DISCUSSION ON TECHNICAL NOTE 407

Initiation of sediment transport in gravel streams

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The discussers congratulate the Author on his presentation which, in its derivation of equation (17), supplies a neat theoretical explanation to their empirically founded equation (20) for predicting the critical discharge at which sediment transport begins. Their objections to the classical Shields diagram arose because the terms slope S , depth d , and sediment diameter D , appear on both ordinate and abscissa, so preventing an independent evaluation of the Shields factor in any situation, such as steep streams, where that factor is not constant. They suggested that velocity would have to be taken into account more explicitly to overcome this problem and therefore concentrated on a critical discharge equation (the Schoklitsch⁶ approach) rather than a critical depth or shear stress equation (the Shields approach). The Author, by introducing the resistance equation, has shown that the basis of the two methods is the same and has proposed a means by which velocity can be effectively involved to provide a satisfactory method of extending the Shields approach to steep streams. There are, however, two problems which currently limit the applicability of his method for the region $d/k_s < 3$ and because of which the Schoklitsch approach, despite its empirical foundation, is likely to prove more practical for the time being.

30. Firstly, there is the question of how the equivalent sand roughness, k_s , is to be calculated for use in Fig. 6. As proposed, it is obtained empirically from equation (23) but this requires that velocity, depth and slope be known in the first place. If they are known, however, the problem ceases to exist and there is no need for any calculation procedure at all, either of Shields or Schoklitsch. Usually, of course, depth and velocity are unknown and an independent estimate of k_s is therefore needed. Probably the best way of obtaining that is to develop a relationship between k_s and the bed material size D . However, although this method is satisfactory for flows with large ratios of depth to bed material size,^{7, 8} the attempt to calculate the Shields factor using D_{50} (Fig. 4) shows that the method requires considerable refinement for use with steep flows and low ratios of depth to bed material size.

31. Secondly, there is the difficulty of using equation (17) to calculate critical discharge in practice as opposed to theory. The Author's analysis indicates that as the constants A and B in the equation depend on the Shields factor, they, too, may be expected to vary with d/k_s . Evaluation of the constants, therefore, involves both

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the empirical dependency on k_s and the extreme difficulty of measuring depth in sediment-moving flows at steep slopes and low ratios of depth to bed material size. Further, equation (17) is based on the assumption that the resistance equation (10) or (23) applies. As the Author points out, though, there is uncertainty over the resistance equation for steep streams with low ratios of depth to bed material size. Research by the discussers shows that, while a relationship between the resistance coefficient f and $\log (d/D)$, such as equation (23), still forms the most practical approach, there is considerable scatter of data around such a relationship and errors of 25–30% in the calculated value of f are common. Thus use of equation (17) in practice is likely to involve as many empiricisms or errors as equation (20). Regrettable though it may seem, therefore, an empirical equation such as equation (20) may be of greater use than the more theoretical approach for the time being. It must be admitted, though, that equation (18), the quantifiable version of equation (17) for $d/k_s > 3$, plots close to the discussers' best-fit empirical equation based on available data. In the long term, the Author's approach is likely to provide the more satisfactory solution to the problem.

References

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The Author would like to thank the discussers for their contribution, with much of which he is in agreement. In the Paper, the Author demonstrated that the empirical Schoklitsch-type equation, derived by the discussers, is equivalent to the classical Shields equation for initiation of motion combined with a resistance equation. Thus any shortcomings of the Shields equation in describing initiation of motion must be reflected in the Schoklitsch-type equation. The Author, therefore, finds it curious that the discussers should apparently consider the empirically derived Schoklitsch-type equation to be preferable.

33. As the discussers have demonstrated,¹ for large grain Reynolds numbers the critical value of the Shields parameter seems to vary for shallow flows in steep streams. In the Paper, the Author was trying to demonstrate that this critical value varied in a more or less systematic way with d/k_s . This was not intended to be taken as a practical method for determining the initiation of motion because, as the discussers point out, it is difficult to determine *a priori* the value of d/k_s . It was intended more as a demonstration of the reason why the Shields equation appears to be less satisfactory for shallow flows in steep streams. A shortcoming which it must necessarily share with a Schoklitsch-type equation.