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AUTOMATED SEDIMENT EROSION RATE APPARATUS FOR MEASUREMENT OF EROSION RATE OF UNDISTURBED SEDIMENTS

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Automated sediment erosion rate apparatus (ASERA) has been constructed and a series of experiments have been performed to verify its efficiency in this study. The replicated results of the noncohesive sediment mixtures for measuring erosion rates showed the excellent agreement among them with an uncertainty of approximately 1%. The experimental results for five different sizes of uniform sediments were discussed and interpreted with the Shields diagram. Showing remarkable results, the efficiency of the advanced apparatus, ASERA, was evaluated to measure the erosion rate of sediments.

Key Words: *ASERA (Automated Sediment Erosion Rate Apparatus), erodibility, erosion rate, critical shear stress*

1. Introduction

Accumulated sediments in lakes, rivers and the bottom of the estuaries are generally consisted of cohesive and noncohesive sediments (e.g., clay, silt and sand et al.). These sediments are vulnerable to be eroded and resuspended by the flood wave, tide and wind current and transported due to motion of flow. Fine-grained, cohesive and noncohesive sediments located generally in the upper parts of the bed are apt to combine with serious contaminants. These contaminated sediments and their impact on local environments and ecosystem have been a major concern in research fields about lakes, harbors, estuaries and near-shore areas of the oceans. Also, currently many hydraulic and coastal structures in river, lake, estuaries and coastal area have been destructed by the flood and storm events due to extraordinary climatic change, of which number has been increased. One of many significant causes affecting the structure safety to be deteriorated has been known as the erosion (scouring) by strong stream around structures.

For last several decades, the erodibility of sediments has been recognized as a spirited subject of research. Since the erodibility of sediments cannot be solely determined from their properties such as bulk density (wet), water content, % of organics, mineralogical composition, particle size and cation exchange capacity, the accurate analysis should be interdisciplinary combining hydraulics, biology, and sediment transport engineering in natural ecosystem. Therefore, many studies have been carried out in order to determine the erodibility in field or laboratory experiments. The sediments erosion rates were measured with the in-situ field experiments [Maa et al. (1998), Ravens and Gschwend (1999), Hawley (2000), Tolhurst et al. (2000)], but these methods are hard to measure in case of the flood or storm. To overcome such difficulty and provide much reliable data, a laboratory apparatus has been developed to reflect in-situ field properties of bottom sediment and measure the erodibility of undisturbed sediments in condition of high stream conditions (e.g. flood or storm) [McNeil et al. (1996), Roberts et al. (1998), Lick and McNeil (2001), Briaud et al. (2001)]. Using the laboratory apparatus to measure the erosion rates, they protruded sediments in thin-walled Shelby tubes with a uniform height of 1mm above the bottom of the flume under designed flow conditions whenever they determined the occurrence of erosion with naked eyes. However, these methods are considerably affected by the estimation and judgment of experimenters because the beginning point of erosion and the decision of protruding sediments are relied on the personal judgments of the experimenter.

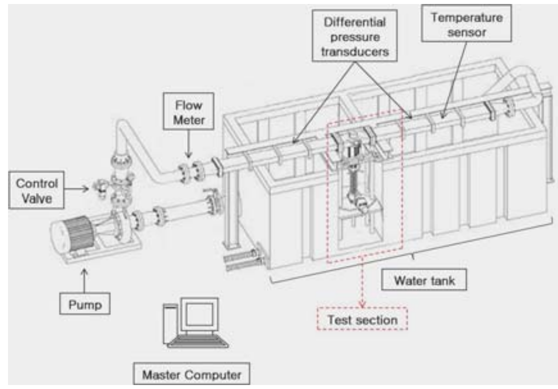
To overcome this defect, Witt and Westrich (2003), Lee et al. (2004), Trammell (2004), and Mendoza et al. (2006) developed the automated method of measuring erosion rates. The protruded height of sediment sample above the bottom could be measured using ultra-sonic sensor, laser, optical sensor and so on. The erosion rates of disturbed sediments were determined using the control program protruding automatically the heights of sediments as they were eroded. The advantage of these experiments is getting more accurate measurement using various sensors than them in the past, but such sensors would be so expensive. Especially, the experiments should be conducted with caution for the interference of air bubbles in flows in case of an ultra-sonic sensor while the laser sensor has the default to disperse the light due to the increment of turbidity and unbalanced sectional erosion of disturbed sediments.

In order to complement such defaults of existing devices above mentioned the laboratory apparatus is developed to measure the erodibility more economically, efficiently, and accurately in this study. This laboratory apparatus called as the automated sediments erosion rate apparatus (ASERA) employs the digital image processing with widespread laser pointers and the CCD camera to measure the erodibility automatically.

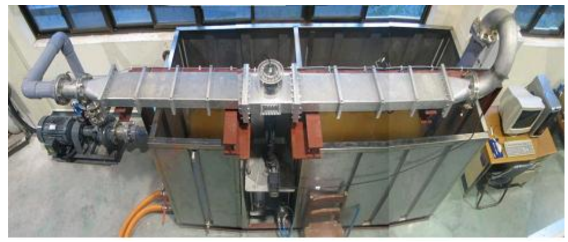
First, the experiments with five different uniform grained sediments have been executed and measured critical shear stress to verify the practicability of the ASERA. Moreover, experimental results were compared with the Shields diagram (Shields, 1936).

2. Laboratory Experiments

The experiments to measure the erodibility in this study were conducted with the ASERA as shown in Fig. 1. The ASERA is composed of the flow circulation system, the measuring



(a) Schematic diagram of the ASERA



(b) View of the ASERA

Fig. 1 Experimental setup

system for flow rate, pressure and temperature, and the computer aided control system to protrude the sediment using the digital image processing. Flow was generated by an electronic pump and controlled accurately by flow circulation system having a stepper motor in a closed rectangular channel. The flume was 275cm long, 20.32cm wide, and 5.08cm deep having a circular inlet and transition section sequentially. Each of pressure transmitter (EJA 110 model in the YOKOGAWA corp. for 0~10000Pa and EJA 120A for 0~200Pa within an uncertainty of 1%) was set up at 35cm upstream and downstream of sediment sample, respectively. And a flow meter and a thermometer were set up on the entrance of the rectangular channel. Furthermore, the accuracy of the ASERA is improved to measure erodibility by applying the image processing method. More details about improved components compared with previous ones in the literature are as follows:

1) Laser pointers to measure heights of sediment bed elevation.
2) Image processing software to estimate eroded depths through images taken by the CCD camera.
3) A shaft to protrude samples automatically as a degree of eroded depth.

With the CCD camera (Camera link type of SONY XCL-5000 Model with 2456×2058 resolution, 15 frames/sec capturing rates), the ASERA can take digital images at 2Hz to consider the time for image process during each experiment.

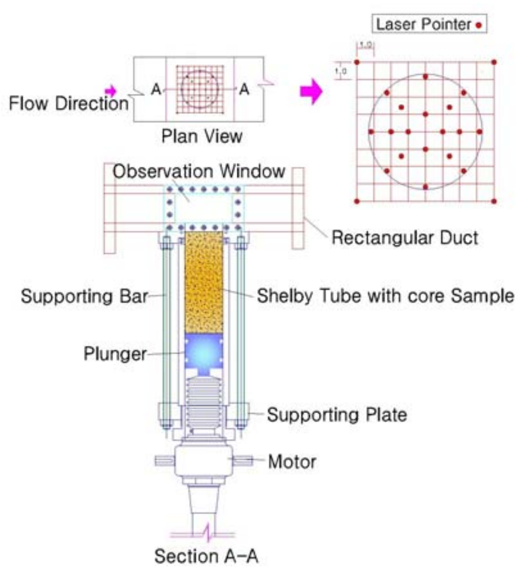


Fig. 2 Array of 22 laser pointers and schematics of test section

And twenty two laser pointers are arrayed as shown in Fig. 2, where four of them are used as the references to illuminate the interface between a sample and bottom of channel and data obtained from other eighteen pointers are utilized to determine the height of protruded sediment sample. The image processing program has been developed for images entered through the image grabber board and the CCD camera to arrange and measure the height of a sample protruded during experiments. The computer aided control system was set up to push a sediment sample upward automatically with an increment of 0.5mm whenever the elevation difference between a surface of sediment sample and bottom of the channel became over the threshold value (0.1mm). At this time, this system was operated to trigger the stepper motor for which it needs 2160 pulses to push up 0.1mm of a sample precisely. The precision of the stepper motor was verified through the experiment showing the difference of 1mm in 250mm of movement or 0.4% uncertainty.

3. Experimental Results

The experiments were executed to show the reproducibility and verify the measurement of shear stress with the ASERA. Before executing the tests, it is introduced the verified linear relationship between pressure head and voltage output, and this relationship allows for the average shear stress to be computed as follows:

$$\tau = \frac{\Delta P \times A}{(2w + 2h) \times L}$$

where τ is the shear stress (Pa), ΔP is the measured pressure difference between two points (Pa), A is the cross sectional area of the flume (m^2), $(2w+2h)$ is the hydraulic radius of the flume (m), and L is the length between the pressure taps (m).

In order to show the validity on estimating shear stress, the tests to estimate the critical shear stress (τ_c) were executed using the five-type noncohesive sediments sample of known particle size. The sediments were sieved to obtain a uniform diameter and the mean diameter (d_{50}) of the sample was taken as the average between the opening size of the sieve above and the sieve containing the material.

Table 1. Results of critical shear stress test

No.	d_{50} (mm)	Discharge (cm^3/sec)	Computed τ_c (Pa)	Shields's τ_c (Pa)
1	1.425	4891.25	0.801	0.811 (±0.085)
2	0.65	2405.18	0.328	0.320 (±0.035)
3	0.35	1599.37	0.209	0.199 (±0.025)
4	0.178	1322.22	0.147	0.152 (±0.025)
5	0.0905	1011.82	0.131	0.119 (±0.025)

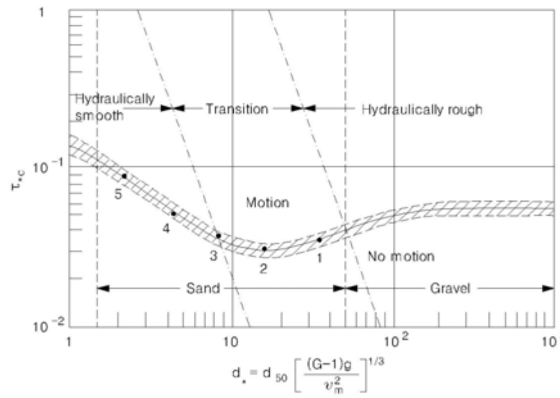


Fig. 3 Comparison of critical shear stress with the Shields diagram

The critical shear stress is defined as that sample eroded 0.5mm during 10 minute, and the critical shear stress is measured at this time using the differential pressure determined. Furthermore, measured critical shear stress using the differential pressure is compared with Shields Diagram. The descriptions of observed sediments motion and the results of the investigation are presented in Table 1, Table 2, and Figure 3. As can been seen from the tables and figure, these show excellent agreement between the computed critical shear stress and values of Shield diagram.

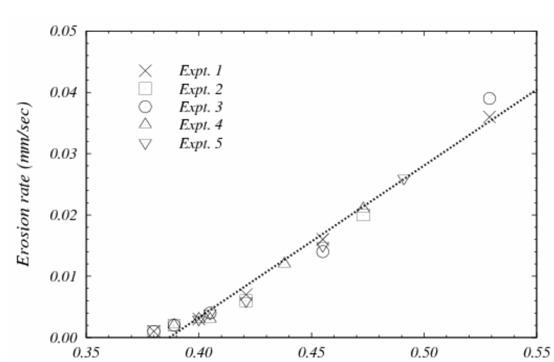


Fig. 4 Replicated erosion rate measurements for five trails

Table 2. Description of motion at observed critical shear stress

No	D_{50} (mm)	Discharge (cm^3/sec)	Computed τ_c (Pa)	Remark
1	1.425	1896.53	0.189	No movement
		2498.32	0.295	Movement of a couple of the smallest grains
		3686.05	0.642	The fore part rolling of grains mass
		4891.25	0.801	Steady rolling grains in all part
		5679.76	1.455	Rapidly rolling many grains
2	0.650	1311.63	0.172	No movement
		1479.48	0.202.	Movement of a couple of the smallest grains
		1647.62	0.256	The fore part rolling of grains mass
		2405.18	0.328	Steady rolling grains in all part
		2498.32	0.414	Rapidly rolling many grains
3	0.350	834.62	0.156	No movement
		974.62	0.161	Movement of a couple of the smallest grains
		1311.63	0.185	The fore part rolling of grains mass
		1599.37	0.209	Steady rolling grains in all part
		2006.53	0.259	Rapidly rolling many grains
4	0.178	673.86	0.068	No movement
		974.62	0.104	Movement of a couple of the smallest grains
		1148.23	0.125	The fore part rolling of grains mass
		1322.22	0.147	Steady rolling grains in all part
		1647.62	0.198	Rapidly rolling many grains
5	0.0905	562.86	0.079	No movement
		669.63	0.090	Movement of a couple of the smallest grains
		831.55	0.110	The fore part rolling of grains mass
		1011.82	0.131	Steady rolling grains in all part
		1611.03	0.209	Rapidly rolling many grains

To determine whether the tests with the ASERA would provide consistent results, the same mixture, which contained various sizes of quartz sand, ranging from 0.1 mm to 2mm and was fully mixed, was used in the repeatability tests. The total results of five tests are presented in Figure 4, and the data consistency from each of the individual erosion rates vs. shear stress tests is quite good. These tests indicate that the tests performed in the ASERA are indeed repeatable.

Conclusion

Experiments were accomplished to verify the efficiency and practicability of the ASERA using the digital image processing, laser pointers and CCD camera. The critical shear stress was measured to show its efficiency and reproducibility using the noncohesive sediments. The average value of critical shear stresses was 0.387Pa value and the RMSE (Root Mean-Square Error) was only 0.005Pa (less than 1% difference among them). Also, the critical shear stresses for the five-uniform grained sediments were determined by the ASERA, and they showed the excellent agreement with the values of the Shields diagram. Based on all results in this study, the efficiency and reproducibility of the ASERA were proved to be excellent to analyze the soil properties.

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