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DUJIANGYAN IRRIGATION SYSTEM: HISTORY AND CHALLENGE

A UNESCO WORLD HERITAGE SITE IN CHENGDU, THE SITE OF IAHR CONGRESS 35TH IN 2013

BY CAO SHUYOU, LIU XINGNIAN, HUANG ER

Chengdu is the capital of Sichuan Province, which is the venue of the 35th IAHR World Congress in 2013. The ancient Dujiangyan Irrigation System (DIS) in Chengdu was listed as a World Cultural Heritage Site by the World Heritage Center, UNESCO in 2000. DIS still plays a crucial role in flood control, irrigation and water supply for Chengdu Plain in Sichuan Province. The immense advances in science and technology achieved in ancient China are graphically illustrated by the DIS. The system is appropriately arranged in accordance with the terrain and topography of the river and Chengdu plain, thus successfully solving the problem of sand discharge, flood control, and water distribution. Consequently the task of gravity diversion could be fulfilled over a long period and across the whole irrigation district. Since the 1940s, series of prototype observations, hydraulic physical model experiments, and numerical modeling, have been conducted to explore the design philosophy, new planning schemes and key techniques for modern reconstruction. At the same time, science mechanisms and river dynamics of this Wonder are being discovered. It is interesting to learn the recorded history of the original construction and sustainable development, engineering and science values, and regular restoration experiences, and a new understanding to the original headwork structure of the DIS.

1 Hydraulic Miracle

The ancient Dujiangyan irrigation system controls the waters of the Minjiang River and distributes it to the fertile farmland of the Chengdu plain. The system is a major landmark in the development of water management and technology. As shown in Fig.1, DIS covers two main components. One is the headwork structure, the key control for water division and intake at Dujiangyan City (Fig. 2), and the other is the water distribution system itself in 7 cities and 37 counties (Fig. 3). For over two thousand years the whole system has functioned perfectly, serving flood control, irrigation, navigation and wood drifting. It has contributed greatly to the wealth of the Chengdu Plain and helped to earn its reputation as "The Land of Abundance".

The system is appropriately arranged in accordance with the terrain and topography of the river and Chengdu plain, thus successfully solving the problem of sand discharge, flood control, and water distribution. Consequently the task of gravity diversion could be fulfilled over a long period and whole irrigation district. The irrigation district covers 3 watersheds with a total area of 23.2 by 10^3 km^2 today, namely Mingjiang River, Tuojiang River, and Fujiang River. DIS is planned to extend to a total irrigation area of 1.01 million ha, based on actual irrigation area of 0.68 million ha at present.

The ancient headwork structure of Dujiangyan was a non-dam intake project. It is located on the top of an alluvial fan where the Minjiang River exits from the Longmen Mountains. The hydraulic headwork structure of ancient Dujiangyan was essentially composed of three main components: (1) Fish Mouth, a diversion embankment diverting flow to the intake stem channel; (2) Flying Sand Sluice, a flood and sediment sluice; and (3) Baopingkou (Top of Precious Vase), a water intake with a flood control function. A series of data analyses,

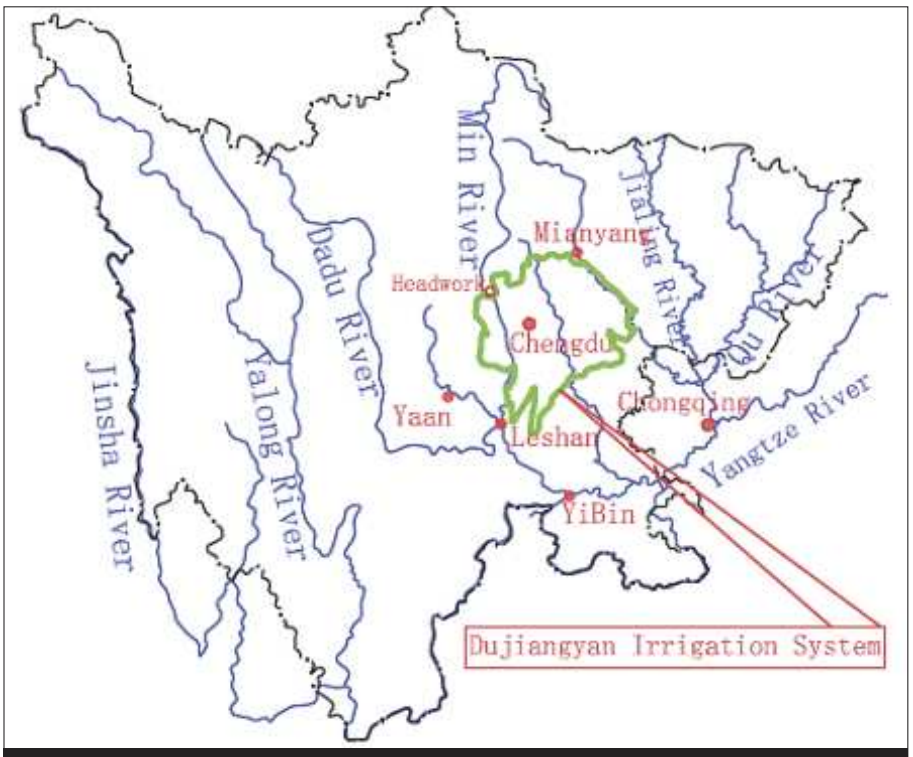

Fig. 1. Location of Dujiangyan Irrigation System (DIS) in Sichuan Province

mathematical modeling studies, prototype observations and hydraulic physical model experiments have been conducted since the 1940s. The purpose of this research is: (1) to investigate the scientific principles corresponding to modern fluid mechanics, including effects of headwork hydraulic structures on flood control, sediment exclusion, and management schemes; and (2) to study the scientific bases for modern sustainable development of the system, including the construction of a reinforced concrete checkgate on Outer River and the water regulation project, Zipingpu reservoir. In spite of the headwork of the DIS being modified over time since the original construction, modern research reveals that the effective sediment exclusion is attributed to the general layout of the three main head hydraulic structures, the utilization of secondary currents in channel bends, and the annual maintenance.

2 History of the original construction and sustainable development

The construction and sustainable development of DIS is an outstanding example of keeping abreast with the times and promoting harmony between mankind and nature. The processes of the original establishment and long period development of DIS can be divided into three main periods: the original construction period, the development period, and the modern period. The original construction of DIS was firstly recorded in a famous book titled as "the Historical Records" by Sima Qian (91 B.C.) in the Han Dynasty more than 2100 years ago. After Sima, numerous historical records of Dujiangyan can be found in history. To understand the Chinese hydraulic civilization one should start from Dujiangyan. As a result the Dujiangyan Study in order to save this civilized heritage based on Dujiangyan's great historical value and modern function is establishment in China.

2.1 Original construction (256B.C. – 206 B.C.)

During the Warring States period of ancient China, the Qin Kingdom conquered the Shu Kingdom in 316 B.C. On the basis of the previous water conservancy project, Li Bing, the governor of the Shu Shire under the Qin State, built a diversion embankment called Yuzui (front-end look like a fish mouth) in the middle part of the Minjiang River at the upper end of the Chengdu Plain where the river just runs out from the mountainous region in 256 B.C.. The division embankment was constructed to stabilize the course of the main flow (the Outer River). Meanwhile, a new channel, the Inner River, was dug out by the side of the hill to divert water. Moreover, Baopingkou (throat of the intake like the tap of a precious vase) was excavated through the hard conglomerate rock mass in order to divert water and also to control flooding. Then, at the upstream of Baopingkou on the side next to the Outer River, Feishayan (a sediment and flow spillway) was built using woven bamboo baskets filled with local pebbles and boulders to discharge the surplus flood water and sediment into the Outer River, assuring the irrigation demand and domestic supply, and eventually, to prevent droughts and floods in the Chengdu Plain. Since then, the project has been honored as the 'Treasure of Sichuan', which played a crucial role in flood control, irrigation and water supply for Chengdu plain. On the other hand, as a part of the Dujiangyan water distribution system, the channel system of Chengdu plain was improved, especially towards river of Chengdu City. As a key river training project, Mingjiang River, Fu Jiang River and Tuojiang River were connected.

2.2 Development period (206 B.C. – 1930s)

The DIS experienced a period of ceaseless development from the Han Dynasty to the early 20th century, over 2100 years. The head control work was improved gradually, and the irrigation area increased step by step. Irrigation channels extended to Chengdu plain quickly to establish a mult-benefit channel network, which ensured irrigation; flood control and navigation in the Chengdu Plain. As a result, Chengdu became the economic center of South-western China. Unfortunately, the DIS was destroyed seriously at least four times owing to historical wars or natural hazards: (1) The headwork was destroyed and washed downstream for 1 km by an extreme flash flood on June 26, 910; (2) During the war of Mongolia China was conquered (1235-1267); (3) During the Sichuan war the Ming Dynasty fell to the Qing Dynasty (1644-1681); and (4) by a flash flood on October 9, 1933, which was induced by the bursting of block-lakes formed by the Diexi earthquake 150km upstream of Dujiangyan on August 25, 1933. In spite of being destroyed a few times, the DIS was recovered quickly. The name "Dujiangyan" first appeared in a historical record in Yuan Dynasty, and the title of the permanent water intake, "Baopingkou" first appeared in the Ming Dynasty.

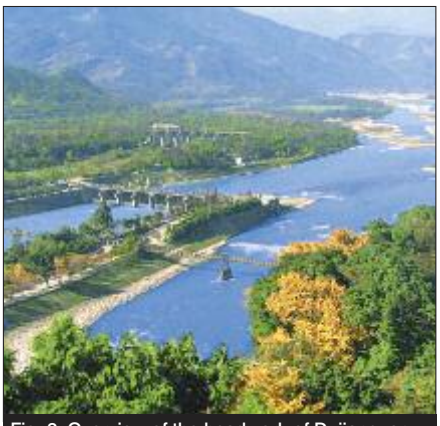

Fig. 2. Overview of the headwork of Dujiangyan (Li & You, 2007)

Fig. 3. Irrigated district of DIS

Fig. 4. Undistorted model of DIS

2.3 Modern times (since 1940s)

The DIS started its modern period in the 1940s. The symbol of the beginning of the modern period was the first planning of permanent solutions and the first modern physical scale model experiments for the DIS in 1941. The Chengdu Hydraulic Laboratory was established in 1941. Three modern experiments on DIS were conducted at the laboratory in 1940s, which are:(1) Scour experiment on Yuzhui (Fish Mouth) and Inner Channel of DIS; (2) Study on backwater of Inner Channel of DIS; and (3) Study on hydropowers of upstream Mingjiang River. A British historian of Chinese science, Joseph Needham, visited Dujiangyan in 1943. He visited the hydraulic model of Dujiangyan. He met the head of the experiments, Dr. Chang Y. L., who got his Ph.D. degree at the University of Manchester. Dr. Chang was a professor of Sichuan University at that time. Joseph Needham was excited by those modern experiments during the Second World War, and presented the DIS to the west as a typical example of the rice-based irrigation systems of South China in both its history and its size. From the point of view of management, he noted that a government-managed irrigation system was constructed around 2200 years ago.

Large scale reconstruction of the DIS includes mainly the checkgate at Outer River finished in 1974 to replace temperate water adjust work, wood-tripods (macha) with bamboo-cages (Zhulong), into a permanent reinforced concrete checkgate, which makes a new development of the DIS.

At the onset of the new millennium, Dujiangyan irrigated 0.668 million hectares of farmland in 7 cities and 37 counties of the Sichuan province (in 2004). Zipingpu reservoir, the second generation project of Dujiangyan was finished in 2006.

3 Scientific and engineering values of DIS

A series of data analyses, prototype observations, mathematical modeling studies and hydraulic physical model experiments have been conducted since the 1940s, to explore the design philosophy, new planning schemes and key techniques for modern reconstruction. A series of physical models was conducted at Sichuan University to study the influences of ZPP dam on DIS (Fig.4). Concepts of modern science in Dujiangyan are summarized as hydrology conditions for the guarantee of water supply, unique topography conditions, scientific layout of headwork, and earthquake resistance ability.

Based on analysis of well-established literature, the headwork system of Dujiangyan has always been a checkgate dam water diversion system. The difference between ancient and modern Dujiangyan is just construction materials and structures. The checkgate dam was constructed by bamboo-cages with wood-tripods in the ancient project as a cofferdam, and by reinforced concrete with steel gate today!

The prototype-model correlation study on Dujiangyan Project shows that the rational general layout of the three main hydraulic head structures function well for flood control and sediment exclusion. The strong secondary currents caused by meandering channels can exclude intensive sediment to maintain the water intake project effectively. Based on modern hydraulics studies, the building of the Outer River checkgate dam improves the environment of water conduction and sediment exclusion since 1974.

As the second generation of Dujiangyan, the Zipingpu reservoir functions mainly for irrigation and water supply, with comprehensive benefits in power generation, flood control, environment protection and tourism. The water supply guarantee rate will be improved by 10 percentage points in the Dujiangyan areas. The Zipingpu reservoir will raise the flood control standard of the downstream Dujiangyan and the whole Chengdu plain, from once every 10 years to once every 100 years. A 100-year frequency flood (6030 m^3/s) from upstream of the reservoir can be reduced by the reservoir to 2390 m^3/s, less than a 10-year frequency flood (3760 m^3/s). As a result, the great Dujiangyan is protected by the Zipingpu dam!

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