The Wushantou Dam as culture heritage in Taiwan

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ABSTRACT

The Wushantou Dam is a historical hydraulic structure, which was built in early 20 century, by the Japanese government. The dam greatly improved the land productivity at the Chia-Nan Plain in the southwest Taiwan. The stories of the dam include the following three topics: (1) achievements of the Chief Engineer Yoichi Hatta, (2) the construction technologies, and (3) three-year rotation of irrigation system. The operating Wushantou reservoir and the downstream Chia-Nan irrigation water ways are still important irrigation system for the Chia-Nan Plain.

Keywords: Irrigation; dam; Tainan; civil engineering, heritage

1 INTRODUCTION

In Taiwan, Chia-Nan Plain is the biggest plain located at the southwest Taiwan with a width of 32 km and a length of 92 km, covering the administrative districts of Yunlin, Chia-I, and Tainan. The Chuoshui River to the north and the Tsengwen River to the south are the boundaries of the plain (Figure 1). Local weather originally governed local agriculture activities, and the land productivity was half of the farms in north and central Taiwan before 1930.

Fig. 1. Location of the Wushantou dam.

To increase the land productivity and mitigate the soil salinization near the coastal area in the Chia-Nan Plain, Mr. Yoichi Hatta, who was a civil engineer in Civil Engineering Bureau of the Taiwan Governor-General Office, Japan, designed and managed the construction of Wushantou Dam at Guantien Village, Tainan, Taiwan from 1920 to 1930.

This study discusses the following three topics: (1) stories of the Chief Engineer Yoichi Hatta, (2) the construction technologies, and (3) irrigation management show the importance of the Wushantou Dam as a culture heritage in Taiwan.

2 ACHIEVEMENTS OF YOICHI HATTA

Mr. Hatta was born at Ishikawa Prefecture, Japan in 1886. He graduated from Department of Civil Engineering, Tokyo Imperial University in 1910. Mr. Hatta worked as a civil engineer in Civil Engineering Bureau of the Taiwan Governor-General Office, Japan and joined several modernization constructions, such as the water works in Tainan, water and sewer services in Kaohsiung, irrigation waterway in Taoyuan, and the Sun-Moon Lake hydropower plant on Taiwan (Katakura, 2013). When Mr. Hatta was conducted to the irrigation waterway project in Taoyuan, he was also assigned to assess the possibility to build an irrigation waterway in the Chia-Nan Plain. In 1919, Mr. Hatta proposed build the Chia-Nan Irrigated Waterway and the Wushantou Dam. Mr. Hatta attempted to solve the irrigating problem of water shortage of the 0.150 million hectors in the Chia-Nan Plain by developing a waterway network to introduce water from Chuoshui River and a large reservoir. The waterway also delivered fresh water to mitigate the soil salinization near the coastal area. Then, He pursued appropriate construction methods from *in-situ* inspections in USA, Canada, Maxico, and Japan and introduced large construction machinery from USA to accelerate the construction speed of the Wushantou Dam project. The

dam is located at the valley of Guantien River. The engineers and workers spent 7 years to excavate a 3.078 km headrace tunnel passing through the Wushanling Mountain to get the water from the Tsengwen River. In 1930, the Wushantou dam was completed as the largest irrigated reservoir in Taiwan, Japan and Asia. Then, the Japanese government officer assigned Mr. Hatta to conduct local infrastructure constructions in Philippine on April 8, 1942. The US submarine sunk the transport ship, Taiyoumaru, passengers, and crew on May 8 on Mr. Hatta's way Philippines. Sudden death of Mr. Hatta committed his wife, Toyoki Hatta, suicide on Sept. 1, 1945, by jumping into the water outlet of the reservoir her husband was built. Therefore, the stories of Wushantou dam are the intangible cultural asset for both sides of Taiwan and Japan.

3. CONSTRUCTION TECHNOLOGIES

Figure 2 shows the map of the Chia-Nan Irrigation waterway designed by Mr. Hatta. The Chuoshui main routes delivered the fresh water from the Chuoshui River for the 50 thousand hector farmlands in the north section between Chuoshui River and Peikang River. The Wushantou reservoir takes responsibility to the fresh water supply to the 100 thousand hector farmlands in the south section of the Chia-Nan Plain. Wushanling tunnel passes through the Wushanling Mountain and intakes fresh water from the upstream of the Tsengwen River to the Wushantou reservoir. On December 6, 1922, natural gas explosion occurred during the tunnel excavation and resulted in 50 deaths and several casualties. The tunnel was completed on December 21, 1929.

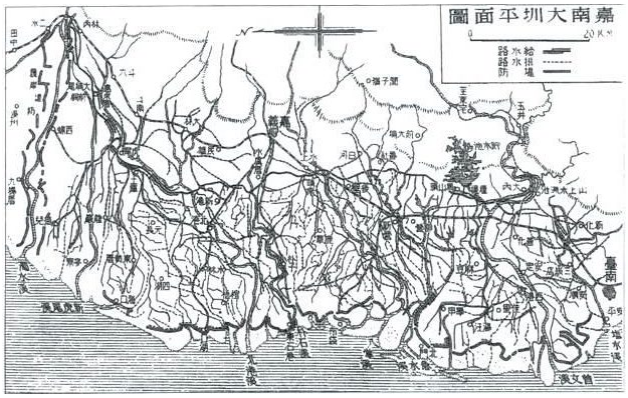

Fig. 2. Map of the Chia-Nan irrigation waterway network (Katakura, 2013).

Table 1 list the scale of the Wushantou Dam, which is the largest dam in Asia and the third largest dam in the world in the early 20 century. In Figure 3, the Wushantou reservoir is also called the "Coral Lake" based on its outlook. In the Chia-Nan irrigation waterway network, in total, 10000 km waterway for the irrigation and additional 6000 km waterway to mitigate the soil salinization were constructed. The gradient of waterway was set to be 1% based on the detail topographic survey.

Table 1. Scale of the Wushantou dam (Ko, 2011; Katakura, 2013).

Item	Value
Elevation (m)	66.66
Dam height (m)	56
Length at the top of the dam (m)	1273
Width at the top of the dam (m)	9
Width at the bottom of the dam (m)	303
Volume of the dam (m^3)	11,020,928
Slope of the two sides of the dam	Upstream 1:3 Downstream 1:2.5~1:3
Cut earthwork of the dam (m^3)	774,000
Fill earthwork of the dam (m^3)	5399,838
Core concrete (m^3)	27,600
Catchment area (km^2)	60
Storage capacity (m^3)	154,158,000


Fig. 3. Top view of the Wushantou reservoir.

3.1 Semi hydraulic fill construction method

Figure 4 shows the local geology near the Wushantou reservoir. The Liuchia fault is close to the dam. Now, the fault is classified to the first category active fault, which has significant movement within 10,000 years. Geologically, faults and earthquakes up to M6.0 are potential threats to the Wushantou dam. Therefore, Mr. Hatta decided to build a flexible earth dam to mitigate possible impacts from the earthquake.

In addition, the materials for the dam construction came from nearby quarry, which consists of a mix of gravels and soils. A total volume of 5.4×10^6 m^3 soils/gravels are required to build the dam. Figure 5 shows the design profile of the Wushantou dam. A concrete core and clay generate a very low permeability zone at the center of the dam to prevent seepage-induced dam failure. The sands covered the clay zone, and gravels are put at the outmost layer. Therefore, the dam design requires soil arrangement as fine contents, sands, and gravels from the dam core to the surface. Fortunately, soils in the neighboring Danei quarry consist of clay but mixing with gravels.

Screening out the gravels, sands, and clay to fulfill the requirement of the dam construction in Figure 5 was a challenge task.

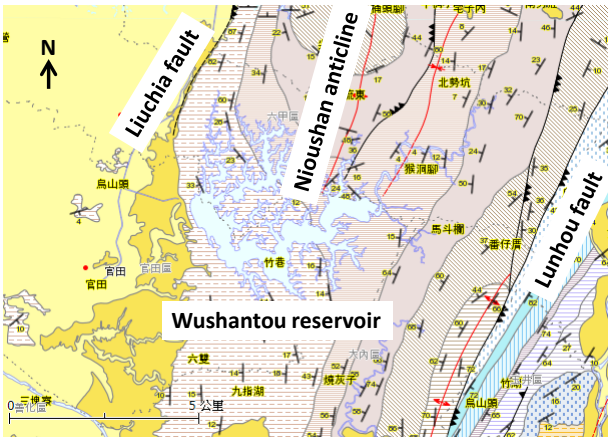

Fig. 4. Local geology near the Wushantou reservoir (Central Geological Survey, Taiwan, 2019).

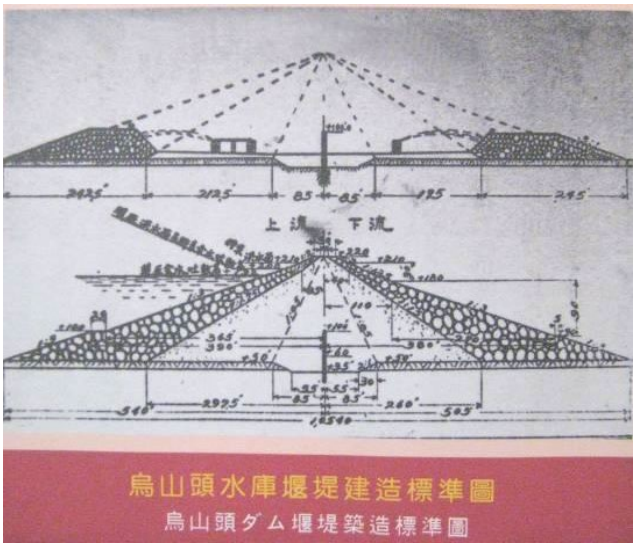

Fig. 5. Design profile of the Wushantou dam.

Mr. Hatta chose semi hydraulic fill construction method to build the dam. At the beginning, the Quaternary ground at the dam site was removed. A concrete core with height of 3.64 m, and the widths at the top and bottom are 0.9 m and 1.52 m, individually (Chen, 2013) was built at the center of the site above the Tertiary ground. Then, earth materials, including gravels, sands, and clay, were excavated and were delivered from the riverside of the Tsengwen River at Danei 20 km away from the dam site using railway (Figure 6). The earth materials were piled up at the two sides of the dam. The river drained into the channels, which were excavated near the concrete core. "Giant Pump" with 450 hp drove the water from the channel to inject the mound of earth materials (Figure 7). When the water flew with soils on its way back to the channel, the large grains deposit first and small grain soils travel longer distance near the core of the dam. Therefore, water in the semi hydraulic fill method grades the soil to fit the requirement of the soil/gravel arrangement in the dam design. Surely, the soil boundaries in the design map are straight lines (Figure 5) but are irregular lines in the completion map (Figure 8). The irregular boundaries increase the slope stability of the dam.

Fig. 6. Earth material excavation at the quarry (Ho, 2007).

Fig. 7. Earth material discharge and water injections.

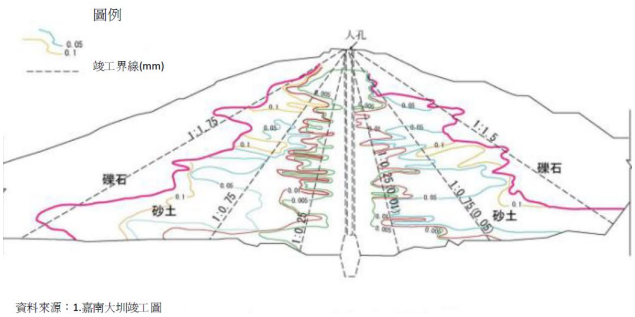

Fig. 8. Actual soil distribution in the dam profile (Public Waterway Chia-Nan Irrigation Waterway Association, 1930).

Table 2 lists the disastrous earthquakes, whose epicenter is near the Wushantou reservoir in Taiwan. The Central Weather Bureau of Taiwan has announced seismic accelerations of large earthquakes at different accelerograph stations since the Chi-Chi earthquake in 1999. The maximum ground accelerations at CHY058, which is located 5.5 km southwest away from the dam, at different directions are listed in Table 2. Wushantou dam remains stable with the requirements of repairing minor slope failures under impacts of earthquakes, typhoons, and heavy rainfalls since 1930.

Table 2. Maximum ground accelerations at CHY058 (Central Weather Bureau, Taiwan, 2019).

YY/MM/DD	Earthquake	U-D(gal)	N-S(gal)	E-W(gal)
1941/12/17	Chung-Pu(M7.1)	---	---	---
1946/12/5	Hsin-Hua(M6.1)	---	---	---
1964/1/18	Pai-He(M6.3)	---	---	---
1999/9/21	Chi-Chi(M7.3)	24.88	57.30	47.44
1999/10/22	Chia-I(M6.4)	30.86	108.62	72.20
2016/02/06	Mei-Nong(M6.6)	67.44	250.12	233.22

3.2 Large construction machineries

Wushantou dam was the first civil engineering project by introducing large construction machineries in Japan. This was an innovative approach to enhance the construction efficiency. Mr. Hatta investigated the construction method and bought numerous construction machineries in USA. The representative machineries are listed as follows (Ko, 2011):

Dump car: 100
Earth moving train: 100
Freight train: 3
Giant pump: 5
Steam shovel: 5
Large concrete mixer: 2
Steam locomotive: 12

These large construction machineries were very expansive and cost 25% of the total budget of the Wushantou dam and the Wushanling tunnel. In a society with labor redundance, it was strange to introduce such expansive machineries to join the construction. However, these machineries increased the construction efficiency and also greatly contributed to the follow-up construction projects on the Keelung Harbor and the Taichung Harbor.

4. THREE-YEAR ROTATION OF IRRIGATION SYSTEM

After the completion of Choushui River main waterway, Wushantou Dam, and Chia-Nan Irrigation Waterway network, it is still not possible to simultaneously and fully supply fresh water to the whole farmlands with 150 thousands hectors. It was common to decrease the irrigation area to solve the problem. However, Mr. Hatta considered that the objectives of constructing Wushantou dam and Chia-Nan irrigation waterway network were enhance the living standard of farmers by increasing the land productivities though water supply. Decreasing the irrigation area was not an option.

Then, Mr. Hatta proposed three-year rotation of irrigation system to operate the Chia-Nan irrigation waterway system as an alternative approach. The total farmlands with 150 thousands hectors in Chia-Nan Plain were divided into three zones. Each irrigation zone has farmlands with 50 thousands hectors, for a three-year planting sequence as rice, sugarcanes, and food grains. Table 3 shows three-year rotation of irrigations. For planting rice, water was fully supplied. For the sugarcanes, water was only available for the planting season. Water supply was terminated when planting food grains. The operating method changes the water supply based on changing crops each year. Therefore, the famers from the whole 150 thousands hectors got water and advantage equally from the irrigation networks.

Table 3. Crops arrangements for three-year rotation of irrigations.

Irrigation zone	A	B	C
Year 1	Rice	Sugarcane	Food grains
Year 2	Food grains	Rice	Sugarcane
Year 3	Sugarcane	Food grains	Rice

CURRENT STATUS OF THE WUSHANTOU DAM

When the Wushantou dam was completed in 1930, the storage capacity was 154,158,000 m^3. The capacity reduced to 78,280,000 m^3 in 2019 (Water Resources Agency, Taiwan, 2019). However, most dams, which were also constructed in 1930s, around the world were abandoned due to the reservoir sedimentation. The soil and water conservations applied to the catchment area by Mr. Hatta extended the life time of the Wushantou reservoir.

Originally, two iron pipes (diameter: 2.7m; thickness: 12.7 mm; length: 162.03m and 168.93m) were set in the water management tunnel. 60 years later, the detection in 1990s found severe abrasion to the iron pipes. Pipe reinforcements were conducted in 1993. New water management constructions were conducted from 1984 to 1994. In 2001, Wushantou hydropower plant was complete. In addition, a new west entrance hydropower plant was constructed at the west entrance of the Wushanling tunnel in 2007.

Due to the concrete aging in the original Wushanling tunnel, a new Wushanling tunnel is constructing. The new tunnel is almost parallel to the old one (Figure 9) and will be completed in 2019.

In 1956 after the World War II, the authority to manage the Wushantou reservoir was renamed as Taiwan Chia-Nan Irrigation Association. In 1969, the Wushantou Reservoir Scenic Area was established with well-equipped camping areas and trails. Wushantou reservoir and the stories of the Chia-Nan irrigation waterway are the main tourist attractions. The statue of Mr. Yoichi Hatta and the tomb of Mr. and Mrs. Hatta (Fig. 10) are located near the north end of the dam. In addition, an exhibition hall demonstrating the data construction data and records, pictures of Hatta's family is located near the water outlet of the reservoir.

Some camp buildings, including the house of Mr. Hatta's Family, were also repaired.

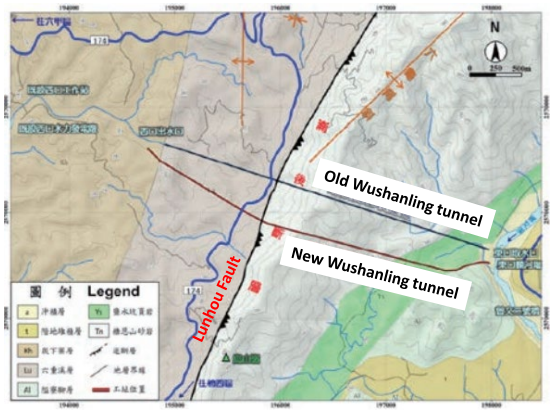

Fig. 9. Location of the new Wushanling tunnel (Hsu et al., 2016).

Fig. 10. Statue of Mr. Yoichi Hatta and tomb of Mrs Hatta.

3 CONCLUSIONS

Mr. Hatta and his crew constructed the Chia-Nan Irrigation Waterway network and Wushantou reservoir with their working efforts and innovative ideas in the early 20 century. The hydraulic facilities irrigate the 150 thousand hector farmlands and improve the land productivity and the life of farmers in the Chia-Nan Plain. The large scale irrigation waterway network was rare all over the world; especially the system is still working well 90 years after its completion.

The economic activities have changed in the Chia-Nan Plain during the past decades. Water demand in agriculture decreases but increases in the industry and people's livelihood. The Wushantou reservoir will be still an important water source for the people in the Chia-Nan plain in the future. In addition, the difficulty to build a new reservoir highlights the great importance to integrate water resources in Wushantou reservoir to the neighboring Tsengwen and Nanhua reservoirs to mitigate challenges of drought and flooding in the future due to the climate change.

Therefore, Wushantou dam and the Chia-Nan Irrigation Waterway network are a cultural and engineering heritage.

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