



The process and strategy for Sun Moon Lake Reservoir sedimentation

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Abstract

Sun Moon Lake Reservoir, managed by Taiwan Power Company and located at the center of Taiwan geographically, was completed in 1934 and planned as a multiple-use project for hydropower, recreation, irrigation, and public water supply source. Its initial storage capacity is 171,620,000m³. The water of the Sun Moon Lake comes from Zhuoshui River by passing through Wujie Dam water tunnels. Sun Moon Lake is an upper reservoir for the pumped-storage power plant. Generating in the peaking hours and the tailwater is stored in the lower reservoir. Then, pumping it back in the off-peak hours for recycling. It serves to moderate the difference between peaking and off-peak power. Sun Moon Lake is also the largest and most important energy storage facility in Taiwan. However, having no scouring sluice makes Sun Moon Lake Reservoir deposit gradually. The current rate of reservoir sedimentation is 18.44% measured in 2017. The sedimentation may affect the maintenance of related facilities, Sun Moon Lake landscape and is also deeply concerned by all walks of life. In order to solve the problem of Sun Moon Lake Reservoir sedimentation, two strategies are implemented. (1) Lowering the amount of sediment inflow from Wujie Dam intakes. (2) Hydraulic dredging.

For reducing sediment inflow from intakes, two methods are undertaken. (1) Adjusting the standard of Wujie Dam intake. (2) Lowering the bottom elevation of Wujie Dam spillway gates. For hydraulic dredging, Sun Moon Lake Reservoir had been dredged 5,000 m³ in 2017 and 10,000 m³ in 2018. Then, it will be planned to dredge 30,000 m³ in 2019. However, the volume of hydraulic dredging is much less than the annual sediment inflow. The process and strategy of reservoir sediment deposits should consider many complex problems of cost, transport, earth-moving, techniques, laws, traffic and tourism. The Sun Moon Lake Reservoir is a famous tourist attraction therefore the sediment deposits is deeply concerned by all walks of life. Removing sediment in the reservoir by scouring sluice is still the most efficient method currently and it affects people's life less than others. While Sun Moon Lake Reservoir is an off-channel reservoir, building new drainage facilities doesn't have self-financing ratio for Taiwan Power company which is a state-owned enterprise. Therefore, Taiwan Power Company is now researching in water power generating with slurry to reduce the sediment deposits. Taiwan Power Company will still continue to solve the problem of Sun Moon Lake Reservoir sediment deposits in the situation of budget constraints.

Keywords: Sun Moon Lake Reservoir, sedimentation, hydropower, dredging

1 General instructions

Sun Moon Lake Reservoir, located at the center of Taiwan geographically and managed by Taiwan Power Company, was completed in 1934 and planned as a multiple-use project for hydropower, recreation, irrigation, and public water supply source. It was originally designed with inundating 8.32km² of floodplain and 171,620,000m³ of storage. It is not only the largest freshwater lake in Taiwan but also an off-channel reservoir by taking Zhuoshui River from Wujie Dam water tunnel. Zhuoshui River's characteristic is muddy all the year round. After the huge earthquake, measured 7.3 on the Richter scale, occurred on September 21, 1999 in Taiwan, it caused landslide of the upper reaches of Zhuoshui River and made sediment move downstream continually. Furthermore, because of having no scouring sluices, Sun Moon Lake Reservoir deposited gradually. According to the measurement in January 2018, the capacity had been reduced by about 18.44 percent, a storage loss of about 31,650,000 m³. Because the outlet of the Wujie Dam water tunnel is located at the Dazhu Lake, east side of the Sun Moon Lake Reservoir, the main sediment deposits accumulate there.

Sun Moon Lake Reservoir is the biggest and most important pumped-storage unit in Taiwan, generating in the peaking hours and tailwater is stored in lower reservoirs (Minghu Xiachi Reservoir、Mingtan Xiachi Reservoir), then pumping it back to the upper reservoir(Sun Moon Lake Reservoir) in the off-peak hours for recycling. Installed capacities for Sun Moon Lake Power System is about 2,772MW, and the percentage of that system is 6.62% of Taipower total installed capacities in 2017. Sun Moon Lake Reservoir is the most important peak-hour power generating system of Taiwan Power Company.



Figure 1.1 Plan around the Sun Moon Lake Reservoir



Figure 1.2 Dazhu Lake

2 Strategies for reducing sediment deposits

The suspended material coming from Wujie Dam intake and having no scouring sluice all result in the sediment deposits of Sun Moon Lake Reservoir. In order to reduce the sedimentation, two sediment control strategies are implemented. (1) Lowering the amount of sediment inflow of Wujie Dam intake. (2) Hydraulic dredging.

2.1 Lowering the amount of sediment inflow of Wujie Dam intake

Wujie Dam was completed in 1934 and maintained the dynamic effective capacity of 730,000m³ to 1,000,000m³ from 1935 to 2018 after scouring. Wujie Dam is designed for lifting the water level of Zhuoshui River to settling coarse sediments, then upper water with lower suspended-solid flows into the intake. By passing through the Wujie Dam water tunnel, 15.118km in length, and the New-Wujie Dam water tunnel, 13.957km in length, flowing into and stored in the Sun Moon Lake Reservoir for power generating finally. The maximum inflow of Wujie Dam water tunnel is 41.13cms, and the other is 41.6cms. Therefore, for reducing sediment inflow, two methods are undertaken. (1) Adjusting the standard of suspended-solids concentration and inflow of Wujie Dam intake. (2) Lowering the bottom elevation of Wujie Dam spillway gate.

2.1.1 Adjusting the standard of suspended-solids concentration and inflow of Wujie Dam intake

When the suspended-solids concentration of Zhuoshui River exceeds 44,000mg/L or inflow exceeds 120cms, Wujie Dam intake gates are closed to stop water inflow. However, in order to reduce the sediment inflow, the maximum values of suspended-solids concentration and inflow were lowered as 22,000mg/L and 65cms in 2014. To promote the operating efficiency of the intake gate, the automatic detective concentration sensor was established in 2018.



Figure 2.1 Wujie Dam plan



Figure 2.2 L Wujie intake



Figure 2.3 New-Wujie intake

2.1.2 Lowering the bottom elevation of Wujie Dam spillway gate

The Wujie Dam was designed for storing water of Zhuoshui River, then draw off the upper water after sediment precipitates. Therefore, Taiwan Power Company is researching into the promotion of the precipitability in the Wujie Dam for reducing the Sun Moon Lake Reservoir sediment deposits. By investigating the deposit of Wujie Dam, it consisted of clay and silt. According to the numerical simulation and estimation of the research carried out by Taiwan Power Company, the current precipitability of Wujie Dam is 68%. However, If the bottom elevation of Wujie Dam spillway gate can be reconstructed and reduced by 6m, the maximum precipitability can reach 89%. In other words, it can prevent 89% of inflow sediment from entering the Sun Moon Lake Reservoir, and the research is almost complete at present.



Figure 2.4 Wujie Dam

2.2 Hydraulic Dredging

2.2.1 Dredging and Removal

There are no scouring sluices in the Sun Moon Lake Reservoir, therefore the conventional strategy to reduce sediment deposits is hydraulic dredging. However, the sediment deposits excavation strategy should be suitable for the environment of the reservoir and consider many complex problems of cost, transport, earth-moving, techniques, laws, traffic and tourism. Because the Sun Moon Lake Reservoir is a famous tourist attraction, the sediment deposits is deeply concerned by all walks of life. Taiwan Power Company dredged 5,000m³ once in 2006. The elevation of the sediment deposits was close to the water level at that time, excavator was used. Then, shipping dredge material to the disposal site near the lake for engineered fill. However, yacht operators protested that shipping had influenced their channel, and the sediment disposal site was also involved with environmental concerns. As a result of the protest and environmental concerns, Taiwan Power Company stopped dredge until 2017 in accordance with the policy and for power generating operation. The volume dredged by excavator was 5,000m³ in 2017, then transporting to disposal pools constructed and surrounded by using rail pile for dewatered. After dewatered, the dredge material were moved to the legal earth dump site by trucking and the disposal pools can be reused. For increasing the dredge volume, Taiwan Power Company enlarged the disposal site and adopted the cutter-suction dredger in 2018. Then, the dredge volume had increased from 5,000m³ to 10,000m³. It is planned to dredge 30,000 m³ in 2019. However, the volume of mechanical dredge, including dry excavation and hydraulic dredging, is limited by many conditions and still much less than the annual sediment inflow of the Sun Moon Lake Reservoir.



Figure 2.5 Dredging by excavator in 2006



Figure 2.6 Sediment removal by shipping in 2006



Figure 2.7 Sediment was placed at Sun Moon Lake nearby for engineered fill in 2006



Figure 2.8 Sediment disposal site in 2017



Figure 2.9 Sediment removal by trucking in 2017



Figure 2.10 Cutter-suction dredger in 2018

Table 2.1 Cost of Sediment Removal from Sun Moon Lake Reservoir

Year	Volume removed,m ³	Unit cost (NTD/ m ³)	Unit cost (USD/ m ³)	Remark
2006	5,000	1,058	35.27	
2017	5,000	7,104	236.80	Including sediment disposal site constructed.
2018	10,000	1,294	43.13	

2.2.2 Water Power Generating With Slurry

Removing sediment in the reservoir by scouring sluice is still the most efficient method currently and it affects people's life less than others. While Sun Moon Lake Reservoir is an off-channel reservoir, building new drainage facilities doesn't have self-financing ratio for Taiwan Power Company which is a state-owned enterprise. Therefore, Taiwan Power Company is now researching in water power generating with slurry. By this way, sediment in the reservoir can be removed and back to the downstream Zhuoshui River finally by passing through existing water tunnels. The full basic design of research is implementing now. Firstly, Taiwan Power Company plans to pipe the slurry from the east side, Dazhu Lake, to the west side, Takuan-1 Power Plant intake. Secondly, the slurry will be adjusted as specific concentration and used for water power generating by passing through existing water tunnels. Finally, the tailwater flows back to Zhuoshui River from Chukung Power Plant.

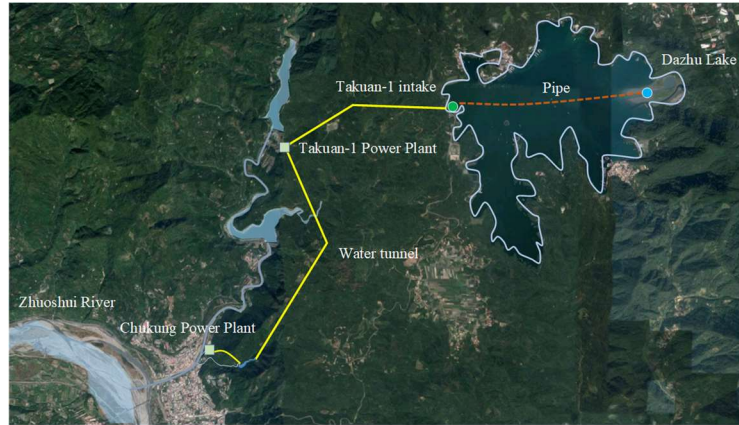


Figure 2.11 The layout of water power generating with slurry

The annual volume of hydraulic dredging is designed for 450,000m³. The hydraulic dredge facilities, including booster pump station, are scheduled to be set up in the Dazhu Lake area. The sediment deposits in the Sun Moon Lake Reservoir consist of silt and clay mainly after the coarse sediment precipitates in the Wujie Dam. Therefore, using cutter-suction dredger with electric power in accordance with the property of sediment deposits and protection of environment. Then, considering hydraulic dredge equipment used in Taiwan's reservoirs, high-density polyethylene pipe of 400mm in diameter from Dazhu Lake to Takuan-1 intake is adopted. The pipeline, 3km in length, around the center of Sun Moon Lake Reservoir will sink with adding concrete blocks except partial pipeline at two sides floats underwater.

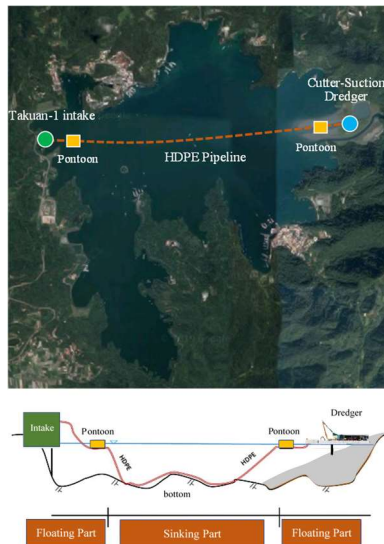


Figure 2.12 The pipeline layout

By piping 250,000mg/L slurry with conditions of 0.25cms inflow, 6.5 hours a day, and 256 days a year, the annual volume of hydraulic dredging in the Sun Moon Lake Reservoir is estimated to be 450,000m³. However, In order to conform to the environmental laws, the suspended-solids concentration of Chukung Power Plant

tailwater must not exceed the legal limit during power generating with slurry. Therefore, there are five turbines of which total inflow is 46.5cms in the Takuan-1 power plant, and the preliminary estimate is that two turbines at least need to be operated. Because there is no research on water power generating with slurry in Taiwan, the influence of slurry on turbine abrasion is unknown yet. However, referring to operation experience of Sanmenxia Reservoir in China, the suspended-solid during water power generating is less than 0.05mm in diameter. According to the investigation, the sediment deposits of the Sun Moon Lake Reservoir is less than 0.03mm in diameter. Then, Taiwan Power Company will make the experiment of power generating with slurry, to confirm the influence on turbine abrasion and test for suspended-solid concentration of tailwater.

3 Conclusions

The process and strategy of reservoir sediment deposits should consider many complex problems of cost, transport, earth-moving, techniques, laws, traffic and tourism. The Sun Moon Lake Reservoir is a famous tourist attraction therefore the sediment deposits is deeply concerned by all walks of life. Removing sediment in the reservoir by scouring sluice is still the most efficient method currently and it affects people's life less than others. While Sun Moon Lake Reservoir is an off-channel reservoir, building new drainage facilities doesn't have self-financing ratio for Taiwan Power Company which is a state-owned enterprise. Therefore, Taiwan Power Company is now researching in water power generating with slurry to reduce the sediment deposits, and will continue to solve the problem of Sun Moon Lake Reservoir sediment deposits in the situation of budget constraints.

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