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Measuring changes in micro and macro roughness on mobile gravel beds

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ABSRACT The aim of this paper is to evaluate some new techniques for measuring micro- and macro-roughness over mobile gravel-bed boundaries both before, during and after flood flows. Changing roughness conditions are investigated both in the Schmiedlaine, a Alpine torrent in the S. Germany, with a D_{50} of 350mm and at Squaw Creek, a mountain stream in Montana with a D_{50} of 128mm. A macro-Tausendfüssler device was used for obtaining detailed measurements of changing cross-sectional roughness at 10cm intervals. A mini-Tausendfüssler, measuring at 2cm intervals was used to reconstruct particle projection and imbrication and bedform arrangement. By means of photo-sieving, the area covered by grains and grain size distributions, grain rounding, and orientations were determined. A fractal approach was implemented in order to determine which measuring interval was most representative of grain and form roughness.

INTRODUCTION

Until recently there has been a lack of detailed studies on roughness during flood flows with active sediment transfer (Bathurst, 1978; Hey, 1979; Egashira & Ashida 1991). A precise roughness coefficient is required that takes into account changing roughness over mobile boundaries. So far, roughness has normally been calculated before or after a flood using representative D_{84} or D_{50} grain size values. These values are not representative of the entire grain size spectrum, nor do they indicate the changing roughness conditions during a particular time of a flood. When depending on only one representative grain size in calculating roughness, there is a danger of omitting factors that vary during the course of a sediment transporting event. Thus when using flow depth over a representative grain size (Bathurst, 1982; Hey, 1979; Egashira & Ashida, 1991) the variability in flow depth may be obtained, but changing grain size distributions remain unknown. Using a new approach whereby roughness is measured with a high temporal and spatial resolution, an absolute k_3 roughness coefficient which correlates well with the Darcy-Weissbach coefficient can be obtained throughout the passage of a flood (Ergenzinger & Stüve 1989). The Darcy-

Weissbach coefficient used to determine absolute roughness has been limited by a lack of knowledge on form and grain roughness, turbulence and bedload transfer. With the proposed techniques, measurements of micro- and macro-roughness as grain and form parameters replace traditional grain size estimates of roughness.

AIMS

Different techniques for measuring changes in grain and form roughness at a micro- and macro-scale are to be compared and combined, both in order to test the validity and limitations of the new methods and to recontruct the arrangement of three-dimensional roughness elements. Two-dimensional changes in macro-roughness are reconstructed during a flood using the macro-Tausendfüssler device. The accuracy of the macro-Tausendfüssler is to be compared with the mini-Tausendfüssler. Also the scope of the photosieving device will be presented and used in combination with the mini-Tausendfüssler to reconstruct bed arrangement prior to and after a flood. The objectives of these are to reconstruct particle projection, imbrication, grain size distributions, grain rounding, and flow directions from grain orientations.

STUDY SITES

Changes in macro-roughness were investigated at Squaw Creek, Montana, USA using the macro-Tausendfüssler along a fairly straight reach with a 2% gradient, an average D_{84} of 33mm in the channel and 200mm of the armour layer (Custer et al, 1987). Bed material is fairly rounded and quite well sorted, enabling the bed to be arranged loosely with little interlocking and few cluster bedforms. The mini-Tausendfüssler was put into action alongside the macro-Tausendfüssler over a gravel bar and bar-

FIG. 1 The detail of macro-topographical measurements achievable with the macro-Tausendfüssler (vertical scale exaggerated by a factor of 6).

channel interface. Squaw Creek is subject to regular snowmelt events that cause dynamic changes in roughness throughout flood events lasting approx. 24 hours.

The photosieving technique was implemented on a gravel bar and in a dry channel bed in the Schmiedlaine, an Alpine mountain stream forming a tributary of the Lainbach, S. Germany. The gravel bar has an average gradient of 4-5 % and a grain size average of 350mm. Material is very poorly sorted and angular. Orographic rainfall produces floods capable of reworking clasts with b-axes of up to 500mm approx. every 15 days. The Schmiedlaine differs from Squaw Creek in that it is a highly meandering valley confined stream. The high curvature bends significantly influence the arrangement of the river bed into crescentic cobble-gravel berms, which are build up from a complex arrangement of cluster bedforms. Clustered particles on the dry channel surface form approx. 80% of the bed topography.

MEASURING TECHNIQUES

1 Measuring macro-roughness

Macro-roughness was measured at Squaw Creek during two entire flood waves using the Tausendfüssler device (Ergenzinger & Stüve 1989). This is a horizontal beam attached over the entire river section which is perforated every 10 cm by a vertical tube. With the help of a rod that is inserted through each tube, the distance to the bed can be measured (Fig. 1). The water surface can also be obtained immediately above the river bed profile. Tausendfüssler measurements were obtained at hourly intervals, so that changes in macro-roughness could be obtained in great detail. From these measurements, the k_3 roughness coefficient was calculated, since it is assumed that turbulence is created by vertical differences in bed topography. This coefficient is calculated in a sequence using the difference between the maximum and minimum value between three adjacent points, so that the last point of a set becomes the second point of the next set. Form and grain roughness are not differentiated but calculated as a single parameter. The two are not differentiated since grain roughness in gravel-bed rivers can actually constitute form roughness such that a large boulder can act as an element of form roughness but could be subsequently transported as a single grain.

2 Measuring micro-roughness in section

Micro-roughness was measured in a similiar manner to macro-roughness, but at a much higher spatial resolution i.e. every 2 cm with the mini-Tausendfüssler (Fig. 2). This device allowed relative particle projection and angles of imbrication as well as roughness conformity to be obtained. Measurements with the micro-Tausendfüssler alongside the macro-Tausendfüssler allowed the accuracy of the device to be checked. Thus k_3 roughness coefficients of the mini-Tausendfüssler were measured against the macro-Tausendfüssler at 10cm intervals for comparison. In order to compare different scales of k_3 roughness, K_3 (2), K_3 (6), K_3 (12), K_3 (10), K_3 (20) and K_3 (40) coefficients were obtained from the mini-Tausendfüssler at 2, 6, 12, 10, 20 and 40cm

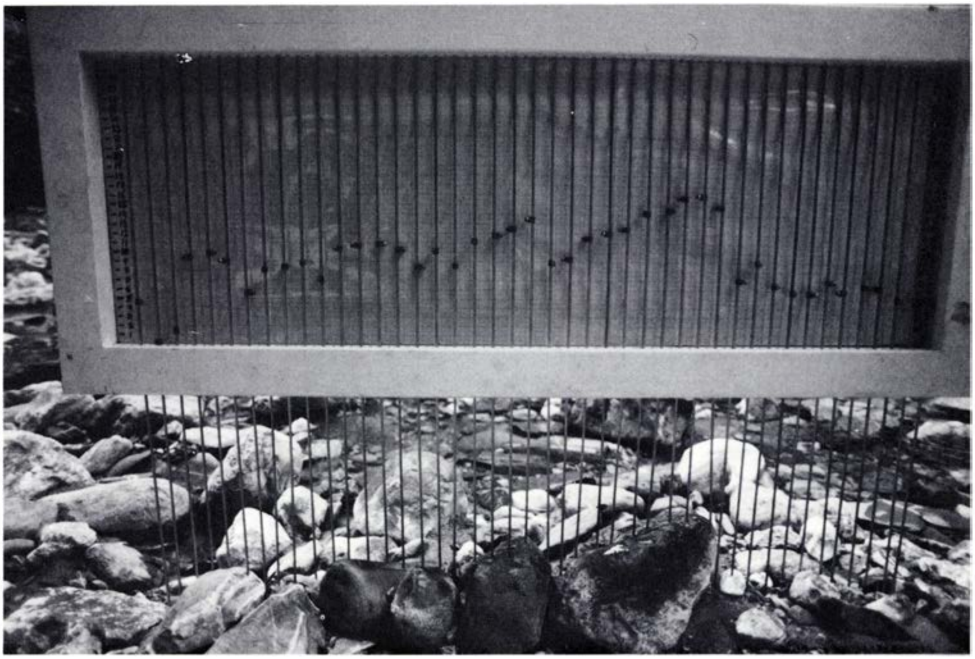

FIG.2 The mini-Tausendfüssler device (Photo: de Jong).

intervals. With the mini-Tausendfüssler, cluster bedforms could be traversed both in longitudinal and lateral sections and their projection compared to the open-bed clasts.

3 Measuring micro-roughness in plan

The photosieving device (Ibbeken & Schleyer, 1986) was implemented in the Schmiedlaine. This consists of a rectangular frame with a camera attached at the top for taking vertical photos of the river bed. The bottom of the frame is demarked by a scale which exactly fits the dimensions of the photo. This enables all photos to be taken from the same height and at the same scale. The photographs are enlarged and each clast is digitised (Fig.3). A special computer programme calculates the grain size distribution of the clasts from the b-axis and also the areas taken up by each grain size class. It calculates the roundness of the clasts by Fourier analysis and their orientation. The photosieving study was carried out before and after each flood over the entire surface of the bar and dry channel, so that characteristics of the clustered and non-clustered bed could be compared.

When combining the photosieving and mini-Tausendfüssler techniques in selected areas, grain roughness can be reconstructed in three dimensions.

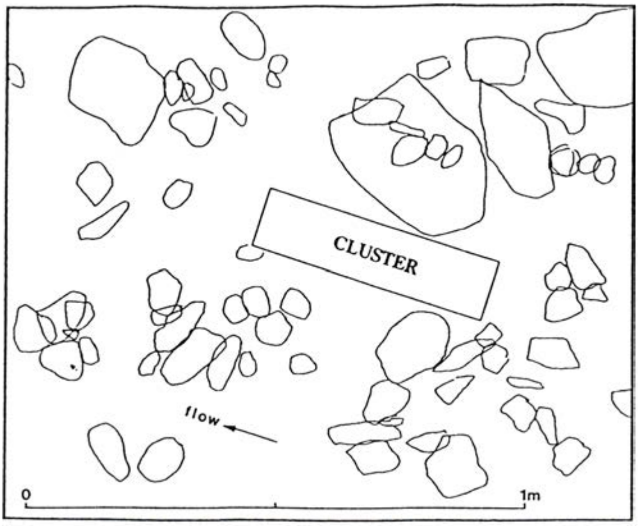

FIG.3 Clast distribution digitised by photo-sieving.

RESULTS AND INTERPRETATION

1 Temporal changes in macro-roughness

Changes in k3 roughness are complex (Fig.4). The advantage of the measuring technique lies in its capability of obtaining detailed measurements over the entire flood period. The dynamics of roughness was investigated in the channel, bar and bar-channel interface (De Jong & Ergenzinger 1992). Mean k_3 values decreased during the flood from 6-3cm. In the channel, maximum roughness (13cm) occurred during the transit time between bedload pulses. On the bar, roughness remained quite static, around 4 cm, with the interface values fluctuating between the bar and channel.

2 A fractal approach towards roughness determination

Results in k_3 roughness were used to test the accuracy of the macro-Tausendfüssler device. Comparison of the actual micro-topographical configurations along the gravel bar and bar-channel interface resulted in a r^2 correlation of 0.68, confirming the accuracy of the device. The k_3 could not be compared in the channel since this exceeded the height of the mini-Tausendfüssler. When k_3 values were compared between the two devices, a 0.72 r^2 coefficient resulted. A fractal approach was used to identify possible deviations in the accuracy of the k_3 values of the mini-Tausendfüssler i.e. by shifting the starting point. Again all roughness elements over 3 cm in height were registered, with a 0.85 r^2 correlation between them. The mean, standard deviation and maximum roughness values for the macro and micro-Tausendfüssler were very similiar.

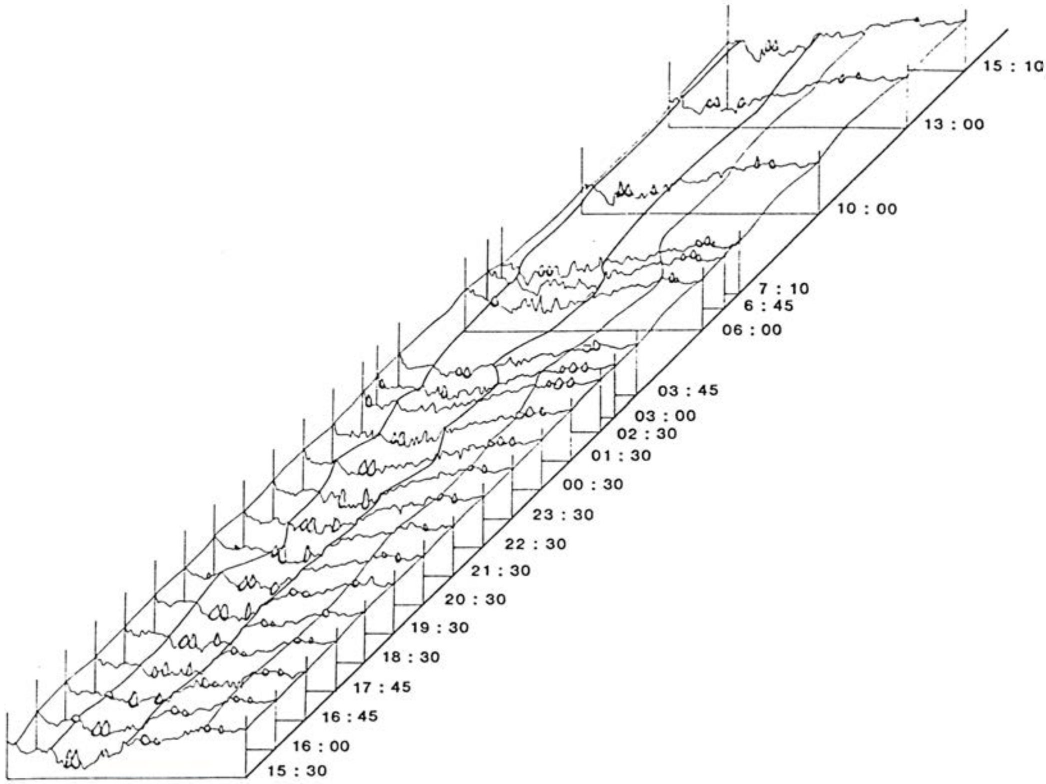

FIG.4 Changes in roughness and geometry over a 24 hour period.

All the different k_3 values i.e. at 2, 6, 10, 12, 20 and 40 cm distance were compared with each other. Even with a k_3 (20), the general pattern of roughness was still maintained i.e. all elements above 9 cm in height were registered in the same way as when using the k_3 (2). This is indicated in Fig.5.

In order to investigate the fate of roughness values at different scales and at different intervals, a fractal approach was applied (Fig.6). The mean, standard deviation and average for the K_3 (2), K_3 (6), K_3 (10), K_3 (12), K_3 (20) and k_3 (40) increase to a maximum at K_3 (20) and decrease at larger intervals. Thus when roughness is measured at a smaller scale, the mean, standard deviation and maxima are all at a minimum and grain roughness is most important. With larger k_3 intervals the average k_3 values decrease (Fig.6) and form roughness becomes more significant. The selected k_3 value has to be representative of both grain and form roughness, where the grain roughness should still be large enough to cause turbulence. At Squaw Creek this would lie around K_3 (20), whereas a larger k_3 value would be necessary in the Schmiedlaine. With this approach it is important to choose a representative k_3 value which is related to the local grain size distribution for every type of gravel-bed river.

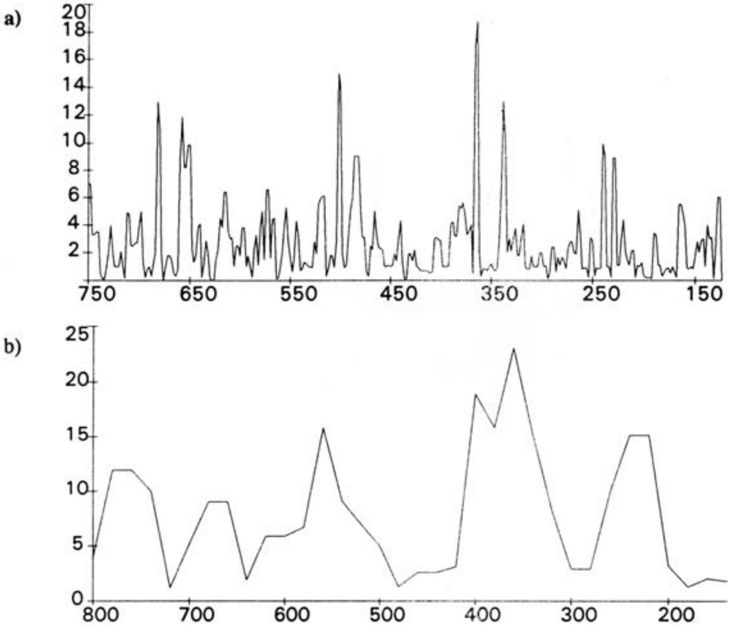

FIG.5 Comparison of a) K_3 (2) and b) K_3 (20).

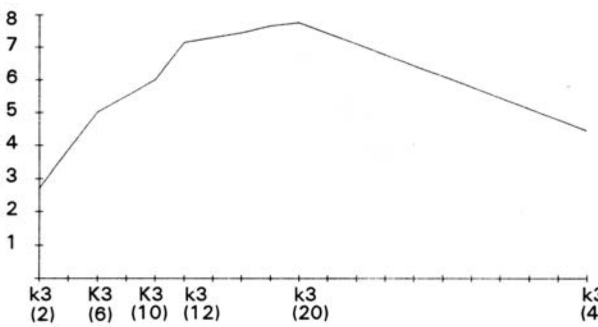

FIG. 6 Fractal relationship between K_3 (2), K_3 (6), K_3 (10), K_3 (12) K_3 (20) and k_3 (40).

3 Clusters: micro or macro-roughness indicators?

Clusters constitute an important part of micro-roughness on river beds (Billi 1988, Brayshaw et al 1983; de Jong, 1991). Measurements in cluster length and width with the mini-Tausendfüssler at 2 cm intervals indicated that micro-bedforms are compact assemblages (Fig.7) that aim to minimise form roughness i.e. although they are projecting identities, they try to achieve a smoothness in form so as to avoid any unneccesary resistance to flow. Thus the arrangement of clasts in roughness elements may achieve the same size as other single roughness elements, but adapted more advantageously. It is only through detailed analysis that such important roughness properties can be evaluated.

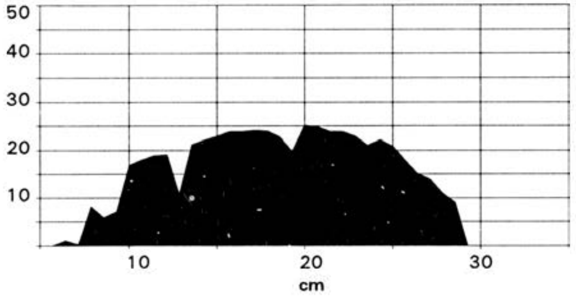

FIG. 7 Measurement of cluster bedforms in cross-section

The photosieving device is a useful, non-destructive alternative to obtaining grain size distributions manually. Figure 8 shows that the areas covered by the individual clasts in a particular grain size group is more indicative of the role that roughness elements play on the river bed than a simple grain size distribution. In the comparison between clustered and non-clustered particles, the grain size distribution (Fig. 8a) runs quite parallel, yet the actual area covered by each of these indicates that the coarsest

A

B

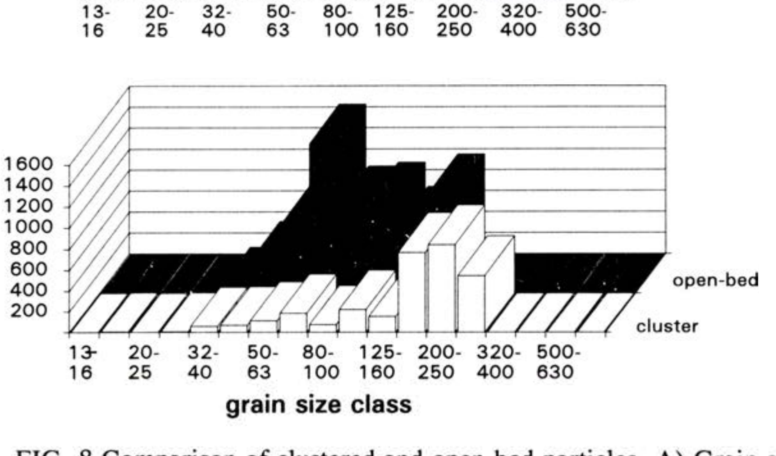

FIG. 8 Comparison of clustered and open-bed particles. A) Grain size categories. B) Areas covered by grains in each category (cm^2).

fraction of a cluster covers most of the bedform and can actually be found on the tail-end of the surrounding open-bed grain distribution.

The grain size and area distributions in other cases show that clusters are considerably coarser than their surrounding open-bed particles. Other important functions such as the orientation of micro-form assemblages in comparison to the rest of the clasts on the river bed confirm a very close relationship. Grain roundness is usually lower in clusters, indicating that angular material forms a major consitutent of roughness elements.

CONCLUSION

More field measurements are necessary to expand our data sets on changing roughness during flood flows in a variety of streams using detailed techniques of monitoring river bed roughness. In modelling gravel-bed rivers, more has to be known on the dynamics of roughness, which is strongly dependant on grain transfer. The micro-Tausendfüssler and photo-sieving techniques indicate that roughness measurements are necessary in great detail and at a grain to grain scale. Grain areas covered in clusters and other bedforms provide a new approach towards defining micro-roughness. Grain and form roughness are very dynamic parameters and cannot be tackled by means of substitution.

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