Conference Paper, Published Version

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Renovation of Existing Reservoir in Taiwan for Sustainability

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ABSTRACT

Nanhua Reservoir began filling in November, 1993. The initial volume was about $150\times10^6 m^3$. Over the years, it has experienced severe siltation. In 2015, the volume was about $100\times10^6 m^3$. The siltation has resulted in a reduction of water supply capability from 1.05×10^6 to 0.72×10^6 CMD. If the condition is left unchecked severe potable water shortage in the region can be anticipated.

A remedial measure consists of construction of a silt-sluice tunnel and a submerged dam downstream form the tunnel intake has been developed. With proper operation, the scheme can balance inflow and outflow sediment and make the reservoir sustainable. Construction of the silt-sluice tunnel began in 2014.

KEY WORDS: reservoir sedimentation; silt-sluice tunnel; submerged dam, sustainable reservoir

INTRODUCTION

Nanhua Reservoir is located on Houku River, a tributary of Tsengwen River in southern Taiwan. The reservoir has two water sources: one from its 108 km^2 drainage area and the other from a transbasin diversion of the neighboring Chishan River. The reservoir is the largest public-water storage facility in Taiwan. Its initial reservoir volume was $105.4\times 10^6 m^3$ and the corresponding water supply capability was 1.05×10^6 CMD.

The reservoir consists of an embankment dam, an inclined multiple-level outlet, with a maximum emergency release of 140 cms and a design water-supply discharge of 10 cms, as well as an ungated overflow spillway, with crest at El.180.0m and a design discharge of 4.330 cms.

Existing Siltation Problem

The reservoir began initial filling in Nov. 1993. Due to young geology, intense rainfall during typhoon and lack of large capacity bottom outlets, sediments from extensive landslide and surface erosion in the drainage basin accumulated in the reservoir. Fig. 1 depicts the changes of the reservoir volume with time. The reduction in reservoir volume can be expressed by the following:

$$V_i = V_0\left(1-\beta\right)^n \qquad (1)$$

Where V_i: volume at nth year after filling; V_0: initial volume; β: amount of annual reservoir volume reduction. It is seen that the reservoir experienced about 2.2% volume reduction annually. The average annual sediment deposited in the reservoir is estimated to be about 3.50 $\times10^6$ tons or about $3.0\times10^6 m^3$. Thus the annual depth of erosion in the drainage basin is 27.7 mm. An analysis was made on the effect of water-supply capability if the reservoir siltation is left unchecked. Fig. 2 shows that the water supply capability can be expected to decrease almost linearly with decreasing reservoir volume. By yr. 2042, 50 years after initial filling, the volume of the reservoir could be only $50\times 10^6 m^3$ and the corresponding water supply capability would be only 0.42×10^6 CMD. It is thus evident that the biggest threat to the sustainability of the reservoir is the loss of volume due to sedimentation.

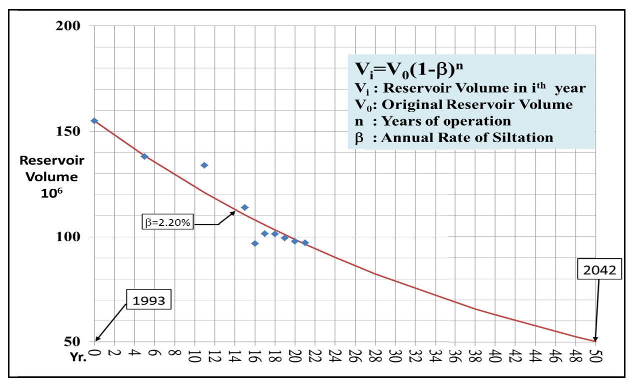

Fig. 1 Rate of Siltation in Nanhua Reservoir

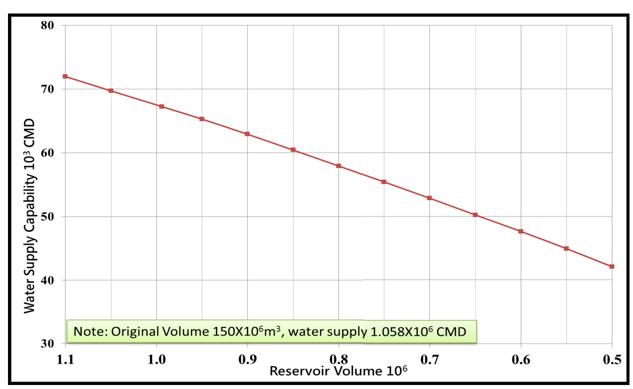

Fig. 2 Effect of Siltation on Water Supply Capability

Sedimentation Characteristics in the Reservoir

Two of the most important sedimentation characteristics in a reservoir are the longitudinal profile of reservoir bed and grain size distribution of deposited material. Fig. 3 depicts the original reservoir bed and the beds in subsequent years of survey. It is seen that about 4,000m upstream from the dam, the reservoir bed does not exist any noticeable longitudinal gradient. This is an indication that suspended sediments in the form of turbid pond settled nearly uniformly m the downstream portion of the reservoir.

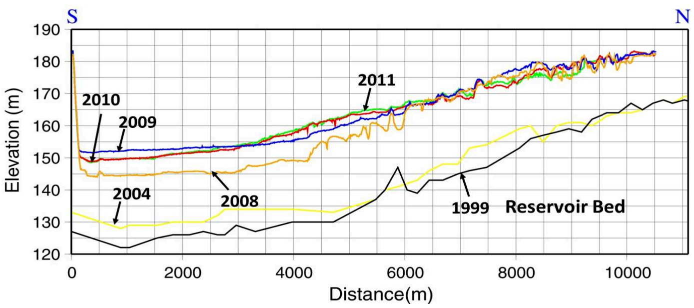

Fig. 3 Longitudinal Siltation Profile in Nanhua Reservoir

Sediment samples taken during different studies indicated that deposited sediments near the dam are mostly fine sand and silt mixed with small portion of clay, with D_{50} in the ranges of 0.010~0.026mm. Penetration tests revealed that from El.152.0m to about EL.144.0m, the deposited sediments are non-plastic sandy silt. The shear strength is below 2Kpa. Below El.144.0m the material has hardened. Compaction effect of later deposits to earlier deposits is thus quite evident.

OVERALL RESERVOIR SUSTAINABILITY SCHEME

The fundamental cause of rapid siltation in Nanhua Reservoir is the lack of large scale bottom outlet to release sediment laden flood flow during heavy storms. Fig. 4 depicts the overall scheme for reservoir sustainability. It consist of a 1,000 cms sediment sluice tunnel (Fig. 5) and a submerged dam with crest at El.165.0m (Fig. 6). The invert of sediment sluice tunnel intake is set at El.135.0m. It will function as a sediment passage way from the reservoir to the downstream river. The submerged dam will be constructed of interlocked steel pile as water barrier and placement of 1(V):2(H) crushed rocks for stability. The dam will divide the existing reservoir into three compartments, namely: the upper reservoir, the volume above El.165.0m; the lower-front reservoir, the volume below El.165.0m and upstream from the dam; and the lower-rear reservoir, the volume below El.165.0m and downstream from the dam. Table 1 shows the volume for each of the three compartments in 1993 and 2013. It can be seen that siltations in the upper, the lower-front and the lower-rear reservoirs are 4.91×10^6, 15.50×10^6 and $37.50\times10^6 m^3$, respectively. Thus most siltation took place in the lower-rear reservoir. The remaining volume in the lower-front reservoir is small, only about $4\times10^6 m^3$.

The idea by segregating the reservoir blow El.165.0m as front and rear reservoirs is to confine as mush as possible the incoming sediment in the front reservoir and to prevent the rear reservoir free from sediment accumulation. At the same time, volumes for the other two compartments shall be maintained for water storage and utilization.

The renovation presents two modes of sediment sluice operations:

1. During Typhoon Seasons
   Actual hydrologic events from yr. 1993 to 2011 were used for analysis. An overall sediment discharge efficiently of 31% was estimated.

2. During Monsoon Seasons
   In Taiwan the period from mid-May for about 3 weeks is the monsoon season. It is planned that during this period, the lower-front reservoir will be emptied and sediments deposited in the lower-front reservoir shall be scoured by monsoon runoff through the silt-sluice tunnel. From past Taiwan experience in another reservoir, it is estimated that the concentration of eroaded sediment will be at least 100,000 ppm. To achieve best overall sediment removal efficiency, some dredging from the lower-rear reservoir to the lower-front reservoir would be needed. If doing so, it is expected that a balance of inflow and outflow sediment can be achieved.

   The concept to drain the lower-front reservoir for sediment scouring is feasible from the viewpoint of water supply because in the lower-rear reservoir there exist an inlet of transbasin diversion from the neighboring Chishan River. At the location of diversion, the drainage area of Chishan River is about $480 km^2$, about 4.4 times of the Nanhua Reservoir drainage area.

CONCLUSION

Reservoir sedimentation is a major cause of affecting water resources sustainability in Taiwan. To overcome the problem, for Nanhua Reservoir, a scheme with the construction of a silt-sluice tunnel and a submerged dam has been developed. The submerged dam will enable the silt-sluice tunnel to operate not only in typhoon season but also in monsoon season and achieve a sustainable reservoir volume. Analyses indicate that the silt-sluice operations will have no measurable negative impact on water supply capability of the reservoir.

Table 1 Reservoir Volume After Construction of Submerged Dam

Zone / Reservoir Volume	Upper Reservoir	Lower-Front Reservoir	Lower- Rear Reservoir	Sum
1993	66.05	19.50	69.50	155.05
2013	61.14	4.00	32.00	97.14
Siltation 1993~2013	4.91	15.50	37.50	57.91

Upper Reservoir: Above El.165.0m;
Lower Front Reservoir: Below El.165.0m, U/S submerged dam;
Lower-Rear Reservoir: Below El.165.0m, D/S Submerged Dam

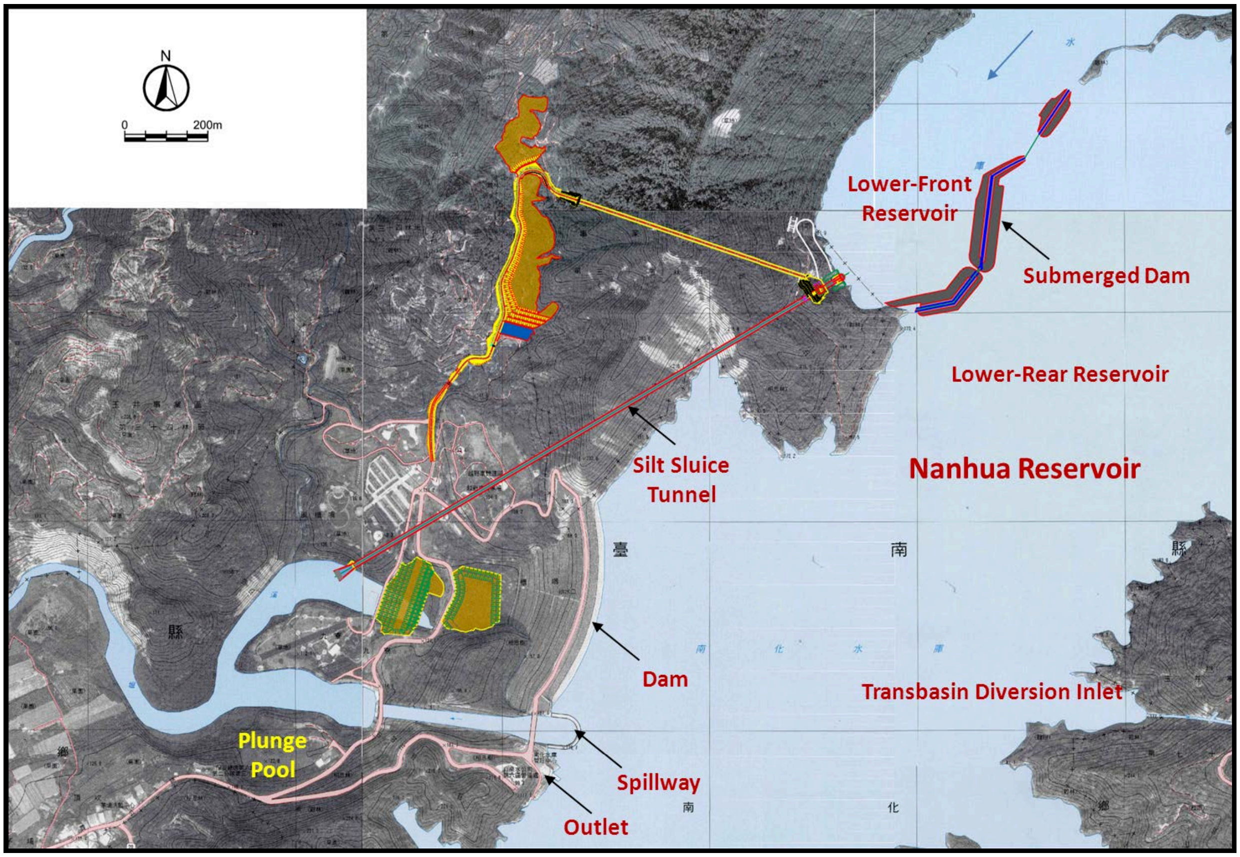

Fig. 4 Nanhua Reservoir Plan View

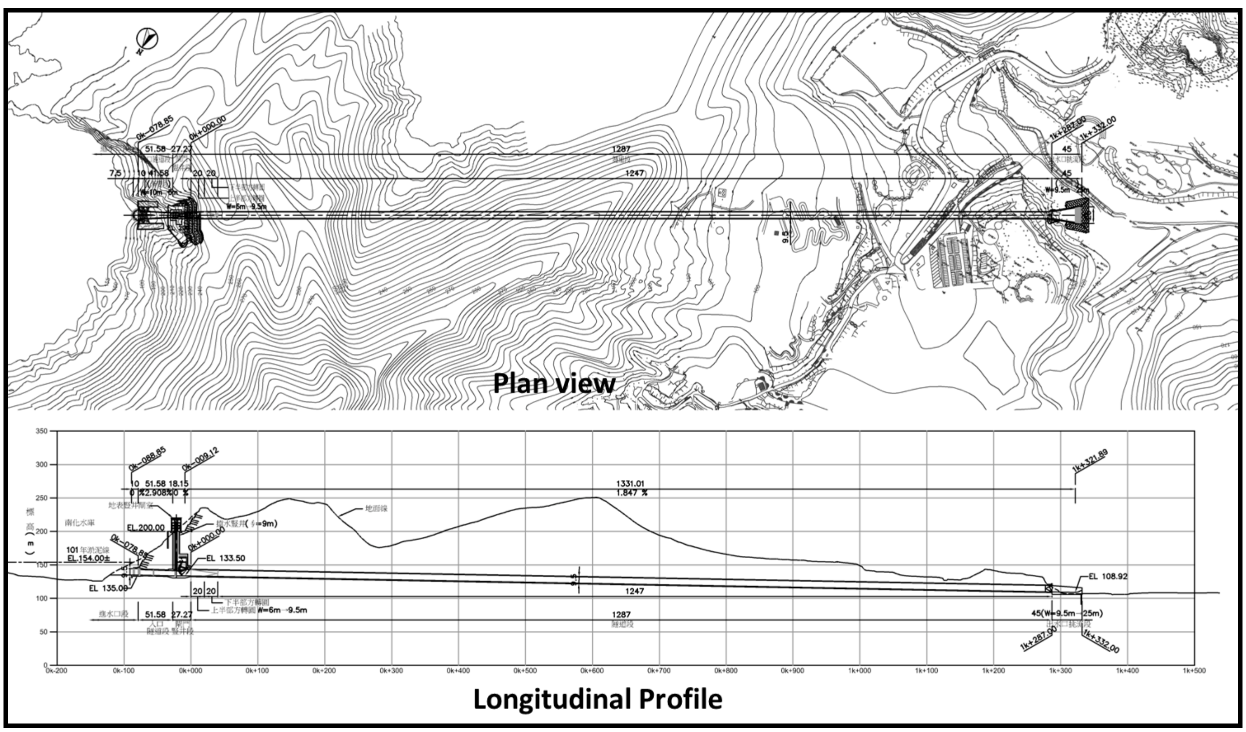

Fig. 5 Silt Sluice Tunnel Layout

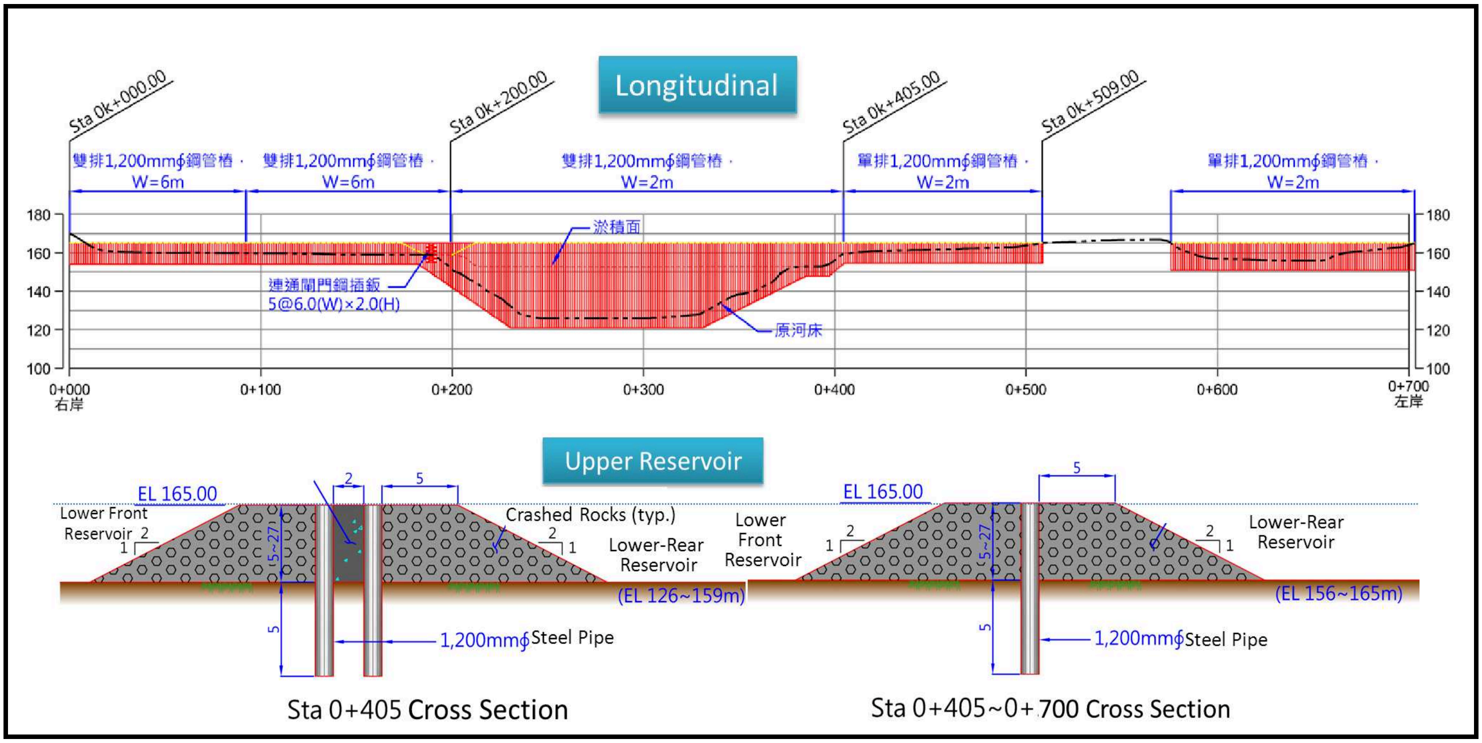

Fig. 6 Submerged Dam Cross-Section