A field investigation of the effect of fine sediment concentration on suspended bed material load

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ABSTRACT

The estimation of sediment transport rate has been an important issue for river planning and management. Landslide and debris flow occur frequently in the watershed in Taiwan due to the weak geology and frequent earthquakes. For example, the 921 Earthquake (Richter scale of 7.3) occurred in central Taiwan in 1999 caused a total landslide area of more than 100 km^2. It was the second-deadliest quake in recorded history in Taiwan.

In this study, four sets of field experiments (3 typhoons and one large rain storm) were conducted during typhoon seasons of 2012 and 2013 to collect the hydraulic and sediment data at the Tzu-Chiang Bridge of the lower Cho-Shui River after the river incision. The main objectives of this study are to increase our understanding of the variations of the sediment transport characteristics, and to evaluate the suitability of the commonly used sediment transport equations for the lower Cho-Shui River after the 921 Earthquake. After comparing with the field data collected by Tsang during 2006-2007, it was found that the concentration of wash load plays an important role in the sediment-laden flow. High concentration of fine sediment tends to damp the turbulence of the flow, and to reduce the uniformities of both the velocity and sediment concentration (bed material load) profiles.

In addition, commonly used suspended load sediment transport equations in general under-predicted the sediment load for the lower Cho-Shui River. With consideration of the effect of concentration of fine sediment on the suspended bed material load, Chiu et al.'s (2000) equation was modified and gave more reasonable sediment discharge estimations.

Acknowledgements

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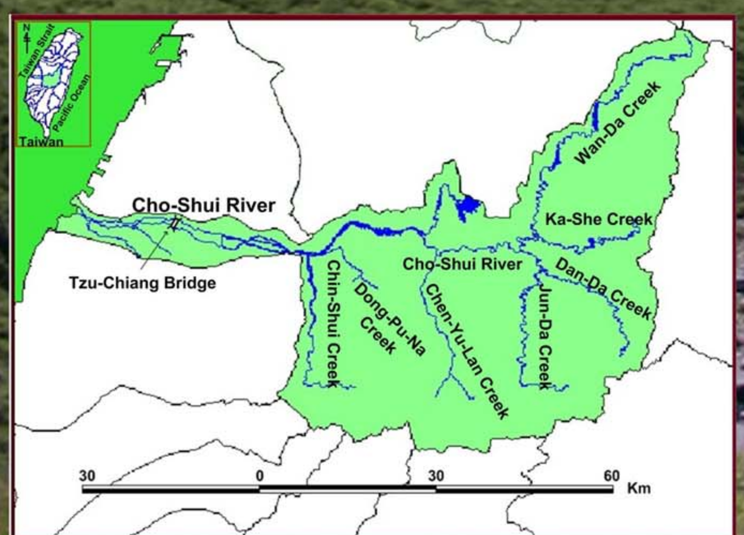
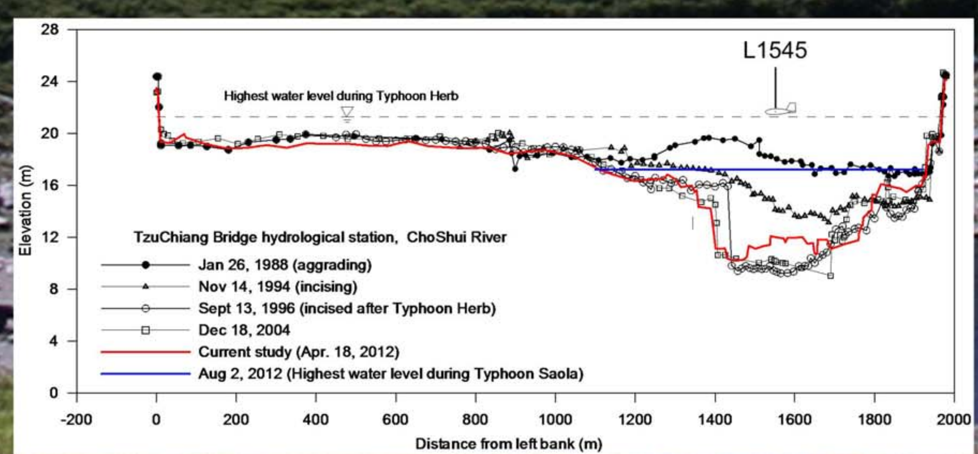
1. Introduction

- The Tzu-Chiang Bridge of Highway 19 on the lower Cho-Shui River in Taiwan, a sand bed river reach with very high sediment load during typhoons, was selected as the suspended load observation station. The river reach was significantly incised after 1996 (Typhoon Herb), and the water surface width was reduced from about 1 km to 300 m during high flows [Fig. 1(c)].
- A portable measuring system (Fig. 2) with a 300 pound USGS sound weight (lead fish) was adopted in this study (Lu et al., 2006). A simple 1,500 cc suspended load sampler with a 20 mm opening and a high speed propeller velocimeter were attached to the lead fish for measuring the suspended load and the flow velocity. Four samples were collected in a vertical (0.05 H, 0.2 H, 0.8 H and water surface) when the flow depth H was greater than 0.75 m



(a) Location map of Cho-Shui River Basin in Taiwan

(b) Aerial photo of Tzu-Chiang Bridge (Sept. 17, 2012)



(c) Variations of cross-sectional shape for river reach near Tzu-Chiang Bridge (1986~2012)

Figure 1 Site description

2. Results

2.1 Variation of suspended load after 921 Earthquake (1999)

- The suspended load concentrations near water surface (WL) during 2006-2007 were much higher than those measured in 2012, indicating the loose material due to landslide decreased with time. (Fig. 3)
- High amount of fine sediment (WL) tends to damp the flow turbulence and reduce the vertical flow mixing. Both velocity and SBML concentration profiles collected during 2006-2007 are less uniform [lower ϕ and β values, Figs. 4(a) and 4(b)] as compared to those collected in 2012 with lower amount of fine sediment [higher ϕ and β values, Figs. 4(c) and 4 (d)]. Also Fig. 5.
- Chiu's flow velocity theory (2002):
  $\phi = \bar{u}/u_{max} = fn(M) = fn(H/B)$
- Modification of Chiu's flow velocity theory (current study): $\phi = \bar{u}/u_{max} = fn(M) = fn(H/B, C_{v(WL)})$
  i.e. ϕ is a function of cross-sectional geometry and WL concentration (Fig. 5)

Figure 2 Portable measuring system

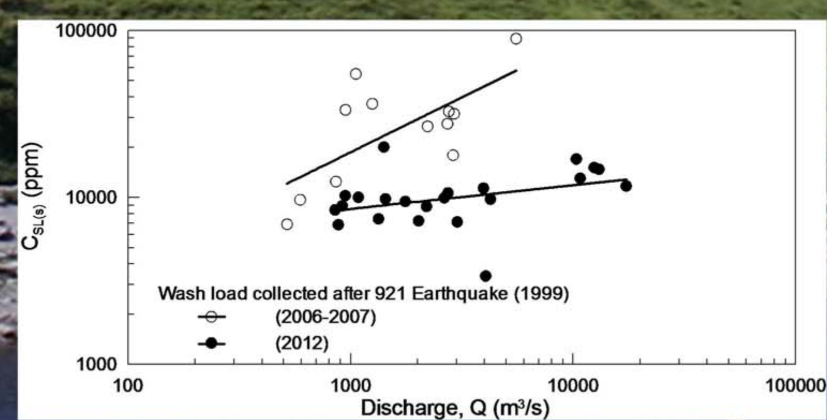


Figure 3 Variation of the relationship between the wash load (suspended load measured near water surface) and flow discharge after the 921 Earthquake (Richter magnitude 7.3, Sept. 21, 1999)

2.2 Effect of fine particle concentration [$C_{v(WL)}$] on suspended bed material load (SBML)

- Fig. 6(a) vs. 6(b)
  The slope and r^2 values for the regression lines for WL [Fig. 6(a)] are smaller than those for SBML [Fig. 6(b)], indicating that the WL are less dependent on the flow intensity (q) as compared to SBML
- SBML(2006-2007) vs. SBML(2012) – Fig. 6(b)
  The concentration of SBML(2006-2007) was higher than that of SBML(2012) for a given q value, indicating that higher WL tends to increase the SBML
- Fig. 7
  The concentration of SBML can be expressed as a function of flow depth H, mean velocity $\bar{u}$ and WL concentration based on all data collected during 2006-2007 and in 2012

$$C_{v(SBML)} = 0.060 \times \bar{u}^{0.4} \times H^{2.228} \times C_{v(WL)}^{0.8} \quad (1)$$

DR= discrepancy ratio= predicted value/ measured value

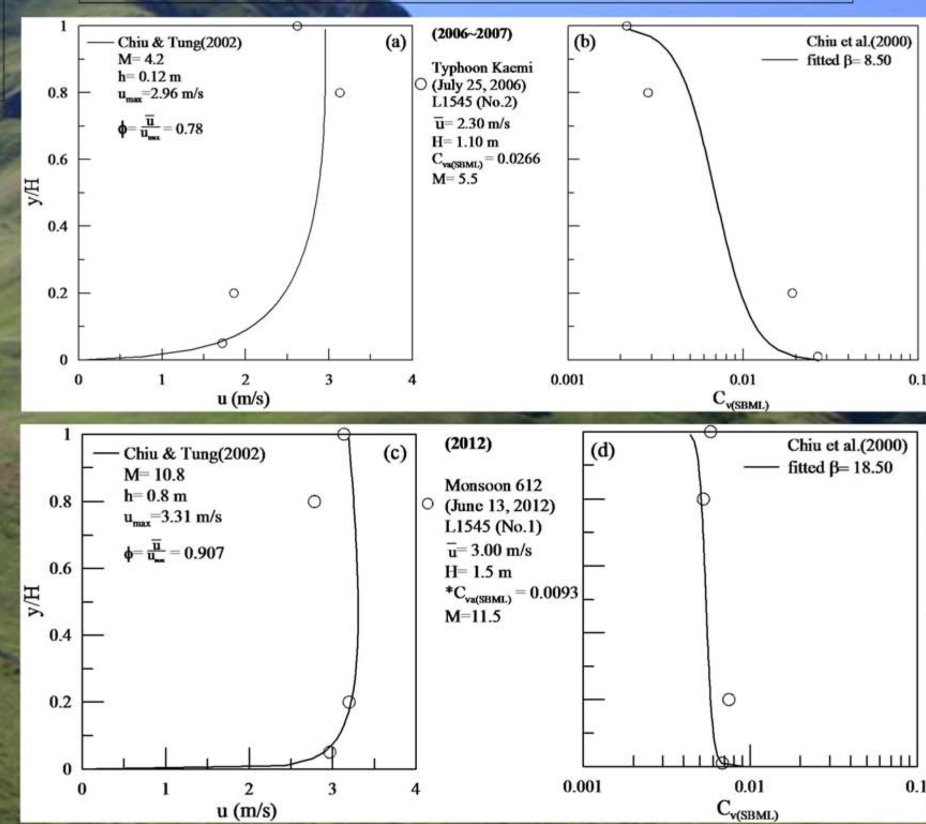


Figure 4 Comparison of velocity and SBML concentration profiles for high WL (2006-2007) [Figs. 4(a) and 4(b)] and low WL (2012) [Figs. 4(c) and 4(d)]

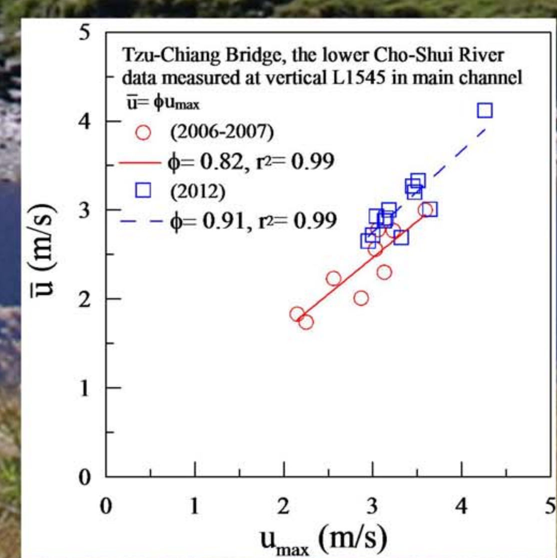


Figure 5 Comparison of ϕ value for periods with high WL (2006-2007) and low WL(2012)

2.3 Prediction of SBML concentration profile – modification of Chiu et al.'s (2000) sediment concentration theory

- Chiu et al.'s (2000) sediment concentration theory

$$\frac{C}{C_{va}} = \left[\frac{1-\frac{y}{H}}{1+\left(e^{M}-1\right)\frac{y}{H}} \right]^{\lambda'} \quad (2)$$

$$\lambda' = \frac{\omega_s u_{max}\left(1-e^{-M}\right)}{\beta u_*^2 M} = \frac{\omega_s \bar{u}\left(1-e^{-M}\right)}{\beta u_*^2 M \phi} = \lambda G \quad (3)$$

$$G(M) = \frac{1-e^{-M}}{M\phi} \quad (4)$$

$$\lambda = \frac{\omega_s \bar{u}}{\beta u_*^2} \quad (5)$$

- Estimation of $C_{va(SBML)}$ and β – Fig. 8
  The reference sediment concentration near the channel bed $C_{va(SBML)}$ and the ratio of sediment and momentum exchange coefficients β can be expressed as

$$C_{va(SBML)} = 0.732 H^{-0.115} \bar{u}^{0.406} C_{v(WL)}^{0.790} \quad (6)$$

$$\beta = 1.530 H^{-0.915} \bar{u}^{1.364} C_{v(WL)}^{-0.154} \quad (7)$$

- Prediction of concentration profile by modified Chiu's method – Fig. 9
  The modified Chiu's method was used to reasonably predict the concentration profile measured for Typhoon Soulik in 2013

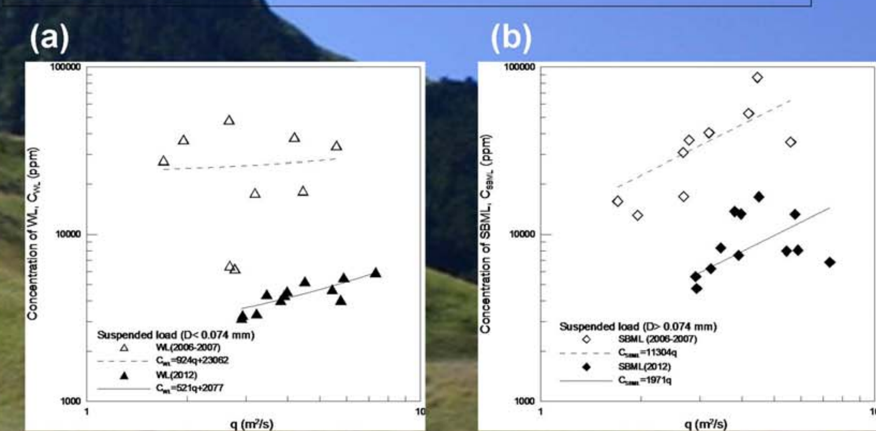


Figure 6 Comparison of relationships of (a)WL vs. q; (b) SBML vs. q for periods with high WL (2006-2007) and low WL (2012) after the 921 Earthquake in 1999

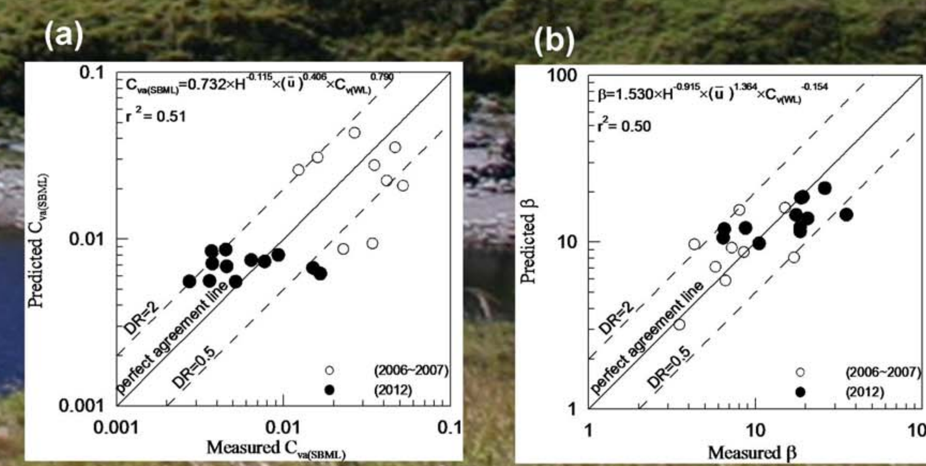


Figure 8 Comparison of predicted and measured values of (a) $C_{va(SBML)}$; (b) β for data collected at Tzu-Chiang Bridge during high flows

2.4 Comparison of measured and predicted SBML for different equations

- Fig. 10 (based on 2012 data)
- Traditional Eqs.– slightly underestimated
  Wu et al.(2000)– overestimated (derived based on Yellow River data with low d_{50} values)
- Modified Chiu (current study)– in general predicted reasonably, including the verification with Soulik (2013) data

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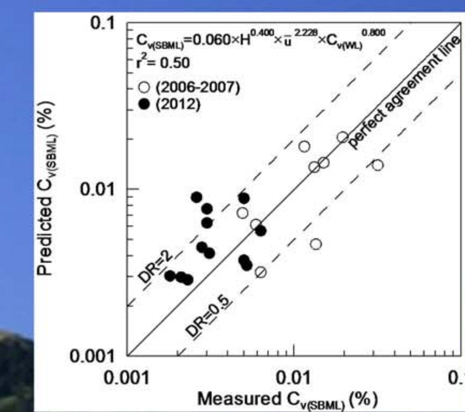

Figure 7 Comparison of predicted and measured suspended bed material load concentration (by volume)

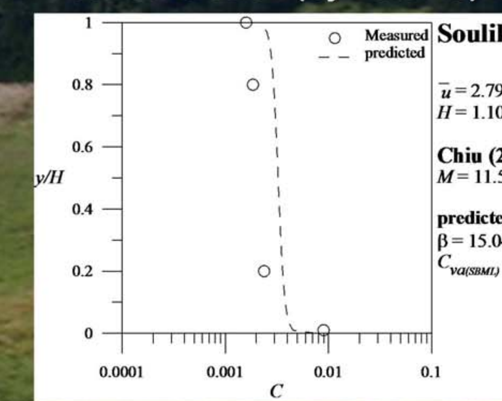

Figure 9 Prediction of suspended bed material load concentration profile using Modified Chiu (2000) for flood induced by Typhoon Soulik in 2013

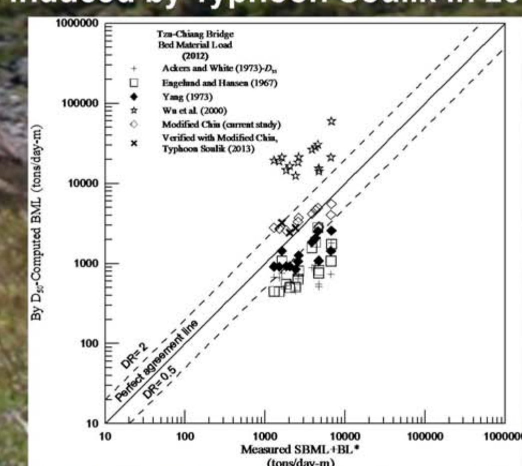

Figure 10 Comparison of measured and predicted bed material load [bed load BL was estimated by Kuo et al.'s (1988) equation (Su et al., 2013)]