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Computation of Transport Capacity of Wash Load in Alluvial Channels at Limiting Stage

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Abstract : For a given hydraulic condition, every channel has a capacity to carry given fine sediment in suspension without their deposition on the bed. This capacity of the channel is termed as limiting capacity of fine sediment transport. This limiting capacity of fine sediment can be computed by Arora et al (1984) method. Khullar et al (2010) has found that fine sediment during their transport through coarse bed stream interact with the bed material and their proportion in the active layer of bed material goes on increasing with increase in concentration of fines in the flow. At limit depositon condition the bed active bed layer will have a definite proportion of fine material. Khullar et al has proposed a method for computing the suspended load transport in an alluvial stream provided the composition of bed material is known. Methods of Arora et al and Khullar et al have been used to find the limiting transport rate of particular fine sediment in an alluvial channel for different assumed hydraulic conditions and the results are compared.

INTRODUCTION

A lot of fine sediment comes into the rivers and streams during the rainy season due to erosion of fines from the catchment due to rainfall and subsequent runoff. Traditionally this fine sediment load is termed as wash load. The limiting capacity of wash load transport in a stream may be defined as the rate at which the stream under given hydraulic condition transports the wash load through it without causing appreciable deposition of the same over the stream bed. In the design of channels it is desired that the wash load entering the channel should not leave any objectionable deposition on the bed as it would reduce the capacity of the channel. If the deposition is excessive, the channel may have to be closed necessitating heavy expenditure on its desilting. Significant deposition took place on the bed and banks of Upper Ganga Canal taking off from river Ganga at Haridwar, near Roorkee in India during the year 1972 due to high incoming sediment load (UPIRI, 1974). Depending on the flow, the fluid, the sediment and the channel characteristics, there exists an upper limit for sustenance of fine sediment in suspension. The concentration of suspended sediments when increased beyond such limit would cause appreciable deposition on the bed. The knowledge about such a limit is very important in the design of channels, sediment extractors, sediment excluders etc.

It was assumed that this wash load does not interact with the bed material and passes through the stream without its deposition on the bed (Garde and Ranga Raju, 2000). Khullar (2002) has found that the fine sediment flowing through a stream having coarse bed material interact with the bed material As soon as the fine sediment reaches near the bed, they are trapped within the pores of the bed material and are sheltered by the coarse particles of the bed material. The proportion of the fines in the bed goes on increasing till the concentration of fines in the flow becomes constant. This happens when the rate of entrainment of fines form the bed material becomes equal to the rate of deposition of the fines into the bed. The proportion of fines in the bed is intimately related to the concentration of fine sediment in the flow for the given hydraulic condition. Khullar

2002 has proposed a theoretical relation to find the proportion of fines at limit deposition state of deposition. As per this relation the theoretical limit for fines in a coarse bed stream is given by

$$p_{\max} = \frac{p_p(1 - p_w)}{(1-p_p)+p_p(1-p_w)} \quad (1)$$

Where p_p is the porosity of the porous bed and p_w be the porosity of the fine material and p_{max} is maximum possible per cent of fine material in bed.

Khullar (2006) analyzed and tested methods of Bagnold (1966), Itakura and Kishi (1980), Arora *et al.* (1984), Westrich and Juraschek (1985), Wiuff (1985), Celik and Rodi (1991) and Nalluri and Spaliviero (1998) for finding the limiting transport capacity of channels and found that Arora et al (1984) method can be used for finding the limiting capacity of wash load transport in alluvial channels.

Khullar et al (2010) has given a method for computing the suspended load transport in an alluvial stream for a given hydraulic condition provided the composition of bed material is known.

From above it is clear that the method of Arora *et al.* (1984) can be used to find the limiting capacity of wash load transport for a given hydraulic condition and the method of Khullar et al (2010) can be used for finding the suspended load transport of fine sediments provided the proportion of fines in the bed layer is known. It is therefore hypothesized that when the pores of the bed material are fully filled by the wash material, the estimates of the wash load transport obtained by using the proposed function for suspended load transport and the method of Arora *et al.* (1984) should be comparable. This hypothesis is tested by assuming a set of hydraulic parameter as discussed below.

TRANSPORT CAPACITY

1). Arora et al (1984) Method

As mentioned above the method of Arora *et al.* (1984) can be used for finding the wash load capacity in alluvial and non alluvial channels. This method is graphical in nature. Khullar (2006) proposed an analytical relation based on this method for finding the concentration of wash load at limiting stage.

The relationships between limiting concentration C and q^* (being defined as , q is discharge per unit width, *í* is kinematic viscosity of water, f is friction factor, w is the fall velocity of wash material, d is size of sediment, D is hydraulic depth, h is depth of flow and S_c is slope parameter given as S is the slope of channel, is the density of water is density of sediment) can be expressed by the following equations:

(i) For 0.43 £ £ 2.0 (2)

(ii) For 2.0 < £ 6.0 (3)

(iii) For 6.0 < £ 63 (4)

These relations have been used to find the limiting capacity of wash load transport in alluvial channels for some hypothetically assumed data given in table 1. The computed transport capacity as per this method is given in table 1.

2). Khullar et al (2010) Method

Theoretical limit of wash material can be computed by using equation 1. Assuming the porosity of the coarse bed material and the wash material as 0.44 the maximum theoretical proportion of fines in the bed layer comes to around 30.5 %. So theoretically speaking the limit state of deposition will be arrived when the proportion of fines in the bed layer corresponds to around 30 %. The concentration of fines in the flow at this state is termed as limiting concentration of fine sediment transport. Below this limit the fine sediment can flow under different equilibrium conditions.

Method of Khullar et al (2010) as described below can be used to find the suspended load carrying capacity of wash load transport provided the proportion of wash material in the bed layer is known. As per this method the dimensionless transport rate is given by

$$\phi_s = 28\left(\xi_s \frac{\tau_o}{\Delta\gamma_s\, d_i}\right)^6 \tag{5}$$

Where is a correction factor called sheltering-cum-exposure-cum-interference coefficient, is effective total shear stress, is total shear stress, is the submerged unit weight of sediment and d_i is the size of the sediment fraction considered. The value of can be computed by using the following relationship

$$\log\left(\xi_s\left(\frac{\tau_o}{\tau_{oc}}\right)^{0.62}\right) = 0.703 + 0.54\log\left(\frac{d_i}{d_a}\right) + \cdot 0.03\left(\log\left(\frac{d_i}{d_a}\right)\right)^2 + 0.0308\left(\log\left(\frac{d_i}{d_a}\right)\right)^3 \tag{6}$$

Here is the critical shear stress for size as per Shields' criterion, is the arithmetic mean size of the bed material. After determining the dimensionless transport the transport rate of individual size fraction can be computed as

$$i_s\, q_s = \phi_s\, i_b\, \gamma_s \sqrt{\frac{\Delta\gamma_s\; g\, d_i^3}{\gamma_f}} \tag{7}$$

And the total suspended load transport, , can be computed by using

$$q_s = \sum i_s q_s \tag{8}$$

Here is the proportion of fine sediment of size d_i in suspension and is the proportion of size d_i in the bed material, g is acceleration due to gravity, is the unit weight of fluid and is the unit weight of sediment.

Theoretical proportion of wash material in the bed layer can be computed by using equation 1. Assuming the porosity of the coarse bed material and the wash material as 0.44 the maximum theoretical proportion of fines in the bed layer comes to around 30.5 %. So theoretically speaking the limit state of deposition will arrive in the alluvial channel when the proportion of fines in the bed layer corresponds to around 30 %. Below this limit the fine sediment can flow under different equilibrium conditions. The suspended load of wash material is thus computed in the alluvial channel for the assumed hydraulic data given in table 1 at theoretically limiting state. The computed transport rate by this method is given in table 1.

COMPARISON OF LIMITING CAPACITY OF CHANNEL

A graphical comparison of the computed transport by Khullar et al (2010) method and Arora et al is presented in Fig. 1. It was noticed from Fig. 1 that the rates of wash load transport computed by using the above stated methods are comparable to a large extent. It may be noted that the proposed function for suspended load transport based on the concepts of sheltering-cum-exposure-cum-interference that are prevalent in the transport of nonuniform sediments whereas the method of Arora *et al.* (1984) is albeit empirical, but produces realistic estimates of the wash load transport rate. It is therefore satisfying that the results of the two approaches are comparable in practical sense.

Table 1. Assumed Data for Computation of Wash Load Transport at the State of Limit Deposition in a Coarse Bed Alluvial Stream

S. No.	h (m)	U (m/s)	q (m^2/s)	n	$S\times10^4$	F_r	d_i (mm)	i_b	d_a (mm)	τ_o (N/m^2)	h (m)	q_s (Khullar et al method) ($m^3/m/s$)	q_s (Arora et al method) ($m^3/m/s$)
1	3.58	1.3	4.65	0.018	1.0	0.22	0.065	30	3	9.31	3.58	0.00311	0.006349
2	5.17	1.3	6.72	0.023	1.0	0.18	0.065	30	1	13.44	5.17	0.008425	0.005365
3	1.07	1.3	1.39	0.018	5.0	0.40	0.065	30	3	13.91	1.07	0.007783	0.012956
4	1.55	1.3	2.01	0.023	5.0	0.33	0.065	30	2	20.10	1.55	0.020586	0.014633
5	6.02	1.3	7.83	0.018	5.0	0.17	0.065	30	3	7.82	6.02	0.002095	0.002717
6	6.11	1.3	7.95	0.023	8.0	0.17	0.065	30	2	12.71	6.11	0.007243	0.019651
7	3.51	1.4	4.92	0.0165	1.0	0.24	0.065	30	5	9.13	3.51	0.002157	0.000896
8	2.02	1	2.02	0.016	1.0	0.22	0.065	30	4	5.26	2.02	0.000723	0.000937
9	0.73	1.3	0.95	0.014	5.0	0.48	0.065	30	1.8	9.54	0.73	0.003842	0.010952
10	0.42	0.9	0.38	0.014	5.0	0.44	0.065	30	1.6	5.50	0.42	0.001108	0.0018
11	0.51	1	0.51	0.018	8.0	0.45	0.065	30	1.4	10.56	0.51	0.004946	0.003795
12	0.82	1.3	1.06	0.019	8.0	0.46	0.065	30	2.5	16.97	0.82	0.013164	0.012998
13	1.44	1	1.44	0.018	2.0	0.27	0.065	30	2	7.47	1.44	0.002153	0.001817
14	1.27	1.1	1.40	0.0185	3.0	0.31	0.065	30	2.3	9.93	1.27	0.003984	0.004828
15	1.19	1.15	1.37	0.0195	4.0	0.34	0.065	30	2.6	12.35	1.19	0.006284	0.006921
16	1.11	1.2	1.33	0.02	5.0	0.36	0.065	30	2.9	14.45	1.11	0.008616	0.009223
17	0.99	1.25	1.24	0.0195	6.0	0.40	0.065	30	3.2	15.48	0.99	0.009628	0.011344
18	0.97	1.3	1.27	0.02	7.0	0.42	0.065	30	3.4	17.73	0.97	0.012703	0.013689
19	0.95	1.3	1.23	0.021	8.0	0.43	0.065	30	3.6	19.72	0.95	0.015689	0.013994

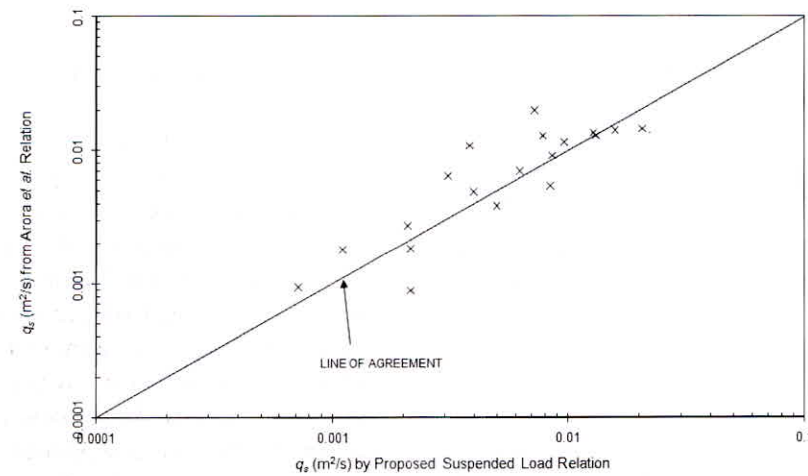

Fig. 1. Comparison of suspended load transport rate at state of limit deposition computed by Khullar et al (2010) method and Arora et al (1984) method.

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