# CFD STUDIES OF MEANDERING CHANNEL

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# DECLARATION

I, Ashish Pathania, Roll No. 2K17/HFE/05 student of M.Tech (Hydraulics & Water Resource Engineering), hereby declare that the Project Dissertation titled "**CFD STUDIES OF MEANDERING CHANNEL**" which is submitted by me to the Department of Civil Engineering , Delhi Technological University, Delhi Report of the Major II which is being submitted to Delhi Technological University, Delhi, in partial fulfilment for the requirement of the award of degree of Master of Technology for the requirements of the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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# CERTIFICATE

I hereby certify that the Project Dissertation titled *"***CFD studies of meandering channel***"* which is submitted by Ashish Pathania, Roll No. 2K17/HFE/05, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment for the requirement of the award of degree of Master of Technology (Hydraulics and water resource engineering) is a record of a project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

**Place: Delhi** **Dr. Bharat Jhamnani**

**Date:** **(SUPERVISOR)**

# 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 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. LES(Large Eddy Simulation) model is used to incorporate turbulence in the model. This model is chosen due to its better performance 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.

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# CHAPTER 1

# INTRODUCTION

Rivers have always been the lifelines of civilizations. The impact of rivers and river banks on the development and growth of a civilization is pivotal. There are very many uses of rivers: irrigation, transportation, domestic purposes, hydroelectricity, tourism, political boundaries, to name a few. When water levels rise suddenly and the increase is way more than the ground can absorb then a flood occurs. Floods have the potential to wreak havoc by causing widespread damage. As a result of flooding, several lives are lost and thousands are forced to flee for safety. One of the key reasons behind the rising water levels is climate change. Therefore, floods have become one of the most debated issues nowadays. In order to make sure that the damage from flooding is minimized, river engineers are developing flood defense systems. Hydraulic model is generally used by water resource experts for predicting floods. Various features like water level profile, average velocity, shear stress forecast and accurate discharge are incorporated in hydraulic models. A complete knowledge about hydrodynamics in open channel flows is a prerequisite for developing an efficient hydraulic model which is capable of modeling the above mentioned features. In order to do so, complete information about hydraulic and geometrical parameters of river streams becomes crucial. With the change in geometrical shape, the flow of rivers change.

## 1.1 OVERVIEW

Hydraulic modeling requires a brief knowledge about available water flowing mechanisms. Information about type of channels and their geometries is discussed below:

### 1.1.1 Channel

A channel may be defined as a broad waterway between two very large areas of land which are quite close to each other. In the same way, a channel can be defined as a waterway or conduit which joins the two. A channel is also designed to connect two different water bodies. Channels are classified into three types as follows:

i. Straight Channel

ii. Braided Channel

iii. Meandering Channel

- **Straight Channel**

When a passage of a channel is free from any variation along its flow then it is known as a straight channel. Normally a naturally occurred fault or error in the base rock controls such a channel. Among natural rivers, true straight channels are very rare. Very short reaches or segments of a channel might be straight but segments of a channel which are straight for a long distance are very rare. An example of straight channel is shown in Fig. 1.1.

**Fig.1.1.** Straight Channel

- **Meandering Channel**

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. The sediment erosion of outer wall of curve (concave) and its deposition on the inner wall of curve (convex) is the main cause of the formation of a meander. In other words, the flow of water causes erosion of outer side of the bend and deposits the eroded sand on the inner side of the bend which leads to the formation of a meander. The outer side and inner side are also known as concave side and convex side respectively. An example of meandering channel is shown in Fig. 1.2.

**Fig.1.2.** Meandering Channel

- **Braided Channel**

A river or a channel is known as braided when the river is forced to split into several channels separated by islands which are called braid bars. Over time these channels get interconnected. In other words channels get diverted from the main channel and then again join it at downstream. An example of braided channel is shown in Fig. 1.3.

**Fig.1.3.** Braided River

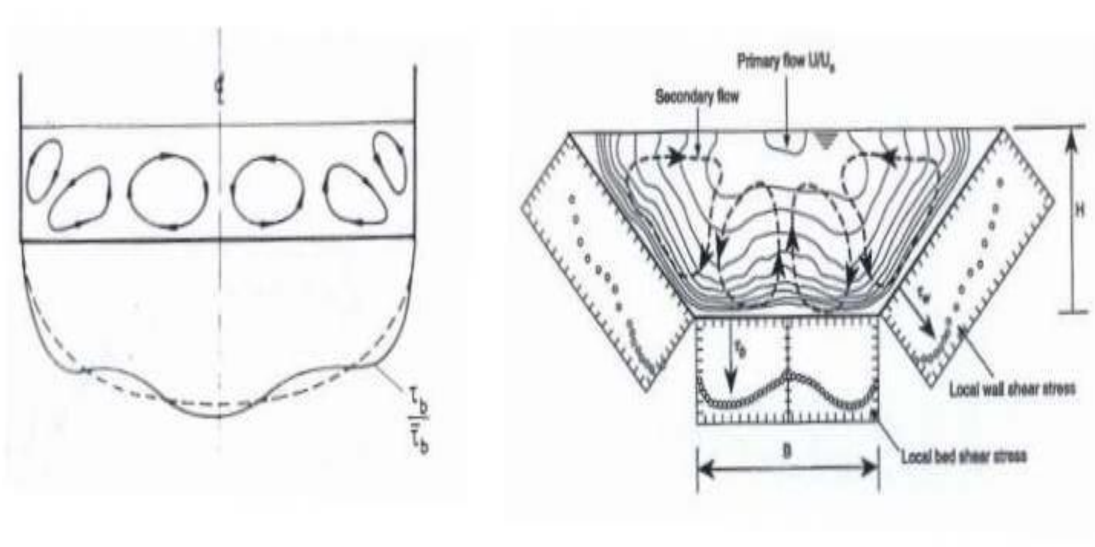
### 1.1.2. Meandering

Probably, Inglis (1947) was the first one who defined the term meandering and it says that during the floods when banks are not tough enough to resist the excess turbulent energy developed in the flow, the banks erode and the river widens and shoals". In other words, the channel which makes its way across the floodplain is called meandering channel. Most of the natural rivers have a tendency of meandering. Straight natural rivers are seldom found except for short segments.

Mostly when river passes through the flat plains then meandering is observed in the middle portion of river. For long distances water rarely flows in straight direction under gravity hence a winding course develops soon. The irregularities of the ground force the river to swing in great s-shaped curves called meanders. The path of flow in a meandering river observes a continuous change along the course which results in a non-uniform energy dissipation over the length of meander. In a meander channel, the motion or movement has two components: longitudinal component which is almost uniform and transverse component which varies a lot over the wavelength of a meander. Generally, a bend or curve in a sinuous course of water which develops due to the erosion of the outer bank of a stream is known as meander. Theoretically, a meander channel is represented by a sine generated curve. One of the factors which control the shear distribution and velocity in a meandering river or channel is the 'meander index' or 'sinuosity'. Sinuosity or meander index of a river tells the deviation in the course of the river from the shortest possible path.

### 1.1.3. Boundary Shear Distribution

The bed and channel walls resist the force which is developed in the direction of flow when water flows in the channel. This resisting force is manifested as boundary shear stress. In other words, the tangential component of hydrodynamic forces which act along the channel bed is known as boundary shear stress. In an open channel, the flow structure gets directly affected by the distribution of this force along the wet perimeter. In order to study velocity distribution and flow field , one should have a thorough understanding of boundary shear stress distribution. Brief analysis of boundary shear stress distribution can provide solutions for many hydraulic problems. Side wall correction, bed form resistance computation, channel migration, sediment transport, dispersion and conveyance estimation, to name a few. Theoretically, when the steady and uniform flow take place then the tractive force depends on unit weight of fluid, bed slope and hydraulic radius. However, it has been well established that such kind of forces are not uniform even when the channel have the simpler geometry and straight path. Furthermore, the tractive force is a quantity which is turbulent and consist a varying component which is being superimposed on the mean value. The reason behind this varying component is the anisotropy among the transverse and vertical turbulent intensity and it is determined as secondary currents. It is responsible for the non-uniform shear stress, according to Gessner, 1973. Even though the secondary velocity comprises about just two to three percent of primary mean velocity, it convects energy, momentum and vorticity toward the corners and gradually makes them move away along the boundaries. As proved by Knight (1983) and Tominaga(1989) that when secondary current flows toward boundary wall then the boundary shear stress increases and boundary shear stress values decreases as it moves away from boundary wall. The distribution of shear stress is affected by the presence of flow cells in the main flow when seen at channel wetted perimeter as shown in Fig. 1.4.




a) Rectangular cross-section (Knight et al., 1983) b) Trapezoidal cross-section (Knight et al., 1994)

**Fig.1.4.** Interactions of boundary shear distribution and secondary flows.

The structure and number of secondary flow cells, sediment concentration, shape of cross-section, distribution of wall roughness in lateral and longitudinal direction and depth of flow are other factors which have an impact on the shear stress distribution in straight channel. These factors observe a many fold increase in number when it comes to meandering channels. This huge increase is attributable to the accretion in 3D nature of flow. A crucial parameter for computing the shear force percentage at channel bed and walls is the sinuosity of the meandering channel.

### 1.1.4. Numerical Modeling

Despite the fact that we have a clear understanding and precise results on the phenomena of flow, there are a few drawbacks in the experimental approach. For instance, data collection is a long process and the data can only be collected for a limited number of instances because of instrument constraints. Therefore, it can be said that usually a model does not works at its best. Experiments are unable to capture the three dimensional behavior of flow and some other complicated tumultuous structures which are innate features of an open channel flow efficiently. In order to deal with such circumstances, approaches which are computational in nature put forward complimentary tools by overcoming such issues. Computational approaches have an edge over experimental studies because of the following features of an computational approach:

- Repeatable
- Flow generation, considering all data points
- Simulation at full-scale
- Turbulence prediction

Numerical modeling can identify some of the difficult turbulent structures like Reynolds stress, secondary flow cells, and vorticities distinctly and effectively. In open channel flows, these structures are very essential for studying energy expenditure. Over the last few years, open channel flows have been modeled numerically and have been validated with experimental results successfully. A mathematical process developed for the simulation of open channel flows using numerical methods and modeling is known as Computational Fluid Dynamics (CFD). It is able to model in-bank flows as well as over-bank flows. A brief description of CFD process is as follows: In order to solve a fluid problem, a prerequisite is the understanding of basic physical fluid properties. This can be acquired by studying basics of fluid mechanics. Then, mathematical equations can be implemented for describing these properties. Navier-Stokes equation is a guiding equation of computational fluid dynamics. This equation is analytican and therefore, can be solved on paper. But in order to solve it on computer, it needs to be translated into discretized form. Finite volume methods are used as translators for discretization of governing equations. After discretization, programs are written for solving them using languages such as C and Fortran. Simulation results are obtained at the end. Simulation results are analyzed and the whole process is repeated until one gets desired results. The accuracy is dependent on mesh quality and flow simulation model.

## 1.2 RESEARCH OBJECTIVE

The primary objectives of this thesis 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.

## 1.3 ORGANIZATION OF THESIS

The thesis is reported as follows: Chapter 2 entails a review of related literature. Chapter 3 presents the various steps involved in numerical modeling of a meandering channel followed by Chapter 4 consisting of all contours and vectors obtained from numerical simulations and present the analysis of results in the form of tables and graphs. Finally, the conclusion and future scope for the research is presented in chapter 5.

# CHAPTER 2

# LITERATURE REVIEW

Many studies have been done in the field of open channel flow especially on boundary shear stress and velocity distribution. A summary of the studies conducted in the domain of boundary shear stress in open channel flow is presented in this section. Many researchers are focusing on boundary shear stress in open channel flow for so long.

Studies are considering various aspects to get to know the factors which have an impact on boundary shear stress. Some examples of such aspects are different channel geometry (straight channel or meandering channel or simple & complex channels with different kind of surface such (smooth or rough)); different cross-section of channels (trapezoidal or rectangular).

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 which is compound in nature. k-ω model, non-linear k-ε model, standard k-ε model, large eddy simulation (LES), Reynolds stress model (RSM) and algebraic Reynolds stress model (ASM), to name a few. ‘Standard k- ε model’ is a good option to simulate the turbulence but it is unable to procreate secondary currents. Although ‘nonlinear k-ε model’ is capable of simulating secondary flows in a compound channel successfully but it is unable to capture several turbulence structures accurately. Due to the fact that ASM makes use of adhoc expressions in order to solve Reynolds stress transport equations, it is economical. But, on the downside, ASM simulation results are not satisfactory and vary from experimental results. Stress transport equation by Reynolds is solved directly to compute Reynolds stresses in RSM but because of a complex model its applicability to open channel is limited. Spatially-averaged Navier-Stokes equation is solved by LES. Eddies which are smaller than mesh are modeled whereas the larger ones are resolved directly. For industrial applications, LES is costly computationally but it is capable of modeling almost all eddy sizes.

**Cokljat &Younis and Basara & Cokljat (1995)** simulation of rectangular open channel flows was done with the help of RSM (Reynolds stress model) and results were compared with experimental data. Simulation results were satisfactory when compared with predicted outputs.

**Thomas and Williams (1995)** experimental results obtained from Hydraulics research lab Wallingord , England 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.

**Salvetti et al. (1997)** LES model was again implemented to simulate the open channel flows and various parameters like velocity profiles and shear stress distributions were obtained by repeated iterations.

**Ahmed Kassem, Jasim Imran and Jamil A.Khan (2003*)*** In this study, diverging channel with sloping base was simulated and k-€ turbulence model with various modifications was used. Boussinesq approximations were used to modify the conditions in k-€ turbulence model.

**Lu et al. (2004)** In this study, numerical simulations were done to simulate the flow in 180 bend. From various turbulence models k-€ model was used and various properties like wall shear distribution and water depth variations were observed.

**Booij (2003) and Vanbalen et al. (2008)** studied the secondary flows in open channel flow through numerical simulations of 180 bend. Effect of secondary flows was observed on various parameters like longitudinal velocity distribution and shear stress etc.

**Esteve et.al., (2010)** Numerical simulations were done for the prediction of flow in a compound meandering channel having flat bed and a medium curvature. Simulation was done using LES. Authors used the Muto and Shiono (1998) configuration. The in-house code LESOCC2 was incorporated for LES simulation. The expected secondary flow variations, water velocities and turbulent intensity came out to be in agreement with the laboratory measurements.

**Ansari et. al., (2011)** Wall shear distributions were analyzed in a trapezoidal channel. Parameters like aspect ratio and bed roughness were varied and their effect was analyzed . The simulation results emphasize the the importance of the study on secondary flows. Secondary flows affect the longitudinal velocity profiles in a channel.

**Khazaee&M.Mohammadiun (2012 )** Finite volume method was used to prepare a CFD model of an open channel .Simulations were carried out for different slopes and different aspect ratios. Effect of providing convergent and divergent section in an open channel was also studied.

**Omid seyed ashraf, Ali Akbar Akhtari &Milad KhatibShaidi (2012)**

They recall the use of standard k-ϵ model for modeling the open channel flows and reasoned that it can simulate many features accurately. But still the effect of secondary flows wasn't observed that much prominent on flow properties.

**Manaswinee Patnaik & K.C. Patra (2013)**

Experimental data was collected 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.

**Arpan Pradhan, Kishanjit Kumar Khatua and Sovan Sankalp (2018)**

Authors studied the difference in the plots of velocity distribution for meandering channels with varying bed roughness. Authors analyzed the effect of curvature and bed roughness of a meandering channel on how velocity varies. They concluded that toward the inner wall velocity distribution stays higher for both instances of bed roughness.

# CHAPTER 3

# METHODOLOGY

## 3.1 Numerical Modeling

A domain of fluid mechanics which makes use of algorithms and numerical approaches for solving and analyzing the problems related to flow of fluids is known as Computational Fluid Dynamics (CFD). In order to perform calculations and simulation of gases and liquids interaction with surfaces defined by boundary conditions, computers are required. One can achieve better and more accurate results by using high-speed supercomputers. Ongoing research yields software which enhances the speed & accuracy of simulation processes which are complex. For example, turbulent or transonic flows. It began in around 1960. With improving speeds of computer processors, CFD simulation is becoming more accurate. Modeling precision, combined numerical accuracy and cost of computation are here factors on which CFD simulation relies on.

The guiding equation of almost every CFD problem is the Navier–Stokes equations. These equations can be made simple by eliminating the terms which describe viscosity to yield Euler equations. Furthermore, removal of vorticity produces full potential equations. Finally, linearized potential equations can be yielded by linearizing these equations for small perturbations in case of supersonic and subsonic flows. A straightforward solution for equation for flow does not exist.

Iteration are done on the basis of boundary conditions provided manually and solution s are obtained.

Numerical simulations of a fluid flow basically consist of four steps:

1. Problem identification

    - Determine the objective of modeling.

    - Selecting the domain of model.

2. Pre – Processing

- Creating geometry using Design Modular tool in ANSYS.
- Meshing of the domain
- Setting up of physics
    - Add materials if required.
    - Selecting an appropriate model (Laminar , Turbulent).
    - Overview the cell zone conditions.
    - Providing the required boundary conditions

3. Solver
    - Initialization of problem .
    - Provide the suitable number of iterations and analyzing the convergence of residuals.
4. Post processing
    - Analysis of results in the form of contours and vectors using CFD Post tool.
    - Obtaining all the relevant graphs and point readings.

## 3.2 GEOMETRY SETUP

In this step of numerical modeling a geometric model is constructed which is further divided into number to nodes. In our case geometry consist of three models of the meandering channels having different sinuosity i.e., 1.47, 2.0 and 2.53. The geometries are constructed using design modular tool in ANSY 18.1. The geometries are shown below:

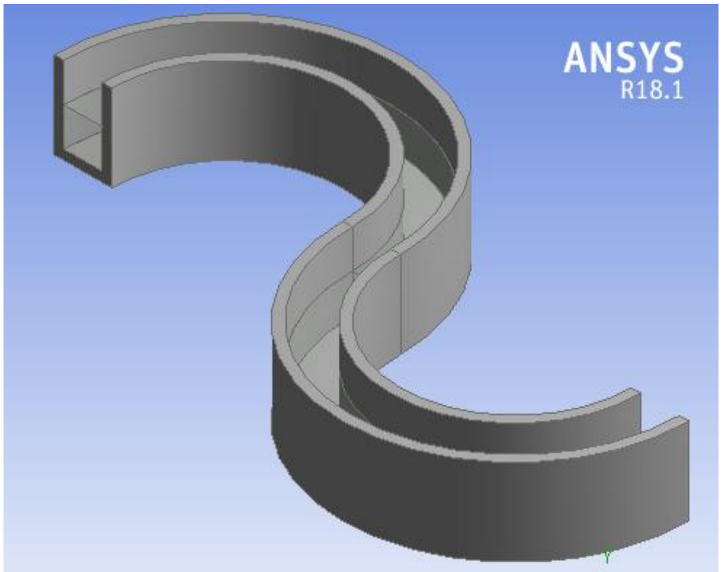



**Fig.3.1.** 3D Meandering Channel of Sinuosity 1.47

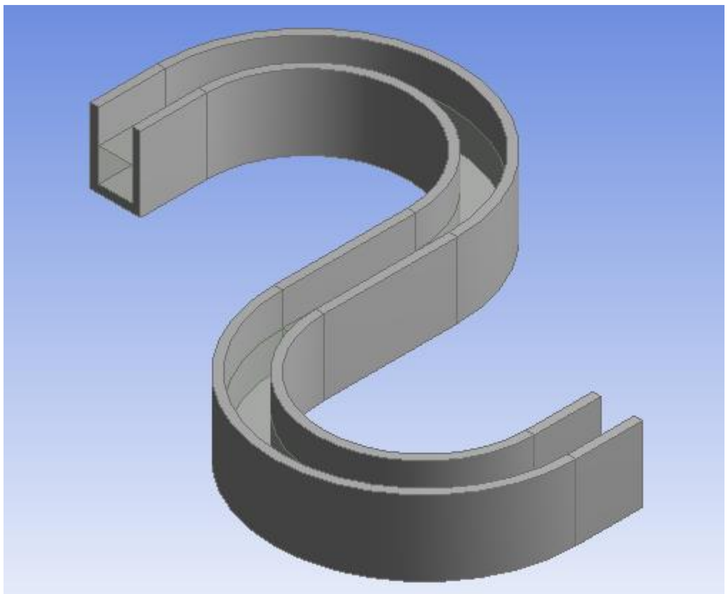


**Fig.3.2**. 3D Meandering Channel of Sinuosity 2.0

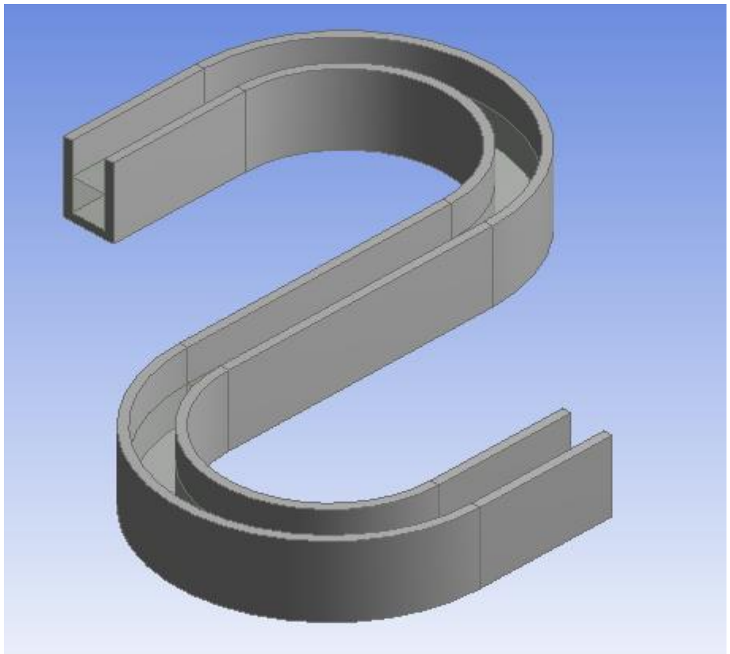


**Fig.3.3.** 3D Meandering Channel of Sinuosity 2.53

All three meandering channels are provided with 180 meander angle and similar inlet dimensions i.e., width and height of 1m.The difference in geometries become more noticeable when we observe the top view of our 3D geometries.

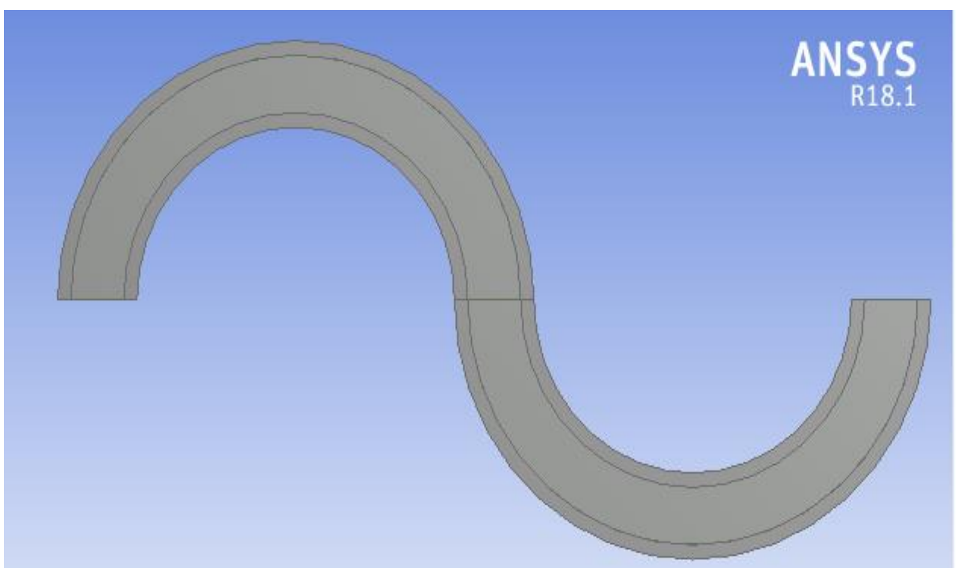



**Fig.3.4.** Top view of Meandering Channel of sinuosity 1.47

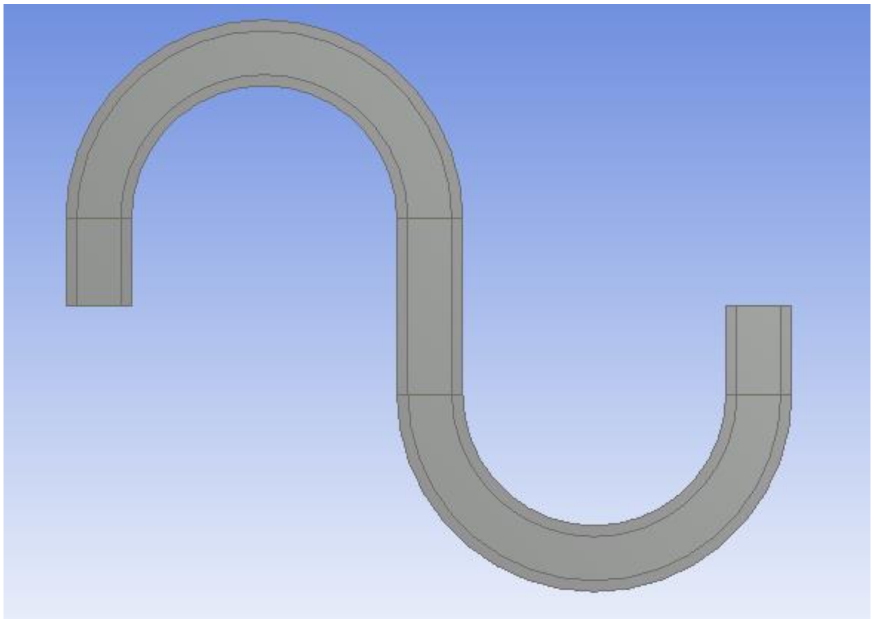


**Fig.3.5.** Top view of Meandering Channel of sinuosity 2.0

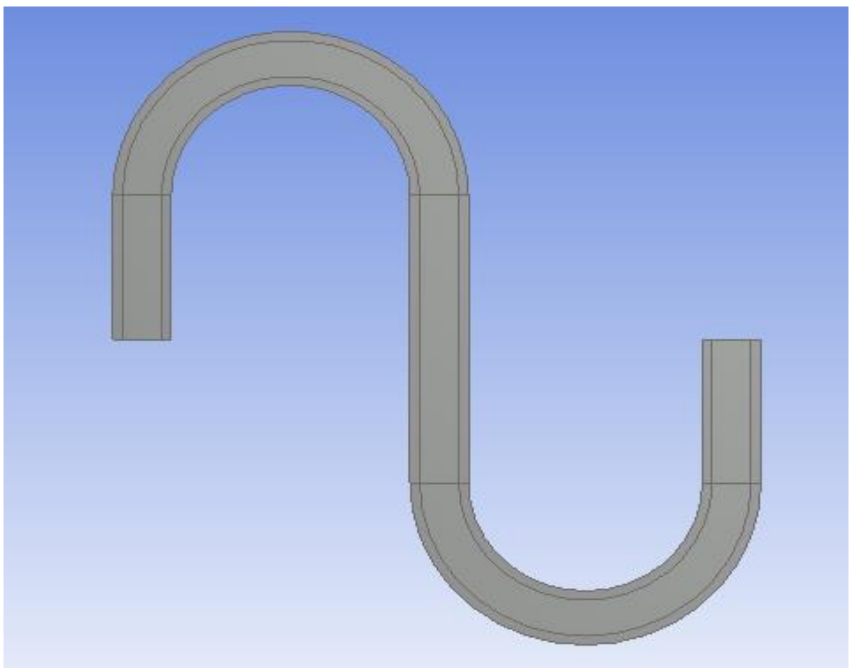


**Fig.3.6.** Top view of Meandering Channel of sinuosity 2.53

## 3.3 MESHING

### 3.3.1 Meshing of domain

Cartesian co-ordinate system is used to for meshing of domain which forms the basis of solving the governing equations for fluid flow (equation of continuity and momentum equation). Continuum is divided into a countable number of nodes. A time marching scheme and a spatial discretization scheme is required by CFD. Domain discretization depends on Finite Volume, Finite element and Finite difference method. In Finite element method domain is divided into number of elements. By integration of shape function and weighted factor in the suitable domain, one gets the numerical solution. This technique is applicable for structured as well as unstructured mesh. Division of domain into countable number of volumes is a key requirement of applying Finite volume method.The equations are solved in the center of cell to calculate the specific variable. Conservation law is taken into account for developing his method. Finite Volume method is appropriate for unstructured domains. Taylor's series approximation forms the basis of Finite Difference method. It is generally used for regular domain.

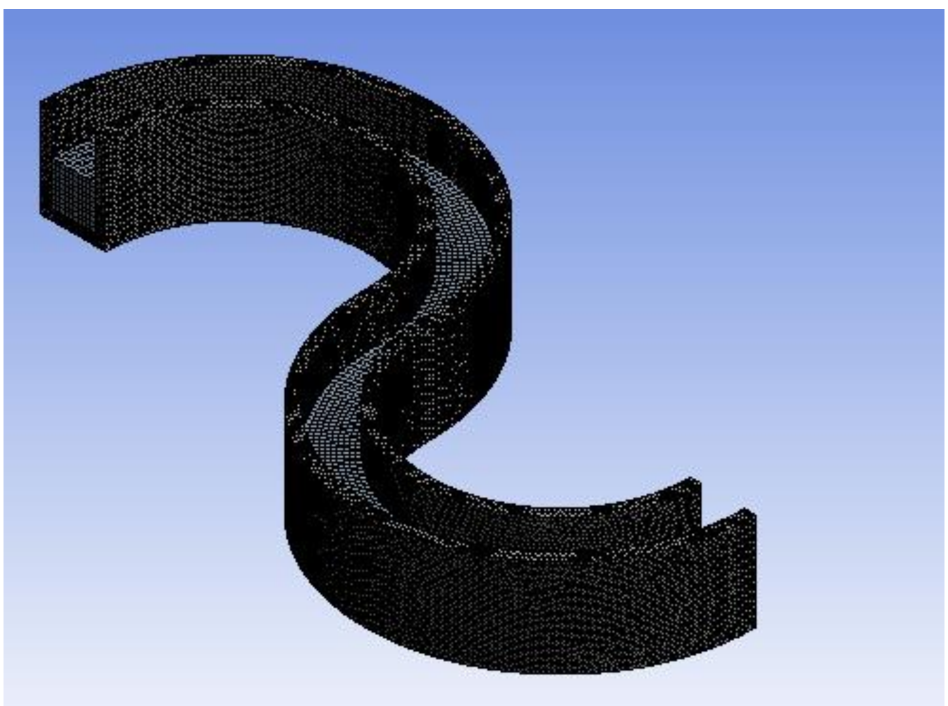


**Fig.3.7.** Overview of Meshing for Sn = 1.47

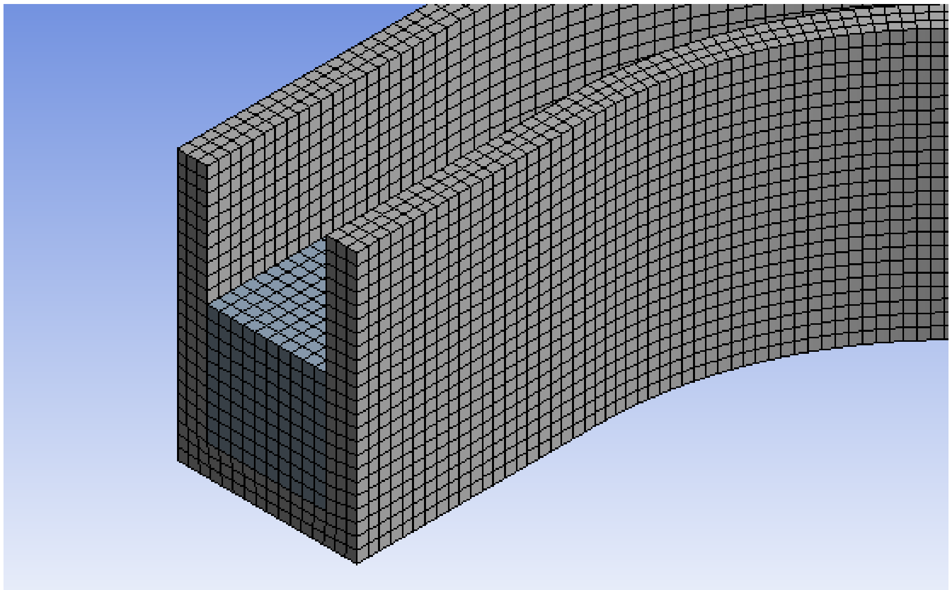


**Fig.3.8.** Zoom view of generated mesh

| Meshing Details | |
|---|---|
| Size Function | Uniform |
| Relevance Center | Fine |
| Transition | Slow |
| Min Size | 0.10 m |
| Max Face Size | 0.10 m |
| Max Tet Size | Default (0.552680 m) |
| Growth Rate | Default (1.20 ) |
| Automatic Mesh Based Defeaturing | On |
| Defeature Size | Default (5.e-002 m) |
| Minimum Edge Length | 0.250 m |

**Table 3.1:** Sizing details of generated mesh for channel of sinuosity 1.47

All the finite element calculations are done on nodes and element values so a statistical idea of nodes and elements of the mesh should be analyzed.

| Statistics | |
|---|---|
| Nodes | 85993 |
| Elements | 312870 |

**Table.3.2:** Mesh statistics for channel of sinuosity 1.47

Named selection is an integral step in meshing operation in which all the significant parts of model are given different names. This step become crucial because later on boundary conditions are mentioned on the basis of named selections. In our case channel is divided into different sections i.e inelt , outlet , flow domain and channel wall.

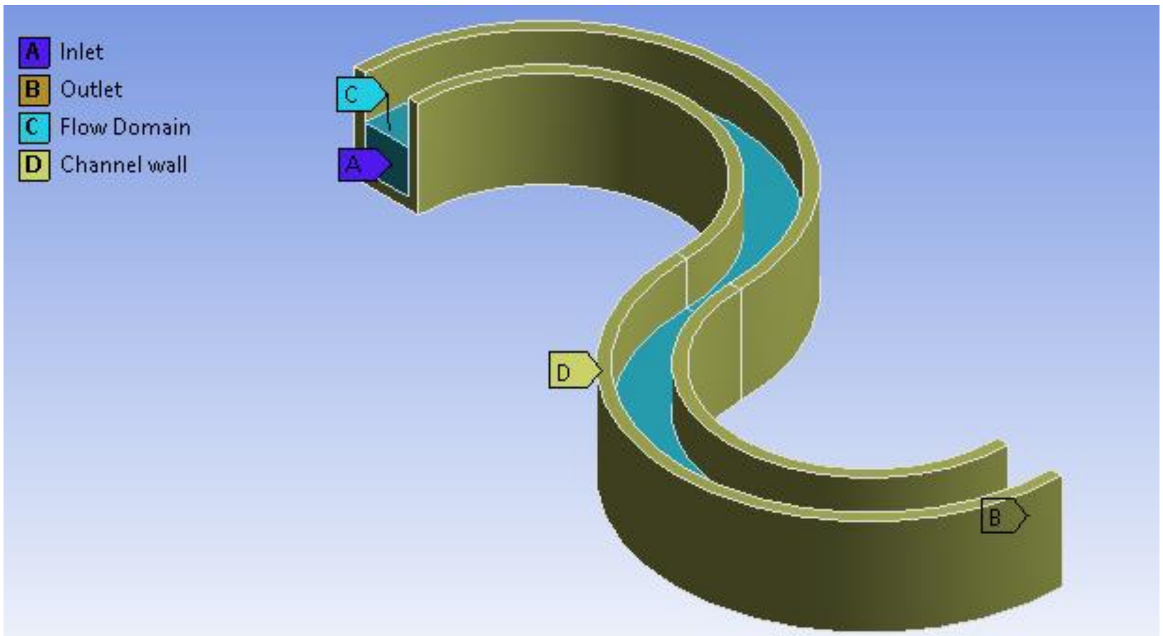



**Fig.3.9.** Named selections of the geometry

### 3.3.2 Grid independence study

To study the effect of grid size and fine meshing on the results of a numerical model grid independence study is carried out. It tends to eliminate the dependence of the numerical modeling results on the finer meshing methods. To perform the grid independence study we compare the results of two different mesh size models in which second meshing is more finer than the first one. If no significant change in results is observed by meshing the model much finer, we can say that over model is grid independent.

In our case we consider the meandering channel with sinuosity 1.47 and undergo its meshing into two different mesh sizes. Then the bed shear stress values obtained from both the meshing sizes are compared.

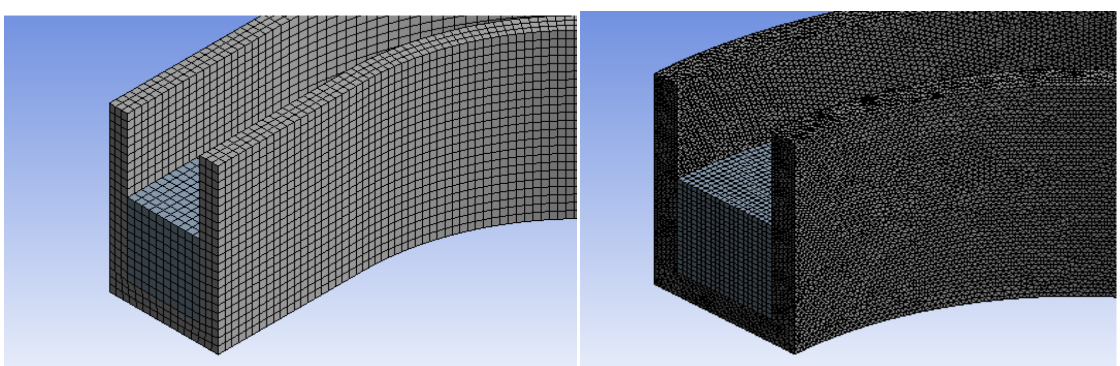


**Fig.3.10.** Zoom view of Meshing 1 and Meshing 2 respectively

A clear comparison can only be seen when we compare the mesh statics of both the meshing sizes.

| Mesh Statistics | No. of nodes | No. of elements |
|---|---|---|
| Meshing 1 | 85993 | 312870 |
| Meshing 2 | 580673 | 2203921 |

**Table.3.3.** Comparison of mesh statistics for meshing 1 and 2

Numerical simulation is carried out for channel with sinuosity 1.47 and discharge 1 cumec for two different mesh sizes. Results are shown below:

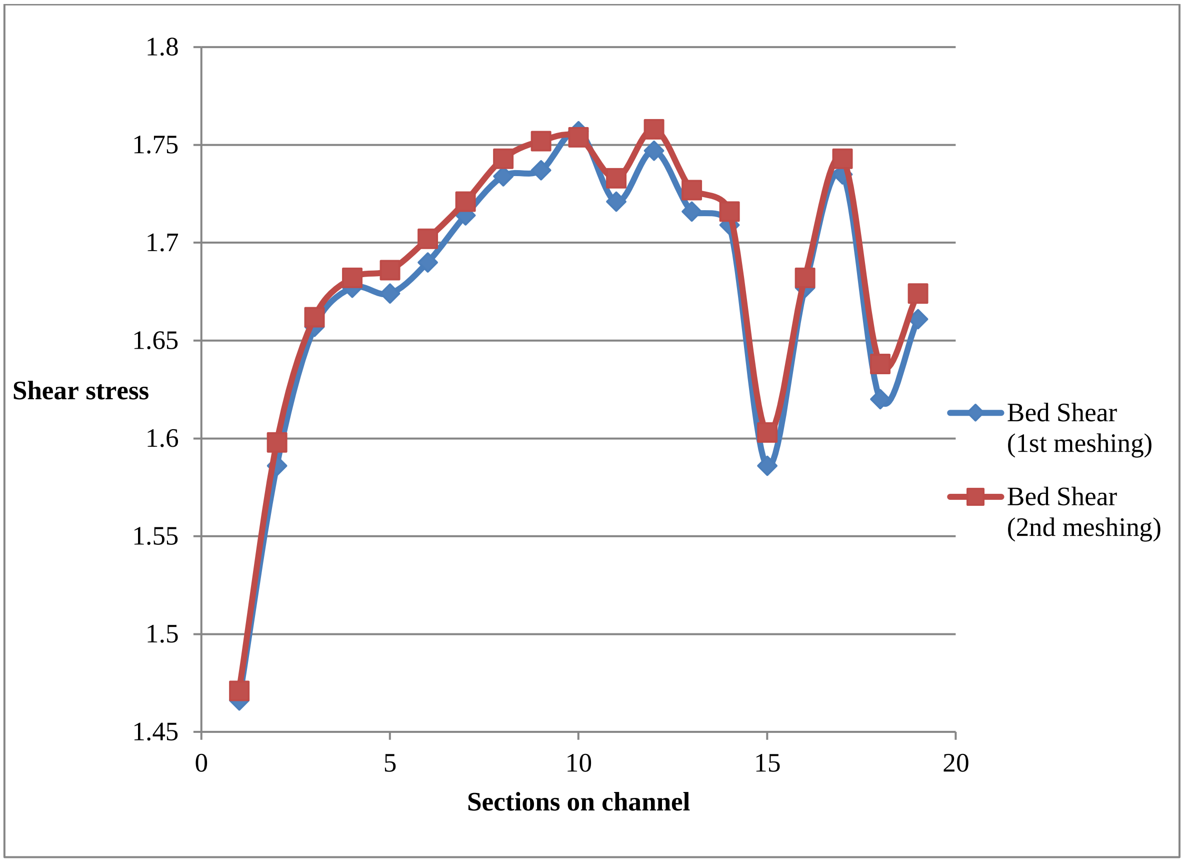



**Fig.3.11.** Comparison of bed shear stress results for meshing 1 and 2

As we see the statistics data for mesh 1 and 2 it is clearly visible that mesh 2 is finer than the mesh 1 but on the other hand it also takes more time for calculations. The results obtained from both the meshing sizes are almost similar and only a minimal difference is observed in the numerical results.

Hence it is evident from the analysis that our model is grid independent and further refinements in the mesh don’t bring any significant changes in our numerical results.

## 3.4 SETUP

After the meshing operation we enter into setup part. In this step suitable models on the basis of number of phases and nature of flow are chosen. Choice of model is a crucial factor requires sufficient learning about model specifications and requirements.

### 3.4.1 Multiphase Models

ANSYS provide various multiphase models depending upon the number of phases required in the model setup. From all the available alternatives VOF (Volume of fluid) model is selected consisting two Eulerian phases i.e. water and air. Also, the flow is specified as open channel flow by ticking the dialog box and implicit approach is chosen over explicit one.

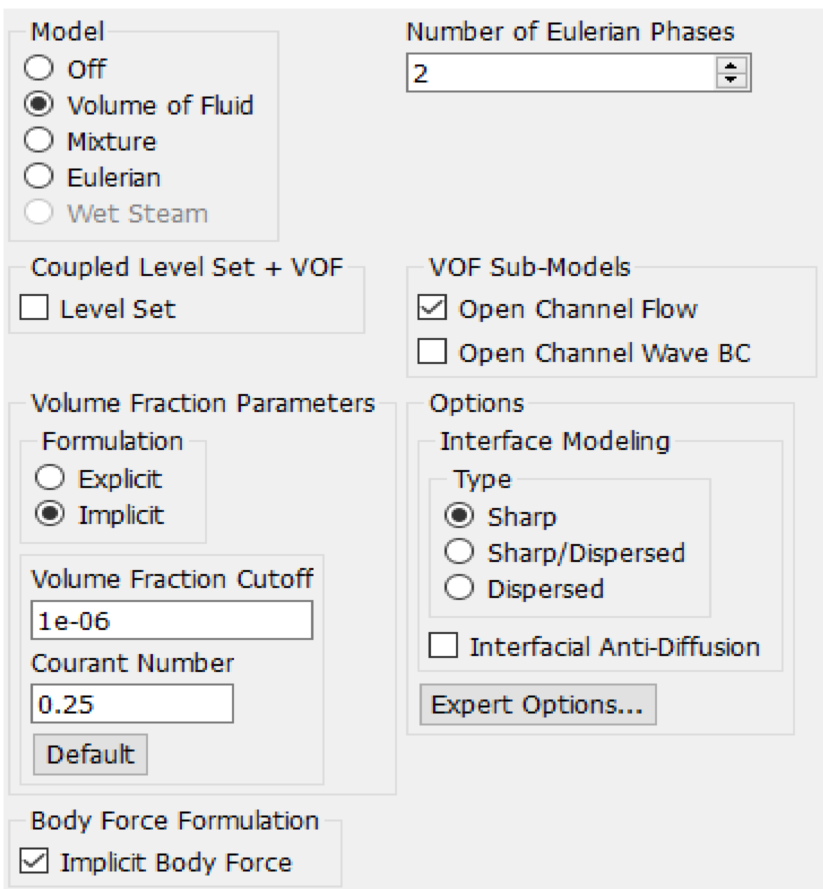



**Fig.3.12.** Selection of multiphase model

### 3.4.2. Turbulence Models

Turbulence is from one of the upper hands of numerical simulation over experimental work. It can be easily incorporated in case of numerical simulation and calculations can be performed easily. ANSYS Fluent provides various turbulence models depending upon required results. Large Eddy Simulation (LES) model is selected to simulate the open channel characteristics.

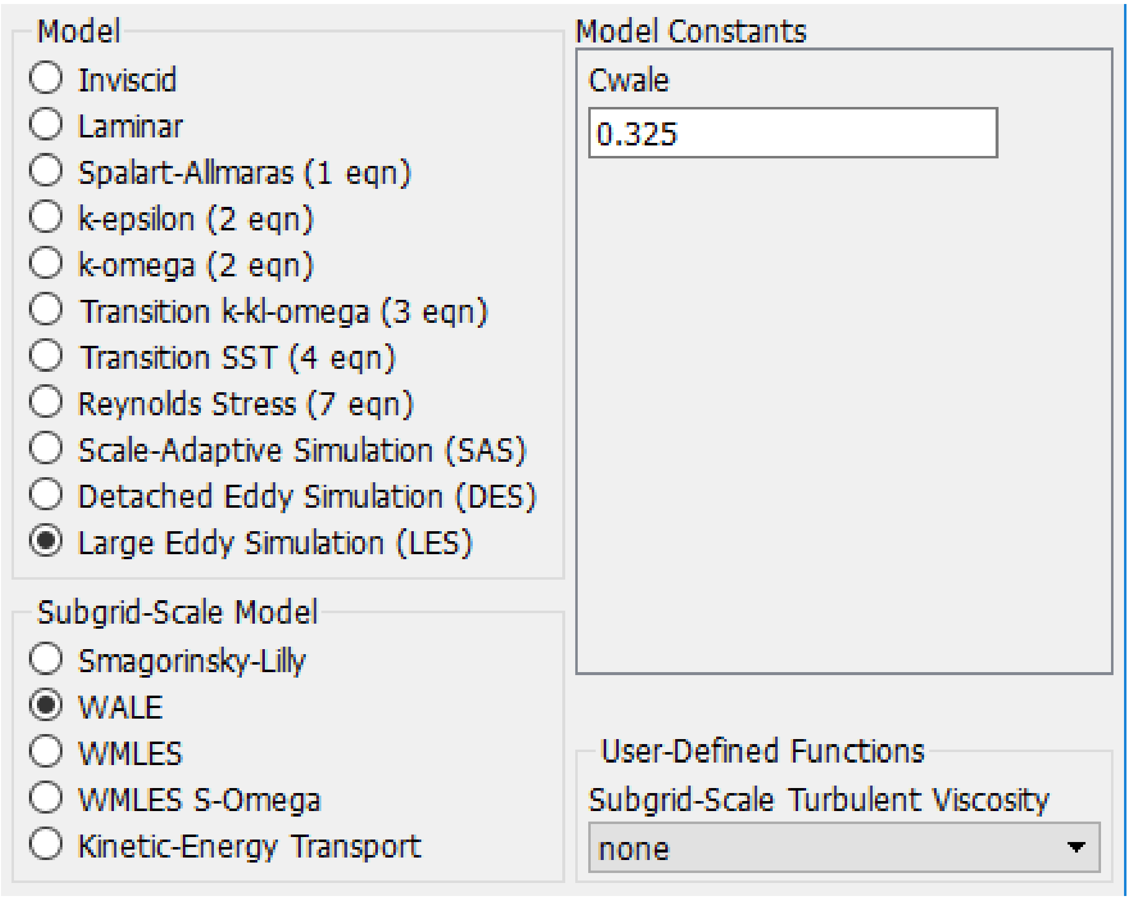



**Fig.3.13.** Selection of turbulence model

LES i.e., large eddy simulation model is chosen over other turbulence models because of its various advantages over other models like better output of open channel flow results. Required sub-grid scale model and model constants are chosen by ANSYS automatically.

### 3.4.3. Large Eddy Simulation (LES)

Turbulence methodologies are categorized into three main types: Large eddy Simulation (LES), k-epsilon modeling and Direct Numerical Simulation (DNS). Space or time averaging is used to model a turbulent flow in k-epsilon modeling. When the solution is time dependent averaging neglects the most of the features therefore, it is unsuitable for the flows which are transient. DNS tries to solve all spatial and time scales and provides a very accurate output. However, it becomes computationally intensive because in order to solve complete range of scales, it needs very small temporal and spatial grids which results in a delay in process and it takes very long time to be solved.

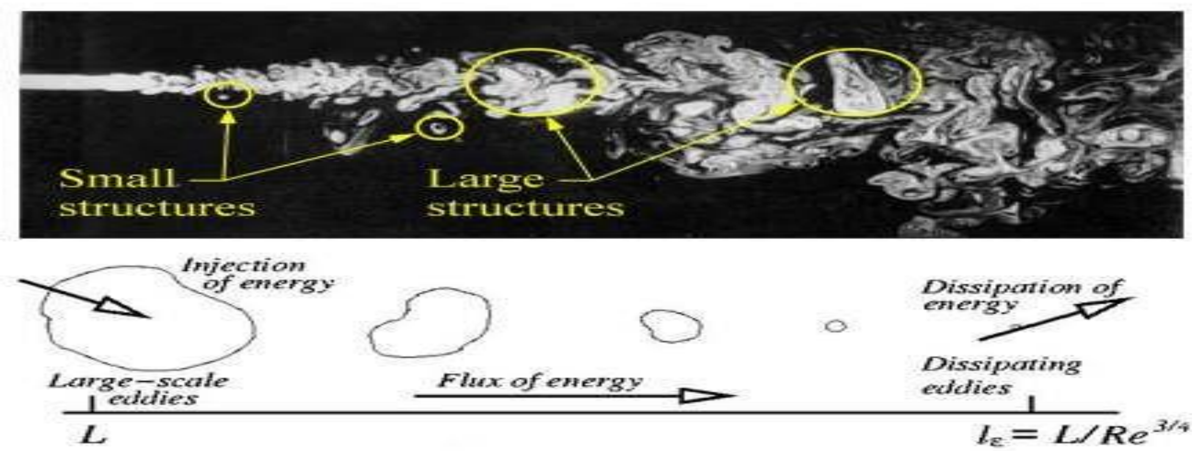



**Fig.3.14.** Energy Cascade Process

LES is a compromise among these models. It solves large spatial scales (DNS) directly while modeling the smaller ones (k-epsilon).First, which carries most of the energy (larger scales) and account for eighty percent of turbulent flow energy and, therefore, is more important. Second, the ones which are universal (smaller scales) and, therefore, easily modeled. A hybrid of these two techniques is the resulting technology which distinguishes the scales (modeled or solved directly) by selective Navier-Stokes equations. Subsequently, simulation of large scale turbulent motions is done directly by LES model and the Smagorinsky model is used to simulate small scale motions (unresolved). This model is similar to DNS as it emphasizes on large scale motions and it also takes into account the small scales of eddies by  using sub-grid scale (SGS) model.

### 3.4.4. Boundary Conditions

Boundary conditions are initial conditions required for the start of iterations in numerical simulation. It is from one of the significant inputs required from designing perspective. Boundary conditions are based upon the type of named selection in the geometry. Basic boundary conditions are as discussed below:

- **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.

i.e. velocity components in all three directions x, y and z are 0.

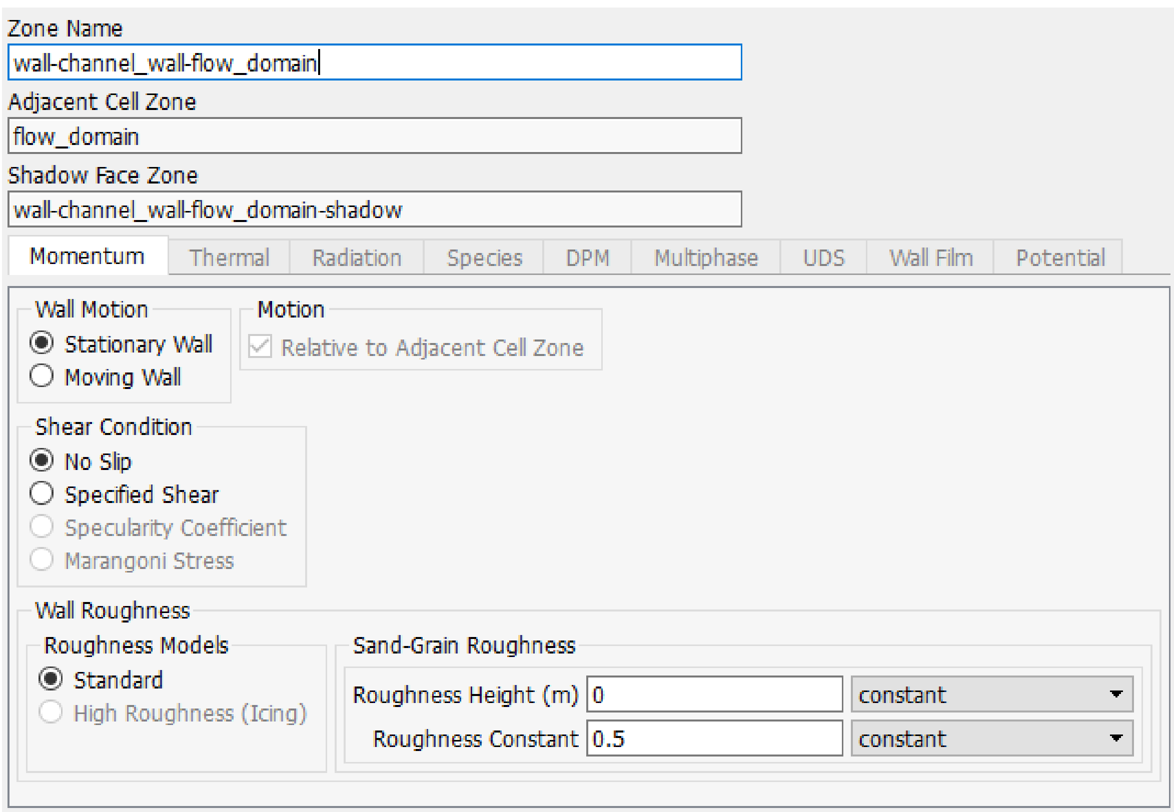



**Fig.3.15.** Boundary conditions for channel wall

- **Inlet:**

To initialize the flow velocity at the inlet is provided in longitudinal direction and in all other directions it is assumed to be zero initially. 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.

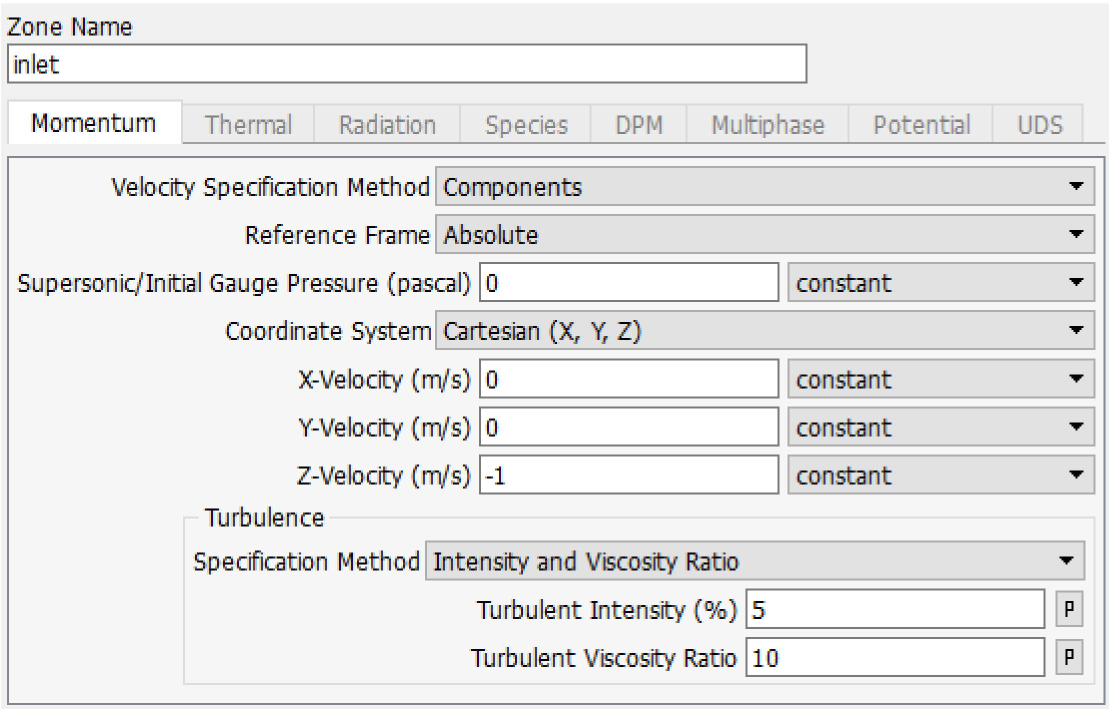



**Fig.3.16. Boundary conditions for inlet**

- **Outlet:**

At outlet pressure boundary conditions are provided i.e. simply zero gauge pressure is provided at the channel outlet. Other factors such as backflow turbulent intensity and viscosity ratio are taken as 5% and 10 respectively. These values are taken by ANSYS itself as per the model requirement.

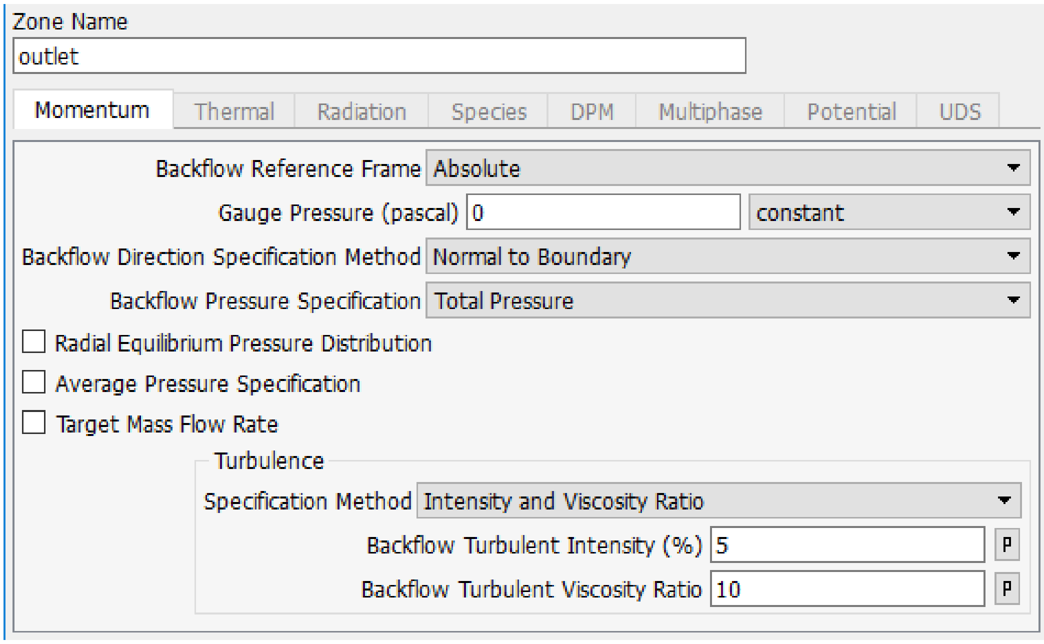



**Fig.3.17.** Boundary conditions for outlet

### 3.4.5. Solver

ANSYS 18.1 solver manager is used to undergo calculations and provide simulation results of the analysis. In this case hybrid initialization is done then calculation is done for 500 iterations. After the completion of iterations the graphical behavior of various residuals is analyzed which give an idea about the accuracy of work done. Lower the value of the residuals more is the accuracy of work done.

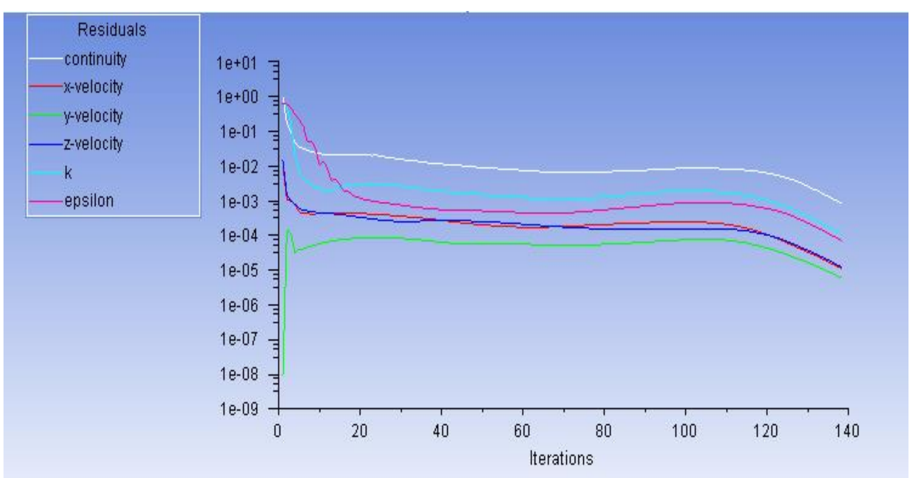



**Fig.3.18.** Value of residuals for channel with Sn = 1.47

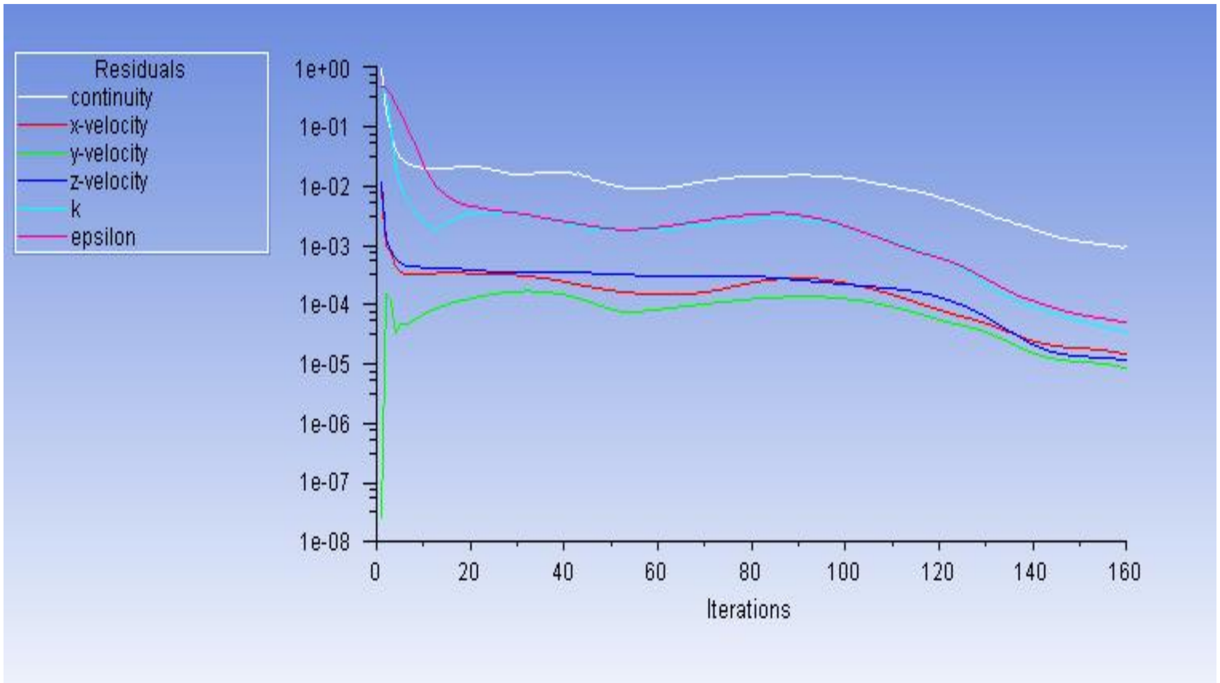



**Fig.3.19.** Value of residuals for channel with Sn = 2.0

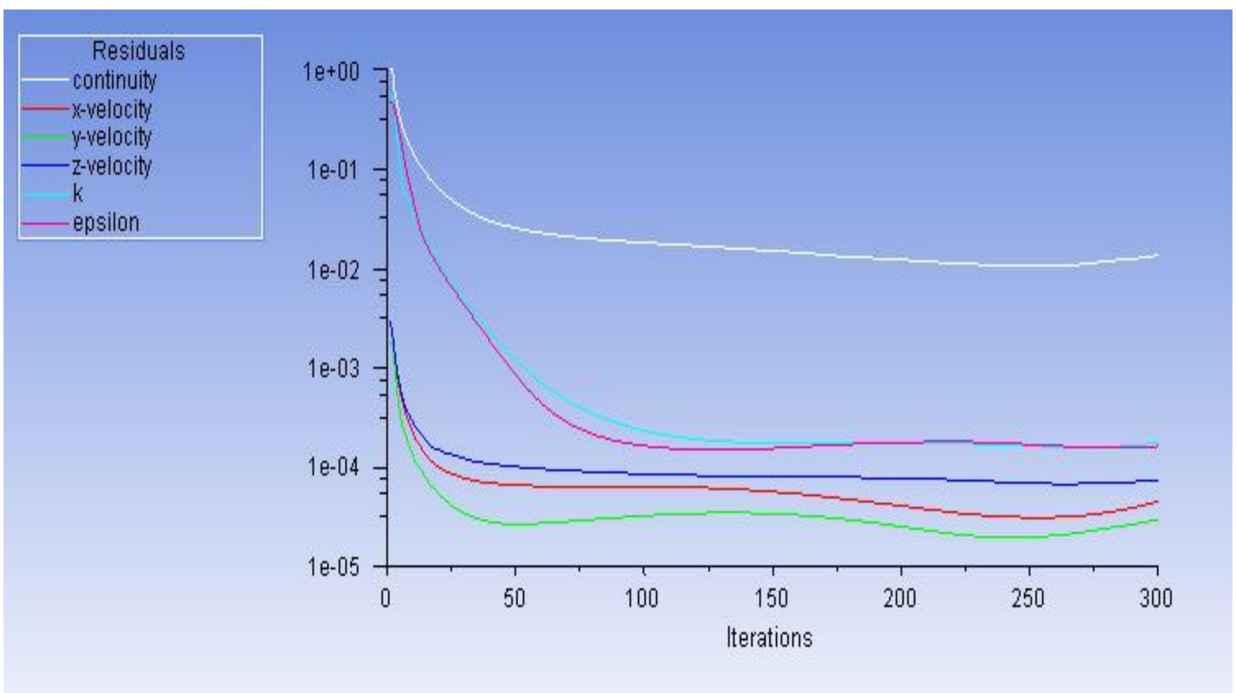



**Fig.3.20**.Value of residuals for channel with Sn = 2.53

# CHAPTER 4

# RESULTS 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. 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.

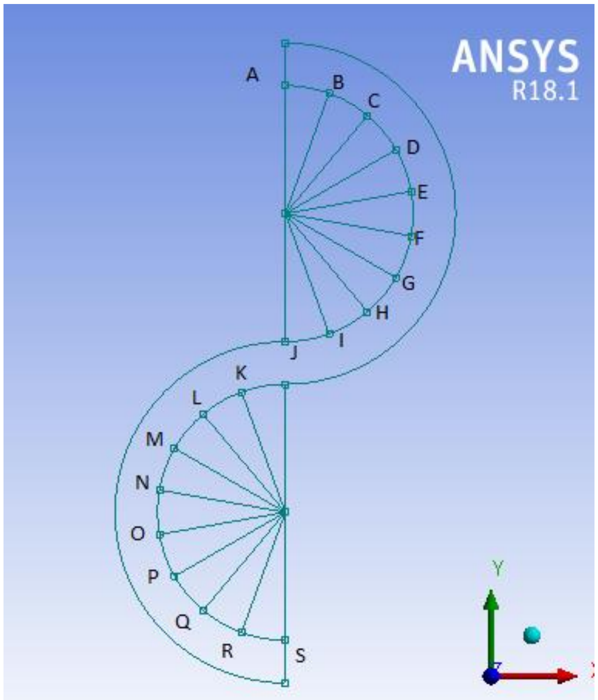



**Fig.4.1.** Sections on the meandering channel

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.

## 4.1 Results

Shear stress analysis for channels with varying sinuosity is shown below :

1. **For Q (discharge) = 1 cumec.**

| S.No. | Section | Vavg | Shear stress(inner wall) | Shear stress(outer wall) | Shear stress(bed) | % Variation |
|---|---|---|---|---|---|---|
| 1 | A | 1 | 1.465 | 1.462 | 1.466 | 0.205 |
| 2 | B | 1.054 | 1.561 | 1.553 | 1.586 | 0.515 |
| 3 | C | 0.983 | 1.659 | 1.628 | 1.657 | 1.904 |
| 4 | D | 0.965 | 1.655 | 1.621 | 1.677 | 2.097 |
| 5 | E | 0.942 | 1.606 | 1.597 | 1.674 | 0.564 |
| 6 | F | 0.934 | 1.567 | 1.541 | 1.69 | 1.687 |
| 7 | G | 0.972 | 1.539 | 1.511 | 1.714 | 1.853 |
| 8 | H | 0.982 | 1.497 | 1.484 | 1.734 | 0.876 |
| 9 | I | 0.985 | 1.454 | 1.446 | 1.737 | 0.553 |
| 10 | J | 1.03 | 1.578 | 1.15 | 1.757 | 37.217 |
| 11 | K | 1.13 | 1.998 | 1.146 | 1.721 | 74.346 |
| 12 | L | 1.2 | 2.171 | 1.215 | 1.747 | 78.683 |
| 13 | M | 1.18 | 2.256 | 1.258 | 1.716 | 79.332 |
| 14 | N | 0.986 | 2.29 | 1.252 | 1.709 | 82.907 |
| 15 | O | 0.972 | 2.303 | 1.321 | 1.586 | 74.338 |
| 16 | P | 0.95 | 2.273 | 1.221 | 1.677 | 86.159 |
| 17 | Q | 0.967 | 2.218 | 1.25 | 1.735 | 77.440 |
| 18 | R | 0.982 | 2.06 | 1.283 | 1.62 | 60.561 |
| 19 | S | 0.998 | 1.654 | 1.321 | 1.661 | 25.208 |

**Table.4.1.** Shear stress analysis for Sn = 1.47 and Q = 1 cumec

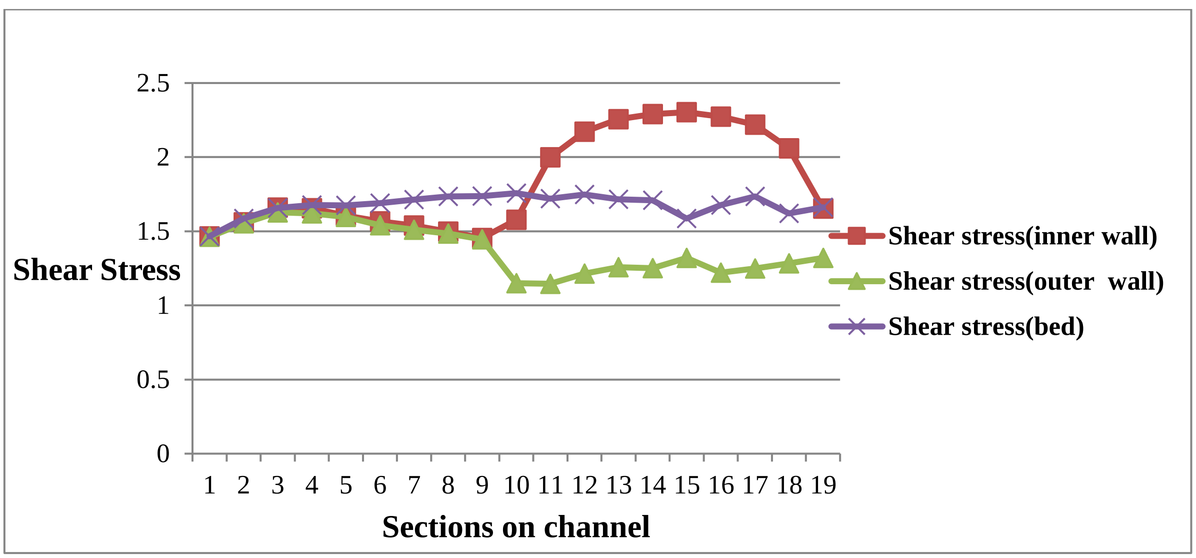



**Fig.4.2** Graphical analysis of shear stresses for Sn = 1.47 and Q = 1 cumec

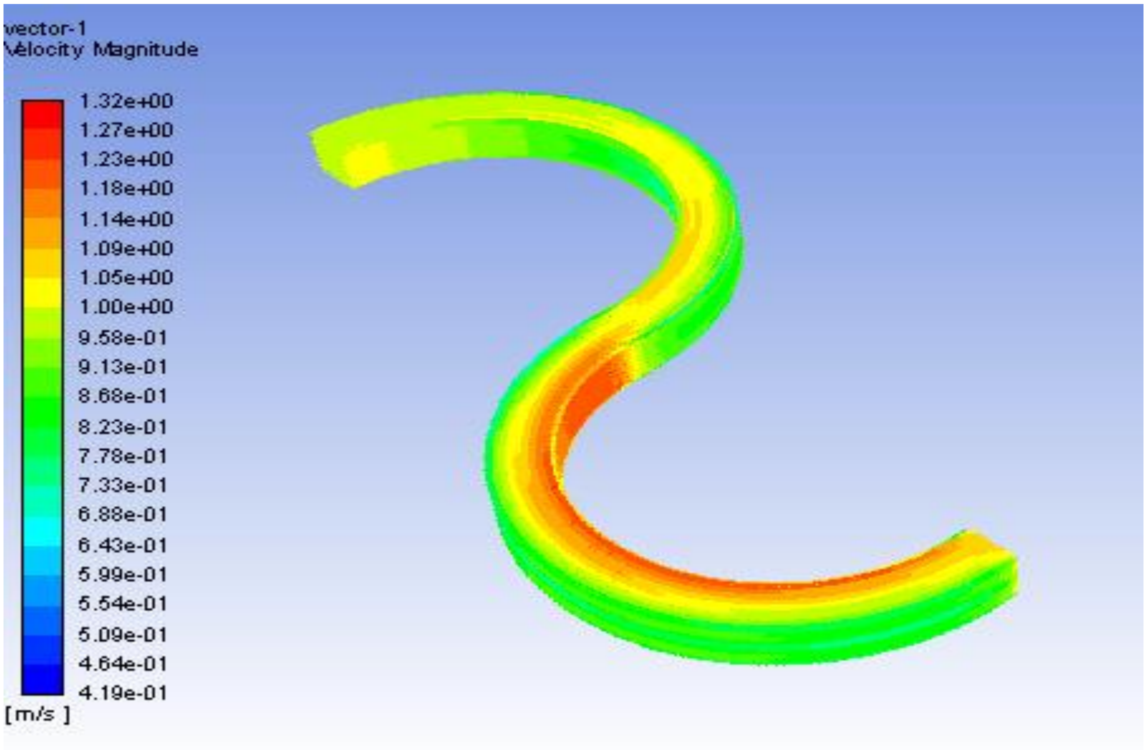



**Fig.4.3.** Velocity contours for meandering channel (Sn=1.47) and velocity 1m/sec

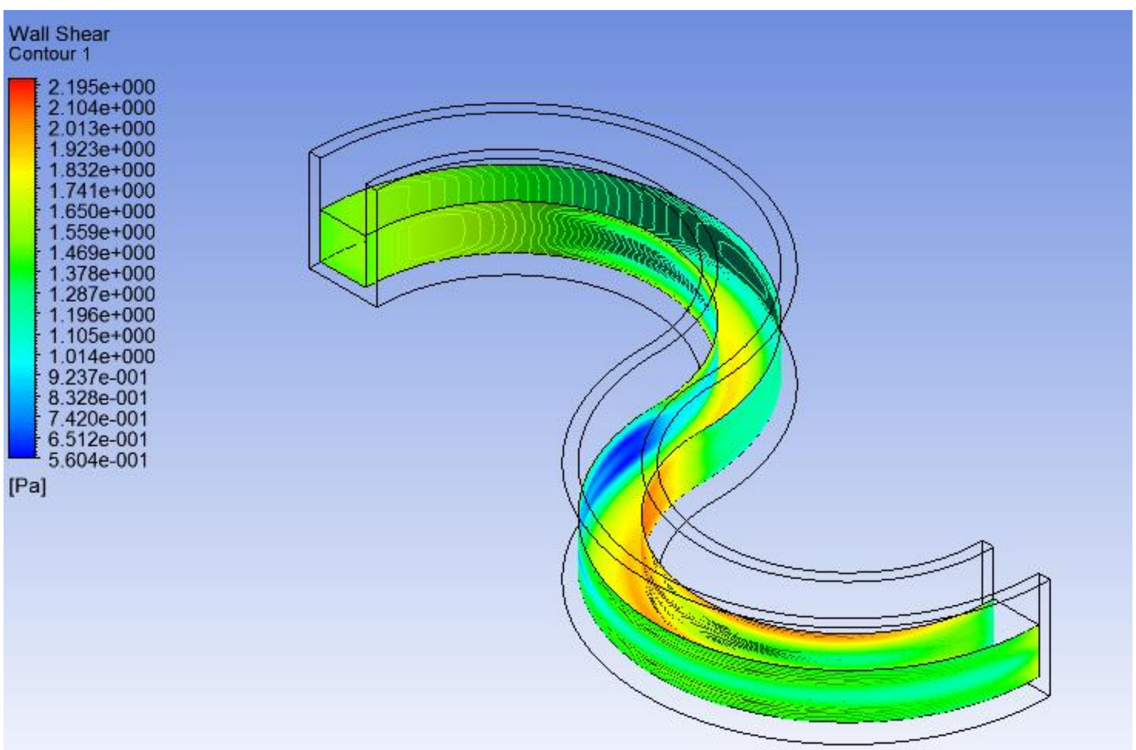



**Fig.4.4.** Shear stress contours for meandering channel (Sn = 1.47) and velocity 1m/sec

| S.No. | Section | Vavg | Shear stress(inner wall) | Shear stress(outer wall) | Shear stress(bed) | % Variation |
|---|---|---|---|---|---|---|
| 1 | A | 1.036 | 1.872 | 1.411 | 1.65 | 32.672 |
| 2 | B | 0.979 | 1.976 | 1.334 | 1.665 | 48.126 |
| 3 | C | 1.008 | 1.994 | 1.283 | 1.576 | 55.417 |
| 4 | D | 1.032 | 1.928 | 1.251 | 1.557 | 54.117 |
| 5 | E | 1.0645 | 1.799 | 1.232 | 1.462 | 46.023 |
| 6 | F | 1.121 | 1.687 | 1.216 | 1.45 | 38.734 |
| 7 | G | 1.036 | 1.596 | 1.211 | 1.476 | 31.792 |
| 8 | H | 1.007 | 1.527 | 1.214 | 1.433 | 25.783 |
| 9 | I | 1.057 | 1.538 | 1.219 | 1.49 | 26.169 |
| 10 | J | 1.09 | 1.471 | 1.232 | 1.472 | 19.399 |
| 11 | K | 1.0632 | 1.855 | 1.227 | 1.723 | 51.182 |
| 12 | L | 1.036 | 1.989 | 1.115 | 1.712 | 78.386 |
| 13 | M | 1.064 | 1.982 | 1.193 | 1.704 | 66.136 |
| 14 | N | 1.0927 | 2.006 | 1.215 | 1.806 | 65.103 |
| 15 | O | 1.113 | 2.04 | 1.301 | 1.845 | 56.802 |
| 16 | P | 1.096 | 2.0479 | 1.296 | 1.771 | 58.017 |
| 17 | Q | 1.082 | 2.011 | 1.304 | 1.746 | 54.218 |
| 18 | R | 1.088 | 1.994 | 1.31 | 1.761 | 52.214 |
| 19 | S | 1.091 | 1.884 | 1.361 | 1.752 | 38.428 |

**Table.4.2**. Shear stress analysis for Sn = 2.0 and Q = 1 cumec

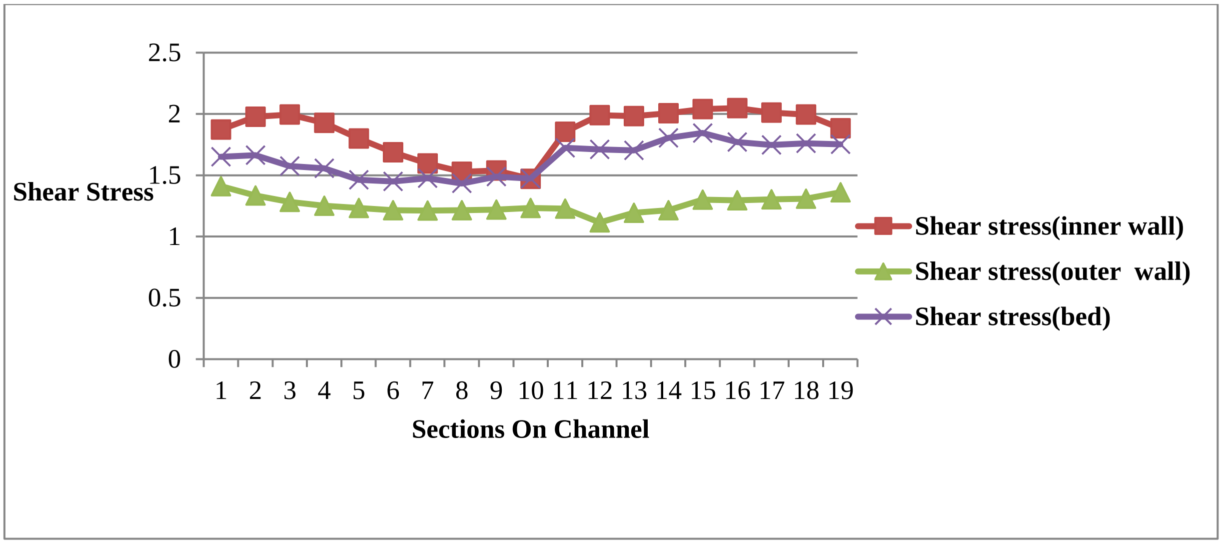



**Fig.4.5.** Graphical analysis of shear stresses for Sn = 2.0 and Q = 1 cumec

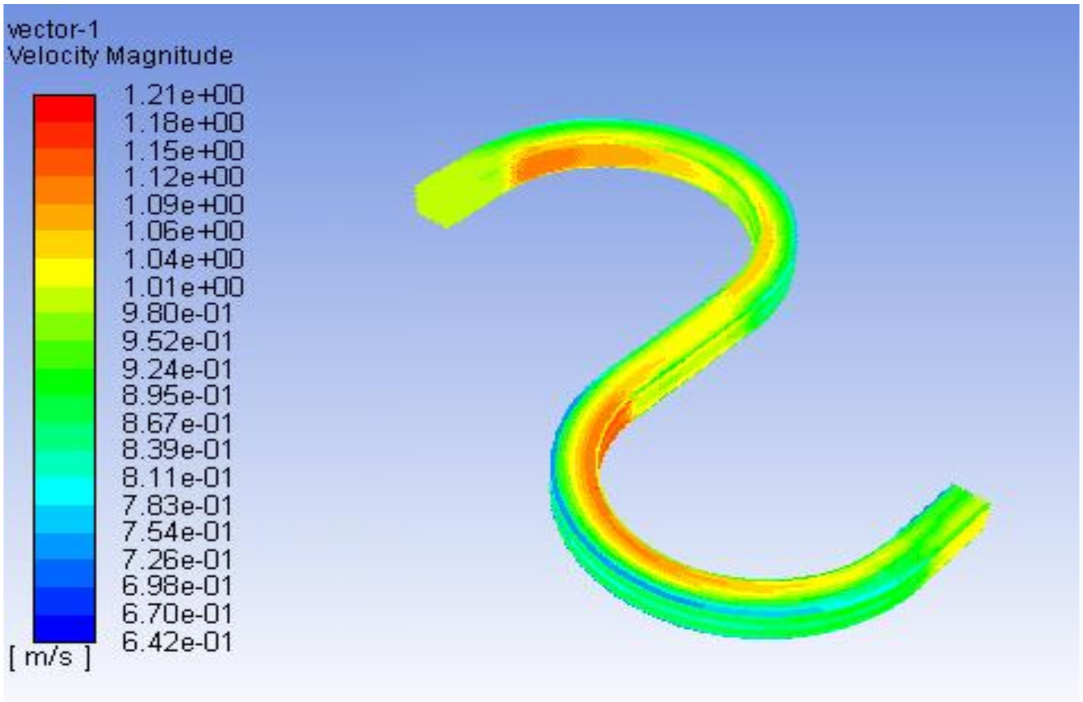



**Fig.4.6.** Velocity contours for meandering channel (Sn=2.0) and velocity 1m/sec

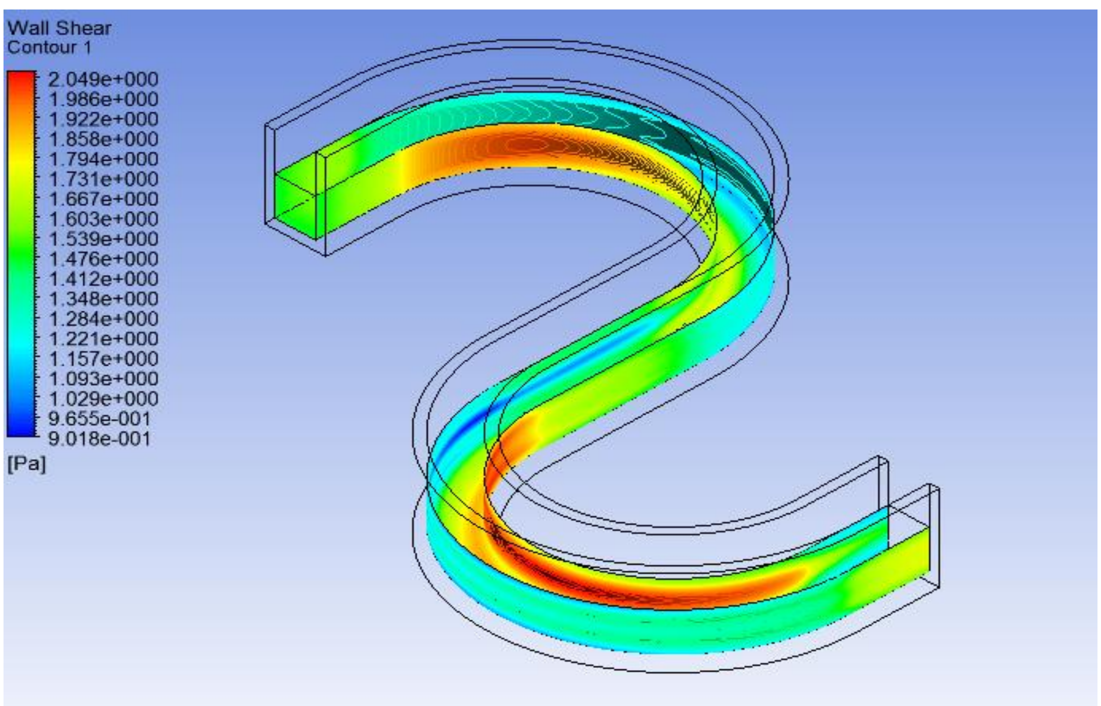



**Fig.4.7.** Shear stress contours for meandering channel (Sn=2.0) and velocity 1m/sec

| S.No. | Section | Vavg | Shear stress(inner wall) | Shear stress(outer wall) | Shear stress(bed) | % Variation |
|---|---|---|---|---|---|---|
| 1 | A | 1.012 | 1.406 | 0.992 | 1.136 | 41.734 |
| 2 | B | 1.037 | 1.411 | 0.978 | 1.131 | 44.274 |
| 3 | C | 1.065 | 1.488 | 0.967 | 1.079 | 53.878 |
| 4 | D | 1.098 | 1.469 | 0.944 | 1.163 | 55.614 |
| 5 | E | 0.956 | 1.438 | 0.939 | 1.169 | 53.142 |
| 6 | F | 0.979 | 1.386 | 0.95 | 1.122 | 45.895 |
| 7 | G | 1.008 | 1.367 | 0.973 | 1.116 | 40.493 |
| 8 | H | 1.062 | 1.356 | 0.964 | 1.226 | 40.664 |
| 9 | I | 1.054 | 1.372 | 0.949 | 1.215 | 44.573 |
| 10 | J | 1.092 | 1.378 | 0.96 | 1.124 | 43.542 |
| 11 | K | 1.066 | 1.446 | 0.955 | 1.148 | 51.414 |
| 12 | L | 1.12 | 1.462 | 0.931 | 1.0953 | 57.035 |
| 13 | M | 1.152 | 1.436 | 0.991 | 1.108 | 44.904 |
| 14 | N | 1.026 | 1.416 | 0.935 | 1.102 | 51.444 |
| 15 | O | 1.014 | 1.406 | 0.975 | 1.087 | 44.205 |
| 16 | P | 0.989 | 1.375 | 0.953 | 1.152 | 44.281 |
| 17 | Q | 0.97 | 1.336 | 0.978 | 1.159 | 36.605 |
| 18 | R | 0.98 | 1.382 | 0.933 | 1.124 | 48.124 |
| 19 | S | 0.992 | 1.366 | 0.978 | 1.181 | 39.673 |

**Table.4.3.** Shear stress analysis for Sn = 2.53 and Q = 1 cumec

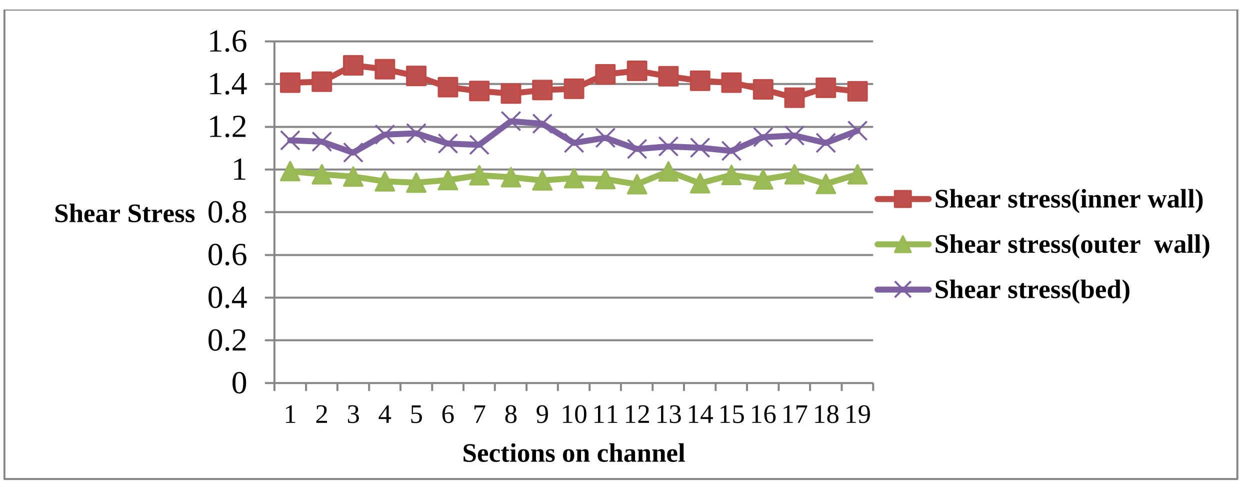



**Fig.4.8.** Graphical analysis of shear stresses for Sn = 2.53 and Q = 1 cumec

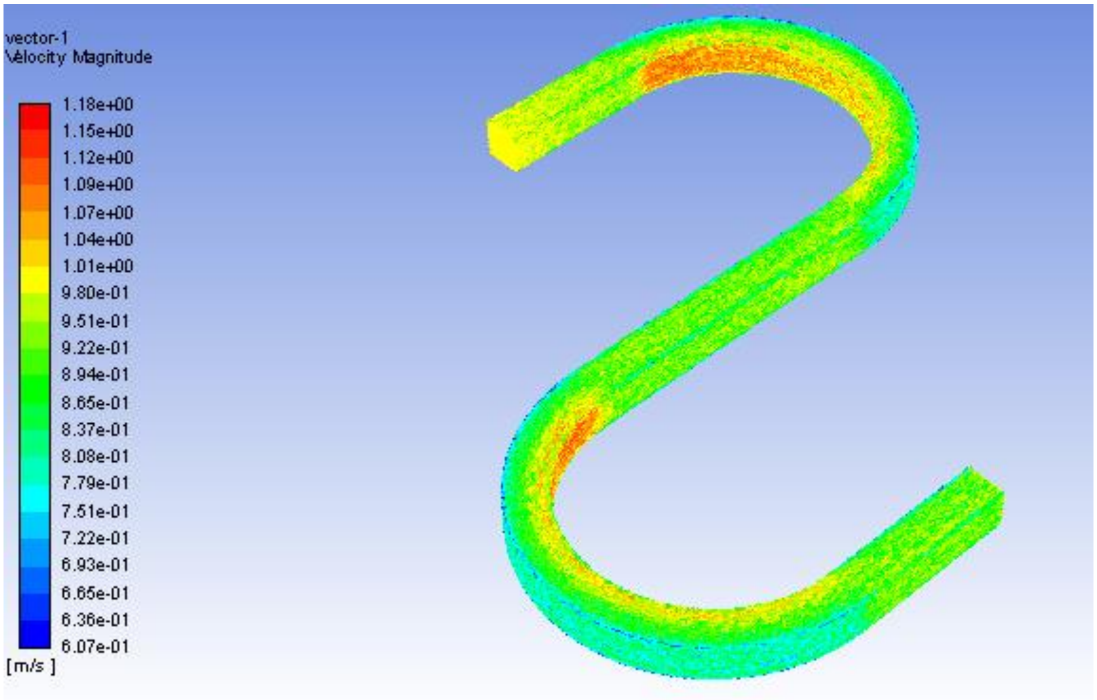



**Fig.4.9.** Velocity contours for meandering channel (Sn = 2.53) and velocity 1m/sec

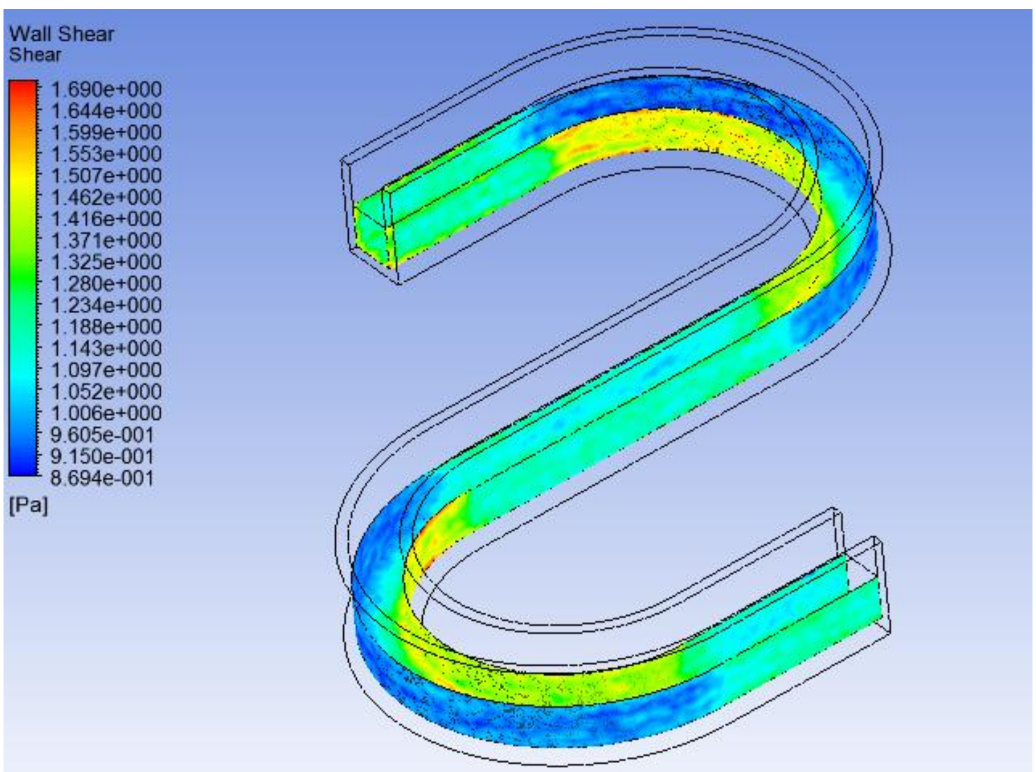



**Fig.4.10.** Shear stress contours for meandering channel (Sn = 2.53) and velocity 1m/sec

**2. For Q (discharge) = 2 cumec.**

| S.No. | Section | Vavg | Shear stress(inner wall) | Shear stress(outer wall) | Shear stress(bed) | % Variation |
|---|---|---|---|---|---|---|
| 1 | A | 2 | 5.467 | 5.432 | 5.464 | 0.644 |
| 2 | B | 1.986 | 5.779 | 5.728 | 5.707 | 0.890 |
| 3 | C | 1.988 | 5.948 | 5.825 | 5.884 | 2.112 |
| 4 | D | 1.976 | 5.788 | 5.71 | 5.973 | 1.366 |
| 5 | E | 1.955 | 5.697 | 5.609 | 5.967 | 1.569 |
| 6 | F | 1.943 | 5.59 | 5.475 | 5.985 | 2.100 |
| 7 | G | 1.964 | 5.481 | 5.376 | 6.036 | 1.953 |
| 8 | H | 1.977 | 5.331 | 5.284 | 6.058 | 0.889 |
| 9 | I | 1.982 | 5.237 | 5.192 | 6.114 | 0.867 |
| 10 | J | 2.12 | 6.226 | 5.139 | 6.123 | 21.152 |
| 11 | K | 2.213 | 7.244 | 4.526 | 6.234 | 60.053 |
| 12 | L | 2.146 | 7.927 | 4.112 | 6.073 | 92.777 |
| 13 | M | 1.987 | 8.132 | 4.256 | 6.003 | 91.071 |
| 14 | N | 2.074 | 8.188 | 4.223 | 5.839 | 93.891 |
| 15 | O | 1.993 | 8.08 | 4.884 | 5.487 | 65.438 |
| 16 | P | 1.984 | 7.73 | 4.911 | 5.648 | 57.402 |
| 17 | Q | 1.994 | 7.369 | 4.823 | 5.888 | 52.789 |
| 18 | R | 1.98 | 7.167 | 4.562 | 5.568 | 57.102 |
| 19 | S | 2.014 | 6.08 | 4.932 | 5.476 | 23.277 |

**Table.4.4** Shear stress analysis for Sn = 1.47 and Q = 2 cumec

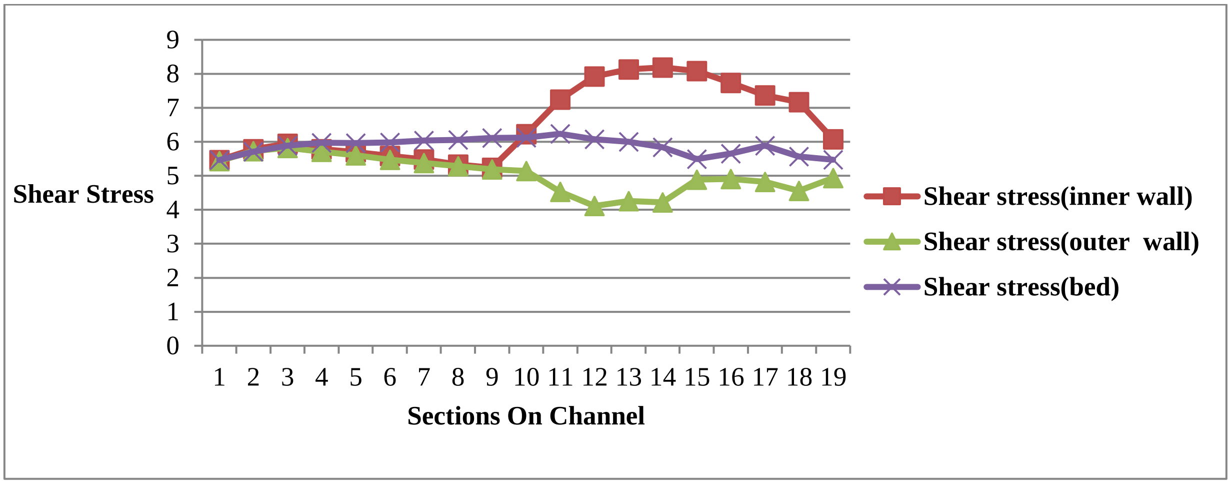



**Fig.4.11**. Graphical analysis of shear stresses for Sn = 1.47 and Q = 2 cumec

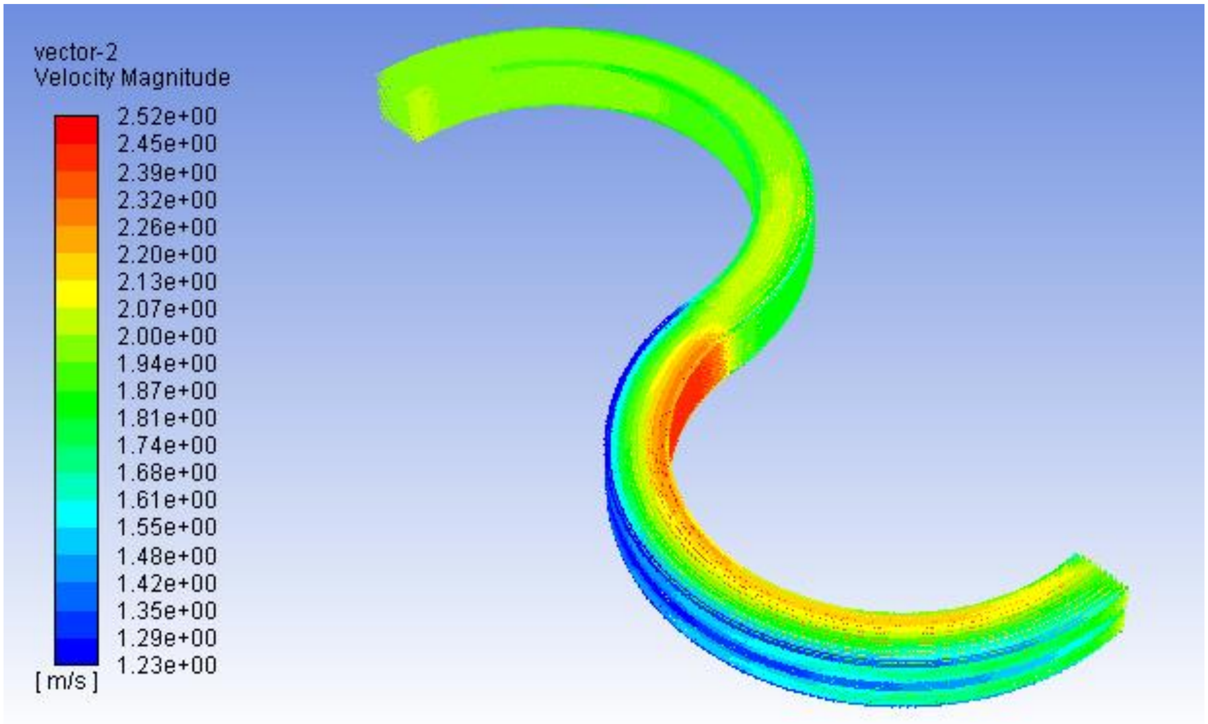



**Fig.4.12.** Velocity contours for meandering channel (Sn = 1.47) and velocity 2m/sec

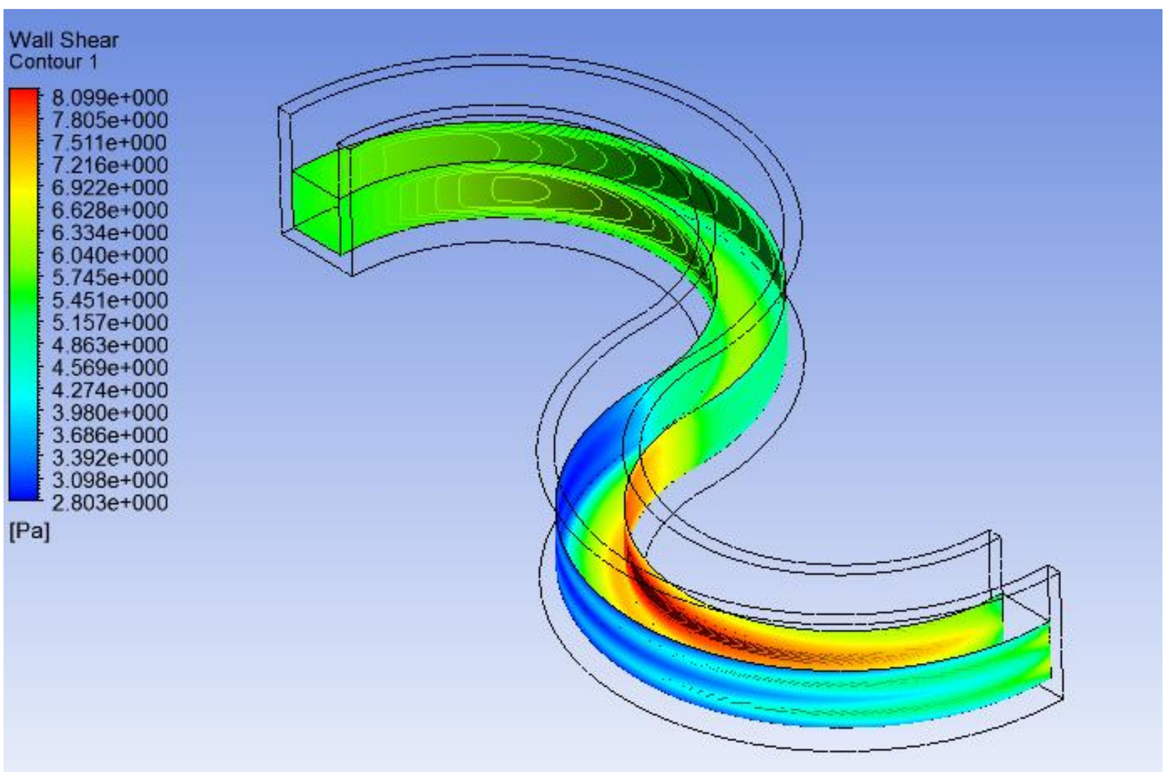



**Fig.4.13.** Shear stress contours for meandering channel (Sn=1.47) and velocity 2m/sec

| S.No. | Section | Vavg | Shear stress(inner wall) | Shear stress(outer wall) | Shear stress(bed) | % Variation |
|---|---|---|---|---|---|---|
| 1 | A | 2.01 | 6.706 | 5.043 | 5.96 | 32.976 |
| 2 | B | 2.12 | 7.031 | 4.812 | 5.89 | 46.114 |
| 3 | C | 2.07 | 7.115 | 4.623 | 5.76 | 53.904 |
| 4 | D | 2.17 | 7.014 | 4.476 | 5.52 | 56.702 |
| 5 | E | 1.91 | 6.59 | 4.382 | 5.42 | 50.388 |
| 6 | F | 1.96 | 6.165 | 4.33 | 5.146 | 42.379 |
| 7 | G | 2.06 | 5.875 | 4.308 | 5.287 | 36.374 |
| 8 | H | 2.18 | 5.636 | 4.291 | 5.155 | 31.345 |
| 9 | I | 2.16 | 5.863 | 4.302 | 5.316 | 36.285 |
| 10 | J | 2.23 | 6.737 | 4.345 | 5.187 | 55.052 |
| 11 | K | 2.12 | 7.042 | 4.265 | 5.91 | 65.111 |
| 12 | L | 2.18 | 6.97 | 3.754 | 5.805 | 85.669 |
| 13 | M | 2.28 | 7.139 | 3.805 | 5.97 | 87.622 |
| 14 | N | 2.16 | 7.09 | 4.121 | 5.749 | 72.046 |
| 15 | O | 2.08 | 7.321 | 4.226 | 6.276 | 73.237 |
| 16 | P | 2.04 | 7.286 | 4.524 | 6.22 | 61.052 |
| 17 | Q | 1.96 | 7.147 | 4.662 | 6.15 | 53.303 |
| 18 | R | 2.01 | 7.16 | 4.603 | 5.64 | 55.551 |
| 19 | S | 1.98 | 6.775 | 4.862 | 6.069 | 39.346 |

**Table.4.5** Shear stress analysis for Sn = 2.0 and Q = 2 cumec

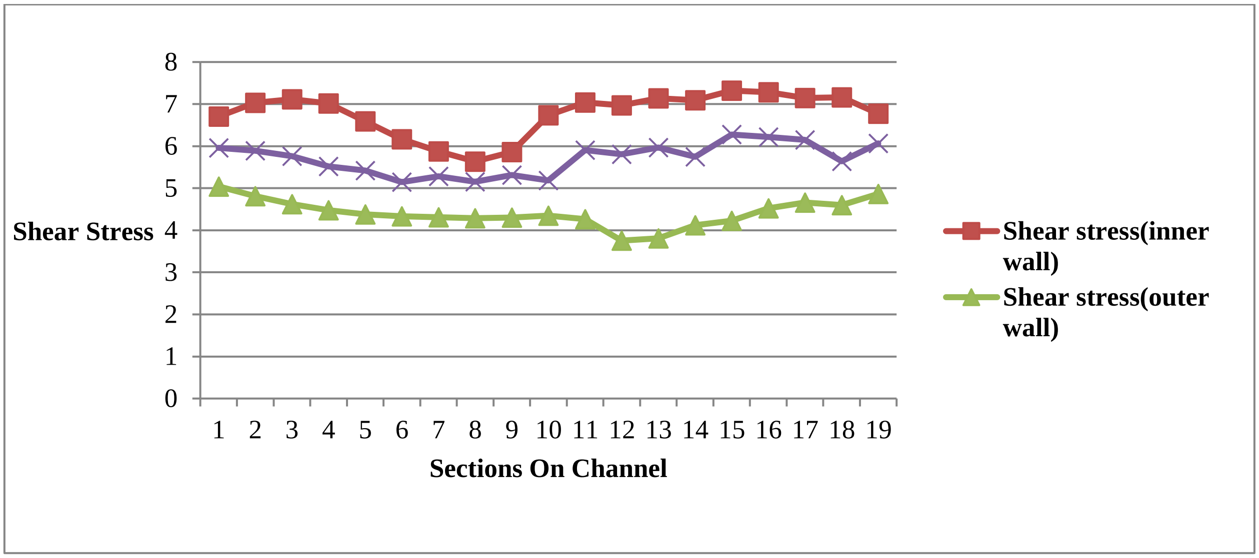



**Fig.4.14.** Graphical analysis of shear stresses for Sn = 2.0 and Q = 2 cumec

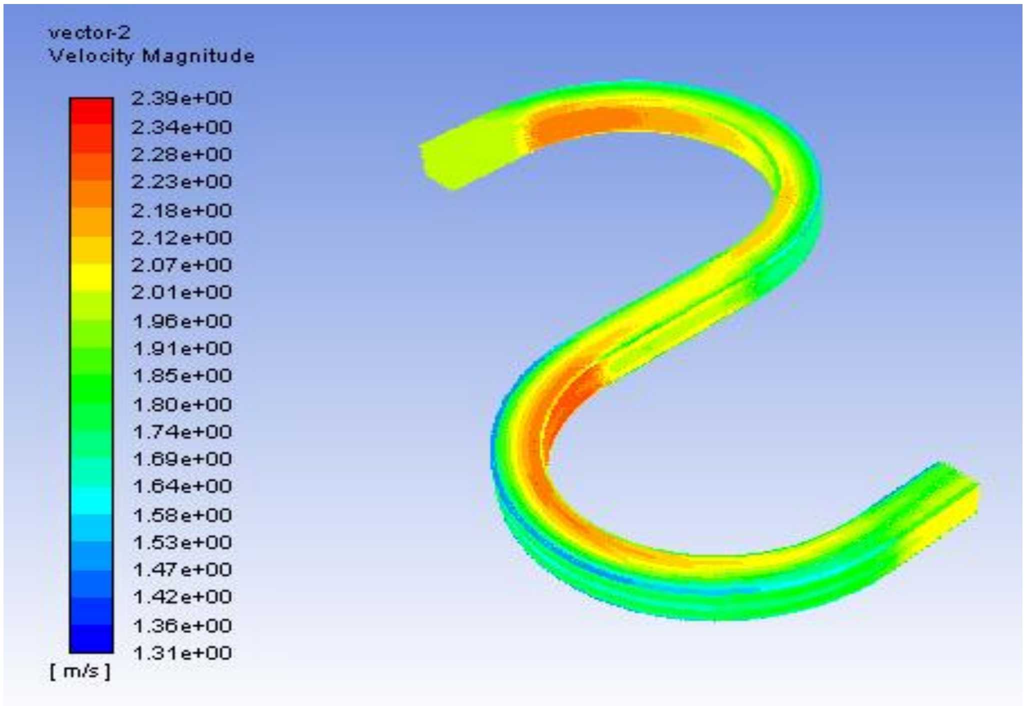



**Fig.4.15.** Velocity contours for meandering channel (Sn=2.0) and velocity 2m/sec

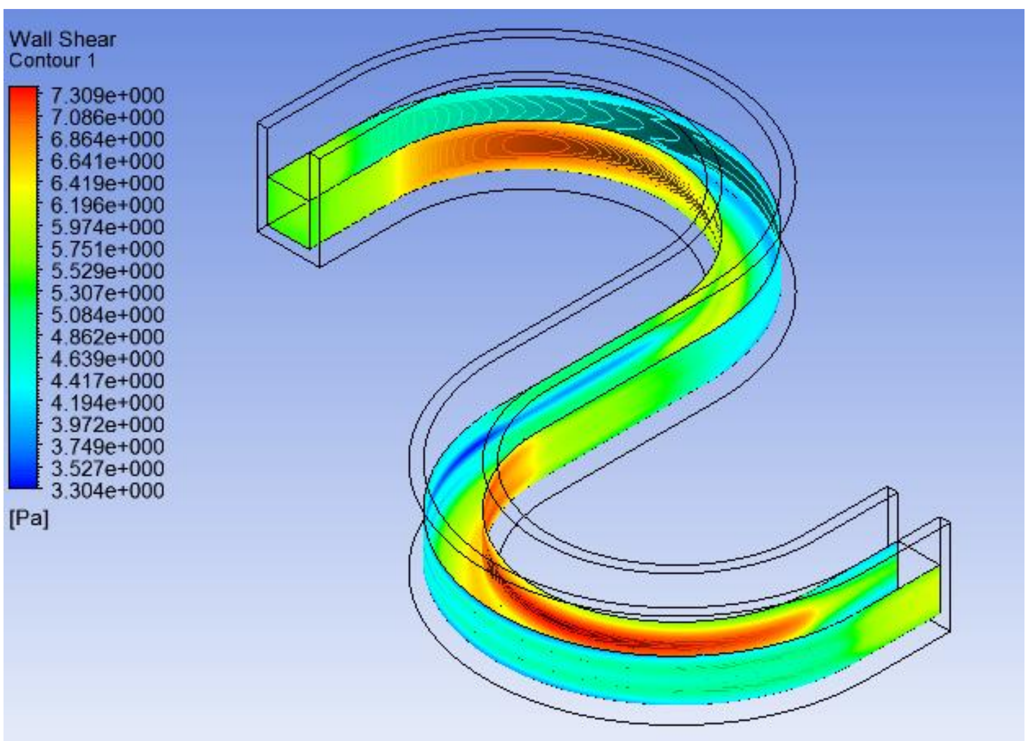



**Fig.4.16.** Shear stress contours for meandering channel (Sn=2.0) and velocity 2m/sec

| S.No. | Section | Vavg | Shear stress(inner wall) | Shear stress(outer wall) | Shear stress(bed) | % Variation |
|---|---|---|---|---|---|---|
| 1 | A | 2.073 | 4.729 | 3.459 | 3.679 | 36.716 |
| 2 | B | 2.026 | 4.792 | 3.332 | 3.846 | 43.818 |
| 3 | C | 2.134 | 5.042 | 3.348 | 3.675 | 50.597 |
| 4 | D | 1.949 | 5.105 | 3.316 | 3.975 | 53.951 |
| 5 | E | 1.889 | 4.884 | 3.224 | 4.442 | 51.489 |
| 6 | F | 1.872 | 4.545 | 3.172 | 4.028 | 43.285 |
| 7 | G | 1.962 | 4.539 | 3.249 | 4.122 | 39.705 |
| 8 | H | 1.992 | 4.958 | 3.332 | 4.419 | 48.800 |
| 9 | I | 2.014 | 5.271 | 3.339 | 3.979 | 57.862 |
| 10 | J | 2.0113 | 4.968 | 3.422 | 4.142 | 45.178 |
| 11 | K | 2.07 | 4.754 | 3.193 | 3.852 | 48.888 |
| 12 | L | 2.136 | 4.795 | 3.095 | 3.953 | 54.927 |
| 13 | M | 2.21 | 4.976 | 3.135 | 4.12 | 58.724 |
| 14 | N | 2.148 | 4.738 | 3.346 | 4.27 | 41.602 |
| 15 | O | 2.112 | 4.69 | 3.273 | 4.442 | 43.294 |
| 16 | P | 1.987 | 4.491 | 3.365 | 4.288 | 33.462 |
| 17 | Q | 2.063 | 4.56 | 3.265 | 4.352 | 39.663 |
| 18 | R | 1.998 | 4.426 | 3.302 | 4.267 | 34.040 |
| 19 | S | 1.972 | 4.325 | 3.35 | 4.124 | 29.104 |

**Table.4.6.** Shear stress analysis for Sn = 2.53 and Q = 2 cumec

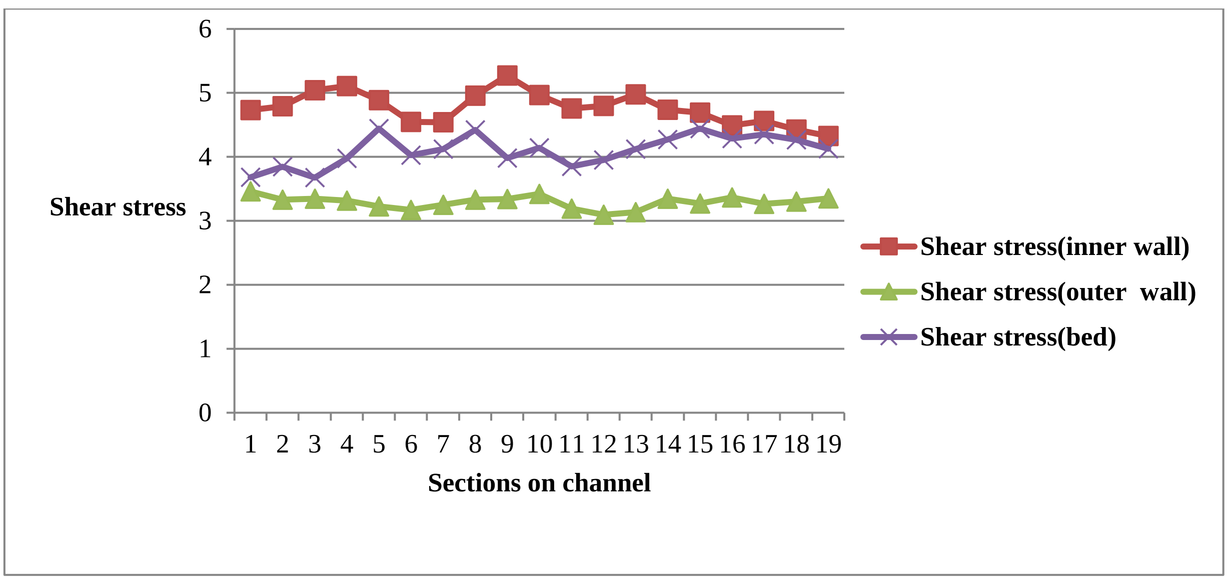



**Fig.4.17.** Graphical analysis of shear stresses for Sn = 2.53 and Q = 2 cumec

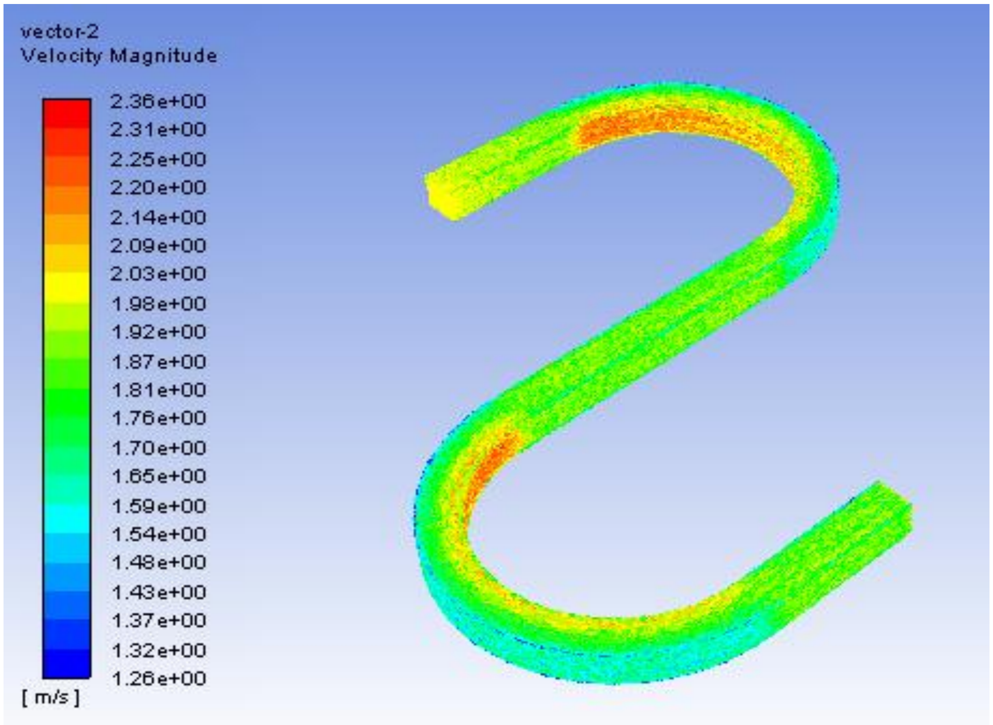



**Fig.4.18.** Velocity contours for meandering channel (Sn=2.53) and velocity 2m/sec

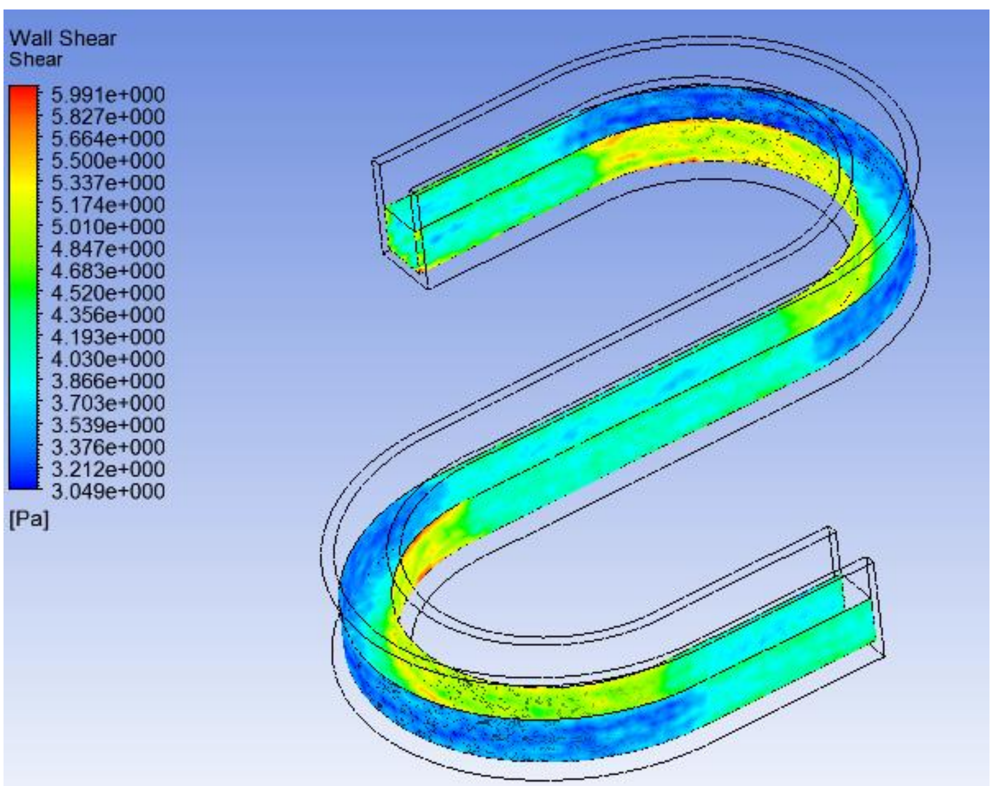



**Fig.4.19.** Shear stress contours for meandering channel (Sn=2.53) and velocity 2m/sec

**3. For Q (discharge) = 3 cumec.**

| S.No. | Section | Vavg | Shear stress(inner wall) | Shear stress(outer wall) | Shear stress(bed) | % Variation |
|---|---|---|---|---|---|---|
| 1 | A | 3 | 11.846 | 11.751 | 11.779 | 0.808 |
| 2 | B | 3.11 | 12.446 | 12.207 | 12.269 | 1.958 |
| 3 | C | 2.967 | 12.517 | 12.329 | 12.503 | 1.525 |
| 4 | D | 2.992 | 12.291 | 12.164 | 12.591 | 1.044 |
| 5 | E | 2.977 | 11.93 | 11.89 | 12.581 | 0.336 |
| 6 | F | 2.948 | 11.766 | 11.716 | 12.588 | 0.427 |
| 7 | G | 2.968 | 11.445 | 11.335 | 12.635 | 0.970 |
| 8 | H | 2.943 | 11.142 | 11.02 | 12.797 | 1.107 |
| 9 | I | 2.956 | 10.998 | 10.987 | 12.976 | 0.100 |
| 10 | J | 3.24 | 13.772 | 9.875 | 12.925 | 39.463 |
| 11 | K | 3.34 | 15.763 | 9.56 | 13.166 | 64.885 |
| 12 | L | 3.16 | 16.699 | 8.766 | 13.236 | 90.497 |
| 13 | M | 3.06 | 17.139 | 8.825 | 12.435 | 94.210 |
| 14 | N | 2.984 | 17.228 | 8.785 | 12.305 | 96.107 |
| 15 | O | 2.897 | 16.441 | 8.552 | 11.942 | 92.247 |
| 16 | P | 2.956 | 16.507 | 8.852 | 11.895 | 86.478 |
| 17 | Q | 2.975 | 15.696 | 8.713 | 12.169 | 80.145 |
| 18 | R | 2.986 | 15.133 | 8.674 | 11.023 | 74.464 |
| 19 | S | 2.995 | 13.349 | 9.436 | 11.795 | 41.469 |

**Table.4.7.** Shear stress analysis for Sn = 1.47 and Q = 3 cumec

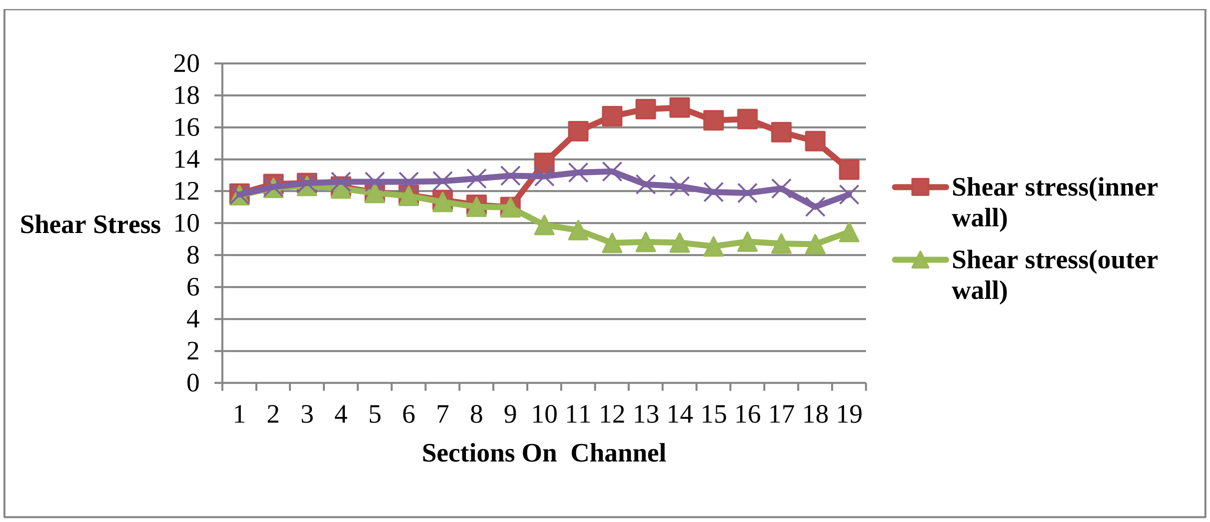



**Fig.4.20.** Graphical analysis of shear stresses for Sn = 1.47 and Q = 3 cumec

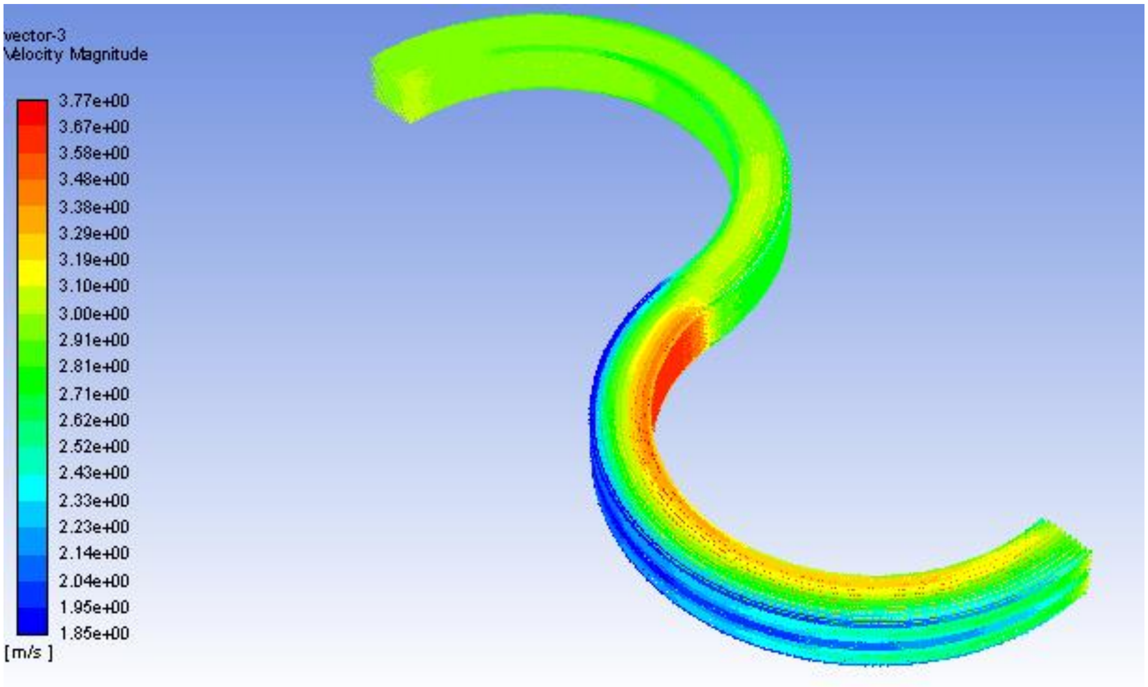



**Fig.4.21.** Velocity contours for meandering channel (Sn=1.47) and velocity 3m/sec

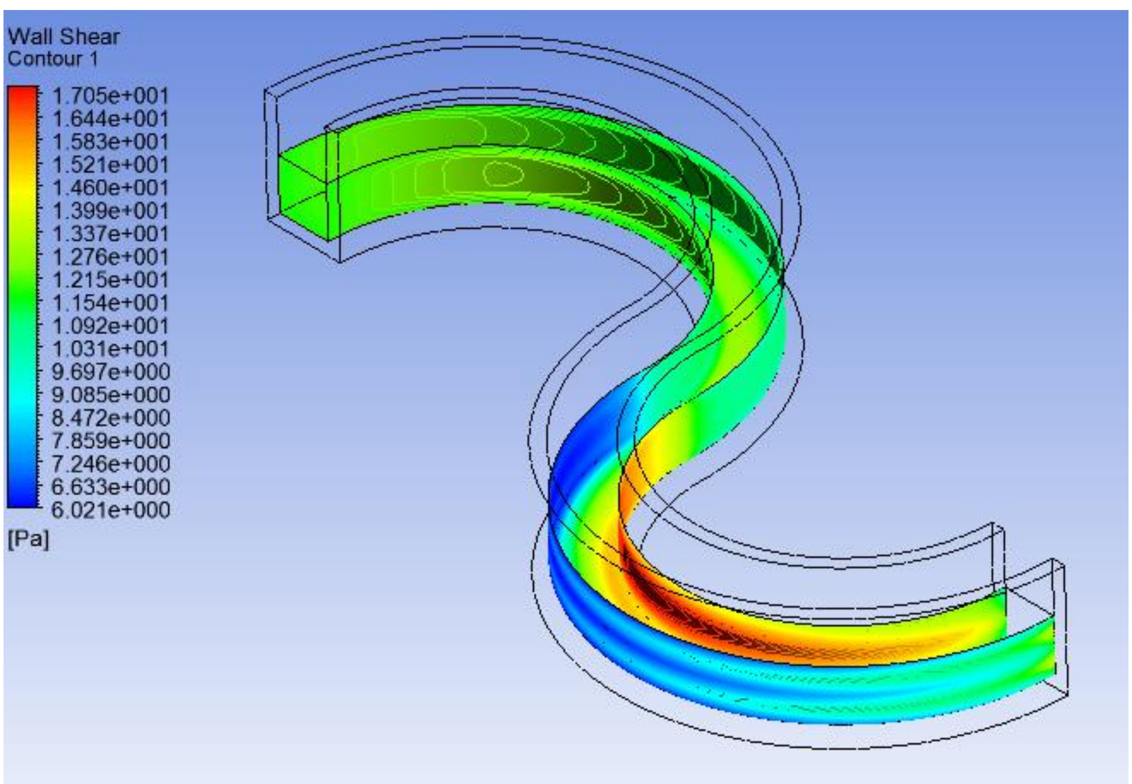



**Fig.4.22.** Shear stress contours for meandering channel (Sn=1.47) and velocity 3m/sec

| S.No. | Section | Vavg | Shear stress(inner wall) | Shear stress(outer wall) | Shear stress(bed) | % Variation |
|---|---|---|---|---|---|---|
| 1 | A | 3.02 | 13.945 | 10.712 | 12.254 | 30.181 |
| 2 | B | 3 | 14.674 | 10.307 | 12.112 | 42.369 |
| 3 | C | 3.08 | 14.956 | 9.998 | 11.928 | 49.590 |
| 4 | D | 3.21 | 14.91 | 9.685 | 11.983 | 53.949 |
| 5 | E | 3.16 | 14.19 | 9.508 | 12.455 | 49.243 |
| 6 | F | 2.92 | 13.51 | 9.254 | 12.416 | 45.991 |
| 7 | G | 2.85 | 12.98 | 9.108 | 12.56 | 42.512 |
| 8 | H | 3.05 | 12.612 | 9.144 | 12.239 | 37.927 |
| 9 | I | 3.14 | 11.927 | 9.224 | 11.636 | 29.304 |
| 10 | J | 3.26 | 13.379 | 9.323 | 11.243 | 43.505 |
| 11 | K | 3.18 | 14.332 | 8.707 | 12.182 | 64.603 |
| 12 | L | 3.22 | 14.63 | 8.659 | 12.065 | 68.957 |
| 13 | M | 3.28 | 14.67 | 8.887 | 12.49 | 65.073 |
| 14 | N | 3.12 | 14.826 | 9.205 | 13.12 | 61.065 |
| 15 | O | 3.15 | 15.09 | 9.597 | 13.806 | 57.237 |
| 16 | P | 3.08 | 15.485 | 8.671 | 13.286 | 78.584 |
| 17 | Q | 2.98 | 15.278 | 8.884 | 13.146 | 71.972 |
| 18 | R | 3.02 | 15.139 | 9.234 | 13.122 | 63.948 |
| 19 | S | 3.11 | 14.503 | 10.262 | 13.142 | 41.327 |

**Table.4.8.** Shear stress analysis for Sn = 2.0 and Q = 3 cumec

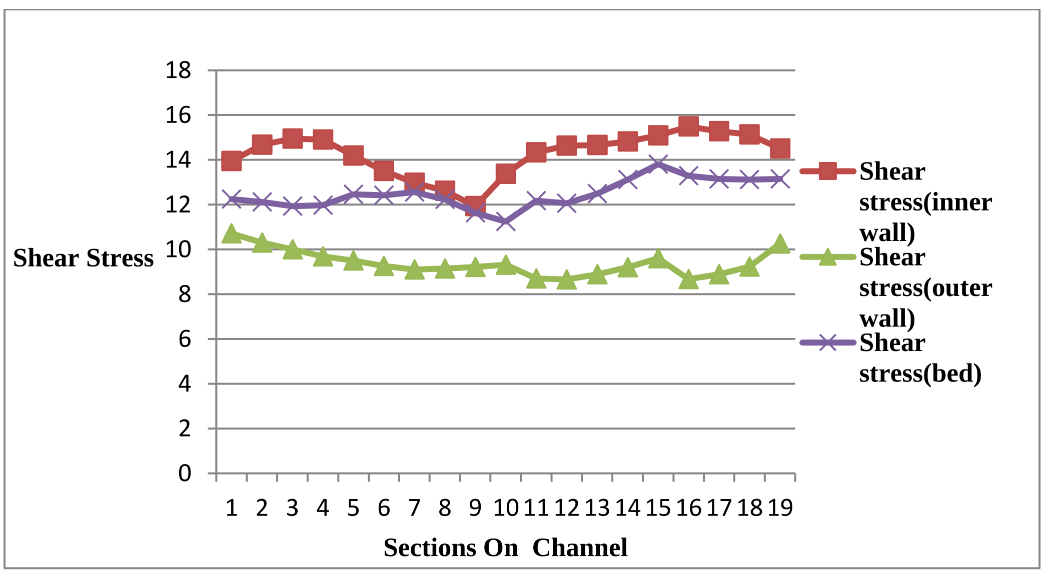



**Fig.4.23** Graphical analysis of shear stresses for Sn = 2.0 and Q = 3 cumec

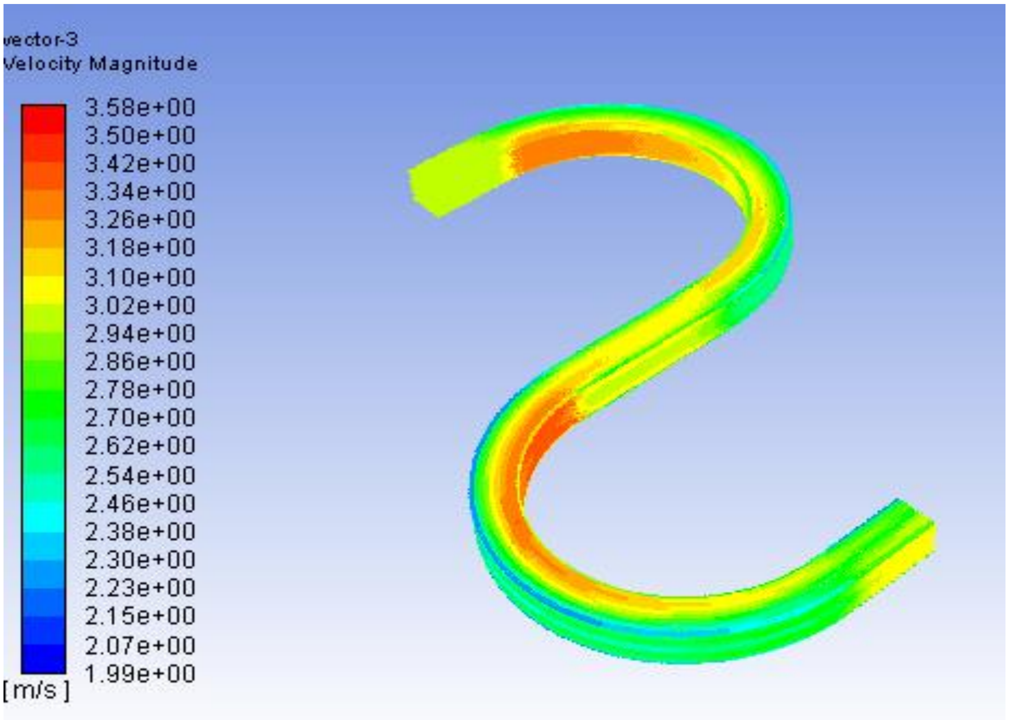



**Fig.4.24.** Velocity contours for meandering channel (Sn=2.0) and velocity 3m/sec

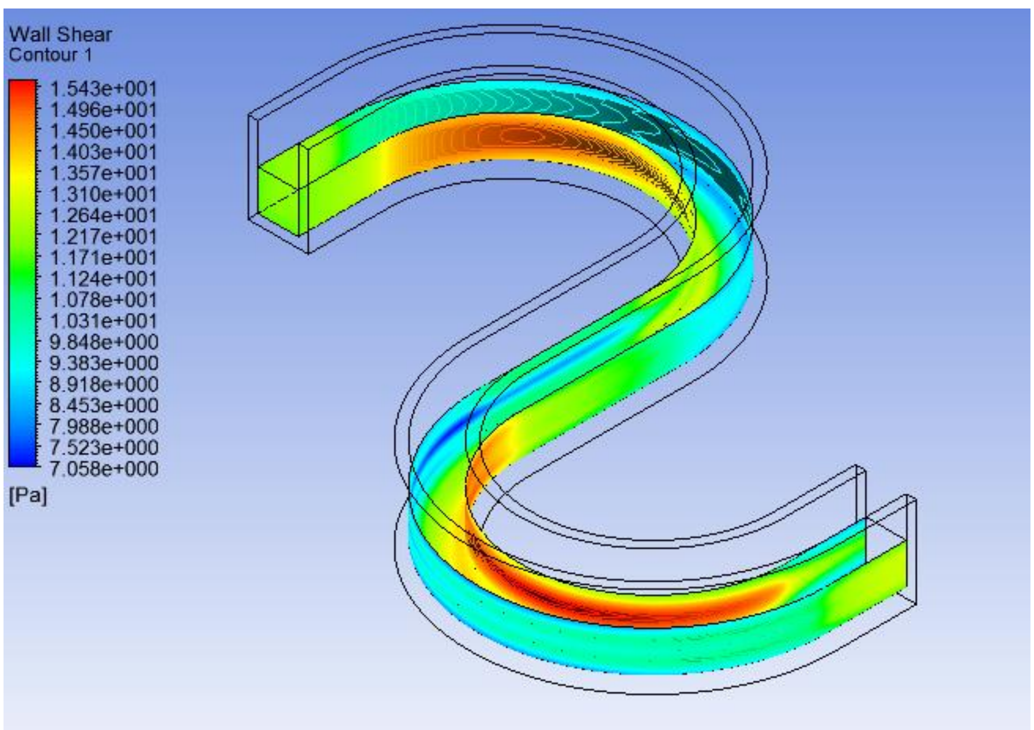



**Fig.4.25.** Shear stress contours for meandering channel (Sn=2.0) and velocity 3m/sec

| S.No. | Section | Vavg | Shear stress(inner wall) | Shear stress(outer wall) | Shear stress(bed) | % Variation |
|---|---|---|---|---|---|---|
| 1 | A | 3.028 | 10.471 | 7.449 | 7.989 | 40.569 |
| 2 | B | 3.11 | 10.488 | 7.006 | 7.83 | 49.700 |
| 3 | C | 3.289 | 10.559 | 6.569 | 8.16 | 60.740 |
| 4 | D | 3.26 | 10.698 | 6.951 | 8.459 | 53.906 |
| 5 | E | 3.38 | 10.251 | 6.679 | 8.697 | 53.481 |
| 6 | F | 3.21 | 9.626 | 6.405 | 8.896 | 50.289 |
| 7 | G | 3.16 | 9.803 | 6.873 | 9.141 | 42.631 |
| 8 | H | 3.19 | 9.344 | 6.972 | 8.283 | 34.022 |
| 9 | I | 2.86 | 9.449 | 6.764 | 8.882 | 39.695 |
| 10 | J | 3.04 | 8.985 | 7.091 | 8.652 | 26.710 |
| 11 | K | 3.07 | 9.419 | 6.625 | 7.959 | 42.174 |
| 12 | L | 3.23 | 10.735 | 6.355 | 7.963 | 68.922 |
| 13 | M | 3.1 | 10.386 | 6.623 | 7.817 | 56.817 |
| 14 | N | 3.28 | 10.412 | 6.776 | 7.958 | 53.660 |
| 15 | O | 3.32 | 10.052 | 6.798 | 8.165 | 47.867 |
| 16 | P | 3.22 | 9.789 | 7.112 | 8.154 | 37.641 |
| 17 | Q | 3.18 | 9.558 | 7.073 | 8.459 | 35.134 |
| 18 | R | 2.98 | 9.324 | 6.982 | 8.554 | 33.543 |
| 19 | S | 2.88 | 9.107 | 7.259 | 8.754 | 25.458 |

**Table.4.9.** Shear stress analysis for Sn = 2.53 and Q = 3 cumec

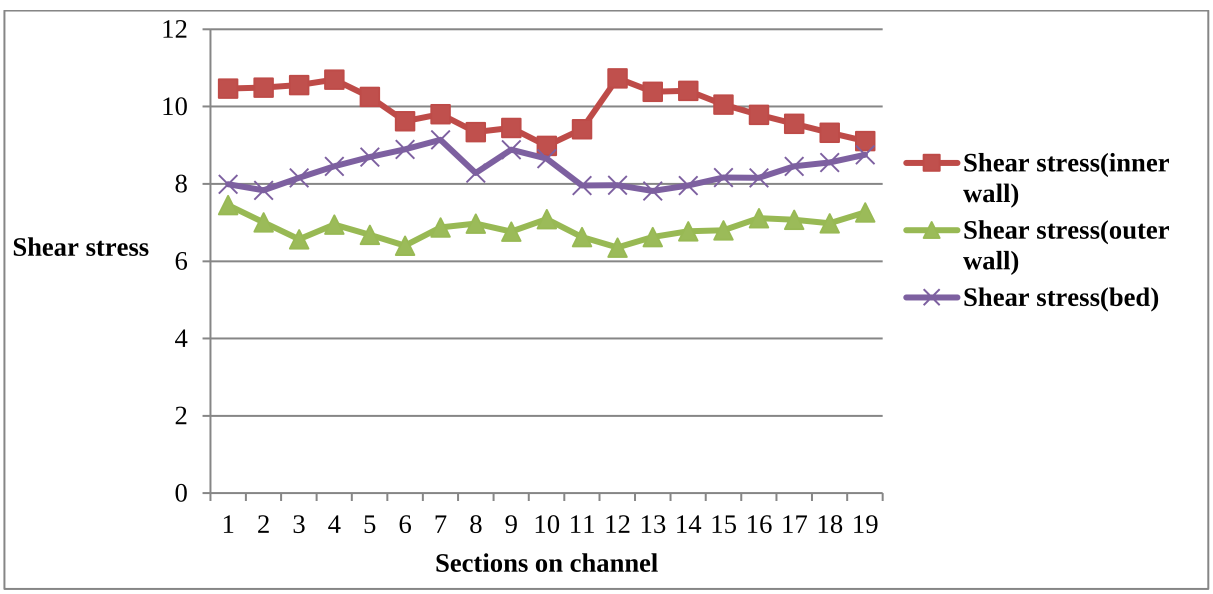



**Fig.4.26.** Graphical analysis of shear stresses for Sn = 2.53 and Q = 3 cumec

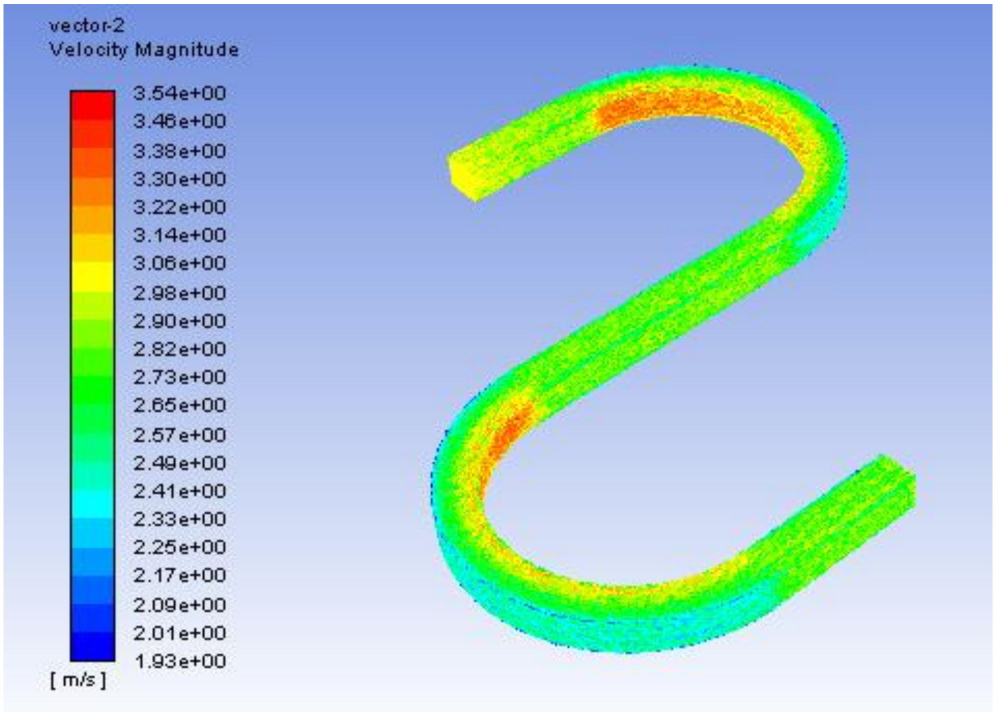



**Fig.4.27.** Velocity contours for meandering channel (Sn=2.53) and velocity 3m/sec

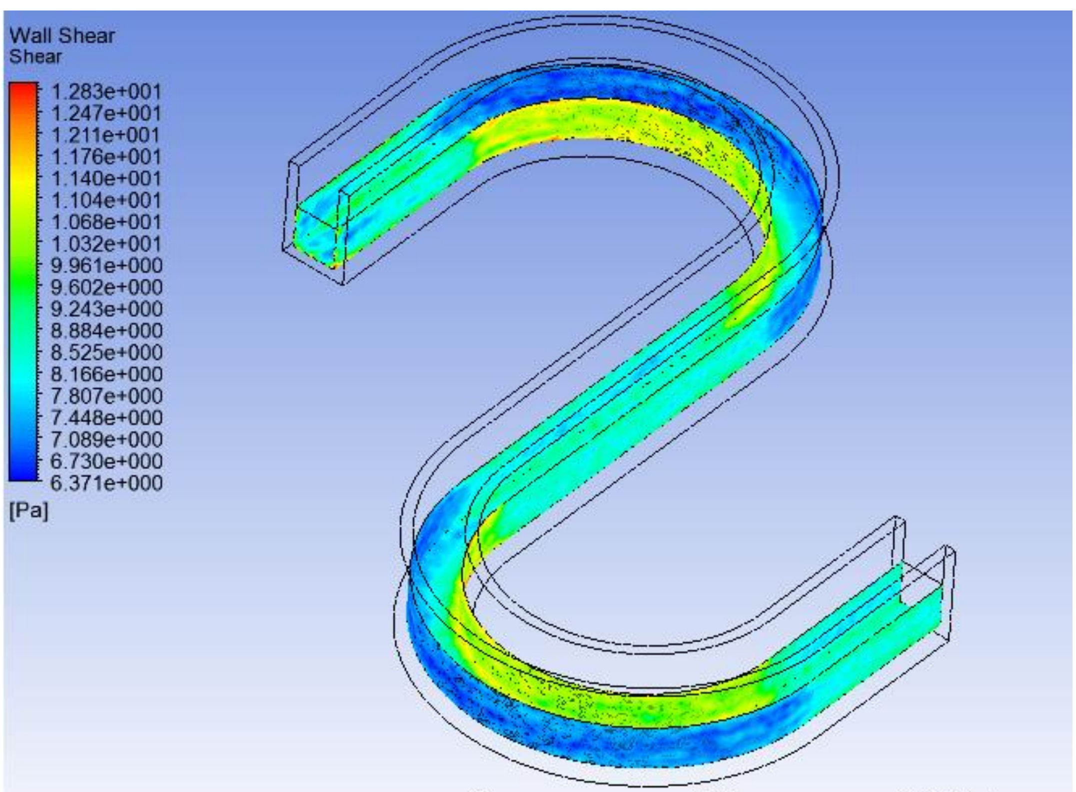



**Fig.4.28.** Shear stress contours for meandering channel (Sn=2.53) and velocity 3m/sec

## 4.2 Discussion

We observe the shear stress values on inner wall, outer wall and bed respectively with the percentage variation between inner and outer wall shear stress values as shown in results section 5.1.Graphical variation of shear stress values is also shown along the sections chosen on the meandering channel. From the analysis in section 5.1 we observed the following outcomes:

- For the meandering channels with Sn = 1.47, shear stress values on inner and outer wall respectively are relatively same on $1^{st}$ meander wavelength and percentage variation is up to 1-2%.On the other hand when water flows through $2^{nd}$ meander wavelength this percentage variation rises up to 80% for discharge of 1 cumec. Similar patterns are observed for other discharge values i.e. 2 and 3 cumec respectively.

- For the meandering channels with Sn = 2.0, significant percentage variation between shear stress values on inner and outer walls is observed in both the meander wavelengths. For $1^{st}$ meander wavelength percentage variation is up to 55% which increases up to 78% on $2^{nd}$ meander wavelength for discharge of 1 cumec. Similar patterns are observed for other discharge values i.e. 2 and 3 cumec respectively.

- Similarly for meandering channel with Sn= 2.53, percentage variation between inner and outer wall shear stress values for 1st meander wavelength is up to 55% and up to 57% on $2^{nd}$ meander wavelength for discharge value of 1 cumec. Similar patterns are observed for other discharge values i.e. 2 and 3 cumec respectively.

# CHAPTER 5

# CONCLUSION

## 5.1 Conclusion

Numerical simulations are carried out to analyze the effect of sinuosity on shear stress distribution in a meandering channel. Velocity distribution is studied in a meandering channel. Observations for shear stress values are made point to point to study the effect of sinuosity. Sinuosity values taken for observations are 1.47, 2.0 and 2.53.Sinuosity values are increased from 1.47 to 2.53 by introducing straighter portions at starting and end of meandering wavelength. Conclusions from analysis and discussion are discussed below:

- 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 implies 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 wavelength as compared to first wavelength in meandering section. 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 stresses.

## 5.2 Future Scope

Present work has a wide range of future scope. Various parameters which were taken constant in this study can be varied to study their effect on flow properties. Present work offers a wide spectrum of research in future as follows:

- Effect of change in geometry of cross-section can be analyzed by changing the geometry from rectangular to trapezoidal or semi circular.

- The bed roughness of channel can be varied from smooth to rough.

- Comparison of results from various turbulence models can be performed.

- Sinuosity values can be varied by introducing curved sections and results can be compared.

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