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Downstream variations of suspended solid concentration due to desilting operation in typhoon event

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Abstract

Even the annual average rainfall is abundant, Taiwan is suffering a desperate shortage of water. Due to high sediment yield generated from upstream watershed during flood, sedimentation problem reduces reservoir storage capacity. The Shihmen Reservoir locates in the Northern Taiwan, which plays an important role for water supply and flood control. However, it has encountered serious sedimentation problem because of abundant sediment deposits in typhoon flood event. While sediment released from reservoir, high concentration sediment-laden flow will affect the water quality of the water treatment plant in the downstream reaches. The data of suspended solid concentration (SSC) in the downstream river reach is a very important information for operating the intake of the water treatment plant. The quasi-two dimensional mobile-bed model, NETSTARS, was applied to investigate the variation of downstream SSC. The measured data of SSC were used to compare with the simulated results for model calibration and verification. The results showed that reservoir desilting operation affects Yuanshan Weir water intake. SSC along downstream river was affected by high suspended concentration sediment releasing from reservoir desilting operations.

Keywords: suspended sediment concentration, sediment desilting operation, mobile-bed model

1 Introduction

Shihmen Reservoir is a multi-function reservoir located in the North Taiwan, which supplies 1,120,000 tons of water for 2 million people every day. The Shihmen reservoir completed in 1963 is formed by a 133 m high embankment dam with six spillways, one bottom outlet, two power plant intakes and two flood diversion tunnels. It is located at the upstream reach of the Dahan River and has a natural drainage area of 762.4 km^2. With a design water level of EL.245 m, the reservoir pool has 16.5 km in length and the surface area of the water has 8.15 km^2. The deposition problem is quite serious in Shihmen Reservoir. Based on the survey data in 2015, the depositional volume had reached to 101 million m^3 and its remaining reservoir storage was 67% of its initial capacity. Due to serious deposition problem in 2004 induced by Typhoon Aere, the stratified withdrawal facility was built beside the dam site in 2009 to ensure water supply capacity and one of the penstocks of power plant was modified in 2012 to improve sluicing sediment through the reservoir. While sediment releasing reduces the depositional rate in Shihmen Reservoir, it also generates great amount of sediment released from reservoir outlets. In order to investigate the effects of suspended solid concentration during desilting operation in typhoon event, the quasi-two dimensional model, NETSTARS (Network of Stream Tube model for Alluvial River Simulation), was applied to study the variation of downstream SSC. The field measured data were used to compare with the results of numerical modeling.

2 Governing equation

NETSTARS is a quasi-two dimensional model that can be used to simulate river bed degradation and aggregation in the fluvial river system. It can be derived from de Saint-Venant based on one-dimensional gradually varied channel flow of continuity and momentum equations as follows.

Continuity equation:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q \qquad [1]$$

Momentum equation:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\alpha\frac{Q^2}{A}\right)+gA(\frac{\partial y}{\partial x})+gAS_f-u\cdot q=0 \qquad [2]$$

where A: cross-section (L^2); Q: discharge (L^3/T); u: lateral inflow velocity (=$C\frac{Q}{A}$, C is lateral coefficient) (L/T); t: time (T); x: Horizontal coordinates (L); q: lateral discharge of per unit width (L^2/T); α: momentum correction coefficient; g: acceleration of gravity (L/T^2); y: water level (L); S_f: friction slope.

In sediment computation, suspended load and bed load were separated to calculate in NETSTARS. The advection–diffusion equation was used to simulate suspended load transport. The sediment continuity equation is shown below.

$$\frac{\partial Q_s}{\partial x}+(1-P)\frac{\partial A_d}{\partial t}=q_{sl} \qquad [3]$$

where Q_s : total load (= suspended load + bed load) (L^3/T); A_d : the variation of sediment transport of per unit width (L^3/T); P: porosity; q_{sl} : lateral sediment discharge of per unit width (L^2/T). The variation of bed elevation can be directly calculated with the sediment transport formula as ：

$$(1-P)\frac{\partial a_d}{\partial t}+\frac{\partial}{\partial x}\sum_{k=1}^{N_{size}}[q_t C_k]+\frac{\partial Q_b}{\partial x}=q_{sl} \qquad [4]$$

where a_d : the variation of sediment transport of per unit width in stream tube (L^2); Q_b : the transport rate of bed load in stream tube(L^3/T); q_t : the discharge in stream tube(L^3/T); C_k : the suspended load concentration of diameter *k* in stream tube. NETSTARS was used to investigate the variation of suspended load concentration in river during typhoon period.

3 Numerical modeling in typhoon events

3.1 Study site and conditions

Sediment releasing data during typhoon events over the past years are shown in Table 1. Modifying a penstock of the power plant was carried out in 2012 for sluicing sediment through the reservoir. In Typhoon Soulik (2013), the outflow sediment amount increased significantly during desilting operation after penstock modification. In Table 1, it is found that the values of sediment sluicing efficiency (SSE) in Typhoon Soulik, Typhoon Trami (2013), Typhoon Soudelor (2015) and Typhoon Dujuan (2015) were more than twice that of Typhoon Saola (2012). In Typhoon Matmo and Typhoon Fungwong, there was no desilting operation. Form the measured data of SSE, modifying the existed facilities to improve sluicing capacity was very beneficial measure for Shihmen Reservoir. In this study, Typhoon Soudelor was chosen as the study case. Location map of the Tamshui River is shown in Fig. 1. The inflow boundary conditions of sediment concentration and discharge at reservoir outlet in Typhoon Soudelor are plotted in Fig. 2. Sediment size distributions at various cross-sections are collected and plotted in Fig. 3.

Table 1: Sediment releasing data in typhoon events

Year	*2012*	*2013*	*2013*	*2014*	*2014*	*2015*	*2015*
Typhoon	Saola	Soulik	Trami	Matmo	Fungwong	Soudelor	Dujuan
Q_{Peak}(m^3/s)	5,385	5,458	2,412	882	110	5,025	3,802
SSE (%)	15	34.3	37.2	-	-	35.6	33.4
Remark	Measured	Measured	Measured	-	-	Measured	Measured

SSE：Sediment sluicing efficiency

Fig. 1: Location map of Tamshui River

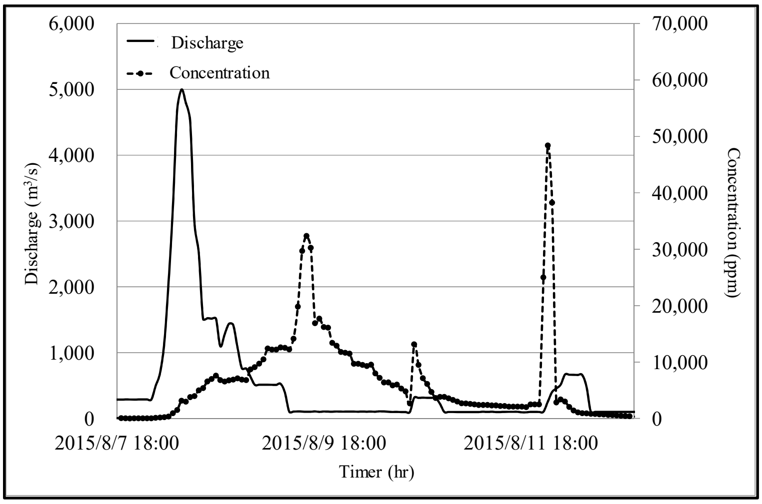

Fig. 2: Inflow boundary conditions in Typhoon Soudelor

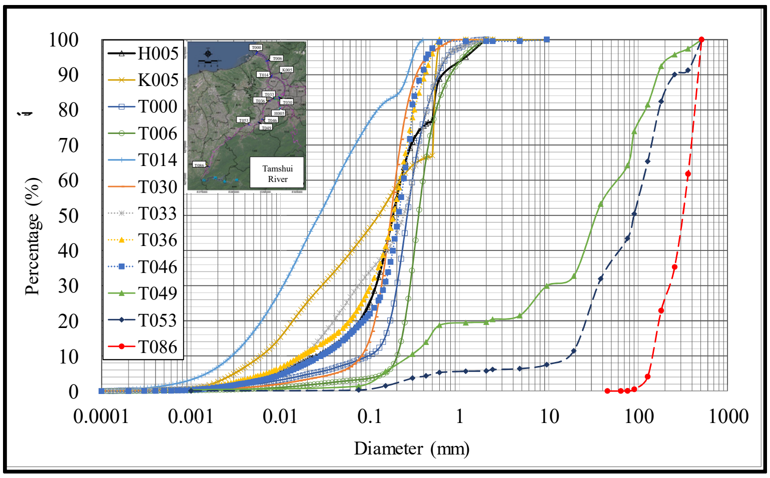

Fig. 3: Sediment size distribution at various cross-sections

3.2 Model verification

The measured and simulated SSC data in Typhoon Soudelor were discussed in this section. In our research, field measured data of SSC were used to verify the simulation at Yuanshan Weir. The variations of SSC at Yuanshan Weir are showed in Fig. 4. The measured data and simulated results have the similar tendency. The arrival time of SSC peak by simulation just had one hour behind the measured one. Variations of SSC peak at different bridges during Typhoon Soudelor are shown in Fig. 5. The tendency of SSC values along the river toward downstream indicates that SSC declines with the distance. The SSC peak decreases down to 10,000 ppm after Chenlin Bridge, which indicates more than 70% reduction of SSC. In this case, the distance between Shihmen Reservoir and Yuansgan Weir are 12.5 km, therefore, The downstream effect of SSC due to desilting operation might transport far away from the reservoir outlet.

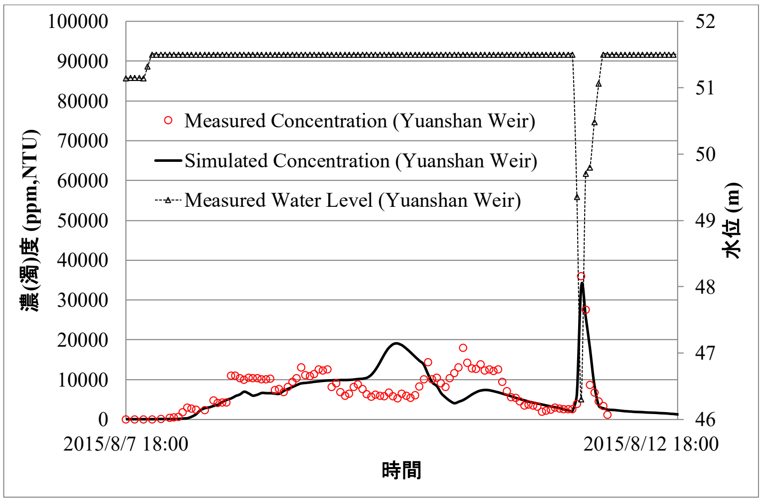

Fig. 4: Variation of SSC in Yuanshan Weir

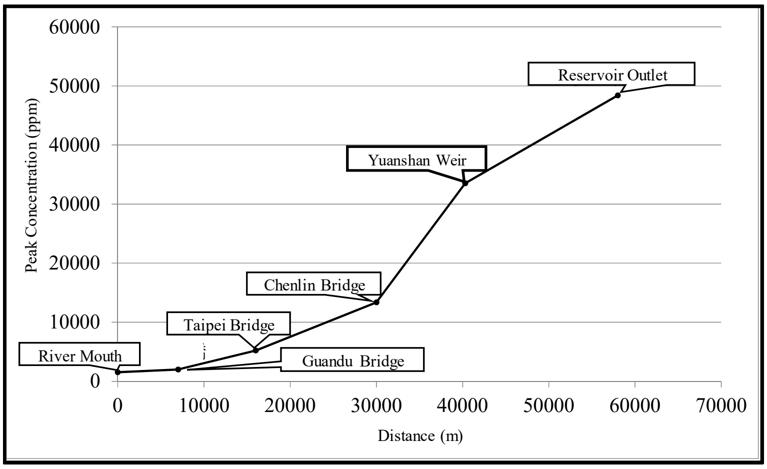

Fig. 5: Variations of SSC peak at different bridges in Typhoon Soudelor

3.3 Model application

In recent years, extreme weather events have happened frequently. To evaluate various scenarios with respect to different countermeasures added, four tests cases (Cases A-D) are implemented. The test cases mainly have the different amounts of inflow sediment and discharge. Regarding the most serious typhoon in recent year, Typhoon Aere (2004) selected as Case A is used to simulate the downstream effect due to sediment releasing. In Case B, penstock modification is added to improve the sediment sluicing efficiency. Case C was considered to improve Case B by adding a sediment bypass tunnel (sediment releasing efficiency is 63.5% = 18.42 million ton). Case D was considered by adding sediment dredging operation (only 0.3 million ton). The simulated variations of SSC peaks at different bridges are shown in Fig. 6. The SSC peaks at different bridges during Typhoon Aere are higher than those of Typhoon Soudelor (2005). When the reservoir released SSC to downstream, the SSC presents a decreasing trend along the river as plotted in Fig. 6. Among test cases, Case D generates highest SSC to the downstream. As shown in Fig. 7, it is also found that bed elevation changes significantly at tidal-river reaches around downstream of the Chenlin Bridge. Obviously, it is affected by high suspended concentration sediment releasing from reservoir desilting operations.

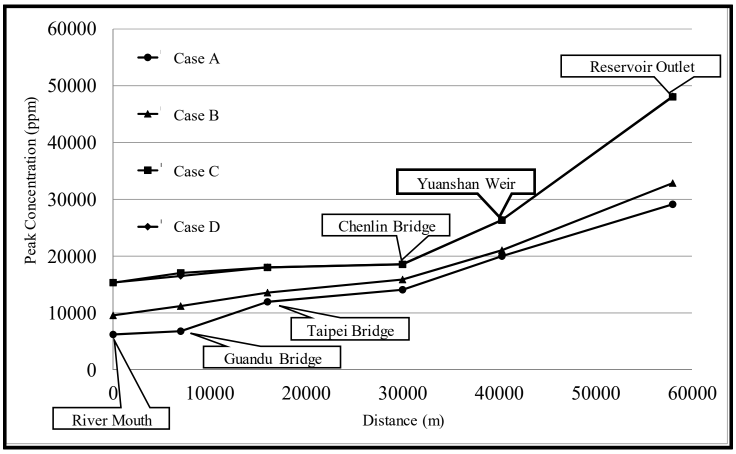

Fig. 6: Variations of peak SSC at different bridges

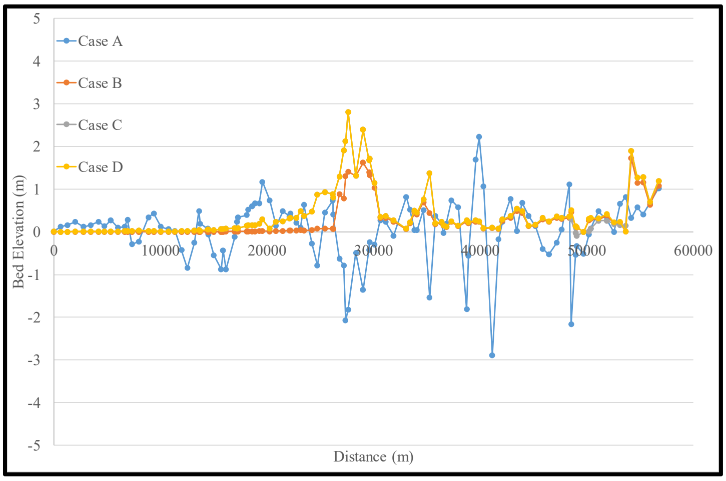

Fig. 7: Changes of bed elevation along the downstream river

4 Conclusions

In the present study, numerical modeling verified with field data was used to investigate the variations of suspended solid concentration (SSC) and bed elevation changes during typhoon events. The conclusions are briefly described as follows.

1. The quasi-two dimensional numerical model, NETSTARS, can be used to simulate the variation of SSC at Yuanshan Weir during Typhoon Soudelor. Although the simulated SSC peak is underestimated, the overall trend agrees with the measured data reasonably.

2. Based on simulated results, the tendency of SSC values declines with the distance. The SSC peak decreases more than 70% of releasing SSC after Chenlin Bridge. In this case, the distance between Shihmen Reservoir and Yuanshan Weir are 12.5 km. It means the downstream effect of SSC might transport far away from the reservoir outlet due to desilting operation.

3. With respect to different countermeasures, four tests cases (Cases A-D) are evaluated. The SSC presents a decreasing trend along the river downstream while sediment releasing from reservoir outlet. Among test cases, Case D generates highest SSC to the downstream. It is also found that bed elevation changes significantly at tidal-river reaches around downstream of the Chenlin Bridge. Obviously, SSC along downstream river is affected by high suspended concentration sediment releasing from reservoir desilting operations.

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