Suction Removal of Sediment from between Armor Blocks

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ABSTRACT: This paper presents the results of an experimental investigation on suction removal of sediment from between armor blocks/stones placed on a loose bed. The process of suction has been investigated. It was found that the vortices that form in the holes between the armor blocks are key to the process. The sediment swept into these vortices is entrained into the main body of the flow by these same vortices (the suction removal of sediment from between the armor blocks). The critical condition for the onset of suction was determined. It was found that the onset of suction is governed by two parameters: (1) the Shields parameter (based on the sediment size); and (2) the ratio of sediment size to stone size, d/D. The variation of the critical Shields parameter for suction as a function of d/D was determined for a broad range of the parameter d/D, namely, 0.001 ≤ d/D ≤ 1. The timescale of the suction process and the downward displacement of stones (the general lowering of the armor layer) have also been investigated.

INTRODUCTION

One of the methods widely used for scour protection is rock dumping on a sand bed. When such a rock layer (armor layer) is exposed to a steady current, the sand underneath will be agitated by the flow turbulence. When the flow velocity reaches values larger than a critical value, the sand will be sucked from between the armor blocks (Fig. 1). This will cause the armor blocks to “sink,” leading to a general lowering of the armor layer. The armor blocks need to be designed such that the suction of sand and the resulting “sinking” of the blocks is not very extensive. (The term suction is adopted here instead of entrainment, because the latter term is often used in the literature to stand for the incipient motion.)

The interaction between an armor layer and the base sediment bed has been the subject of a great many investigations. Raudkivi and Ettema (1982) focused on the stability of the armor layer itself. In a follow-up study, Raudkivi and Ettema (1985) concentrated on scour around a cylindrical bridge pier in a sediment bed with an armor layer of coarser sediment. Worman (1989) was concerned with the initiation of erosion of the base sediment bed underneath an armor layer used as a protection measure around a bridge pier. Subsequently, Worman (1992) has investigated the incipient motion of the base sediment covered by an armor layer with different coverage ratios.

The so-called armoring process in rivers (the process by which the finer particles are winnowed out and the bed surface coarsens) is also relevant to the process of the interaction between the armor layer and the base sediment bed. A recent review on armoring can be found in Raudkivi (1998, p. 99).

To prevent the finer base material from washing out, filters are frequently used in protection works. In this case, there are usually at least three layers of materials: (1) top armor layer; (2) filter layer (with much smaller particle size); and (3) base sediment bed. One of the key concerns here is to ensure the stability of the base material against flow through the filter layer (de Graauw et al. 1984; Brauns et al. 1993). Bakker et al. (1994) [see also Bezuiven et al. (1987)] have developed a semiempirical theory describing the critical condition for the instability of the base material.

Although quite a substantial amount of knowledge has accumulated on the interaction between an armor layer and the base sediment bed over the past years, no study is yet available investigating the process of suction removal of the base material from between the armor blocks. Although the base sediment bed becomes unstable when the incipient condition is reached, the sediment (although in motion) may be trapped in the holes between the armor blocks, leading to insignificant sediment transport. With the suction of the sediment from the base sediment bed, the sediment will be carried away from the bed in large quantities, and this will obviously have serious implications for the armor layer.

The suspension of sediment in boundary layers from a rigid/sediment bed has been investigated extensively in the past. The mechanism of suspension has been shown to be linked to the turbulent bursting process [i.e., Grass (1983), Sumer and Oğuz (1978), Sumer and Deigaard (1981), Sumer (1986), Dyer and Soulsby (1988), and Nino and Garcia (1996)]. Basically, the low-speed wall streaks/zones act as the “source” of sediment in the process of suspension from the bed; the sediment swept into these zones is eventually put into the flow by the entrainment of these flow structures. Although the mechanisms are different, there are similarities between the process of suspension in boundary layers and the process of suction from between the armor blocks. The vortices forming in the holes between the armor blocks are, in the present case, the mechanism responsible for transporting the sediment away from the bed, as will be detailed in this paper.

The purpose of the present investigation is to study the process of suction from a base sediment bed covered by an armor layer. The study focuses on the mechanism responsible for the suction process, critical conditions for sediment suction, and implications for the armor layer.

EXPERIMENTAL SETUP

The experiments were carried out in a water flume, 0.6 m wide, 0.8 m deep, and 28 m long. The current was achieved by recirculating water in the flume (Fig. 2).

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