Application for Japanese Pipe Hydrophone in Taiwan for Estimating Bedload Discharge

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In Taiwan, about the sediment monitoring method mostly was sampling by man in the past. The monitoring data were concentrate on wash load and suspended load. Method for bed load is few and results in lack of monitoring data.
In Japan, the pipe hydrophone developed started in 1992. There were a lot of studies and monitoring station for pipe hydrophone. Base on those research results of Japanese pipe hydrophone, present study came clarify the relationship between sound pressure and momentum to estimate bedload discharge for each components. For clarifying the influence for sediment particle impacting angle, tests are carried out such that the steel ball to hit the pipe hydrophone in air and change the impact angle from 0 to 90 degree. Differences of sound pressure value on different impact angle are evaluated. For clarifying the particle velocity formula using restrict, observed the particle velocity in flow channel, which is analyzed by camera at 240 fps, is compared with the velocity calculated by Ashida-Michiue formula.
According to those experiments, following results are obtained: (1) Influences of collision angle from 0 to 90 degree on sound pressure were not so much significant. (2) The measured velocity was faster than the velocity computed by Ashida-Michiue formula in 2~3 times, and (3) Sound pressure for the same particle in different flow situation, the difference of sound pressure value will be under 10 times, though there were some matters to be solved,
After variable estimate sediment discharge by the sound pressure and momentum relationship, in this study, the average sound pressure and the modified velocity of particle to estimate particle mass are used and the impulse of hydrophone impacted are applied to estimate sediment discharge.

Key words: Bed load, Hydrophone, Estimation of Sediment volume

1. Introduction

For prevention of sediment-relate disaster, monitoring the sediment transporting be an important topic. In Taiwan, about the sediment monitoring method mostly was sampling by man in the past and concentrated on wash load and suspended load. Method for bed load is few and results in lack of monitoring data.

In Japan, use a pipe hydrophone that uses an acoustic signal to measure the sediment transport rate by set a microphone in a steel pipe for many years.

In Taiwan, started use the pipe hydrophone in 2016, there was continuous to improve the methods to the estimation of Sediment volume.

2. Research methods

For improve the estimation of sediment volume, in this study, research the relationship between the sound pressure and the collision angle, the difference of particle velocity between measured velocity and computed velocity, and sound pressure difference for the same particle in different flow situation.

2.1 Sound pressure and collision angle

About the hydrophone calibration curve by sound pressure and momentum, use different experimental conditions to explore the different momentum with a direct angle to impact the pipe.

When the sediment particles transported in the water and hit the hydrophone, the impact angle are variety.

To propose a more accurate relationship between sound pressure and momentum, in this study design an experiment for research to improve the relationship.

For different momentum, use steel balls with different size and mass that between 4 to 22 mm and 0.26 to 45.2 gram (**Table 1**).

Table 1 The size and mass of steel ball

Size(mm)	Mass(g)	Size(mm)	Mass(g)
4	0.26	15	13.8
6	0.88	18	23.9
8	2.10	20	28.4
10	4.09	22	45.2
12	7.06		

Adjust the impact angle with 0º、45º、60º and 90º (**Table 2**). Clarify the influence of sound pressure by impact angle.

Table 2 Impact angle

Item	Angle(º)
Case 1	0
Case 2	45
Case 3	60
Case 4	90

The experiment environment settle show on **Fig. 1**, make the steel balls free fall and hit the pipe hydrophone at specified angle. Record by camera with 240 fps to calculate the velocity when steel ball hit the hydrophone.

Fig.1 Steel ball free fall at 60º

2.2 Measured velocity and computed velocity

For clarify the different between the measured velocity and computed velocity of particle in flow, in this study design a moveable bed experiment to compare both.

Use a flow channel which width 0.4 meter, length 10 meter, and depth 0.5 meter, set the channel slope with 0.8º and 1.5º.

Use two particle size that include 3 mm and 5 mm, and adjust flow discharge with 0.027 CMS and 0.040 CMS (Table 3).

Table 3 Experiment conditions of velocity compare

Item	Slope(º)	Particle Size(mm)	Discharge (CMS)	Water Depth(m)
Case 1	1.5	5	0.040	0.042
Case 2	1.5	5	0.027	0.033
Case 3	0.8	3	0.040	0.055
Case 4	0.8	3	0.027	0.040

Layout experiment particles in the flow channel, make the layer thickness more than 3 cm (**Fig. 2**). Record by camera with 240 fps to analysis particles velocity by frames.

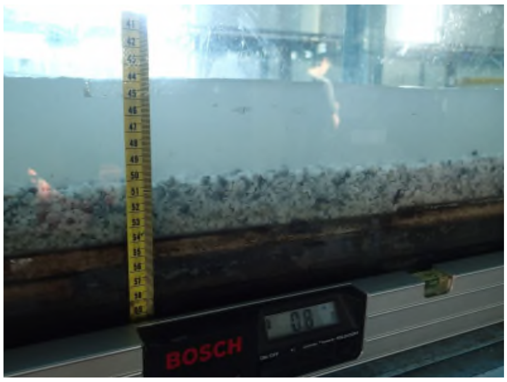

Fig.2 Layout experiment particles

Calculated theory velocity by Ashida-Michiue formula as **Eq. (1)**, u_s is the particle velocity in m/s, Ar is the Ashida coefficient, u^* is friction velocity, and u_c^* is critical friction velocity.[*Ashida, K., & Michiue, M, 1972*]

$$u_s = Ar \times (u^* - u_c^*) \quad (1)$$

2.3 Sound pressure difference for the same particle in different flow situation

For clarify the sound pressure and momentum relationship , in this study set up the parameters are the slope of flow channel and particle size.

The slope of flow channel used 0.8º and 1.5º. The particle size used 10 mm and 20 mm in this experiment (**Table 4**).

Table 4 Experiment conditions of sound pressure in different flow situation

Item	Slope(º)	Particle Size(mm)	Discharge (CMS)	Water Depth(m)
Case 1	1.5	10	0.040	0.055
Case 2	0.8	10	0.040	0.055
Case 3	1.5	20	0.040	0.055
Case 4	0.8	20	0.040	0.055

Release a single particle at upstream of the flow channel, record particle's moved situation by camera with 240 fps to analysis particles velocity by frames and collect the sound pressure by hydrophone at downstream of the flow channel.

3. Results

Collected the experiment data for sound pressure and analysis the experiment video for particle velocity, there following the experiment results.

3.1 The influence on sound pressure by impact angle

The result of sound pressure and momentum relationship with different impact angle is shown on **Fig.3**, the sound pressure difference less than 400 mVolt at same momentum.

The sound pressure were not decrease intensely with dividing force by impact angle

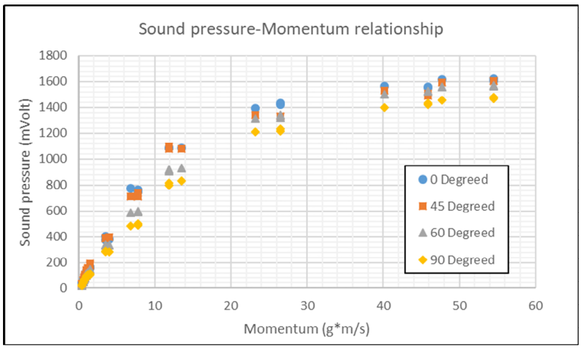

Fig. 3 Sound pressure–Momentum relationship with different impact angle

3.2 The different between measured velocity and computed velocity

The result of actual velocity by measured and estimate velocity by formula is shown on **Fig. 4**, the particle size 5 mm (Case 1&2) had higher actual velocity than theoretical velocity.

The particle size 3 mm (Case 3&4), there had similar velocity between actual velocity and theoretical velocity.

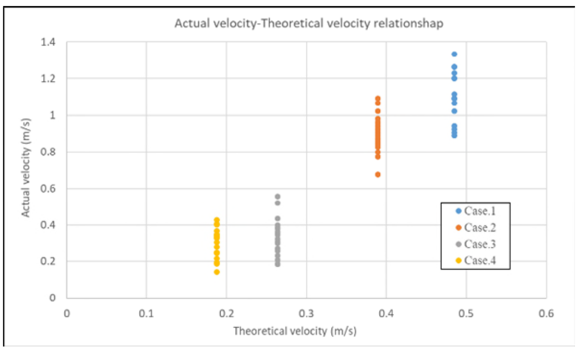

Fig. 4 Actual velocity – Theoretical velocity relationship

3.3 The sound pressure in different flow situation

The result of sound pressure in different flow situation is shown on **Fig.5**, when the slope of flow channel at 1.5° and particle size is 10 mm, there had one order momentum range.

The sound pressures were dispersion in one order range at both slope and particle size.

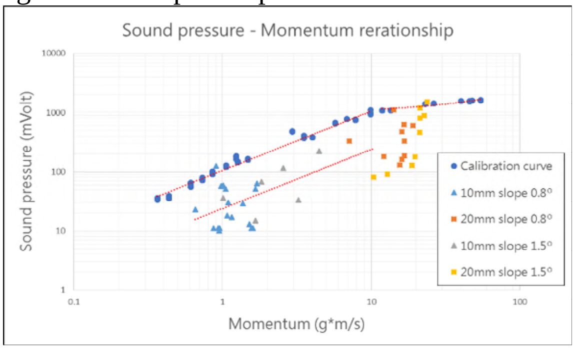

Fig. 5 Sound pressure-Moment relationship

4. Discussion

According to experiment results, discussion why the parameters influence estimated of sediment volume.

4.1 The influence on sound pressure by impact angle

The sound pressures changed at the same momentum were affected by the impact angle. When the particles hit the hydrophone with different angle which keep away the center of circle, the sound pressure is weaker. But the difference of impact angle is not sensitive in the relationship between sound pressure and momentum.

4.2 The different between measured velocity and computed velocity

Compare actual velocity and theoretical velocity with water depth and sediment size, the actual particle velocity is bigger than the theoretical particle velocity.

The possible reason is that the Asihda-Michiue formula only calculate the particle velocity for behavior of bed-load. This proposed method has higher accuracy only when the particle size is much smaller than the water depth. When using this method to estimate particle velocity, the ratio of water depth to particle size should be greater than 10 times.

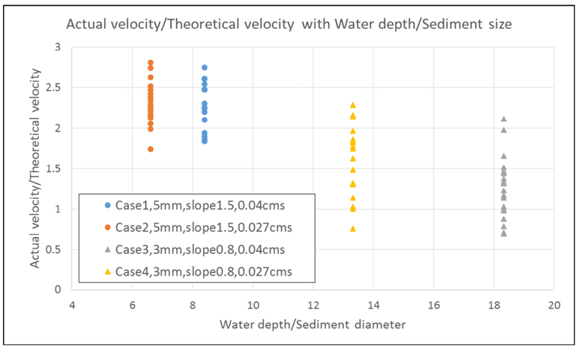

Fig. 6 Actual velocity/Theoretical velocity with Water depth/Sediment size

4.3 The sound pressure in different flow situation

According to the experiment results, the sound pressure generated by the same momentum is fluctuating in one order sound pressure range at not saturation part which is shown **Fig.7**.

The possible reasons one is caused by the irregularity of the impact angle, the other is estimate particle velocity error. The actual particle velocity in flow is fluctuating above and below the average velocity from Ashida-Michiue formula.

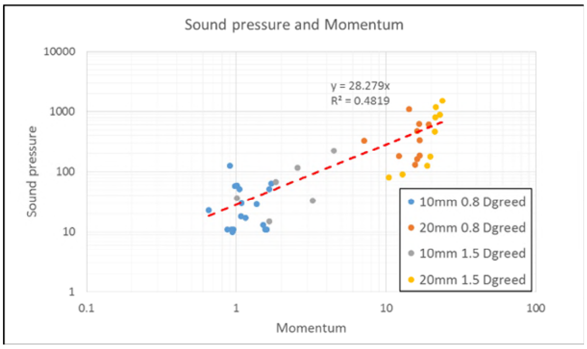

Fig. 7 Sound pressure and momentum (Not saturation part)

In this study, can state the relationship by an empirical formula as **Eq. (2)**.

$$\mathrm{S.P.} = 28.279 \times \mathrm{Momentum} \qquad (2)$$

5. Conclusion

The relationship between sound pressure and momentum in the air is investigated by collision experiments. In the air, the sound pressure is proportional to the momentum in a range (momentum less than 10g*m/s or sound pressure less than 1000mVolt). The sound pressure generated by the same momentum impact will be weakened due to the different impact angles.

The relationship between average water flow velocity and particle velocity is investigated by channel experiment. In this study, used Ashida-Michiue formula to estimate particle velocity and verified by experiment data. Ashida-Michiue formula is only used for the behavior of bed-load, the ratio of water depth to particle size should be greater than 10 times. Within the scope of application, the difference between the caculated particle velocity and the actual particle velocity is smaller than two times.

The relationship between sound pressure and momentum in water is investigated by channel experiment. In the flow channel, the sound pressure is positively correlated with the momentum. The speed of the particles in the experiment is fluctuating, a static method is proposed to establish the relationship. An empirical formula of sound pressure and momentum is provided as **Eq. (2)**.

In this study, the average sound pressure and the modified velocity of particle to estimate particle mass are used and improved estimating sediment discharge.

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