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Citation	Proceedings of the 2nd International Workshop on Sediment Bypass Tunnels (2017): 1-8
Issue Date	2017
URL	http://hdl.handle.net/2433/245494
Right	
Type	Research Paper
Textversion	author

Kyoto University

May 9-12
Kyoto-Japan
2017

2nd International Workshop on
Sediment Bypass Tunnels

Design concepts of desilting tunnel at Shimen Reservoir in Taiwan

Yan-Jhih Lin, Min-Chen Lee, Hsien-Tsung Chiang, Ting-Hua Chang and Bin-Ru Tsai

Abstract

In northern Taiwan, Shimen Reservoir is the main water conservation facility, which has the function of irrigation, electric power generation, water supply, flood prevention and tourism (Figure 1). Through 53 years of operation, the most challenging issue of the reservoir is severe siltation. The capacity of the water conservation is decreasing and 20% of the effective storage volume was lost due to siltation. Furthermore, the frequency of heavy rainfall has increased due to global climate change, so it has become imperative to develop measures to enhance silt-sluicing and flood-discharging capabilities of the reservoir. Accordingly, Water Resources Agency (WRA) planned to build a desilting tunnel, whose intake structure is situated at Amuping area, 7 km upstream from the dam. After completion, the tunnel could carry silt as well as coarse and fine sand outward to the outlet structure. The desilting tunnel is expected to deal with 6.4×10^5 m^3 silt per year and increase 600 m^3/s flood-discharging capability as well.

Keywords: desilting tunnel, Shimen Reservoir

1 Project overview

1.1 Project background

For Shimen Reservoir, the 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.

Because of the obvious climate change in previous decade, extreme hydrological events happened frequently, large amount of sediment is flushed into the reservoir. According to the silt survey in 2015, the capacity of the water conservation decreases from 3.09×10^8 m^3 to 2.08×10^8 m^3, which means only 67.4% of its original storage volume is remained.

Therefore, WRA planned to build a desilting tunnel. The basic design has been completed right now, and the following turn-key basis bid will be announced in 2017. The project is expected to be completed in 2022.

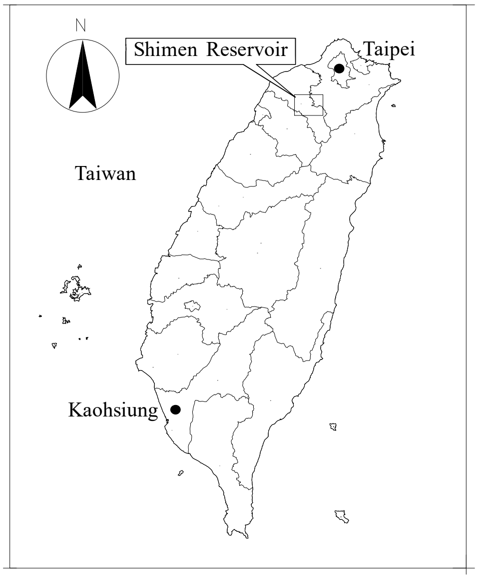

Figure 1: Location of Shimen Reservoir in Taiwan

1.2 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 hydrological events happened.

In order to solve the problem of severe siltation, the agency proposed the integrated desiltation strategies (Table 1). Recently, by the methods of mechanical removal upstream, 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 of the reservoir, is expected to deal with 6.4 × 10^5 m^3 silt per year. The desilting tunnel is designed to provide 600 m^3/s flood-discharging capability as well.

Table 1: The integrated desilting strategies of Shimen Reservoir

Item	*Mechanical Removal* [10^3]	*Dredging* [10^3]	*Hydraulic Desilting* [10^3]	*Desilting Tunnel* [10^3]
Sediment Discharge [m^3/yr]	400	500	1170	640

2 Layout of desilting tunnel facilities

The desilting tunnel consists of the intake structure, adit, desilting tunnel, sifting facilities, outlet structure, and deposition pool. The length of the intake structure is 80 m and is situated at Amuping area, 7 km upstream from the dam. The length of the desilting tunnel is 3,702.2 m with a various slope from 10% to 2.863% (Figure 2). The 3D sketch intake shows in Figure 3a. The typical cross section is 8 m in width and 7 m in height (Figure 3b). Some information and dimensions about the tunnel shows in Table 2. For the requirement at maintenance stage and the usage during the construction period, an adit is designed for 306 m in length and connects to desilting tunnel.

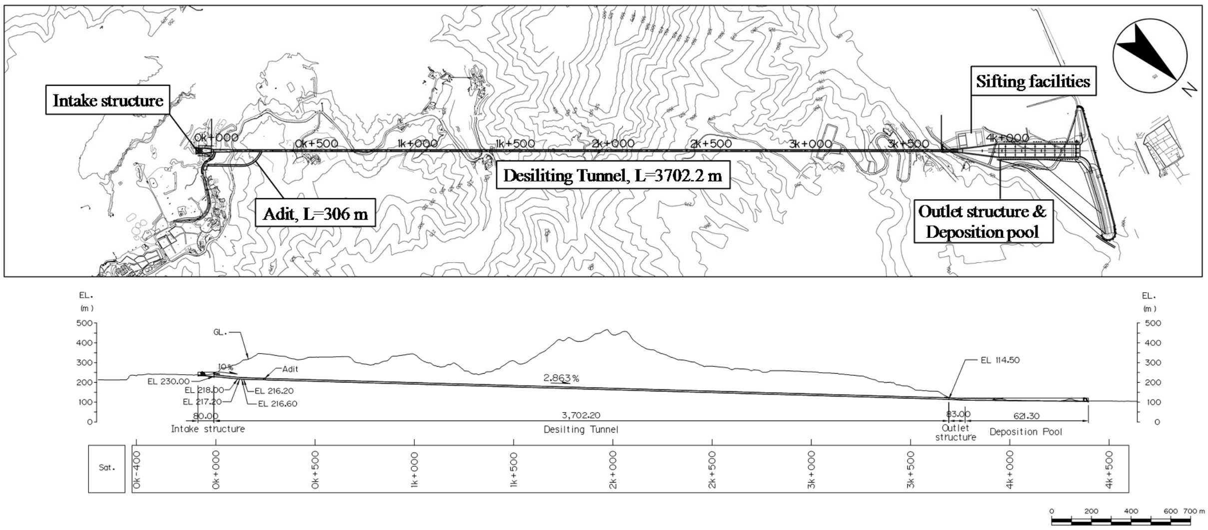

Figure 2: Plan view and profile of the sediment desilting tunnel at Shimen Reservoir

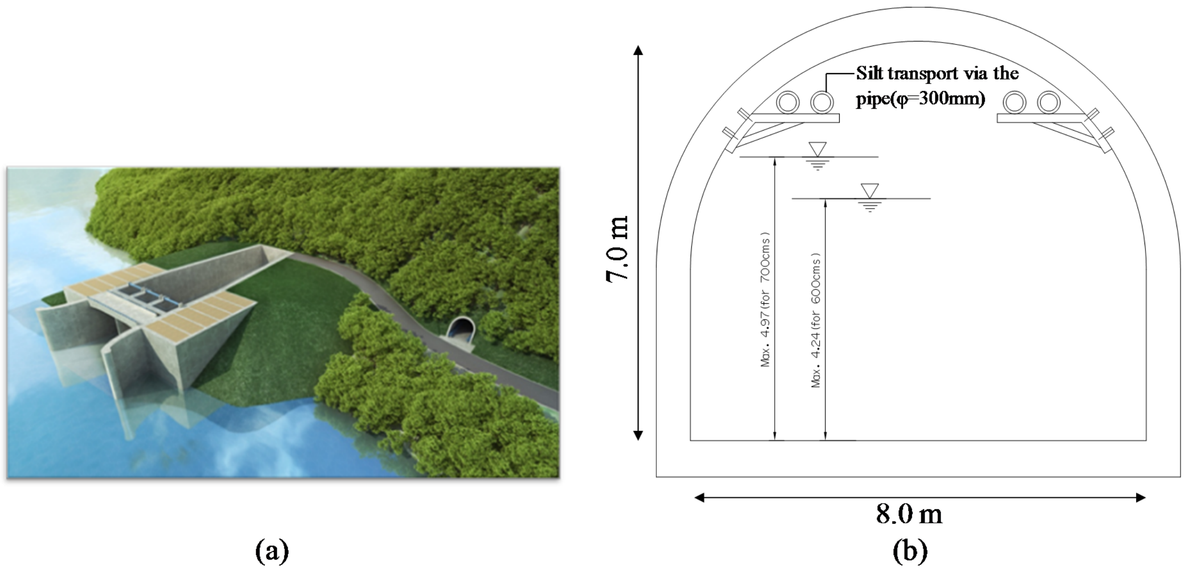

Figure 3: (a) 3D sketch for the intake; (b) Typical desilting tunnel cross section

The desilting tunnel is a transportation channel which dredging boats dredge upstream and the silt transport via the pipe in the tunnel. The silt will be screened by sifting facilities at the exit of the tunnel and be separated into fine sand and coarse sand as usual. During typhoon and flood period, the fine sand, which is stacked in deposition pool, is discharged to the downstream and the coarse sand will be reused.

Table 2: Information and dimensions of desilting tunnel

Sat.	*0k-010~ 0k+000*	*0k+000~ 0k+070*	*0k+070~ 0k+110*	*0k+110~ 0k+150*	*0k+150~ 0k+200*	*0k+200~ 3k+692.2*
Width [m]	14.2~12	12	12~8	8	8	8
Height [m]	11.1~8	8	8~7.5	7.5	7.5~7	7
Lining thickness [cm]	80	80	60	60	60	60
Slope	10%	10%	10%	8%~2.863%	2.863%	2.863%
Flow velocity [m/s]	9.7~11.9	11.9~16.1	16.1~17.0	17.0~17.7	17.7~17.9	17.9~20.2
Section type			Variation			Standard

3 Hydraulic analysis and model test

3.1 Hydraulic design of intake structure

- 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 4 and 5.

3.2 Model test results of 1/40 whole field model

The deposition pool has three channels with 621.3 m in length. Two cases were simulated in field model and with the difference in channel width (Case A: 20 m for each channel; Case B: 15 m for each channel). In order to confirm the behavior and results of desilting, a 1:40 scale undistorted model test was proceeding, as shown in Figure 6.

The results of test are summarized as the follows:

- Under the condition of reservoir storage at El. 242 m, the modified design discharge 600 m^3/s can get into the intake smoothly.

- According to the results of experiment, the sediment flushing rate of Case B (85.2~90.1%) is better than Case A (69.2~84%). But the total sediment discharge amount of Case B (1.1 × 10^5 m^3) is less than Case A (1.3 × 10^5 m^3).
- Concern about the more discharge amount, The deposition pool is designed base on Case A (20 m for each channel).

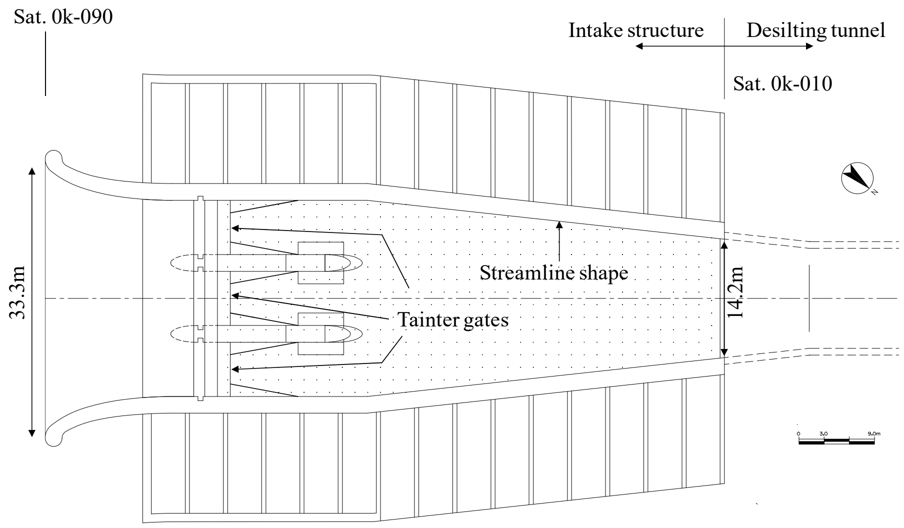

Figure 4: Design of intake structure and hydraulic analysis of intake

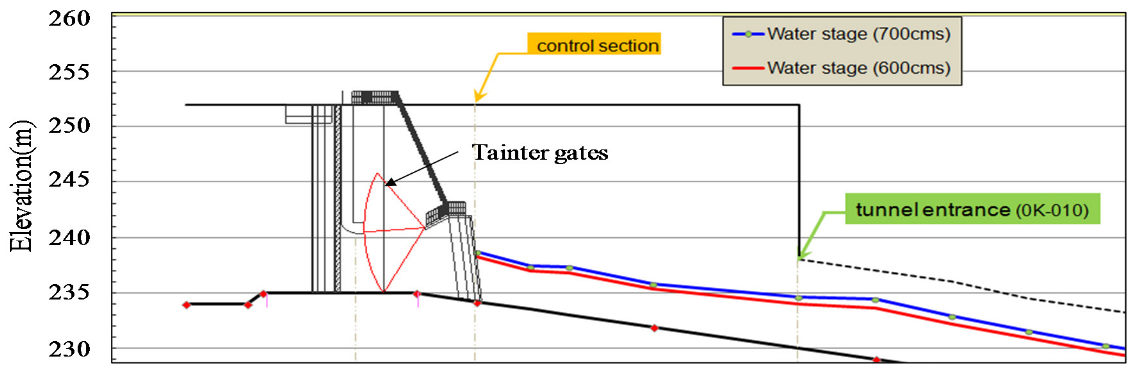

Figure 5: Hydraulic analysis of intake

4 Characteristics

4.1 Multifunction of desilting tunnel

The desilting tunnel in Shimen Reservoir is expected to deal with 6.4 × 10^5 m^3 silt per year and provides 600 m^3/s flood-discharging capability as well. Recently, the processing and elimination of silt from the reservoir becomes more and more serious problem. Therefore, we plan to dredge upstream, 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. The coarse sand is screened by the facilities and is separated from the fine sand, then be sold and reused. Besides, unnecessary water storage from the reservoir will be drained by the desilting tunnel, and the fine sand, which is stacked in the deposition pool, will be flushed toward downstream at typhoon period (Figure 7). Thus, the desilting tunnel not only solves the problem of sediment of the reservoir but also the problem of silt elimination.

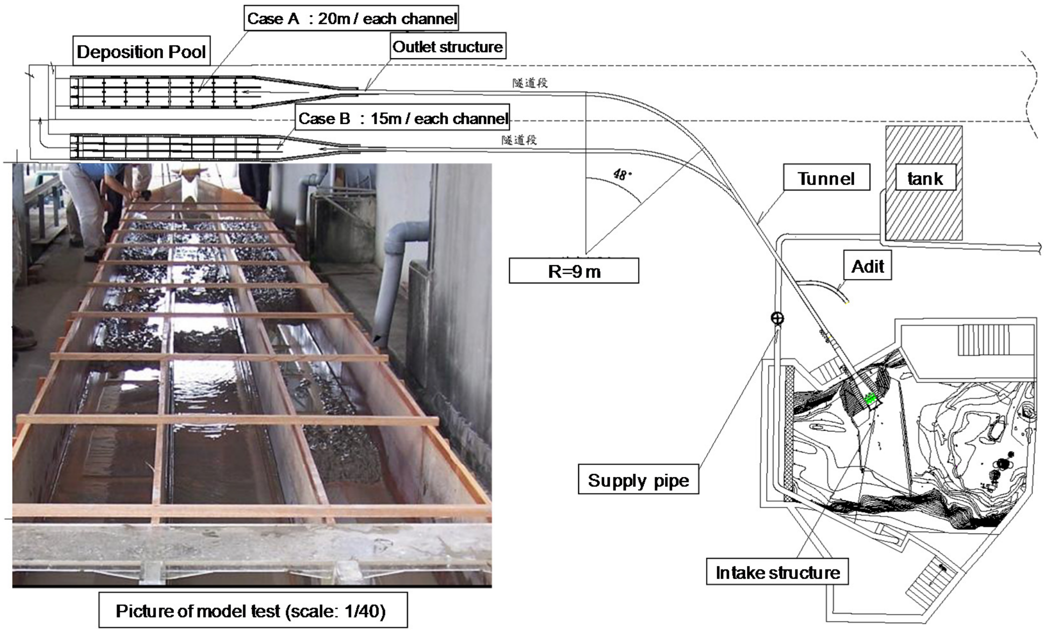

Figure 6: Layout of physical model for sediment desilting tunnel (scale: 1/40)

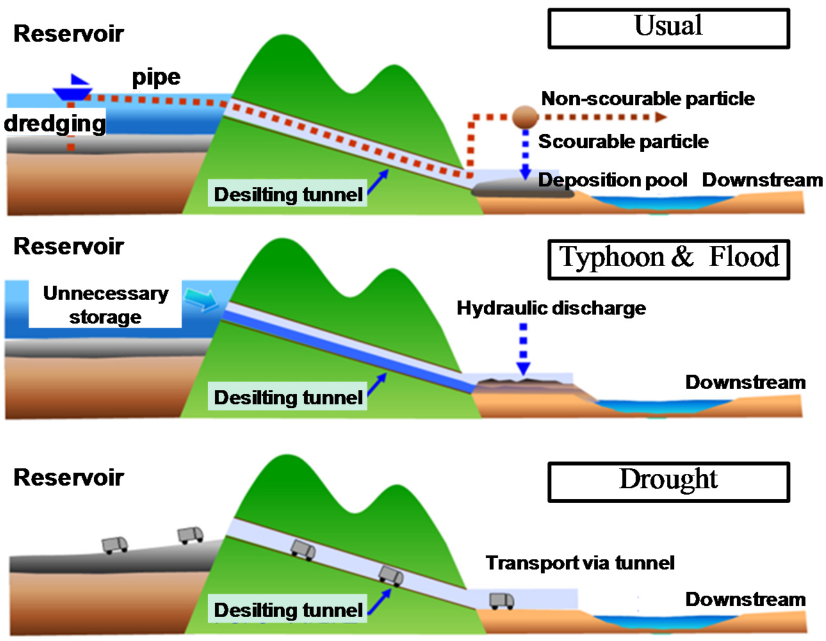

Figure 7: Multifunction of the desilting tunnel at Shimen Reservoir

Furthermore, the desilting tunnel can be used as an access road which provides the trucks pass by during drought period. As the reservoir level below El. 210 m, the mechanical machines can dig directly on the river bed at Amuping area, which elevation is around El. 236 m. It's definitely a more efficient method compared with dredging.

4.2 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 can be 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 (1.00 mm) sieve
- Fine sand, which passing the No.18 and retained on the No.200 (0.074 mm) sieve
- Scourable particles, which passing the No.200 sieve and store in the deposition pool

The vibratory screen with No.4 sieve screened out gravel and wood first. The rest is transported to sand washers and sand separators, then be separated into fine sand and coarse sand. A sand washer and a separator connect as a set in series and parallel for three sets (Figure 8). Over 50% of the silt is expected to be sold and reused, and the amount is about 3.2×10^5 m^3 per year.

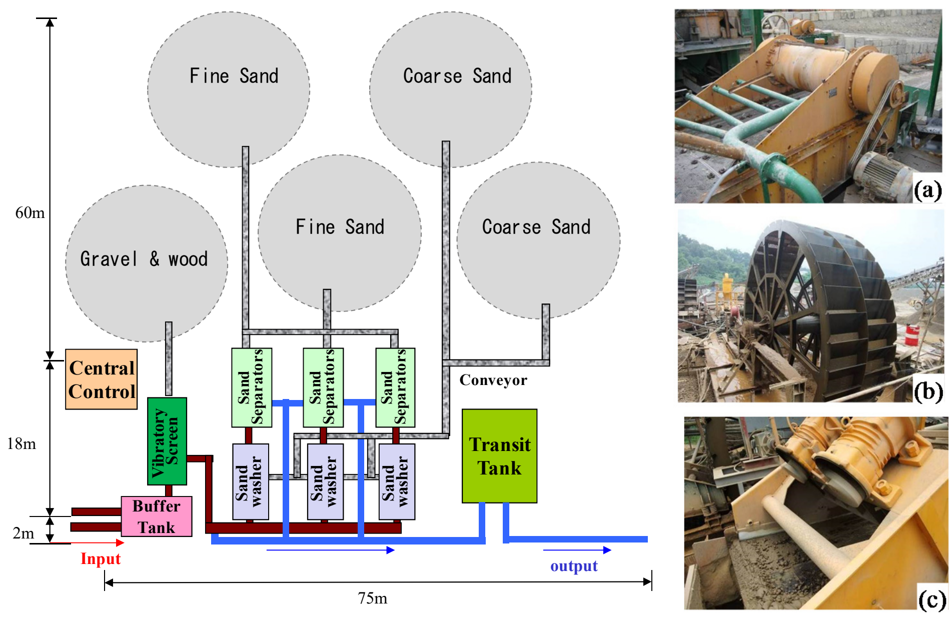

Figure 8: Process and layout of the sifting facilities; Sifting facilities (a) vibratory screen (b) sand washer (c) sand separators

5 Conclusions

In order to solve the problem of severe siltation in Shimen Reservoir, a desilting tunnel is planned to built and is expected to enhance the desilting and flood-discharging capability. The requirements are to deal with 6.4×10^5 m^3 silt per year and provide 600 m^3/s flood-discharging capability.

According to the hydraulic analysis results, the intake is designed as streamline shape and the typical cross section of the tunnel is 8 m in width and 7 m in height. Hydraulic model test shows that flood discharge with 600 m^3/s can go through the intake smoothly, and the sediment flushing rate of deposition pool, which has three channels (width 20 m each), is 69.2~84%.

By the sifting facilities, which consist of vibrating screen, sand washers and sand separators, 50% of silt can be selected and reused. Thus, it not only solves the problem of sediment of the reservoir but the problem of silt elimination.

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