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Computation of Critical Shear Stress for Non-Uniform Sediment

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Abstract: ***Civil engineers associated with water resources development come across various kinds of problems related to alluvial rivers and channels like Floods, Meandering and Flood Control, Sediment Load Computation, Silting of Reservoir, erosion etc.***

To define incipient motion condition is very critical process and is of prime important for design any hydraulic structure. Many investigators study the critical shear stress at incipient condition. For uniform as well as non-uniform sediments. Many came up with the formulae to describe the incipient condition still there is a scope to study these parameters. In this present study, the incipient motion conditions. for non-uniform sediment is tried to compute based on various parameters with the help of experimentation.

Experiments on critical shear stress and bed load transport of different fractions for non-uniform sediment are reported in this study.

Study of hydraulic parameter such as depth, velocity, discharge, sediment characteristics etc. were investigated with the help of experiments. Experiments were conducted in a 10-meter-long, 0.30-meter-wide and 0.45-meter-deep tilting flume in P.G Hydraulic Lab of BV(DU) College of Engineering, Pune.

The results were obtained, analysed and conclusion were made.

Index Terms: Keywords: Critical Shear Stress, Non-Uniform sediment, Steady Flow, Critical Tractive Stress.

I. INTRODUCTION

A. *Introduction*

Incipient motion in alluvial channel treated as the beginning of the movement of sediment particles from the channel in response to excessive flow that induced shear stress which has a certain critical value. Knowledge on entrainment of sediment particles is significantly important in the study of sediment transport problems like design of stable channel, sedimentation etc.

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knowledge of degradation, erosion, aggradation may lead to safe design of any hydraulic structure. Judgment of entrainment of sediment particles in alluvial channel is important as it involves parameter identification influencing incipient motion and accordingly formulation developed for determination of critical shear stress and further it will be applicable in modelling aspect in sediment transport.

Generally, study of incipient motion carries in two parts i.e. one corresponding to uniform sediment and other for non-uniform sediment. Uniform sediment involves single sediment size having well graded while nonuniform sediment involves mixture of two or more different size particles. Obviously, study on nonuniform sediment is much more complex than that of uniform sediment corresponding to incipient motion. Various studies have been conducted on incipient motion for uniform and non-uniform cohesion less sediments. Practically sediment transport phenomenon is very difficult to understand. River are carrying tonne's of sediment depositing and eroding the banks at many places. In Ganga river total annual load at Calcutta (mouth of the river) was calculated as 411 · 106 t Erosion rate (549 t km−2 yr.−1) is among the highest in this river system.

B. Sediment transport principles

It depends on the balance of gravitational forces acting in order to set the particles in a roof, and drag forces acting either to suspend them in the flow or to shove them downstream. The sediment canal can be traveled and transported by channel. The rock surrounding the drainage reservoirs is the ultimate origin of the sediment. Until a fragment of the height that can be carried out from the basin is broken or weathered, the sediment yield is small. Weathering rock is called the chemical and physical mechanisms producing soil and sediment from procedures. Rock is called weathering. The product can be easily carried silts, clay, sands or cobbles or rocks, depending on the type of rock and the type of weathering method.

If sediments from the slopes of the mountain are not supplied straight to a channel, they may accumulate in a college deposit at the foundation. The sediment obtained straight from the hillside can be stored momentarily at the base of the slope, and so the movement of sediments does not necessarily take place straight across the stream system once it is set into action. Still then, it can be stored in the flutter, bed or stream bank for a while before moving out of the drainage system. It is possible for this reason. Thus, sediments from a drainage basin are constantly exported but a single grain of sediments may be loaded and eroded several times before they leave the system.

C.Nature of sediment problem

Civil engineers associated with water resources development come across various types of problems related to alluvial rivers and channels.

Some of these important parameters are briefly discussed below-Land Erosion and Soil Conversation

1. Floods, Meandering and Flood Control
2. Sediment Load Computation
3. Silting of Reservoir
4. Degradation, Aggradation and Local Scour
5. Stable Channel Design
6. Silt Excluder and Silt Extractor
7. Navigation
8. Miscellaneous

D.Incipient motion condition

If a slope and a movable bed slope consist of an uniform and non-cohesive material are flowed through an open channel. Experiments in the channel were performed under constant uniform bed circumstances. The materials consisting of the bed are discovered to be fixed for tiny dumps. This flow is the same over an attached bed. However, when the release is increased by some value, it will be discovered that the individual particles have random movement on the bed. In other words, the flow condition of sand particles only begins to move. It is recognized as a critical condition of sedimentary particles or as their incipient movement. For example, depending on the choice of the criterion, condition for incipient motion can be any one of the following

I. A single particle moving;

II. A few particles moving;

III. General motion on the bed;

IV. Limiting condition when the rate of sediment transport tends to zero.

The knowledge of the hydraulic conditions at which sediment particles of a known size just start moving is of considerable importance to hydraulic engineers. The permissible slope (or depth) for stable channels carrying clear water and flowing through coarse granular material is determined from the condition that for the given discharge, the (or depth) must be such that the material on the bed and sides does not move. Similarly, in the computation of the sediment load that's move along the bed, hydraulic conditions for incipient motion are important. They are also of use in studying the mechanism of deposition in reservoirs, surface erosion and in study river bed variation. From a theoretical point of view the conditions for incipient motion are of great significance, because these conditions are associated with the equilibrium of various forces acting on the individual particles. When the material comprising, the bed is coarse and non-cohesive, it is mainly the submerged weight of the sediment particle that resists the motion. The coarse particles move as single entities. However, when the material is fine and contains silts and clays, cohesive forces are predominant and they resist motion Three different approaches have been used to establish the condition for incipient motion of sediment particles comprising bed. These are described as: i) Competency: Here the size of the bed material d is related to either bed velocity (or bottom bed) or mean velocity of flow, which just causes the particle to move. ii) Lift concept: In the case it is assumed that when the upward force due to the flow (i.e. lift) is just greater than the submerged weight of the particle, the condition of incipient motion is established. iii) Critical tractive force approach: This approach is based on the idea that the tractive force exerted by the flowing water on the channel bed in the direction of flow is mainly responsible for the motion of the sedimentary particles.

II. LITERATURE REVIEW

The study of incipient motion condition is very important for many problems related to hydraulic engineering such as design of stable channel, bridges, canals, problems associated with degradation, aggradations, changes in plan form of river etc. To study incipient motion condition critical tractive stress approach is more rational. This systematic approach was first introduced by Shields (1936) [1]. He analyzed the equilibrium condition of a particle lying on bed, composed of uniform material. He emphasized that critical shear stress is mainly a function of a Reynold's number of a particle at initiation of motion. Further study was carried out by White (1940)[2], Iwagaki (1948)[3], Egiazaroff (1965)[4]Yalin and Kurihara (1979)[5] but this study was based on the forces acting on the single particle and most common thing was uniformity of sediment. Many more investigators studied the critical tractive stress for uniform sediment.

The aspect of shielding effect was studied by Wilberg and Smith (1987) , Parker et.al. (1990) [6],

Many investigators have concluded that the critical shear stress is a function of sediment size but at the same time there is influence of bed slope as well. Few of them considered bed slope also such as Neill (1967) [7] showed that critical shear stress increases as channel slope increases. Later experimental and field studies were carried out by Ashida and Bayazit (1973) , Mueller et.al. (2005) Schvidchenko et.al. (2000-2001) [8] and indicated that motion is slope dependent even on low slopes ($S< 0.01$) and for small size particles ($Re < 102$). Shield stress is applicable for lowland rivers as well as steep mountainous rivers. Chiew and Parker (1994), Lamb et.al. (2008) [9] carried out studies of critical shear stress on non-horizontal slopes of bed. Rakesh Kumar (2017) [10] is recently study on incipient motion condition for non-uniform sediment condition and Many investigators have studied incipient motion condition for uniform as well as for non-uniform sediment

All the investigators till now presented the critical tractive stress as a function of sediment characteristics such as their mean diameter, its standard deviation etc. Previously less emphasize was given on the channel bed slope as a influencing factor on critical shear stress. The present study is to carry out the effect of channel bed slope on the initiation of the motion for non-uniform sediment in unobstructed flow.

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III. EXPERIMENTAL SET UP AND METHODOLOGY

A.Experimental setup

The experiments were carried out in Post Graduate Hydraulic Laboratory of Bharati Vidyapeeth Deemed University College of Engineering, Pune.

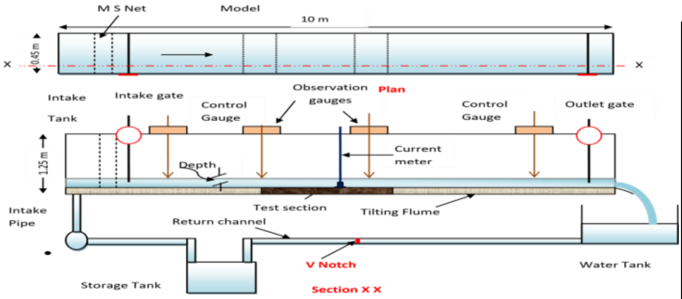
Experiments were conducted in 10-meter-long, 0.30-meter-wide and 0.45-meter-deep flume. The recirculating flow system was served by a 50hp, pump which is locate at the downstream end of the flume are variable speed and centrifugal.
The flume used which is having the minimum slope of 0.001 and maximum slope of 0.003. The average slope is considered from field studies. The flume slope will be adjusted as per the requirement throughout the experiments. Test section of size 1.0-meterlong, 0.75-meter-wide and 0.10-meter- will be provided in the flume for laying the sediment sample.

B. The study parameters

The following range of hydraulic and other parameters were used for the model studies.

1. slope: 0.001 and .003
2. The discharge range: The discharge was kept changing as per the requirement of experiment and corresponding to the water depths. The requirement of the experiment was to get the velocities from lower to higher values. Accordingly, the discharge was varied for each run of experiment for each model the discharge varies between 0.00284 m^3/sec to 0.01550 m3/sec.
3. The scale of model decided 1:20 tentatively.
4. Depth of flow: Water level was kept accordingly 10cm -15cm in correspondence with the field experience.
5. Velocity: Velocity of flow measured by current meter and the observed minimum and maximum velocity in between 0.1 m/sec to 0.35 m/sec.

C. Sketch for experimental set up



D.Experimental procedure

Following procedure is adopted while conducting experimentation in hydraulic lab

1. It was placed on a predetermined path and filled with the necessary combination of sediments.
2. At first very small release into the flume was permitted so that the sediment bed was saturated completely. Then the discharge was augmented by increments and the tail portal adjustment maintained uniform flow each time.
3. As soon as the critical condition was observed by the movement of a small number of particles of the necessary sediment size, discharge (Q) and associated uniform flow depth (d) were noted.
4. The sample of moved sediment was collected at the end of the flume.
5. The size distribution for the transported material will be carried out for all the cases.
6. The experiments will be repeated for different discharges and at different slopes.
7. The results were tabulated and analyzed accordingly.

Conclusions were based on the analysis of experimental data by a 5hp, variable-speed, centrifugal pump located at the downstream end of the flume.

IV. RESULT AND DISCUSSION

The following formulas are used to calculate parameters for the use of experimental information, for example critical shears
As per Egiazaroff the dimensionless critical shear stress for any size di.

$$\tau^{*}ci = \frac{0.10}{(\log 19di/da)^2}$$

According to Hayashi the value of Ƭ*ca is computed as follows.

$$\frac{\tau^{*}ci}{\tau^{*}ca} = \frac{da}{di} \quad \text{,for di/da < 1.0}$$

$$\frac{\tau^{*}ci}{\tau^{*}ca} = \left(\frac{\log(8)}{\log(8di/da)}\right)^2, \quad \text{for di/da>1.0}$$

The observed data is tabulated and analysed for further study.

Table No.1- The following table contains experimental parameters.

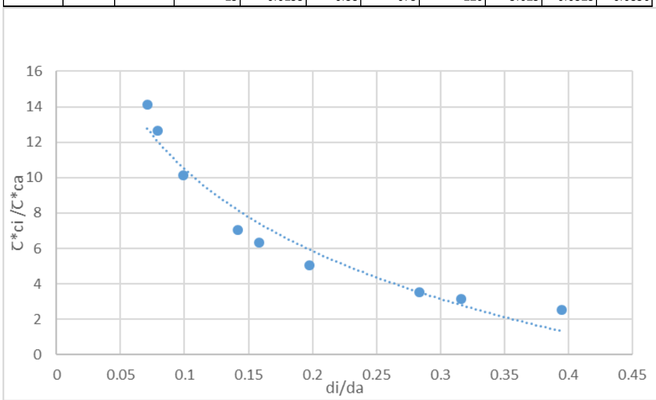
Run No.	Sample	Depth (cm)	Slope	Velocity (m/sec)	Discharge (m^3/sec)	Sediment (Kg)
1	1	8	0.001	0.08	0.00284	1.572
2			0.003	0.14	0.00328	1.811
3		12	0.001	0.11	0.00524	2.629
4			0.003	0.24	0.00839	1.620
5		15	0.001	0.28	0.01268	1.928
6			0.003	0.35	0.01550	2.888
7	2	8	0.001	0.09	0.00284	1.569
8			0.003	0.15	0.00328	1.567
9		12	0.001	0.1	0.00524	2.269
10			0.003	0.23	0.00839	1.702
11		15	0.001	0.27	0.01268	2.018
12			0.003	0.34	0.01550	2.598
13	3	8	0.001	0.11	0.00284	1.629
14			0.003	0.17	0.00328	1.970
15		12	0.001	0.09	0.00524	2.393
16			0.003	0.22	0.00839	1.823
17		15	0.001	0.26	0.01268	1.993
18			0.003	0.33	0.01550	2.769

Table No.2 – The following table contains observed and calculated data in present study.

Sr. No	σg	da	di	di/da	Ʈ*ci	Ʈ*ca	Ʈ*ci /Ʈ*ca
1	2.41	1.5192	4.75	3.127	0.00626	0.0150	0.4172
2	2.75	2.1184	3.28	2.242	0.01216	0.0234	0.5188
3	3.07	1.8966	2.28	2.504	0.00975	0.0203	0.4812
4			1.18	2.159	0.01312	0.0246	0.5327
5			0.6	1.548	0.02551	0.0374	0.6827
6			0.3	1.729	0.02045	0.0326	0.6265
7			0.15	1.501	0.02715	0.0388	0.7000
8				1.076	0.05279	0.0566	0.9329
9				1.202	0.04232	0.0501	0.8439
10				0.777	0.10137	0.0787	1.2875
11				0.557	0.19710	0.1098	1.7953
12				0.622	0.15798	0.0983	1.6073
13				0.395	0.39206	0.1548	2.5320
14				0.283	0.76232	0.2159	3.5307
15				0.316	0.61105	0.1933	3.1610
16				0.197	1.56824	0.3097	5.0640
17				0.142	3.04930	0.4318	7.0613
18				0.158	2.44419	0.3866	6.3220
19				0.099	6.27298	0.6194	10.1280
20				0.071	12.19719	0.8637	14.1227
21				0.079	9.77677	0.7732	12.6440

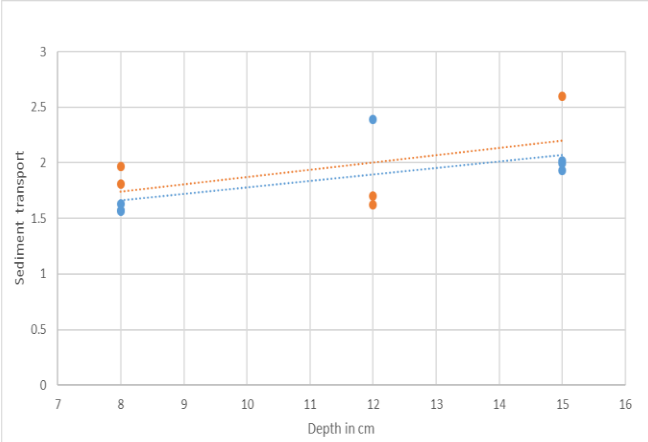
Table No.3 – The following table contains variation of Shear stress of sediments with bed slope

Sample No	σ_g	Slope	Depth (cm)	Discharge (m3/sec)	Velocity (m/sec)	Area (cm²)	Perimeter (cm)	R (cm)	Sf	Ʈo
1	2.41	0.001	8	0.0028	0.08	360	106	3.396	0.0188	0.0499
			12	0.0052	0.11	540	114	4.737	0.0197	0.0523
			15	0.0127	0.28	675	120	5.625	0.0298	0.0788
		0.003	8	0.0033	0.14	360	106	3.396	0.0249	0.0660
			12	0.0084	0.24	540	114	4.737	0.0292	0.0773
			15	0.0155	0.35	675	120	5.625	0.0333	0.0882
2	2.75	0.001	8	0.0028	0.09	360	106	3.396	0.0200	0.0529
			12	0.0052	0.1	540	114	4.737	0.0188	0.0499
			15	0.0127	0.27	675	120	5.625	0.0292	0.0774
		0.003	8	0.0033	0.15	360	106	3.396	0.0258	0.0683
			12	0.0084	0.23	540	114	4.737	0.0286	0.0757
			15	0.0155	0.34	675	120	5.625	0.0328	0.0869
3	3.07	0.001	8	0.0028	0.11	360	106	3.396	0.0221	0.0585
			12	0.0052	0.09	540	114	4.737	0.0179	0.0473
			15	0.0127	0.26	675	120	5.625	0.0287	0.0760
		0.003	8	0.0033	0.17	360	106	3.396	0.0274	0.0727
			12	0.0084	0.22	540	114	4.737	0.0279	0.0740
			15	0.0155	0.33	675	120	5.625	0.0323	0.0856



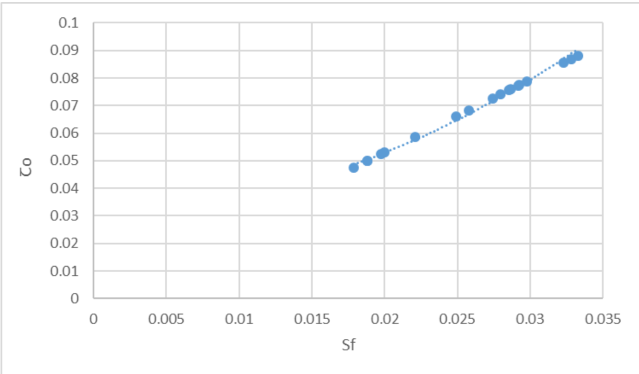
Graph no. 1 – variation of $Ʈ^*$ci /$Ʈ^*$ca vs di/da

The above graph shows the comparison betwee Ʈ*ci /Ʈ*ca vs di/da it present that the increase the value of arithmetic mean divide by any size of sediment is increases the value of Ʈ*ci /Ʈ*ca is also increases.



Graph no. 2 – variation of Sediment vs Depth

The above graph shows the relation between sediment and depth if we increase the depth as well as particle moving capacity is also increase



Graph no. 3 – variation of Ʈo vs Sf

The above graph shows the relation between shear stress and energy slope the result come out from that experiment is increase the slope as well as increase the shear stress of sediment particle.

V. CONCLUSION

Following are the conclusion carried out from experimentation

1) The critical shear stress computed by Hayashi method which is best suited in this present study for the data.
2) Percentage sediment movement is observed as 25% for σg-3.07 .It is the higher than the other two values.
3) It was observed that there is significant effect bed slope on the critical shear stress.
4) It was found that as discharge increase, the sediment movement also increase. Particularly finer particles movement is more for higher discharge .for lower discharges as 0.00284m3/sec the sediment movement was less . it may be due to the shielding or hiding effect . which was described by wilberg and smith (1987)[20], parker(1990)[21]
5) It was observed that the critical shear stress for individual particle is increase as per the ratio of da and di was also increase.

6) The above results shows that sediment transport capacity varies with the value of (σ_g).

A. List of Symbols

di – Any size of sediment in sample .
da – arithmetic mean diameter of sediment.
σ_g – Geometric standard deviation.
Rb – Hydraulic radius with respect to bed.
R – Hydraulic radius.
Sf – energy slope.
Ꞇo- Average shear stress on channel boundary.
Ꞇ*ca- Critical shear stress of arithmetic mean.
Ꞇ*ci- Critical shear stress of individual particles.

REFERENCES

1. shild (1936) analysed equilibrium condition of particle.
2. White(1940),Iwagaki(1948) , Egiazaroff(1965) they were studied uniformity of sediment.
3. Wilberg and smith (1987), and parker (1990) mainly studied the shielding effect.
4. Neil(1967) analysed that the critical shear stress increase as channel slope increase.
5. Cheiw and Parker (1994) carried out studies of critical shear stress.
6. Rakesh kumar (2017) recently studies on incipient motion of non uniform sedimrnt.

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