An experimental study of flow over artificial bed forms

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Abstract

The boundary characteristics of flow over bed forms determine their behaviour and interaction with associated turbulent flow and sediment transport. The effects *of* bed-form geometry, surface roughness and discharge on boundary shear stress, pressure, water surface profile and separation length have been investigated experimentally at shallow (relative to bed-form height) flow depths. The length of separation zone was found to depend on the Fraude number, grain roughness and bed-form geometry, and to be significantly greater than as measured previously at greater relative flow depths. Boundary shear stress is influenced strongly by discharge and bed-form geometry, and weakly by surface roughness.

Introduction

Bed forms play an important role in the hydraulics of alluvial channels, being associated with both sediment transport and flow resistance. The turbulent flow, sediment transport and bed-form geometry constitute a mutually dependent system with continuous feedback interactions between the components. The complexity of the relationships in this "trinity" has been discussed by Leeder (1983), who warns against the treatment of any one component in isolation. The behaviour of the individual components is, however, little better understood at present than the interactions between them, and there is therefore some justification for investigating them independently. The understanding of processes in isolation that can be obtained through well-controlled experiments - even in highly artificial situations - provides a basis for developing an understanding of complex process interactions.

The boundary characteristics of the flow over a bed form, particularly the boundary shear stress, boundary pressure, and the length of separation zone, are important parameters in the flow - sediment transport - bed-form interaction. The boundary shear stress controls the movement of sediment grains and therefore determines the sorting of sediment *on* the bed-form surface, the rate of bed-load transport, and the bed-form geometry. It also determines the skin friction component of bed resistance. The distribution of pressure over a bed form determines the form resistance component of bed resistance. The length of separation determines the remaining area of bed over which skin friction is applied and therefore the relative importance of the resistance components. Engel (1981) has presented a discussion of the practical significance of the length of separation.

Progress has been made in the analytical description of these flow characteristics (e.g. McLean and Smith, 1986; Mendoza-Cabrales, 1987; Mendoza and Shen, 1990) and will be further advanced by continuing developments in computational fluid dynamics. Experimental and field measurements are also necessary, however, for validation and calibration of the analytical models and for improving our understanding of the underlying physical processes. Various experimental studies have been reported. Laursenet al. (1962) measured distributions of velocity, pressure and boundary shear stress for air flow over triangular bed forms in a closed conduit. Raudkivi (1963) measured these characteristics as well as turbulence intensity for flow over a stabilised, natural ripple. Vanoni and Hwang (1967) measured velocity and pressure distributions over a stabilised ripple bed. Rifai and Smith (1971) conducted experiments with flow over a train of two-dimensional, smooth, triangular bed elements. On the basis of their measurements of velocity and turbulence intensity, they concluded that flow *over* triangular bed elements reproduces the essential characteristics of flow over alluvial dunes. Jonys (1973) measured pressure distributions and velocity profiles, from which he inferred boundary shear stresses, over naturally developed, unstabilised dunes. Vittal etal. (1977) conducted experiments on the flow of both water and air over a train of two-dimensional triangular bed elements. They used a fixed element height and a range of element lengths to study the effects of varying upstream slope on pressure and boundary shear stress distributions. They also examined the effects of surface roughness by coating the elements with sand grains for some experiments. Fehlman (1985) measured velocity, pressure and boundary shear stress distributions over smooth and roughened triangular bed elements with different flow conditions and a constant geometry.

Most experimental investigations of separation length have been conducted on downstream-facing vertical steps (e.g. Walker, 1961, Tani, 1957, Etheridge and Kemp, 1979). Chang (1970) used an iron angle section rather than a step. Raudkivi (1963; 1976) reports results for separation behind a stabilised ripple. Karahan and Peterson (1980) used streaming bi-refringence (the interpretation of velocity gradients from transmitted light interference patterns) to measure separation lengths for smooth dune-shaped beds with a constant geometry and for a range of flow conditions. Engel (1981) conducted a comprehensive set of tests on a downstream-facing vertical step and a train of idealised triangular dunes with different geometries and roughnesses. He produced a graphical predictor of the separation length as a function of dune height, length and sediment median grain size, based on his experimental results.

The experimental study reported here was carried out to extend the range of conditions investigated previously. Engel's (1981)

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