Establishment Of Velocity Profiles And Shield Curves In Mobile Boundary Channel

Sreenath Mahankali[1]

[1]*M.Tech(Structures), CVR College of Engineering & Tech, Hyderabad*

[1] *mahankalisreenath.m@gmail.com*

Abstract

Open channel flow is a branch of hydraulics is a type of liquid flow with in a conduit with a free surface known as channel. The rate of water flow will be affected by the deposition of the sediments in the channel which refers to incipient motion. The present paper focuses on the incipient motion of sediment particles under shallow flow conditions. Incipient or threshold conditions are established when the flow intensity in a channel is barely enough to entrain the particles in a movable bed. The hydrodynamic forces of the fluid, acting on the particles, are responsible for their motion. In open channel flow, the velocity is not constant with depth. It increases from zero at the invert of the channel to a maximum value close to the water surface. Laboratory experiments are conducted to investigate the effect of low relative depth and high Froude's number on dimensionless critical shear stress (shields parameters).The purpose of this was to study possible changes in velocity distribution with the decreasing relative depth and increasing Froude's number.

Keywords: *Incipient Motion, Open channel flow, Shield Curves,*

I. Introduction

Basically, Fluids are classified as liquids and gases. Out of the two in this paper we are going to study mainly about liquids. Among the liquids, water is the primary resource for many purposes. So, the water can be transported from one place to another place by natural ways like rivers or artificially human constructed conveyance structures like canals and pipes. And these with closed tops can be named as Closed Conduits where as open tops are named as Open Channels. Drinking water mostly carried through Closed Conduits like Pipes (not to entrain outside particles into water and to be safe for drinking) and Irrigation water is carried through Open Channels (may be lined or unlined). The flow in an closed conduits like pipes (having not full) with free surface and open channels are both referred to as Free-Surface flow or Open Channel flow. In this paper, work has done on the Open channel flows by forming a relation between velocity profile distribution and specific energy.

.

2. Velocity Profiles

2.1 Closed Conduits:

All the fluid particles in a flow do not travel with same velocity. Suppose velocity of a particle in the centre of the cross section may not be equal to the velocity of the particle in the edges. Reasons for it may be viscosity, friction; eddy losses etc.., The shape of the velocity curves are different for laminar and turbulent flows. If the flow is laminar then its velocity distribution attains the shape of parabola where as if its turbulent flow, then it has different shape depending upon Reynolds number. Velocity distribution in laminar flow across the cross section varies from minimum at boundaries to maximum at the centre of the pipe as shown in Fig. 2.1.

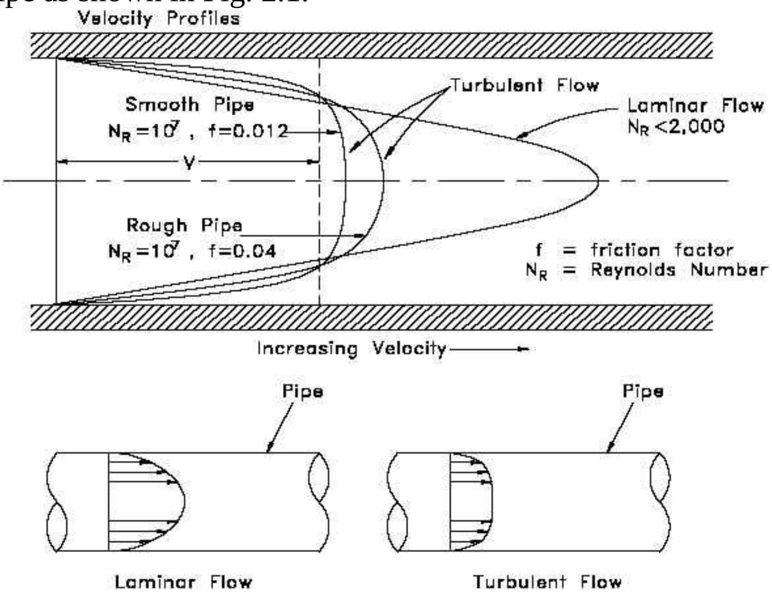

Fig 2.1: Velocity Profiles

2.2: Open Channels:

In open channel flow, the velocity is not constant with depth. It increases from zero at the invert of the channel to a maximum value close to the water surface. The velocity difference results from the resistance to flow at the bottom and sides of the channel. The velocity profile of the open channel flow is shown in Fig 2.2

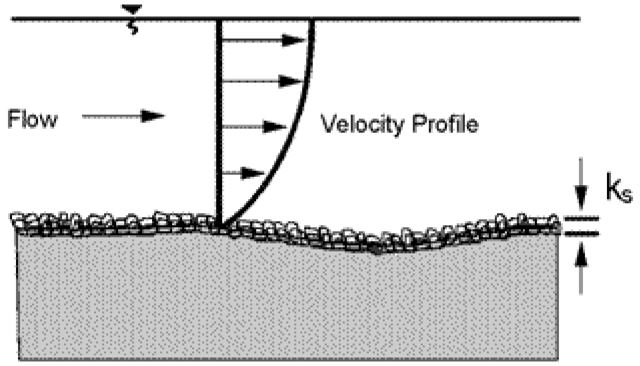

Fig 2.2: Velocity profile in Open channel

3. SHIELD CURVES

The fundamental concept for initiation of motion was introduced by Shield and from that concept, he made a set of observations that have become very popular in the field of fluid mechanics. He deduced relationship between the ration of the bed shear stress and the gravitational force on a particle as function of boundary Reynolds number by using dimensional analysis and fluid mechanics. Based on the best curve fittings to that ratio, the legendary Shields curve was born. Later numerous experiments were carried by many scientists of them Buffington & Montgomery gave a good summary (Buffington & Montgomery, 1997). Buffington also gives a critical analysis of the developments since Shields did his first findings (Buffington, 1999). In fact Shields did not derive a model or an equation, but published his findings as a graph (Figure 3.1). It is inconvenient that the Shields diagram is implicit; the friction velocity appears in both the horizontal and the vertical axis. However with modern computers this should not be any problem.

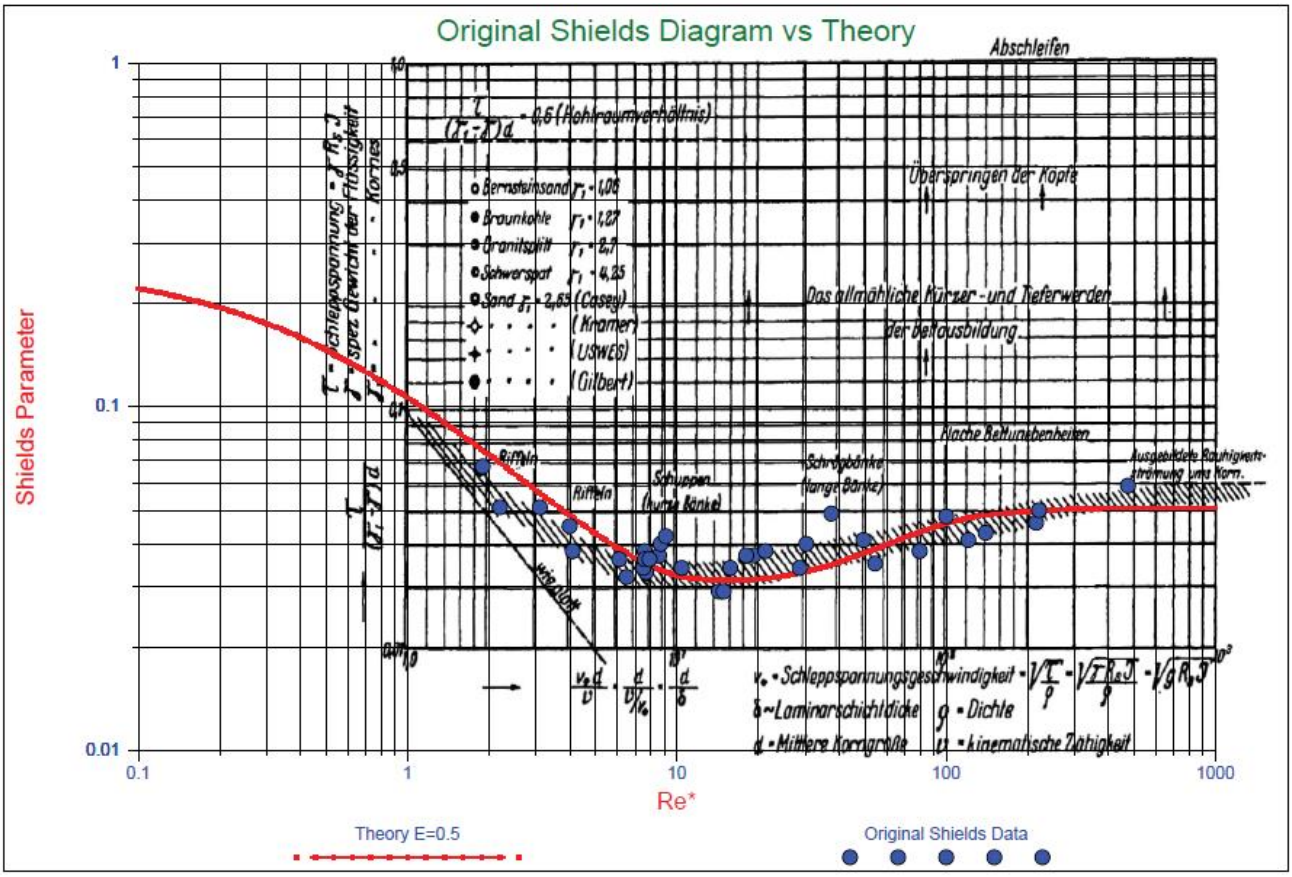

Fig 3.1: The original Shields diagram (Shields, 1936) and the resulting theoretical curve from the research.

4. INCIPIENT MOTION

4.1 INTRODUCTION:

Incipient motion represents the difference between bed stability and bed mobility. Initiation of motion of sediment particles on the bed of an open channel as tractive force of the fluid increases has been the subject of several investigations. It is very important for the canal engineers to see their work function well, means that the alluvial canal or channel should remain under or at incipient motion. The underlying assumption of this assertion of maintaining channel under or at incipient motion is that once the channel undergoes incipient motion and it will remain at incipient motion. Generally, the information of bed slope, water surface slope, discharge and average flow depth over a test section are required to represent the incipient motion condition. The response of an alluvial bed of forcing by a fluid which flows through and over the bed has been the subject of continuous injury for over a century. This phenomenon is at the centre of a wide range of particle and fundamental problems. Literature is replete with such kind of studies. The dynamics of this sediment transported by a water flow is still not completely understood. On the other hand from an engineering point of view a reliable way to predict the incipient motion condition for designed flow condition is required. Different methods are available in the literature for identifying the incipient motion. All these different methods are giving little scatter and according to buffington & Montgomery , this scatter in shield curve is due systematic biasis that investigators should be aware of when choosing and comparing dimensionless critical shear stress values from the literature. All experimental studies of analyzing incipient motion condition involve the immediate collection of the data after setting the laboratory flume under the incipient motion condition. Here, it may be noted that all studies which are found in literature deal with the so called test selection behavior of incipient motion.

4.2 APPROCHES FOR INCIPIENT MOTION PREDICTION:

For turbulent flow the beginning of moment of sediment is not as well defined and no single criterion to define the threshold condition has been universally accepted. Paintal argues that there will always be some probability of grain movement as long as there is any fluid motion; hence the threshold of movement becomes a definitional construct. Many approaches for defining the threshold condition for turbulent flows have been proposed and implemented over the years. Among those the most common method of defining incipient motion are:

1.Extrapolation of bed load transport rates to either zero or low reference value:

2. Visual observation:

3. Development of competence functions:

4. Theoretical calculation:

5. SHIELD CURVE EQUATIONS

5.1 DIFFERENT RELATIONSHIPS PROPOSED FOR SHIELDS SHEAR CONCEPT AT INCIPIENT MOTION

A closer scrutiny of the Shields diagram (in a log-log illustration) shows that the critical Shields parameters θc follows distinct distribution with the Reynolds number R* (Graf 1971; Raudkivi 1976; Yang 1996; Chein and Wan 1999; Yalin and da Silva 2001). In particular, θc declines with increasing R* following a declining straight line in the lower region as R* is smaller than around 2, θc is constant while R* is sufficiently large in the upper region (say R*> 400, Graf 1971), and in the intermediate region, the θc similar to R* curve follows a saddle shape (Chien and 1999). For the lower and upper regions, the determination of θc is quite straightforward with sediment and fluid characteristics, where for the intermediate region, it is inconvenient. Yet for the intermediate region, a lower and upper logarithmic asymptote of θc in relation to R* can be identified, and in between there exists a smooth transition. Since the original publication of shields (1936), the derived (threshold) curve has been extended and has received numerous revisions due to additional data having become available (Miller et al., 1977; Mantz, 1977;Yalin and Karahan, 1979; Buffington and Montgomery 1997). The original Shields data showed considerable scatter and could be interpreted as representing a band rather than a well-defined curve (Bufffington,1999).

Rouse (1931) transformed Shields band into a solid line. Thereafter, a number of empirical threshold curves has been developed (e.g., Chien and Wan, 1983; Hager and Oliveto, 2002; Cao et al., 2006). These empirical threshold curves represent relationship between the critical bottom shear stress and/or shear velocity and sediment characteristics, or between dimensionless parameters incorporating the principal flow and sediment particles. Buffington and Montgomery (1997) present a summary of empirical relationships for directly predicting critical shear stress values. To allow direct computation of the critical velocity (or stress) through the entrainment function (θc), some researchers has proposed using a new parameter called dimensionless grain diameter, which is defined as :

$$d* = \left[\left(g\,\frac{d3}{v2}\right)(Ys - Y)/Y\right]^{\frac{1}{3}}$$

which is commonly used in threshold curves (van Rijn,1993). Liu (1957,1958) developed a dimensionless grouping given by $u*/w_s$, the movability number (as termed by Collins and Rigler,1982) which has been used as an alternative to the shields entrainment function ,where, w_s is the settling velocity of particles. Bonnefille(1963) was an one of the first two present the threshold in terms of d*. chine and wan (1983) modified the shield curves and presented a relationship between θ_c and d* for six subdivided region Rao and Sitaram (1999) developed the relationship based on the principle of velocity relation of turbulent flow. Hager and Oliveto (2002) subdivided the domain of interest into three portions, depending on d*.paphitis (2001) presented a series of sample analytical formulae for the different threshold curves. He which θ_c was plotted against R*.A single curve representing mean threshold values was also presented. A sample analysis was performed with d* instead of R*. He also plotted movability number u^*/w_s as a function of R*and presented analytical formulae describing the single line curve and the limits of the envelops. Cheng(2004) fitted a power function to data of incipient sediment motion in laminar flows, plotted as R* versus d*,with R* varying from 0.02 to 48.8.Cao et al.(2006) developed an explicit formulation of the shield diagram by deploying a logarithmic matching method. Critical analysis on different formulas for shields curves can be found in Beheshti and Ashtiani (2008).

Results of shields and sub sequent development of relationship based on shields diagram used the similarity theory to the issue of incipient particle movement using turbulence variables. but the major drawback of the shields is the that the viscous sub layer does not have any effect on the velocity distribution when R*≥70, but his diagram shows that shear stress still varies with R* when the latter is greater than 70. This highlights the need for modification needed to shields approach. Use of similarity theory is essential in developing the fluid flow concept. Rao (1989) has used modified mixing length concept and developed incipient motion relation by using Nikuradse's experimental data and several other incipient motion observations. Here,it is felt that to present more simplified form of Rao's equation, which will be used in accurate determination of the critical or threshold flow conditions for incipient motion.

The following equation has been developed by Dr.G.Sreenivasulu. Dept.of Civil Engineering. Indian Institute of Science, Bangalore. He worked a lot on the Incipient motion and shield's curve and published his report in 2009.

$$\Theta_c = \frac{0.12}{R_x^{1/3}} e^{-0.16 R_x} + 0.05 e^{\frac{-10}{R_x}}$$

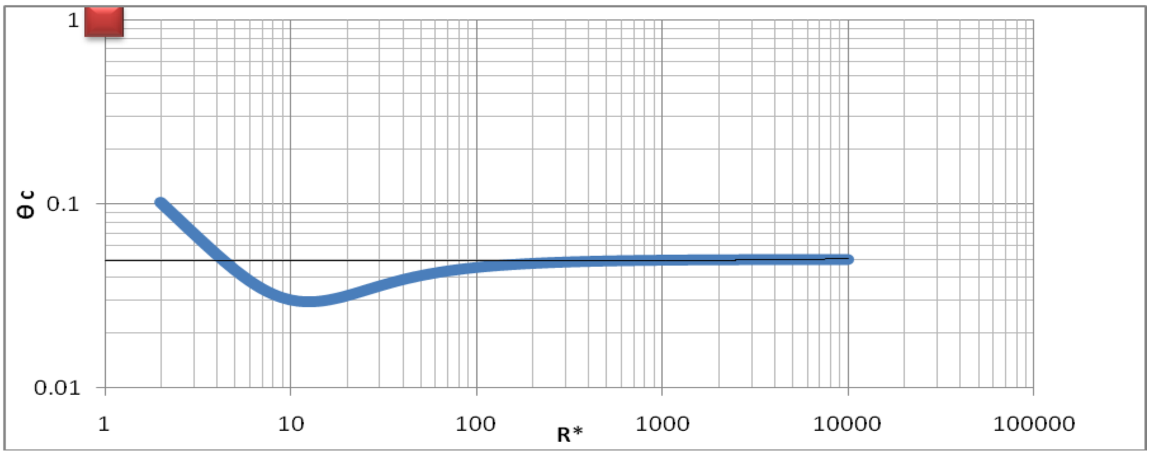

Fig5.1: Shield's curve

6. EXPERIMENTS IN FLUME

The experimental part of the report was made in Hydraulics Laboratory of RGMCET. The tests were divided into two parts: Rigid-bed and Mobile bed (sand-bed).

6.1 Experimental Facilities :

The tests were conducted in a 6 m long and 0.3 m wide rectangular glass-walled flume with depth of 0.6 m. The slope of the flume is -2% to +2%. Two gates (upstream and downstream) are kept to control a discharge from a head tank. Water entered the flume through a fixed stilling basin and a pipe.

Fig 6.1: Hydraulic Tilting Flume

The flume is supported at one end on a fixed pivot and at the other end by screw jack arrangement to raise or lowering the slope of flume.

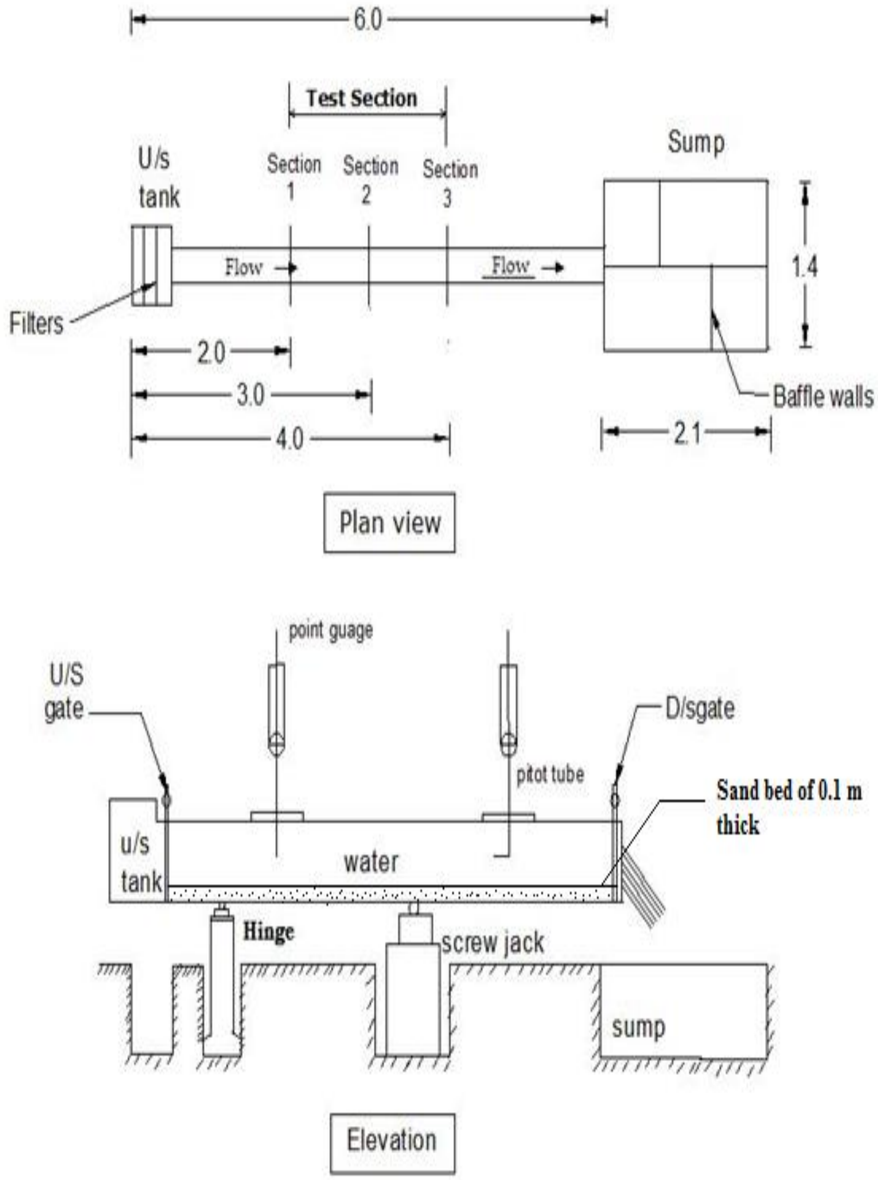

Fig 6.2: Schematic view of Tilting flume

6.2. Experimentation:

The experiments are conducted in the laboratory tilting flume. The size of flume is 6.0 m in length, 0.3 m in width, 0.6 m in deep and slope is ± 2%. The bed slope of this flume can be adjusted either in positive and negative direction with the help of jack and pinion arrangement. Photograph of the flume is show in figure 6.1 sand bed thickness is 0.10 m is maintained in the flume.

Quartz silica sand of the size d_{50}=1.1 mm is used to observe the temporal and spatial variations at incipient motion.

6.3 Procedure And Measurements

Initially, the sand bed was made plane for all the experiments with a required bed slope,s_0. The depth of flow can be adjusted with the help of tailgate at the downstream end. Then the inflow discharge Q is allowed from the upstream end of flume. Initially the discharge allowed such that no transport condition prevails. Then by slowly increasing the discharge at upstream location the incipient condition is set by carefully observing the bed material motion. After reaching stable condition, the water surface elevation are measured with an accuracy of ±0.015mm of water head at regular interval along the length of the flume by using a digital micro manometer in order to determine the water surface slope, $s_{n.}$ flow depths, y, along the central line of the canal were measured at regular intervals using a point gauge, and the average depth 'y-' was obtained. The amount of Q is measured either volumetrically or with calibrated triangle notch. Thus the basic variables S_0,Q,S_n and y- were obtained in every experimental run. Typical experimental data are observed are represented in the form of tables and graphs which were discussed in the results.

6.4. Data Analysis:

Shear stress and stream power are the major variables to quantity the incipient motion condition. Hence the data analyzed by measuring the shear stress stream power experimentally over the test reach.

6.5. Bed Shear Computation

It is seldom possible to maintain in perfect uniform flow conditions in laboratory channels. Hence the gradually varied flow equation , with energy/momentum correction factor as unity, is used in computing the energy/friction slope, S_f as fallows;

$S_f=S_0+S_w(1-F^2)$……………(2)

Thus by knowing S_f, the bed shear stress ,τ_b is computed by the following relation

$\tau_0= \Upsilon\ y\ S_f$............................ (3)

Where,

1. S_0=bed slope,
2. S_w=water surface slope,
3. F=fraud number =U/√gy,
4. y=depth of flow, and
5. ϒ= unit weight of water

7. Results, Analysis And Discussions

7.1 Establishment of Velocity Profile distribution in Mobile bed (Sand bed):

The presence of corners and boundaries in an open channel causes the velocity vectors of the flow to have components not only in the longitudinal and lateral direction but also normal direction to the flow. In this experiment, velocities along the normal direction to flow are considered.

For the establishment of velocity profiles, micro manometer is used to calculate the velocities up to the head differences of 1/1000 mm.

The total flume is divided into the three sections at which velocity profiles are established. The velocities at different depths are found out by lowering and raising the pitot tube in the water.

Table 7.1: Observations of Velocity Profiles at section 2

Depth of water (m)	Velocity (m/s)
0.004	0.06
0.007	0.074
0.026	0.1033
0.066	0.1254
0.106	0.1306

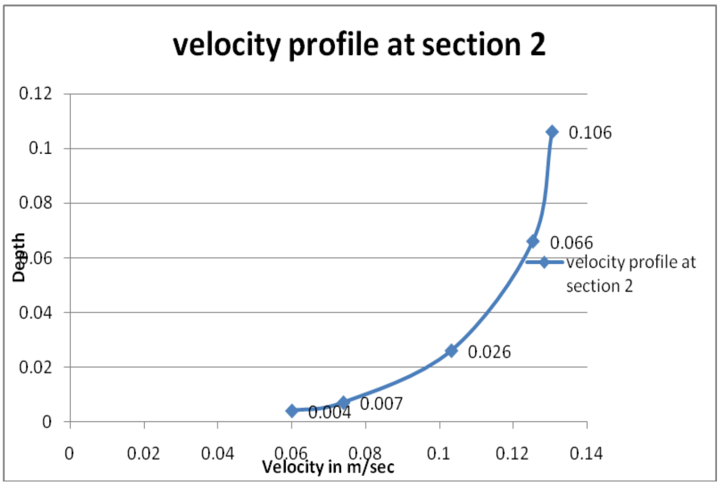

Fig 7.1: Velocity Profiles at section 2

Table 7.2: Observations of velocity Profiles at section 3

Depth of water (m)	Velocity (m/s)
0.004	0.1306
0.007	0.1337
0.026	0.146
0.066	0.149
0.106	0.1505

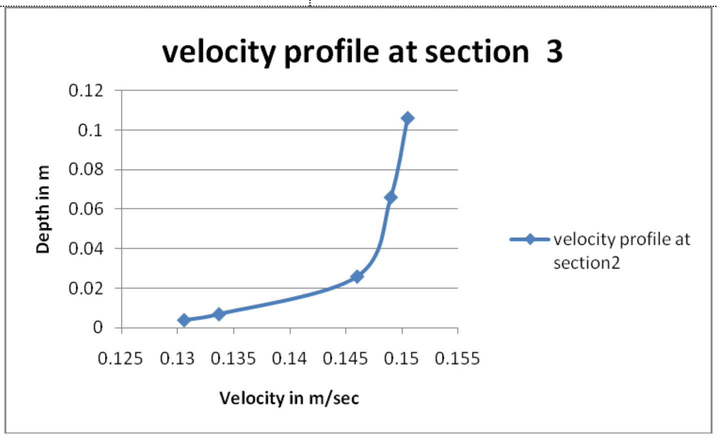

Fig 7.2: Velocity Profiles at section 3

Table 7.3: Observations of Velocity Profiles at section 4

Depth of water (m)	Velocity (m/s)
0.004	0.064
0.007	0.079
0.026	0.091
0.066	0.102
0.106	0.116

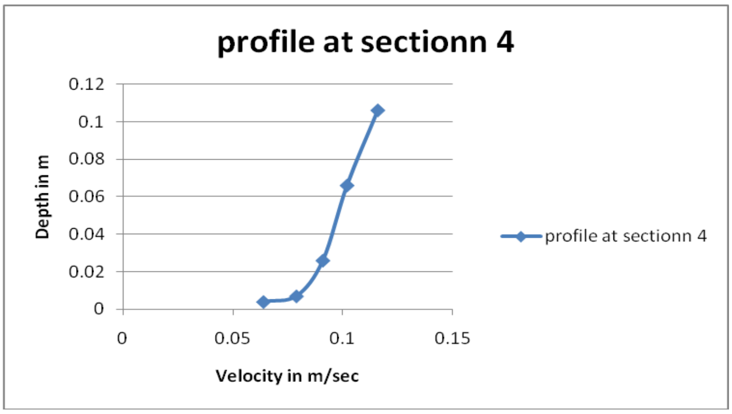

Fig 7.3: Velocity Profiles at section 4

7.2. SHIELD CURVES:

A. Shield an American scientist first started working on the incipient motion in early 1930's. He worked on open channel flows and derived some conclusions about the open channel flows. There have been numerous additions, revisions, and modifications of the Shields curve since its original publication. *Shields* [1936], *Grass* [1970], *Gessler* [1971], and *Paintal* [1971] recognized that incipient motion of a particular grain size is inherently a statistical problem, depending on probability functions of both turbulent shear stress at the bed and inter granular geometry (i.e., friction angles) of the bed material, the latter being controlled by grain shape, sorting, and packing [*Miller and Byrne*, 1966; *Li and Komar*, 1986; *Kirchner et al*.,1990; *Buffington et al*., 1992]. Consequently, there is a frequency distribution of dimensionless critical shear stresses for any grain size of interest. Reanalyzing *Shields*' [1936] data and correcting for sidewall effects and form drag. The equation developed by Shield is as follows

$$\Theta c = \frac{0.12}{R_x^{1/3}} e^{-0.16 R_x} + 0.05 e^{\frac{-10}{R_x}}$$

For $D_{50} = 1.10*10^{-3}$m size of sand, ϴc and R_* are calculated and plotted over the shield curves.

Where ϴc is calculated by

$\Theta c = \dfrac{To}{(rs - r)d}$

Where

$T_o = \Upsilon * y * S_f$;

y=depth

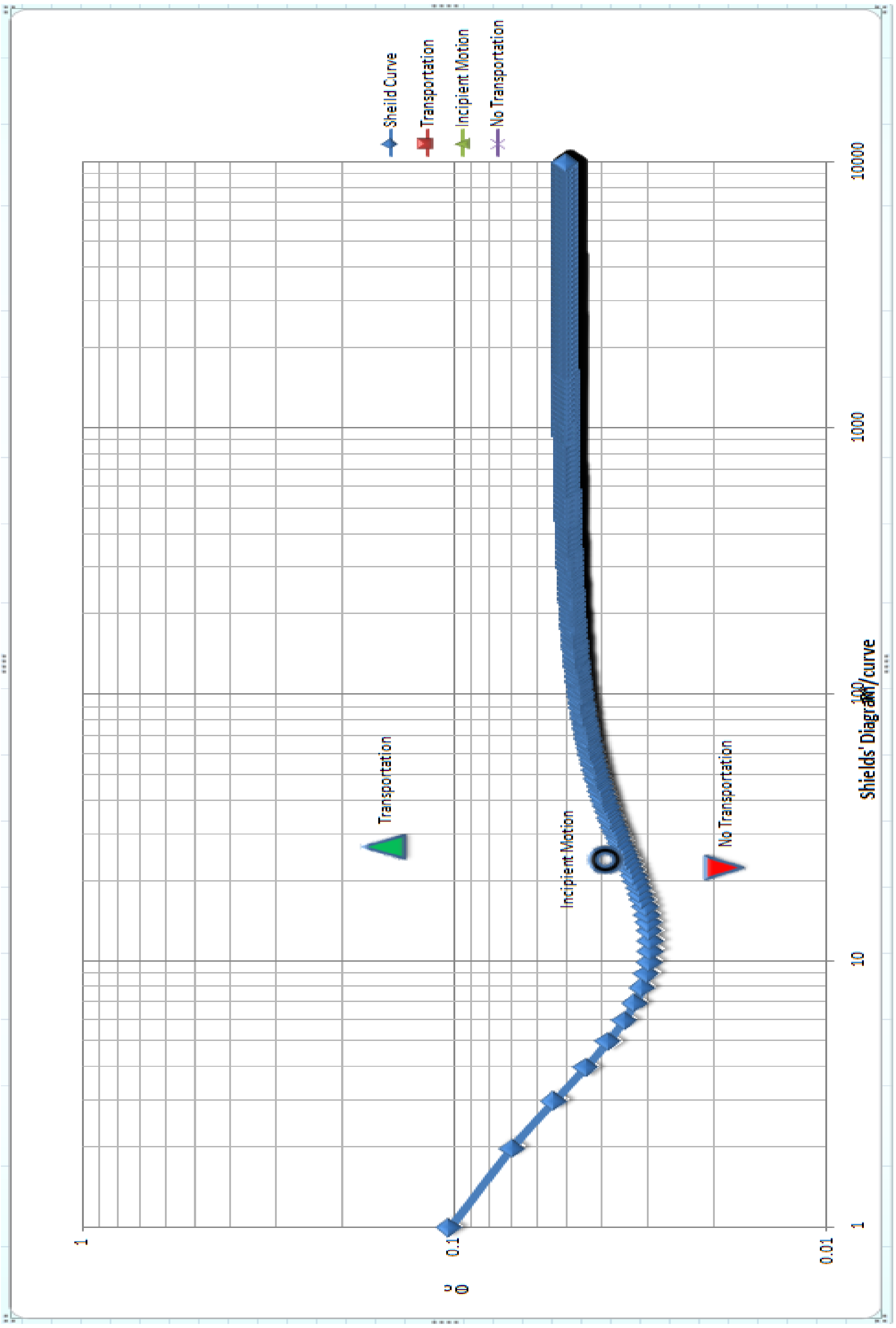

Fig 7.6: Result Graph of Shield curve

8. CONCLUSIONS

1. Experiment have been conducted for verifying Shield Curve and velocity profiles
2. Incipient Motion: Based on the Experiments conducted in the lab, for certain particular velocities, the particles are about to shake at incipient motion
3. Based on Shields analysis, Critical Shield parameter which has been obtained for study shows that, the points below the Shield curve shows that there is no transport, the points on the Shield curve shows the Incipient motion and the points above Shields curve shows there is transportation.

REFERENCES

[1] Dr.Gopu Sreenivasulu, "*Seepage Effects on stream power, resistance, incipient motion and regime of sand bed channels including its design*", ISBN-10: 3844397434.

[2] Stefan Vollmer and Maarten G. Kleinhans, "*Predicting incipient motion, including the effect of turbulent pressure fluctuations in the bed*" published 4 May 2007.

[3] S.A. Miedema, "*Constructing the SHIELDS CURVE, A New Theoretical Approach and its Applications*"

[4] Burkhard Rosier, Frédéric Jordan, Giovanni De Cesare Jean-Louis Boillat and Anton Schleiss, "*Determination of Velocity Profiles and bed morphology using UVP transducers to investigate the Influence of lateral overflow on mobile bed*"

[5] John M. Buffington and David R. Montgomery, Department of Geological Sciences, University of Washington, Seattle, "*A systematic analysis of eight decades of incipient motion studies, with special reference to gravel-bedded rivers*"

[6] MARCO PILOTTI and GIOVANNI MENDUNI,
"*Beginning of sediment transport of incoherent grains in shallow shear flows"*

[7] Jens M. Turowski, Alexandre Badoux and Dieter Rickenmann "*Start and end of bed load transport in gravel bed streams"* published 23 February 2011.