan-Nan Sima temple beside the Tongjiyan dam. The management regulation recorded the size of water gates, water allocation methods for irrigation, labors and materials of annual repairs, and maintenance of irrigation structures etc in detail. With the development of society and irrigation technology, some new pieces have been added to the management regulation, however the joint management forms by official and people has lasted in the Tongjiyan irrigation area to this day.

2.4 Ziquejie Terraces

Ziquejie Terraces located in Xinhua of Hunan Province in South Central China are built on hills with altitude of 460m-1540m and surface slope of 25°-40°. This area is
rich in water resources with an average annual precipitation of 1700mm. Home to several ethnic groups, Ziquejie Terraces are the result of fishing and hunting culture evolving into agricultural civilization. In the earlier time, the lack of plains at Ziquejie has forced the ancient people to reclaim terraces. By the 10th century AD, Ziquejie Terraces had been licked into shape. Now Ziquejie Terraces covering a total area of 6416 hectares still support more than 17000 people of 16 villages, and the traditional way of life and cultural diversity have been retained.

The irrigation and drainage system at Ziquejie is made up by three parts: water storage project, irrigation and drainage canal system, and control devices. Ziquejie has good climate, lush vegetation, and thus good conditions for water resources conservation. In the valleys of Ziquejie, there are many streams that do not dry up throughout the year. The total length of streams and rivers has reached more than 170 km. These streams are dammed up with small weirs. In normal times, these weirs ensure water supply for the terraces; during torrential rains, the flood water can overflow and drain away from the top of the weirs. A few meters upstream from the weir is the water inlet. The angle between the mouth and the stream is larger than 60° so as to ensure safety. Grit chambers and flushing sluices are built behind the weirs to reduce canal silting. With ridges that are 0.2-0.3m high, the terrace fields are the major water retaining works. Each hectare’s terrace field can retain 750-900m$^3$ of water, and the Ziquejie Terraces as a whole has a water-retaining capacity of 10 million m$^3$. Coupled with the abundant water retained within the soil, the water-retaining terrace fields provide adequate water supply for the terrace agriculture. Ziquejie Terraces fully utilize natural valleys and streams as the main drainage canals. Besides, drainage outlets are built in the proper place of the terrace fields and canals to ensure the discharge of waterlogging and tail water. Perpendicular to the contours, these valleys and streams can either be dammed up to be water sources or serve as main drainage canals. Together with delivery canals and field blocks that are built along the contours, the valleys and streams have formed the irrigation water network of Ziquejie Terraces. Ziquejie Terraces are an example of overall planning and exploitation of water and land resources. As a result, a balance has been struck between the scenic cultural landscape and ecological environment.

Figure 6. A photo of Ziquejie Terraces.
2.5 Quebei Pond

Quebei Pond is located in Shouxian in the middle of Anhui Province and on the southern bank in the middle reaches of the Huai River. Also called “Anfeng Pond", it dates back to the period when Monarch Zhuang of Chu Kingdom ruled (601 B.C. – 593 B.C.). Quebei irrigation system mainly comprises four major parts, i.e. water storage work, embankment and sluice work, irrigation and drainage canal system and accessory facilities as well as flood relief work. With a landform where it is high in the east, south and west but low in the north, Quebei was only a seasonable pond with a canal attracting water inflow and an embankment with sluices for water storage and irrigation upon initial completion. The sluice work is the regulatory work of Quebei and it regulates the water flow and canal water distribution through opening and closing. According to Shui Jing Zhu, the geographic work of the 4th century, the Pi River and the Shanyuan River flew into Quebei via Wumenting. Five sluices were distributed around the pond, i.e. Jing, Dukou, Yangtouxi and Xiang sluices and also the water inlet sluice near Wumenting which were connected to the trunk canal. In the 6th century, the number of irrigation and water guide sluices increased to 36. Due to rapid increase in population after the middle of the Ming Dynasty, nearly half of the lands to the south of Quebei were reclaimed and turned into farmlands at the end of Qing Dynasty, with a mean water storage of about 30 million cubic meters. Through reconstructions, 28 sluices were preserved in Qing Dynasty. In the 1950s, Foziling and other reservoirs were constructed in the upper reaches of the Pi River and Quebei was incorporated into the new Pishihang Irrigation District – the largest irrigation district in China. Pidong Trunk Canal branched out from the trunk canal of the Pi River and flew into Quebei. There are still 21 sluices at Quebei today and most of them still have their names of the Ming and Qing Dynasties preserved until today. Quebei Irrigation district has 2 trunk canals, 54 branch canals, 151 lateral canals and 298 irrigation canals in a total length of 678.3km. The canals are constructed with several hundred water diversion sluices, regulatory sluices and water return sluices to satisfy the irrigation and flood relief needs within the irrigation district. Totally 114 administrative villages of 13 townships have benefited from this project.

Quebei is a paradigm of sustainable management of irrigation project. In the the second century BC, the government already set up an administrator for Quebei there. The iron seal of water supervisor of the second century AD excavated here epitomizes the local government’s authority over Quebei. Wang Jing, the famous irrigation expert then, established an annual repair policy for Quebei and erected a stele to publicize this policy. A well-established annual repair system was already in place in the 3th century. In the 19th century, there was already a well-established system of water use, annual repair and operating expense management for Quebei. In the 19th century, the water users signed a New Covenant which became a civilian regulation on maintaining the grassroots irrigation order. Anfeng Pond Branch of Shouxi County Water Affairs Bureau is directly in charge of Quebei today and the routine administration and maintenance fees are allocated from the public finances.
Figure 7. Quebei Pond Irrigation System

Figure 8. The Iron Seal of Water Control Officer (the 2nd century AD)

Figure 9. Inscription on a Tablet (19th century).

Figure 10. Inscription on a Tablet (16th century).
2.6 Tuoshan Weir

Tuoshan Weir is located in Yinzhou District, Ningbo, Zhejiang Province and on the Yin River which is a tributary of Fenghua River. The weir blocks the upflow of the salty tides from the lower reaches and thus is a typical project of water desalination and irrigation in the southeastern coast of China. Since its completion in the Tang Dynasty (833 AD), it has gradually developed and formed an irrigation system comprising the canal headwork, the canal system, the irrigation regulation work, and the water storage project. The headwork comprises the river dam, the Jiongsha Sluice, the Official Pond, and the Flood Pond. The river dam is 113.6m long, including the 107m-long overflow section which forms a 6-degree arch towards the upstream. The river dam is also called Tuoshan Weir which is a dry-laid masonry dam with slit energy dissipation underneath. The dam base comprises wooden piles and jackstones. Tuoshan Weir is the most time-honored masonry gravity dam in China. The bottom of the weir is tilted towards the upper reaches at an angle of 5 degrees. Proposed more than 1000 years earlier than the contemporary dam base theory, such a slanting bottom reinforces the anti-slipping stability of the dam body by 100%. The dam body takes an oval shape; the riverbed is about 5m thick at the maximum in the middle while the thickness gradually decreases to 2m on both wings, which reinforces the rigidity of the dam by 7 folds. The cambered profile of the dam body works as an arched dam and reduces the erosions of floods on both banks to a very large extent in the same principles as the energy dissipation mechanism of contemporary mechanics. The canal system of Tuoshan Weir comprises the trunk canals, the branch canals and the lateral canals. Nantang River, the trunk canal, flows through the downtown of Ningbo and its tail water is discharged into the moat of Ningbo. The trunk canal is 24.5km long and there are also 2 sub-trunk canals, 19 branch canals and more than 100 lateral canals with a total length of 673.23km. The administration by both official and civilian organizations is kept in all its ages and ensures continuous operation of the project. In memory of Wang Yuanwei, the founder of Tuoshan Weir, the villagers constructed Tuoshan Temple on Tuoshan Mountain. Meanwhile, large-scale temple fairs are also held at Tuoshan Temple on March 3, June 6 and Oct. 10 of each year on the lunar calendar to commemorate Wang Yuanwei and the construction of Tuoshan Weir. These Sacrificial activities have become important local cultural symbols.

![Figure 11. Tuoshan Weir.](image)
2.7 Zhuji Shadoof Irrigation System

As a living fossil of the ancient water-carrying device of shadoof, the Zhuji Shadoof Irrigation System is located at Quanfan and Zhaojia villages, Zhaojia Town, Zhuji City, Zhejiang Province and on the alluvial basin of Huangtan Brook at the foot of the main peak of Zhoumagang of Kuaiji Mountain with an average annual rainfall of 1462mm. The soils are primarily sandy soils and there are rich groundwater resources which are buried at a depth of only 1-3m in the drought period and within 1m in the rainy season. The inhabitants at Zhaojia Town of Zhuji are descendants of migrants from Central China in the 12th century and they primarily belong to two families—the He’s and the Zhao’s. Their ancestors dug well and carried water for irrigation and agricultural development and hence the births of Quanfan and Zhaojia villages. The sheel and genealogy in the villages show that shadoof and well irrigation was already the main irrigation mode of the Zhao’s in the 17th and 18th century at the latest and the ancient people already had a scientific understanding of groundwater circulation.

Figure 12. Lifting water from well with Jiegao.

Zhuji Shadoof Irrigation System comprises a river weir, ancient wells, shadoofs and field canals. The weir, located on Huantan Brook, serves to increase infiltration of surface water and the water-carrying capacity for irrigation. One well, one shadoof, one piece of farmland and field canals constitute an independent and well-established well irrigation unit. Such field is called “Jishui Field”, with “Jishui” meaning “water-lifting”. The core zone of the system comprises 118 ancient wells and an irrigation area of 27 hectares. A well is normally 2-5m deep and takes the shape of an inverted bell. The diameters of the well mouth and bottom are usually 1-2m and 1.5-2.5m respectively. The well walls are dry-laid with pebble stones and some of the wells in silt field have pinewood supports at the bottom. The exterior circumference of the well walls has broken stones and sand as the reverse filter. A Jiegao, or shadoof, comprises a pile, a lever, a rod and counterweight stones. The tailor-made water-carrying barrel comprises a wooden axle which is connected to the lower end of the pile. The local people call this combination of a well and a shadoof “Ao Well”. Ao Well also refers to the process of well irrigation and water carriage. To lift water, the operator stands on two bamboo beams or a wooden plate set up at the well opening and push the lever so that the barrel sinks into well water. The use of the lever reduces effort needed to lift a barrel of water. A straw braid is located where the water flows out from the well to protect the barrel from damages. A “rain factory” (a simple hut) is
distributed among several wells for shelter from rain, rest and farming tool storage. There were many shadoofs and wells in Zhuji historically and their combinations were called “Ao Well” by the local people. There used to be more than 8,000 wells in this basin before the 1930s and 3,633 wells in 1985 with an irrigating area of 440 hectares. However, many wells have been buried in the urbanization process in the past 30 years. Today, the number of Ao Wells in Quanfan Village is the largest; in the core area of well irrigation, there are still 118 ancient wells which irrigate about 27 hectares of farmland.

3. LEARNINGS FROM HERITAGES

These Historic Irrigation Schemes reflect the diversity of traditional irrigation schemes in China. In terms of environmental compatibility, systematic planning, low-impact development, fine structure design, ecology-friendly building materials and irrigation management, they are of distinctive Chinese characteristics. And the traditional irrigation science and technology, building and using experience, water management philosophy, and irrigation management mechanism embodied in them are of great reference value for modern irrigation development.

a. Adaptation to local condition

Vast in territory, China is a country with manifold diversity in terms of terrain and hydrological conditions, which is reflected in the various layouts, types, structures and materials of irrigation schemes. For instance, the Historic Irrigation Scheme Quebei Pond is a water storage irrigation scheme constructed by building dikes along three sides of a piece of water-logged low-land; Dongfeng Weir is an example of water diversion without dam, while Tongji Weir, located at the mountain pass, diverts water for irrigation with the help of dam; Tuoshan Weir and Mulanbei Water Conservancy Project, located at coastal flatland, are built to resist saline water and retain fresh water, and Mulanbei sets up a gate at the weir so as to handle the drastic variation in water level and to adjust its flood discharge capability; Zhuji Shadoof Irrigation System has perfectly made use of the advantageous local underground water condition; Ziquejie Terraces have made the most of local soil, geological and water conditions, including the natural stream network and plot distribution. Other contributory factors of the diversity include project features and local culture. However, diversity is not what traditional irrigation schemes pursue on purpose; instead, it’s a natural result of maximizing the profit of water use with the minimum projects and facilities by comprehensively considering natural, social and cultural conditions and coordinating among water for irrigation and for domestic use.

b. Systematic planning

A good planning for traditional irrigation systems is usually featured with great vision and systematicness. Systematicness refers to the fact that components of the system work as an organic whole instead of a stiff combination, and a perfect example would be the headwork of Tongji Weir, the dam, shiplock, flushing sluice, intake gate, and flood discharge gate of which are laid out in an organic way; the engineering system and the natural geography are systematically integrated, and the environment has not been modified in a rigid way, which can be seen in Quebei Pond’s utilization of the low-land landscape and natural water system; land and water development and water supply are considered in a systematic and comprehensive approach, and examples include the overall planning of land and water resources and irrigation system at the Ziquejie Terraces, and the multifunctional Mulan Weir and Tuoshan Weir which are capable of resisting salty tide and storing fresh water.
c. Low-impact development mode

A good traditional irrigation scheme usually adopts mild ways to collect water, and such examples include the low dam water intake of Tongji Weir and Tuoshan Weir and the shadoof irrigation of Zhuji, and in this way, the impact of irrigation projects on the environment has been minimized. Besides, compared to the steel and concrete used in modern projects, the traditional materials such as stones and wood are more environment-friendly and have no negative impact on soil and rivers in the long term.

d. Advancing with the times

The fact that many historic irrigation schemes have lasted for hundreds or even thousands of years correlates closely with their capability to adapt to the social demand and changes. In the cases of Dongfeng Weir, the headwork has been moved upstream several times due to riverbed undercutting so as to ensure the water supply. In the case of Quebei Pond, as the population grows, the area of land reclamation expands, and the capacity of water regulation improves through the building of dikes, watergates and canal system. As the society develops and the project system evolves, the management regulations of Tongji Weir and Quebei Pond are also improving.

e. Irrigation management

Traditional irrigation management covers two aspects: project management and water management. And the management is government-led and private-sector participation is encouraged so as to ensure the fairness of water distribution among upstream and downstream users. The shifting of three irrigation water sources at Tongji Weir is a model system taking a variety of water demands into consideration. The joint management by official and people was born of China traditional social structure and cultural background. Namely, local governors have the duty consciousness and cultural background of building water conservancy projects to be benefiting the local people. The water conservancy projects prompted local people to form social community for the regular manage the water conservancy projects. Based on this, the local government was responsible for building, maintaining and repairing of the projects, and making management regulations. The local people in the social community performed regular management under the supervision of local government.

Historic irrigation schemes in China are repaired each year in winter when the agricultural demand for water is small. During this period, water storage structures and canal systems are dredged and water gates are repaired. For instance, the annual repair practice at Quebei Pond was established during the Three Kingdoms Period (220-280 AD). Another outstanding feature of irrigation management in pre-modern China is the connection of the public and the government through worshipping river god and sacrificial rites. By commemorating the founder of and the contributors to the project, people formed a consensus on appreciating the contribution made by previous generations and the determination to protect the heritage. During the rites, the management meeting is held. In this way, the authority of the management system is enhanced.

4. CONCLUSIONS

The traditional irrigation projects those have been utilized for hundreds of years or even more than thousand years have the historically scientific nature and rationality. The empirical knowledge and engineering philosophy reflected in these heritages, such as adaptation to local conditions and advancing with the times, systemic and low
impact planning, and especially management mechanism giving consideration to both upstream/downstream area, thorough annual repairs systems, and division of responsibilities between and cooperation of government and private sector, can serve as a valuable reference for contemporary irrigation construction and development. Obviously, modern irrigation has much advanced on engineering materials, technology and efficiency. Whereas extremely skillful projects just like Duijiangyan, Ziquejie Terraces, could not be created by means of modern engineering planning and designing theories. Much more engineering design specifications and technical standards have been enhancing security level and construction efficiency, but also constraint of engineers.

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