Available online at www.sciencedirect.com
ScienceDirect
International Journal of Sediment Research 28 (2013) 210-219
INTERNATIONAL JOURNAL OF SEDIMENT RESEARCH
www.elsevier.com/locate/ijsrc

Study of deposition of fine sediment within the pores of a coarse sediment bed stream

N.K. KHULLAR[1], U.C. KOTHYARI[2], and K.G. Ranga RAJU[3]

Abstract

Elaborate experiments were performed in a 30 m long, 0.5 m deep and 0.2 m wide laboratory flume to study the process of infiltration of fine sediment into the pores of coarse sediment forming the channel bed material. Different concentrations of suspended load of fine sediment of size 0.064 mm were passed over the channel bed made up of three different types of coarse sediments; two uniform and one nonuniform. The proportion of fine sediment infiltrated into the pores of bed material for each equilibrium concentration of suspended load of fine sediment in the flow was studied during several experimental runs. The proportion of fine sediment within the pores of bed material increased with an increase in the equilibrium concentration of suspended load of fine sediment in the flow. This process continued till the pores within the coarse sediment bed were filled up to the capacity with the fine sediment transported by the flow in suspension. The theoretical value was identified for limit for maximum proportion of fine sediment that can be present within the pores of bed material. On further increase in the concentration of suspended load of fine sediment in the flow, deposition of fine sediment occurs on the surface of the flume bed in the form of ripples of the fine sediment. This condition is defined as `depositional condition'. Experimental observations on these and related aspects are presented herein.

Key Words: Fine sediment, Flume experiment, Bed material, Concentration of suspended sediment, Deposition condition

1 Introduction

During the periods of heavy rainfall, the fine sediment eroded from catchment area reaches upto the river and flows in suspension with the river flow. Some of the particles of fine sediments reaching the river bed, are retained within the pores of the river bed due to sheltering by coarse sediment particles forming the river bed. This process of deposition of suspended fine sediments within the pores of coarse sediment of river bed material continues till the rate of entrainment of deposited fine sediment (which also occurs simultaneously with the deposition) from the bed becomes equal to the rate of its deposition.

The presence of excessive amount of fines in the stream bed could adversely affect the spawning of salmon and other species of fish and is critical for assessing the biologic and economic impacts from upstream anthropogenic and natural fine sediment releases into rivers (Einstein, 1968; ASCE task committee, 1992; Diplas and Parker, 1992 and Wooster et al., 2008) It has been observed by several investigators that fines infiltrate and deposit within the pores of the coarse stream bed over a definite top thickness of the coarse bed termed herein as the active bed layer. As more fines are added they saturate the active bed layer of the coarse bed and start appearing on the stream surface layer. Subsequent clear-water flows over such beds result in entrainment of fines from the pores of the active bed layer.

Einstein (1968). studied the process of deposition or infiltration of fines in suspension into the pores of the gravel bed for the purpose of design of artificial spawning grounds for anadromous fish and found that fine particles intrude into the pores of the coarse bed during their routing through the coarse bed streams. He further found that the rate of infiltration/deposition was proportional to the local concentration of sediment in the flow. Sowers and Sowers (1970) found that the fine soil particles in flow infiltrate into coarse stream bed and the mode of deposition of these fines is mainly controlled by the relative size of settling fines and the voids of the gravel bed. According to Milhous (1973), a surface bed layer called pavement layer exists in gravel bed streams. This layer acts as a sink for the suspended sediment, which tends to deposit between the bottom of the pavement and the top of the subsurface called the silt reservoir. Alonso et al. (1988) studied the deposition of fines in coarse gravel matrices and observed that the proportion

[1] Prof., Dr., Department of Civil Engineering, PAU Ludhiana-India, E-mail: khulrdce@rediffmail.com
[2] Prof., Dr., Department of Civil Engineering, IIT Roorkee-India, E-mail: umeshfce@iitr.ernet.in
[3] Formerly Prof., Dr., Department of Civil Engineering, IIT Roorkee-India, E-mail: kgrarfce@iitr.ernet.in
Note: The original manuscript of this paper was received in Oct. 2011. The revised version was received in Oct. 2012. Discussion open until June 2014.

of fines in the bed was directly related to concentration of suspended sediment in the flow. Jobson and Carey (1989) pointed out that alluvial streams can extract fine sediment from flow and store them in their bed when the incoming concentrations are high and release the sediment to the flow when the incoming concentrations are low. The mechanism of storage in the stream bed depends upon the relative size distribution of the suspended sediment particles and bed material, as well as the flow hydraulics. Diplas and Parker (1992) conducted experiments for modeling gravel-bed-streams and to study the deposition of fines into and their releases from the bed using silica flour having d_{50} of 0.08 mm and 0.11 mm as fines. As soon as the fines were introduced into the channel they started to deposit on the bed and infiltrating below its surface. According to Diplas and Parker (1992) the fines infiltrated into the bed and created a seal that prevented any deeper penetration of fines. The depth of infiltration depended on the difference in size between the penetrating grains and the coarser bed material and the dimensionless boundary shear stress. Both type of fines used created a seal within the substrate which was deeper for fines of size 0.08 mm and shallower for the other sizes. The seal was more in depth in the areas of higher dimensionless shear stress. According to Diplas and Parker (1992) the amount of fines deposited in the bed depends on the dimensionless boundary shear stress, the fall velocity of fines, the particle Reynolds number and the mean flow concentration of fines. Huang and Garcia (2000) stated that the process of extraction of fine sediment from flow when incoming concentrations are high would be greatly affected by the composition of the bed material. A detailed review of this process has also been reported by Diplas and Parker (1992) and Khullar (2007).

Cui et al. (2008) developed a theory that describes the processes of fine sediment infiltration into the gravel bed. As per this theory, the highest possible fine sediment fraction resulting from fine sediment infiltrating an immobile clean gravel deposit is an exponential decay function with depth and thus implying that significant fine sediment infiltration occurs only to a limited depth. A better understanding of the mechanisms of fine sediment infiltration into gravel-bedded channels is therefore, becoming increasingly important.

Basile et al. (2010) illustrated through use of a quasi two dimensional model for routing of the sediment through a river that suspended sediments are deposited within the bed during their increased concentration in the flow and are entrained from the bed during the clear water flow. Lu et al. (2010) used a 2 dimensional mathematical model to predict the space-time changes of the deposition/erosion process due to construction of hydro power projects over river such as Three Gorges Project. Their study shows that severe deposition occurs within bays and concave bank lines without upstream reservoir and small deposition occur within the reservoir.

It has also been observed that fine sediments infiltrate and deposit within the pores of the stream bed over a definite top thickness of the coarse sediment forming the bed material which is termed herein as the active bed layer. Kumar (1988) and Rahuel et al. (1989) considered the active layer thickness to be a function of flow depth whereas Borah et al. (1982), Parker (1990) and Correia (1992) considered it to be a function of particle size. The former appears appropriate for a dune-bed (because the height of the dune is related to the flow depth) and the latter for a flat bed. Khullar (2003) proposed that the thickness of active bed layer is a function of depth of flow, ratio of critical shear stress, total shear stress and the d_{50} of the bed material.

The review presented herein indicated that rate and mode of deposition of the fine sediment is intimately connected with the near-bed concentration of suspended load of fine sediment in flow, relative size of fine sediment, the bed material characteristics and the bed shear stress. There is however paucity of data on process of deposition of fine sediments within the pores of the coarse sediment during the flow of suspended load of fine sediment through a coarse sediment bed stream. Results of an experimental investigation on this process are presented herein.

2 Experimental set-up and procedure

The experiments were performed in a re-circulating tilting flume having width = 0.204 m, depth = 0.5 m and length = 30 m. The flow to the flume was re-circulated by using a centrifugal pump located just on the downstream of the tank that collected the out flow from the flume. The characteristics of the sediment used in the present experiments are given in Table 1. The sediment bed of about 10 cm thickness was prepared for experimentation by spreading the desired sediment on the surface of flume bed.

Table 1 Characteristics of sediments used for experimentation

Sediment designation	d_a (mm)	d_{50} (mm)	d_{65} (mm)	σ_g	M_k	R
1*U*	1.794	1.8	1.9	1.15	0.806	28.125
2*U*	1.03	0.96	1.2	1.3	0.744	15
M	2.73	2.1	3.15	2.25	0.31	32.81
W	-	0.064	-	-	-	1

Here d_a =arithmetic mean size of sediment, d_{50} = particle size such that 50 % of particles are finer than this size by weight, d_{65} = particle size such that 65 % of particles are finer than this size by weight, σ_g = geometric standard deviation, M_k = Kramer's coefficient of uniformity. R is the ratio of d_{50} of coarse sediment in bed to the size of fine sediment used.