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Sustainability of Shimen Reservoir by desilting tunnel in Taiwan

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ABSTRACT

Earthquake and typhoon are two major natural hazards in Taiwan. Earthquake-triggered landslide in mountain areas accompany with torrential rainfall supply large amount of sediment to river basin and cause sediment accumulated in reservoir. Considering the strategies used to reduce sediment delivery or prevent sediment deposition, hydraulic desilting has proven to be the most effective and economical method. Thus desilting tunnels have been implanted to release sediment of reservoirs in Taiwan recently.
Shimen Reservoir, after 54 years of operation, is facing severe siltation problem. According to siltation survey, 33% of the storage volume was occupied by silt. To solve the problem, Water Resources Agency (WRA) decided to construct a desilting tunnel with intake structure located at Amuping area, which is 7 km upstream from the dam. After completion, the tunnel could carry silt as well as coarse and fine sand to the outlet structure. The desilting tunnel is expected to discharge silt and enhance flood-discharging capability as well.

Keywords: Shimen Reservoir; sediment; desilting tunnel

1 INTRODUCTION

In recent year, abnormal hydrologic activities caused by climate change trigger frequent and extreme rainfalls. The tendency of reducing rainfall duration and increasing rainfall intensity becomes more and more obvious. The difference of annual precipitation is significant. Referring to Figure 1, the annual precipitation reaches 3,568 mm in wet years which is over two times of those in dry years (1,572 mm). Climate changes in the last couple of years, Taiwan has suffered the continuous drought in year 2014, 2015 and 2017.

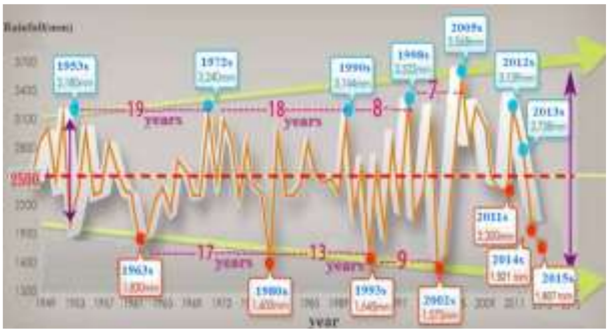

Fig 1. Annual precipitation in Taiwan

Moreover, heavy rainfall and landslide had caused reservoir to lose capacity rapidly. For example, Aere typhoon in 2004 and Morakot typhoon in 2009 caused Shimen, Zengwen and Nanhau reservoirs to lose capacity about 9% to 12% of its original storage volume (Table 1). Especially for Aere typhoon, the flood-induced high sediment concentration more than 200,000 Nephelometric Turbidity Unit (NTU) in Shimen Reservoir cut-off water supply for 18 days.

Table 1. Typhoon events cause reservoirs lose capacity

Reservoir	Typhoon (Year)	Original storage (10^6m^3)	Siltation (10^6m^3)	Ratio
Shimen	Arre (2004)	309.12	27.88	9%
Zengwen	Morakot (2009)	748.40	91.08	12%
Nanhau	Morakot (2009)	158.05	17.06	11%

2 STRATEGIES AGAINST SEDIMENTATION

In general, three different strategies are considered for reservoir sediment management:

- Reduce sediment delivery (catchment management)
- Prevent sediment deposition (route sediments)
- Increase or recover reservoir volume (removal of deposited sediments)

Figure 2 shows a variety of sediment management techniques proposed by Kondolf et al. (2014) including the three strategies. A combination of several measures from the above categories is necessary to maintain reservoir capacity and achieve reservoir sustainability. In overall, hydraulic desilting is the most effective and economical method to release sediment out of reservoir.

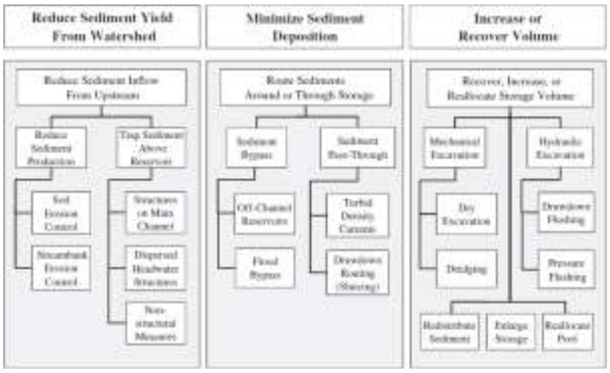

Fig 2. Diagram of sediment management options for reservoir sustainability (Kondolf et al.2014)

Based on the consideration, hydraulic desilting projects have been implanted for many reservoirs in Taiwan (Figure 3). For example, a rehabilitation program of Agongdian reservoir was completed in 2005 which practices empty flushing sediment in flood season every year. Two sluicing tunnels are under construction for Zengwen and Nanhau reservoirs separately to discharge the high turbidity water during flood period. Furthermore, a desilting tunnel is under construction and a sluicing tunnel is under planning for Shimen reservoir.

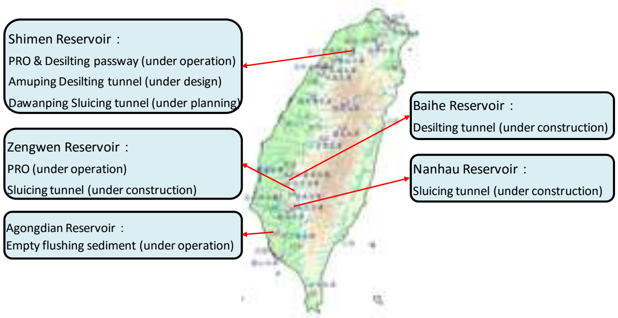

Fig 3. Hydraulic desilting project in major reservoir

Shimen Reservoir is a unique case in all of the reservoirs. In order to solve the problem of severe siltation, WRA proposed a integrated desiltation strategies as shown in Figure 4. By the combination of mechanical removal, dredging, and hydraulic discharge, the sediment discharge amount is up to 2.07×10^{6}m^{3}/yr. It should be especially noted for the hydraulic desilting passway, which is reconstructed from existing penstock in 2012 and works as a bottom outlet for the dam with a discharge capacity of 300 m^{3}/s. The passway has desilted 3.1 million m^{3} of sediment during the typhoon period in 2013-2016.

In order to solve the problem of severe siltation, WRA decided to build a desilting tunnel, which is a bypass tunnel with the intake structure at river section 19—about 7 km upstream from the dam and discharge coarse sand and fine sand directly. The desilting tunnel is expected to deal with sever siltation and enhance the flood-discharge capacity. The details of desilting tunnel for Shimen Reservoir are introduced as follows.

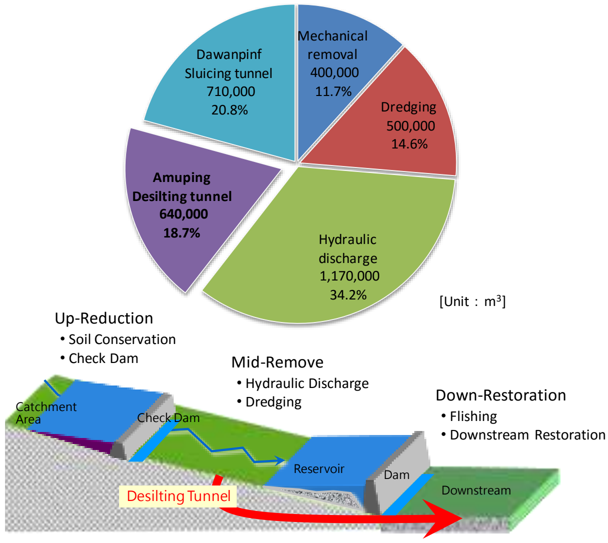

Fig 4. Integrated desiltation strategies for Shimen Reservoir

3 DESILTING TUNNEL OF SHIMEN

Shimen Reservoir is the main water conservation facility in northern Taiwan, which possesses the function of irrigation, electric power generation, water supply, flood prevention and tourism. The Shimen Reservoir dam impounds the water from Dahan River with the catchment area of 763.4 km^{2}. The designed storage volume is 3.09 × 10^{8}m^{3} and the assumed sediment discharge is 3.42×10^{6}m^{3}/yr. The location of Shimen Reservoir is shown in Figure 5.

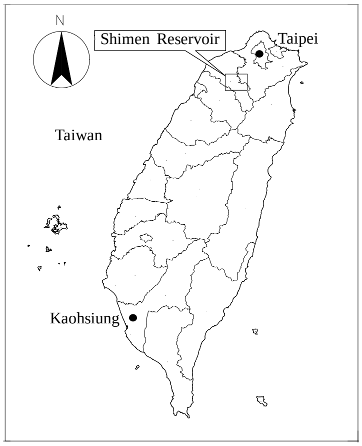

Fig 5. The location of Shimen Reservoir

Because of the climate change today, heavy rainfall have occurred frequently which causes large amount of sediment flushing into the reservoir. According to the siltation survey, the capacity of the water conservation decreases to 2.08×10^{8}m^{3}, which is only 67.4% of its designed storage volume. The profile of river bed at

Shimen Reservoir for each heavy typhoon event shown in Figure 6. In addition, the loss of water storage may affect water supply and impact existing infrastructure, particularly to the outlet works and turbine intakes.

In order to solve the siltation problem, WRA planned to build a desilting tunnel. The project is expected to be completed in 2022.

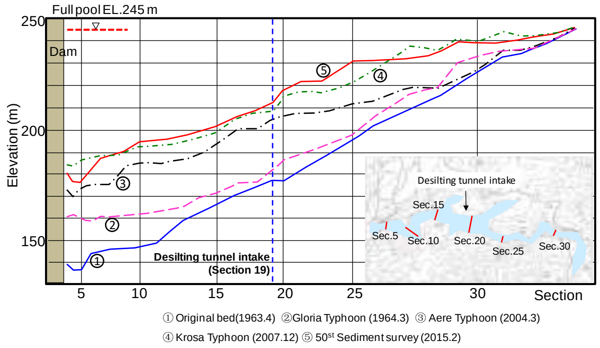

Fig 6. Siltation survey for the typhoon events

3.1 Layout of Desilting Tunnel

The desilting tunnel consists of intake structure, adit, desilting tunnel, sifting facilities, outlet structure, and deposition pool. The general layout is shown in Figure 7. The intake structure is 80 m long and situated at Amuping area, which is 7 km upstream from the dam. The length of the desilting tunnel is 3,702.2 m with a varied slope from 10% to 2.863%. The typical cross section of the desilting tunnel is hood-type with 8 m in width and 7 m in height as Figure 8 shown. A 306 m long adit connected to desilting tunnel at millage of 0k+309 serves as the access route during construction period and also works as the maintenance route after completion.

The desilting tunnel works as a transportation channel in which four steel pipes are installed and the silt dredged by the upstream dredging boats is transported via the pipes. The silt will be screened by sifting facilities at the exit of the tunnel and be separated into coarse sand and fine sand respectively. The coarse sand is valuable and can be used as the mixing materials for concrete. On the other hand, the fine sand will be stored in the deposition pool and discharged to the downstream during typhoon or heavy rainfall period.

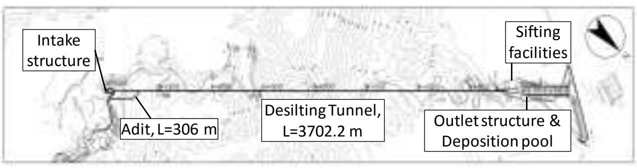

Fig 7. Plan view of the sediment desilting tunnel at Shimen Reservoir

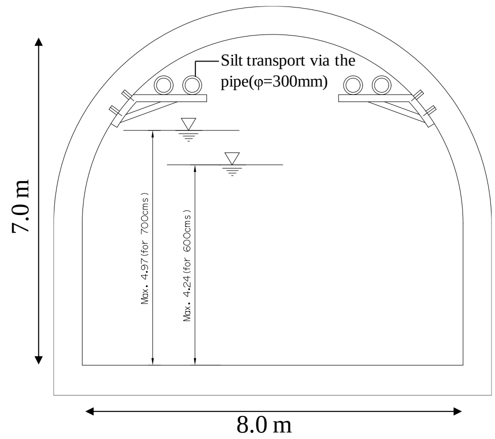

Fig 8. Typical desilting tunnel cross section

In addition, the intake structure is designed by the following criteria:

·The design flood-discharging capability for tunnel is 600 m^3/s (El. 242 m) and the maximum discharge is 700 m^3/s.

·Ensure the required freeboard in the tunnel and the safety of operation while desilting operate (The freeboard remains 25% with 600 m^3/s and 15% with 700 m^3/s).

·To avoid the flow chock happening, the shape of intake is designed as streamline shape. The width at the entrance of tunnel is 14.2 m as shown in Figure 9.

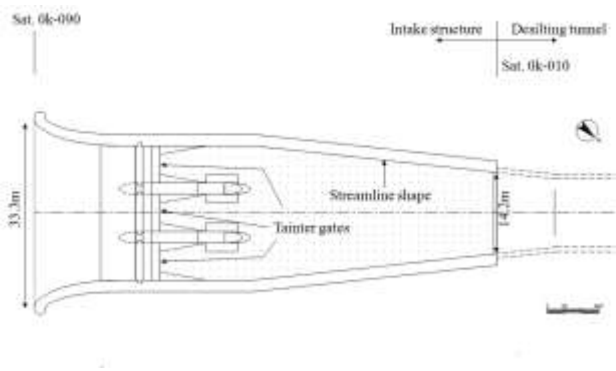

Fig 9. Plan view of intake structure

3.2 Objectives

Two major objectives arise from the desilting tunnel:

· Enhance the desilting capability and decrease sediment of the reservoir.

·Enhance the flood-discharging capability to ensure the safety while extreme hydrology events happened.

WRA has proposed a integrated desiltation strategies to solve the problem of severe siltation. By adopting the methods of mechanical removal, dredging, and hydraulic desilting, the sediment discharge amount is up to 2.07×10^6 m^3/yr. Furthermore, the Amuping desilting tunnel, which is a bypass tunnel for the reservoir, will be built and is expected to discharge silt 6.4×10^5 m^3 per year.

The desilting tunnel is expected to provide 600 m^3/s flood-discharging capability and enhance the safety of Shimen Reservoir as well.

3.3 Multifunction of Desilting Tunnel

The processing and elimination of silt from the reservoir becomes more and more serious problem in recent years. Therefore, WRA plan to dredge the silt from the upstream area where the percentage of coarse sand (diameter ≧ 0.1 mm) is over 50%. The silt transport via the pipe in the tunnel and be screened by sifting facilities at the exit of the tunnel. Since the coarse sand is valuable, it will be screened, separated from the fine sand and then sold and reused. Besides, unnecessary water storage from the reservoir will be drained by the desilting tunnel. The fine sand, which is stacked in the deposition pool, will be flushed toward downstream at typhoon period. Thus the desilting tunnel not only solves the problem of sediment of the reservoir but also the problem of silt elimination.

Furthermore, the desilting tunnel can be used as an access road which provides the trucks transportation during drought period. As the reservoir level is below El. 210 m, the mechanical removal measure can be adopted on the river bed at Amuping area where the elevation is around El. 236 m. It's definitely a more efficient method compared with dredging. The multifunction of the desilting tunnel is shown in Figure 9.

3.4 Reused by Sifting Facilities

According to the efficiency concern, one vibrating screen, three sand washers and three sand separators are designed to install, along with the area about 6,000 m^2 including the storage area. The silt is separated by the facilities and divided into 4 parts:

·Gravel or wood, which retained above No.4 (4.76 mm) sieve.

·Coarse sand, which passing the No.4 and retained on the No.18 (1.00mm) sieve.

·Fine sand, which passing the No.18 and retained on the No.200 (0.074mm) sieve.

·Scourable particles, which passing the No.200 sieve and store in the deposition pool.

The process and layout of the sifting facilities is shown in Figure 10. The vibratory screen with No.4 sieve screened out gravel and wood first. The rest is transported to sand washers and sand separators to be separated into fine sand and coarse sand. It is assumed that over 50% of the silt can be classified as coarse sand and re-usable, the amount is about 3.2×10^5 m^3 per year.

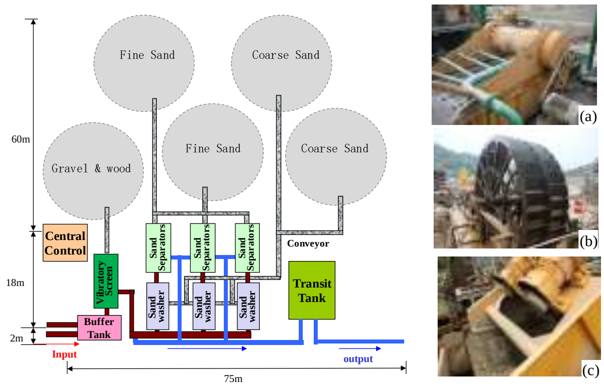

Fig 10. Process and layout of the sifting facilities (a) vibratory screen (b) sand washer (c) sand separators

4 CONCLUSION

Due to the climate change, extreme hydrology events have occurred frequently, large amount of sediment is flushed into the Shimen Reservoir. The capacity of the water conservation decreases from 3.09×10^8 m^3 to 2.08×10^8 m^3 in the past 54 years, which is 67.4% of its designed storage volume. It is predicted that heavy rainfall and landslide may cause reservoir to lose capacity more severely and may even cut-off water supply.

In order to sustain the life and ensure the safety of Shimen Reservoir, WRA has completed many measures such as soil erosion control of the upstream areas, digging, dredging, flushing and sluicing. Considering all of the remediation measures, hydraulic desilting proves to be the most economical and rapid method.

Taking effectiveness and economical efficiency into account, a desilting tunnel is planned to construct and is expected to enhance the desilting and flood-discharging capability. The purpose is to deal with 6.4×10^5 m^3 silt per year and provide 600 m^3/s flood-discharging capability.

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