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

Effects of Dredging on River Stability in Tachia River, Taiwan

Lin-Wan You, Keh-Chia Yeh
Department of Civil Engineering, National Chiao-Tung University
Hsinchu, Taiwan

ABSTRACT

A preliminary investigation of dredging effects on longitudinal riverbed profile is made by simulating 64 dredging arrangements with varying bed slope and channel-to-floodplain width ratio. The results indicate that dredging operation with minimal change of existing riverbed profile is not necessarily the most desirable option to maintain channel stability. This study shows that a good dredging arrangement could potentially enhance channel stability with smaller amplitude of fluctuation in the difference in average unit stream power along the channel. To maintain channel stability, effective dredging operation is required to consider its influence on river regime.

KEY WORDS: Dredging, longitudinal riverbed profile, bed slope, channel-to-floodplain width ratio, channel stability, unit stream power, river regime.

INTRODUCTION

Taichia River is located in central Taiwan (see upper part of Fig. 1) with a length of 140 km and a basin area of 1,336 km^2. It has 22 major in-stream structures along the river including 19 bridges and 3 dams. Because of frequent occurrence of landslide events in the upper part of the river basin, compounded by the presence of in-stream structures, the continuous movement of sediment throughout the river system is often disrupted or interfered. As the result, there is a clear indication that the river has significant deposition build-up at the upstream of the dams while severe erosion at the downstream.

It is known that longitudinal riverbed profile is strongly influenced *by* discharge, bed slope, bed materials, and geologic structure of the river basin. Dredging is a commonly adopted engineering means for navigation improvement, construction and reclamation, flood control, and mining (IADC 2010). This man-made modification of natural flow processes disrupts the dynamic equilibrium between the movements of water and sediment (Dunne and Leopold 1978). Radoane and Dumitriu (2003) indicated that riverbed tectonic uplift has more important influence than river erosion on the shape of longitudinal profile. That is the reason why Tachia River is very difficult to develop an equilibrium profile with a high concavity. Monjezi et.al (2013) showed that the dredging has no significant effect on the reduction of water surface elevation in major floods. On the other hand, they also pointed out that the sediments move faster after dredging and sedimentation decreases in riverbed. To improve flow conveyance capacity by upstream dredging would alter the flow regime of the river and bring about the reduction in sediment source for downstream. Hence, dredging would cause instability in channel bed and potentially damage the safety of river structures.

This paper considers the characteristics of sediment source in the river basin and investigates the channel longitudinal profile response to dredging in the sediment production area. Furthermore, attempt is made to find a better arrangement of dredging for maintaining water course stability and to restore the continuation of sediment transport throughout the river system.

In this study, Section 2 presents available field data and an 1D hydraulic and sediment transport model (SRH-1D), and its calibration and validation. Analysis and discussion of model application to dredging via simulation on the different dredging arrangements on longitudinal profile are illustrated in Section 3, followed by conclusions in Section 4.

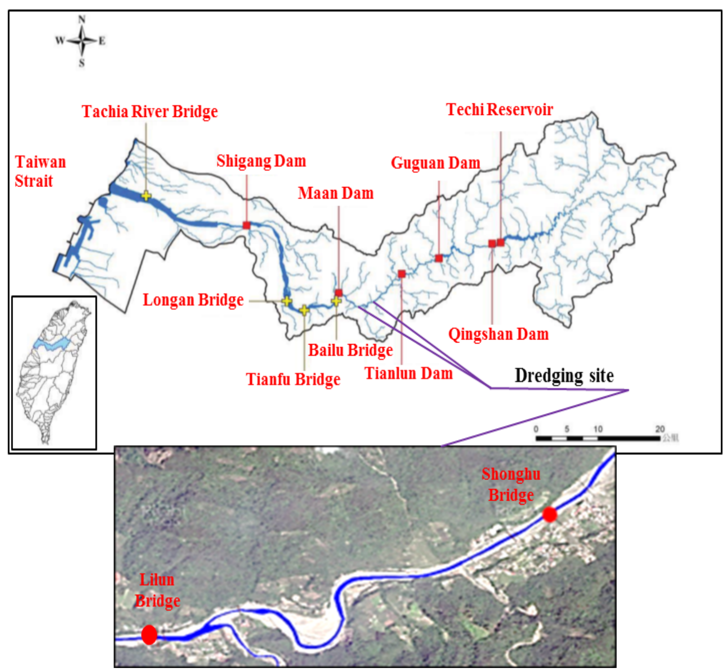

Fig. 1 Map of the Tachia River Basin, Taiwan.

MODEL CALIBRATION AND VALIDATION

The Study River Reach

The study river reach extends from the upstream of Tianlun Dam to the Tachia River mouth to the Taiwan Strait (see upper part of Figure 1) within the Tachia River basin. The length of studied reach is approximately 66 km.

Mathematical Models: SRH-1D

In this study, the computer software SRH-1D (Sediment and River Hydraulics – One Dimension) is used. The model is a one dimensional hydraulic and sediment transport model for use in natural rivers and man-made channels.

Required Model Inputs

Channel cross-sections and bed materials

Along the study river reach, channel cross-section measurements at 143 locations are available in 2011, 2012 and 2013 from The Third River Management Bureau, Taiwan Water Resources Agency. Also, information about bed materials is available from the measurements conducted in 2011.

Roughness coefficient

In this study, the procedure of Cowen (1956) is adopted for determining the values of Manning's roughness coefficient *n* by first select a base value of *n* for the bed material and then adjustment its value according to channel irregularities, alignment, obstructions, vegetation, and other factors. The mathematical model of the Tachia River within the study reach has been calibrated in which the Manning coefficient value is determined for each river section based on water surface and channel bed profile.

Boundary conditions (BCs)

Hourly flow rate and sediment discharge data at the Tianlun Dam were used as the model upstream boundary condition. On the other hand, hourly water elevation at Taichung Port located at the mouth of Tachia River is used as downstream boundary condition in the model study.

Sediment transport equation

In this study, the sediment transport equation used in the study is developed by Wu et al. (2000) for computing sediment carrying capacities of the river.

Calibration and validation of mathematical model

The basis used to calibrate SRH-1D is to compare the computed longitudinal profile with the observed profile in 2012. For model validation, comparison is made of its predicted longitudinal profile and observed profile in 2013. Figure 2 shows a comparison of predicted and observed longitudinal profiles and channel bed elevation along the study river reach from 2012 to 2013. It can be observed that SRH-1D predicts quite well the longitudinal profile for bed deposition and degradation. Hence, one can conclude that the model can be used to investigate the effect of dredging operation on the longitudinal profile of the study reach.

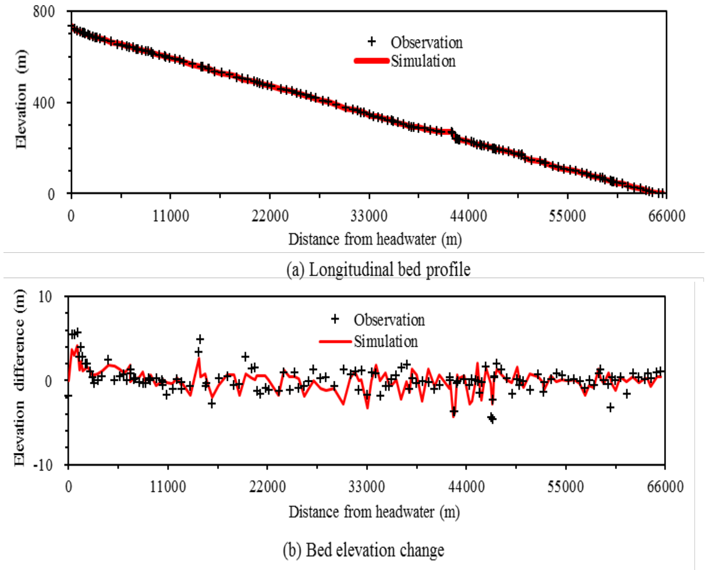

Fig. 2 Comparison of predicted and observed (a) longitudinal profile and (b) bed elevation change in 2012-2013

MODEL APPLICATION AND ANALYSIS

The study reach is divided into three river segments according to the annual trend of deposition and erosion as follows:

From the River Mouth to Shigang Dam

There is little landslide zone that provides sediment from the land surface. The major concern in this river segment is riverbed erosion and its induced bridge pier scour;

From Shigang Dam to Maan Dam

Fluvial erosion and deposition appear concurrently in this reach because significant terrain undulation and mining operation have greatly influenced on this channel segment after the Chi-Chi Earthquake in 1999, the largest event in Taiwan in the past 60 years.

From Maan Dam to Tianlun Dam

After the Chi-Chi Earthquake, significant uplift of the local land surface and increase in sediment source of the watershed have great influenced on this river segment. Dredging is often implemented in this channel segment.

This study attempts to investigate the effects of different dredging arrangements along the river segments from Maan Dam to river mouth on longitudinal riverbed profile. The investigation is done by changing the channel-to-floodplain width ratio and the bed slope according to Sinha and Parker (1996) who provided four measures to quantify the river profile concavity based on wavelike progradation, abrasion, basin subsidence and water and sediment inflow from tributaries. They noted that the degree of concavity varies depending on a set of dimensionless numbers. In this paper, the effect on sediment inflow which, in turn, on the longitudinal profile is ignored and the remaining three dimensionless parameters are considered through the width ratio and bed slope.

The selected dredging sites along the study river reach are 77, 76-2, 76-1, 76 between Shonghu Bridge which is 6872 m distant from the headwater and Lilun Bridge which is 10427 m distant from the headwater as shown in lower part of Fig. 1. Model simulation of 64 dredging arrangements are made from the combinations of two bed slopes in each of four selected dredging sites and two channel-to-floodplain width ratios (B_c/B_f) at sites 77 and 76-1. The two bed slopes considered are the original bed slope value (S_o) and dredged slope $S_0 = 1.2S_0$. The two values of B_c/B_f are 0.6 and 0.8.

From the viewpoint of maintaining river course stability, this study attempts to identify the most desirable dredging arrangement at the selected sites so that the resulting change in riverbed profile is minimal. For this reason, the river segment from Maan Dam to the river mouth is divided into 102 cross-sections at which the change in the lowest channel bottom elevation before and after dredging is determined by simulation. The segment-averaged river course stability indicator used in this study is the mean absolute error (*MAE*) defined by

$$MAE_s = \frac{\sum_{x=1}^{102} \left| z'_{x,s} - z_{x,s} \right|}{102}, s = 1,2,\ldots,64 \quad (1)$$

where $z_{x,s}$ and $z'_{x,s}$ are, respectively, the lowest riverbed elevation at channel cross-section '*x*' before and after the dredging considering dredging arrangement scenario '*s*'. A smaller value of *MAE* indicates a more stable channel bed response.

Based on the numerical simulation of 64 dredging arrangements, it is found that the values of *MAE* vary in the range of (0.8818, 0.8851). The *MAE* value corresponding to the best and the worst dredging arrangements are shown in Table 1 and Fig. 3. Interestingly, the dredging arrangement (D1) with no slope change and $B_c/B_f = 0.6$, which represents minimal change of existing riverbed profile resulted in significant riverbed profile change with *MAE* value of 0.8844 m close to the worst case.

Table 1. The best and worst dredging arrangements

Dredging Arrangement			Best (D62)	Worst (D11)
Dredging Site	77	Slope	$1.2S_0$	S_0
		B_c/B_f	0.8	0.6
	76-2	Slope	$1.2S_0$	$1.2S_0$
	76-1	Slope	$1.2S_0$	S_0
		B_c/B_f	0.6	0.8
	76	Slope	$1.2S_0$	S_0
MAE (m)			0.8818	0.8851

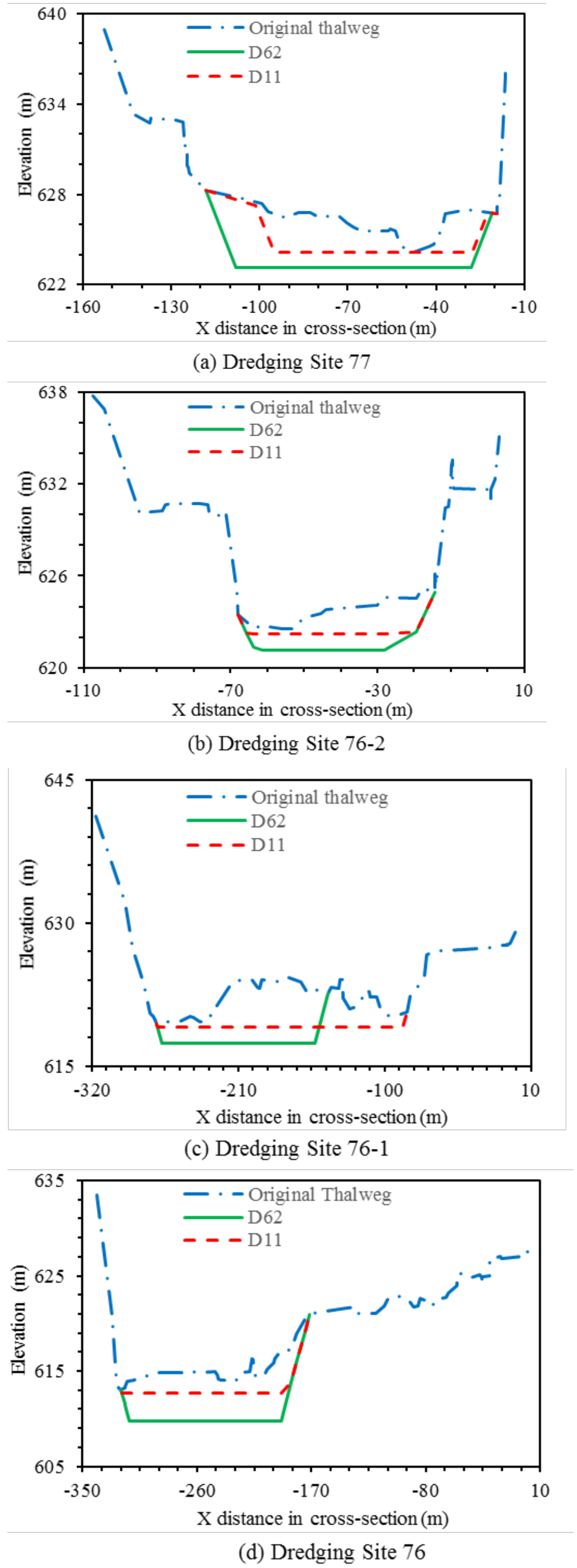

Fig. 3. The best and worst dredging arrangements at the four dredging sites.

Yang and Stall (1976) indicated that unit stream power is the dominant factor in determining the total sediment concentration of streams with gravel beds. Yang (1973) defined unit stream power P as the time rate of potential energy loss per unit weight of water:

$$P = VS \tag{2}$$

where V is the velocity of flow in the longitudinal direction and S is the friction slope. Focusing on the range 9701 m ~18298 m to headwater, this study compared D62 (the best) with D11 (the worst) with respect to the difference in bed elevation from the viewpoint of unit stream power in Fig. 4. The figure shows that average unit stream power has effect on the erosion and deposition of riverbed. The comparison of 64 dredging arrangements indicates that the dredging with the most desirable arrangement (D62) the difference in average unit stream power along the channel has the smallest amplitude of fluctuation.

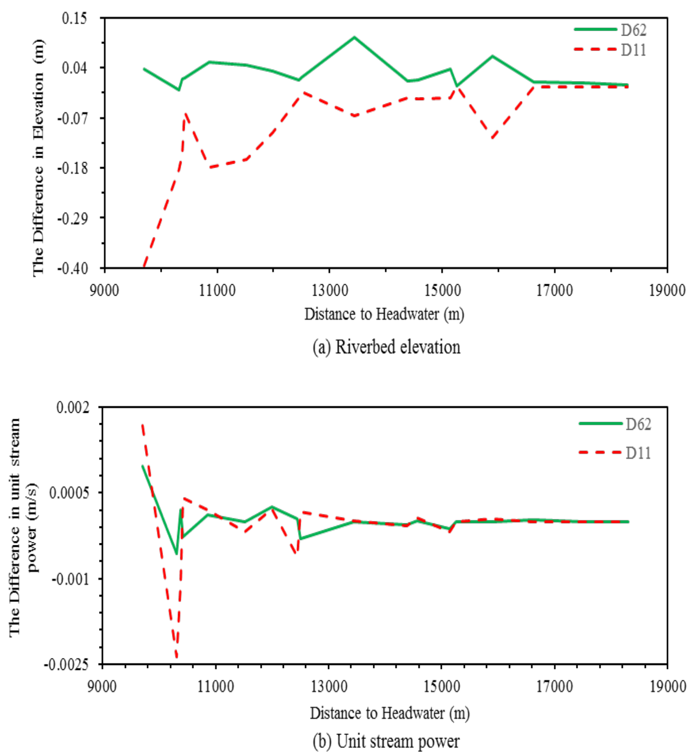

Fig. 4 The differences in (a) bed elevation and (b) unit stream power between dredging and non-dredging.

CONCLUSIONS

Landslide events induced by frequency occurrences of torrential rainfalls have significantly increased sediment input to the Tachia River from the basin after Chi-Chi earthquake. Compounded by the presence of many in-stream structures (i.e., dams and bridges) the river regime of the Tachia River is *highly complex and variable.* To improve flow conveyance capacity by dredging in the upstream reach would alter the flow regime of the river and bring about the reduction in sediment source for the downstream. This study conducts a preliminary investigation on the effects of different dredging arrangements along the river on longitudinal riverbed profile. Model simulation of 64 dredging arrangements are made from the combinations of two bed slopes in each of four selected dredging sites and two channel-to-floodplain width ratios at two of four sites.

By using the mean absolute error (*MAE*) for the segment-averaged river course stability indicator, this study identifies the best and the worst dredging arrangements corresponding to the smallest and largest *MAE* values. The analysis of 64 simulation results indicates that the dredging operation with minimal change of existing riverbed profile is not necessarily the most desirable option to maintain channel stability. Based on the unit stream power, which is the dominant factor in determining the total sediment concentration of streams with gravel beds, this study shows that dredging with the most desirable arrangement results in the smallest amplitude of fluctuation in the difference in average unit stream power along the channel.

To maintain channel stability, effective dredging operation is required to consider its influence on river regime. This study presents a preliminary investigation attempting to identify the best dredging arrangement in the Tachia River by considering limited combinations of slope and cross-section changes at four selected dredging sites. A more comprehensive design of dredging scenarios should be made in the future research for identifying the optimal dredging arrangement.

ACKNOWLEDGMENTS

The authors are grateful to the Third River Management Bureau, Taiwan Water Resources Agency and Taiwan Central Weather Bureau for providing the data needed for this study.

REFERENCES

Bray, N. and Cohen, M. (2010). Dredging for Development, Published by IADC and IAPH, 80 pp.
Dunne, T. and Leopold, L.B. (1978). Water in Environmental Planning, W H Freeman and Co, San Francisco, 818 pp.
Radoane, M., Radoane, N. and Dumitriu, D. (2003). Geomorphological evolution of longitudinal river profiles in the Carpathians, Geomorphology, 50: 293–306.
Monjezi, R., Heidarnejad, M., Lor, M. A. and Hoseini, E. (2013). The Study of Effect of Dredging and Dike Construction on the Flow Hydraulic and Reduction of Flood in Downstream of the River (Case Study: Karun River Downstream Between Ahvaz and Farsyat), J. Civil Eng. Urban., 3(4): 170-175.
Phillips, J.V. and Tadayon, S. (2006). Selection of Manning's Roughness Coefficient for Natural and Constructed Vegetated and Non-Vegetated Channels**,** and Vegetation Maintenance Plan Guidelines for Vegetated Channels in Central Arizona, U.S. Geological Survey Scientific Investigations Report 2006-5108, 41 pp.
Wu, W., S.S.Y. Wang, and Jia, Y. (2000). Nonuniform sediment transport in alluvial rivers, Journal of Hydraulic Research, Vol. 38(6):427-434.
Sinha, S.K. and Parker, G. (1996). Causes of concavity in longitudinal profiles of rivers, Water Resources Research, 32(5): 1417-1428.
Yang, C.T. (1973). Incipient motion and sediment transport, J. Hydraul. Div. ASCE, 99(HY10): 1679-1704.
Yang, C.T. (1976). Minimum unit stream power and fluvial hydraulics, J. Hydraul. Div. ASCE, 102(HY7): 919-934.