12th International Conference on Hydroscience & Engineering
Hydro-Science & Engineering for Environmental Resilience
November 6-10, 2016, Tainan, Taiwan.

Modeling the processes of fluvial scouring and sediment transport of Dajia River, Taiwan

Dong-Sin Shih, Yuan-Ya Liao, Hui-Cheng Chang
Department of Civil Engineering, National Chung Hsing University
Taichung, Taiwan

ABSTRACT

This research used modeling approach and included field investigations to study the mechanisms of maximum fluvial scouring depth and sedimentation transport processes of Dajia River. As we know, frequent typhoons usually bring heavy rains and flash floods to Taiwan, resulting in severe riverbed scores and carrying huge sedimentations into the river. Dajia River has many important dams spanned cross the river, which tends to block huge sedimentations and to be deposited in channels. In order to better understand the process of fluvial scouring and sediment transport, the research applied WASH123D numerical model with combined modified empirical formula to calculate maximum scoring depth in the river.

KEY WORDS: WASH123D numerical model, Dajia River, scoring depth, Sedimentation transport.

INTRODUCTION

The mountains of Taiwan are high and lofty, and rainfalls concentrate in the raining season of spring, joined by floods brought in by typhoons in summer and autumn. The riverbeds are mostly steep with water running wild and become completely dried out intermittently when the weather gets dry. The riverbeds are mostly steep with water running wild and become completely dried out intermittently when the weather gets dry. The floods are filled with high density sand with tremendous erosion power to silt watercourses, especially in the dam reservoir areas; the deployment of dam reservoir and river-crossing structures cause frequent waterbed erosion in the midstream and downstream of the rivers. We selected Dajia River Basin for our study site, as illustrated in Figure 1, the statistics show that the problems over the years are mainly related to floods, sloping land, and mudslides. This research takes the Dajia River Basin as the study object and, from an overall perspective of the basin, the silt remediation and management is discussed, including the development and application of movable bed sediment transport system model. The objective is to propose specific improvement strategies.

THEORETICAL BASIS

The WASH123D model (WAterSHed Systems of 1-D Stream-River Network, 2-D Overland Regime, and 3-D Subsurface Media) is an integrated numerical modeling for distributed catchment areas, capable of simulation for variable flow and algorithms for pollutant transmission, as well as simulation for sediment erosion and deposition. This is a research carried out in the lab hosted by Professor Yeh, commenced in 1998 (Yeh et al. 1998, 2006). The WASH123D model for the controlling equations of river is mainly used to derive the quality and momentum conservation and solve continuous and momentum equations. The former is shown in Eq. 1:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=S_S+S_R-S_e+S_I+S_1+S_2 \qquad (1)$$

Among which, t indicates the time term [T], x indicates the rive length along the X-axis [L], A is the river cross section [L^2], Q is the water flow volume [L^2/T], right-hand side of the equation is the system increase volume [$L^3/T/L$], S_S is manual injection or outflow volume, S_R water drop volume, S_E is evaporation volume, S_I is infiltration volume, S_1 and S_2 are volumes of surface runoff to rivers.

The sediment transport volume usually comes in suspended load and riverbed load, with non-uniform particle size taken into consideration. The general sediment transport control equation with qualitative changes of balanced riverbed sediment is indicated in Eq. 2.

$$\frac{\partial (PM_n)}{\partial t}=P\left(D_n-R_n\right) \qquad n\in\left[1,\ \ N_S\right] \qquad (2)$$

P is the river cross-sectional wetted perimeter [L], M_n is wetted perimeter-averaged concentration of the n-th bed sediment in mass per unit bed area [M/L^2], D_n is the deposition rate of the n-th sediment in mass per unit bed area per unit time [$M/L^2/T$], R_n is the erosion rate of the n-th sediment in mass per unit bed area per unit time [$M/L^2/T$], and N_S is the total number of sediment size fractions.

General Scour for River Bed

We used the formula that Su and Lu (2013) proposed, see on following Eq. 3, which is estimating general scouring via regression of field investigation. It uses the average riverbed gradient S_0 of cross sections to replace the surface gradient S_w of water depth, which to facilitate engineering practices. And its applicable conditions are based on the assumption of short-term general scouring on semi-straight flow riverbeds, i.e. the riverbed scour is made by single flood events, not long-term general scours.

$$y_{ms} = 2.80 \times \frac{q^{0.80} \times S_0^{0.35} \times \sigma_g^{0.74}}{D_{50}^{0.28}} \quad (3)$$

Where q is the section unit discharge (m^2/s) of flux density flood peak; S0 is the average bed slope of river course; σ_g is the sediment size distribution factor, expressed as $\sigma_g = \sqrt{D_{84}/D_{16}}$; D_{50} is the mean particle size of bed material (mm). The applicability and constraint of equation are q=4.46~23.88 (m^2/s); S_0=0.1~0.718%; D_{50}=2~136 （mm）; σ_g=5.35~19.96.

RESEARCH METHOD

In the mobile bed scour simulation of the lower reach of Dajia River, the simulation range must be confirmed first, the hydrologic and physiographic data in the region are collected and compiled. The hydrologic and river course concept model of WASH123D hydrologic model is built by GMS, and all the conditions and parameters to be used are set (including initial condition, boundary condition, hydrologic and geologic factor parameters). In order to make the model meet the actual situation, the one-dimensional water level and scouring depth of actual event are verified, to further simulate different recurrence intervals, river course sediment discharge, and specific vulnerable section landslide.

The dam in the Dajia River basin influences the two boundary conditions, discharge and sediment concentration. Therefore, this study takes the lowest Shihgang Dam as the boundary of upper and lower scour and deposit of dam body, to analyze the simulation results of the reaches above Shihgang Dam (Ma'an Dam~ Shihgang Dam) and below Shihgang Dam (Shihgang Dam~ estuary) in historical typhoon and flood events and different scenarios, as shown in Figure 1. There are two flow control points in the study area, Shihgang Dam and Ma'an Dam, the data of the two flow control points, and the two gauging stations are located in Houfeng Bridge (CS28-1) and Dajia River Highway Bridge (CS07-1).

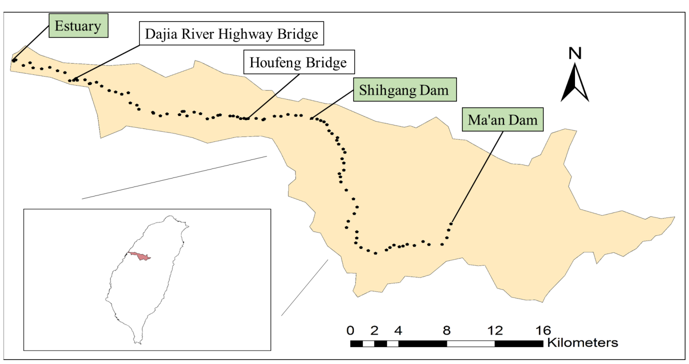

Fig. 1 Study area coverage

The river bed particle sizes sampled from Dajia River are distributed irregularly, so the researchers use the relationship of σ_g and D_{50} in the Su & Lu (2013) equation (expressed as $D' = \sigma_g^{0.74} / D_{50}^{0.23}$), and remove the extreme distribution from D_{16} and D_{84} , the trend line of logarithmic result and equation are shown in Figure 2. The maximum erosion depth of historical event and situation simulation are calculated by using this regression curve.

The sediment concentration setting is measured from the four typhoon events in 2013, Soulik (2013/07/13 02:00 ~ 2013/07/17 04:00), Trami (2013/08/20 00:00 ~ 2013/08/23 23:00), Kong-rey (2013/08/27 16:00 ~ 2013/08/31 15:00) and Usagi (2013/09/21 00:00 ~ 2013/09/24 23:00). The sampling time and observation points for various events are shown in Eq. [4]. Each event was measured for 96 hours, and the observation points were in the Shihgang Dam impounding zone. The measured sediment concentration values are used to discuss the overall sediment transport.

$$Q_s = 0.0057 Q^{2.217} \quad R^2 = 0.8296 \quad (4)$$

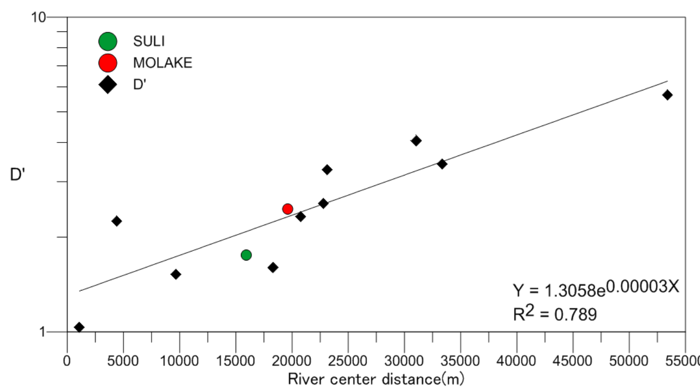

Fig. 2 Relation between D' value and river center distance

MODEL SIMULATION RESULT AND ANALYSIS

This study uses the Sediment Transport Module of WASH123D for simulation study of sediment transport in Dajia River basin. The model simulated water level result is compared with the measured data, and then the model simulated parameters are verified and corrected. In addition, in the river course scour simulation, the measured value of scouring brick is compared with the model simulated value.

Water Level Verification

In terms of one-dimensional model, this study takes the discharge at Shihgang Dam during Typhoon Morakot (simulation interval is 2009/08/08 0:00 to 2009/08/12 0:00) as upstream boundary condition, the Dajia River Highway Bridge is used as the water level check point during Windstorm Morakot, the water level comparison result is used to verify one-dimensional model. The data of section water level check point during the windstorm are from Houfeng Bridge and Dajia River Highway gauging stations. However, Houfeng Bridge was washed off during Typhoon Sinlaku, so the water stage data of gauging stations are deficient, the output water depth and flow velocity are compared with the field measurement results.

The large section and altitude data in 2009 are used for simulation of Typhoon Morakot (work period from June 1, 2011 to March 26, 2012), the simulation period is August 8 0:00, 2009 to August 12 0:00, 2009, the model output interval is 1 hour, there are 97 hours, and Shihgang

Dam has the maximum discharge 5410.16 cms at 16:00, August 9, 2009. The measured stage of Dajia River Highway Bridge gauging station is compared with the simulated water level in Figure 3.

Another event simulation selects Typhoon Soulik, the large section and altitude data in 2013 are used for simulation. The simulated period is July 12 12:00, 2013 to July 15 0:00, 2013, there are 60 hours, and Shihgang Dam has the maximum discharge 6702.93 cms at 10:00, July 13, 2013. The water levels at another control point Dajia River Highway Bridge are compared in Figure 4, the actual and simulated water levels in the ascending segment tend to be matched, and the simulated value of peak stage is 57.51 m, slightly smaller than the actual 57.56 m. The simulation result of falling segment has the same trend as the discharge, but the actual water level in falling segment is very different from the simulated water level, this problem is the same as the condition in Figure 3, the error is -0.05 m, the relative error is -1.0%. The relative error of water level at Houfeng Bridge and Dajia River Highway Bridge is -0.8% and -1% respectively, quite close to the actual condition, so as to verify the water level.

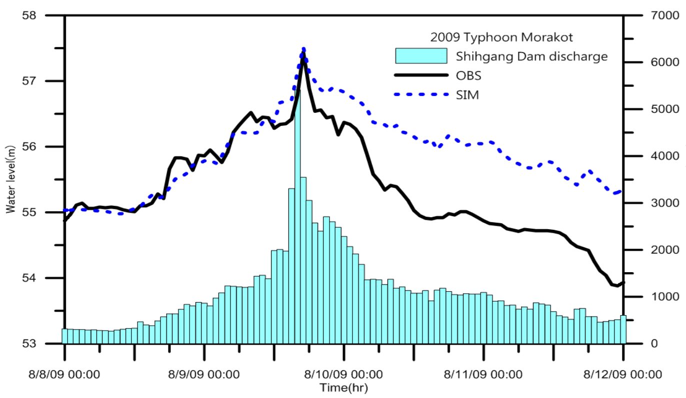

Fig. 3 Water level and flow at Dajia River Highway Bridge during Typhoon Morakot

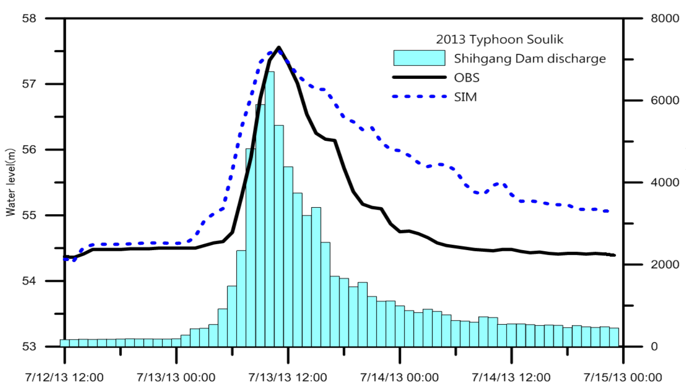

Fig. 4 Water level and flow at Dajia River Highway Bridge during Typhoon Soulik

The results show that the simulated water level error of this model is less than 10%, the model simulated water level result can be used as the parameter for subsequent river course simulated sediment transport. In the hydrologic and hydraulic simulation of Dajia River by WASH123D, in the simulated Morakot and Soulik typhoon and flood events, the water level error is less than 7.4% and 1.0% respectively, the maximum erosion depth and actual value are 8.01% and 0.19%, meaning the combination of this model and Su &Lu (2013) equation and Blench (1969) equation for calculating the river stage, flow velocity and maximum erosion depth of Dajia River has reasonable simulation results.

Scour Depth

The historical data of erosion are derived from the comparison between the scouring brick measured values measured by the team of Prof. Zhao-yao Lu of Chung Hsing University and the model simulated values, "experimental study of sediment transport relationship in Dajia River reach (1/3)" implemented by Chung Hsing University commissioned by Water Resources Planning Institute, WRA, MOEA in 2008. The field scouring brick is located nearby the downstream section (CS27) of Houfeng Bridge (Figure 5), the scouring brick measurement (OBS) value is measured to calculate the elevation of river bed during flood peak, and the elevation change with the scouring brick is -1.56 m. This model simulates the elevation change of this event, the difference between the bed elevation of maximum scour near flood peak and the original bed elevation is ΔH_{max}=-2.06 m. Therefore, the model simulation error is -0.5 m. In addition, after the typhoon event, the difference between the measured scouring brick location and the original elevation is -1.0 m, and the section simulation result of this model is -0.39 m, the error is -0.61 m.

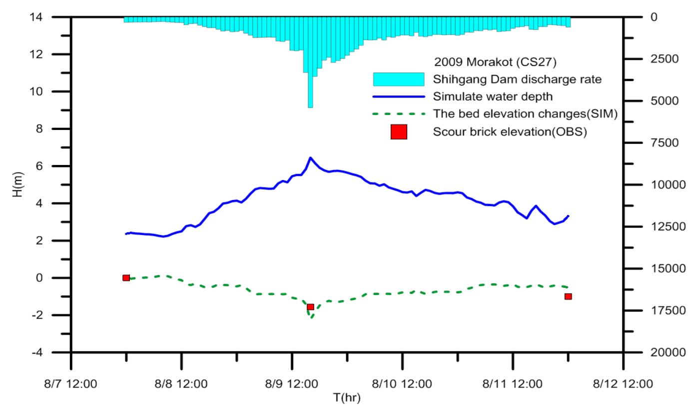

Fig. 5 Bed elevation changes of various sections of river course during Typhoon Morakot in 2009 (CS27)

In the section 22 Fengzhou Levee, the scouring brick measured value is compared with the model simulated value. The field scouring brick is located nearby section 22 of Fengzhou Levee (Figure 6), the scouring brick measurement (OBS) value is used to calculate the river bed level during flood peak, and the elevation change of scouring brick is -0.55 m. This model simulates the elevation change of this event, the difference between the maximum scoured bed elevation nearby flood peak and the original bed level is ΔH_{max}= -0.68 m. Therefore, the model simulation error is -0.13 m. In addition, after the event, the height difference between the measured (OBS) value and the original scouring brick is +0.17 m, the model simulation result is +0.35 m, the error is +0.18m.

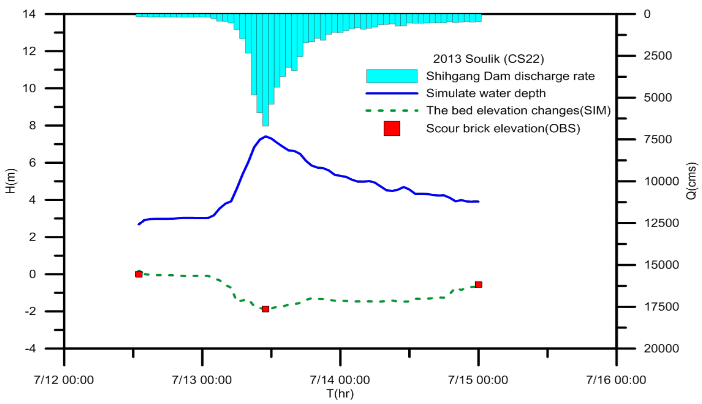

Fig. 6 Bed elevation changes of various sections of river course during Typhoon Soulik in 2013 (CS22)

Therefore, the Typhoon Morakot Disaster in 2009 is discussed according to overall channel change. The interval from the downstream of Shihgang Dam to Houfeng Bridge has erosion after the event, the mean erosion depth is about 0.41 m. The scour in the interval from Houfeng Bridge to section 20 is gentle, the mean erosion depth is about 0.07 m. The section below the section 20 has deposition, the average deposit is about 0.26 m. The scour and deposit changes in the downstream channel of Shihgang Dam after 2013 Typhoon Soulik event are shown in Figure 6. The overall channel change is discussed and classified. In the interval from the downstream of Shihgang Dam to section 15, there is erosion after the event, the mean erosion depth is about 0.40 m, the section below Sun Yat-sen Freeway Bridge has deposit, and the average deposit is about 0.21 m.

Suspended Load Transmission Simulation Analysis

The environment of suspended load concentration in various typhoons is built by using the altitude data measured from Dajia River large section, and the water level, flow velocity, flow and sediment concentration are given. The hourly water level and flow velocity data of various sections are the water level and flow velocity information simulated by Typhoon Morakot one-dimensional river course simulated by WASH123D model. The discharge of upstream boundary condition is the measured value of Shihgang Dam during typhoon. In terms of Shihgang Dam suspended load sediment concentration setting, the regressed value of suspended load concentration corresponding to the sediment concentration measured at Shihgang Dam in typhoon event by TDR is used.

For the suspended load concentration simulation results of various sections, one section of upper, middle and lower reaches in the study area is reviewed respectively. The horizontal axis represents time, there are 37 hours, from August 9 0:00, 2009 to August 10 12:00, 2009. The left side of vertical axis represents the suspended load concentration, the unit is g/m^3. The right side of vertical axis represents the water level, the sections are the upstream Houfeng Bridge (CS28-1), and midstream Dajia River Highway Bridge (CS07-1). The transmission of SS concentration is simulated by WASH123D model. The model simulation exports one data every 30 seconds for comparison and analysis.

The difference between the SS concentration peak time of Shihgang Dam and the peak time of Houfeng Bridge water level hydrograph is 13 min, and the difference from the peak time of Houfeng Bridge SS concentration is 15 min. Therefore, the delay ratio is 1.15. The difference between the Shihgang Dam SS concentration peak time and the peak time of Houfeng Bridge stage hydrograph is 47 min, and the difference from the peak time of Houfeng Bridge SS concentration is 65 min. Therefore, the delay ratio is 1.38.

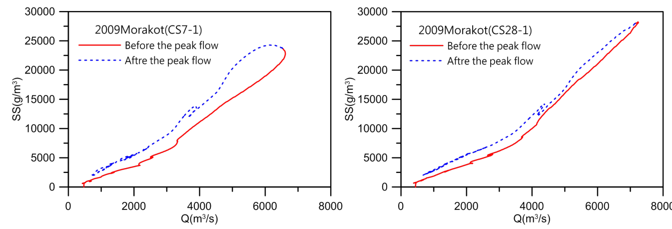

Fig. 7 Suspended load hydrographs during Typhoon Morakot

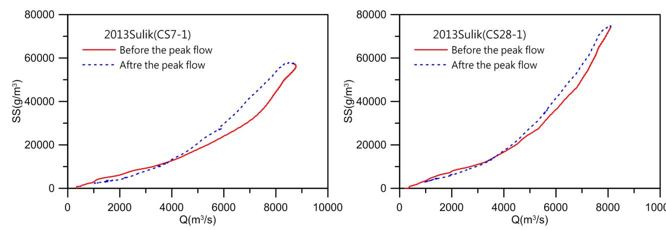

Fig. 8 Suspended load hydrographs during Typhoon Soulik

CONCLUSIONS

This study discusses various erosion and deposition mechanisms in river channel, and discusses the effect of dam body improvement on the overall sediment scour and deposit in Dajia River. The major factor influencing the general river course scour is the flow velocity, the flow, gradient ratio, sectional form and Manning roughness are the factors influencing the maximum erosion depth. As this model cannot simulate the scour influenced by batholite, the interval is the deeply scoured reach during flood peak. The interval from section 29 to section 13 is about 0.63 m. The section nearby estuary has deposit after the event. The empirical equation shall be corrected by field case. In terms of channel deposit, this model estimates the river bed suspended load concentration transport to estimate the river course transport deposit. In the suspended load sediment transport simulation analysis, the sediment transport rate is lower than the flowing water velocity, the maximum concentration delay of sediment and the maximum water stage do not occur at the same time. The findings show the relationship between the suspended load concentration transmission rate and water stage delay, it decreases as the distance between river course section and Shihgang Dam increases.

ACKNOWLEDGMENTS

The authors acknowledge funding of project (MOST 103-2625-M-009-001) from the Ministry of Science and Technology, Taiwan for this research.

REFERENCES

Blench, T. (1969), "Mobile-bed fluviology," University of Alberta Press, Edmonton, Canada.

Gerritsen, H., Vos, R.J., Kaaij, T., Laneand A., and Boon, J.G. (2000), "Suspended sediment modeling in a shelf sea (North Sea)," Coastal Engineering, 41:317-352.

Su, C.C., Lu, J.Y. (2013), "Measurements and prediction of typhoon-induced short-term general scours in intermittent rivers," Natural Hazards, 66(2): 671-687.

Yeh, G. T., H. P. Cheng, J. R. Cheng, and Jerry H. Lin. (1998). A Numerical Model to Simulate Water Flow and Contaminant and Sediment Transport in Watershed Systems of 1-D Stream-River Network, 2-D Overland Regime, and 3-D Subsurface Media (WASH123D: Version 1.0). Technical Report CHL-98-19. Waterways Experiment Station, U. S. Army Corps of Engineers, Vicksburg, MS 39180-6199.

Yeh, G.T., Huang, G.B., Zhang, F., Cheng, H.P., Lin, H.C. (2006), "WASH123D: A Numerical Model of Flow, Thermal Transport, and Salinity, Sediment, and Water Quality Transport in WAterSHed Systems of 1-D Stream-River Network, 2-D Overland Regime, and 3-D Subsurface Media." A Technical Rep. Submitted To EPA. Dept. of Civil and Environmental Engineering, Univ. of Central Florida, Orlando, FL.

Zeng, W., Beck, M.B. (2003), "STAND, a dynamic model for sediment transport and water quality." Journal of Hydrology, 277, 125-133.

Yeh, G.T. and Zeng, W. (2005), "A General paradigm of modeling one-dimensional river/stream watershed water quality."

Water Resources Planning Institute, Water Resources Agency, Ministry of Economic Affairs (2010), "Final Report of Experimental Studies on Dajia River Sediment Transport Characteristics."