Application of hydrophone system for the sediment discharge monitoring in the Fuji River

Kunihiro Tomita, Zhengxing Ye, Kazuma Shigemura, Hideki Tanaka, Akira Komachiya, Tetsuya Kurebayashi, Takeshi Kado and Masaharu Fujita

Key words: bedload, sediment capture pit, hydrophone, loadcell, sound pressure

1 Outline of the observation system

Fujikawa Sabo Office has been observing sediment discharge using hydrophones since 2010. In order to check the accuracy of the observation, a sediment capture pit with load cells was set up directly behind the hydrophone on the right bank of the 50th groundsill of the Omu River in 2013, and the sediment discharge obtained from pit and hydrophone were compared. The pipe type hydrophone has a diameter of 48.6 mm and a length of 500 mm and is designed to calculate the bed load discharge with the sound pressure generated when gravel etc. collide with the hydrophone. The sediment capture pit with a load cell is 2.0 m × 2.0 m in width and 1.6 m in depth, and is designed to measure and record the weight of the sediment captured in the pit at intervals of 15 minutes. In order to control the inflow of sediment during observation, the opening of the capture pit to take in sediment is set in a slit form of 0.40 m in width (Figure 1).

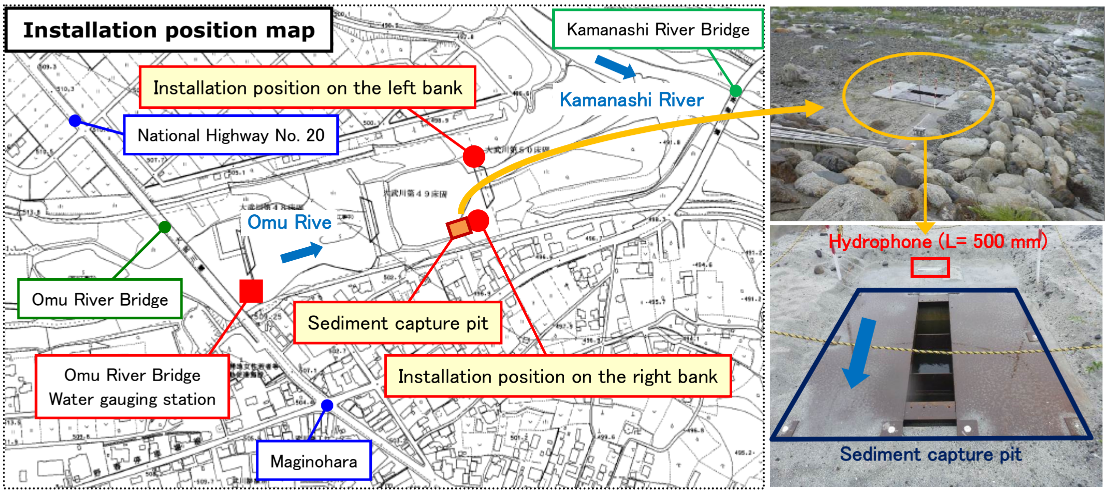


Figure 1: Installation of observation devices at the 50th groundsill of the Omu River

2 Observation results

Observation at the time of a flood using sediment capture pit was conducted 5 times from 2013 to 2016 and the observation results are shown in Table 1. A cross-section of the sediment capture pit and the condition of the sediment captured in pit are shown in Figure 2 and Photo 1.

Table 1: List of observation results

Target flood	Bed load discharge (m^3/m)		Maximum grain size of sediment in the pit (mm)	Maximum water level (m)	Volume ratio (hydrophone/ pit)	Remarks
	Hydrophone	Pit				
2013 Typhoon No. 18	0.85	6.47	178.3	0.618	13.1%	
2013 Typhoon No. 26	0.05	5.05	19	0.381	1.2%	
2014 Typhoon No. 18	0.53	5.09	37.5	0.403	10.4%	
2015 Typhoon No. 18	3.55	4.97	179.3	0.632	71.4%	
2016 Typhoon No. 16	0.35	0.33	37.5	0.217	104.5%	Introduction of the sediment inflow control device

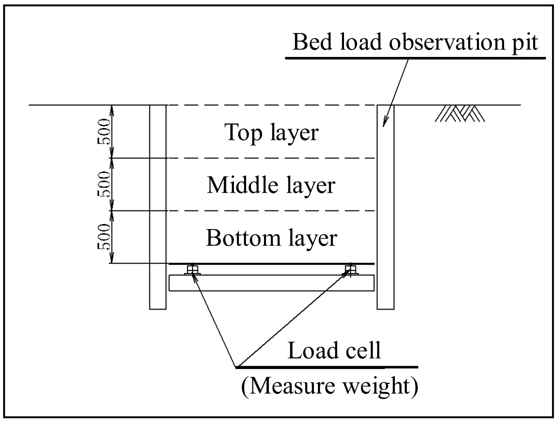


Figure 2: Cross-sectional view of the sediment capture pit

Photo 1: Sedimentation in the pit (2014 Typhoon No. 18)

3 Consideration

We compared the observation results of sediment discharge by hydrophone and sediment capture pit in several major floods since 2013 and some consideration were made for the results.

3.1 Comparison of the observation results from the capture pit with load cells and the hydrophone

Table 1 shows the results of sediment observation with hydrophones and observation pit at 50th groundsill of the Omu River. In all the cases, the value of observation from the sediment capture pit is greater than the measurement value of the hydrophone. For the factors of this event, the following can be considered based on past research findings.

(1) From the comparison and consideration of the results of observation with hydrophone, sediment in the capture pit, and grain-size distribution, it was found that hydrophone is unable to detect the movement of sediment with a fine grain size. and since hydrophone has a limit on the detectable grain size so that the observation values of hydrophone are smaller than those of capture pit

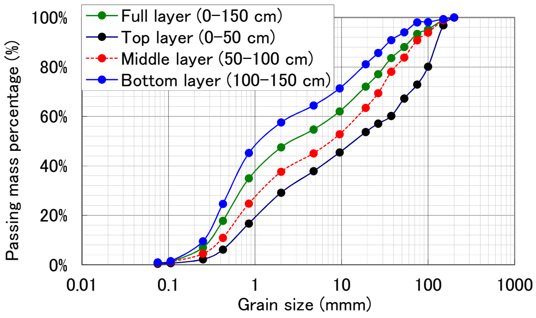
(2) In addition to the sediment that flows into the capture pit through the hydrophone directly in front of it, sediment may also come in from the direction across the slit.

3.2 Correction of the bed load discharge considering the grain size detectable by hydrophone

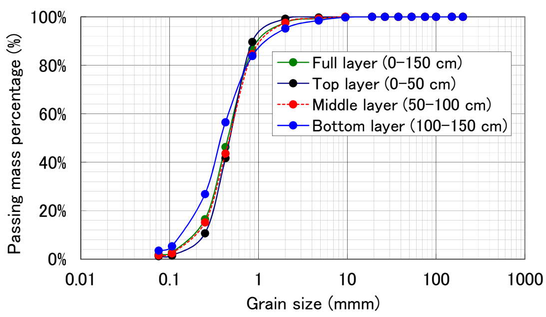
Previous studies reported that the grain size limit detectable by hydrophone is not less than 2 mm (Mizuyama, Ye *et al*. 2015, Mitsunaga *et al*. 2015). Accordingly, we read the ratio of grain detectable by hydrophone from the grain-size distribution curve of the sediment captured by the pit (see Figure 3) and corrected it considering the ratio of detectable grain size for the observation values of the sediment capture pit. Table 2 shows the corrected values. For flood in 2013 Typhoon No. 26, the observation values of the hydrophone were almost equal to sediment in the pit, but for other floods, the corrected values of sediment discharge observed by hydrophone were almost greater than those captured in pit.

Table 2: Bed load discharge considering the detectable grain size

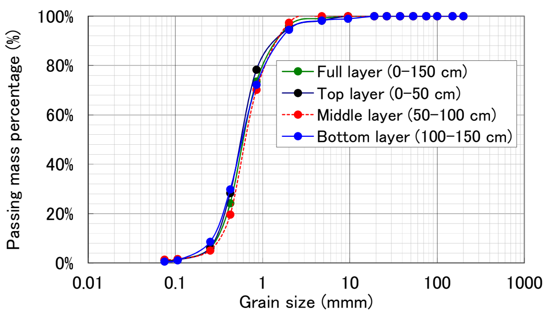
Target flood	Observed sediment discharge (m^3/m)		Ratio of sediment in the pit with the grain size of not less than 2 mm	Sediment observed by hydrophone that corrected by grain size (m^3/m)	Volume ratio of sediment (hydrophone/ capture pit)
	Hydrophone	Sediment in the pit			
2013 Typhoon No. 18	0.85	6.47	52%	1.63	191.8%
2013 Typhoon No. 26	0.05	5.05	1%	5.00	99.0%
2014 Typhoon No. 18	0.53	5.09	4%	13.25	260.3%
2015 Typhoon No. 18	3.55	4.97	28%	12.68	255.1%
2016 Typhoon No. 16	0.35	0.33	27%	1.296	392.7%



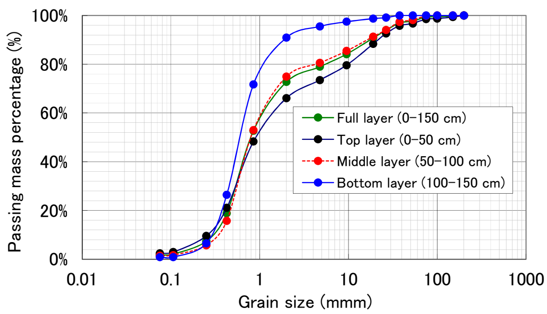
(1) 2013 Typhoon No. 18



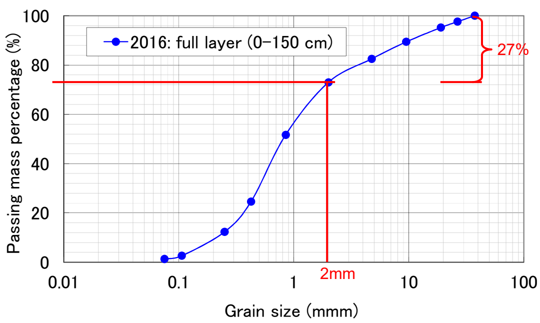
(2) 2013 Typhoon No. 26



(3) 2014 Typhoon No. 18



(4) 2015 Typhoon No. 19



(5) 2016 Typhoon No. 16

Figure 3: Grain-size distribution curve of the sediment in capture pit

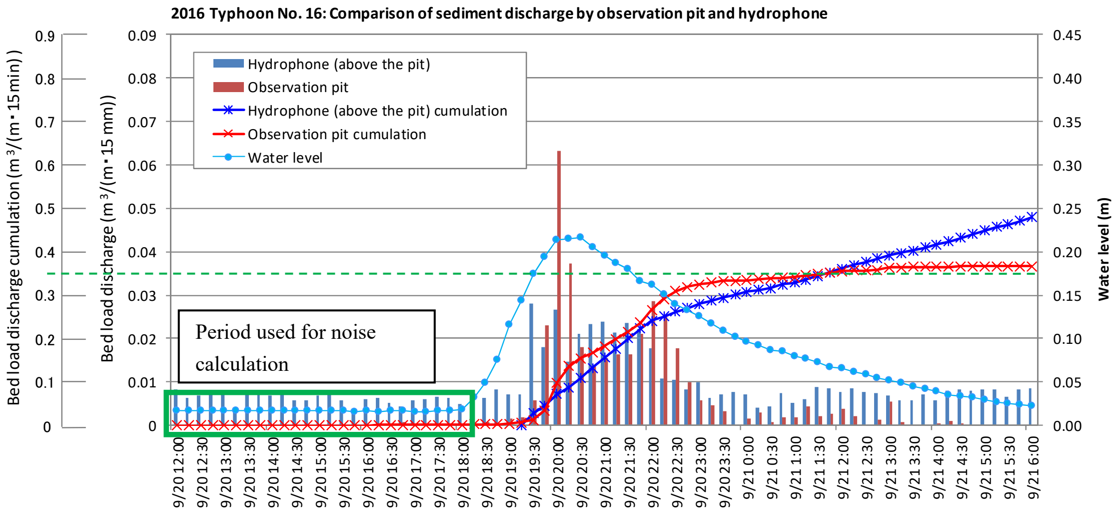
3.3 Removal of noise from hydrophone

The hydrophone detects sound other than the sound from collision of run-off sediment during a flood, and give affects to the accuracy of calculated sediment volume (Suzuki *et al*. 2013). In order to correct the observed value of sediment discharge with more accuracy, it is necessary to remove the sound noise other than the collision of sediment.

Since noise is considered to be generated by the effect of water depth, flow separation, etc., it is difficult with the present knowledge to determine the quantity of noise in the same way.

Therefore, we chose the case of 2016 Typhoon No. 16 and estimated noise volume from the observation values of the hydrophones before sediment flows in and corrected the observation values of the hydrophones (see Figure 4 (B), Table 3). The volume of the noise-corrected value of sediment discharge become 0.14~0.19 m^3/m (40~55% decrease). In addition, the ratio of transport of sediment not less than 2 mm captured by capture pit was 27% (see (5), Figure 3). When this grain-size ratio was taken into consideration in correcting the sediment discharge observed by hydrophone, the volume ratio was 158%~212%. Accordingly, the value of bed sediment discharge observed by hydrophone, which was corrected by considering noise and the detection limit on grain size by hydrophone, was nearly twice of the value of sediment discharge observed by capture pit (see Table 3). For the reasons of this difference, further conservation and studies would be needed.

(A) Observation data (without noise correction)



(B) Correction by noise removal

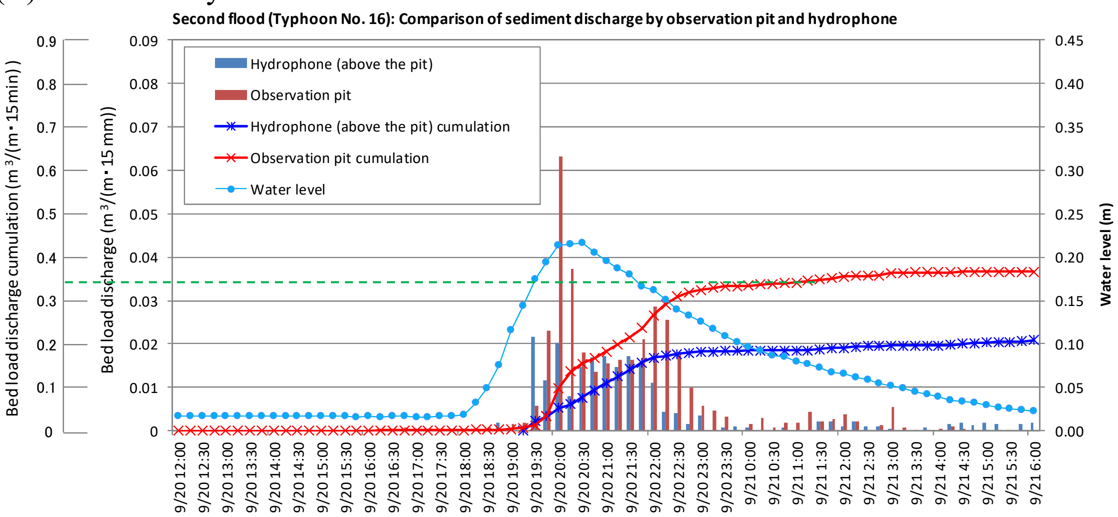


Figure 4: Time sequence diagram of sedimentation in hydrophone and capture pit (Typhoon No. 16 of 2016)

Table 3: Comparison of the sediment discharge corrected by noise / grain-size distribution

Target flood	Measuring method	Observed sediment discharge (m^3/m)	Noise corrected (40～55% decrease) ※1 (m^3/m)	Corrected with grain size distribution (27% grain size not less than 2 mm) ※2 (m^3/m)	Volume ratio of observed sediment discharge (hydrophone/pit)
2016 Typhoon No. 16	hydrophone	0.35	0.14～0.21	0.52～0.70	158%～212%
	Capture pit	0.33	—		

※1: see Figure 4,
※2: see Figure 3, (5)

3.4 Conclusion

From the results of study so far reported, we confirmed that the results of observation by hydrophone suggest that observation of bed load discharge with better accuracy is possible when the effect of noise and that ratio of grain size detectable by hydrophone are corrected and that it will be possible in the future to enhance the accuracy of observation under various conditions by considering various hydraulic / sediment transport conditions and observation status.

4 Utilization of sediment discharge observation by hydrophone

Since the reaction characteristics of hydrophone are considered the same as for the sediment that passes through the sediment bypass tunnel, it would be possible to observe passing sediment if a hydrophone is set on the undersurface of the body of the sediment bypass tunnel, etc. Further, it would be possible to observe the sediment passing through the sediment discharge tunnel from both aspects of bed load and suspended sediment if observed with a turbidimeter at the same time near the exit of the bypass. Accordingly, since the grain size of run-off sediment is generally estimated from the results of observation with hydrophone (Mitsunaga *et al*. 2015), these data can be used to design sediment bypass tunnels, study maintenance methods, etc. in the future.

Further, if the maximum and minimum grain sizes of bed material is previously known, the distribution of bed material during a flood would be estimated by the observation values of hydrophone and sediment transport formula. By comparison of the distribution of grain size in a flood to those of producted sediment and the armor coated bed matarial, whether the sediment production in the upstream area is active or not would be estimated. It is an important information for estimating the sediment inflow to the dam in future.

Utilization of hydrophones brings information on time that is effective for efficient promotion of future river system erosion control plans, comprehensive sediment management, crisis management in the downstream, etc. Therefore, it would be important in the future to study the method of further utilization and improve the accuracy by obtaining and accumulating data in various basins.

References

Mizuyama, T. Comparison and study of the bed load measurement method in Japan and Switzerland

Ye, Z., Tomita, K., Fujita, S., Tsutsumi, D., Uchida, T., Mitsunaga, T., Moriya, T., Watanabe, M. (2015). Sediment discharge observation with hydrophone in the Omu River and evaluation, Collection of JSECE Presentation Summaries, A126-A127

Mitsunaga, T., Moriya, T., Uchida, T., Tomita, K., Kano, M. (2015). Sediment discharge observation in the control area of the Fujikawa Sabo Office. *Journal of the Japan Society of Erosion Control Engineering*, 68(1), 83-87.

Suzuki, T., Uchida, T., Okada, A., Takahashi, K., Yamashita, S., Kosuge, Y., Fukumoto, A. (2013). Applicability of bed load observation method using sound pressure data obtained by a hydrophone, *Journal of the Japan Society of Erosion Control Engineering*, 66(1), 4-14.

Iuchi, T., Uchida, T., Yoshimura, N., Tsuruta, K., Tanaka, Y., Kamahara, J., Sakurai, W. (2016). Flume experiment into the influence of the noise due to water flow and non-collision against the pipe on measurement of sediment discharge using hydrophone data. *Journal of the Japan Society of Erosion Control Engineering*, 69(3), 4-14.

Tomita, K., Ye, Z., Mitunaga, T., Fujita, M. (2015). Estimation of the situation of sediment runoff in upstream reaches by means of hydrophone data: based on the analysis of observation data obtained in the district of Fujikawa Sabo Office. SBT 2015 ETH Zurich.

Authors

Kunihiro Tomita (corresponding Author)
Zhengxing Ye
Kazuma Shigemura
Civil Engineering and Eco-Technology Consultants Co., Ltd., Japan
Email: tomita@kensetsukankyo.co.jp

Hideki Tanaka
Akira Komachiya
Tetsuya Kurebayashi
Takeshi Kado
Fujikawa Sabo Office, Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan

Masaharu Fujita
Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan