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Effect of Sinuosity on Shear Stress Distribution in Meandering Channel

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Abstract*: *Rivers have always been the lifelines of the civilizations and meandering is a well known natural phenomenon in which a river deviates from its straight path and form a curvature of reverse order. To study the flow characteristics of a meandering river understanding of shear stress distribution in a meander section is of immense importance. Shear stress distribution in a meandering section depends upon various factors like shape of cross section, slope and hydraulic radius etc. Among all these factors sinuosity is a crucial factor which affect the shear stress distribution in a meandering section. This research put forward the effect of variation in sinuosity on shear stress distribution.CFD(Computational Flow Dynamics) analysis is adopted over experimental work due to its reliability and accuracy. ANSYS 18.1 is used for the simulation of meandering channels. In this research we design three meandering channels with sinuosity values 1.47, 2.0 and 2.53. Each model is simulated for three different values of discharge i.e. 1,2 and 3 cumec. Hence a total of 9 models are created for the analysis. Meshing is done for the domain and its accuracy is examined by performing grid independence study. LES(Large Eddy Simulation) model is used to incorporate turbulence in the model. This model is chosen due to its better efficiency and accuracy over others in open channel simulations. The results show that shear stress on inner wall of meandering channel is more than that on outer wall. Velocity profiles are found to be in agreement with shear stress distribution. Percentage difference between inner and outer wall shear stress values decreases as we increase the sinuosity.

***Keywords*: Meandering, Shear stress distribution, Sinuosity, Velocity distribution.**

I. INTRODUCTION

When in a straight channel, a deviation from axial path occurs and a reverse order curvature develops then it is known as a meandering channel. A bend or a curve in a river is known as meander. It may be defined as the degree of the adjustment of sentiment load and water in river. One of the factors which control the shear distribution and velocity in a meandering river or channel is the 'meander index' or 'sinuosity'. The objectives of this study are:

- To determine the boundary shear stress distribution in simple meandering channels.
- To study the velocity profiles of water as flow propagates in a meander path.
- To study the effect of sinuosity on boundary shear stress distribution in a meandering channel.

Sinuosity or meander index of a river tells the deviation in the course of the river from the shortest possible path. In this study emphasis is given on boundary shear stress distribution of a meandering channel and the effect of sinuosity on shear stress distribution. For decades, researchers have been focusing on studying the flow in s meandering channels of both types simple and compound, numerically and experimentally. Several numerical models are available to carry out simulation of the secondary structures in a meandering channel. Thomas and Williams (1995) obtained experimental results from Hydraulics research lab Wallingord , England and were compared with numerical simulations .LES (Large Eddy Simulation) Model was used to simulate the turbulence in the model. Simulation results for shear stresses and secondary flows were analyzed with the laboratory observations and it was observed that they were quite similar. While Lu et al. (2004) opted for a slightly different approach in case of turbulence model. Numerical simulations were done for flow in 180 degree bend. From various turbulence models k-€ model was used and various properties like wall shear distribution and water depth variations were observed. When further investigation was done it is found that LES (Large Eddy Simulation) Model is more suited for simulating flow in meandering channels. Manaswinee Patnaik & K.C. Patra (2013) collected experimental data form a physical meandering channel available in laboratory. Various parameters like aspect ratio and cross section were kept constant during observation. Shear stress distribution on channel walls was measured in laboratory. The shear stress contours in lateral and longitudinal direction was derived using modeling software ANSYS 13.0. LES turbulence model was used to simulate the experimental data. From this study it was evident that Large Eddy Simulation model was providing results closer to the experimental ones. This study didn't elaborate the effect of sinuosity on meandering phenomenon whereas they stated it as critical parameters which affect shear stress distribution of the channel.

II. METHODOLOGY

CFD(Computational Flow Dynamics) studies on meandering channel are performed with the help of ANSYS 18.1.There are various steps involved in designing of meandering channel which are discussed below.

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A. Geometry

Design modular is used to create 3 simple rectangular meandering channels with different sinuosity values of 1.47, 2.0 and 2.53. The cross section of channels is taken to be rectangular with 2m height and 1m width and depth of flow is 1m.Thickness of wall is 0.25m with and Radius of curvature for the channel was kept 3m.

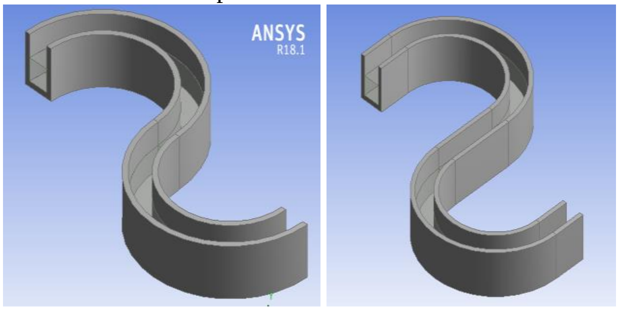

Fig.1.Geometry with sinuosity 1.47 and 2.0 respectively

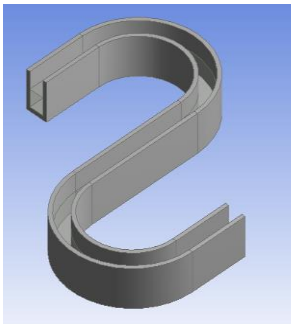

Fig.2.Geometry with sinuosity 2.0

B. Meshing

Meshing is defined as the process of dividing the domain into number of cells where the values of variables are calculated. Finite volume method was opted for meshing of domain and then named selection of model was done to provide adequate boundary conditions under the setup section.

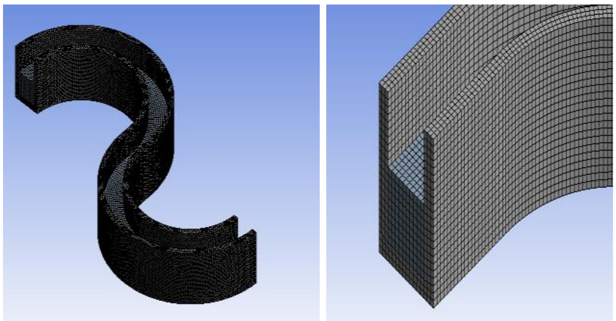

Fig 3 Meshing of geometry

After successful meshing of domain named selection of various channel components is done to provide adequate boundary conditions under the setup section.

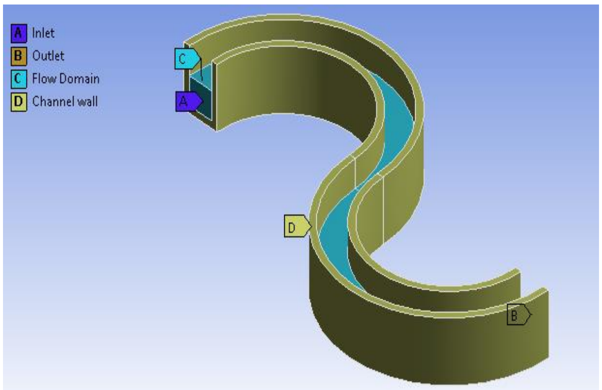

Fig 4 Named selection of geometry

C. Setup

In this section required materials for analysis were added from fluent database like water and air. From the list of multiphase models VOF (volume of fluid) model was selected. Flow was defined as open channel flow and turbulence was incorporated. LES (Large Eddy Simulation) model was selected from turbulence models to simulate open channel flow. After the selection of suitable models boundary conditions were provided at required locations.

- Inlet - Velocity boundary condition was provided at inlet. Velocity was provided in longitudinal direction only and kept zero in other directions. From a particular meandering channel three different models are obtained by providing different velocities at the inlet of the channel. Three different values of velocity are 1m/sec, 2m/sec and 3 m/sec.
- Outlet - Pressure boundary condition was provided at outlet. In all cases zero gauge pressure was kept at outlet.
- Channel wall - The channel wall is described as stationary wall while specifying the boundary condition. No slip shear condition is selected for channel wall which says that at the wall surface relative velocity of fluid with respect to wall is zero.

III. RESULT AND DISCUSSION

Analysis of shear stress distribution in a meandering channel is carried out by dividing the channel into number of sections. Each meander wavelength having meander angle of 180 is divided into 10 sections at depth of 0.4m. Hence every channel in our analysis is divided into 19 sections. Shear stress values on these sections are measured at bed, inner wall and outer wall respectively.

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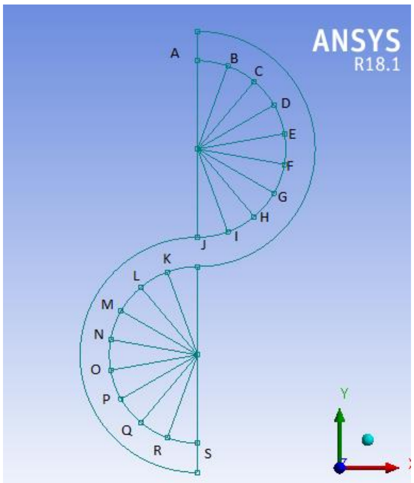

Fig 5 Sections on the meandering channel

Shear stress analysis is done for all three meandering channels at three different discharge values i.e., 1cumec, 2cumec and 3cumec.Hence a total of nine models are considered for this shear stress analysis. Contours of velocity and shear stress distribution are also obtained for all models for a better understanding of flow behavior. Shear stress values were taken in Pascal(Pa).

1. For Q(discharge) = 1 cumec.

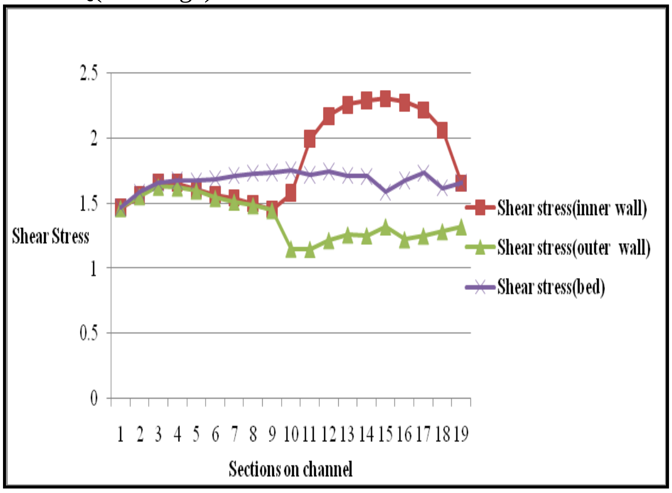

Fig 6 Graphical analysis of shear stresses for Sn = 1.47

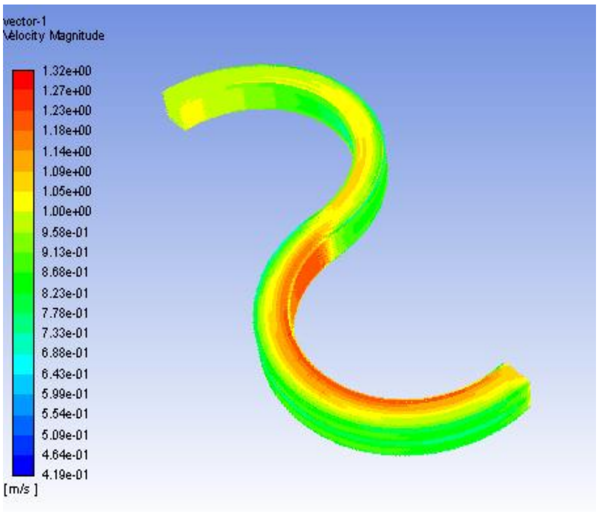

Fig 7 Velocity contours for sinuosity 1.47

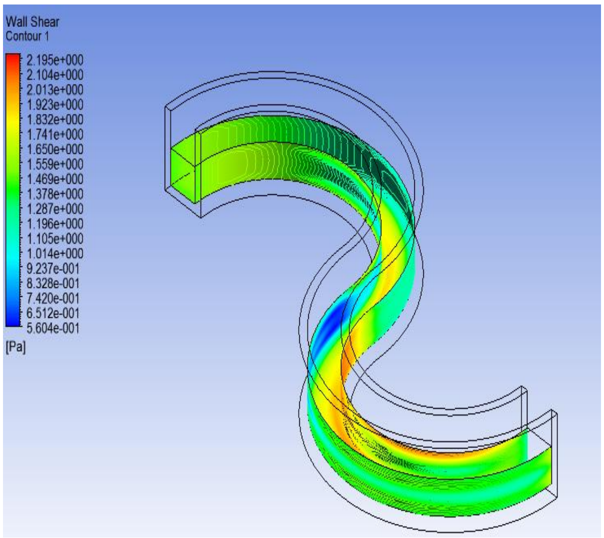

Fig 8 Shear stress contours for sinuosity 1.47

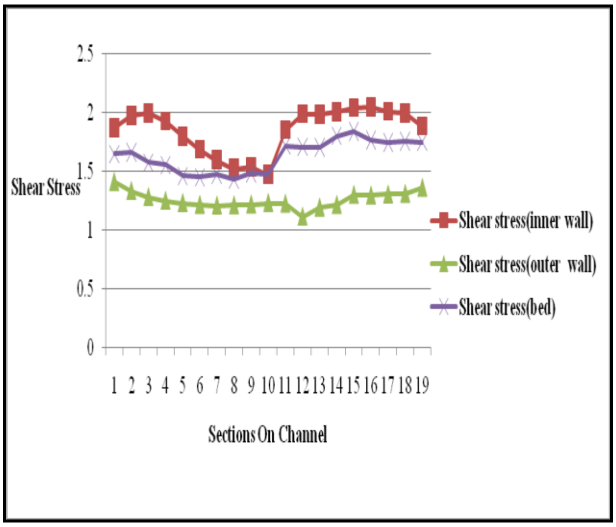

Fig 9 Graphical analysis of shear stresses for Sn = 2.0

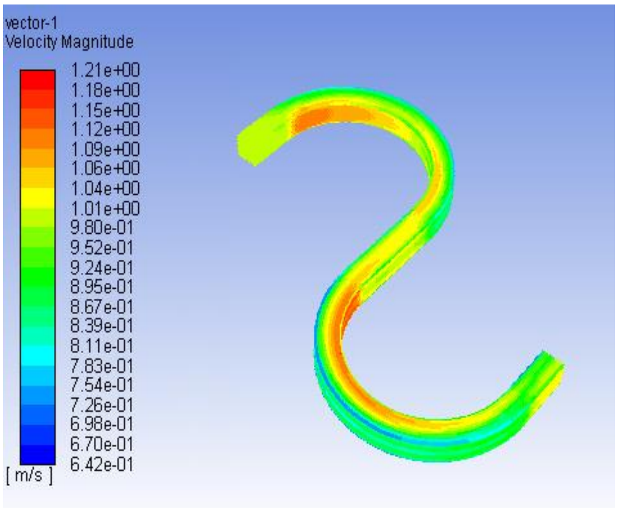

Fig 10 Velocity contours for sinuosity 2.0

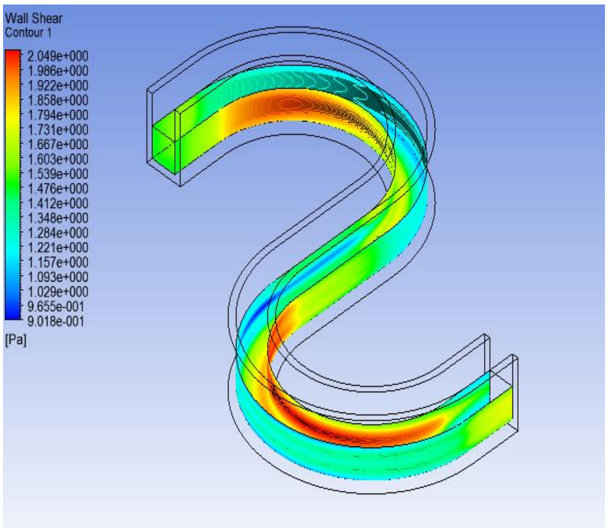

Fig 11 Shear stress contours for sinuosity 2.0

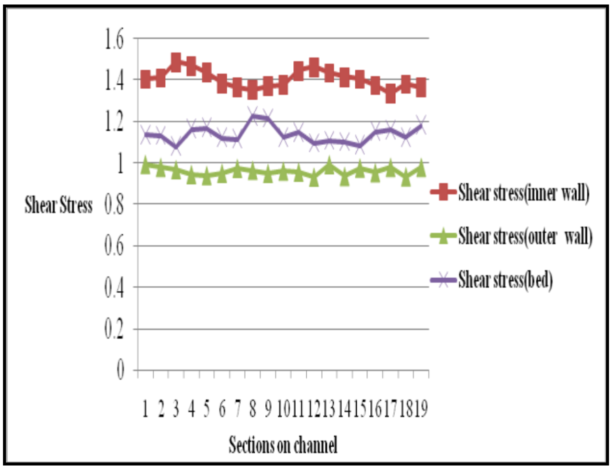

Fig 12 Graphical analysis of shear stresses for Sn = 2.53

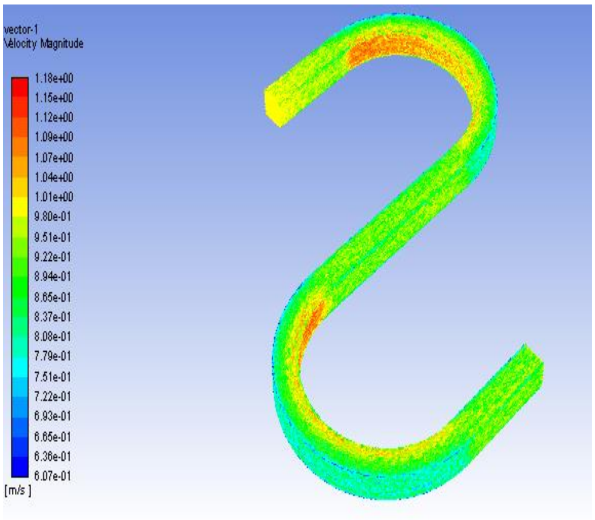

Fig 13 Velocity contours for sinuosity 2.53

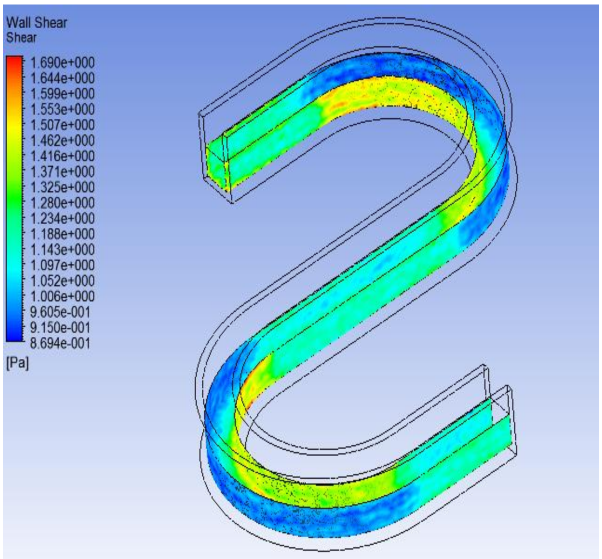

Fig 14 Shear stress contours for sinuosity 2.53

2. For Q(discharge) = 2 cumec.

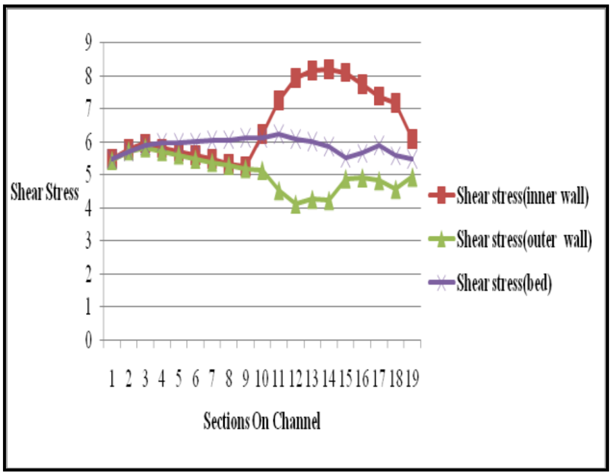

Fig 15 Graphical analysis of shear stresses for Sn = 1.47

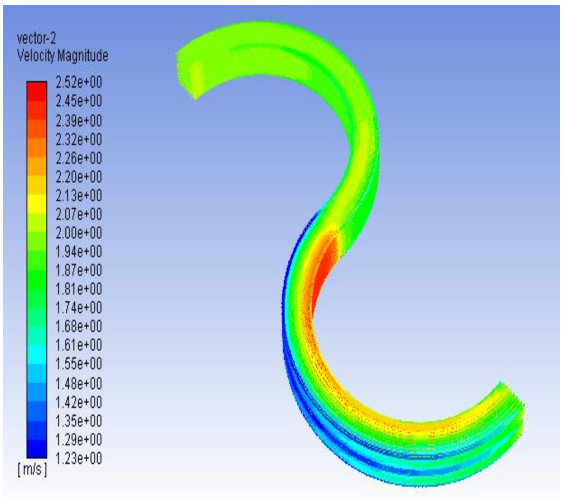

Fig 16 Velocity contours for sinuosity 1.47

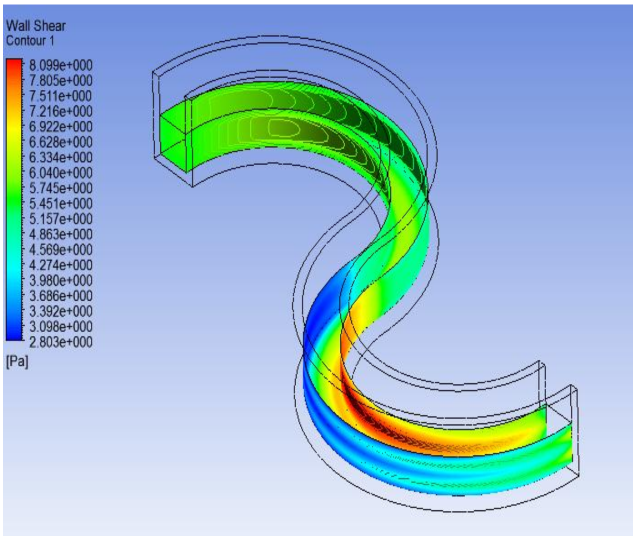

Fig 17 Shear stress contours for sinuosity 1.47

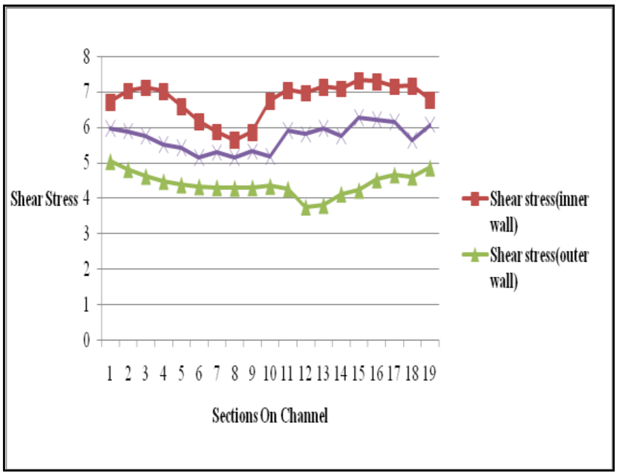

Fig 18 Graphical analysis of shear stresses for Sn = 2 .0

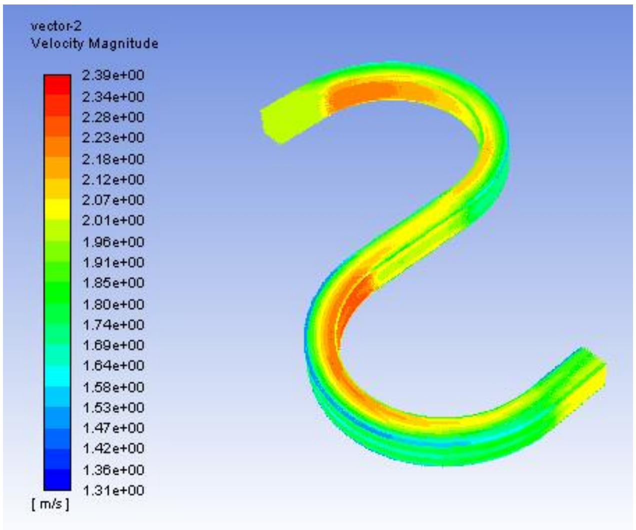

Fig 19 Velocity contours for sinuosity 2.0

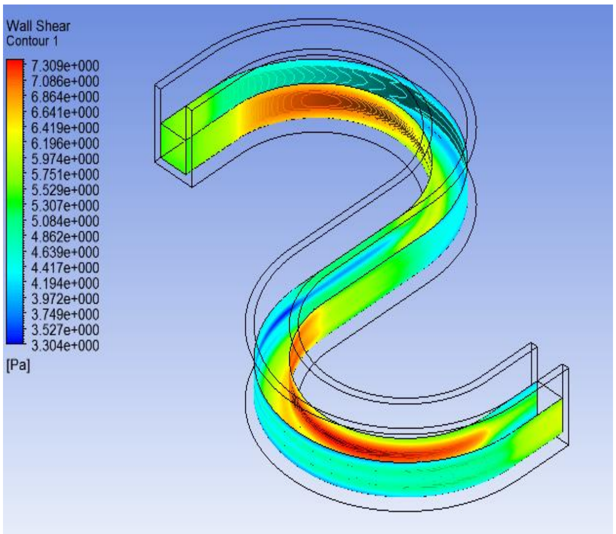

Fig 20 Shear stress contours for sinuosity 2.0

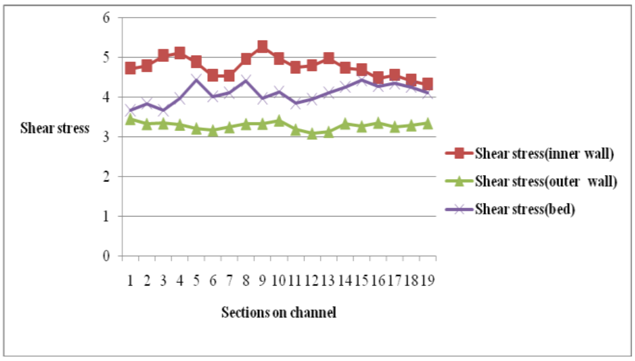

Fig 21 Graphical analysis of shear stresses for Sn = 2 .53

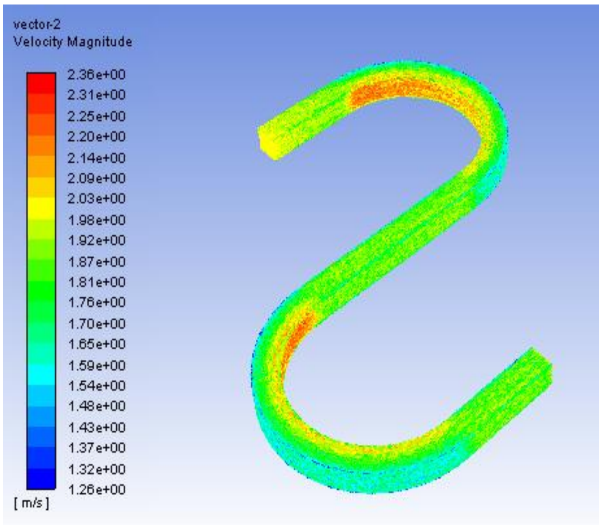

Fig 22 Velocity contours for sinuosity 2.53

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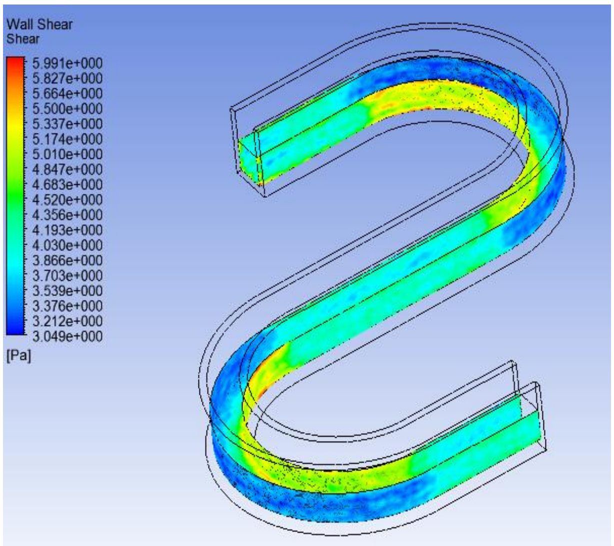

Fig 23 Shear stress contours for sinuosity 2.53

3. For Q(discharge) = 3 cumec.

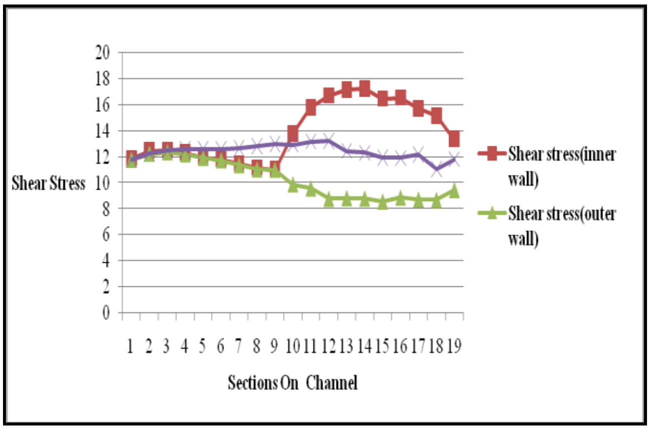

Fig 24 Graphical analysis of shear stresses for Sn = 1.47

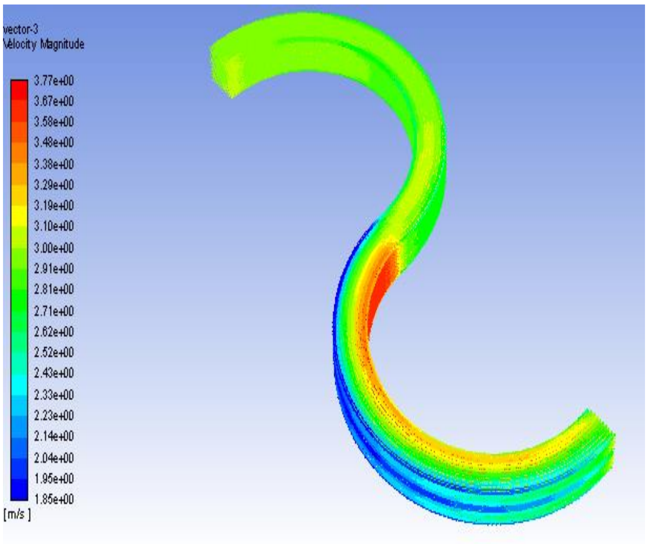

Fig 25 Velocity contours for sinuosity 1.47

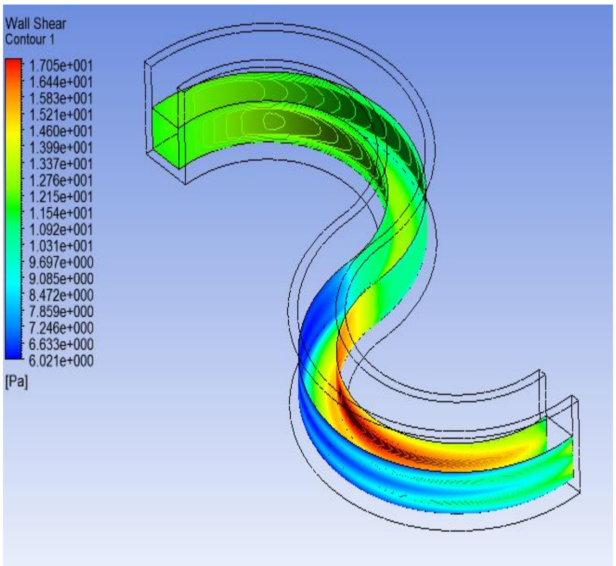

Fig 26 Shear stress contours for sinuosity 1.47

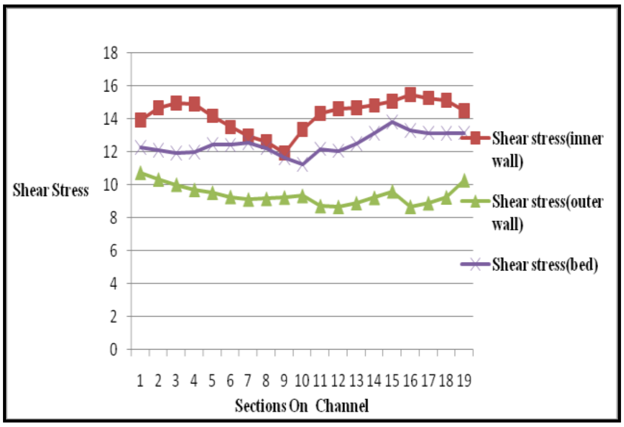

Fig 27 Graphical analysis of shear stresses for Sn = 2.0

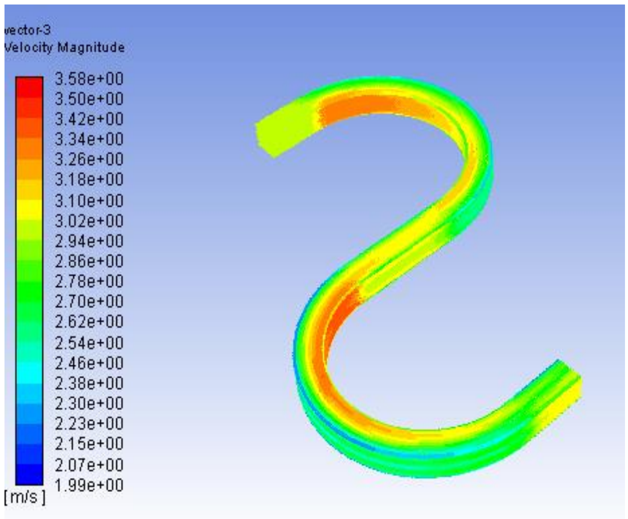

Fig 28 Velocity contours for sinuosity 2.0

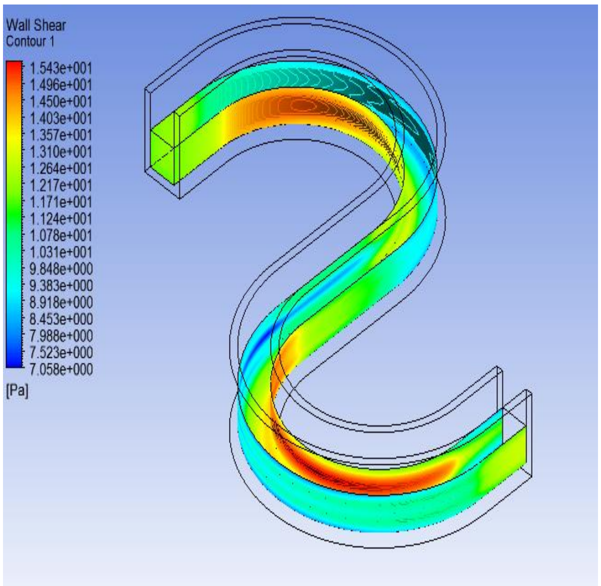

Fig 29 Shear stress contours for sinuosity 2.0

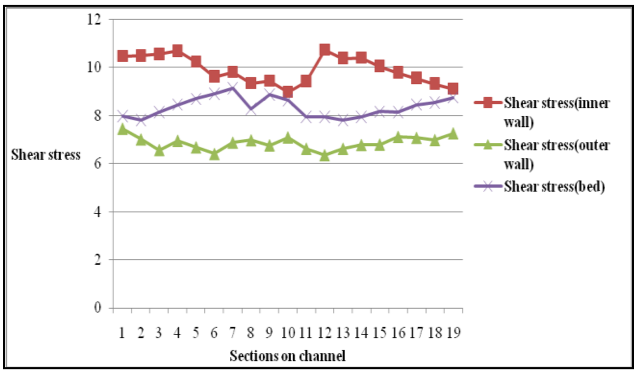

Fig 30 Graphical analysis of shear stresses for Sn = 2.53

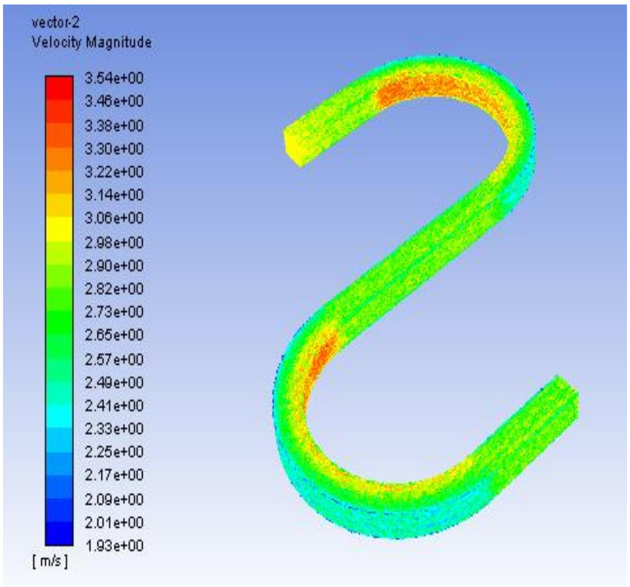

Fig 31 Velocity contours for sinuosity 2.53

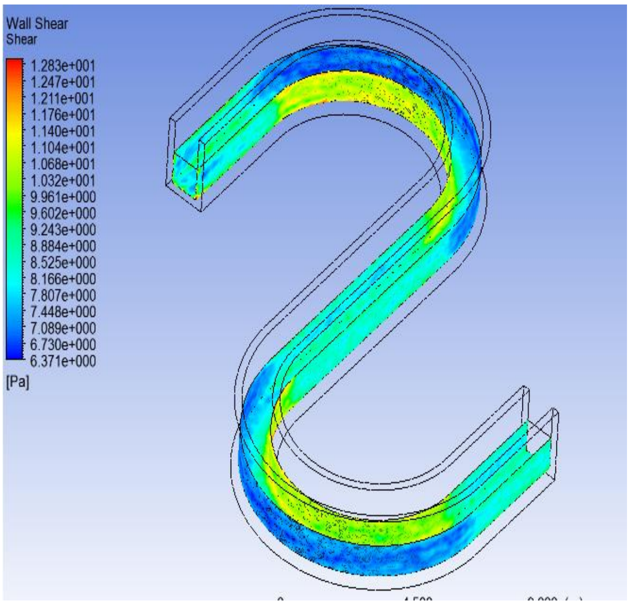

Fig 32 Shear stress contours for sinuosity 2.53

IV. CONCLUSION

- In all 9 meandering models it is observed that shear stress values on inner wall are higher than that of outer wall in meandering section.
- It is observed that percentage difference between shear stress on inner wall and outer wall decreases as the sinuosity increases which imply that presence of straighter portion in meandering section reduces the percentage difference of shear stress between channel walls.
- Inner wall shear stress values are higher on second half of channel as compared to first half. It shows that inner wall shear stresses goes on increasing as meandering propagates.
- Velocity profiles are observed to be in agreement with shear stress distribution as higher water velocity is observed at inner wall as compared to outer wall of meandering section.
- A subsequent increase in shear stress values is observed when discharge is increased at the inlet of meandering section which implies toward linear relationship between discharge and wall shear stresses.
- Sections J, K, L, M, N and O are considered to be critical having more inner wall shear stress values and higher percentage difference between inner and outer wall shear stressesA conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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