[NCRAES-2019] ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

CRITICAL SHEAR STRESS NEAR BRIDGE PIER FOR NON-UNIFORM SEDIMENTS

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ABSTRACT

The preeminent purpose of study is to obtain critical shear stress near circular bridge pier for non-uniform sediments. This paper describes the main reason of local scour are generally classified into flow condition, structure, and riverbed material used in it. Scouring is significant factor which affects on the safety of bridges. Scouring develops around the pier on the bed channel with non-uniform sediments achieve the great on scour depth prediction. In this a flume experiment has been conducted to predict the relative parameters of shear stress for various size of pier diameter and scour depth using the non-uniform sediments. From the analysis a relationship between scour depth and angle its scour depth may be developed. The critical shear stress is calculated from the Shields graph and dimensional shear stress. A comparative study done in this experimental work which included four runs with different velocities of three sets

***Keywords**: Critical shear stress, scour, non –uniform sediments, pier, scour prevention, structure, scour depth.*

I. INTRODUCTION

The shear stress developed near the circular bridge pier due to the critical velocity, just at the moment when the sediments start to move, (vibrate) is called as "Critical Shear Stress". The critical shear stress is calculated by using the Shields graph & Shields formula.

Due to action of scouring on the bridge pier, many bridges have failed world- wide. Scouring is the local lowering of bed stream elevation which takes place around bridge pier depends upon the size of river bed particles and stream velocities. Bridge pier scour can be modeled using variety of methods. One approach is to derive a theoretical equation or set of equations to describe the scouring process. The scouring process around bridge pier is extremely complex so, many simplifications & assumptions are required to obtain in analytical model.

The objective of this study is to mainly study of characteristics of velocity flow, non-uniform sediments, scouring effect and critical shear stress near circular bridge pier for non-uniform sediments. The water exert tractive force on bed material in the direction of flow, this results in to particle lift from the bed and just start to moving in the direction of flow this condition is called as incipient motion. Many researchers have conducted various studies to predict the maximum depth and diameter of scour hole. An attempt has been made to review few previous studies related to scour .Scour has been the major concern for safety of marine and hydraulic structures. A large number of hydraulic structures failed as the local scour progresses undermine the foundations. Recent study by Guney showed that the Local scours around bridge piers influence their stabilities and play a key role in bridge failures. In his study local scours around bridge piers resulting from unsteady flow was measured. It was concluded that the main mechanism that drives the formation and evolution of the scour hole around bridge pier is horse shoe vortex motion. The failure of bridge structure is occurs due to more scouring near bridge pier and increase in critical shear stress.

ISSN 2348 – 8034
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II. LITERATURE REVIEW

2.1 By Ferdous Amed and Nallamuthu Rajaratnam, Fellow, ASCE

They studied the results of a laboratory study on flow past cylindrical piers placed on smooth, rough, and mobile beds. Experimental results are presented on the flow in the plane of symmetry, including the frontal down flow and the effects of bed roughness and the scour hole on it. The Clauser- type defect scheme describes the velocity profiles better than the log-law and defect law. Frontal down flows as large as 95% of the approach flows were observed. Experimental results are also presented on the deflected flow and bed shear stress field. Bed roughness increased the magnitude of bed shear stress and the area over which the shear amplification was felt and also resisted the skewing of the flow near the bed, thus leading to smaller yaw angles of the bed shear vectors.

2.2 B. W. Melville1 and A. J. Sutherland

This is the design method for the evaluation of equilibrium depths of local scour at bridge piers is presented. The method is based upon envelope curves drawn to experimental data derived mostly from laboratory experiments. The laboratory data include wide variations inflow velocity and depth, sediment size and gradation, and pier size, shape, and alignment. Local scour depth evaluation is based upon the largest possible scour depth that can occur at a cylindrical pier, which is $2.4D$, where D = the pier diameter. According to the method, this depth is reduced using multiplying factors where clear-water scour conditions exist, the flow depth is relatively shallow, and the sediment size is relatively coarse. In the case of nonrectangular piers, additional multiplying factors to account for pier shape and alignment are applied.

III. METHODOLOGY

3.1 Data Collection

3.2 Materials and Testing

i. Concrete
ii. Sediments
   - Sieve analysis
   - Specific gravity
   - Density of sediments

3.3 Casting

Pier was casted well before conductance of experiment. The casting was done at mid of September (10th Sept.).Pier is of 70 mm diameter.

3.4 Experimental Arrangement

The experiment was conducted in tilting flume of dimensions 6m length, 0.2m wide and 0.3m in depth. The flume is provided with baffle walls at inlet and outlet chamber which were used to keep flow of water steady and calm. The circular shape pier was made of M20 grade concrete, having length 300 mm, diameter 70 mm. The pier was placed at center of section and then bed material (sand) was placed around it. The flume was kept horizontal while performing the experiment and flume was provided with gate to control discharge of flow and maintain the uniformity. The depth of scour was measured with point gauge.

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Fig.1 Arrangement of Pier in Tilting Flume

Fig.2 Tilting Flume

3.5 Parameters:
Shape of Pier - Circular Pier Velocity of Flow
1. V1
2. V2
3. V3
4. V4

IV. OBJECTIVES

The prominent objective this experimental work is to determine stresses developed around the bridge pier due to scouring and establish relation between various flow parameters.

- To determine the critical shear stress around Circular bridge pier using non uniform sediments.
- To determine the scouring depth around circular bridge pier.
- To establish a relation between velocity of flow and scouring at bridge pier.
- To estimate the maximum scour depth.
- To find out conditions for this maximum scour depth.
- To provide bed scour data.

V. EXPERIMENTAL WORK PERFORMED

5.1 Experimental Setup
The experiment was conducted in tilting flume of dimensions 6m length, 0.2m wide and 0.3m in depth. The flume is provided with baffle walls at inlet and outlet chamber which were used to keep flow of water steady and calm. A section of 2m length and 120mm depth was prepared by using acrylic sheet. The pier was placed at center of section and then bed material (sand) was placed around it.

The flume was kept horizontal while performing the experiment and flume was provided with gate to control discharge of flow and maintain the uniformity. The depth of scour was measured with point gauge.

5.2 Description of Bed Material

The bed material of non-uniform sediments was used for the experiment. Having specific gravity 2.7 and size ranging from 150 microns to 4.75 mm. Bed materials was washed thoroughly with clean water to remove silt and organic material.

5.2.1 Sediment Sampling:

- Non-cohesive river bed sand is used as sediment in the experimental work. Two Samples of sediments are prepared as given below.
- Sample No: - 1 d50 = 1.18 mm and

Geometric standard deviation σg = 1.6

- Sample No: - 2 d50 = 2.36 mm and

Geometric standard deviation σg = 2

C. **σs= √d84/d16**

Where,

d84 = Sediment size for which 84% by weight of sediment is finer.

d16 = Sediment size for which 16% by weight of sediment is finer.

5.2.2 Sediment Analysis:

Geometric standard deviation use for sediments is non-uniform. The standard deviations were calculated for sediments, when it should be greater than 1.6 or 2 then the sediments are non-uniform sediments.

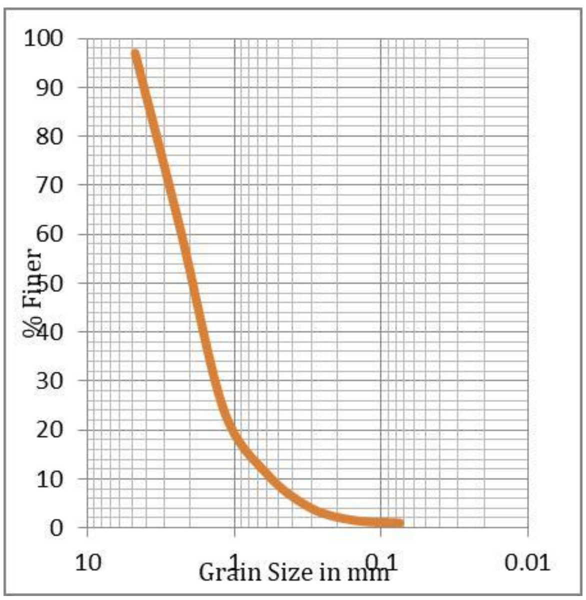

Fig.3 Sieve Analysis Graph

5.3 Experimental Procedure:

- Preliminary runs were carried out to calculate the discharge of water through flume by volumetric method.
- Then velocity of the flow was calculated by analytical method and it was compared with theoretical velocity.
- Section was prepared and bed material was placed around pier.
- Bed material was compacted gently and was leveled.
- The section was filled with water slowly, so that entrapped air was removed.
- A wooden frame is prepared with thread arrangement on it. This arrangement is used to take reading at 30 degree and 5 mm interval.
- This wooden frame was placed over top of the flume to take angular readings of scouring.
- Valve was kept at fixed position to keep steady flow condition for a run.
- Steady flow was maintained for five minutes and velocity was measured.
- Scour hole depth was measured using point gauge.
- Same procedure was repeated five times for a single set keeping the same velocity.
- Four sets of four different velocities were taken to measure scouring at different velocities.
- Same procedure was adopted to carry out runs.
- Readings were noted down and analyzed for developing relation between velocities, scour depth, pier dimensions.

5.4 Analogy:

To determine the shear stress and critical shear stress we used Empirical formula and Shield formula from shear stress graph and Shield's graph.

$$\tau_c = \frac{\tau * C}{(\lambda s - \lambda w) d50}$$

Where,

1.= Shear stress around pier d_{50} = Particle size

λs = Specific weight of water λw= Specific weight of sediments

5.5 Time Scour Study:

It was observed that initially scouring depth increases considerably. For this time period rate of particle moved out was more. As the time passes this rate get decreased and finally maximum scour depth is obtained. The total runs performed were 12 and data and results were collected. The extend of scour hole is not depend on velocity and depth of flow. The extend and depth of scour hole is not related to any of these parameters.

5.6 Presentation of data:

The knowledge of maximum scour depth, extent of scour and critical shear stress around the obstruction or bridge pier is necessary for the safe and economical design of foundation for a bridge pier. If scour is large in quantity, it affects the stability of the foundation and leads failure of bridge. Therefore, the depth of the foundation for the bridge pier depends on the above parameter and it is necessary to estimate scour depth accurately.

An underestimation of scour depth will result the failure while overestimation will increase the cost of structure. The present study have been done for the developed the relation for critical shear stress, to calculated critical velocity form various methods and work out the extend of scour for a particular type of bed material and shape of the pier.

Basically this present study was done for the critical shear stress on non-uniform sediments, knowing that, river bed is composed by the material containing the particles of different sizes, which undergoes natural armoring process at the low values of shear stress; this restricts the erosion of bed. Because the mixture contains moved out of section was decreases. As time progresses at some instant reading doesn't changed. It means that the scour depth doesn't change with respect to time therefore this scour depth or this is also called as condition of equilibrium of scour. It is defined as the sediments coming into reached are equals to sediments going out of it. This time for the maximum scour depth is then used for the study critical condition.

5.7 Extent of Scour Hole

The study has been conducted to work out the maximum scour depth for pier and three types of bed material. The contour map of the scour hole are prepared for all three types of the material used in the present study .This scours are the lines joining the equal scour points around the circular pier with respect to original bed level as shown in figure. They are divided through 30° from flow direction in clockwise sense. It was used to calculate extent of scour along flow direction and perpendicular to it.

Shear stress near the bridge pier: As knowing that the shear extended by the flowing water on the bed is responsible for the sediments transportations and this shear stress is critical shear stress. Taking clue from earlier study here considers the bed material and shape of the pier is circular. For determining the shear stress near the bridge pier, it is worked out from the critical velocity (Uc). It is defined as the average velocity at which just start to scour near the bridge pier.

5.8 Studies for Critical Velocity

The shear stress exerted on the bed by flowing water is responsible for the movement of the sediments particles. If the uniform sediments are there then it is very easy to calculate its value. But in case of non-uniform sediments the shear stress on the different fraction of sediments is different under the conditions of critical velocity this non-uniformity of the sediments affects the critical shear stress.

5.4 Presentation of Data : Set 1 Run 1, Velocity -0.295 m/sec Table No.1

Angle Distance	**30:**	**60:**	**90:**	**120:**	**150:**	**180:**	**210:**	**240:**	**270:**	**300:**	**330:**	**360:**
35	1.3	1.6	1.5	1.1	1.2	0.6	0.7	0.9	1.1	0.9	0.7	0
40	1.1	1.5	1.6	0.9	1.3	0.6	0.6	0.7	0.7	0.5	0.4	0
45	0.8	1.3	0.8	0.7	1.1	0.6	0.5	0.5	0.6	0.3	0.5	0
50	0	0.7	0.6	1	0.9	0	0.7	0.4	0	0.2	0.3	
55		0.6	0.3	0.6	0.7		0.5	0.4	0.3	0.3	0.5	
60		0.4	0	0	0.3		0.4	0.3	0.4	0.2	0.5	
65		0			0		0.3	0.2	0.2	0	0	
70							0.2	0.1	0			
75							0	0				
80												
85												
90												

Similarly we take 4 sets and each set containing 3 runs and we compare each set with other

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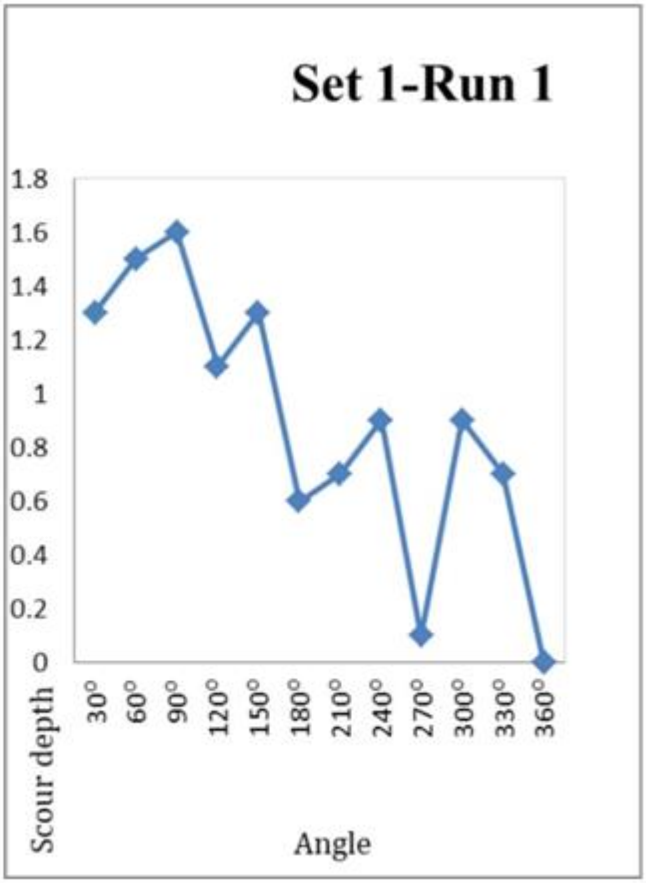

Fig.4 Scour Depth vs Angle Set 1 Run 1

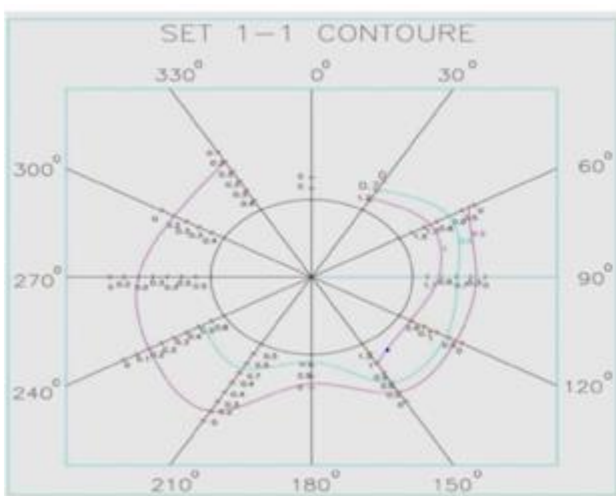

Fig.5 Contour Set 1 Run 1

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VI. ANALYSIS OF DATA

6.1 Comparison between sets for depth:

6.1.1 Comparison between set 1 and set
V1 =0.248 m/sec; V2= 0.176 m/sec; % change in velocity= 29 %

Table No.2

Angle	SET 1	% increase in depth	SET 2
60^0	1.7	39.28	2.8
90^0	1.8	18.18	2.2
120^0	1.7	10.52	1.9
240^0	1	33.33	1.5
270^0	1.6	23.80	2.1
300^0	1.7	6.25	1.6

6.1.2 Comparison between set 2 and set
3 V2=0.176 m/sec; V3= 0.317 m/sec
% increase in velocity= 80.11%

Table No.3

Angle	SET 2	% increase in depth	SET 3
60^o	2.8	35.71	1.8
90^o	2.2	13.63	1.9
120^o	1.9	-5.26	2
240^o	1.5	-50	3
270^o	2.1	-47.61	3.1
300^o	1.6	-93.75	3.1

6.1.3 Comparison between set 1 and set 4

V1=0.248 m/sec; V4= 0.226 m/sec; % change in velocity= 8.87 %

Table No.4

Angle	SET 1	% change in depth	SET 4
60^o	1.7	54.54	1.1
90^o	1.8	80	1
120^o	1.7	54.54	1.1
240^o	1	-50	2
270^o	1.6	-33.33	2.4
300^o	1.7	-43.33	3

6.1.4 Comparison between set 2 and set 4

V2=0.176 m/sec; V4= 0.226 m/sec; % increase in velocity= 28.40 %

Table No.5

Angle	SET 2	% increase in depth	SET 4
60^o	2.8	60.71	1.1
90^o	2.2	50	1
120^o	1.9	42.10	1.1
240^o	1.5	-33.33	2
270^o	2.1	-14.28	2.4
300^o	1.6	-87.5	3

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6.2 Graphical Representation and Analysis for Depth and Angle:

On X axis we plot angle

On Y axis we plot scour depth

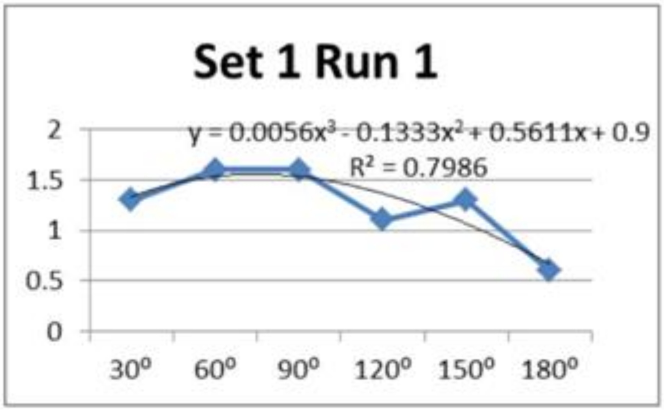


Fig.6(A) Graphical Representation of Set 1 Run 1(0⁰-180⁰)

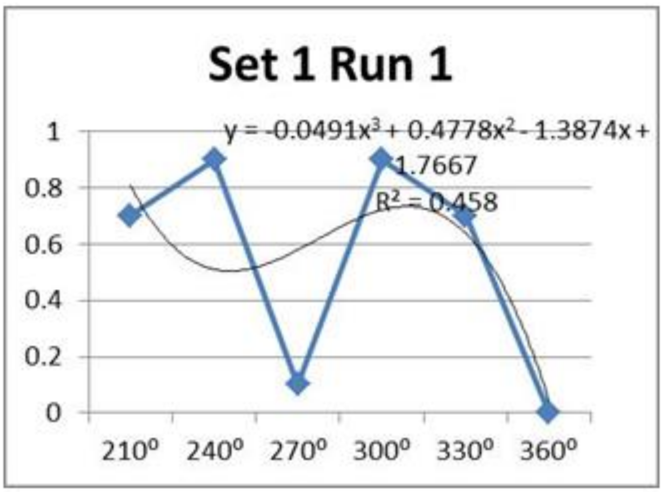
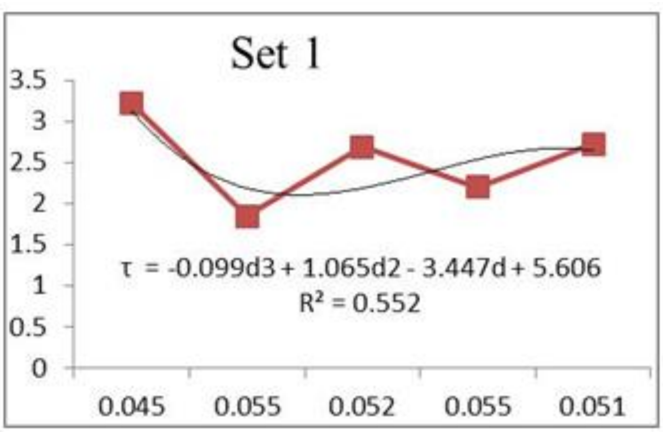


Fig.6(B) Graphical Representation of Set 1 Run 1 (210⁰-360⁰)

6.3 Shear stress analysis:



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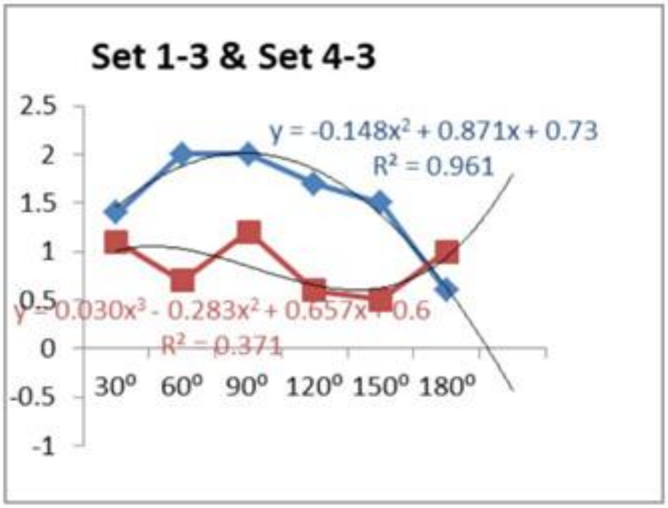

Fig.7 (A) Comparison of Set 1-3 & Set 4-3

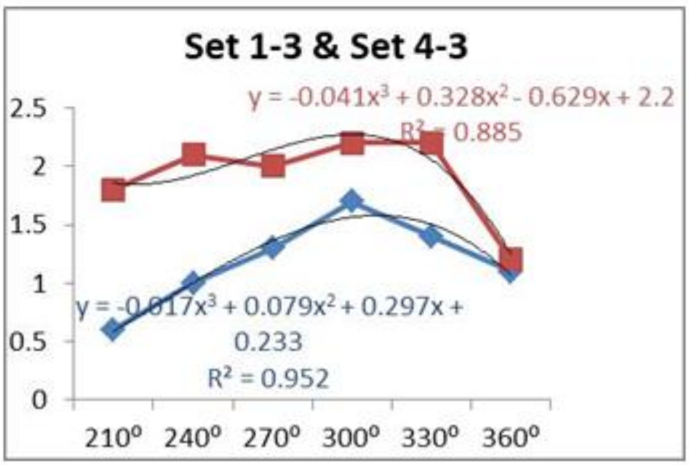

Fig.7 (B) Comparison of Set 1-3 & Set 4-3

In the above equation, below each graph the value of x represents angle and if we replace x by co ordinate of angle, we get most probable values of scour depth for velocity of that set. Such process is done for all the 1-4 sets and 3 runs each. Shear stress analysis is done for all the 4 sets as shown for set-1.

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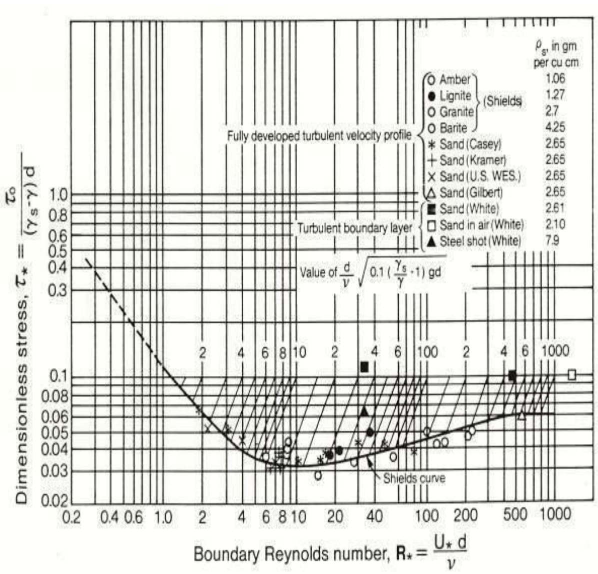
VII. SHIELDS GRAPH/ DIAGRAM



The shield's diagram empirically shows how the dimensionless critical shear stress (i.e. the shear stress required for the initiation of motion.)

A shield's value above the shield's curve means that there is erosion, below means negligible erosion.

7.1 Shield's Formula:

$$\tau c = \frac{\tau_* C}{(\lambda s - \lambda w) d50}$$

Where,

τ = Shear stress around pier

d50 = Particle size

λs = Specific weight of water

λw= Specific weight of sediments

by using above formula calculation for critical shear stress has been done.

VIII.CONCLUSION

The critical shear stress of sands in a stream depends on many parameters whose effects are complicated and interrelated. Scouring is greatly depended on actual site conditions. Hence, no precise relationship between shear stress of sand and scour depth can be expected. For more accuracy more précised and large Scaled instrument must be used. Scale effects are major impacting factor to study scour depth phenomenon.

Although this assumption is not precisely correct, it seemed to afford a reasonable basis for comparison of scouring in streams of greatly different velocity. However, first as time passes scour depth increases but after sometime it become gradual, the scour due to dumbbell Shape Bridge pier is less as compared with circular bridge pier.

8.1 Critical Shear Stress

The average of velocities of 4 different sets is calculated and then the critical shear stress for each set is determined by using the shield's formula.

Sr.No.	Critical Velocity	Critical Shear Stress
1	0.248m/sec	0.01042N/m2
2	0.176m/sec	0.01896N/m2
3	0.317m/sec	0.01191N/m2
4	0.226m/sec	0.013906N/m2

8.2 More précised and digital instruments

More precise instruments like flow meter, high definition cameras are required to record more precise and accurate readings.

8.3 Shape of the pier and sediments

Shape of pier and size sediments greatly affect the scour pattern and depth of Scour hole.

8.4 Actual site conditions

Scour hole patterns, depth of scour hole and shear stress are majorly affected by the actual site conditions such as sediment size distribution, bed slope, velocity of flow, depth of flow and discharge through channel.

REFERENCES

1. *Chapter 9- threshold of movement (forces on bed particles) , ocw.mit.edu*
2. *Kuninori Otsubo & Kohji Muraoka "critical shear stress of cohesive bottom sediments"*
3. *Peter R. Wilcock, "Methods For Estimating The Critical Shear Stress Of Individual Fractions In Mixed-Size Sediment" water resources research, vol. 24, no. 7, pages 1127-1135, July 1988*
4. *Peggy A. Johnson And J. Sterling Jones "Shear Stress At Base Of Bridge Pier" transportation research record 1350 PP 14-18*
5. *R J Garde, U C Kothyari "Scour Around Bridge Piers", PINSA 64, a, no 4, July 1998, PP 569-580 ISSN 2348 – 8034 Impact Factor- 5.070*
6. *Report of federal highway administration's turner-Fairbank highway research center (TFHRC) J. Sterling Jones hydraulics laboratory in response to state transportation departments*
7. *D. Max Sheppard, "Large Scale And Live Bed Local Scour Experiments", Florida department of transport, September 2003*
8. *Vincenza C. Santoro, Pierre Y. Julien, Everett V. Richardson, Steven R. Abt, "Velocity Profiles And Scour Depth Measurements Around Bridge Pier"*
9. *Shaghayegh Pournazeri Fariborz Haghighat S. Samuel Li, "A bridge pier scour model with non-uniform sediments", Proceedings of the Institution of Civil Engineers, October 2014*
10. *Previous study on "Critical shear stress around bridge pier for non-uniform sediments" by students of civil engineering, Bharati Vidyapeeth deemed university, Pune*
11. *Ferdous Ahmed and Nallamuthu Rajaratnam, "Flow Around Bridge Piers", journal of hydraulic engineering, 1998, 124(3): 288-300*
12. *Previous study on "Critical shear stress around bridge pier on uniform sediments" by students of civil engineering, BVCOE Lavale, pune.*