April 9-12
Taipei-Taiwan
2019

3rd International Workshop on
Sediment Bypass Tunnels

The Conversion of Shihmen Reservoir's #2 Penstock into A Silt-Sluice Way

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Abstract

Shihmen Reservoir is one of the most important water resources facilities in northern Taiwan. Completed in 1964, the reservoir was designed with a small bottom outlet and a large surface spillway. The resulting "store turbid-water and discharge clear-water" operation during typhoons caused considerable siltation in the reservoir. Since there exists no alternative dam site for future development, measures to balance inflow and outflow sediments and to make reservoir volume sustainable become necessary.

To develop a sizeable bottom outlet without the need of constructing a new intake in a 70m deep water environment, a scheme to convert one of the existing penstocks into a silt-sluiceway had been implemented. This paper presents the conversion scheme and operation experiences of silt-sluiceway from 2013 to 2016.

Keywords: bottom outlet, penstock, silt-sluice, reservoir sedimentation

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1. Introduction

On August 24 and 25, 2004, Typhoon Aere evaded northern Taiwan, with an average precipitation in the watershed of about 973mm in 2 days. The intense storm caused severe landslides and resulted in 27.88Mm^3 of sediments deposited in Shihmen reservoir. Figure 1 depicts the reduction of reservoir volume from river closure in 1963 to 2015. As shown, about 1/3 of the volume had been lost due to siltation.

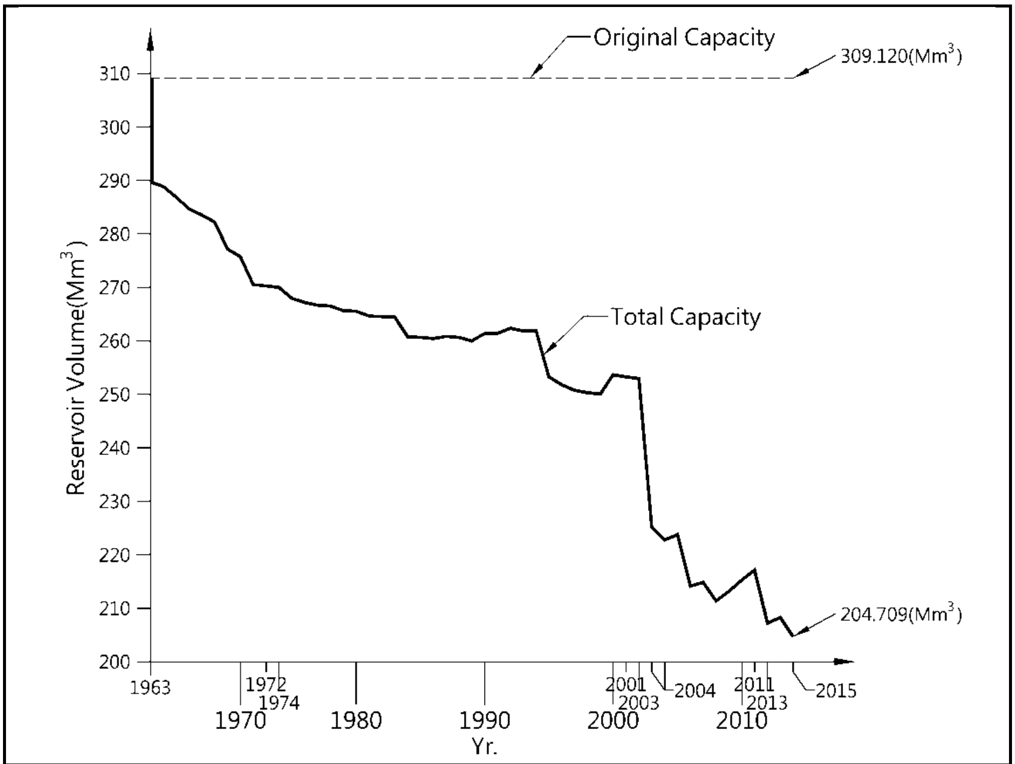

Figure 1 Shihmen Reservoir Volume, 1963~2015

Photo 1 Mud Flow from Penstock Following Typhoon Aere

In addition to the loss of reservoir volume, one important impact was a prolonged period of high turbidity in the lower part of the reservoir and waters withdrawn from PRO or turbines were too turbid to be purified. That led to a suspension of potable water supply for 18 days during a hot and humid summer season. Figure 2 shows that on or before September 1, the reservoir had formed a stratified turbid pond with a clear interface at about El.207m. The turbidity was less than 100NTU above the interface versus 100,000NTU below. From September 1 to September 30, this interface lowered only about about 7m. The average falling rate of 1 cm/hr is about 1/180 of falling speed of a single 0.008mm diameter particle. Photo 1 shows mud-flow released from penstock at that time.

Due to a lack of large bottom outlets in the original design, Shihmen Reservoir can only rely on spillway (crest elevation eL.235.0m) and/or two tunnel spillways (invert elevation of intake at EL.220.0m) to release flood and turbid flow during typhoon seasons. This resulted in the so-called “store turbid water and release clear water” operations, and high rate of siltation in the reservoir.

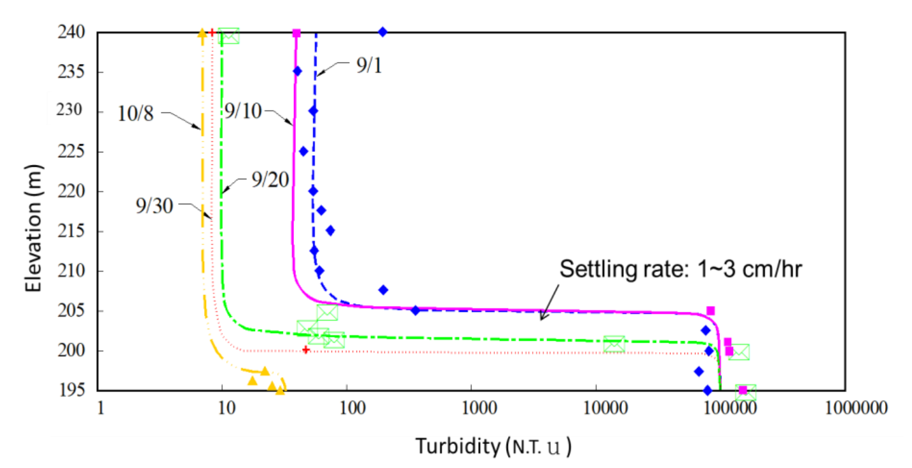

Figure 2 Turbidity in Front of Intake Following Typhoon Aere(2004)

Water supply from Shihmen Reservoir is vital to northern Taiwan, for irrigation for industry and for potable water supply. To resolve the siltation and turbidity problem during storms, the Government passed legislation for renovation of the Reservoir. The scope of renovation included construction of a new surface intake for potable water release and development of schemes for sediment sluicing.

Since water depth in front of the dam is about 70m, it was decided that the only feasible way to develop a sizable silt-sluice way near the bottom of the reservoir is to convert one or both power penstocks.

This paper presents design consideration of this conversion and summarizes results of operation from 2013 to 2016.

2. Project Layout

The power intake is a 88 high RC structure, with a slope of 1(V): 0.52(H). Figure 3 shows the center line of the intake is at EL.173.0m and the plant consists of two 4.57m outside diameter penstocks. Each penstock has three segments; the first segment is 185m long grouted steel pipe, the second segment is 60m long un-grouted steel pipe and the third segment is 85m long steel pipe buried underground. The power plant houses two independent 62,500 BHP Francis units.

Several conversion options were considered, including removal of both turbine/generator units. It was finally decided that there is a need to keep at least one unit in order to facilitate starting of power system in northern Taiwan in an event of a total blackout. The scheme which was adopted is to remove the #2 4.57m diameter penstock immediately upstream from the buried segment. The penstock upstream was then connected to a 3.6m diameter, 45° bend steel pipe to the right. Near the end of the penstock a gate house structure was constructed. Within the gate house, the 3.6m diameter steel pipe was bifurcated into two flow passages, each equipped with an upstream vertical gate, a downstream jet-flow gate and a flip-bucket terminal structure. Flow is discharged into the afterbay. Figure 4 depicts a plan view of the conversion and Figure 5 shows details of the layout in the gate house and the discharge structure. Figure 6 shows a 3D view of the newly constructed structure. The design discharge is 300 cms.

To restore the power production function of both units, a new bifurcation was constructed to connect the #1 penstock with both turbine units, as shown on Figure 4.

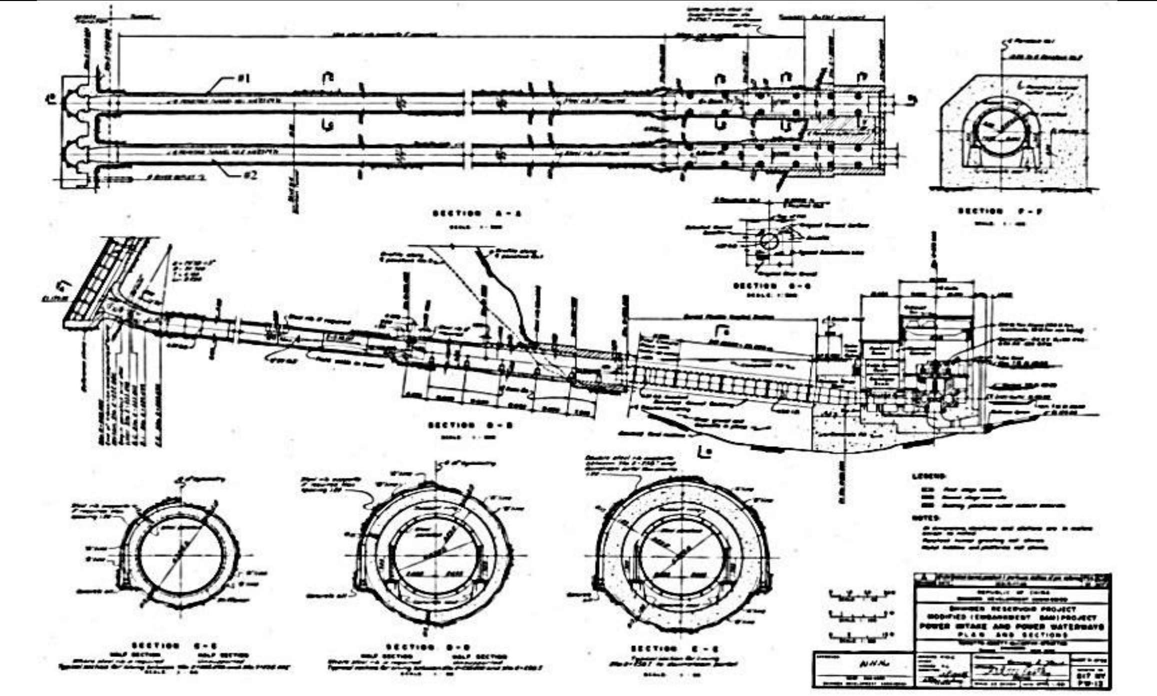

Figure 3 Plan & Elevation Views of Penstocks

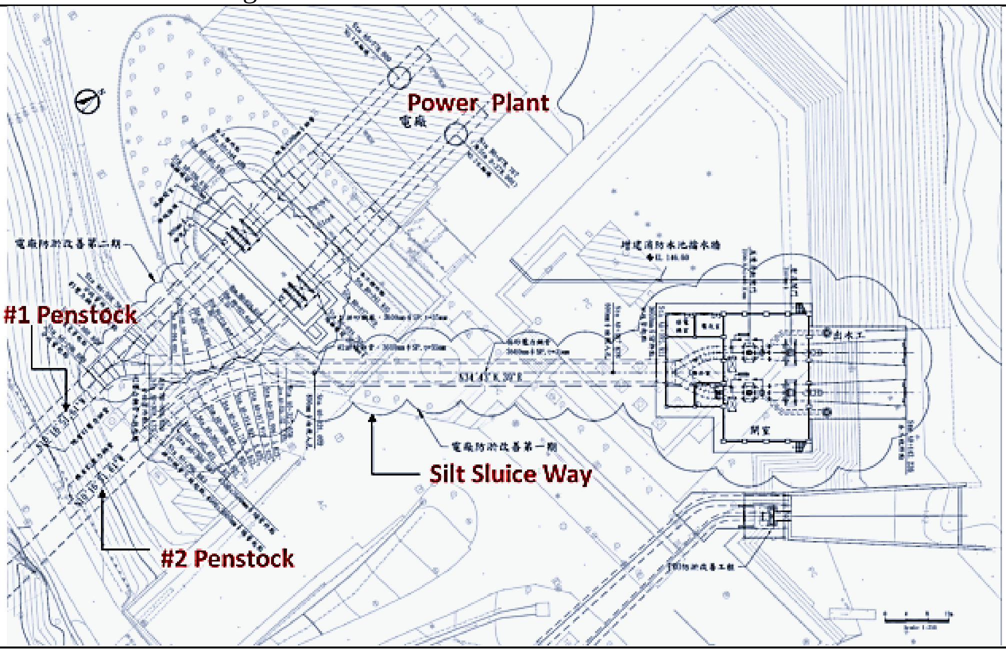

Figure 4 Penstock Modifications as A Silt Sluice Way

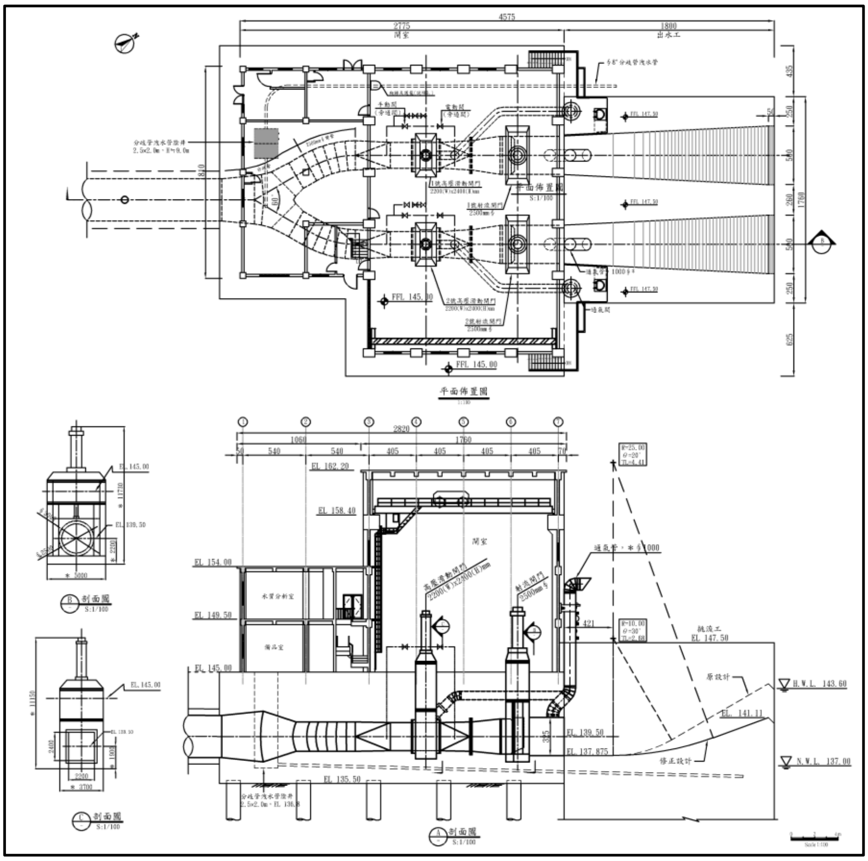

Figure 5 Detail Layout of the Gate House and Discharge Structure

3. Result of Initial Operation

The conversion work was completed in 2012. Photo 2 shows the initial sediment sluicing operation in 2013 during Typhoon Soule. The contrast in color of discharge between the surface spillway and the silt sluiceway is quite apparent.

Photo 2 Operation of Spillway & Penstock Silt Sluice Way During Typhoon Soule

From 2013 to 2016, the converted silt sluiceway had been in operation during 5 medium to small scale typhoons. Data were obtained on total sediment inflow and outflow from each outlet structure. The results are summarized in Table 1. As shown, the total inflow volume of these five storms was about 1.21 billions m^3, the total inflow sediment was 20.36 millions tons and the average inflow sediment concentration was about 16,700 ppm. Total sedimentation discharged by the converted silt-sluiceway was about 1.60×10^6 tons under a total flow rate of $118.88\times10^6 m^3$, resulting an average concentration of 13,500 ppm which is about 2.4 times of the average value, 5,463 ppm. At the same time, it is seen that the ratio of sediment outflow to inflow for the 5 events was about 32.8%. Indicating that 2/3 of the inflow sediments were still trapped within the reservoir.

It is to be noted that due to a need to withdraw flow from the river downstream from the dam for potable water use, the operation of this converted silt-sluiceway during these storm events was some what restricted to control turbidity. Such a restriction has now been removed. Thus a substantial increase in sediment sluicing efficiency can be anticipated in the future.

Table 1 Summary of Converted Sluiceway Operation from 2013 to 2016

Yr.	Name of Typhoon	Precipitation (mm)	Inflow Discharge				Outflow Discharge									Sediment Sluice Ratio (%)
			Water Volume (10^6m^3)	Peak Dicharge (m^3/s)	Sand Quantity (ton)	Mean Crncentration (ppm)	Water Volume		Sediment Discharge					Average Concent		
							Total Volume (10^6m^3)	Sluiceway Volume (10^6m^3)	Total Volume (10^6m^3)	Power Plant (10^3t)	PRO (10^3t)	Sluiceway (10^3t)	Others (10^3t)	Sluiceway (ppm)	Overall Discharge (ppm)	
2013	Soulik	450	264.10	5,458	9.219	34,907	261.19	16.74	3.230	1,623	162	613	832	36,619	12,366	35.0
2013	Tami	525	165.31	2,412	3.205	19,388	175.47	23.22	1.193	259	231	457	246	19,681	6,800	37.2
2015	Soudelor	501	296.39	5,634	2.542	8,576	291.26	15.12	0.904	132	280	182	310	12,037	3,103	35.6
2015	Dujuan	334	195.19	3,802	1.882	9,642	161.27	22.68	0.614	201	130	152	131	6,702	3,807	32.6
2016	Megi	442	294.85	4,268	3.510	11,904	293.26	41.12	0.732	114	280	201	137	4,888	2,496	20.9
Total	—	—	1215.84	—	20.358	16,743	1,182.45	118.88	6.673	2,329	1,083	1,605	1,656	13,501	5,643	32.8