Identify the physical characteristics of bedload transport using accelerometer

P Harsanto¹*, B P Kamiel² and Nursetiawan¹

¹Civil Engineering Department, Universitas Muhammadiyah Yogyakarta
²Mechanical Engineering Department, Universitas Muhammadiyah Yogyakarta

*Corresponding author: puji_hr@umy.ac.id

Abstract. Real-time sediment transport discharge monitoring in rivers is a challenge. One of the difficulties is the existence of the transport sediment on the bottom of the river bed, the water flow making it invisible to the naked eye, and the flow of velocity itself creates a barrier to measure and install devices in the river. Vibration-based sediment transport measuring instruments have been developed in developed countries. Only a few people in Indonesia have created a technique for quantifying transport sediment. The experiment was carried out in a flume with sediment of a specified diameter flowing through it. An accelerometer was installed at the bottom to measure the vibration induced by the sediment movement at the channel’s bottom. Impact energy is created when sediment grains collide with the channel's bottom. The amount and size of the sediment determine how much energy is released. The accelerometer measures the amplitude of the vibration signal that is produced by the energy. The statistical parameters can be used with alternating quantities of data. The findings of the experiments reveal that the larger the parameters value linearly with the sediment grain size.

keywords: accelerometer, measurement, sediment characteristics

1. Introduction
Riverbank erosion is the main problem in rivers, especially in urban areas. This is due to the presence of houses or public facilities that are located close to the river. Retaining walls is a solution to prevent riverbank erosion. The retaining wall foundation, located at the bottom of the riverbed, becomes extremely vulnerable if the river degradation-aggradation process is very dynamic [5] [11].

The process of degradation and aggradation is closely related to sediment transport [12]. Meanwhile, the equilibrium condition of the riverbed elevation is highly dependent on the volume of sediment flowing in the river. Thus, the estimation or calculation of the sediment transport volume becomes highly necessary. The sediment from the volcanic eruption has change[d] the river morphology on its tributaries [7]. The sediment transport influences in the cross-section along the river banks are due to erosion and sedimentation [6] [9].

The measurement of sediment transport has been a distinctive challenge. One of the difficulties in measuring sediment discharge is because the bedload flows at the river's bottom, so it is not visible. In Indonesia, the Indonesian river management agency (Balai Besar Wilayah Sungai, BBWS) has not placed any serial sediment transport measurement equipment. Real-time or series sediment transport measuring instruments need to be developed. A commonly used sediment transport measuring instrument is a sediment catcher bottle placed on the riverbed. This measurement method is sampling or
intermittent in nature which is used to approach events in a series. Up to date tools that can serve serial data are sensors that capture the vibration of sediment when passing through the tool. The resulting vibration can be in the form of sound or object vibration.

Nowadays, technology has entered into various fields, especially electromechanics. One technology that is quite common in electromechanical science is the accelerometer, a sensor for measuring the acceleration of an object, either dynamic or statistical acceleration [8]. Dynamic measurements are the acceleration measurements on moving objects, while statistical measurements are measurements of the earth's gravity. Examples include vibrations that occur in vehicles, buildings, and machines. In addition, it can also be used to measure vibrations that occur on the earth, engine vibrations, dynamic distances, and speeds with or without the influence of the earth's gravity.

Several studies or tests were carried out using accelerometer sensors. Within the scope of electromechanics and electrophysics [3] [4] [13], there has been no specific research or test discussing its application to civil engineering in general or sediment transport in particular. Seismic sensors can detect vibrations caused by the movement of sediment grains on the riverbed [12].

The existence of accelerometer technology allows researchers to research the form of testing physical models in the laboratory regarding sediment vibrations detected by accelerometers to determine the characteristics of sediment gradations. In this study, the capture of vibrations caused by sediment passing through a flow in the flume was carried out. The purpose of the study was to detect the characteristics of the vibrations produced by moving grains at the bottom of the flume test. The moving grains on the bottom of the channel will give a vibrating effect on the flume base plate. The effect of vibration is captured by the accelerometer sensor, stored in the log data and used to analyze the type of vibration generated. The research was conducted at Civil Engineering Laboratory, Universitas Muhammadiyah Yogyakarta Indonesia.

2. Material and Methods

2.1. Experimental Methods

Sediment grain size is one of the important parameters in the sediment discharge estimation formula. Experiments in this study were carried out to identify the correlation between the pattern of amplitude and grain diameter of the sediment under the condition that the flow hydraulics were kept constant.

![Experiment test scheme](image)

**Figure 1.** Experiment test scheme

The movement of sediment captured by the accelerometer is sliding, rolling, or jumping. While the movement of floating sediments certainly does not cause a vibration effect at the bottom of the channel, this sediment condition is not considered. For the tool's three sediment movements to be captured properly, this experiment was carried out by flowing one grain of sediment in one flow condition. In the same flow condition, sediment grains with different diameters flowed.

The setting of the instrument and the experimental steps are as follows: 1) determining the flow conditions that can drain sediment into a bedload, 2) flowing one grain of sediment with a certain size
10 (ten) times, 3) the movement of sediment causing a vibration effect on the flume bottom, 4) capturing the effect of vibration by the accelerometer, 5) storing the vibrations directly on the computer.

This experiment used a flume width of 10 cm and a length of ± 3.4 m from the sediment feeding location to the flume outlet. The flume is set with a channel slope of 0.01, a flow depth of 0.024 m (2.4 cm), a flow velocity of 0.97 m/s, and a flow discharge of 0.0024 m$^3$/s. The accelerometer is installed at the flume base in two places: at 0.4 m and 2.3 m from the sediment feeding location. In this study, the sediment diameters were 8 mm, 10 mm, 12 mm, 14 mm, 16 mm, 18 mm, and 20 mm.

This test is carried out by flowing 1 (one) grain of sediment (sediment feeding) based on an alternative grain diameter. The experiment does ten times for each diameter. The vibration amplitude rate generated by flowing sediment will be recorded by the accelerometer sensor, which will then be translated by the DAQ module and sent to the computer as numerical data in the form of vibration amplitude rate. The accelerometer is set via MATLAB software with a reading rate of 1652 amplitude points per second and a reading time of 15 seconds.

2.2. Statistical Parameters
To study the effect of particle size on the signal registered by the accelerometer, the 8 mm to 20 mm particle size were used in the flume experiments. Statistical analysis methods with time domains such as variance, standard deviation, root mean square (RMS), crest factor, kurtosis can be used to distinguish the characteristics of the vibration signal that occurs.

a. Mean
The mean, usually expressed as $\overline{x}$, is the sum of the sample values divided by the number of ($n$). It can be interpreted that the mean value is generally used as a measure of data that dominates the entire data.

$$\overline{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$  \hspace{1cm} (1)

b. Standard Deviation
The standard deviation ($\sigma$) indicates how much fluctuation a signal has from its mean value. A low standard deviation indicates that the sample is close to the mean, while a high standard deviation indicates that the sample is far from the mean. The standard deviation can also be considered an effective measure of the energy or power of a vibration signal.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}}$$  \hspace{1cm} (2)

c. Kurtosis
Kurtosis indicates whether the shape of the data or signal is flat or pointed. The normal component is shown with very low kurtosis, while the damaged components have high kurtosis.

$$kurt = \frac{\sum_{i=1}^{n} (x_i - \overline{x})^4}{(n-1)\sigma^4}$$  \hspace{1cm} (3)

d. RMS
Root Mean Square (RMS) is an indicator of the energy level of the vibration signal.

$$RMS = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \overline{x})^2}$$  \hspace{1cm} (4)

e. Variance
The variance is the square of the standard deviation, $\sigma^2$, which is formulated as:

$$\sigma^2 = \frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}$$  \hspace{1cm} (5)

f. Peak Value
The peak value is an analysis carried out by looking at the energy intensity generated by vibrations at the time domain and frequency domain data peaks.

$$peak = \frac{\max(x) - \min(x)}{2}$$  \hspace{1cm} (6)

Diagnosis is made at the peak value by looking at the changes in the resulting amplitude of the statistical variation used.
4. **Crest Factor**

Crest Factor \( (C_f) \) is a statistical measurement that is quite widely used in signal analysis. This parameter is defined as the ratio of the maximum absolute value of the signal's RMS value.

\[
C_f = \frac{\text{max}(|x(n)|)}{\sigma}
\]  

(7)

3. **Results and Discussions**

The data recorded by the accelerometer is the value of the vibration amplitude, which is recorded every 1/1652 second.

**Figure 2.** The vibration amplitude rate of particle size 8 mm

**Figure 3.** The vibration amplitude rate of particle size 10 mm

**Figure 4.** The vibration amplitude rate of particle size 12 mm
Figure 5. The vibration amplitude rate of particle size 14 mm

Figure 6. The vibration amplitude rate of particle size 16 mm

Figure 7. The vibration amplitude rate of particle size 18 mm

Figure 8. The vibration amplitude rate of particle size 20 mm
Before the sediment flows, the flume already gets vibrations due to the movement of the water flow. This vibration can be recorded properly by the accelerometer. Likewise, when sediment flows in the flume, the movement of the sediment causes vibrations that the accelerometer can record. The results of the recording can be shown in Figures 2 to 8.

The sediment that passes through the flume bottom can cause vibrations signal that the accelerometer can capture. From Figure 8, it can be seen that the larger the diameter of the sediment grains, the larger the amplitude [13] [17] [8]. The shape of the particles, and the different sizes of are play an important role in their transportation on the bed [15]. The increase in amplitude is caused by the different momentum energy of each grain [5]. This new processing approach proves to be well suited for bedload transport monitoring using an accelerometer and allows us to establish a relationship between the grain size and the amplitude signal properties [2].
Figure 9 (a-g) shows the relation between statistical parameters and particle size. A regression line is drawn to describe the trend of the relationship. The impacts from saltating particles scale linearly with the size of particles of the linear momentum [14].

Figure 9 shows that the size of the bedload particles transported over the bed can be estimated from the amplitude [16]. Furthermore, the seismic or vibration measuring techniques were used to determine bedload transport by grain-size classes and become a developed method such as geophone and acoustic method [10].

4. Conclusions
The experiment to identify the movement of sediment through the flume with an accelerometer has been carried out well. The signal vibration and statistical analysis can identify the sediment grain size. Our study revealed some limitations regarding the captured signal when the movement of grain is saltating. To improve the accuracy, we propose to perform further experiments using small grain size and more extended time recording.

Acknowledgements
This research was funded by the Ministry of Education and Culture of the Republic of Indonesia contract number: 165/E4.1/AK.04.PT/2021/ date 12th July 2021 through PDUPT scheme. The main title of the research is "Smart System Accelerometer for Sediment Disaster Mitigation".

References
[1] Alihosseini, M & Thamsen, PU 2018 Experimental and Numerical Investigation of Sediment Transport in Sewers Proceedings of the ASME 2018 5th Joint US-European Fluids Engineering Division Summer Meeting Volume 3: ASME
[2] Cook KL, Andermann C, Gimbert F, Adhikari BR, Hovius N 2018 Glacial lake outburst floods as drivers of fluvial erosion in the Himalaya Science 362(6410): 53–57
[3] Gimbert, F., Fuller, B. M., Lamb, M. P., Tsai, V. C., and Johnson, J. P. L. 2019 Particle transport mechanics and induced seismic noise in steep flume experiments with accelerometer-embedded tracers Earth Surf. Process. Landforms 44(1): 219-24
[4] Harsanto, P 2015 River Morphology Modeling at the Downstream of Progo River Post Eruption 2010 of Mount Merapi Procedia Environmental Sciences 28: 148-157
[5] Ikhsan, J., Kurniati, R., Harsanto, P., and Nursetiawan 2020 Analysis of Sediment Transport on the Upstream Code River, Indonesia Civil Engineering and Architecture 8(4): 475-482
[6] Ikhsan, J., Legono, D., Rahardjo, A.P., Harsanto, P. and Fujita, M 2020 Dynamics of lahar-affected river tributaries of the Progo river after the 2010 Mt. Merapi eruption IOP Conference Series: Earth and Environmental Science 437(1): 012009
[7] Khodegaonkar, A. D., Anekar, N., Girase, S. B., and Hirmukhe, S. S 2014 Vibration Measurements From Seismometer To Miniature Accelerometer: A Study. International Journal of Engineering Sciences 7(1): 1-10

[8] Legono, D 2005 Important issues on sediment-related disaster management in Indonesia. International Symposium on Fluvial and Coastal Disasters: Coping with Extreme Events and Regional Diversity. Kyoto: 1-8

[9] Rinaldi, M. and S. E. Darby 2007 9 Modelling river-bank-erosion processes and mass failure mechanisms: progress towards fully coupled simulations. Gravel-Bed Rivers VI: From Process Understanding to River Restoration: 213-239

[10] Roth, D. L., et al. 2016 Bed load sediment transport inferred from seismic signals near a river Journal of Geophysical Research: Earth Surface 121(4): 725-747

[11] Schmandt, B., et al. 2017 Seismic array constraints on reach-scale bedload transport Geology 45(4): 299-302

[12] Tsai, V. C., et al. 2012 A physical model for seismic noise generation from sediment transport in rivers Geophysical Research Letters 39(2)

[13] Wyss, C. R., Rickenmann, D., Fritschi, B., Turowski, J. M., Weitbrecht, V., Travaglini, E., Bardou, E., and Boes, R. M. 2016 Laboratory flume experiments with the Swiss plate geophone bed load monitoring system: 2 Application to field sites with direct bed load samples Water Resour. Res., 52(10) 7760–7778

[14] Yiu, E.M.-L., Chen, F.C., Lo, G., and Pang, G 2012 Vibratory and Perceptual Measurement of Resonant Voice Journal of Voice 26(5):675.e13-675.e19

[15] Barrière, J., et al. 2015 An advanced signal processing technique for deriving grain size information of bedload transport from impact plate vibration measurements Earth Surface Processes and Landforms 40(7): 913-924

[16] Wyss, C. R., et al. 2016 Laboratory flume experiments with the Swiss plate geophone bed load monitoring system: 2. Application to field sites with direct bed load samples Water Resources Research 52(10): 7760-7778

[17] Rickenmann, D 2017 Bed-Load Transport Measurements with Geophones and Other Passive Acoustic Methods Journal of Hydraulic Engineering 143(6)