



The Rehabilitation and Improvement Project of Baihe Reservoir

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Abstract

Baihe reservoir has a multi-purpose features, including water supply, irrigation, flood control and tourism. However, it is also well known for severe siltation in Taiwan. When Baihe reservoir was completed in 1965, its capacity was 25 million cubic meters. But current storage capacity is about 10 million cubic meters, only 43% of the original capacity. Therefore, rehabilitation of this reservoir has become an urgent task, not only for water supply and irrigation, but also for the safety of reservoir. Severe siltation has caused problems in the reservoir's flood detention ability.

Heightening of the dam core and sediment pass-through tunnel construction were priorities for the safety of reservoir flood control. The maximum discharge capacity of the Baihe sediment pass-through tunnel is 287cms. This tunnel is designed as a new outlet at the bottom of the reservoir and will be used to not only distribute the flood discharge of the spillway but also reduce the sediment deposition of the reservoir. This tunnel is currently under construction and expected to be completed in 2019.

However, the Baihe reservoir's capacity is not easy to maintain since the sediment deposition is about 500,000 cubic meters per year. Therefore, the Water Resources Agency has planned a complete reservoir sediment venting strategy for adjusting the reservoir operation to "empty reservoir" and "storage" periods, respectively.

According to the strategy, the reservoir will implement a reservoir empty operation from mid-May to late-July each year. During this period, the sediment pass-through tunnel is used to minimize the sediment brought from floods, and the siltation of the reservoir could be washed out by floods. The irrigation water during this period must be supplemented from the neighboring Yun-Shui River. Therefore, a Yun-Shui river trans basin diversion project, which contains several tunnels and bridges, is under planning with a total length of 2.45 kilometers. The design conveyance capacity is 4 cms.

In the storage period, a sediment bypass tunnel is necessary for sediment venting. This tunnel uses a five-year frequency flood as the design flow and the discharge is 200 cms. The intake is located on the riverbed below the high water level of the reservoir. When floods occur, sediment will be bypassed from the tunnel to the downstream river. This bypass tunnel, with a total length of 1,515 meters, is under design now.

Keyword : Baihe Reservoir, Reservoir Siltation, Sediment Pass-through Tunnel, Sediment Bypass Tunnel

1 Introduction

Baihe reservoir is in the hilly area of southern Taiwan and is built on the Baishui River. It was completed in 1965 for a multi-purpose features, including water supply, irrigation, flood control and tourism. Agricultural irrigation is its main water supply target. According to recent statistics, the Baihe reservoir supplies an average of 23 million tons of irrigation water per year, which is 97% of the total water supply. It has an irrigation area of 2,900 hectares.

The main facilities of the Baihe reservoir include the main dam, the saddle dam, the spillway and three outlets, namely the main outlet, the Baishuixi outlet and the Benjiyu outlet. The basin area of the reservoir is 26.55 square kilometers, and the full water level is EL.109.0 m. When it was completed in 1965, its capacity was 25 million cubic meters. But current storage capacity is about 10 million cubic meters, only 43% of the original capacity. Table 1 lists the basic data of the reservoir. Figures 1 show the map of the reservoir.

The Baihe Reservoir is located in the poorly cemented sedimentary rock area. The bed rocks are mainly loose sandstone and mudstone. Therefore, when the heavy rain occurs, the slope collapse in the reservoir basin causes serious siltation problems. Serious siltation caused the following problems in the operation of the reservoir:

1. After the reservoir capacity is reduced, the water supply ability of the reservoir will also decrease, causing frequent fallow in the irrigation area. The water supply to the reservoir has dropped from 30 million tons per year 50 years ago to only 23 million tons now.
2. The silt blocking the outlets makes the water supply operation of the reservoir difficult, and the function of the emergency discharge at the outlets is affected during the flood. The water intake elevation of the main outlet is EL. 85.0m, but the siltation elevation nearby is often above EL.100m. The operator must artificially increase the height of the inlet tower to maintain the water intake function.
3. Severe siltation has caused problems in the reservoir's flood detention ability, because of the decrease of reservoir capacity. The highest flood level of the reservoir has been raised above the height of the core of the dam thus creating safety concerns.

Because of these problems, the Water Resources Agency promoted a series of reservoir reconstruction projects and planned a complete reservoir sediment venting strategy. It is expected that the reservoir will show prosperity again after 50 years of use.

Tab. 1: Table of Baihe reservoir basic data

Basic Data			Basic Data		
Reservoir	Catchment area	26.55km ²	Dam	TYPE	Earth filled dam
	Full water level	109.0m		Crown elevation	EL112.77~112.85m
	Max flood level	110.00m		Height of main dam	42.77~42.85m
	Original total capacity	2,509 million m ³		Length of main dam	210.0m
	Current total capacity	1,018 million m ³		Crest width of main dam	12.0m
Spillway	TYPE	Radial gate Controlled	Main Outlet	Height of saddle dam	8.5m
	Design discharge flow	735cms		Length of saddle dam	130.0m
	Max discharge flow	672cms		Crest width of saddle dam	8.0m
	Crest elevation	104.0m	BenjiHu Outlet	Design discharge capacity	64.2cms
	Width of crest	27.0m		Top of inlet towel	95.0m
	Length of chute	337.0m		Bottom of inlet towel	85.0m
	Radial gate	W8m×H5.54m×3m		High pressure gate	W1.5m×H2.2m×2m
BaishuiXi Outlet	Design discharge flow	5.0cms	BenjiHu Outlet	Design discharge capacity	4.65cms
	Diameter of tunnel	2.0m		Top of inlet towel	95.0m
	Length of tunnel	143.8m		Bottom of inlet towel	91.0m
	High pressure gate	W0.6m×H0.8m×2m		High pressure gate	W0.8m×H0.9m×2m

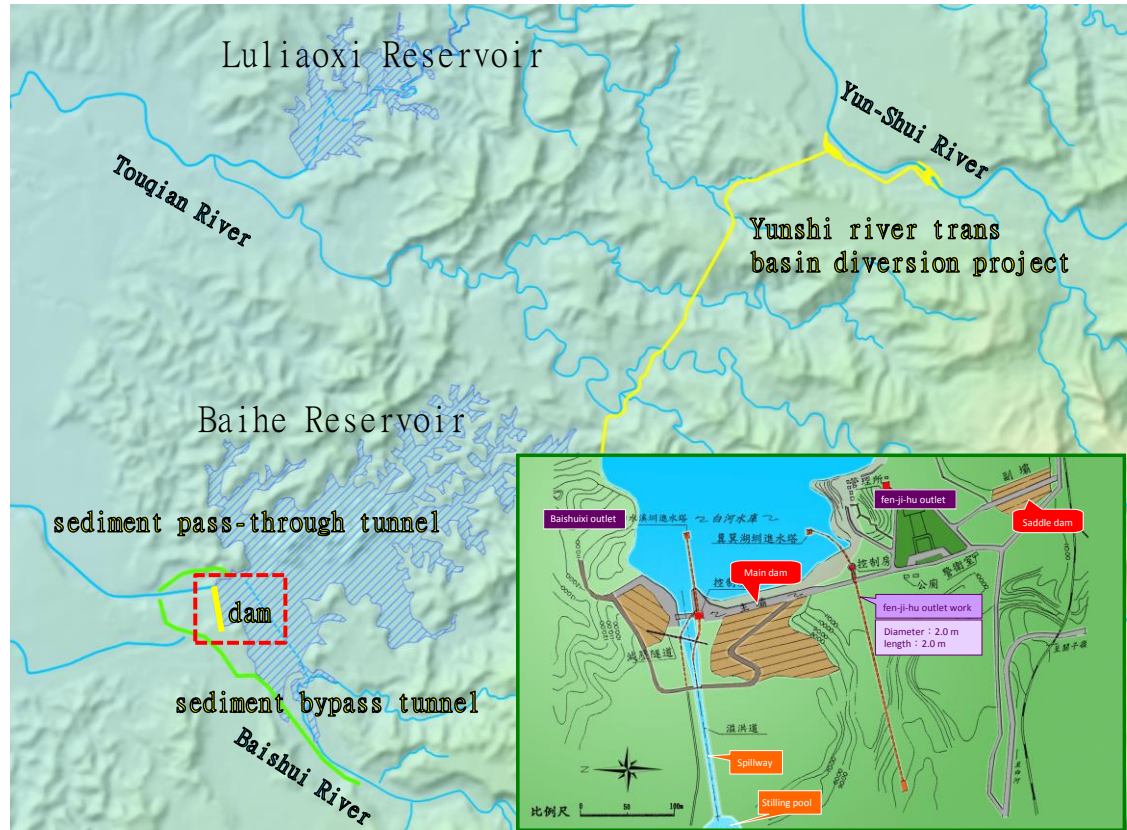


Fig. 1: Map of Baihe reservoir

2 Reconstruction project of reservoir

The Water Resources Agency has promoted a project of Baihe reservoir reconstruction since 2013. The purpose is to restore the water supply capacity of the reservoir and improve the sediment flushing ability. The main works includes: restore the capacity of the reservoir, heighten the core layer of the dam, repair the function of the outlet, and increase the flood discharge capacity of the reservoir, etc. All the reconstruction works is shown in Fig.1 and described as follows:

1. Restore the capacity of the reservoir: The capacity will restore to 20 million cubic meters by the mechanical excavation method before 2027, and the amount of excavation is expected to be 10 million cubic meters.
2. Repair the function of outlets: The reservoir will repair the inlet towers and replace the control gates of the main outlet 、baishixi outlet and benjiyu outlet in 2019.
3. Heighten the core of the main dam and saddle dam: According to the safety assessment, the maximum flood level of the reservoir (M.W.L. 111.37m) at the maximum possible flood (PMF) is already higher than the height of the original dam core layer, causing safety concerns. Therefore, the core of the main dam and the saddle dam are both raised to an elevation of EL.112.0m to comply with the safety regulations. This heightening work has been finished in 2017. The cross-section of the dam improvement as shown in Fig.2.
4. Build a new sediment pass-through tunnel: The new sediment pass-through tunnel is located in front of the dam, not far from the main outlet. The tunnel inlet elevation is two meters below the main outlet, which is EL. 83.0m. Therefore, after the completion of the new tunnel, it can not only increase the amount of flood discharge by 287cms, but also serve as the bottom outlet to eliminate the sediment. This pass-through tunnel, with a total length of 584 meters, will be finished in 2019. The plan and profile of the tunnel are shown in Fig.3 & Fig.4.
5. Build a new sediment bypass tunnel: The intake of new sediment bypass tunnel is located on Baishi river, on the upstream side of the reservoir's water storage range. In the storage period, a sediment bypass tunnel is necessary for sediment venting. This tunnel uses a five-year frequency flood as the design flow and the discharge is 200 cms. The intake is located on the riverbed below the high water level of the reservoir (H.W.L. 109.0m). When floods occur, sediment will be bypassed from the tunnel to the downstream river. This bypass tunnel, with a total length of 1,515 meters, is under design now. The plan and profile of the tunnel are shown in Fig.5 & Fig.6.
6. Plan a trans basin diversion project from Yunshi river: After the completion of sediment pass-through tunnel and bypass tunnel, the reservoir will implement a reservoir empty operation from mid-May to late-July each year. During this period, the

Technical drawing of the Baihe Reservoir spillway project, showing the intake tunnel, outlet tunnel, gate chamber, spill way, and Eenergy Dissipator. The drawing includes elevation markers, flow direction, and various structural details.

Key features and labels:

- Intake tunnel**: The main intake structure, labeled with $R=100m$.
- Outlet tunnel**: The main outlet structure, labeled with $R=200m$.
- Gate Chamber & Shaft**: The central structure where the intake and outlet tunnels meet.
- Spill way**: The structure for excess water, labeled with $R=100m$.
- Eenergy Dissipator**: The structure for dissipating the energy of the water, labeled with $R=100m$.
- Flow**: Indicated by a blue arrow pointing towards the spill way.
- Ok+383.02**: Elevation marker at the intake tunnel entrance.
- Ok+307.80**: Elevation marker at the outlet tunnel entrance.
- Ok+312.00**: Elevation marker at the gate chamber.
- Ok+014.00**: Elevation marker at the spill way.
- Ok+006**: Elevation marker at the Eenergy Dissipator.

Table 1: Elevation and structural data for the spillway project.

Structure	Structure (m)	Structure (m)	Structure (m)
W055	258379.8, 6.1	195990.20	112.71
N06	2583860.77	196000.32	112.89
N062	2583836.78	195961.81	112.88
NH04	2583828.21	195915.04	92.40
GA37	2583896.71	195981.91	
GT08	2584024.55	196034.39	
GT02	2583980.88	195971.07	

Table 2: Elevation and structural data for the spillway project.

Structure	Structure (m)	Structure (m)	Structure (m)
W055	19611.54	196063.34	19579.70
N06	2584035.28	258115.05	195949.94
NH04	88702.00	258117.11	
GA37	88702.00	258117.11	
GT08	25.74	50.40	
GT02	58.74	58.74	
Spill way	13.47	8.00	
Eenergy Dissipator	258132.81	258132.81	
Ok+383.02	258137.78	258137.78	

Fig. 4: Profile of Baihe reservoir sediment pass-through tunnel

3 Sedimentation prevention strategy of reservoir

When the reservoir reconstruction project is finished in 2027, the reservoir will restore to 20 million cubic meters of storage capacity. However, the reservoir catchment area still produces an average of 500,000 cubic meters of sediment per year. In order to maintain this 20 million cubic meter storage capacity, the Water Resource Agency has planned a complete operational strategy to prevent siltation.

This strategy shares the water source of the Yunshui river with the Luliaoxi Reservoir in the adjacent catchment. According to the plan, the water source of the Yunshui river is mainly used to supply the Luliaoxi Reservoir, and only supports the Baihe Reservoir during the empty period. With the water source support of the Yunshui river, the Baihe Reservoir can have sufficient water source to perform a relatively long empty flushing operation.

According to the plan, the Baihe Reservoir will be divided into three phases each year, as follows:

1. Empty flushing operation during flood season (mid-May to mid-July): During this period, there are plum rain and the first stage of typhoon season. If it is not raining, the reservoir will store water at a low water level and control the water level below EL.95m. The purpose is to keep the function of the water supply, and the silt at the bottom of the reservoir can be wet. In order to make a better scouring effect when the flood occurs.

Water storage at low water levels is not sufficient to supply irrigation water, and water supply from the Yunshui river is need during this empty flushing period.

If it rains, the reservoir will vent to empty before the flood. The flood from the Baishui River will carry the sediment through the pass-through tunnel to the downstream of the dam. During this process, the flood will wash the bed of the reservoir and increase the amount of sediment discharged.

2. Water storage operation during flood season (mid-July to late November): During this period, there is a second stage of the typhoon season. Although the flood will still carry sediment into the reservoir, for sake of water supply during the dry season, the reservoir must be started to store water and fill the reservoir before the end of the flood season.

The sediments carried by the floods during this period can be removed by the bypass tunnel to let the sediment flow through the bypass tunnel to the downstream of the dam before entering the reservoir.

3. Water storage operation during dry season (late November to mid-May): During this period of the dry season, the reservoir operation is dominated by water supply.

According to this operational strategy, Baihe Reservoir can raise water supply ability to nearly 27 million tons per year. And an annual average of 500,000 cubic meters of sediment is also close to 400,000 cubic meters, which can be eliminated by hydraulic flushing. Therefore, the amount of mechanical excavation is less than 100,000 cubic meters per year, which can reduce the burden on the management unit and make the sustainability of the reservoir possible. Table 2 lists the result of the Baihe reservoir water resource allocating analysis.

Tab.2: Table of Baihe reservoir water resource allocating analysis result

Period of empty flushing	Irrigation water supply	Civil water supply	Discharge amount of storage venting	Discharge amount of empty flushing	Discharge amount of spillway	Total sediment	Sediment of empty flushing	Sediment of turbid flushing	Sediment of bypass flushing
Mid-May to late-July (Concerned Yunshui river project)	2670	68.4	309	1484	368	50	23.8	0.8	20.2
Mid-May to late-July (Not concerned Yunshui river project)	2653	68.4	308	867	110	50	15.3	0.4	20.2

4 Conclusion

It is inevitable that reservoirs in the hilly areas of southern Taiwan will face serious siltation due to geological characteristics. After 50 years of use, Baihe Reservoir summarizes past observations and experiences as a guide for reconstruction reservoir project. We believe that after this reconstruction, the future operation of the reservoir will be better and sustainable.

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