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Transverse velocity distribution in relation to bed load movement in natural channels

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Abstract

The transverse velocity distribution in a plane normal to the direction of flow with respect to bed load movement is analysed. There are limited studies on the transverse velocity profiles in natural channels with B/y_0 aspect ratio greater than 10. The findings are based on observations under field conditions in two rivers namely Sungai Lui and Sungai Semenyih. In this paper, results of field experiments on the effects of velocity to bed load profile were examined. The findings indicated that velocity was not the only determining factor to the change in bed load profile. Other contributing factors responsible for the change include bed slope and composition of the bed load.

1 Introduction

Natural channels are known to change their slopes, widths, depths and velocities with space and time. The velocity of flow is largely dependent on the geometry of the channel which undergo deformation continuously due to the processes of erosion and deposition. An accurate estimation of the amount of sediment and bed roughness rely on a good understanding and ability to simulate the velocity profile.

Transverse velocity distribution is considered as one of the determining factors in predicting the movement of bed load. Several experimental investigations have been done using flumes where bed shear stresses are constant and the velocity profiles estimated under controlled conditions [1,2,3].

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Under predetermined conditions, with no variation in channel geometry, the velocity profile may give less accurate estimation of discharge when applied to natural channel.

A great deal of research has also been performed on generation of mathematical or numerical models highlighting the bed features and the transport mechanism of bed load [4,5,6]. Several researches concentrated on suspended sediments and the overall transport of sediments. Vanoni concluded that sediment appears to damp out the turbulence and reduces the momentum transfer [7]. Thus the increase in velocity due to the addition of sediment to a clear stream does not give rise to an increased sediment-transport capacity since it is accompanied by a reduction in turbulence and in the entrainment force at the stream bed.

Contributions on mathematical modelling became significant when Coleman establishes that the Karman coefficient is independent of the amount of suspended sediment in an open channel flow which contradicts the previous findings by past investigators [8]. Karim and Kennedy introduced a method for calculating the suspended-sediment concentration distribution that corresponds to the power-law velocity profile[9].

Whiting and Dietrich proposed accurate calculation of the local boundary shear stress using simple roughness algorithm [10]. Chiew studied the formation of bed features in non-uniform sediments in relation to velocity [11]. Gaweesh and van Rijn studied the sampling efficiency factor and proposed a computation method to determine the mean bed load transport [12]. Guo and Wood derived an expression for calculating suspended-sediment transport rates by assuming a parabolic distribution of eddy viscosity, which results in a von Karman-Prandtl-type velocity profile and Rouse's sediment concentration profile [13].

In practically all the studies conducted, emphasis were given to suspended load and total load in relation to the mean velocity and other hydraulic characteristics except those of Low.

Not many have specifically studied the transverse velocity distribution in relation to bed load movement. In this study, the overall transverse velocity distribution has been observed to have influential effects on the bed load movement. This paper presents, examines and interprets the results of field experiments on the effect of velocity on bed load profiles.

In this study, the transverse velocity profiles were measured in relation to bed load movement in several river cross-sections. The investigation is confined to rivers with aspect ratio, B/y, greater than 10 and discharge not exceeding 10 m^3/s.

2 Measurements and Instruments

There are a total of two gauging stations namely at Kg. Lui along Sungai Lui and at Kg. Sg. Rinching along Sungai Semenyih. Sungai Lui and Sungai Semenyih basins have catchment sizes of 68.1 km^2 and 225 km^2 respectively. The Kg. Lui station is located at longitude of 101° 52' 20" E and latitude of 03° 10' 25" N while Kg. Sg. Rinching station is located at 101° 49' 25" E and 02°

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54' 55" N. The range of river stages for Sungai Lui and Sungai Semenyih observed during this study were between 77.18 m to 77.24 m and 21.72 m to 21.74 m respectively. Minimum and maximum discharges observed were between 2.852 m^3/s to 7.253 m^3/s. Width of the rivers ranges between 13.5 m and 15 m. The catchment and the gauging stations are shown in Figure 1. Typical cross-sections for both Sungai Lui and Sungai Semenyih are shown in Figures 2a and 2b.

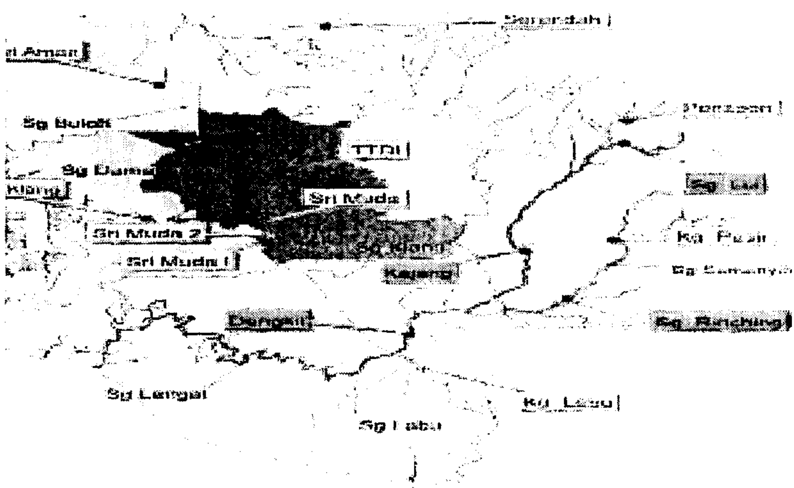

Figure 1 Locations of the gauging stations

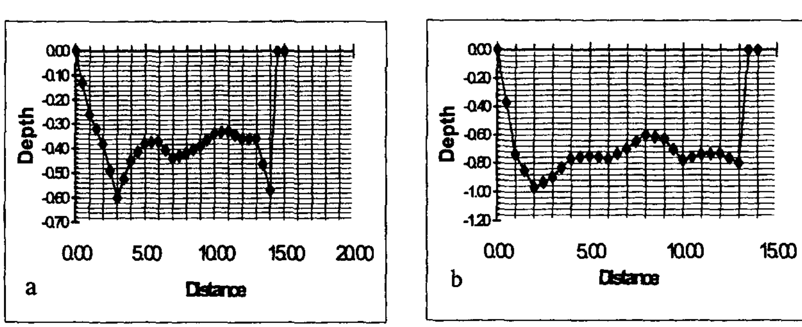

Figure 2 Typical cross-sections for (a) Sungai Lui and (b) Sungai Semenyih

Flow velocities were measured using a standard C-31 current meter attached to a wading rod with a propeller that measured flow in terms of revolutions per second. The current meter was connected to a counter that registered the velocity of flow.

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Flow velocities were measured at a depth of 0.1 m interval from the water surface. The measuring period was 50 seconds. Measurements were made in the vertical direction and three to six measurements were carried out successively starting 0.1 m from the water surface. All measurements were made at one-third, middle and two-third of the span.The flow depths at all the gauging points vary between 0.3 m to 0.77 m

Samples of bed load were collected using a Helley-Smith bed load sampler. The sampler has a weight of about 60 kg. Bed loads were collected through a nozzle of 90.0 mm × 90.0 mm size into a bag with a mesh size of about 150 μm. Data were collected in ten field experiments under low to medium flow conditions. Measurements were carried out at the points of gauging. Measuring period varies from 3 minutes to 10 minutes depending on locations and nature of flow. The sampler was placed on the channel bed with the nozzle facing the upstream end opposing the direction of flow to enable bed load to be collected through its nozzle. Measurements were carried out at every 2 meters across the width of the channel.

3 Results and discussions

The transverse velocity profiles as shown in Figure 3, was constructed from ten samples measured at two gauging stations.

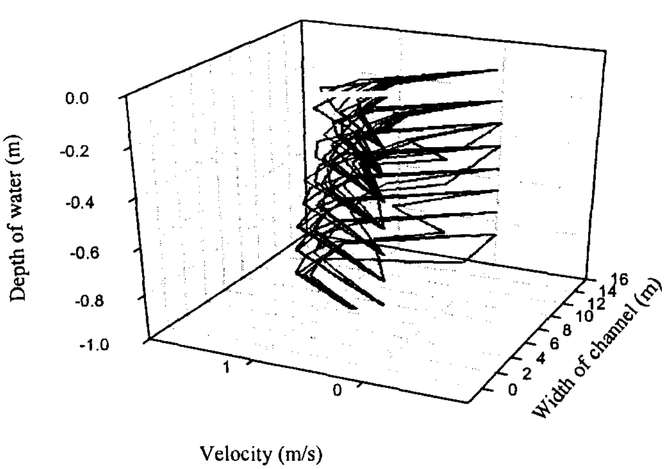

Figure 3 Transverse velocity profile

From these velocity profiles it can be seen that the maximum velocities occur somewhere in the middle of the river cross section and gradually decreases as it reaches the river edges. There are three to a maximum of six measuring points along each vertical (at one-third, middle and two-third of the span) due to the irregular in shape of the bed profile. The point of maximum velocity in the

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vertical direction is almost at the water surface. These are illustrated in Figures 4(a) - (c). The observed velocity profiles reduced in a more linear form instead of parabolic.

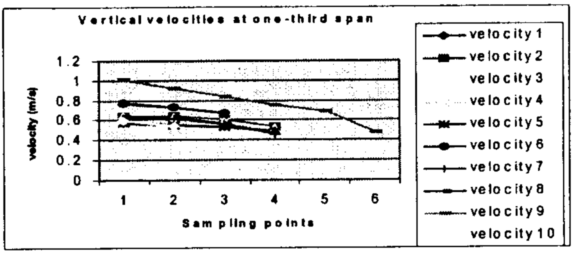

Figure 4a Vertical velocities at one-third span

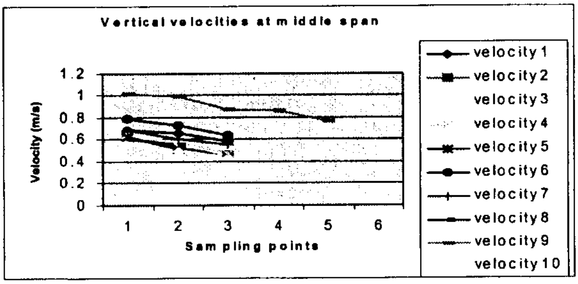

Figure 4b Vertical velocities at middle span

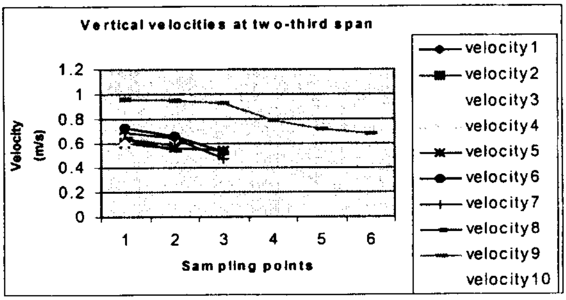

Figure 4c Vertical velocities at two-third span

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The profile of percentage of bed load with velocity is as plotted in Figure 5 with details of percentage of bed load and their compositions tabulated in Table 1. Bed load is measured in terms of percentage for comparison purposes as the samples were taken on different days with different total load.

From the graph it can be noted that an increase in velocity does not necessarily signifies an increase in percentage of bed load. Analysis showed that seven out of ten samples showed an increase in the trend but 3 samples gave contradicting results, namely samples 1, 6 and 8.

Despite the small velocity the percentage of bed load measured is greatest for sample 1. This result is doubtful, as the amount of total load measured is very small it is highly probable that the error introduced is large.

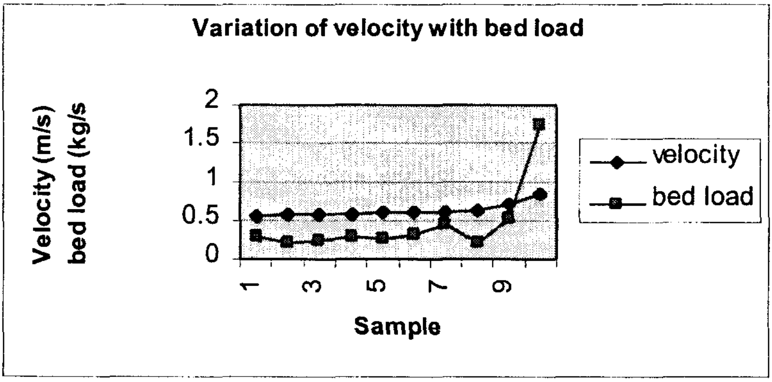

Figure 5 Profile of bed load with velocity

For samples 6 and 8, it was observed that the percentage bed loads decreased with increased in velocity even though the bed load composition for the two samples are comparable to that of samples 5, 7 and 9, i.e., sand making up 85-95% of the bed load material.

The observation for sample 6 can be explained by comparing the observation to that of sample 3. Both have approximately the same percentage bed load and bed load composition. However, the bed slope of sample 6 is milder compared to that of sample 3. Thus the reduction in bed load observed in sample 6 can be attributed to the bed slope despite an increase in the velocity.

Similar reasoning could be given to explain the observation on sample 8. Comparing the observation of sample 8 to that of sample 2, it can be noted both samples have the same percentage bed load, i.e., 13% at different measured velocity. It was noted that for sample 8 the measured bed slope during sampling was 0.00725 compared to sample 2 with a steeper measured bed slope of 0.00833. This indicated that while the percentage of bed load is the same and

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composition of the bed load for sample 8 has a higher sand composition, the bed slope does exert an influence on the bed load

Table 1 Measured velocity, sediment transport rates and composition of bed load

No.	Vel. m/s	Bed load kg/s	Susp. Load kg/s	Total load kg/s	% b/l	% s/l	% gravel	% sand	Bed slope
1	0.543	0.29189	0.11288	0.40477	72	28	18.95	81	0.003
2	0.559	0.21689	1.42209	1.63898	13	87	20	80	0.00833
3	0.5769	0.24324	1.03718	1.28042	19	81	25	75	0.00725
4	0.584	0.29595	1.0313	1.32725	22.3	77.7	16.4	83.16	0.00725
5	0.5987	0.26757	0.87412	1.1417	23.4	76.6	4	95.5	0.00725
6	0.6003	0.31216	1.45409	1.76625	18	82	13.4	87.2	0.005
7	0.6027	0.43581	0.81602	1.25183	35	65	9.05	90.95	0.00367
8	0.624	0.21892	1.47014	1.68906	13	87	10.5	89.2	0.00725
9	0.692	0.53108	0.84908	1.38016	38.5	61.5	12.8	86.9	0.0043
10	0.823	1.73423	0.88046	2.6147	66	34	18.4	81.5	0.004

Observations on samples 3, 4 and 5, where the bed slopes were the same, showed that percentage bed load increased when velocity is increased. It was also noted that the percentage composition of sand in the bed load in the three samples were in the increasing order as velocity increased. These observations suggested that the increased in percentage bed load may be attributed to both, i.e., increased velocity and increased percentage of sand composition in the bed load.

Observations on samples 7, 9 and 10 showed that the percentage bed load increased as velocity increased, despite the decrease in percentage of sand composition in the bed load.

This suggests that at higher velocity, i.e., between 0.6 to 0.8 m/s the percentage bed load depends on the velocity. At lower velocity, i.e., between 0.5 to 0.6 m/s, the percentage bed load depends on velocity, bed slope and percentage of sand composition in the bed load.

4 Concluding remarks

The results from field observations in natural channels indicate that several factors affect the percentage of bed load that include velocity, bed slope and composition of sediments that made up the bed load. At higher velocity, i.e., between 0.6 to 0.8 m/s the percentage bed load depends on the velocity. At lower velocity, i.e., between 0.5 to 0.6 m/s, the percentage bed load depends on velocity, bed slope and percentage of sand composition in the bed load.

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References

[1] Ackers, P., and White, W.R. "Sediment Transport : New Approach and Analysis," *Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers*, **Vol.99**, No. HY11, 2041-2060, 1973.

[2] Low, H.S. " Effect of sediment density on bed-load transport," *Journal of Hydraulic Engineering*, **Vol.115**, No.1, January,125-138, 1989.

[3] Mantz, P.A. " Cohesionless, fine-sediment bed forms in shallow flows," *Journal of Hydraulic Engineering*, ASCE, **Vol.118**, No.5, 743-764, 1992.

[4] Voogt, L., van Rijn, L.C. and van den Berg, J.H. "Sediment Transport of Fine Sands at High Velocities," *Journal of Hydraulic Engineering, ASCE*, **Vol.117**, No.7, 869-890, 1991.

[5] Scarlatos, P.D., and Li, L "Analysis of Fine-Grained Sediment Movement in Small Canals," *Journal of Hydraulic Engineering, ASCE*, **Vol.118**, No.2, 200-207, 1992.

[6] Umeyama, M. and Gerritsen, F. "Velocity Distribution in Uniform Sediment-Laden Flow," *Journal of Hydraulic Engineering, ASCE*, **Vol.118**, No.2, 229-245, 1992.

[7] Vanoni, V.A. "Transportation of Suspended Sediment by Water," *Transactions, ASCE* Paper No. 2267, 67-133, 1944.

[8] Coleman, N.L. "Velocity Profiles with Suspended Sediment," *Journal of Hydraulic Research*, **19,** No.3, 211-228, 1981.

[9] Karim, M.F., and Kennedy, J.F. "Velocity and Sediment-Concentration Profiles in River Flows," *Journal of Hydraulic Engineering, ASCE*, **Vol.113**, No. 2, 159-178, 1987.

[10] Whiting, P.J., and Dietrich, W.E. " Boundary shear stress and roughness over mobile alluvial beds," *Journal of the Hydraulics Engineering, ASCE*, **Vol. 116**, No. 12, 1495-1511, 1990.

[11] Chiew, Y.M. " Bed features in non-uniform sediments," *Journal of Hydraulic Engineering, ASCE*, **Vol. 117**, No. 1, 116-120, 1991.

[12] Gaweesh, M.T.K., and van Rijn, L.C. " Bed load sampling in sand bed rivers," *Journal of Hydraulic Engineering, ASCE*, **Vol. 120**, No. 12, 1364-1384, 1994.

[13] Guo, J. and Wood, W.L. "Fine Suspended Sediment Transport Rates," *Journal of Hydraulic Engineering, ASCE*, **Vol.121**, No. 12, 919-922, 1995.