HOW INCIPIENT MOTION DETERMINATION JUDGMENT AFFECTS DIFFERENT PARAMETERS IN SEDIMENT TRANSPORT INVESTIGATION

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Abstract: Incipient condition plays a significant role in the field of sediment transport and channel stability and different parameters based upon it are used in the sediment initiation and transport formulas both for the development and application purposes. Its determination depends upon the subjective judgment of the investigator. Effects of this judgment on sediment transport and flow parameters have been investigated in this paper by considering three flow conditions of M (when small number of particles start to move), M₁ (when large number of particles starts to move), and M₂ (when very large number of particles starts to move). Data used in this paper were collected from a sediment transport study conducted in the hydraulics laboratory of the University of Manitoba (Canada). Effects of each flow condition on sediment transport, critical discharge, critical velocity, and flow depth parameters were investigated and a significant variation in results was found when flow conditions varied. This variation was more pronounced with the smaller sediment sizes as compared to the larger ones. For the critical discharge, a difference between M and M₁, M₁ and M₂ and M and M₂ conditions ranged from 36-118%, 16-129% and 61-211%, respectively. Likewise, other parameters of flow depth, critical velocity, sediment loads were significantly affected when the conditions were altered. Among the three conditions the M₁ appeared to be more reliable and realistic to be used for the incipient motion determination.

INTRODUCTION

Owing to the variation in particle sizes and their positioning in different directions, incipient motion of sediment for all particles does not occur at one time. Vibration of bed-material particles is an indication that movement is about to begin. This indicates the response of particles to the passing flow, which causes pressure differences and shear stresses that lead to lift and drag forces. If these forces increase over time, the in-place vibration may change to motion. Meanwhile, other particles may respond to increasing shear stresses and pressure differences over their surfaces by a more-abrupt initiation of motion, without vibration. As individual particles begin to move, they leave behind vacant spaces that change the local flow field at the bed surface. These alter lift and drag forces acting on other particles and may help to mobilize several particles simultaneously (Matin 1993).

Incipient motion of sediment in channels, natural or man made, has great significance in the field of sedimentation, especially when prediction is desired. It is the beginning of movement of sediment particles that were stationary some time before. As soon as they have initiated their movement they continue to move for an unspecified time and distance. The precise discharge and time at which initial movement occurs is a subjective determination, therefore investigators have different point of views in this regard. Some argue that it takes place when a small number of particles starts to move while others disagree and say this is just a settlement stage and
incipient motion takes place when a significant number of particles starts to move. Some observers consider initiation of sediment transport to occur when the first few particles start moving, whereas others may say that it occurs when a large number of particles starts to move over a large part of the bed surface.

This paper investigates this subjective determination (judgment) issue so that a possible accurate condition could be found when the incipient motion takes place. For this purpose three flow conditions M, M₁ and M₂ were assumed and their effects on flow depth, critical velocity, critical discharge, and sediment load parameters were investigated both qualitatively and quantitatively.

SIGNIFICANCE OF THE STUDY

Threshold parameters like \( V_c \), \( d_c \), and \( q_c \) are required in the development of incipient motion and sediment transport formulae, in their application for sediment load prediction, and other sediment related and channel stabilization studies. It is, therefore, a fundamental step to make a right judgment about the incipient motion so that these threshold parameters may be recorded correctly. Importance of the incipient motion can be imagined from the fact that most of the sediment transport formulae developed are based on the premises of sediment transport theories of excess shear \( q_b \propto f(\tau - \tau_c) \), excess stream power \( q_b \propto f(\omega - \omega_c) \), excess discharge \( q_b \propto f(q - q_c) \), and excess velocity \( q_b \propto f(V - V_c) \), which involve a parameter that rely upon the threshold condition. Therefore, a small error regarding the threshold condition judgment could seriously affect the structure of sediment transport formulae based upon them and their predicted results. Nice examples of sediment transport formulas in which threshold parameters were used are Schoklitsch (1962), Bagnold (1966), Wilcock and Southard (1989), Ashiq (1997). Likewise, the threshold condition determination is equally important for the sediment incipient motion prediction formulae (Ashiq and Bathurst (1999), irrespective of the theories used and approach followed for their development i.e. characteristic diameter size (reference particle size) approach \( q_c = 0.0345 \sqrt{D_{50}^{3/2} S^{-1.12}} \) , Milhous 1982] or fractional sizes approach \( \tau_{c1}^* = \tau_{c50}^* (D/D_{50})^{-1} \) , Andrews and Erman 1986].

EXPERIMENTAL METHODOLOGY

For the purpose of data collection an experimental setup (Figure 1) was re-designed and constructed in the hydraulics laboratory of the University of Manitoba, Department of Civil Engineering (Winnipeg, Canada) during 2003. At completion, an adjustable slope flume channel of 10 m long, 0.7 m wide, and 0.945 m deep was available to be used in this study. Further details regarding the construction, equipment used, and problems faced during the study may be found in Ashiq et al (2004). During this study, five different sediment sizes were used and for each size slopes were varied 6 times. The sediment material sizes used and the corresponding slopes adopted are given in Table 1, whereas the collected sediment data and other related parameters may be seen in Table 2.
For determining the incipient condition at which movement of sediment starts, the data corresponding to three different flow conditions were recorded: a) when small number of particles started to move, $M$; b) when large number of particles started to move, $M_1$; and c) when very large number of sediment particles started to move, $M_2$. Values of the critical velocity, flow rates, flow depth and sediment load parameters were recorded for the $M$, $M_1$ and $M_2$ conditions and are given in Table 2.

Figure 1 Measurements in progress with a flume channel in the hydraulics lab of the University of Manitoba (2003).

Table 1 Sediment sizes used and the corresponding slopes adopted during the experimentation [University of Manitoba, Canada 2003].

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Channel Slope (%)</th>
<th>Bed Material Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.16 - 2.13</td>
<td>6.350 - 7.938</td>
</tr>
<tr>
<td>2</td>
<td>1.16 - 2.75</td>
<td>4.763 - 6.350</td>
</tr>
<tr>
<td>3</td>
<td>1.30 - 3.03</td>
<td>3.175 - 4.763</td>
</tr>
<tr>
<td>4</td>
<td>1.14 - 2.86</td>
<td>1.588 - 3.175</td>
</tr>
<tr>
<td>5</td>
<td>1.17 - 2.90</td>
<td>0.794 - 1.588</td>
</tr>
</tbody>
</table>

EFFECTS OF THE FLOW CONDITIONS’ SELECTION ON FLOW DEPTHS

The general trend of variation between the depths recorded under all the three flow conditions ($M$, $M_1$, and $M_2$), for the five bed sediment sizes used, is evident from the bar chart heights and trend lines as depicted in Figs. 2-6. According to that the depths recorded under the $M$ condition are less than the $M_1$ and $M_2$ for all the sediment sizes, except for 6.350-7.938 mm size (largest size, Fig. 2) for which they are greater than the $M_2$ condition but smaller than $M_1$ condition. The reason for this anomaly is that during the $M$ and $M_1$ flow (conditions) period, the transported sediment from the upstream reach deposited at the location of measurements, which reduced the flow depth. Likewise, for the 4.763-6.350 mm size the trend line for the $M_1$ crossed $M_2$ when depth exceeded 40 mm, due to the reason that bed surface which was a bit uneven some time ago changed to a plane one, resulting in a decrease in the flow depth under the $M_2$ condition. Other minor variations in the flow depths for the $M$, $M_1$ and $M_2$ flow conditions for the 3.175-4.763 mm and 1.588 - 3.175 mm sizes were due to: i) a series of pits in the channel bed in the longitudinal direction (Fig.7); and ii) a wavy bed and water surfaces during measurements (Fig.8). Likewise, fluctuations in depths under the $M$ and $M_2$ conditions for the smallest size (0.794-1.588 mm) were due to the wavy water surface and sediment deposition at the point of measurement (Fig.6).
Table 2  Sediment transport and other related data collected during experimentation at the University of Manitoba (2003).

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Remarks</th>
<th>Channel Width (m)</th>
<th>Temp. (°C)</th>
<th>Slope (%)</th>
<th>Flow Depth (cm)</th>
<th>Flow Velocity (m/s)</th>
<th>Sediment Concentration (g/l)</th>
<th>Critical Vel. (m/s)</th>
<th>Critical Conc. (g/l)</th>
<th>Flow Rate (m^3/s)</th>
<th>Duration of Experiment (hrs)</th>
<th>pH</th>
<th>Vt of Bed</th>
<th>Vt of Sediment Load</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td></td>
<td>0.94</td>
<td>19.5</td>
<td>1.3</td>
<td>0.40</td>
<td>0.04</td>
<td>0.07</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
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<td>0.94</td>
<td>19.5</td>
<td>1.3</td>
<td>0.40</td>
<td>0.04</td>
<td>0.07</td>
<td>0.00</td>
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<td>0.06</td>
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<td>0.06</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
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<td>19.5</td>
<td>1.3</td>
<td>0.40</td>
<td>0.04</td>
<td>0.07</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>6</td>
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<td>19.5</td>
<td>1.3</td>
<td>0.40</td>
<td>0.04</td>
<td>0.07</td>
<td>0.00</td>
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<td>0.06</td>
<td>0.00</td>
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<td>0.94</td>
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<td>1.3</td>
<td>0.40</td>
<td>0.04</td>
<td>0.07</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Where M = condition when small number of particles started to move.
M1 = condition when large number of particles started to move.
M2 = condition when very large number of particles started to move.
EFFECTS OF FLOW CONDITIONS’ SELECTION ON THE SEDIMENT LOAD AND CORRESPONDING FLOW PARAMETERS

To investigate effects of incipient condition determination judgment on the depth, critical vertical, discharge, and sediment load, these parameters were analyzed for all the five sizes used in the study. In this analysis critical discharge vs. sediment load, slope vs. critical velocity, and sediment load vs. critical velocity were plotted and then trend lines were fitted to find the general

Figure 2 Variation in flow depth for the sediment size of 6.350 - 7.938 mm.

Figure 3 Variation in flow depth for the sediment size of 4.763 - 6.350 mm.

Figure 4 Variation in flow depth for the sediment size of 3.175 - 4.763 mm.

Figure 5 Variation in flow depth for the sediment size of 1.588 - 3.175 mm.

Figure 6 Variation in flow depth for the sediment size of 0.794 - 1.588 mm.

Figure 7 A series of pits in the longitudinal direction observed during the experimentation.
trend of relationships among the respective variables. Out of all these plots only 0.794-1.588
mm size plots are presented here for the purpose of demonstration (Figs. 9-11).

In critical discharge vs. sediment load plots, for the largest four sizes which almost belonged to
the coarser size of sediment, the relationships were found to be of polynomial nature. While for
the smallest size, a size which belonged to the fine sediment material, the linear relationship was
found more appropriate. Both for the coarse and fine sizes the sediment loads under the three
flow conditions (M, M₁ and M₂) increased from M towards M₂. The only size for which (partly)
deviation recorded was the largest size (i.e. 6.350-7.938 mm), for which somewhere in the
middle of the plot the M and M₁ lines crossed each other. This deviation from the general trend
could be due to aggradations at the point of measurements.

On the other hand for the slope vs. critical velocity plots, for all the five sizes, a linear
relationship was found more appropriate and clearly the critical velocity values increased with
the flow conditions i.e. from M toward M₂. Nonetheless, in the case of the sediment load vs.
critical velocity plots, the best relationships were of polynomial nature for the four coarser sizes
and for the fine size the linear relationship was found to be the best one.

Figure 8 A wavy bed surface observed during the experimentation.

Figure 9 Variation in sediment load under M, M₁, & M₂ flow conditions for sediment size of 0.7941-
0.588mm.

Figure 10 Variation in critical velocity under M, M₁, & M₂ flow conditions for sediment size of 0.794 -
1.588 mm.

Figure 11 Variation in critical velocity under M, M₁, & M₂ flow conditions for sediment size of 0.794 -
1.588 mm.
QUANTITATIVE EFFECTS OF FLOW CONDITIONS' SELECTION ON CRITICAL DISCHARGE, VELOCITY, AND DEPTH

When the critical discharges were compared under the M and M₂ flow conditions, the variations of 27.84-55.5%, 31.43-92.88%, 28.67-54.89%, and 81.76-101.48% respectively were recorded for the coarse sizes (size 1-4) and 61.16-211.84% for the fine (size 5). The variations between the M and M₁ were found to be 12.32-24.68%, 13.57-66.44%, 12.77-32.07%, and 37.44-39.88% respectively for the coarse sizes and 36.05-117.82% for the fine size of 0.794-1.588 mm. While for the M₁ and M₂ flow conditions the variations ranged between 16.24-129.21% for the fine size and 12.96-29.5%, 8.97-15.88%, 11.41-25.66%, and 18.52-90.75% respectively for the coarse sizes. It showed that the discharge significantly changed with the selection of flow condition when altered from M to M₁, M₁ to M₂ and M to M₂. Likewise, variation in discharge increased with the decrease in sediment size which means that the finer sizes are more susceptible to the variation as compared to the coarse ones. A similar, general trend of variation was also found with the other two parameters of velocity and depth, with a few exceptions. A numeric set of values for variations in critical discharges, velocity and depth under the three flow conditions may be seen in Table 3.

Table 3 Variations (in percentage) in critical discharge, critical velocity, and flow depth under the M, M₁ and M₂ flow conditions for the five sediment sizes used.

<table>
<thead>
<tr>
<th>Str. No</th>
<th>Sediment Size (mm)</th>
<th>Critical Discharge</th>
<th>Critical Velocity</th>
<th>Flow Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M1-M (%)</td>
<td>M2-M (%)</td>
<td>M2-M (%)</td>
</tr>
<tr>
<td>1</td>
<td>1.500-1.625</td>
<td>12.86-28.05</td>
<td>5.71-14.57</td>
<td>6.25-12.73</td>
</tr>
<tr>
<td>3</td>
<td>5.000-5.250</td>
<td>12.86-28.05</td>
<td>5.71-14.57</td>
<td>6.25-12.73</td>
</tr>
<tr>
<td>4</td>
<td>6.625-6.875</td>
<td>12.86-28.05</td>
<td>5.71-14.57</td>
<td>6.25-12.73</td>
</tr>
<tr>
<td>5</td>
<td>8.375-8.625</td>
<td>12.86-28.05</td>
<td>5.71-14.57</td>
<td>6.25-12.73</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Based upon the study results, the following specific conclusions may be drawn from this study:

- When the determination judgment regarding the incipient motion is not made accurately the recorded data could be significantly underestimated/overestimated, therefore a very careful decision has to be made.

- The coarser sizes were found to be less affected with the subjective judgment as compared to the finer one under these flow conditions. Therefore, for studies in which finer sediments are to be dealt with, more care should be followed. However, it is important to mention that only one fine size sediment material was available for this investigation and further tests with more fine sizes would be helpful to further generalize this part of the conclusion.
• It seemed more appropriate to take the $M_1$ flow condition for the incipient motion determination, which represents a condition when large number of sediment particles start to move over a large part of the bed surface.

**NOTATIONS**

$D_i = \text{particle size for } i\text{th size fraction;}$

$D_{50} = \text{particle size for which } 50\% \text{ of the material is finer.}$

$V = \text{flow velocity;}$

$V_c = \text{critical flow velocity (i.e. velocity at threshold point);}$

$q = \text{water discharge per unit width;}$

$q_c = \text{critical discharge per unit width;}$

$q_b = \text{bed load discharge per unit width;}$

$S = \text{slope;}$

$\tau = \text{shear stress;}$

$\tau_c = \text{critical shear stress}$

$\tau^*_{ci} = \text{Shield's parameter for particle size } D_i;$

$\tau^*_{c50} = \text{reference shear stress parameter used in Parker et. al (1982) for } D_{50}\text{ size;}$

$\omega = \text{stream power; and}$

$\omega_c = \text{critical stream power.}$

**REFERENCES**


