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THE PULSATING NATURE OF BED LOAD TRANSPORT WITH AND WITHOUT CLUSTER MICROFORM

Sulaiman M.S.[1], S.K. Sinnakaudan[2], M. M. Rosmadi[3] and M.R. Shukor[4]

***Abstract**: Generally agreed that the pulsating nature of bed load transport at mountain rivers are influenced by cluster microform. Those clusters can be either individual discrete structures or interconnected structures comprised of various shapes and groupings. The existing of particle clusters tends to entrap the moving particles; hence delay the sediment entrainment and motion at fluvial systems. This paper reports the field scale conducted to quantify bed load transport with and without cluster microform. The bed load rate was measured physically by using the Helley-Smith bed load sampler within the marked 4m x 6m grid. The bed load rate was measured at various cluster orientation and arrangement to test the hypothesis that cluster delay the sediment entrainment and release the finer particle in pulses once the clusters are destroyed. It is evident that the transport rates at the stoss side and wake tail were 36-79% and 81-98 % behind the rates demonstrates by the loosely clustered grid. The results consistent with the previous observation that clusters delay the sediment entrainment and motion at gravel bed rivers.*

***Keywords**: cluster microform; bed load transport; entrainment; gravel bed rivers.*

INTRODUCTION

Cluster bedforms are believe to play important role in maintaining the river stability and hence delay the sediment entrainment at gravel bed rivers (Reid et al., 1992; Church et al, 1998; Strom and Papanicolaou, 2008; 2009; Hendrick et al., 2010). The researchers believe that anchor clast must be mobilized before a cluster is destroyed. The second thought however considers clusters to be less significant in channel stability and sediment transport (de Jong, 1995). Based on the current definition from the literature, Strom & Papanicolaou

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[1] Research Student, Water Resources Engineering and Management Research Centre (WAREM), Institute for Infrastructure Engineering & Sustainable Management (IIESM), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia, E-mail: mohd.sofiyan@yahoo.com

[2] Head, Water Resources Engineering and Management Research Centre (WAREM), Institute for Infrastructure Engineering & Sustainable Management (IIESM), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia, E-mail: drsshan@yahoo.com (Member, IAHR).

[3] Research Student, Water Resources Engineering and Management Research Centre (WAREM), Institute for Infrastructure Engineering & Sustainable Management (IIESM), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia, E-mail: mamat_deep@yahoo.com

[4] Research Student, Water Resources Engineering and Management Research Centre (WAREM), Institute for Infrastructure Engineering & Sustainable Management (IIESM), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia, E-mail: mohdrizal@yahoo.com

(2008) defined the clusters as discrete, organized groupings of particles that sit above the average elevation of the surrounding bed surface. However, Hendrick et al. (2010) defined the clusters as organized groupings of particles that protrude above the gravel bed surface in a variety of forms. The similarity between their definitions is that the clusters are organized in a distinct group and with various forms and shape. However, Strom and Papanicolaou (2008) suggest that the clusters form as the result of interaction between the flow field, entrainable sediment and stable bed morphology differed from the hypothesis proposed by Hendrick et al. (2010).

This research tested the hypothesis that cluster formation are delaying the sediment entrainment in gravel bed rivers and release the finer particle in pulses once the clusters are destroyed. The results are based on field observation at the selected site.

MORPHOLOGICAL DESCRIPTION OF CLUSTER MICROFORM

The gravel bed rivers typically exhibit two scale-classes of bedforms namely macroscale and microscale. The macroscale or macroforms can be defined as reach unit in fluvial system having the distinct morphological features such as step-pool and pool riffle sequences (Whittaker & Jaeggi, 1982). Microscale or cluster microform is type of bedform arising from the structural organization of the surface grains (Strom & Papanicolao, 2008). This cluster can either be isolated discrete setting or can form interconnected structures comprised a network group of particles. Various researchers give the different point of view on cluster definition and how these cluster form at the river bed. Wittenberg (2002) concludes that the establishment of bed structure is determined by valley form and by particle lithology, size and shape. At the competent flow, the least stable particles move into a stable positions to create structural bedforms. However, Wittenberg (2002) speculated that the comprehensive names for various arrangements of pebbles on the river are exclusive for microforms or bed structures as clusters are explicit definition and likely the most common microtopography at gravel bed river. Strom & Papanicolaou (2008) believe that the cluster microforms are produced by the interaction between the flow field, entrainable sediment and stable bed morphology. Meanwhile Hendrick et al. (2010) noted that clusters are formed during the recession of a high flow event and capable of transporting and depositing an anchor clast that subsequently impedes small particles during subsequent flow events. Various attempts were made by previous researchers to distinguish the types of microforms such as based on cluster shape, cluster geomorphic properties, spatial arrangement and of orientation of obstacle clasts, wake and stoss sides. Cluster is generally formed around the anchor or obstacle clast, against which a stoss of imbricate clast develops and behind which a wake tail grows (Fig 1). Clasts making up the stoss are generally smaller which can range up to ninetieth percentile compared to wake clasts that are much finer (Reid et al., 1992).

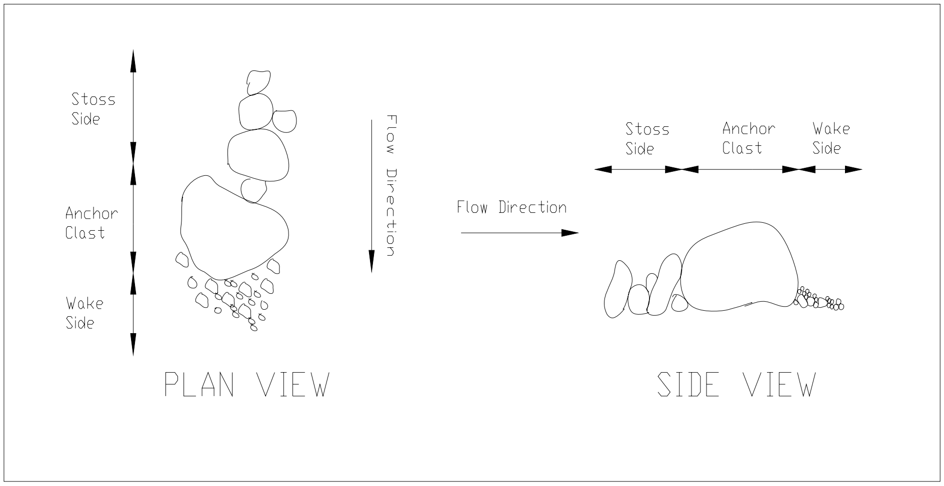


Fig 1. The location of stoss side and wake tail within the cluster

ENTRAINMENT AND ENTRAPMENT AT CLUSTER AVAILABILITY

The previous study by Reid et al. (1992) on the clast transport had proven the importance of cluster to the river stability. The marked particles were deployed at the gravel bed river altogether with the electromagnetic sensors to register the entrainment of metal tagged clast. The differentiation is made between the further-travelled loosely clustered clasts and the shorter-travelled stoss- and wake-seeded clasts. The results show that 81% of the seeded clast travel at loosely clustered clasts compared to 54% and 35% respectively for stoss- and wake-seeded clasts. Reid et al. (1992) proposed the order of distance travel as *cluster wake<cluster stoss<loosely clustered<open plane bed* regardless of channel diversity.

The latest development of the sediment entrainment study is described by Hendrick et al. (2010) by emulating the photo point monitoring approach. The 5m x 5m plots were identified and marked which is having the cluster within. Two photographs were taken for each cluster with digital camera. The first photograph was taken at the wider setting at constant height and scale which also allowed the identification of isolated particles in the vicinity of the cluster and the second photograph is the close up photo of cluster to document the cluster in more details. The objective of the Hendrick et al. (2010) study was to determine the competence of the flow to entrain cluster vs. isolated particles during each flow event by the means of measuring the size of mobilized particles from the close up photograph before and after each event. The results show that clusters delay sediment transport by acquiring the higher flow and velocity to entrain the particles within the clusters. The sediment entrainment from clusters is limited by the flow hydraulics rather than a limited availability of larger sizes within cluster (Hendrick et al., 2010).

The estimation of shear stress is important when dealing with the sediment motion. Since the original Shield criterion does not account the effect of hiding function and relative size effect of particles (Hendrick et al., 2010), the power law equation was proposed to determine the entrainment of the clustered sediment particles (D_i) and is given by

$$\tau_{cr}^{*} = a(D_i/D_{50})^{b} \qquad (1)$$

where $\tau_{cr}^{*} = \tau_{cr}/(\rho_s - \rho)\, g D_i$ is the mean shear stress at initial motion of the individual sediment particle of interest, D_i, ρ_s is the density of sediment, and g equal to the acceleration of gravity. The notation a and b were determined by fitting the equation (1) to the data pairs $(D_i/D_{50}, \tau_{cr}^{*})$. In equation (1), a and b represent the dimensionless critical shear stress and selective entrainment respectively. The equal mobility pattern occurs when $b = 1$. If $b < 1$, the particle finer than D_{50} are mobilized. Conversely, the larger particles are also mobilized if $b > 1$. The study by Hendrick et al. (2010) by using the power law indicate the critical shear stress $a = 0.06 - 0.085$ lied at the upper range of the compiled critical shear stress value of 0.012-0.087 for natural rivers as proposed by Buffington and Montgomery (1997). Reid et al. (1992) proposed the critical shear stress value of 0.013-0.114 for clustered particles which encompass the previous suggested values. The consistency of observed high critical shear stress value indicates that more forces needed to entrain the particle at cluster availability.

STUDY AREA

The study location of riffle unit at pool-rifle system was selected as it exhibits the cluster settings as previously described by Strom and Papanicolaou (2008) and Hendrick et al. (2010).This research was carried out during the low to intermediate flow condition ($1.5519 m^3/s – 2.0123 m^3/s$). The bankfull discharge was estimated at $3.5277 m^3/s$. The square grid of 1m x 1m was marked along the riffle transects to control the complexity of structural organization at river bed (Fig 2&3). The reference point was marked and numbered as ‘zero’ and followed by consecutive number. By using the Wolman pebble count along the riffle transect, the median size distribution (D_{50}) was recorded as 42 mm, which lies within the gravel-bed stream classification (Bunte & Abt, 2001). The water surface and bed slope stood at 0.0061 m/m and 0.0112 m/m respectively.

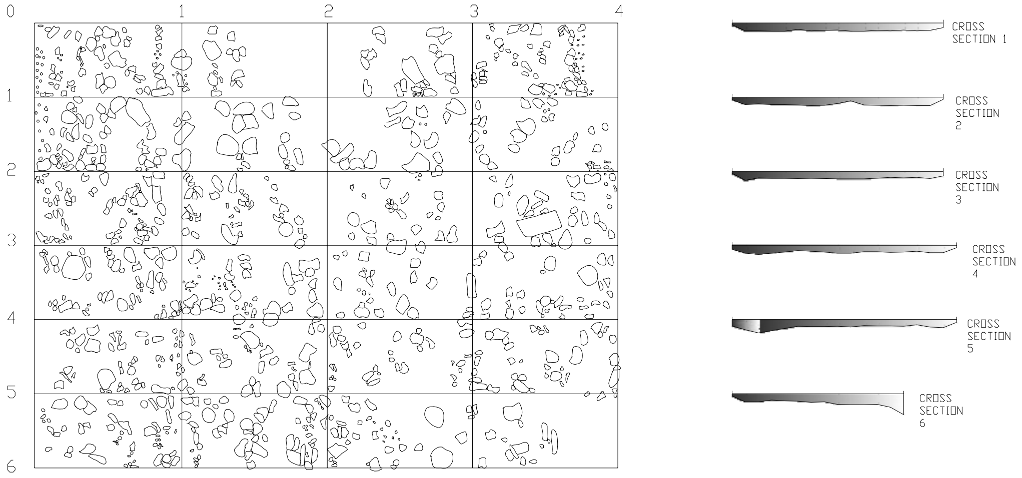


Fig 2. Structural organization at river bed

Fig 3. Study area (looking downstream)

TRANSPORT RATE AT CLUSTER BEDFORM

The bed load measurement was conducted by using the Halley-Smith sampler having the nozzle opening of 0.076 m at the duration of 10 minutes. Two methods of execution were carried out. The first method is by measuring the bed load rate within 4 m x 6 m grid. A systematic 4 m x 6 m grid were developed by choosing the straight reach which having the cluster bedform in its vicinity. The pulsating nature of bed load rates within this grid were measured by selecting the random location at each meter across the riffle transect. 20 measurement points were selected by taking the anchor clast of cluster formation as the reference location. The measurements were alternate between the stoss side location and lee side location of the anchor clast (Fig 4). Table 3 shows the results of discrete bed load rate at the predefined location as per Fig 4.

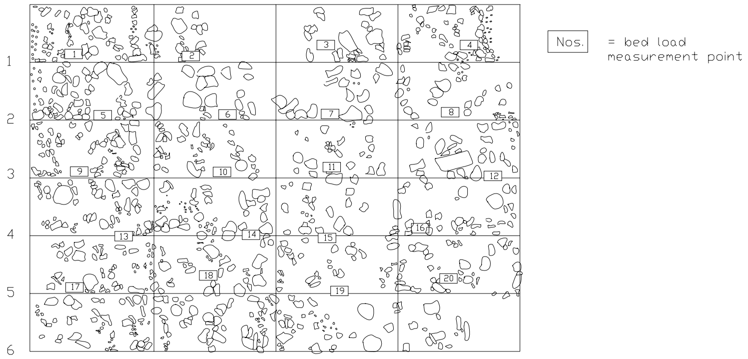
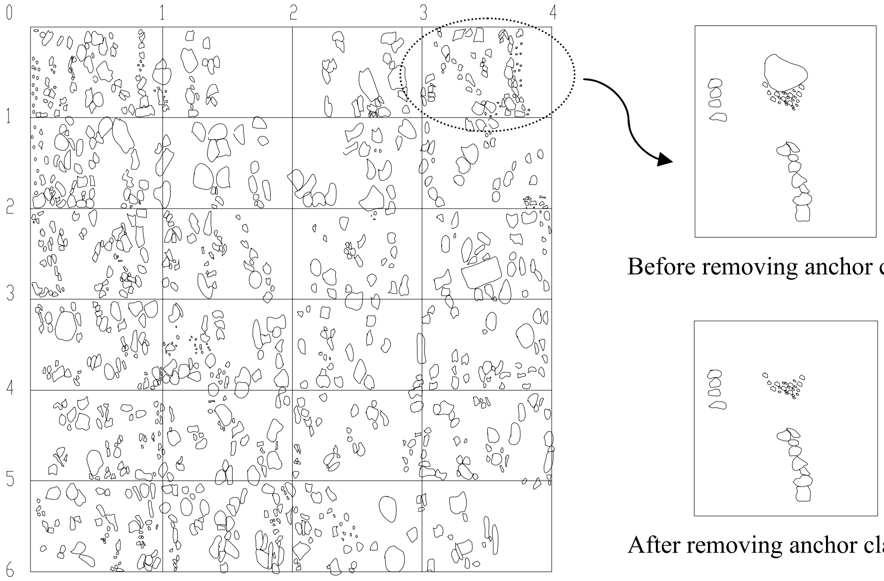


Fig 4. Deployment location for Halley-Smith sampler

Table 3. Bed load data for each location

Location	Bed Load Rate (kg/s)	Remarks		Location	Bed Load Rate (kg/s)	Remarks
1	0.00231	Stoss side		11	0.00370	Stoss side
2	0.00317	Stoss side		12	0.00361	Stoss side
3	0.00097	Wake tail		13	0.00058	Wake tail
4	0.00011	Wake tail		14	0.00323	Stoss side
5	0.01203	Loosely clustered		15	0.00290	Wake tail
6	0.01263	Loosely clustered		16	0.00026	Wake tail
7	0.00987	Stoss side		17	0.00533	Stoss side
8	0.00927	Stoss side		18	0.01561	Loosely clustered
9	0.00500	Stoss side		19	0.01127	Loosely clustered
10	0.00509	Stoss side		20	0.00098	Wake tail



Before removing anchor clast

After removing anchor clast

Fig 5. Bed load measurement with and without cluster formation

The second method of the measurement was carried within the local scale of the selected grid (Fig 5&6). The sampler was placed at the wake tail of the anchor clast to locally simulate geomorphic of river bed having cluster bedform. After that, the anchor clast was manually removed from the sampled river bed to represent the condition of destroyed clusters. Another measurement was executed as a comparison from the previous setting. The results are shown in Table 4.

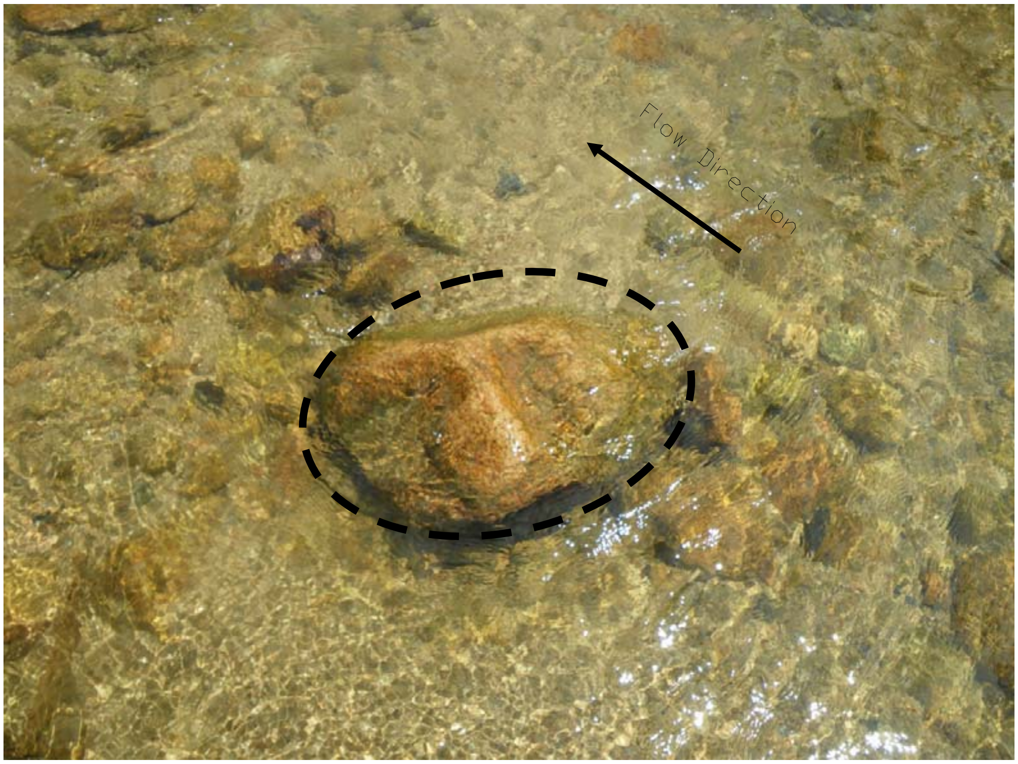


Fig 6. The anchor clast view at field scale

Table 4. Bed load with and without cluster formation

Condition	**Bed load rate (kg/s)**
With clusters	6.5789×10^{-5}
Without clusters	2.1867×10^{-2}
Without clusters (measurement after one day)	3.4563×10^{-3}

DISCUSSION

The results from both Table 3 and 4 shows that clusters provide pivotal role to trap the sediment motion; hence delaying the bed load rate at gravel bed rivers. For first method, the results indicate that the transport rates at stoss side were 36-79% behind the transport rates at loosely clustered grid. When the measurement point took place at the wake tail of the cluster region, the transport rates were 81-98 % behind the rate at loosely clustered region. Though the loosely clustered area demonstrate higher transport rate, the wake tail provide the delaying mechanism to the moving particles by the means of entrapping them in front of the anchor clast or the finer particles tend to hinder behind the anchor clast by the ejection-like and sweep-like motions generated by the protuberant clast (Robert et al., 1996). These hindered particles are hard to be entrained because of hiding and relative size effect. The result seems consistent with the previous percentage revealed by Reid et al. (1992) and Hendrick at al. (2010). Reid et al. (1992) deployed the marked particles at the stoss side and wake tail to observe the transport pattern compared with pattern at the loosely clustered region. It is reported that the travelled marked particles at the stoss side is 33% behind the travelled particles at loosely clustered region. For marked particles at the wake tail, its 60% behind opposed to loosely clustered particles. Hendrick et al. (2010) analysis from the photo point imaging discovered that entrained clustered particles were 7-80% behind entrained non clustered particles.

For second method, the results support the theoretical background from Strom et al. (2004) that clusters delay the sediment entrainment and release the finer particle in pulses once the clusters are destroyed. The measurements without the clusters (by removing the anchor clast) are made as the representative for destroyed cluster while the next day measurement at the same spot as a representative for non clustering bed. The bed load rate at the cluster availability is 98% behind the rate during complete breakup of cluster (after 1 day) as shown in Table 4. If the anchor clast is removed and the instantaneous measurement is made, the bed load rate is 500% higher than the normal rate when the cluster is completely breakup. These results support the numerical prediction of bed load at the clusters availability as proposed by Hassan and Church (2000) and Strom et al. (2004).

The conventional approach to predict the bed load transport is by emulating the shear stress approach such that:

$$\overline{q_b^*} = c(\tau^* - \tau_{cr}^*)^n \tag{2}$$

where n and c=constants; τ^*=dimensionless bed shear stress; τ_{cr}^*=critical dimensionless bed shear stress. However, clusters are more stable than the individual particles and are able to entap the incoming particles and release them in pulses (Strom et al., 2004). A possible correction for was developed to cater the cluster stability as expressed by Hassan and Church (2000)

$$\overline{q_b^*} = \left[\frac{\tau^* - \tau_{cs}^*}{\tau^* - \tau_{ci}^*}\right]^m \tag{3}$$

as the bedload relation of the surface material and the transported bed material. For this relation, m=constant; τ_{cs}^*=dimensionless critical shear stress for the coarsened surface material; τ_{ci}^*=critical shear stress for the transported material. However, Strom et al. (2004) demonstrate that the equation (3) did not represent the evolution of the clusters in the unsteady flow event. Therefore, the new function was developed to cater the three evolution phases namely sink, no affect and source. In phase I, clusters act to retain the incoming sediments and reduce the mean bedload rate. Phase III represents the conditions where the clusters were disintegrate and become the source of sediment and increase the mean bed load rate. However, phase II denoted as the buffer zone between phase I and phase II where the cluster do not alter significantly the mean transport rate but do increase the magnitude of fluctuations as compared to the phase I and III (Strom et al., 2004). The role of clusters on the bed load rate can be expressed as

$$q_b^*(\tau^*) = \begin{cases} q_{bf}^*(\tau^*) + q_{bc}^*(\tau^*) & \text{for } \tau^* < \tau^*_{cr(cluster)} \\ q_{bf}^*(\tau^*) & \text{for } \tau^* \geq \tau^*_{cr(cluster)} \end{cases} \tag{4}$$

where q_i=particular dimensionless bedload rate $(i = b, bf, bc)$; q_{bf}^*=bedload due only contribution from the flow; q_{bc}^* =bedload due purely contributios of cluster; τ_{cr}^*=dimensionless stress when complete breakup of all clusters occurs.

CONCLUSION

The results show that the clusters play vital role in the sediment transport dynamics. The sediment transports were largely influenced by this cluster formation. Thus, deploying the hand held sampler at the random predefined position at gravel bed rivers may affect the reading if there is an occurrence of cluster bedform. Furthermore, the existing bed load prediction which applies the channel-averaged deterministic approach can be further evaluated and modified by taking into account the cluster effects. This effect encompasses the relative size effect imposed by the protruding anchor clast which play key role for maintaining the clusters.

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