SUSTAINABLE COUNTERMEASURES USING FREQUENCY ANALYSIS AND DESILTATION STRATEGY IN A RESERVOIR

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Abstract: The annual mean loss of reservoir storage due to sedimentation is already higher than the increase of capacity by construction of new reservoirs for water supply, irrigation and hydropower. Thus, the sustainable use of the reservoir is more important and the storage is not guaranteed in the long term. Therefore, for prolonging the reservoir life, the desiltation strategy of the reservoir is always an important issue for reservoir long term operation. By dredging or excavation, deposited sediment may be mechanically removed from reservoirs because of valuable material for construction and connivance implementing. But, based on the characteristics of reservoir to classify suitable desiltation strategies is more efficient to deal with sedimentation problem. This study depended on frequency analysis method and venting efficiency of excited facilities for total inflow sediment volume and bypass with sediment replenishment strategies to planned valuable desiltation methods in wushe reservoir in taiwan. The characteristic of adopted reservoir in taiwan which have reliable and completed data in its historical records has been identified by the parameters of the turnover rate of water (cap/mar=total capacity/mean annual runoff) and sediment (cap/mas=total capacity/mean annual inflow sediment). Based on the frequency analysis, estimation of sediment transport capacity equation, experimental results with 3d numerical model and historical data, the inflow and outflow boundary condition of sediment were presented. In addition, using 1d numerical model, the flushing efficiency of bypass of objective case had been simulated to suggestion, using and planning to implement in wushe reservoir. In addition, the valuable historical excavation volume was also considered to implement sediment replenishment. Therefore, the results of desiltation strategies in this study are reasonable to maintain reservoir capacity as possible as we can and make sure the reservoir functions can prolong working.

Keywords: Sedimentation, desiltation strategy, frequency analysis, flushing efficiency

1. GENERAL INSTRUCTIONS

In recent years, there are many huge earthquakes happened in the world. Terrible tsunami and nuclear radiation impacts were usually following the earthquake and many lives was passed away due to serious damage. For example, the 8.8 Richter magnitude scale earthquake was happened at Chile in

2010 and a 9.0 Richter magnitude scale earthquake with 40.5m Tsunami height was happened at East Japan in 2011. In 1999, Taiwan also suffered from an earthquake in Chi-Chi area at central Taiwan which magnitude reaches 7.3 Richter magnitude scale. After the earthquake, not only buildings were destroyed in the urban area but also geological condition was changed in mountain vicinity. The soil and rock of the mountainside were collapsed and decrease glued capacity between sediment particles. Therefore, when heavy rainfall occurred in watershed, land collapse would happen and large sediment would be washout into river, especially in steep slope area of mountains. And, the land development by mankind in the watershed would also accelerate soil erosion in recent years due to limited living land and leisure purpose. As such huge sediment moved into a reservoir, serious sedimentation problem reduced storage of reservoir due to decrease of flow velocity and without bottom outlet. However, there are many countermeasures to deal with deposition sediment in the reservoir, such as check dam, excavation, dredging, flushing, sluicing, venting, bypassing and replenishment sediment at downstream. But, not all of the countermeasures are suitable for specific reservoirs and the cost-benefit ratio of each strategy is different. The suitable methods were mainly depended on hydrological patterns and geological conditions. Therefore, classified characteristics of reservoirs and investigated suitable countermeasures should be studied first.

In Japan, desiltation strategies were classified into four kinds in all reservoirs. Based on the characteristics of hydrological and geological conditions in reservoir watershed, suitable desiltation strategies were adopted to implement for individual reservoirs. The four kinds of desiltation strategies usually be distinguished to deal with sedimentation problem in Japan and such kinds can be identified by the parameters of the turnover rate of water (CAP/MAR=total capacity/Mean annual runoff) and sediment (CAP/MAS=total capacity/Mean annual inflow sediment) (Sumi, 2011). The first kind of all, the flushing strategy was suited to execute if the annual quantity of inflow discharge is large enough to flush sediment. The second kind of all, the bypass and venting strategy is an option to take care inflow sediment if the refilled rate of capacity by clear water is about 10 times in one year. The third kind of all, the sediment replenishment technique at downstream river upland is useful for preventing downstream river from bed degradation and increase sustainable living habitat for aquatic livings at the downstream reach of dam if the capacity of reservoir is large enough or inflow sediment volume is not so huge. In addition, in order to realize inflow sediment and suitable countermeasures, frequency analysis of deposited sediment of large reservoirs and the applicability of the asset management for reservoir sediment management are investigated to classify the characteristics of reservoirs (Sumi et al., 2009; Sumi and Kantoush, 2010).

Based on the classification of desiltation strategies, when CAP/MAR is around 10, the bypass idea might be implemented to prevent sedimentation in such reservoir. In Japan, sediment bypass tunnel at Miwa Dam for fine sediment had been constructed in 2004 and successful operated in recent years. Besides, for both fine and coarse material, the Nunobiki Dam was completed in 1908 and Asahi Dam was completed in 1995(Harada, 1997). These two dams had been successfully introduced to realize sustainable reservoir management (Kataoka, 2003). In addition, sediment bypasses at Matsukawa Dam and Koshibu Dam are under construction from 2009 to 2013 year. Therefore, the bypass strategy was planned to divert more inflow sediment volume in selected reservoir. Based on designed information of bypass system which under operating and construction in Japan, the literature contents show that the tunnel radius is between 2.9m and 5.2m, the tunnel length is from 258m to 4,300m, the tunnel slope is from 1% to 4%, the designed discharge is from $39m^3/s$ to $370m^3/s$, the operation frequency is about 1 to 13 times per year and tunnel shape is hood and horseshoe shape. But, there is no stander procedure for designing bypass system until now. Actual executed design is by the way of discussion for most acceptable conditions of budget and objective. Integrated reviewing cases in Japan and under designing, the tunnel flow velocity, the path line of bypass tunnel, the intake and outlet location and impacts of environment should be considered at the same time. According to the operation results of Asahi dam and Miwa dam, more than 80% bypassed efficiency can be expected in past 10 year’s record. Especially in Asahi dam, the bypassed sediment includes all coarse material and some part of fine material can be bypassed. The designed discharge of bypass tunnel is only $140m^3/s$ that value is lower than 1 year return period (Kataoka, 2003).

Recently, the replenishment technique also has been implemented to prevent downstream river from bed degradation and increase suitable living habitat for aquatic animals downstream of the dam [Sumi et al, 2012]. Such restoration methods could be implemented in bad hydrological and geographic area which drawdown flushing could not be practiced, for example Taiwan and Japan. Therefore, the downstream replenishment technique had been implemented to prevent downstream river from bed degradation and increase suitable living habitat for aquatic organism at downstream of the dam in past 15 years in Japan. Okano et al. (2004) started to study reservoir sedimentation management by coarse sediment replenishment below dams and summarized sediment replenished project in Japan from 1999 year to 2004year. Such as Tenryu, Otakine, Abukuma, Ara, Oi, Naka, Kuzuryu, Yodo, Kanna, and Tone had been constructed by Ministry of Land, Infrastructure and Transport (MLIT). The replenished sediment effects on the downstream river of Yahagi dam and appropriate grain size with less turbidity using sediment treatment system in Kizu River were following to investigate (Seto et al.,2009 ; Sumi et al.,2009). The interaction of relative flow field and morphological evolution during replenishment experiments were also analyzed (Kantoush et al., 2010). The conceptual idea was before flood coming, the sediment had been constructed at the downstream flood plain and after flood was passing, the replenished sediment was flushed to the sea. Such field test in Japan focused on coarse material that deposition in the reservoir and replenished at downstream upland for creating suitable environment for aquatic livings. However, the replenishment strategy needed huge discharge to flush replenished sediment, therefore, replenished sediment always constructed before flood coming and implemented during wet season. Using this method, deposited sediment in reservoir can be periodically excavated and then transported to be placed temporarily downstream of the dam at floodplain. But, replenished volume was based on the sediment transport capacity of the channel and the environmental conditions. Refer to the experience of replenished volume in Japan; it is up to 10% of annual deposition volume in reservoir could be successful executed.

Therefore, this study followed the research process of Sumi and Kantoush (2010) to classify the mainly reservoirs and weirs in Taiwan and adopted frequency analysis method to estimate inflow sediment volume to recognized suitable desiltaion strategies for objective reservoir. Numerical model and physical model was executed to realize releasing efficiency of existed structures. Then, alternative strategies were investigated to discuss sustainable countermeasures.

2. DESCRIPTION OF FILED RESERVOIR

2.1 Selection of objective reservoir

Based on the classification of desiltation strategies using CAP/MAR and CAP/MAS parameters, the main important reservoir in Taiwan were figured out to show suitable desiltation strategies. As mentioned before, the serious sedimentation reservoirs, Shihmen reservoir, Wushe reservoir and Tsengwen reservoir were also classified to show suitable countermeasures in Figure 1. The Figure 1 shows that most of reservoirs in Taiwan were suited to execute bypass, venting strategy and sediment replenishment combining with check dam. According to the analysis, the reservoir life is obviously decreased due to Chi-Chi earthquake and the earthquake almost affects all kind of reservoirs. The Figure 1 also shows the priority countermeasures of the classified kind, the Shihmen and Wushe reservoir were suited for using bypass, venting strategy combining with sediment replenishment and Tsengwen reservoir was agreed with replenishment and check dam strategy. Due to most sedimentation problem and similarity magnitude scale of reservoir, the Wushe reservoir was choose to investigate sustainable countermeasure using frequency analysis and desiltation strategies. Besides, the more popular desiltation strategies of bypass and sediment replenishment technique were adopted to investigate.

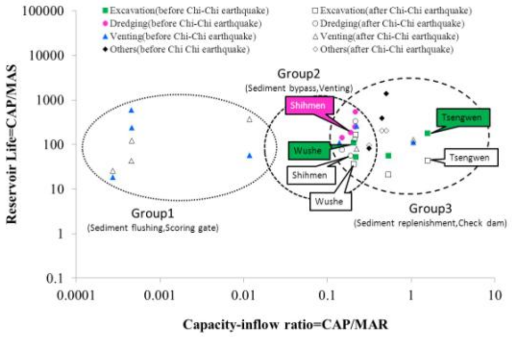


Figure 1. Reservoir characteristics in Taiwan

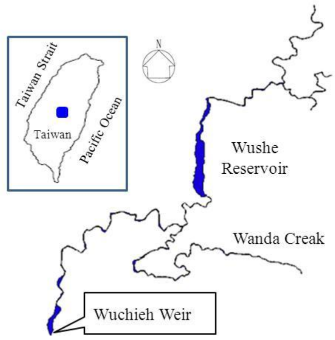
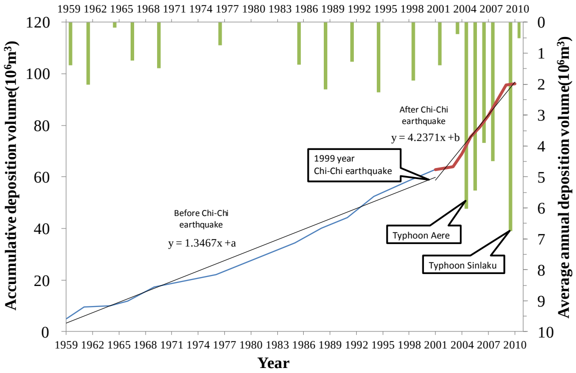


Figure 2. Sketch of Wushe reservoir and river system

2.2 Description of Wushe reservoir

Wushe reservoir located at central Taiwan (Figure 2) and it belongs to the Taiwan Electric Power Company. The Wushe reservoir has a natural drainage area of 219 km^2. The Wushe dam was formed by the concrete gravity and located at the upstream reach of the Jhuoshuei River and flows westward to the Taiwan Strait. The Wushe dam constructed in 1951 is a 114 m height and 7 m width at the top of arched gravity dam with two spillways, one permanent river outlet, one tunnel spillway and one power plant intake controlled by gates. And, there is a new power plant intake with 22 m^3/s intake discharge at 983m elevation is under construction for electric power at. The elevations of the spillway crest, permanent river outlet, flood diversion tunnel and power plant intake are 998.9m, 927.65m, 989.8m and 938m, respectively. The designed capacity of the two spillways is 850m^3/s, the permanent river outlet is 87m^3/s, the tunnel spillway is 1,200m^3/s and the power plant intake is 24m^3/s, respectively. With a maximum water level of 1005m, the reservoir pool impounds about 7.5 km in length and the initial storage capacity was 1.5x 10^8m^3. Incoming sediment particles have settled down significant along the reservoir since the dam was completed. Based on the survey data, the longitudinal bed profile along the reservoir is plotted in Figure 3. As shown in Figure 3, the Wushe reservoir has accumulated a great amount of sediment after Chi-Chi earthquake and the impact effects reached 3 times deposition volume from $1.36*10^6m^3$ to $3.33*10^6m^3$ per year. Specifically in 2004 year and 2008 year caused by Typhoon Aere and Typhoon Sinlaku, the deposition volume is about $6.00*10^6m^3$ and $6.76*10^6m^3$, respectively. Therefore, the serious sedimentation problem was caused bed elevation arising 6 m in those two years (Figure 4). By recent survey data in 2010, the storage capacity was estimated to be 35.86% of its initial storage capacity. From longitudinal variation of Wushe reservoir and relative elevation of facilities in Figure 4, the delta position is starting to move forward downstream from 2007 year due to Typhoon Sinlaku and the location of delta is about 2 km from the dam site. Moreover, the bed elevation is higher than power plant intake and permanent river outlet (PRO). Due to frequently operation of power plant intake, the facility is still been worked well. But, unfortunately for PRO can't be operated after dam was constructed due to never open it in past years. And, the figure also shows that huge sediment settled down after delta location and also the upstream area of delta. According to the field survey of sediment size in 2005 (Taiwan Electric Power Company, 2005 ; as show in Figure 5), the mean size of coarse material at NO-6 is about 3mm and fine sediment at NO-1 and NO-2 is about 0.02mm. The measurement locations are showed at Figure 6. The Figure 5 also shows that, from NO-5 to the dam site, the deposition sediment belongs to silt and clay (size less than 0.075mm) and the deposition volume is about 70 % of total deposition volume due to the location of NO-5 is about at 70% volume of reservoir impounding area. Moreover, the grain size also indicated that the fine sediment would deposit after delta location and coarse material settled at the upstream of delta area with 30% total deposition volume.



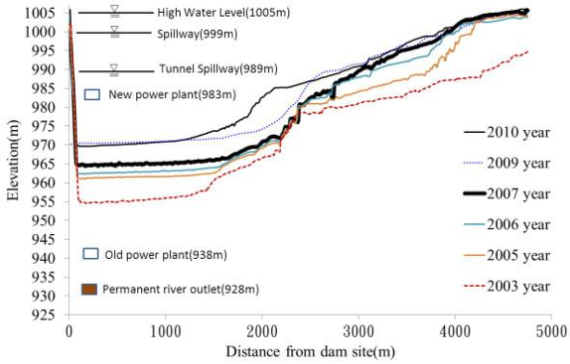


Figure 3. Variation of sedimentation in Wushe reservoir

Figure 4. Longitudinal variation of Wushe reservoir and relative elevation of facilities

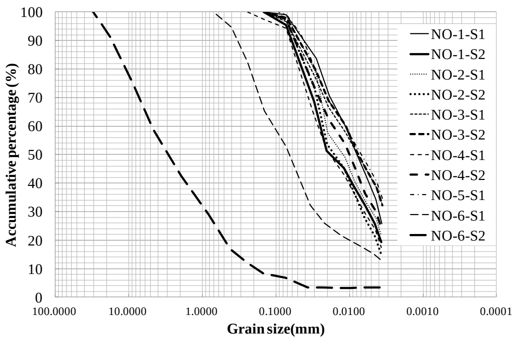


Figure 5. Grain size of deposition sediment

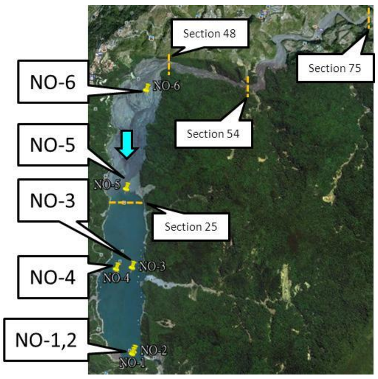


Figure 6. Sketch of investigation location of sediment grain size(Taiwan Electric Power Company, 2005)

3. METHODS

3.1 Frequency analysis of deposited sediment volume

In this study, frequency analysis methods were adopted to estimate the performance of deposition sediment. The field data was also mainly used to select proper frequency analysis method. According to the historical records of 19 years deposition volume in Wushe reservoir, the most popular used stochastic methods of Gumbel distribution, Normal distribution and Lognormal distribution were employed to estimate deposition volume for each return period. According to the biggest inflow discharge of historical record is up to 50 year return period of Typhoon Sinlaku (as show in Figure 7), the frequency analysis is estimated from 2 year to 200 year return period. Figure 8 shows the results of frequency analysis. Comparison of three methods and historical data of field, the relative good approach was selected on Gumbel distribution as shown in Figure 8. Before 10 year return period, the Normal distribution and Gumbel distribution is closed to each other. However, entirety consideration of covering 200 year return period, the Gumbel estimation is the best fitting and finally been adopted for deposition sediment volume of objective case,50 year return period.

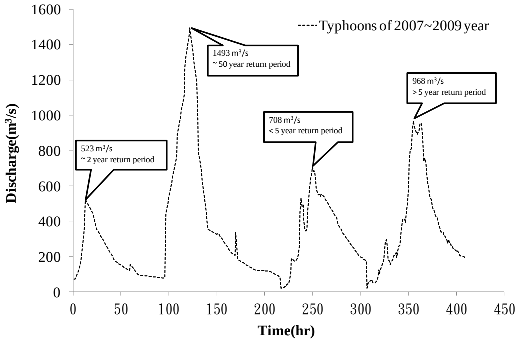


Figure 7. Flow hydrograph from 2007 year to 2009 year

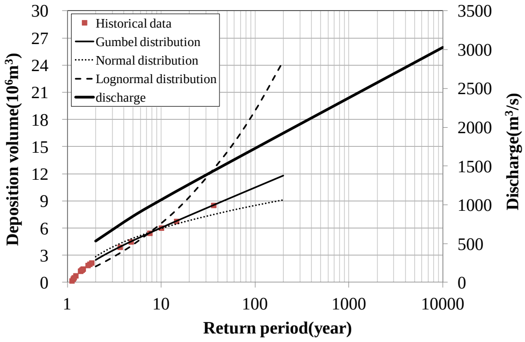


Figure 8. Frequency analysis of deposition volume

3.2 3.2 Relationship between inflow discharge and sediment

The actual flood event is unsteady and inflow discharge with sediment is strongly depended on upstream flow condition. As a result, the useful suspended sediment transport equation of reservoir was employed to estimate fine sediment. The adopting equation (Chien, 1999) as following:

$$\rho_* = K(\frac{V^3}{gRw})^m \qquad (1)$$

Where ρ_* = Transport capacity (kg/ m ^{3})
K = Coefficient (kg/ m ^{3})
V= Average flow velocity(m/s)
g= Gravity(m/s^2)
R= Hydraulic radius (m)
w = Falling velocity(m/s)
m= Index

The coefficient **K** and index **m** can be decided from the value of V^3/gRw (Chien, 1999). Based on the field survey of grain size in 2005 as show in Figure 5 and deposition volume in Figure 3, the fine sediment quantity from field measurement was compare to the simulation results using equation (1). Based on the mainly record inflow discharge of rainfall in 2005, the volume ratio of total deposition volume between field measurement and simulation results is 77% and 76 %, respectively. The calibrated values of coefficient **K** and index **m** are 1.0 and 0.6, respectively. The relative error is about 1% and such accuracy possesses confidence to use equation (1) for generating inflow hydrograph of fine sediment. And, the quantity with hydrograph of fine and coarse material could be distinguished and obtained. Figure 8 shows the relationship between inflow discharge and inflow sediment volume using equation (1). The estimation case was depended on Typhoon Sinlaku (Figure 9(a)) and also suitable for 50 year return period of inflow discharge. The figure indicated that the volume of fine sediment is about 68% and coarse material is about 32% (Figure 9(b)).

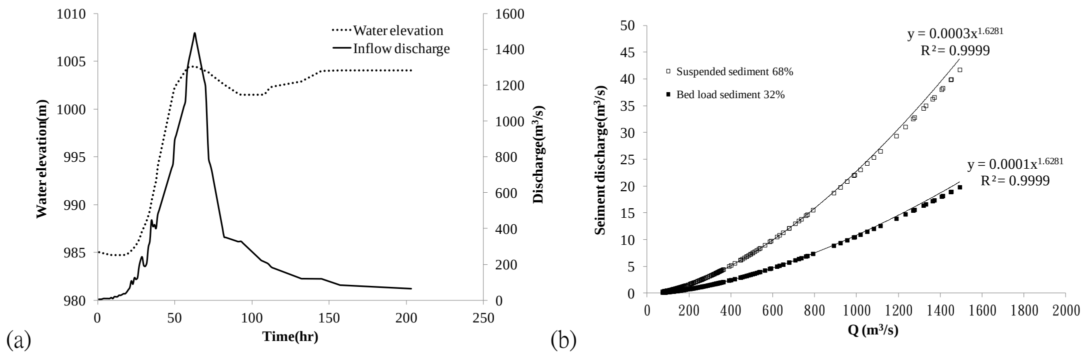


Figure 9. (a)Flow hydrograph of Typhoon Sinlaku (b) Estimation of inflow sediment discharge

3.3 Numerical model and physical model

The 3D numerical model and physical model were adopted to investigate venting efficiency of outflow discharge of existed structures. The 1D model was employed to investigate flushing efficiency of bypass tunnel and topography after bypass system was operated.

3.3.1 3D simulation model

Because of the total inflow sediment was decided not only the deposited sediment but also the outflow sediment volume of existed facilities. Therefore, a commercial CFD solve model, CFX-11.0 from ANSYS, Inc. (2006), was adopted to simulate venting efficiency of suspended sediment in Wushe reservoir. The simulation fluid was assumed to be isothermal and incompressible. The boundary condition of bed was set to be no slip condition, the inflow flux was set as mentioned in paragraph 3.2, the outlet flux was set by reservoir operation and free surface was rigid-lid approximation. Simulation area was from section 48 to the dam site.

3.3.2 1D simulation model

The NETSTARS model (Lee and Hsieh, 2003) is employed to simulate the impacts of upstream river during bypass operation of the Wushe Reservoir. The NETSTARS model is an uncoupled sediment routing model. It consists of hydraulic routing and sediment routing. Suspended load and bed load are treated separately in sediment routing.

The NETSTARS model solves the nodal point problem as same as CHARIMA model. The node is assumed to be a virtual section that could not accumulate water and sediment. The allocation of link discharges at a node is considered in proportion to the discharges resulted from previous time step, and the sum of link discharges is assumed to be zero at a nodal point. The allocation of the suspended load at the node is assumed to be proportional to the allocations of the flow discharge, and the net flux of the suspended sediment due to longitudinal dispersion is assumed to be zero at a nodal point.

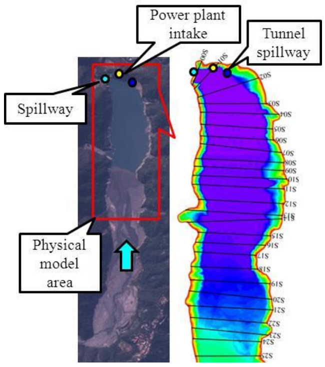
The NETSTARS model adopts some good ideas of CHARIMA and GSTARS models to develop a powerful tool for resolving the problems of unsteady sediment process in a channel network. Since the NETSTARS model is a 1-D model, secondary current and local scour can’t be simulated. But, the transverse bed evolution can be computed due to using the stream tube concept. Considering the tube boundary for satisfying equal conveyance requirement across the channel, the transverse bed evolution can be estimated. Besides, adding transverse transport term into the convection-dispersion equation, the suspended load would be simulated.

3.3.3 Physical model

In addition, a physical model was also constructed to verify the venting efficiency as shown in Figure 10. In this study, the Froude similarity was adopted to scale the dimensions of flow patterns due to the free surface condition. According to the specific ratio (X-Y-Z scale = λ =50) of physical model, the theoretical scale of flow patterns were derived from similarity process and the results were listed in Table 1. The used grain size of physic sediment is the same as field because of the relaxation time of 0.02mm which grain size was deposited in physical model area is smaller than 10^{-4} and this value is much smaller than the flow time scale (Manninen et al., 1996). That means during experimental duration, the settling performance of fine sediment can be ignored. Besides, according to the similarity using eq. (1), the sediment concentration ratio would become to 1. Therefore, the mainly ratio and scale were listed in Table 1.

Table 1 Theoretical scale of flow patterns and sediment properties

Items	Flow patterns					Sediment properties		
	X ,Y scale [m]	Z scale [m]	Water level [m]	Velocity [m/s]	Discharge [m^3/s]	Time [s]	sediment size[m]	Sediment concentration [ ]
Ratio	λ_X	λ_Z	λ_Z	$\lambda_X^{1/2}$	$\lambda_X^{5/2}$	$\lambda_X^{1/2}$	1	1
Scale	50	50	50	$\sqrt{50}$	$50^{5/2}$	$\sqrt{50}$	1	1



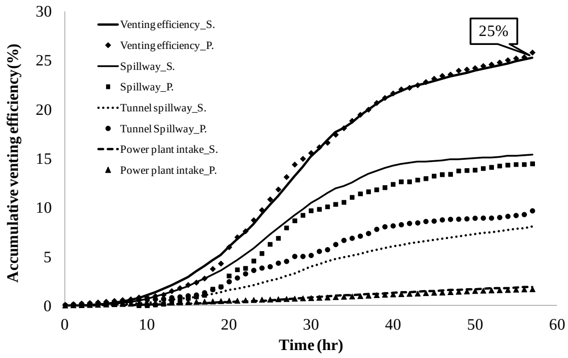


Figure 10. Experimental area with outflow structures of physical model **Figure 11.** Venting efficiency of existed facilities

4. RESULTS AND DISCUSSION

4.1 Venting efficiency and numerical model verification

According to the numerical simulation and physical experiment, the figure 11 shows the total venting efficiency of existed structures of objective case, Typhoon Sinlaku, and the value is about 25% which value is from the experiment results of Typhoon Sinlaku and compared to the numerical model. In figure 11, the venting efficiency belongs to spillway, tunnel spillway and power plant intake are about 15%, 8% and 2%, respectively. This means that the deposition volume is about 75%. Therefore, according to the frequency analysis and assumed outflow venting efficiency of other return period have the same value of Typhoon Sinlaku, the total inflow sediment volumes were obtained as table 2 listed. According to the historical measurement of deposition volume (Figure 3), the annual average deposition volume after Chi-Chi earthquake is about $3.33*10^6 m^3$ and this value is 3.58 year return period of sediment. This means the incoming sediment volume do not accompany with hydrological condition anymore due to earthquake impact. Therefore, owning to designed purpose was Typhoon Sinlaku condition, the 3.58 year return period of sediment is chosen and 50 year return period of clear water is adopted due to objective inflow discharge is about 1493 m^3/s that value was recorded from Typhoon Sinlaku and deposited sediment volume was closed to annual average. Besides, this study employed sediment transport equations and historical hydrological record with 2005 and 2008 river bed investigation to verify 1D numerical model at upstream area. Based on the simulation results in figure 12, the sediment transport equation of Meyer-peter & Muller formula was the best fitting to the field measurement and the manning N was ranged from 0.08 to 0.1. Therefore, the coefficients that had been decided can be used to simulate the bed evolution of upstream river and bypass efficiency for selected bypass case.

Table 2. Performance of frequency analysis value

	Deposited sediment volume($10^6 m^3$)			Inflow sediment volume($10^6 m^3$)	Inflow water discharge (m^3/s)
Return period (year)	Gumbel distribution	Normal distribution	Lognormal distribution	Gumbel distribution	Taiwan Electric Power Company (2009)
2	2.17	2.50	1.64	2.90	531
3	3.00	3.35	2.47	4.00	
3.58	3.33	3.65	2.86	4.44	
4	3.53	3.83	3.12	4.71	
5	3.92	4.16	3.66	5.23	851
10	5.08	5.03	5.55	6.77	1063
20	6.19	5.75	7.85	8.26	1266
30	6.83	6.13	9.39	9.11	
50	7.63	6.56	11.57	10.17	1529
100	8.71	7.10	15.00	11.61	1726
200	9.78	7.59	19.01	13.04	1923

4.2 Bypass efficiency

According to the designed bypass discharge of Asahi was 140 m^3/s which value was small than 1 year return period and had high performance of sediment bypass effect, a similar conceptual idea was adopted to implement in Wushe reservoir and bypass discharge 450 m^3/s that value was closed to 2 year return period (531 m^3/s) and 10.5 m height of check dam was designed at section 54. Based on the 50 year return period of discharge and 3.58 year return period of sediment, the performance of bypass using 1D numerical model showed that 71% inflow sediment would be bypassed to the downstream and 21% sediment would over flow into the reservoir. This means that about 8% sediment would deposit at the upstream of check dam.

4.3 Desiltation performance

Based on the results of sustainable research, the reservoir life can be prolonged due to desiltation strategies (as shown in figure 13). The effect of Chi-Chi earthquake in Wushe reservoir led to the life reduced from 110 year to 36 year. But, according to the desiltation strategies, the reservoir life would cover to 214 year using bypass system. It shows obviously improvement of reservoir life by using desiltation strategies. But, there is 21% deposition volume need to deal with by valuable desiltation strategy. The Figure 2 indicated that the Wushe reservoir also suitable for replenishment strategy to deal with sediment. As a result, the remained sediment volume can be take care by sediment replenishment. Besides, according to the experience in Japan and Taiwan (Central water resources bureau, 2009), up to 10% replenished sediment of annual deposition volume in reservoir had been successful implement. Therefore, a reliable experiment of more than 21% replenished sediment should be planned to test. However, according to the historical excavation volume of Wushe reservoir is about $1x10^5m^3$, the same execution volume is adopted to discuss reservoir life in this study.

The figure 13 shows the effects of desiltation strategies. When sediment replenishment strategy is executed, the reservoir life would prolong from 36 year to 46 year after Chi-Chi earthquake. If bypass system and sediment replenishment are both implemented to reduce sedimentation, the reservoir life would prolong from 36 year to 250 year. This effect shows that 2 times original designed reservoir life would present. However, there is still 16% sediment remained in the reservoir. The detail of desiltation strategies were listed in Table 3. Based on the construction schedule, the designed bypass tunnel was planned to execute from 2023 year. Therefore, when bypass tunnel was constructed, the remained reservoir capacity would become to $10.50x10^6m^3$. Moreover, if replenishment was implemented from 2011 year, the remained storage in 2023 year is about 11.80 10^6m^3. Besides, according to the sediment routing after bypass system is executed at upstream river of 50 year return period(figure 14), the local scour was happened at downstream of check dam and delta deposition at the upstream of back water area. It is about 2 m degradation and aggradation of local scour and delta deposition location, respectively. In addition, the effect area of downstream local scour is about 600m. Therefore, for the stability of river bed, the degradation control should be covered during this distance to protect check dam.

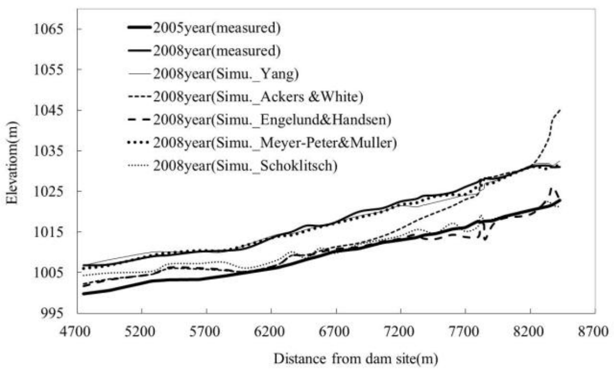


Figure 12. Verification of 1D numerical model at upstream river

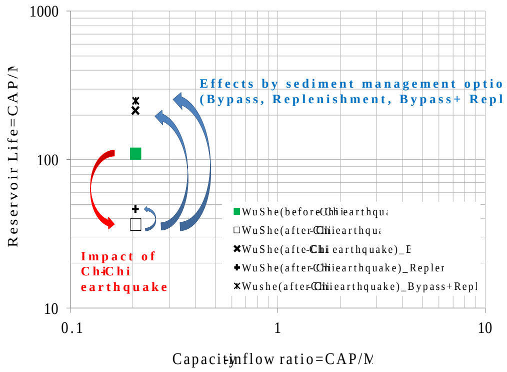


Figure 13. Evolution of Wushe reservoir characteristics due to desiltation strategies

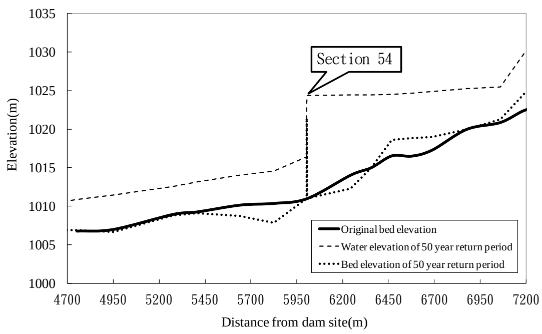


Figure 14. Water elevation and bed elevation after bypass operation of designed flood

Table 3. Detail information of desiltation strategies in Wushe reservoir

Items	2010 Capacity (10^6m^3)	Construction finished (year)	Capacity when Construction finished (10^6m^3)	Before Desiltation strategy		After Desiltation strategy	
				Average annual deposition value(10^6m^3)	Reservoir life(year)	Average annual deposition value(10^6m^3)	Reservoir life(year)
No strategy	53.79	—	—	3.33	36	3.33	36
Bypass	53.79	2023	10.50	3.33	36	0.70	214
Replenishment	53.79	2011	11.80 (2023year)	3.33	36	3.23	46
Bypass + Replenishment	53.79	2023+2011	11.80	3.33	36	0.60	250
Remark：1.Annual incoming sediment volume $4.44*10^6 m^3$							
Remark：2.Venting efficiency of existed facilities 25%							
Remark：3. Flushing efficiency of Bypass 71%							
Remark：4. Sediment replenishment volume $1x10^5m^3$							

5. CONCLUSIONS

Due to the serious sedimentation problem in Wushe reservoir after Chi-Chi earthquake in 1999 year, desiltation strategies were investigated to obtained sustainable operation from 2009 year. Therefore, in this study, the suitable desiltation strategies of bypass system with venting strategy had been classified and planned to implement in Wushe reservoir. Based on the historical data of deposition volume and frequency analysis method, the Gumbel estimation was adopted to investigate deposited sediment volume. The fine sediment transport equation is employed to generate the quantity of suspending load and bed load using inflow hydrograph and transport sediment is also classified by field grain size survey. The valuable venting efficiency of existed facilities were obtained from experiment and calibrated from 3D numerical model. Therefore, the total inflow sediment volume was combined with deposited sediment and outflow sediment. Besides, according to the field survey of desiltation strategies in Japan, up to 10% sediment replenishment can be executed, more than 80% moved efficiency can be implemented by bypass strategies, and almost 100% transported efficiency can be implemented using drawdown flushing strategies. It shows that the flushing strategy possesses highest moved efficiency to move out deposited sediment in a reservoir. However, the drawdown flushing strategies can not be executed in the objective reservoir. Therefore, based on the efficiency of bypass and sediment replenishment, the divert sediment volume were calculated from 1D numerical model and historical valuable excavation volume, respectively. According to the study results, the bypass efficiency is about 71% of objective case and the reservoir life is prolonged from 36 year to 250 year after bypass and sediment replenishment countermeasures is executed.

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