Probing temporal variation of suspended load to bedload ratio using seismic saltation model

Chao-Ting Meng[1], Wei-An Chao[1,2], Yu-Shiu Chen[3]

[1]Department of Civil Engineering, National Yang Ming Chiao Tung University, Hsinchu 300, Taiwan.

[2]Disaster Prevention and Water Environment Research Center, National Yang-Ming Chiao Tung University, Hsinchu 300, Taiwan

[3]Disaster Prevention Research Center, National Cheng-Kung University, Tainan 701, Taiwan

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INTRODUCTION

The temporal and spatial variation of sediment load is an important indicator for assessing the lifespan of a reservoir, especially the information on bedload transport (Figure 1). The bedload flux usually can be estimated by an operational fixed proportion of suspended load. Our study chose the Da-Pu Dam (location: Chia-Yi, Taiwan, 23.29°N, 120.64°E). The Da-Pu Dam is the last check dam before entering the reservoir area (Figure 2). Combining survey data on river bed (e.g. cross-sections, sediment particle sizes, monitoring data of water level, suspended load and time-lapse images), our study applies a seismic saltation model to estimate the bedload flux and compares the results with the measured suspended load. Results revealed that the proportion relationship between bedload and suspended load varied with time and changes in river parameters (Figure 3) under the Typhoon Lupit event.

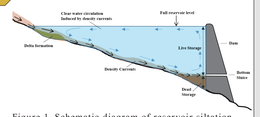


Figure 1. Schematic diagram of reservoir siltation

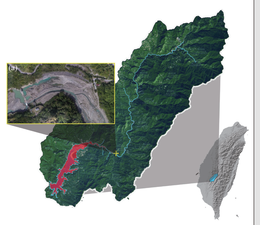


Figure 2. (a) Location of the Da-Pu dam (Chia-Yi town, Taiwan, 23.29°N, 120.64°E).

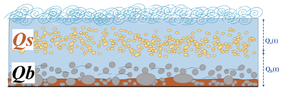


Figure 3. Schematic diagram of temporal and spatial variations in bedload and suspended Load

STUDY SITE

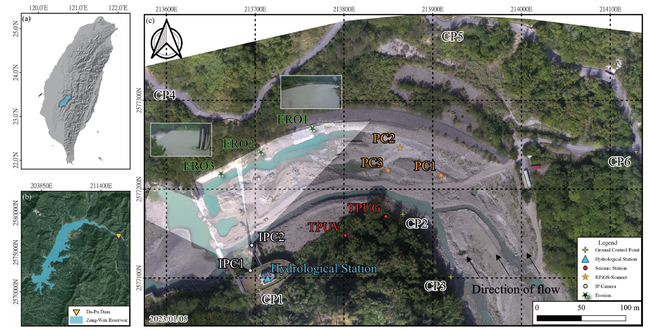


Figure 4. (a) and (b) Locations of the Zeng-Wen Reservoir and the Da-Pu dam (Chia-Yi town, Taiwan). (c) Orthophoto of the study site. CP denotes ground control points used in the orthophoto, blue triangle represents the Da-Pu hydrological station, white circles represent IP cameras, orange stars denote the RPiGs-Scanner used for particle size analysis, and the green and black explosion shape represents the erosion area of the riverbank.

PREDICTION

WHY IS THE 8-40 Hz FREQUENCY BAND CHOSEN FOR PREDICT BEDLOAD

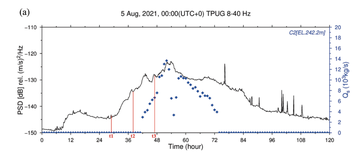


Figure 8a. 8 – 40 Hz PSD time series and Q_s data. Vertical lines indicate the time points of t1, t2 and t3 corresponding to the low, normal and high of water stage, respectively.

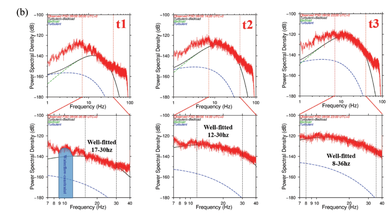


Figure 8b. PSD curves of prediction (blue, green, black) and observation (red) for the time-points of t1, t2 and t3. At t1 time, the frequencies dominated by turbulent flow is less than 10 Hz and the primary bedload frequency of 12.9 Hz that the model aims to predict.

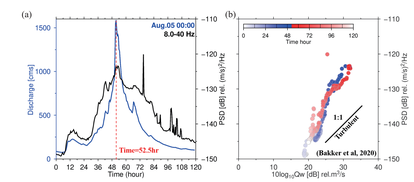


Figure 9. (a) Relationship between the power spectral density (PSD) in the frequency range of 8-40 Hz and discharge (August 5, 2021, 00:00 ~ August 10, 2021, 00:00). A time of 52.5 hour (red dash line) represents the beginning of the decrease in discharge. (b) Comparison of the frequency range of 8-40 Hz with the discharge computed in $10\log_{10}Qw$ [dB] rel.m^3/s. The slope of data distribution is higher than 1, supports the 8-40 Hz PSD mainly generated by the bedload transport.

METHODS

SPECTRAL ANALYSIS

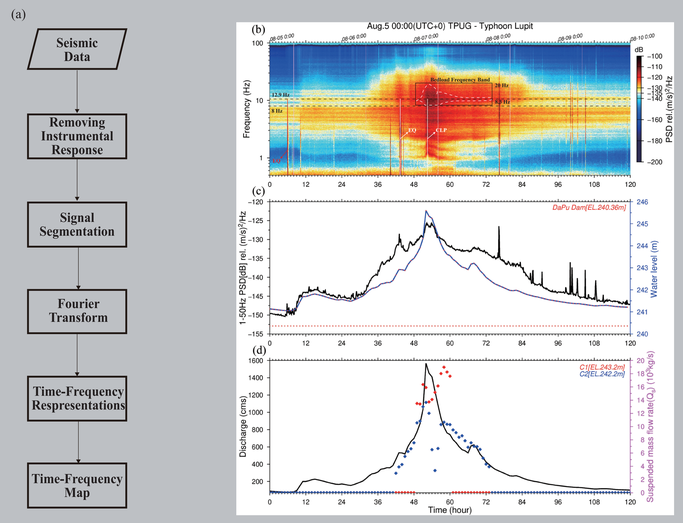


Figure 5. (a) Flow chart of Time Frequency Analysis. (b) Spectrogram. (c) Time series data of water level and power spectral density (PSD) averaging by frequencies from 1 to 50 Hz (d) Time series data of suspended mass flow rate (Qs) and discharge.

SEISMIC SALATATION MODEL

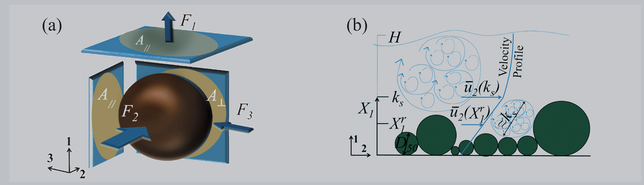
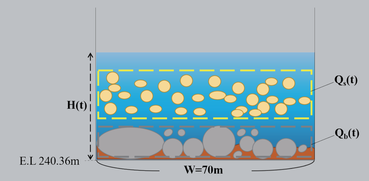


Figure 6. Schematics for the model. (a) Three-dimensional representation of the different fluctuating components of forces acting on a given riverbed grain. These forces act on the perpendicular areas associated with the different directions. (b) Two-dimensional representation of the average velocities and turbulent flow structures considered in the model. A velocity profile that deviates from the usual logarithmic profile sets the average velocities within the bed roughness. The model analysis is conducted at the reference height X_1^r at which consider turbulent eddies with a correlation length l_c of the order of the roughness scale k_s and traveling downstream at an average velocity $\bar{u}_2(X_1^r)$ The turbulent intensity carried by these eddies is proportional to the macroscopic shearing rate of the water layer within the bed roughness. (Florent Gimbert, Victor C. Tsai, and Michael P. Lamb, 2014)



Fixed Parameters	
Phase velocity, V_{c0} (m/s)	1136.0
Station-to-river distance, r_0 (m)	80
Avg. river width, W(m)	70
Median grain size, D_{50}(m)	0.042
Grain density, ρ_g(kg/m³)	2600
Threshold stress, α(dimensionless)	0.173
Slope, θ(˚)	0.57
Particle roughness, σ_g	1.48
Quality factor, Q_0	4.0

Figure 7. Schematic cross-section of the Zeng-Wen river (LHS) and fixed model parameters for Typhoon Lupit event (RHS). H(t) represents the water depth that changes over time, W represents the average river width of the Zeng-Wen river (assumed to be 70 m due to the lack of accurate cross-sectional data), Qs(t) represents the suspended load that changes over time, and Qb(t) represents the bed load that changes over time. The riverbed elevation is at 240.36 m.

DISCUSSION

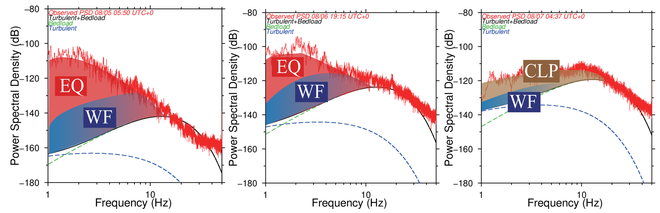


Figure 10. Results show that PSD amplitude at frequencies less than 10 Hz can be contributed by other seismic sources such as earthquake (EQ), embankment collapse (CLP), and water fall (WF).

EQ: Earthquake WF: Water fall CLP: Embankment collapse

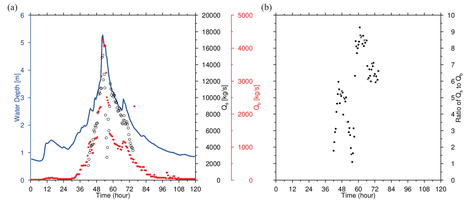


Figure 11. (a) Relationship between suspended load (Q_s) and model inverted bedload (Q_b) in water depth. (b) The ratio between suspended load (Q_s) and inverted bedload (Q_b)

The irregular black dashed line (frequency band: 8.3 to 20 Hz, time interval: 47.5hr to 74hr, energy: -120 dB to -100 dB) circled in the spectrogram represents the bedload frequency band of interest for future discussion (see Figure 5b).

REFERENCE

1. A physical model for seismic noise generation by turbulent flow in rivers, Florent Gimbert, Victor C. Tsai, and Michael P. Lamb, 2014.
2. Field Application and Validation of a Seismic Bedload Transport Model, Maarten Bakker, Florent Gimbert, Thomas Geay, Clément Misset, Sébastien Zanker, Alain Recking, 2020.