

CHARACTERISTICS AND VALUE ANALYSIS OF ANCIENT WEIR PROJECTS

CARACTÉRISTIQUES ET ANALYSE DE LA VALEUR DES ANCIENS PROJETS DE DEVERSOIR

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ABSTRACT

Among China's 42 World Heritage Irrigation Structures, 18 are weir-dominated projects. Ancient weir projects differ significantly from modern barrages and dams. Most are arranged in a curved pattern or obliquely to the river, intentionally extending the weir axis length. While this may seem to consume more labor and construction materials, such layout increases the overflow section and capacity of the weir, effectively reducing the water level above the weir, and simultaneously disperses and transmits the water flow shear force that causes dam failure to the river embankments. Some ancient weirs also utilize naturally formed step-pool systems in rivers to construct weirs on pools, leveraging the energy dissipation effect of deep pools to reduce the impact of floods on the weirs. These construction methods of ancient weir projects can effectively mitigate the impact of floods, enhance engineering resilience, and extend the project life cycle. This not only embodies the wisdom of the ancients but also demonstrates the concept of respecting nature and the unity of man and nature, which is a historical practice of the contemporary "river ethics" concept. From the perspective of modern engineering technology, these practices have scientific theoretical basis and have been widely applied, such as long-axis weirs like "curved weirs" and "duckbill weirs", and the use of artificial step-pool systems for mountain river regulation. In-depth research on these ancient water conservancy projects with multidisciplinary participation to excavate the wisdom of the ancients can not only provide reference for the construction and management of contemporary water conservancy projects but also play an important role in enhancing national cultural confidence.

Keywords: World Heritage Irrigation Structures; ancient weirs; oblique layout; step-pool system; cultural confidence.

RESUME

Parmi les 42 ouvrages d'irrigation du patrimoine mondial de la Chine, 18 sont principalement des projets à déversoirs. Les projets des anciens déversoirs diffèrent considérablement des barrages et des barrages modernes. La plupart sont disposés en courbe ou à l'oblique par rapport à la rivière, prolongeant intentionnellement la longueur de l'axe des déversoirs. Bien que cela puisse sembler consommer plus de main-d'œuvre et de matériaux de construction, un tel plan augmente la partie déversante du barrage et la capacité du déversoirs, réduisant ainsi efficacement le niveau d'eau au-dessus du déversoir, et disperse et transmet simultanément vers les digues de la rivière, la force de cisaillement de l'écoulement de l'eau qui provoque la rupture du barrage. Certains anciens déversoirs utilisent également des systèmes de gradin-petit réservoir formés naturellement dans les rivières pour construire des déversoirs sur les petits réservoirs, afin d'exploiter l'effet de dissipation d'énergie des petits réservoirs profonds afin de réduire l'impact des inondations sur les déversoirs. Ces méthodes de construction d'anciens projets de déversoirs peuvent atténuer efficacement l'impact des inondations, améliorer la résistance technique et prolonger le cycle de vie du projet. Cela exprime non seulement la sagesse des anciens, mais démontre également le concept de respect de la nature et l'unité de l'homme et de la nature, qui était une pratique historique du concept contemporain d'«éthique fluviale». Du point de vue de l'ingénierie moderne, ces pratiques ont une base théorique scientifique et ont été largement appliquées, telles que les déversoirs à axe long comme les «déversoirs à crête courbe» et les

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«déversoirs en bec de canard», ainsi que l'utilisation de systèmes artificiels de gradin-petit réservoir pour la régulation des rivières de montagne. Des recherches approfondies sont menées sur ces anciens projets de conservation de l'eau, avec une participation multidisciplinaire pour mettre en lumière la sagesse des anciens, peuvent non seulement servir de référence pour la construction et la gestion des projets contemporains de conservation de l'eau, mais aussi jouer un rôle important dans le renforcement de la confiance culturelle nationale.

Mots-clés : Ouvrages d'irrigation du patrimoine mondial; Anciens déversoirs; Plan oblique; Système de «gradin-petit réservoir»; Confiance culturelle.

1 Introduction

Irrigation heritage projects have withstood hundreds or even thousands of years of climate change and natural vicissitudes and are still inherited and used today, which fully proves their scientificity and rationality in planning, design, construction and management. The construction of these irrigation projects cannot be accomplished overnight. From the initial conception to the final realization of their due benefits, they often require countless attempts, revisions and improvements. With the in-depth understanding of natural laws and the continuous emergence of new construction materials, these projects have undergone multiple transformations and adjustments in the long river of history, thus accumulating rich scientific experience. These experiences still have important guiding significance for the construction and management of modern water conservancy projects. For example, the fish mouth project of Dujiangyan underwent multiple adjustments in position and materials during the Qing Dynasty, and it was not until the modern adoption of concrete materials that a permanent project was finally formed. The Zhengguo Canal, due to the downcutting of the Jing River, has led to the continuous upward movement of the water intake, leaving numerous relics of ancient water diversion inlets. When Mulan Weir was first constructed, it was destroyed repeatedly by floods and tidal surges. It was not until the weir was built at the location with the least impact from floods and tides that it has been in continuous use to this day. These irrigation heritage projects demonstrated excellent environmental adaptability and low-impact development characteristics in historical periods. On the one hand, this was limited by the scientific and technological level and construction materials at that time; on the other hand, it also reflected the ancient Chinese philosophical thought of following natural laws and pursuing the unity of man and nature.

China is a country with a vast territory and diverse landforms, which has nurtured distinctive irrigation projects. At present, China has 42 World Heritage Irrigation Structures, covering almost all types of irrigation projects, making it the country with the richest variety, the widest distribution and the most significant benefits. Among these projects, 18 are dominated by weirs, which is the largest number among all project types. World Heritage Irrigation Structures is an emerging academic field. At present, most scholars conduct research on the historical and cultural value of heritage projects, while few conduct in-depth research from the perspective of water conservancy science and technology. Based on the understanding and research of China's World Heritage Irrigation Structures in work, the authors introduce the engineering characteristics of weir-type projects in China's World Heritage Irrigation Structures and analyze their engineering scientific and technological value and connotation.

2 Characteristics and Value Analysis of Ancient Weir and Dam Projects

As a type of river-blocking water diversion irrigation project, weirs have wide applicability in mountainous and hilly areas. In Sichuan, Hunan, Jiangxi, Zhejiang, Anhui, Fujian and other places in China, a large number of weir projects have been built since ancient times. The landforms in these areas are different, so the ancients built distinctive weirs according to local conditions.

For example, in the Sichuan Basin, due to the relatively flat terrain, the ancients built many large-scale weirs such as the Tongji Weir in Sichuan to meet the irrigation needs of large areas of farmland. In the hilly areas of Zhejiang and Jiangxi, the ancients used the terrain elevation difference to build many stepped weirs to achieve efficient water diversion irrigation. The weir projects built along the coast of

Fujian have the function of storing fresh water and repelling salt water, so the site selection is very important considering the dual impact of floods and tides. In short, China's weir projects are adapted to local conditions and have their own characteristics, fully demonstrating the wisdom and creativity of the ancients in water conservancy engineering construction.

2.1 Oblique Layout of Weirs and Dams with River Channels

Most ancient weirs adopt an oblique layout with the river in planning and arrangement. For example, in the Tianbao Weir in Fuqing, the builders intentionally lengthened the dam axis, and the weir is arranged obliquely with a length of 216m. If designed as an orthogonal straight weir, about 90m would be sufficient to intercept the water surface, as shown in Figure 1.



Figure 1 Schematic diagram of Tianbao Weir project layout

From an intuitive analysis, the oblique angle between the weir crest axis and the flow direction leads to an increase in the overflow front length. Under specific flow conditions, the water head decreases accordingly; or under a fixed water head, the discharge over the weir increases. The actual length of the weir body is the key factor determining its flow capacity—the longer the actual length, the stronger the flow capacity. The design of the oblique weir with a long dam axis not only ensures the water conveyance efficiency of the main canal downstream but also reduces the adverse impact on the flood discharge capacity of the weir during flood seasons.

A series of model test data reveal that there is a special hydraulic phenomenon in oblique weirs—the "self-submergence phenomenon"^[1]. Specifically, the water flow discharged from the overflow weir collides with the river bank, causing the water surface to rise and form a fish-back-like water surface shape. Due to the interaction of the discharged flow streamlines, local submerged flow may occur in the part of the weir section near the bank. To solve this problem, Tianbao Weir designed a funnel-shaped structure on the right bank, and the right bank water intake is exactly located at the tip of the funnel. This design can not only regulate the river flow, ensure smooth water intake at the water intake during the dry season and transport it to the irrigation area through the main canal, but also largely eliminate the "self-submergence phenomenon".

Further analysis shows that when the water flow impacts the obliquely arranged weir parallel to the river channel, the water flow shear force decreases with the increase of the weir inclination angle. If the weir is inclined to be parallel to the river channel, theoretically the shear force of the water flow on the weir will approach zero, thus greatly enhancing the weir's ability to resist floods. This is also the theoretical basis for the adoption of the fish mouth diversion dike non-dam water diversion form in large rivers.

2.2 Weir Construction in Wide River Sections

Different from the modern practice of building dams in narrow canyon areas, ancient weir construction usually chose wide river sections. In these places, the ancients sometimes used naturally formed sandbars or bedrock in the riverbed to connect two sections of the river-blocking weir. For example, the Jiang-Xi Weir project in Longyou is located in the wide area after the river flows out of the mountains, and skillfully uses natural sandbars to construct two weirs, Jiang Weir and Xi Weir, as shown in Figure 2; the Wushitan Weir in the Liaohe Irrigation District also builds the dam at the position where the river channel suddenly widens, and uses bedrock boulders above the water surface in the river channel as supports to divide the weir body into two sections to enhance its stability. From these examples, it can be inferred that the ancients had a certain degree of scientific understanding of river dynamics. They recognized that in wide river sections, the flow velocity will be significantly reduced, and by connecting sandbars and bedrock, the weir is divided into multiple parts, thereby improving its torsional strength. In addition, as can be seen from the diagram of Jiang-Xi Weir, Jiang Weir, sandbar and Xi Weir can all overflow and discharge flood during flood periods, which greatly reduces the obstruction of the project to floods, and correspondingly, the impact of floods on the project is also reduced, reflecting the simple concept of harmonious coexistence between man and nature of the ancients. They not only demonstrated wisdom in technology but also embodied respect and compliance with nature in philosophy. This practice not only effectively utilized natural conditions but also reduced damage to the environment, enabling weir projects to better integrate with the surrounding natural environment. In this way, the ancients not only realized the function of water conservancy projects but also protected the ecological environment, demonstrating their profound understanding and respect for natural laws.



Figure 2 Aerial view of Jiang-Xi Weir

2.3 Utilization of Bend Circulation for Sediment Flushing

Ancient weir projects are usually located at the curved parts of rivers, with water intakes set on the concave banks of the rivers. For example, the Tianbao Weir mentioned above and the Chatan Weir shown in the figure have their water diversion inlets located on the concave banks. This layout enables the weir to use the inertial trend of natural water flow to guide the water smoothly into the irrigation channel. According to the theory of bend circulation in hydraulics, when the water flow enters a bend, under the action of centrifugal force, the surface water flow will move towards the concave bank of the river, while the bottom water flow will move towards the convex bank, thus forming a closed circulation, which is usually called bend circulation. When bend circulation meets longitudinal water flow, a spiral flow is generated^[2]. This flow pattern ensures that the water intake on the concave bank can draw more

surface clear water and reduce sediment deposition in the water intake and channels. The main dam and auxiliary dam of Chatan Weir are connected by a sandbar and built at a large-angle turn of the river, guiding the mid-channel part of the water flow into the channel smoothly, while the excess water overflows laterally to reduce the direct impact on the weir, as shown in Figure 3. During flood seasons, Chatan Weir functions similarly to the "Feisha Weir" of Dujiangyan. Through the bend circulation movement, most of the sediment is effectively discharged into the downstream river channel, thereby reducing the siltation of the channels and ensuring the long-term stable operation of the irrigation system.



Figure 3 Aerial view of Chatan Weir

2.4 Weir Construction on Pools

The riverbeds of steep mountain rivers are often composed of alternating steep sections, gentle sections and deep pools, presenting a series of stepped shapes, which is called the step-pool system, as shown in Figure 4. The typical morphological characteristics of step-pool rivers are reflected in the large undulations of the longitudinal profile of the bed surface with a series of inflection points. Along the river, the water flow alternates between rapid flow and slow flow, and there are also many inflection points on the water surface line, presenting an obvious continuous stepped shape. Through slow and continuous erosion and downcutting, the river makes the riverbed have a curved characteristic in the longitudinal direction. The sediment particles at the steps in the riverbed are relatively coarse, with large pebbles and even boulders, while the sediment particles in the deep pools downstream of the steps are finer than those at the steps, and very fine sand can also exist^[3].

As early as 1957, Leopold and Wolman noticed this river geomorphic feature, but the term did not appear until the 1980s. Judd called this landform "steps" in 1964, and it was not until 1982 that Whittaker and Jaeggi, and in 1985 Petts and Foster, all called it the "Step-Pool system", after which this term was widely accepted^[4]. The existence of deep pools has a significant hydraulic energy dissipation effect, which can effectively slow down the scouring force of water flow on the riverbed, thus keeping the basic area of the riverbed relatively stable, which is also an important manifestation of river maturity. At present, the use of artificially constructed step-pool systems for mountain river regulation has been widely applied.

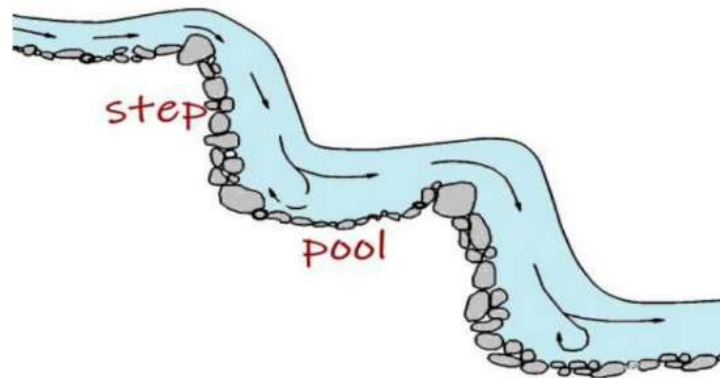


Figure 4 Schematic diagram of step-pool system

However, the utilization of this river landform did not begin with the research of modern scholars. As early as thousands of years ago in ancient China, our ancestors had conducted in-depth observations and ingenious utilization of this river landform. In 27 AD, Lu Wentai led people to build weirs on pools and dig canals to divert water for irrigation on the Baisha River, successively building 36 weirs, which is not just a simple cascade development model^[5]. When constructing these weirs, the ancients skillfully utilized the characteristics of step-pool systems, and most weirs were built at the lower edges of deep pools. These deep pools can effectively use their energy dissipation effect, summarizing the water control method of "deeply dredge the pools, lowly build the weirs", reducing the impact of water flow on the weirs, thereby extending the service life of the weirs and improving their water storage capacity. This ancient and wise utilization method demonstrates the ancients' profound understanding of natural laws^[6].

2.5 Application of Traditional Construction Materials

In ancient times, the construction of weir projects mainly relied on earth and wood materials. Due to their vulnerability, these materials were often attacked and destroyed by floods, so large-scale repairs were required almost every year. With the evolution of history, by the Song Dynasty, with the rise of large-scale stone structures such as seawalls and the significant progress of engineering technology, masonry technology began to be gradually applied to the construction and maintenance of weir projects. At the same time, the traditional Chinese wooden mortise and tenon structure technology was also skillfully integrated into masonry technology, which not only reflected the significant improvement of engineering construction technology but also marked technological innovation.

For example, in the Northern Song Dynasty, people built Mulan Weir, a large-scale and exquisitely designed stone river-blocking weir for storing fresh water and repelling salt water. The construction of this weir project fully demonstrated the high level of masonry technology at that time, and its "general pillars" are repeatedly cited in literature as a symbol of technological achievement. In the Tang Dynasty, the Tuoshan Weir project was originally constructed with an earth-wood structure, and in the Song Dynasty, it was reconstructed with a masonry structure.

After reconstruction, each stone slab of Tuoshan Weir weighed several tons. To further enhance the stability of the dam body, craftsmen also drilled holes in the stone slabs and poured molten iron into them, making these huge stones tightly connected together. In addition, records of Tianbao Weir show that in the Song Dynasty, people had already used molten iron to reinforce the dam foundation, which further proves the advancement and innovation of engineering technology at that time. Overall, the upgrading of construction materials is the development trend of ancient weir projects, and the progress of modern dam technology is also an important manifestation of this trend.

3 Conclusion

Irrigation heritage projects that have been inherited for thousands of years have withstood severe tests of various climate changes, demonstrated extremely high engineering resilience and adaptability, and have been proven to be models of sustainable operation. The reasons are nothing more than two aspects: first, the planning and design of these projects are scientific and conform to natural laws; second, the operation and management systems of the projects are in line with the historical trend. In agricultural society, irrigation projects were not only simple irrigation projects but also social water conservancy projects, bearing the profound development of society, economy, science and technology, and culture. Therefore, when we study and excavate the value of these irrigation projects today, we need more experts and scholars from different disciplines to participate and interpret the profound connotations contained in these precious historical projects from different perspectives.

The wisdom of these irrigation projects is not only a treasure in the water conservancy field but also a crystallization of the wisdom and creativity of the Chinese nation. With their unique design concepts and exquisite construction techniques, these ancient water conservancy projects not only solved practical problems such as agricultural irrigation and flood control and drainage at that time but also left valuable experience and enlightenment for future generations. In modern society, with the rapid development of science and technology and the increasingly prominent environmental problems, the wisdom of ancient weir projects is once again shining with new light. The sustainable development concepts contained in these ancient projects, such as water-saving irrigation and ecological restoration, provide valuable ideas for us to meet the challenges of water shortage and environmental degradation.

In the planning and construction of water conservancy projects, we can learn from the ecological design concepts of ancient weir projects, pay attention to protecting the natural ecological environment, and realize the harmonious coexistence of water conservancy projects and the ecological environment. At the same time, through systematic publicity and display of the wisdom and concepts contained in these projects, letting the public understand the intelligence of our ancestors has important practical significance for enhancing national cultural confidence and cultivating the consciousness of heritage protection. These projects not only demonstrated the wisdom of the ancient people in technology but also reflected the profound heritage of the Chinese nation in culture. They are not only witnesses of history but also models of the combination of modern science and technology and traditional wisdom, which are worthy of in-depth research and inheritance.

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