TRANSPORT DISTANCES OF MARKED COBBLES IN A STEEP MOUNTAIN STREAM

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ABSTRACT
Field measurements of travel length in sediment transport were performed in a small experimental catchment of the Dolomites (Rio Cordon 5 km²). A set of 420 sorted marked pebbles (0.032 < D < 0.512 m) was displaced across the stream and their movements were checked periodically. These measurements are compared with the results of other authors.
A dependence of transport distance on difference between flow discharge and incipient motion flow discharge is enhanced by the present research.

Keywords: sediment transport, field measurements, travel length, incipient motion, mountain streams and bedload

INTRODUCTION
An estimate of sediment transport in a river is the result of the single movements of the whole moving bed material. The transport differs in the two cases of uniform bed material and sorted material bed. An attempt to solve it, is to divide the material bed in classes and to apply the relationships obtained from uniform bed studies, to the single classes. This way ignores the interaction among elements of different size. Some authors attempted to explain this interaction and to give a solution, but this was feasible only in defined cases and conditions.
During his experiments, Einstein (1937) found different travel lengths associated to grains of the same size in quasi-uniform bed conditions. All successive field and experimental researches confirmed it except mountain streams with high slope and large size range of bed pebbles. In fact the interaction among elements of different size assumes its weight in sediment transport.
Godone and Maraga (1989) gave a relationship which links the travel length L to the peak discharge Q, based on the coarse fraction transport measurements in river Gallina (North Western Alps):

\[ L = a \ln Q + b \] (1)

Later, Church and Hassan (1992) proposed, to estimate the travel length of the streambed elements, the following no dimensional relationship:

\[ \frac{L}{L_{D_{50}}} = 1.77 \left[ 1 - \log_{10} \left( \frac{D}{D_{50\text{SUB}}} \right) \right]^{1.35} \] (2)

with L travel length of element of diameter D, \( L_{D_{50}} \) travel length corresponding to \( D_{50} \), diameter of the median size of streambed material and \( D_{50\text{SUB}} \) diameter of median size of subsurface layer bed material.

THE FIELD MEASUREMENTS
The experimental site is the Rio Cordon (basin, 5 km²) a tributary of the Fiorentina river in the Piave river basin. Since 1986 an equipped station has been operating to observe the flow discharge and the total sediment load during floods events. The total discharge, flows in an inlet channel where fine sediment transport and water discharge are intercepted by an inclined grid (0.02 m spacing) whereas the coarser sediment transport stops and deposits downstream the grid in a separated collecting basin (Fattorelli et al. 1988). A stage-discharge relationship has been calibrated for the inlet channel of the station. The water depth at the inlet channel is continuously measured from march till november. Ultrasonic sensors, placed in the collecting basin detect the presence of coarser sediments whose whole volume is measured at the end of flood or consistent flow events. A precedent study (Lenzi, 1992) recognized a representative granulometric curve of streambed material whose characteristics are $D_{16} = 0.020$; $D_{25} = 0.037$, $D_{30} = 0.05$, $D_{40} = 0.07$; $D_{50} = 0.09$; $D_{75} = 0.2$; $D_{84} = 0.26$ and $D_{90} = 0.33$ m with bigger pebbles diameter equal to 0.8 m.

A sample of 420 cobbles ranging from 0.032 m to 0.512 m has been placed across two sections, located 160 and 135 m upstream the experimental station respectively, by transversal rows 1-2 m spacing. The average slope of the reach is 13.6%. The sample, whose granulometric distribution is similar to the stream’s, is subdivided in 9 diametric classes by index Ø variation of 0.25 or 0.5 (see Table I). The analysis of the movements was conducted in a dynamic form by five consecutive surveys during three months. After each inspection an average travel length was computed by averaging the relative single travel lengths weighted with their frequencies of movement. The average travel length referred to a period is given by the subtraction between two successive measurements (Lenzi and D’ Agostino, 1998). Table II shows the measurements of five periods relative to consistent peak discharge.

OBSERVED TRAVEL LENGTHS

Godone and Maraga (1989) deduced the coefficients of equation (1) $a = 12.5$ and $b = 4.82$ from their field measurements. This values reflect the peculiarity of the site, because a relationship peak discharge-travel length hides the granulometric distribution of the river and can not be extrapolated. In fact the Rio Cordon measurements give $a = 29.1$ and $b = 10.2$ considering only the classes from 0.054 m to 0.108 m and the data are scattered. A more suitable agreement is obtained by the following interpolation:

$$L_i = 0.63 \ Q_i^{2.67} \ D_i^{0.27}$$  \hspace{1cm} (3)

Figure 1 shows the comparison between field measurements and eq. (2). Considering $D_{50}/D_{50\text{SUB}} = 2.5$, two main behaviour can be distinguished. First, a selectivity of travel lengths, according with flow rate and diameter, for water discharges value less or next to 2 m³/s. This value represents the threshold for measuring an incipient bed load transport at the experimental station (1 m³ in 10 hours). Second, the transport lengths of the different diameters tend to approach a same value when flow discharge overcomes this threshold as underlined by points corresponding to $D/D_{50\text{SUB}} < 4$ and $Q = 4.3$ m³/s. In this case the findings of Church and Hassan (1992), whose equimobility trend was already suggested by Wilcock (1992), are approached. Substituting $D_{50\text{SUB}}$ with $D_{50}$ (see figure 2) another view is obtained: the lower is the water discharge, the bigger is the range $L/L_{D50}$ and vice versa. These results mean that once mobilized, gravel of different size travel...
together. This aspect is enhanced for the bigger flood discharges which mobilize a large range of streambed materials than for the lower flood discharges which mobilize only a small part of them. The same conclusion could be deduced by figure 3 where travel lengths of classes 1,2,3,4 and 5 are related to the flood peak discharge.

An attempt to study travel length coupling discharge and streambed material dimension was made by Church et al. (1992) who plotted travel length available measurements versus the difference between peak discharge and flow incipient motion discharge. They obtained a relationship which compared with present measurements gave no significative results, because the expression of the incipient motion discharge (Bagnold’ s formula, 1980) predicted no movements for the measured peak discharges.

Lenzi and D’ Agostino (1998) and D’ Agostino et al.(1999) introduced a criterion to establish a field incipient motion condition based on the ratio \( L_i/D_i \) and obtained a good agreement between the incipient motion discharge \( q_{ci} \) (per unit width) from Rio Cordon data and the empirical relationship given by Bathurst (1987):

\[
q_{ci} = 0.15 g^{0.5} D_i^{1.5} S^{-1.12}
\]

with \( q_{ci} \) incipient motion discharge per unit width. The equation (4) was derived, using flume data for the range 0.25 < \( S < 20\% \) and 0.003 < \( D_i < 0.044 \). Figure 4 shows the transport length \( L \) versus the difference \( q_i - q_{ci} \) in Rio Cordon data (Lenzi and D’Agostino, 1998). A linear dependence of transport length on the difference between peak discharge and incipient motion discharge appears once overcome a limit value (0.2 m\(^2\)/s). The difference \( q_i - q_{ci} \) represents the influence on transport length given by the forces (due to water flow) responsible of transport and by the attitude of gravel to motion (expressed in the form of initiation movement discharge).

CONCLUSIONS

Travel length of gravel in steep mountain streams is needed in the analysis of bed morphology during time and field incipient motion.

Present travel length measurements show the influence of water discharge beyond incipient motion value in the streambed material movements: the bigger is the difference between them the more the streambed material moves all together. In condition of negligible bedload, the measurements have shown high size-selective movements for cobbles smaller than \( D_{50} \). On the contrary, the movements of the same cobbles tended to be homogeneous at higher sediment transport rates (about twice the threshold conditions given by a 2 m\(^3\)/s discharge).

A successive data elaboration exhibits the depending of travel length on flow peak discharge and on incipient motion flow discharge. This depending appears well defined above a limit value of \( q_i - q_{ci} \) that represents the real threshold condition towards a total bed particle entrainment. This result means the control exerted on sediment transport by the hydrodynamic forced due to water flow and by the weight of gravel and slope stream which express the attitude to motion qualified by incipient motion flow discharge.

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REFERENCES


SYMBOLS

a constant
b constant

\(D_i\) average diameter of the granulometric class i

\(D_{50}\) diameter of median size of streambed material

\(D_{50\text{SUB}}\) diameter of median size of subsurface bed layer

\(g\) gravitational acceleration = 9.81 m\(^3\)/s

\(L_i\) average travel length of the granulometric class i

\(L_{50}\) average travel length of median size of streambed material

\(Q\) peak water discharge

\(q_{ci}\) incipient motion discharge for unit width

\(q_i\) peak water discharge for unit length
### S slope

<table>
<thead>
<tr>
<th>Diametric class (mm)</th>
<th>Ø index</th>
<th>Average class diameter $D_i$ (mm)</th>
<th>Number of pebbles</th>
<th>Corresponding diameters of stream bed material</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.0 - 45.0</td>
<td>-5.0, -5.5</td>
<td>38</td>
<td>223</td>
<td>$D_{25}$</td>
</tr>
<tr>
<td>45.0 - 64.0</td>
<td>-5.5, -6.0</td>
<td>54</td>
<td>121</td>
<td>$D_{30}$</td>
</tr>
<tr>
<td>64.0 - 76.0</td>
<td>-6.0, -6.25</td>
<td>70</td>
<td>27</td>
<td>$D_{40}$</td>
</tr>
<tr>
<td>76.0 - 90.5</td>
<td>-6.25, -6.5</td>
<td>83</td>
<td>18</td>
<td>$D_{45}$</td>
</tr>
<tr>
<td>90.5 - 128.0</td>
<td>-6.5, -7.0</td>
<td>108</td>
<td>11</td>
<td>$D_{55}$</td>
</tr>
<tr>
<td>128.0 - 181.0</td>
<td>-7.0, -7.5</td>
<td>152</td>
<td>5</td>
<td>$D_{65}$</td>
</tr>
<tr>
<td>181.0 - 256.0</td>
<td>-7.5, -8.0</td>
<td>215</td>
<td>5</td>
<td>$D_{75}$</td>
</tr>
<tr>
<td>256.0 - 362.0</td>
<td>-8.0, -8.5</td>
<td>304</td>
<td>5</td>
<td>$D_{90}$</td>
</tr>
<tr>
<td>362.0 - 512.0</td>
<td>-8.5, -9.0</td>
<td>430</td>
<td>5</td>
<td>$D_{95}$</td>
</tr>
</tbody>
</table>

Table I – Characteristics of sample with corresponding diametric class of stream bed material.

<table>
<thead>
<tr>
<th>Class</th>
<th>Average diameter</th>
<th>31.08.1993 $Q=0.500$ m$^3$s$^{-1}$</th>
<th>15.09.1993 $Q=0.720$ m$^3$s$^{-1}$</th>
<th>30.09.1993 $Q=0.735$ m$^3$s$^{-1}$</th>
<th>03.10.1993 $Q=4.30$ m$^3$s$^{-1}$</th>
<th>30.10.1993 $Q=1.70$ m$^3$s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.038</td>
<td>0.150</td>
<td>0.540</td>
<td>0.480</td>
<td>74.300</td>
<td>10.800</td>
</tr>
<tr>
<td>2</td>
<td>0.054</td>
<td>0.040</td>
<td>0.200</td>
<td>0.180</td>
<td>67.900</td>
<td>9.500</td>
</tr>
<tr>
<td>3</td>
<td>0.070</td>
<td>0.020</td>
<td>0.050</td>
<td>0.130</td>
<td>64.000</td>
<td>3.000</td>
</tr>
<tr>
<td>4</td>
<td>0.083</td>
<td>0.015</td>
<td>0.030</td>
<td>0.030</td>
<td>58.300</td>
<td>2.000</td>
</tr>
<tr>
<td>5</td>
<td>0.108</td>
<td>0.010</td>
<td>0.010</td>
<td>0.010</td>
<td>58.300</td>
<td>1.000</td>
</tr>
<tr>
<td>6</td>
<td>0.152</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>24.000</td>
<td>0.030</td>
</tr>
<tr>
<td>7</td>
<td>0.215</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.800</td>
<td>0.020</td>
</tr>
<tr>
<td>8</td>
<td>0.304</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.030</td>
<td>0.010</td>
</tr>
<tr>
<td>9</td>
<td>0.430</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.010</td>
<td>0.010</td>
</tr>
</tbody>
</table>

Table II – Average movements of gravel of class i with corresponding peak discharge.
Figure 1. No dimensional transport length $L_i/L_{D50}$ versus $D_i/D_{50}$. 

Figure 2. No dimensional transport length $L_i/L_{D50}$ versus $D_i/D_{50}$. 

Church and Hassan (1992)
Figure 3. Average transport length versus water discharge for different diameter sizes.

Figure 4. Transport length versus difference $q_i - q_{ci}$ from Rio Cordon data.