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Subjectivity Effect on the Determination of Incipient Sediment Motion

Kesan Subjektif ke atas Penentuan Pergerakan Awalan Sedimen

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ABSTRACT

Visual observation is the most common method to define the incipient sediment motion to-date. However, the definition can be subjective between researchers, whereby the incipient or threshold criteria of sediment motion depends on the interpretation when the sediment becomes mobile from the state of immobility. This study attempt to investigate the variation of incipient sediment motion value over varying sediment sizes due to subjectivity effect. Three observers with different research background individually determined the critical shear stress, using the same definition of threshold critera. The Shields profile obtained was similar for coarser particles and started to deviate for fine sediment region. This paper found that the existence of variation in the incipient sediment motion, in particular for finer sediment size, with particle Reynolds number Re < 10.*

Keywords: Incipient sediment motion; visual observation; Shields diagram

ABSTRAK

Pemerhatian secara visual adalah kaedah yang paling biasa digunakan untuk menentukan pergerakan ambang sedimen. Walau bagaimanapun, definisi boleh menjadi subjektif mengikut penyelidik, di mana nilai ambang pergerakan sedimen bergantung kepada penafsiran keadaan sedimen bergerak dari keadaan pegun. Kajian ini melihat variasi nilai pergerakan ambang sedimen dengan menggunakan saiz sedimen berbeza mengikut kesan subjektif. Seramai tiga orang pemerhati dengan latar belakang penyelidikan yang berbeza menentukan nilai kritikal tegasan ricih secara individu menggunakan definisi pergerakan ambang yang sama. Profil Shields yang diperolehi adalah sama bagi partikel kasar dan mula melencong bagi kawasan sedimen halus. Kajian ini mendapati terdapat perubahan/keragaman bagi pergerakan ambang sedimen, terutamanya bagi saiz sedimen halus, dengan nombor partikel Reynolds Re < 10.*

Kata kunci: Pergerakan awalan sedimen; pemerhatian secara visual; rajah Shields

INTRODUCTION

The moment or point at which sediment begins to deposit ought to be closely related to the condition under which sediment first begins to move. This condition is the threshold of movement or also known as the threshold criteria. The bed shear stress or shear velocity at the beginning moment of particle movement is commonly denoted as the critical bed shear stress or critical shear velocity.

Buffington et al. (1997) in his exhaustive review, listed the four most common methods of defining incipient motion. They are; (i) extrapolation of bed load transport rates to either a zero or low reference value (ii) visual observation (iii) development of competence functions that relate shear stress to the largest mobile grain size, from which one can establish the critical shear stress for a given size of interest; and (iv) theoretical calculation.

Out of these four methods, visual observation is the most widely approach employed. The method is direct, straightforward and the simplest but the definition of how much movement constitutes initial motion is subjective and very much depends on the observer's own interpretation (Wilcock 1988). The concept of threshold criteria of sediment motion rest on the observer's background of sediment motion, perception of movement, in particular when the first movement is not deterministically measured (Bohling 2009) .

The definition of incipient or threshold criteria is adopted from the work of Kramer (1935), whereby three definitions of visual grain motion were given i.e. weak, medium and general. The movement of particles can either be as few particles are moving at isolated spots, many particles are moving or a general movement on the entire sediment surface (Buffington & Montgomery 1998; Bohling 2009). Terms of threshold criteria such as "individual initial motion," "several grains moving" and "weak movement" were thrown into the pool of incipient sediment motion definition (Yang 1996).

Although work on incipient sediment motion have been exhaustively done, the unity definition of when the sediment moves is yet to be achieved. The definition of threshold critiera of sediment motion varies between researchers (Kanellopoulos 1998). As most of the data used to develop the well established Shields diagram was visually obtained, it was expected to see a rather big envelope on the original Shields curve. It should be highlighted that the observed critical shear stress from other experiments were found not to be within the close vicinity of the standard Shields curve, which have striked inquisitive research on the area. The work of incipient sediment motion has spanned over more than eight decades, looking into the variation of sediment characteristics, definition and flow regime (Buffington & Montgomery 1998). One of the reasons in the deviation and scatter of the critical Shields parameter data was due to the different interpretation of threshold sediment motion used in the studies (Bohling 2009; Borg et al. 2013; Buffington and Montgomery 1998; Cao et al. 2006; Choi and Kwok 2001; Mir-Jaafar-Sadegh et al. 2004). The emergence of big envelope is contributed by the stochastic behavior of turbulence, that it is difficult to precisely determine the initial movement of particles, even within the same experimental setup (Bong et al. 2013; Cao et al. 2006). Although numerous researches have been conducted and abundant data are available on the critical value, a modified, universal Shields diagram is yet to be developed (Alfadhli et al. 2012).

As the Shields diagram was developed from various data sources, even the difference in experimental methods, devices can obviously lead to discrepancies between data, let alone the subjectivity definition of threshold criteria. Although Kramer (1935) has described the definition of incipient sediment motion, the subjective judgment of experimental observers' plays an important role. As such, to overcome the dispute of specific definition, experiments were conducted by the same person to ensure a consistent definition throughout.

Therefore, making comparison of data collected from the same devices and repeated by different observers are permitted. The visual observation in determining the starting of the motion is essential tobe repeated. It is just as likely for the eye to be slightly random reading the motion, so the averaged data from measured values are approximately correct whilst the random errors, too will be averaged out (William et al. 1980). Thus methodical study of different observers is crucial to identify the subjectivity effect on the incipient sediment motion. This study attempts to investigate the threshold sediment movement based on three different observers over varying sediment sizes.

The conventional and most commonly presented of incipient sediment motion is utilizing the Shields curve/ diagram. The diagram has the dimensionless critical shear stress τ_c^* in the y-axis and the particle Reynolds number, representing the sediment characteristics in the x-axis. This dimensionless critical shear stress, also known as Shields parameter is the ratio of bed shear stress to the relative weight of a particle, and is expressed as

$$\tau_c^* = \frac{\tau_c}{\rho g\,(s-1)d} = F(Re^*) = F\left(\frac{ud}{v}\right) \tag{1}$$

where τ_c^* is Shields parameter, τ_c is the critical bed shear stress, ρ is the fluid density, $Re*$ is the particle Reynolds number, $u_*\left(=\sqrt{\tau_c/\rho}\right)$ is shear/friction velocity in the boundary and v is the kinematic viscosity of fluid.

As the shear velocity is not exactly a velocity and merely a representation of bed shear stress, Yalin (1992) came up with different presentation of Shields parameter, which eliminate the shear velocity and is expressed as

$$\frac{\tau_0}{\rho g\,(s-1)d} = F(D_{gr}) = F\left[\frac{(s-1)gd^3}{v^2}\right]^{1/3} \tag{2}$$

where τ_0 is the mean bed shear stress and D_{gr} is the dimensionless grain size parameter.

EXPERIMENTAL METHOD

In order to measure the level and rate of soil erosion, Liem et al. (1997) invented and developed a device that would measure and record it. The erosion measurement device development was based on a design that was put forward by scientist Kühl and his colleague Schünemann. However, the design had been slightly modified by Schünemann & Kühl (1993) in order to be able to use samples that have been already prepared instead of using in-situ collected samples from the field. The device was mainly intended to assist in evaluating and assessing the optimal sediment motion at the interface of solid and the fluid that are in contact. This is done by applying velocity to the water column from one point. This creates a radial uniform velocity pattern on top of the sediment bed, with an exposed surface area of the sample used was 8,170 mm^2. Shear stress is applied uniformly by placing a propeller that has a diameter of 50 mm above the sediment surface. In order to prevent the circulating flow, when the propeller start operating, five baffle plates were fixed and perpendicularly placed at the inner wall of experimental chamber.

The erosion chamber used in this study as shown in Figure 1, helps in determining the relationship between the shear stress produced on the surface of the sediment sample and the corresponding the revolutions per minute of the propeller. In this test, a single size bed was created and used by putting together many sand samples of the same size. The process of the test involves increasing the angular velocity of the propeller slowly and using the tachometer to regulate it up to when the sand particles start to move continuously. The start of the continuous movement is observed and recorded. For each set of sediment size, the experiments were repeated at least three times for each observer to ensure consistency. In this study, approximation of bed shear stress $\tau_c \sim \rho u_c^2$ was taken, where denotes as the critical fluid velocity obtained when the first sediment movement was observed.

The critical fluid velocity was calculated based on from the relation of angular velocity ω (i.e. from the rotational propeller) and radius chamber, r given as

$$u_c = r\omega. \tag{3}$$

where $= \dfrac{2_\pi}{\text{time of 1 rev}}$.

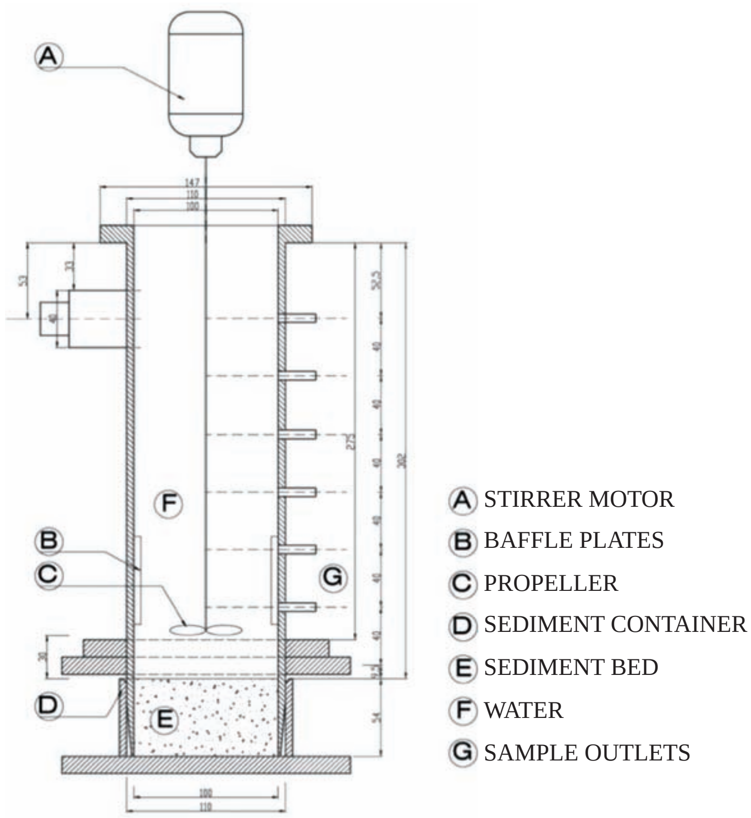

FIGURE 1. The erosion chamber used in this study

The aim of the present study was to investigate the effect of subjectivity on incipient sediment motion, where each set of experiment was repeated by three different observers. The characteristics of observers are described in Table 1. Prior experiments, these three observers were briefed the definition of incipient sediment motion, including the Kramer's (1935) description. However, for this study, we opted the determination of incipient sediment motion as when approximately 5% of the sediment bed (regardless of its location and position) is continuously moving. This criterion was taken as we wanted to be consistent with the definition used by Camuffo (2001), Schellart (2003) and Seco (2014), where similar device was used in their studies. As such, the observations made indicate the threshold behaviour of representative graduated sand sediment under forced turbulence in the laboratory.

TABLE 1. Observers characteristics

Observer	Gender	Status	Research experience
O1	Female	PhD student	> 2 years
O2	Female	Research Assistant	> 2 years
O3	Male	Undergraduate student	< 1 year

Twelve sizes of sediment were investigated, ranging from 150 µm to 2000 µm was made to put into the chamber. The sediment depth was made consisten at 5 cm for each experiment. The motor was systematically increased from the initial 50 revolution until threshold sediment motion was observed. As have been previously discussed, the value of critical Shields parameter for each sediment size was obtained from an averaged fluid velocity value of three data. The sediment bed was re-scraped to ensure the bed level prior repeating the experiments.

There were three researchers involved in this experiment. Observer 1 and 2 have slightly same experiences in handling the erosion chamber. They were familiar with the experiment that involved criterion of sediment motion. Whilst observer 3 was quite new in working with the chambers and sediment motion. The test was set-up and started at the same condition and the observers been briefed again prior the experimental work. The RPM reading was obtained using eye-leveled tachometer that hit to the reflectant at the propeller, taken when the visual of 5% sediment consistently moving on the bed surface was obtained. The critical value was obtained as the averaged values, taken from at least three measurement for each sediment size.

RESULTS

Test durations were usually between 1 to 2 hours after which sediment bed preparation and water input to chamber were completed. For each set of sediment size, statistical analysis was conducted including the mean, standard deviation (SD) in critical shear stress, τ_c^* have been calculated, shown here in Table 2.

TABLE 2: Statistical analysis of the measurement taken by Observers 1, 2 and 3.

Groups	Count	Sum	Average	SD
Observer 1	12	2864.00	238.67	4212.24
Observer 2	12	2791.40	232.62	5231.90
Observer 3	12	3501.76	291.81	3253.60

TABLE 3. ANOVA Analysis

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	25461.66	2	12730.83	3.01	0.063	3.28
Within Groups	139675.14	33	4232.58			
Total	165136.81	35				

Table 3 shows the F-ratio 3.01 is lower than the F crit value 3.28. Even though Observer 3 has slightly higher reading between others, it has no statistically significant in terms of differences. From the results so far, there was also no statistically significant difference between observers as determined by one way ANOVA.

The critical velocity, u_c for each sediment size was calculated based on the RPM readings, which were converted to angular velocity then subsequently to the linear fluid velocity by using Equation 3. The obtained results are listed in Table 4.

The relationship between the critical shear stress and Re_* are shown in Figure 2. Data shows that the profile of incipient sediment motion is similar to the established Shields curve (shown in Figure 2 as solid line). Critical shear stress is monotonously increased for finer sediment and reached a rather constant value at ≈ 40 for $Re_* > 10$. However, due to the nature of velocity calculated differ from the usual uni-directional horizontal velocity obtained n a flume, the values critical shear stress obtained in this study are O(10). The band of Shield's diagram was expand to higher shear stress in this chamber and located way above the Shields curve.

TABLE 4. The critical velocity and associated critical Shields parameter

Grain Size (mm)			u_c (m/s)			τ_c^*		
d_{min}	d_{max}	d_{av}	Observer 1	Observer 2	Observer 3	Observer 1	Observer 2	Observer 3
0.150	0.212	0.181	0.41	0.42	0.56	91.60	96.35	292.46
0.212	0.355	0.284	0.41	0.43	0.61	58.55	64.46	173.98
0.355	0.500	0.428	0.44	0.49	0.62	41.65	52.23	125.92
0.500	0.600	0.550	0.46	0.50	0.63	30.33	36.51	84.60
0.600	0.710	0.655	0.48	0.51	0.67	25.50	28.68	58.01
0.710	1.000	0.855	0.50	0.56	0.73	23.48	29.88	50.06
1.000	1.180	1.090	0.64	0.63	0.79	29.58	28.53	49.96
1.180	1.400	1.290	0.65	0.64	0.83	23.97	23.32	45.17
1.400	1.700	1.550	0.68	0.71	0.84	21.95	23.93	39.28
1.700	2.000	1.850	0.84	0.84	0.90	28.15	27.97	34.03
2.000	2.360	2.180	0.90	0.88	0.96	26.90	26.15	32.52

Less significant variation was observed in the threshold criteria for coarser particles where the effect of subjectivity was not evident. Figure 2 shows that the measured τ_c by all three observers were in agreement in the mobility limit of sediment, particularly for region where particle Reynolds number $Re_* > 20$. However, subjectivity of threshold criteria came into effect for $Re_* < 20$ when the critical shear stress started to deviate, particularly for Observer 3. The profile for finer particles size showed greater gap in observation although it should be stressed here that the increasingly monotonous profile for low Re_* is consistently similar. The threshold criteria measured by Observer 3 was steadily have higher values compared to other observers.

In terms of the obtained Shields profile, its echoed with the findings from other researchers, whereby the Shields parameter for finer sediment (within the hydraulically smooth region) needs more forces to move compared to the coarser particles (Wilcock 1988). Experimental data shows that even the definition of incipient sediment motion was fixed, the obtained Shields parameter has difference up to 10%, particularly at lower Particle Reynolds number.

The difficulty of making a consistent decision and to have similar concept of incipient/threshold throughout the experiment increases as the sediment size decreases. In this case, Observer 3 was newly trained and the adjustment is always determined by association with the known quantitive relations where the 5% motions occured.

The reason generally accepted for the slight difference is that there have always two kinds of errors in experimental results. The random and systematic error which cannot really be eliminated (William et al. 1980). The comparison of the both trained observer 1 and 2 also gives slightly different readings (Table 1). The errors can be minimized by getting many measurements by different observers, calibrating the devices properly and setting up the same procedure for each experiment.

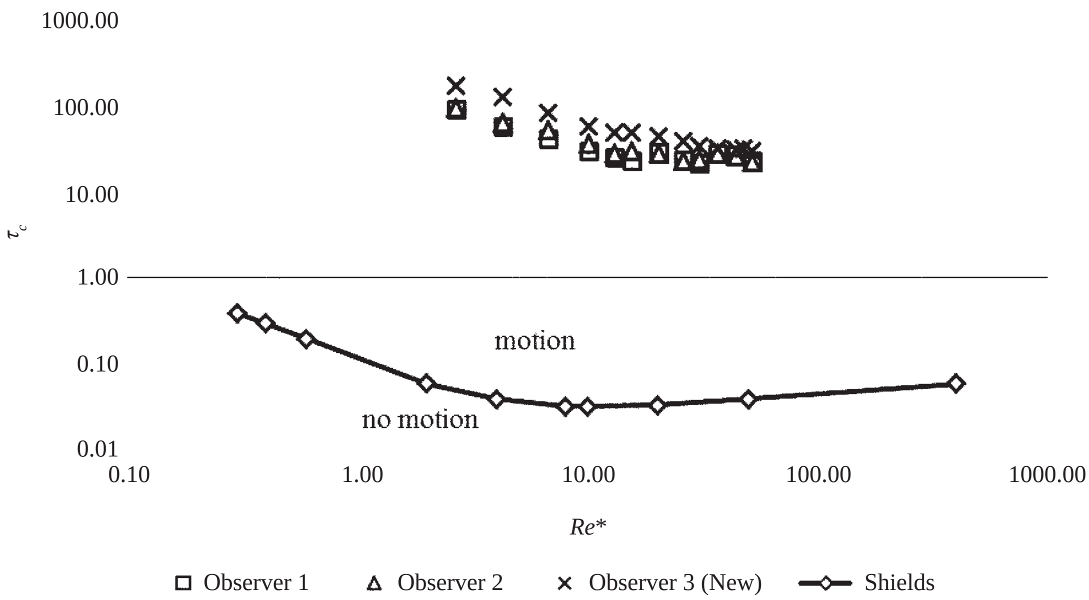

FIGURE 2. The Measured Shields parameter by Observer 1, 2 and 3, with the Shields curve

CONCLUSIONS

Incipient motion is one of the main parameters in sediment transport models in rigid boundary channels.The variation in the available data for Shields diagram is believed due to the considerable differences in setting the definition and visual observation errors. The experience of observers also plays an important role in ensuring the consistency of the data. This research showed that within the same setting, subjectivity effect is essentially important for finer size sediment, particularly for $Re_* < 10$, whereas the effect came to cease for coarser particle size. The variation of incipient sediment motion for low indicate that the mobility of fine sediment has wider range. The cohesive forces between each particles might be effective and hinders sediment entrainment

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