BOUNDARY LAYER STUDIES ON ROUGH FLAT PLATES UNDER NEGATIVE PRESSURE GRADIENT

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Technology
In
Civil Engineering

SUBMITTED
BY

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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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In partial fulfillment of the requirements
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Under The Guidance of

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This is to certify that the thesis entitled, “**BOUNDARY LAYER STUDIES ON ROUGH FLAT PLATES UNDER NEGATIVE PRESSURE GRADIENT**” submitted by **Vivek Gupta** in partial fulfillment of the requirement for the award of **Master of Technology** degree in **Water Resources Engineering** with specialization in **Civil Engineering** at the National Institute of Technology Rourkela is an authentic work carried out by his under my supervision and guidance. To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Research Guide

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ABSTRACT

There has been substantial research on boundary layer development on different objects. In this research project velocity distribution and boundary layer generation helps us to design the objects according to the steam lined bodies. Rough flat plate had been used as object in the experiment. It will help the objects to move easily in fluids.

For the basic understanding of flow characteristics over a rough flat plate, the experiment was carried out in the laboratory using a low speed wind tunnel. Velocity reading are observed at specified locations over the rough flat plate (wood surface with stacked on different grade emery papers) with a free stream velocity. With the concept of 0.99U (free stream velocity) velocity profile is plotted at location of working sections length in the longitudinal direction .The boundary layer thickness ranges from 1.2mm to 59.2mm is generated for the model of 100cm length. To produce negative pressure in experiment, the flat plate is being inclined. The boundary layer growth gives a brief idea of fluid flow over a flat surface. Comparative study is done between four rough flat plates for better understanding of boundary layer theory. Tabular results of local velocity at every section had discussed here for the laminar to turbulent flow.

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ABL	*Atmospheric Boundary Layer*
µm	*Micrometer*
y	*Distance from the surface*
$^\circ$	*Degree*
$\frac{dp}{dx}$	*Pressure gradient*
U	*Mean Velocity*
$\frac{dV}{dx}$	*Velocity gradient for Horizontal*
$\frac{dU}{dy}$	*Velocity gradient for Vertical*
δ	*boundary layer thickness*
L	*length*
U_∞	*free stream velocity*
$U_{(x,y)}$	*velocity at a point in space(2D)*
V	*velocity of object*
c	*velocity of light*
R_e	*Reynold's number*
R_{ex}	*Reynold's no. at any x*
CFD	*Computational Fluid Dynamics*
LES	*Large Eddy Simulation*
MHD	*Magneto Hydro Dynamic*
m	*meter*
mm	*millimeter*

CHAPTER 1

INTRODUCTION

1.1: Basic ground of boundary layer:

Motions are relative motion, but we are generally take motion with respect to ground, it is known as relative motion .So all kind of motions are relative motion. When body moves or being stationary relative motion occurs due to blowing of wind. Wind blows due to density difference and it is a natural phenomenon. Basic platform of the boundary layer generation is made from this point. When the wind touches the model placed in the working section feels a resistance , due to this resistance velocity gradient will develops near the surface of the model .At some height from the surface ,where the velocity gradient does not exist .Bernoulli equation are applied only these areas where velocity gradient does not exist.

Everybody shows boundary layer either less or more depends on different parameters, like velocity, roughness etc. With the help of all effects on the velocity profile on roughness and inclination, it will be easy to study the analysis of boundary layer along with these effects. Design of roof in the hilly areas, design of automobile, design of any open industry it will be helpful to use these results. Till now some work has been done on the effect of boundary layer on only flat plate means smooth flat plate. Some small blocks are put in the model to create to simulate the roughness in the natural world. There are some objects are situates in the working section of the low speed wind tunnel.

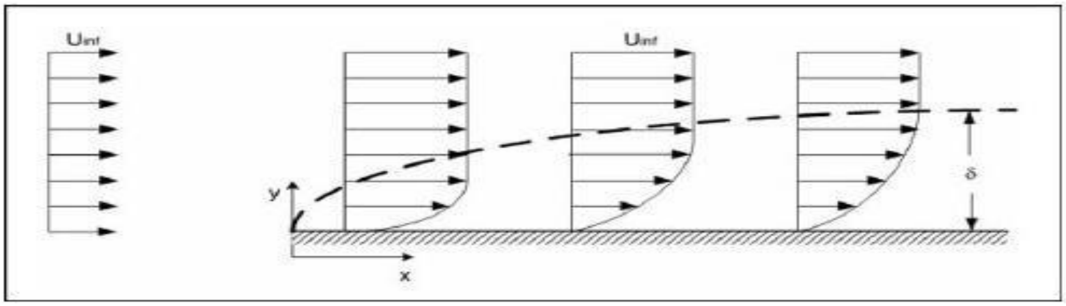


Fig: 1.1: boundary layer with velocity profiles

1.2: Boundary layer:

The phenomenon of boundary layer is a layer near to a surface where viscous effects are prominent. When real fluid flows over a solid body or a solid plate, the fluid particles adhere to the boundary of the stationary surface and the phenomenon of no slip condition occurs. This results that the velocity of fluid near to the boundary will be same as that of boundary. If the boundary is stationary, the velocity of fluid at the boundary will be zero. Further away from the boundary, the velocity will be increase gradually and as a result of this variation of velocity, the velocity gradient will exist. The velocity of fluid increases from zero velocity on the stationary boundary to the free stream velocity of the fluid in the direction normal to the boundary. The extent of atmospheric boundary layer (ABL) thickness is quite high and all types of structures lies with atmospheric boundary layer thickness. To conduct wind tunnel experiments on the small scale replica of a structure (civil, mechanical or any), it is necessary that the models should lie within boundary layer zone. But, in wind tunnel, the boundary layer thickness is very small and hence constant attempts have been made by different researchers to increase boundary layer thickness by different means.

In the first part of experiment, the study was based on the fact that reading was taken with some obstruction like 40 grades (375µm) in approaching flow. With these reading velocity profile were plotted and then growth of boundary layer were also drawn. Now we place different grades of roughness in the wind tunnel like 50 grades (345µm), 60 grades (290µm), 120 grades (125µm). This different kind of roughness gives us new dimension in the results. In the second part of experiment reading were taken in presence of a rough flat plate and to create negative pressure provides some angle to the particular roughness of the flat plate. As increasing the inclination of the flat plate thickness of boundary layer is also increased in comparison to previous cases. This is because obstruction helps in the generation of vortex formation and consequent turbulence. Boundary layer study is of utmost important for stability and design point of view the boundary layer of a fluid flowing is the thin layer close to the wall in a flow region; viscous forces are very prominent within that layer range. Viscous force is a force like friction force in the same phases of substances, here it is liquid. As the layer which separates boundary layer is very thin, it is very important to investigate the information of flow within it. The main stream flow velocity within these layer tends to zero while approaching the wall to increase the velocity (no-slip condition). Also the gradient of this velocity component in a normal direction of the surface is large than the gradient in the stream flow direction. Effect of the velocity profile in the lateral direction is also important in the structure design of any three dimension object.

1.2.1: Boundary layer thickness:

A very small consideration shows that boundary layer thickness, as the thickness where velocity approaches to main stream velocity, is not an entirely acceptable concept. Since the velocity in boundary layer increases in asymptotic manner so the distance ‘y’ depends upon measurement of accuracy**.**

1.2.2: Effect of pressure Gradient:

When the area is converging where the fluid wants to flow, velocity is increasing for that section. Due to increasing velocity pressure will be reduced for that section and these decreasing of pressure are known as negative pressure gradient. The actual meaning of the negative pressure gradient is decreasing of pressure with respect to some distance x in any direction.

If the free stream is accelerating or decelerating, substantial changes take place in the boundary layer development. For an accelerating free stream the pressure falls in the direction of flow , the pressure gradient being given by differentiating Bernoulli’s Equation in the free stream as ,

$$\frac{dP}{dX} = -U\frac{du}{dx}$$

The boundary layer grows less rapidly than in zero pressure gradient and transition to turbulence is inhibited. For the decelerating free stream, the reverse effects are observed. The boundary layer grows more rapidly and the shape factor increases in the downstream direction.

The pressure rises in the direction of flow, and this pressure rise tends to retard the fluid in the boundary layer more severely than that in the main stream since it is moving less quickly. Energy diffuses from the free stream through the outer part of the boundary layer down towards the surface to maintain the forward movement against the rising pressure.

However, if the pressure gradient is sufficiently steep, the diffusion is insufficient to sustain the forward movement, and the flow along the surface reverses, forcing the main stream to separate. It is this separation, or stall as it is sometimes called, which leads to the main component of drag on bluff bodies and to the collapse of the lift force on an aerofoil when the angle of incidence is excessive.

1.2.3: Effect of kinematic viscosity:

On increasing temperature kinematic viscosity increases but in our project the effect of this factor was not considered due to fact that there is very little increase in kinematic viscosity for low temperature range between (300.15 k 306.15 k).

1.2.4: Mathematical expression for boundary layer:

In 1905, Ludwig Prandtl, the famous German scientist, presented the concept of boundary layer in mixing length theory and derived the equations for boundary layer flow by correct reduction of Navier-Stokes equations. He hypothesized that for fluids having relatively small viscosity, the consequence of internal friction in the fluid is substantial only in a narrow region surrounding solid boundaries or bodies over which the fluid flows. Thus, close to the body is the boundary layer where shear stresses exert an increasingly larger effect on the fluid as one moves from free stream towards the solid boundary. However, outside the boundary layer where the effect of the shear stresses on the flow is small compared to values inside the boundary layer (since the velocity gradient $\frac{\partial u}{\partial y}$ is negligible), the fluid particles experience no vorticity and therefore, the flow is similar to a potential flow. Hence, the surfac*e* at the boundary layer interface is a rather fictitious one that divides rotational and irrotational flow. Fig 28.1 shows Prandtl's model regarding boundary layer flow. Hence with the allowance of the immediate vicinity of the surface, the flow is frictionless (in viscid) and the velocity is U (the potential velocity). In the region, very near to the surface (in the thin layer), there is viscosity in the flow which signifies that the fluid is retarded until it adheres to the surface (no-slip condition). The transition of the mainstream velocity from zero at the surface (with respect to the surface) to complete amount takes place means full free stream velocity across the boundary layer.

Boundary layer thickness is δ which is a function of the coordinate direction x. The thickness is considered to be very small compared to the characteristic length L of the domain. In the normal direction, within this thin layer, the $\frac{\partial u}{\partial y}$ gradient is very large compared to the gradient in the flow direction $\frac{\partial u}{\partial y}$. Development of the velocity gradient reduces the velocity of flow, so as we are going upward direction means vertical direction from the surface these velocity gradient amounts will decreases and when it reaches on certain limit it will be zero. At that point free stream velocity meets and this will be the point with which formation of boundary layer has been done.

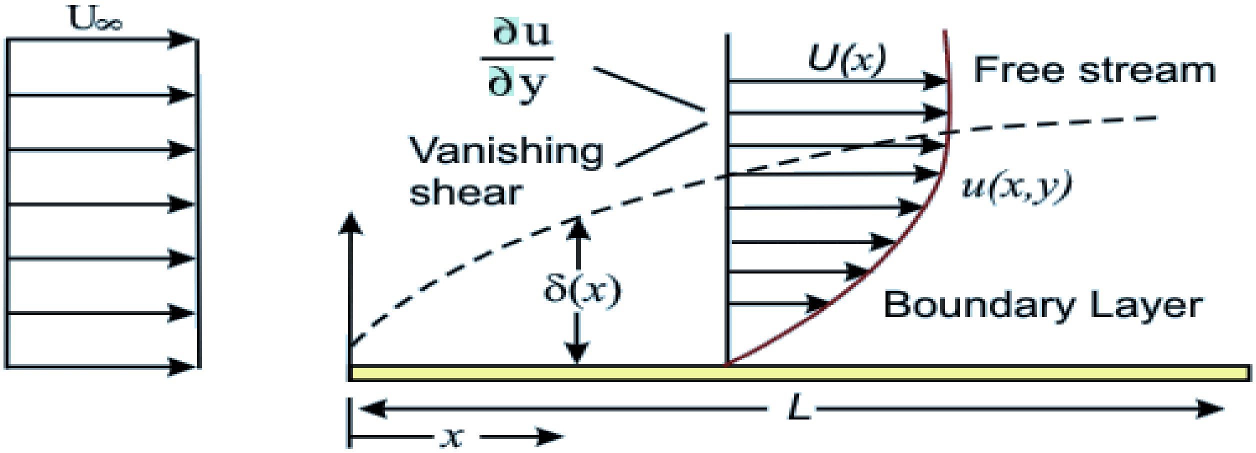


Fig: 1.2: boundary layer formation with the generation of velocity gradient

This says that the *u* component of velocity with two velocity profiles of *u(x, y)* at different *x* locations differs so that we are taking two sections 15 cm and 30 cm from the leading edge only by scale factors in *u* and *y*. Therefore, the velocity profiles at all values of *x* can be made compatible if they are strategized in coordinates which are made dimensionless with reference to the scale factors. The free stream velocity *U(x)* at any section *x* is equal to same 12.3 m/s an obvious scale factor for *u*, because the dimensionless *u(x)* varies between zero and unity with *y* at all sections with 5 cm gap between them. There is a new scale factor for *y* denoted by *g(x)*, is proportional to the local boundary layer thickness so that *y* itself varies in zero to one.

1.2.5: Application of Boundary layer:

The problem of laminar to transition and transition to turbulent flow in boundary layers is of main practical attention. Transitional studies are interested by a necessity to understand these physical issues and to apply this concept to the reduction and control of transition. For example, the high skin friction drag of laminar boundary layer flow compared with the low friction drag of turbulent flow is very attractive to those who wants to design high performance automobiles and aircraft. On the other hand, there are many cases where the mixing and heat transfer rates of turbulent boundary layer are desirable, *e.g.,* for combustion. Separation and reattachment of laminar and turbulent flows occurs in many practical engineering applications, in external flows like those around airfoils and buildings both in internal flows systems such as diffusers, combustors and channels with sudden expansions.

Boundary layer helps us to design the prototype with the help of model. We put model in the working section of the wind tunnel. Aspect ratio of model should be exactly same as we want to make the original. There is some speed limitation in the low speed wind tunnel. Classification of the wind tunnel is very important for the observation point of view.

1.3: Wind tunnel:

Wind tunnel is a tool with the help of this tool we can solve our design problem. Like how much boundary layer thickness, displacement thickness, energy thickness should be. Wind tunnel is helping us to find out boundary shear distribution also with that our analysis related to the roughness. Condition of stability of any structure is also observed by these tools but which kind of wind tunnel is used for which purpose is very important.

There are 5 types of wind tunnels

1. High speed wind tunnel
2. Supersonic wind tunnel
3. Hypersonic wind tunnel
4. Low speed wind tunnel
5. Subsonic and transonic wind tunnel

These wind tunnels are designed for their use point of view. The basic classification of the wind tunnel is depends on Mach number.

$$\text{Mach number} = V/C$$

Here V stands for relative velocity of the object and C stands for the velocity of light.

Boundary layer distribution with the help of velocity profile we can produce a curve through this curve, we can design the structure compiled with steam line body. It will be helping the object to flow in the fluid easily. The places where the speed is very high this boundary layer consideration is very important. Study in the Low speed wind tunnel gives better result for automobile for high speed. The speed limitations for the low speed wind tunnel are 10 m/s to 25 m/s.

1.4: OBJECTIVE

Objective of this work is to compare the different types of curves on boundary layer and to investigate the effects of roughness and effect of inclination on the boundary layer through velocity profiles.

Objective of this work are –

1. To determine the effect of roughness on boundary layer growth.
2. To find the pattern in boundary layer for different-different inclinations.
3. Generation of velocity profile in each 5 cm distance from the leading edge in the longitudinal direction.
4. Analytical results on velocity profile for a particular height in the tabular form.
5. Showing the effect of inclination and roughness on velocity profile at some laminar and turbulent zone.

CHAPTER 2

LITERATURE

REVIEW

2.1 OVERVIEW ABOUT LITERATURE SERVEY

For the study of boundary layer we need to know about velocity profiles first. There are so many papers about the development of boundary layer growth. Actually the main reason behind the study of boundary layer is to design something. In this relative world concept of relative velocity is very important, with the analysis of relative motion if you plan or design a moving part as well as the stationary part, it will be helpful for the stability of these part. For high velocity automobile or aircraft it is necessary to analyze about the boundary layer. There are some papers, written by researchers about different objects, which are placed in the working section of wind tunnel and they also investigated different parameters like inclination, pressure gradient, roughness and velocity which are explained in this chapter.

2.2 LITERATURE ABOUT FORMATION OF BOUNDARY LAYER

S.Goldstein et al. (1930) studied solutions of the boundary layer equations in the field of hydrodynamics. For a steady two dimensional motion the boundary layer equations are solved at any given instance of velocity distribution. The assumptions made for this distribution is expressed as a polynomial function of distance from the wall. Here in this paper we are investigating three cases which are as follows:

i. In case of initial distribution velocity vanishes at wall but its gradient which is acting along the normal remains.
ii. In this case velocity in initial distribution does not vanish at all.
iii. In this case both the components i.e. velocity as well as its normal gradient vanishes.

The solution was concluded as a power series whose coefficients are function of the distance from the wall and has to be calculated from ordinary differential equations. He wanted to find velocity field by a step by step process.

G.B Schubauer et al. (1947) analyzed the laminar boundary layer oscillation and stability of flow by mathematical model. While performing experiment he observed oscillations on the plate when the flow changes from laminar to transition and from transition to turbulent. Damping screens were used to reduce the turbulence in the wind stream. A description of how the oscillations were discovered, and in which manner they are related to transition and how to control this situation was investigated. Comparison was made in which oscillations were compared to velocity variations. Stability theory predicts all the characteristics of wave motion based on experimental growth.

Donald (1953*)* measured the boundary layer on smooth flat plate in supersonic flow.

Turbulent boundary layer in a low speed wind tunnel is compared with a simple analysis based on functional similarity and it was reported that the boundary layer is unique within the accuracy of the experimental data. Mean equations of motion are found including distribution of shear stress through the boundary layer. Effort was made to generalize the relationship known as the law of the wall to flow with variable density.

Problems faced in the development & use of the floating surface element & various instrumentations are also discussed. In 20 inch supersonic wind tunnel, mean and local surface friction was measured on a plate having flat surface. For free stream Mach number of 2.0, 2.6, 3.7 and 4.5 boundary layer flow was studied. The experiments having Reynolds number ranging from 2x10^5 to 9x 10^6 including a few measurements in laminar flow but emphasize transition and the turbulent region. For fully turbulent flow on effective Reynolds Number is defined. Finally turbulent boundary layer profile measurements are examined.

Messiter (1970*)* proposed a boundary flow near the trailing edge of a flat plate but arrived at the same solution as that of Goldstein. He depicted that the solution obtained by Goldstein of the boundary layer breaks at some point downstream from the trailing edge and also found second order correction to Goldstein’s solution.

Cook (1978*)* placed a elliptic wedge in front of air flow, means roughness and barriers are placed in wind tunnel.

He discussed about the idea of roughness, barrier and mixing-device simulation. The functions of the various physical components are demonstrated and their performance is assessed. He concluded that entirely naturally grown boundary layers give the best simulations, but at large scale factors while smaller scale factors require that some artificial assistance be given, inevitably reducing the quality of the simulation. The degree of assistance and the degree of 'artificiality' of the resultant simulation is a matter of choice, and this paper goes some way towards quantifying the effects.

Suh & Taik Sik Lee (1987)

For large Reynolds number two dimensional incompressible laminar flow induced by a constant slip velocity was studied both analytically and numerically on the surface of a finite plate. It was found that the thickness of the thin layer downstream of the trailing edge increase in square root of the distance from the trailing edge. Numerical integration of the boundary layer equations confirmed two asymptotic natures of the flow field. Analytic result is approached near the trailing edge and jet flow solution is attained for downstream of the plate.

Robert I.M Lachlan (1990) investigated boundary layer on a finite plate. He studied the problems regarding the flow over a finite plate whose surface is flat and with a uniform free velocity. For obtaining accurate numerical solutions having Reynolds number upto a range of 4000 multigrid is used. With the help of Fourier boundary conditions computational domain is small and there is no loss of accuracy. With first order triple deck theory excellent agreement was found near the back or trailing edge but it was found that the comparisons which has been made previously between computations, experiments and triple deck theory depicts to be misleading. Triple deck theory only amounts for half the drag and the remaining is due to displacement effect and skin friction even at R= 4000.

Jon William Dotter (1994) measured upstream for mean and compressible turbulence with a Mach 3.0 flow. Reynolds shear stress was directly measured using turbulence transformation. Results concluded that there are some effects due to compressibility and these effects are largely accounted due to density fluctuations as compared to velocity and are implemented in new turbulence models.

Takeshi Ishihara et al. (1999) studied turbulent flow over a three dimensional steep hill using wind tunnel. He investigated turbulent flow over a circular hill which is having a cosine square shaped cross section by using split fiber probes having high turbulence and separation. For three velocities component profiles regarding means and variances are compared with no hill boundary layer. Speed up flow occurs not only at hilltop but also at midway. Variance in longitudinal and vertical velocities are observed at hill height ($z/h = 1$) while at a height oh $z/h =$b 0.125 lateral velocity was observed.

V.I Kornilov et al. (2002) reviewed techniques and results for skin friction measurements in an incompressible pressure gradient turbulent boundary layer. In the field of aerodynamics the experimental definition for the local and integral value of friction drag is one of the primary problems. This paper gives a comparative information about a number of direct and indirect techniques when they are applied in a incompressible boundary layer of a flat plate under the situation of formation of positive and negative stream wise pressure gradients.

V.G.Lushchik (2003) analyzed transition to turbulent flow in boundary layer on a flat plate in presence of negative pressure gradient.

For an incompressible fluid flow with a negative free-stream pressure gradient Transition to turbulence in the boundary layer on a flat plate is investigated numerically. For examining the transition the author developed the three-parameter turbulence model. The calculated results were compared with the available experimental data

Using the three-parameter turbulence model transition to turbulence in the boundary layer on the plate is investigated numerically for a flow with a negative free-stream pressure gradient and a high external perturbation level. The effect of the pressure gradient parameter k on transition was investigated with an initial external turbulence intensity e_o=0.01–0.05. It is depicted that the transition Reynolds number Re^*_Θ calculated from the momentum thickness varies slightly with increase in the parameter k and the Pohlhausen form-parameter Λ_Θ. The significant dependence of Re^* on the turbulence intensity e_o corresponds to both qualitatively and quantitatively the few experimental data available.

Kay Gemba (2007) measured boundary layer on flat plate. In the field of aerodynamics basic understanding of flow characteristics over a flat plate is necessary. Wind tunnel was used to gather information about various parameters and characteristics for fluid flow. At four different locations throughout the plate readings were taken at an average free stream velocity U_∞ of 19.1±0.3m/s which gives the Reynolds number for the flow. The boundary height ranged from 3mm to 29mm. Using velocity profile displacement thickness as well as momentum thickness were calculated. He also determined the skin friction coefficient using three different techniques. On comparing the datas with the theoretical data of 0.0037 the best result for C_f was evaluated with the help of equation in terms of Reynolds number.

Bert and Peter (2010) they put aerodynamically different position of the cyclist and did analysis in CFD. They put full scale model in the wind tunnel.

Aerodynamically studied different cyclist positions and did CFD analysis and full scale wind tunnel tests. With the help of Computational Fluid dynamics (CFD) three different cyclist positions were evaluated to provide reliable data and to check the accuracy of the CFD simulations .wind tunnel experiments were performed. He concluded that the detailed flow field information as well as accuracy is a strong advantage of CFD as compared to wind tunnel tests.

Kazuki and Nagayama ***(2012)*** they developed a numerical simulation technique for unsteady turbulent dispersion over a complicated terrain.

Using a Large eddy simulation model (LES) unsteady numerical simulation technique was applied to dispersion fields over complicated terrain and did the comparison of these simulated results with the corresponding wind tunnel experiments. Simulation model assures high accuracy within practical computational limits and this analytical method is an unsteady turbulent flow and dispersion simulation model that has become an alternative approach to wind tunnel experiments and significantly reduced examination durations.

P.K.Singh (2012*)* he developed mathematical model in heat and mass transfer in a flat plate and put an inclined plate in the viscous medium.

He studied the problems regarding the hydro magnetic convective flow of a in a steady two dimensional state over an inclined plate in a medium having porosity. Convective flow is due to the buoyancy forces which are caused due to fluctuation in density starts. Through this study of convective MHD boundary layer flow with combined buoyancy forces arising due to thermal and mass diffusion on inclined plates, the main observations are that both Prandtl and Eckert numbers affect the temperature field quite considerably.

P.P. Puttkammer et al. **(2013)** investigated boundary layer over a flat plate. He measured velocity profile of a flat plate at zero angles up to a Reynold’s number 14000. The velocity profiles which are generated have been compared with theory. Boundary layer equation are derived and solved numerically as well as analytically. He concluded that numerical analysis showed velocity profiles similar to Blasius solution.

Witold Elsner et al. (2014) studied transitional rough boundary layer by numerical methods. γ-$Re_{\theta t}$ model was used for verification of boundary layer modelling. For the verification of model with zero and non-zero pressure gradient test in addition high pressure turbine blade cases were chosen. He concluded that the modelling approach proved to be precise

And the result depicted that combined effect of wakes and surface roughness could be favorable for the efficiency of blade.

Mark P Simens et al. (2014) investigated the effect of surface roughness on laminar separated boundary layers. He varied location as well as size of the roughness for better understanding of boundary layer.

CHAPTER 3

EXPERIMENTAL

SETUP

&

METHODOLOGY

3.1: OVERVIEW

Normally, experimental work having some physical exercise, it is having some setup with the help of this only we can carried out the experiment. Setup should be accurate and precise so that we can take reading effectively. Here in our case, there are some objective. For the fulfilment of the objective we have perform some experiment. We are performing a experiment for showing the effect of roughness and inclination on the velocity profiles. With the help of velocity profiles

We are going to present comparison curves for the effect of variation in boundary layer for inclination and for roughness.

For carrying out research on boundary layer study a Low Speed Wind Tunnel is built in the Hydrodynamics Laboratory of NIT Rourkela as shown in Fig.3.1The speed of air in this wind tunnel can be varied from 10 to 25 m/s.

Fig.3.1: Low Speed Wind Tunnel

The wind tunnel consists of a testing section somewhere in the central region where the velocity variation in the air stream is nearly uniform. The dimensions of the various components of the wind tunnel are given in Table 3.1 Experimental models are placed here to carry out studies done on the objects to find the effect of the air stream on them. The photograph of the testing section is shown in Fig.3.2. In the working section air blows from effuse to diffuser with some constant mean steam velocity until there had been no variations performed in the gear box arrangement.

TABLE NO: 3.1Dimensions of Wind Tunnel Components

Components	Length	Inlet (m)	Outlet (m)
Effuser	1.3 m	2.1 X 2.1	2.1 X 2.1
Test Section	8 m	0.6 X 0.6	0.6 X 0.6
Diffuser	5m	0.6	1.3

3.2: LOW SPEED WIND TUNNEL

It is a device in form of a long duct for producing a moving airstream for experimental purposes. It is used to study the effects of air moving past solid objects. The model science has assumed an important role in engineering. As it is not only makes it possible to study the behavior of the structure or machines where mathematical methods are impossible, time-consuming or inaccurate but also results in economy since it is easier and cheaper to effect changes in a model rather than the prototype.

There are four essential components:

3.2.1: EFFUSER:

This is placed upstream of the working section. In it the fluid is accelerated from rest to approximately at upstream end to the required conditions at the working section. The effuse contain a conversing cone, screens and other devises to refuse the turbulence and produce a uniform airstream at the exit. It is the section from where air is coming in the system. Number of small-small entrance is made due to symmetrically flowing of air. In our institute the entry point of the effuser is a big square converging to the working section side.

Fig.3.2: Effuser zone of the Low Speed Wind Tunnel

3.2.2: WORKING SECTION:

It is here that the model is placed is placed in the air stream leaving the downstream end of the effuser and the required observations are made. The working section consists of accessories to hold the instruments and models and devices for facilitating the motion of the model in all directions relative to airstream.

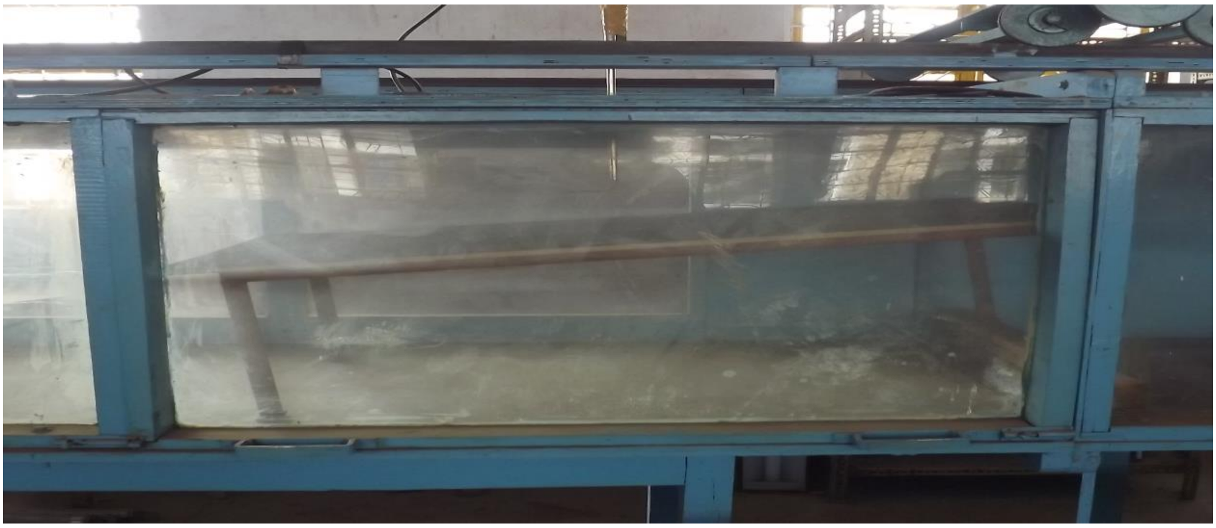


Fig.3.3: Working Section of the Low Speed Wind Tunnel

3.2.3: DIFFUSER:

The function of the diffuser is to recover the kinetic energy of the airstream leaving the working section efficiently as possible. Diffuser is like part of cone cut to some height from vertices. It is the part of the wind tunnel increasing the diameter from some distance to the working section to the fan.

3.2.4: DRIVING UNIT:

Power is supplied continuously to maintain the flow through suction. There is a gear box system in the driving unit of the wind tunnel. As much the requirement of the velocity we want for the experiment, provides by the motor. This is done using a fan or propeller and a motor.

Fig.3.4: Driving Unit of the Low Speed Wind Tunnel

3.3: APPARATUS & EQUIPMENTS USED:-

For this experiment there are some important things to collect. Like telescopic pitot tube, special arrangement of trolley, preparation of rough flat, digital veloci manometer.

3.3.1: Telescopic Pitot tube:

Telescope probe meter contains the velocity, temperature and humidity sensors. It measures velocity inside test section of wind tunnel at different height from surface longitudinally and in transverse direction .when using the probe makes sure that sensor window is fully exposed and orientation dimple is facing upstream.

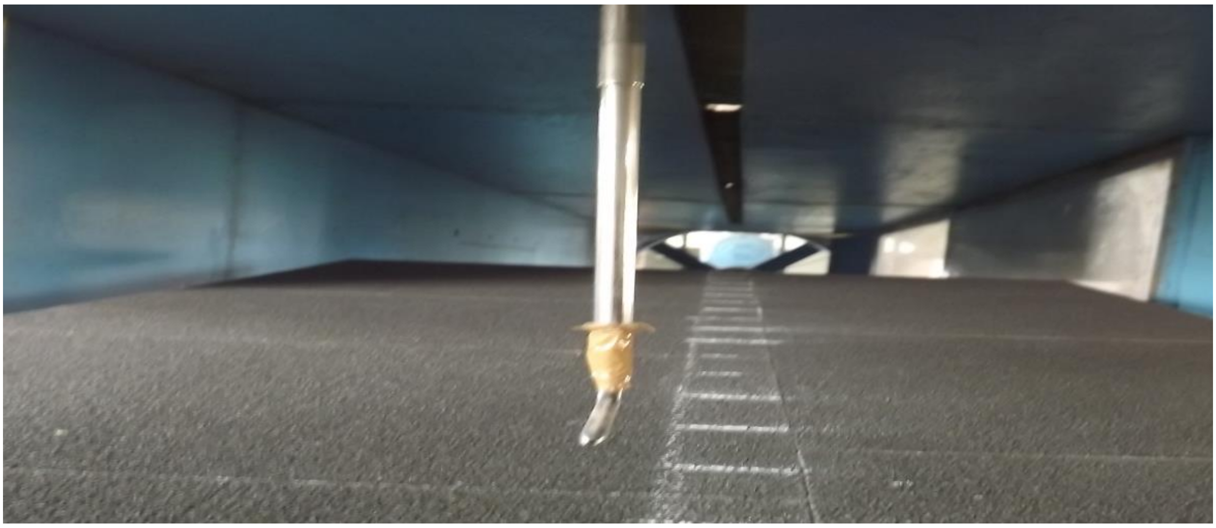


Fig.3.5: Telescopic pitot tube

3.3.2: Trolley with special arrangement:

Trolley basically used in wind tunnel for the movement purposes. From one section to another section reading is required so it's the Trolley which makes work easier. We are arrange a special type of trolley for this work to take the readings parallel to the surface. Actually there are two type of ways to perform observations. First readings parallel to the surface and second parallel to the flow. Here we are taking the first option for reading parallel to the flow.

Fig.3.6: Trolley arrangement

3.3.3: Rough Flat plate:

Preparation of rough flat plate is started before the experimentation. To introduced roughness on the flat plate emery paper is being used. Different grades of emery papers are using for this experiment. The grain size of emery paper is dependent on that which grade of emery paper is having more or less roughness. As the diameter of the grains is increasing the roughness of emery paper is also increasing. Therefore 40 Grades roughness is having more rough surface than 50 Grade, 60 Grade, and 120 Grade. Using the A4 sizes emery paper to cover the flat plate. For the purpose of pasting emery paper to the flat plates, we are using fevicol. There are some specification for the flat plate.

Fig: 3.7: flat plate with roughness 40 grade(375µm), 50 grade(345µm), 60 grade(290µm), 120 grade(125µm) respectively

TABLE NO: 3.2 Specifications for the flat plate

Serial no	Flat plate	Dimension
1.	Length	100 cm
2.	Width	50 cm
3.	Thickness	12 mm
4.	Material	wood

We are using different grades of roughness in our experiment for showing the effect of roughness on boundary layer and these are some specifications of the emery paper.

TABLE NO: 3.3 Specifications of the emery paper

Serial no	Grade no of emery paper	Size of emery paper
1.	40 Grade	375µm
2.	50 Grade	345µm
3.	60 Grade	290µm
4.	120 Grade	125µm

3.3.4: Stand and arrangement for the inclination:

There is iron stand of height 30 cm from the surface. We have placed our rough flat plate on this stand and situated in the working section of the low speed wind tunnel. A stand of required weight to hold the glass in a fixed position inside the test section of the wind tunnel.

To create negative pressure in the wind tunnel for flat plate, using some specific height blocks under the trailing edge of the iron stand. We are using three wooden blocks of same height for creating 2 degree, 4 degree and 6 degree.

3.3.5 Digital veloci manometer:

For the observation point of view digital instruments are very good. They give us exact results without any human error. There are two rubber pipes one for the static and other for the dynamic pressure head. This is the direct power operated device, no battery is used in the instrument anymore.

Fig 3.8: Digital veloci manometer

3.4: **Procedure:**

To study the effect of boundary layer flat plates of length 100cm and width 50cm with different surface roughness is considered. Four different surface roughness' are taken in the current study, namely 40, 50, 60 and 120 Grade. The value of the grain size in 40, 50, 60 and 120 Grades are 375 µm, 345 µm, 290 µm and 125 µm respectively. For the current study; 21 positions along the length of the plate are considered for velocity measurement in the vertical direction. However data for 8 such sections at 15 cm interval from the leading edge are considered. At each such section, velocity data is taken initially at 1mm interval and later the interval is increased to 5mm when the free surface velocity is achieved.

Measurements are taken with a Telescopic Pitot Tube which is connected to a Digital Veloci Manometer shown in Fig. 3. The pitot-tube is moved across the testing section throughout the length of the flat plate. The pitot-tube is held in the appropriate position and the corresponding velocity is taken directly by the digital manometer. Some wedges are used to give the inclination of rough flat plate. We are using different roughness plate for the velocity observation for effect of roughness at constant inclination. For showing the effect of inclination using a particular roughness plate for different inclination.

CHAPTER 4

RESULT

&

DISCUSSION

4.1 OVERVIEW

In the previous chapter the experimental procedures has been described with the outlines are given for the experimental procedure carried out on the series of the tests. This chapter will now extant the results of these tests in terms of the local velocity profile distributions and boundary layer graphs and also the rough flat plate geometry and dimensions. With the help of velocity profile generation of boundary layer is very important.

Main steam velocity of the wind tunnel, we have taken 12.3 m/s. We have taken velocity as a constant parameter throughout the experiment. Roughness and inclination of the rough flat plate are two variable parameters. The experimentation has been done at different –different sections. So there is a other parameter of different sections along the length. When fluid flows over a long surface, flow divides into three kind of flows named laminar flow, transition flow and turbulent flow. Here according to the Reynolds number also we concludes our results.

Now here we are showing variation in velocity profiles of rough flat plates with different – different inclination from the horizontal in different sections. It is the series of experiments. Observations have been taken in the longitudinal direction of the flow. For the analysis of velocity profile observations are taken at leading edge, 15 cm from the leading edge, 30 cm from the leading edge, 45 cm from the leading edge, 60 cm from the leading edge, 75 cm from the leading edge, 90 cm from the leading edge and 100 cm from the leading edge means at the trailing edge.

4.2 VELOCITY PROFILES

Velocity profiles shows the variations at each point above the surface. With the help of these points we can make a pattern to study the variation on boundary layer for the rough flat plate.

4.2.1 Variation of velocity profile on 40 grade (375µm), 50 grade (345µm), 60 grade (290µm), 120 grade (125µm) roughness plate with 0° inclination from the horizontal.

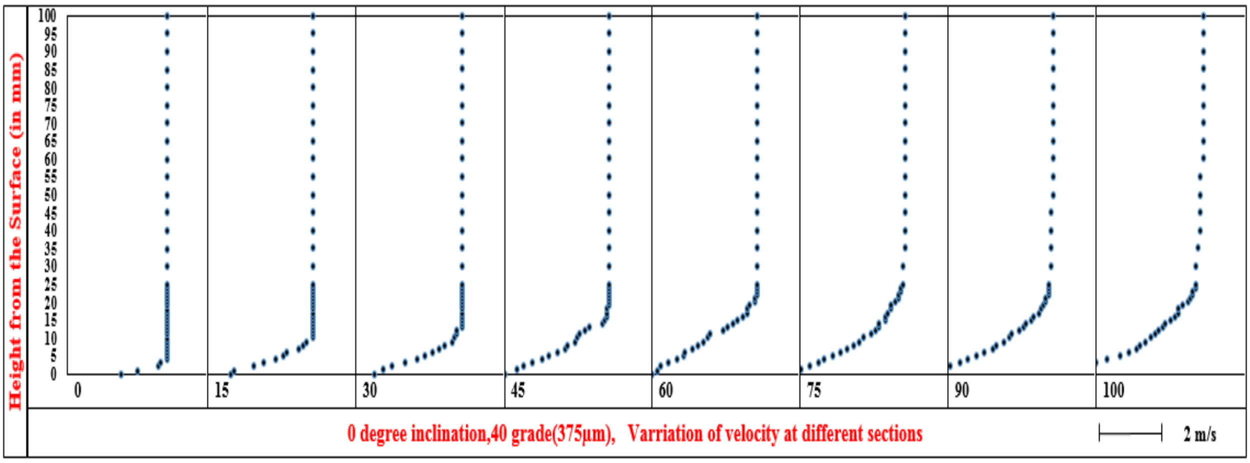


Fig. (4.2.1.a) variation of velocity in 0°inclination for 40 grade (375µm)

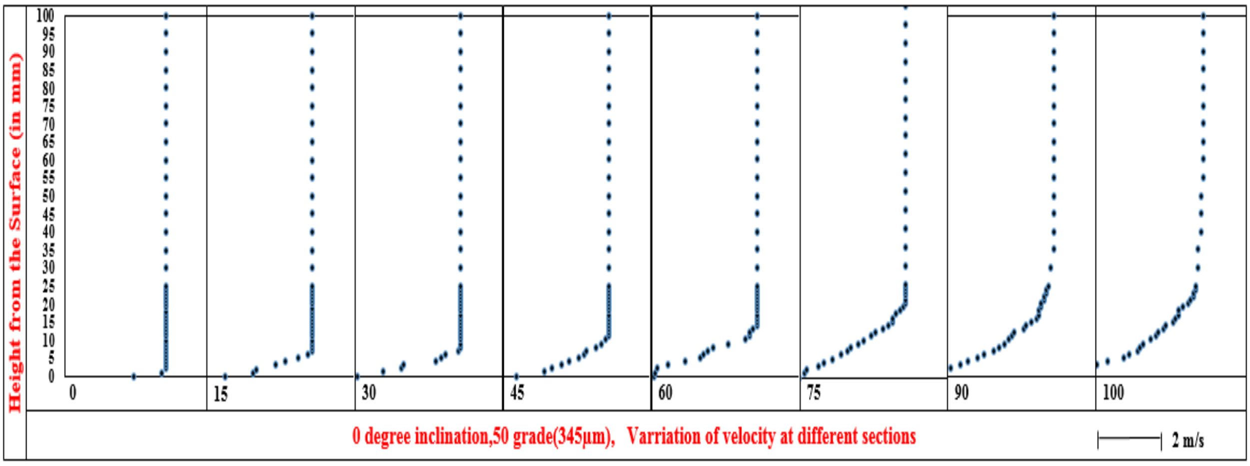


Fig. (4.2.1.b) variation of velocity in 0°inclination for 50 grade (345µm)

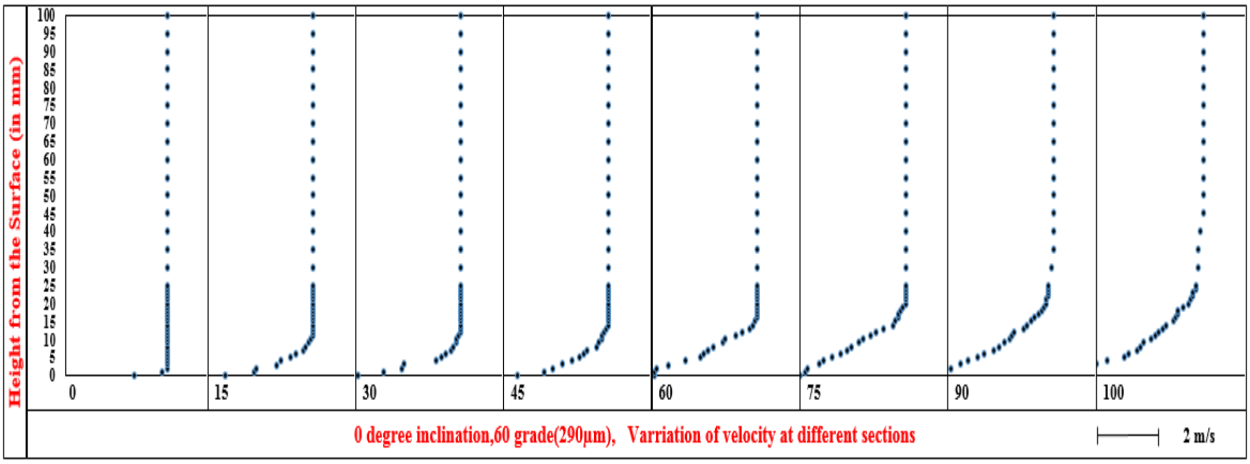


Fig. (4.2.1.c) variation of velocity in 0°inclination for 60 grade (290µm)

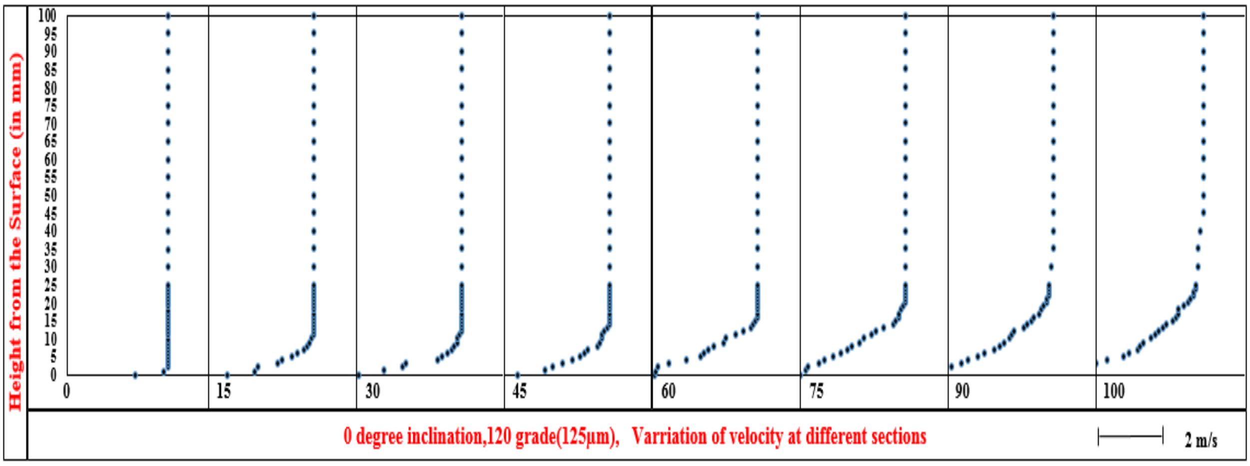


Fig. (4.2.1.d) variation of velocity in 0°inclination for 120 grade (125µm)

4.2.2 Variation of velocity profile on 40 grade (375µm), 50 grade (345µm), 60 grade (290µm), 120 grade (125µm) roughness plate with 2° inclination from the horizontal.

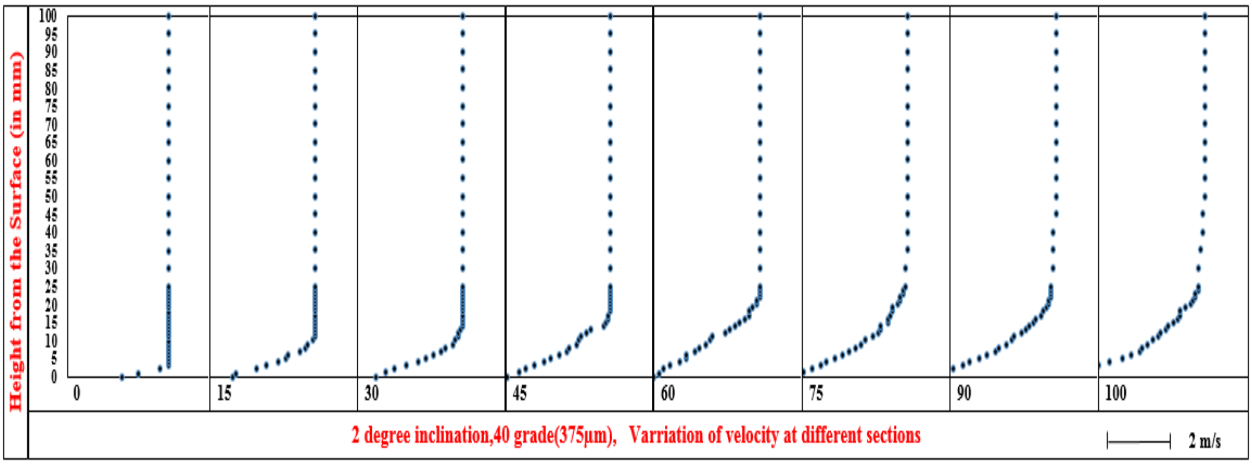


Fig. (4.2.2.a) variation of velocity in 2°inclination for 40 grade (375µm)

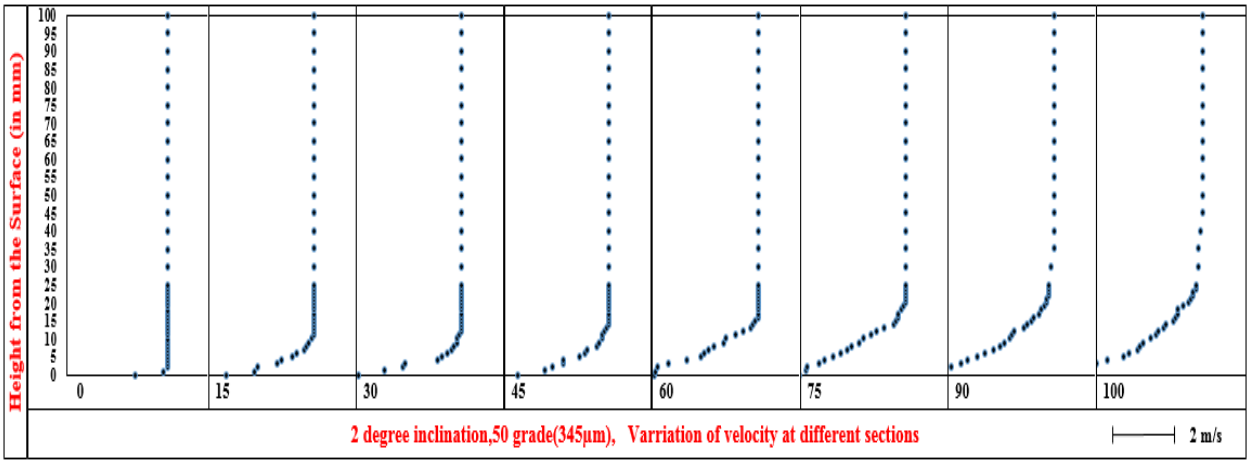


Fig. (4.2.2.b) variation of velocity in 2°inclination for 50 grade (345µm)

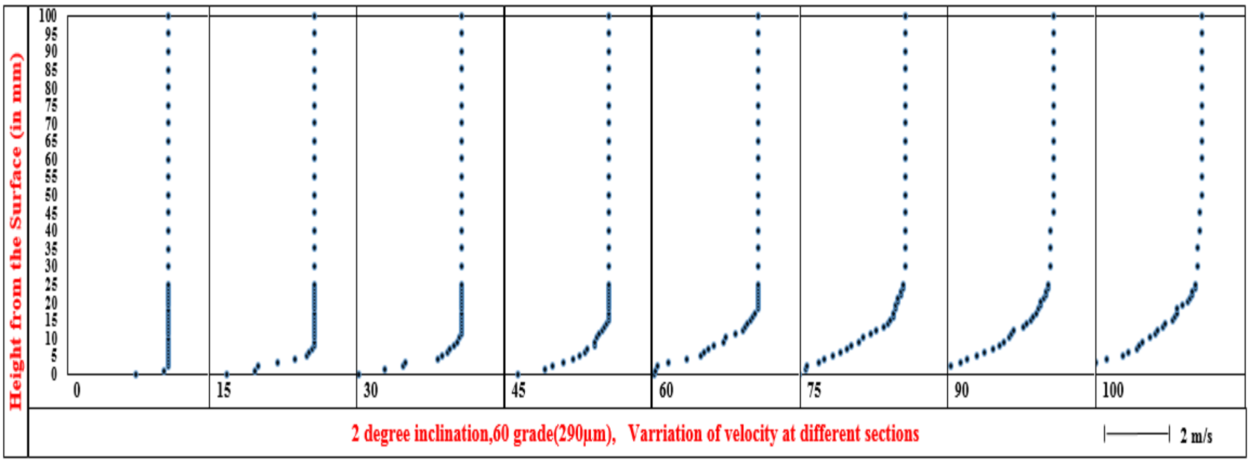


Fig. (4.2.2.c) variation of velocity in 2°inclination for 60 grade (290µm)

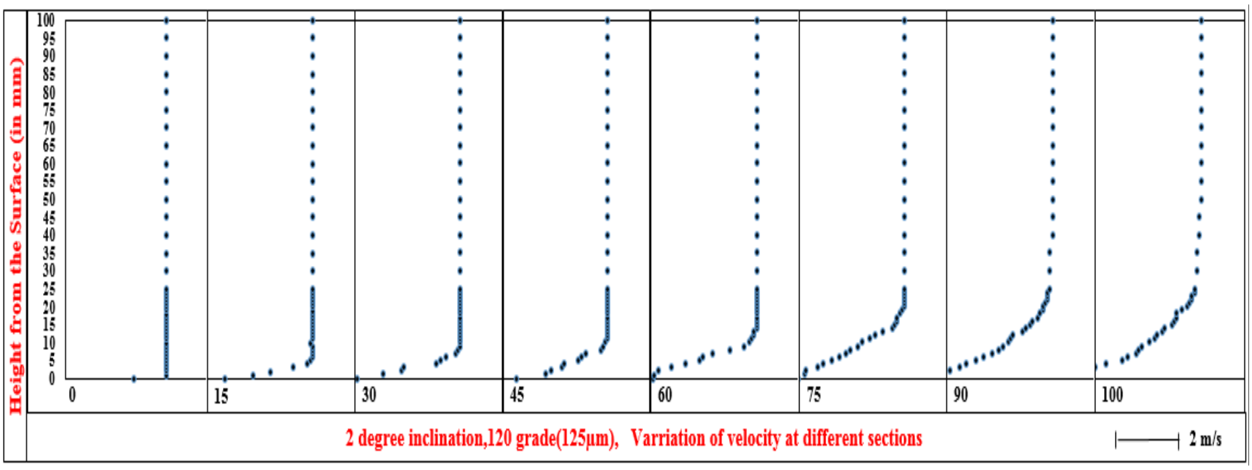


Fig. (4.2.2.d) variation of velocity in 2°inclination for 120 grade (125µm)

4.2.3 Variation of velocity profile on 40 grade (375µm), 50 grade (345µm), 60 grade (290µm), 120 grade (125µm) roughness plate with 4° inclination from the horizontal.

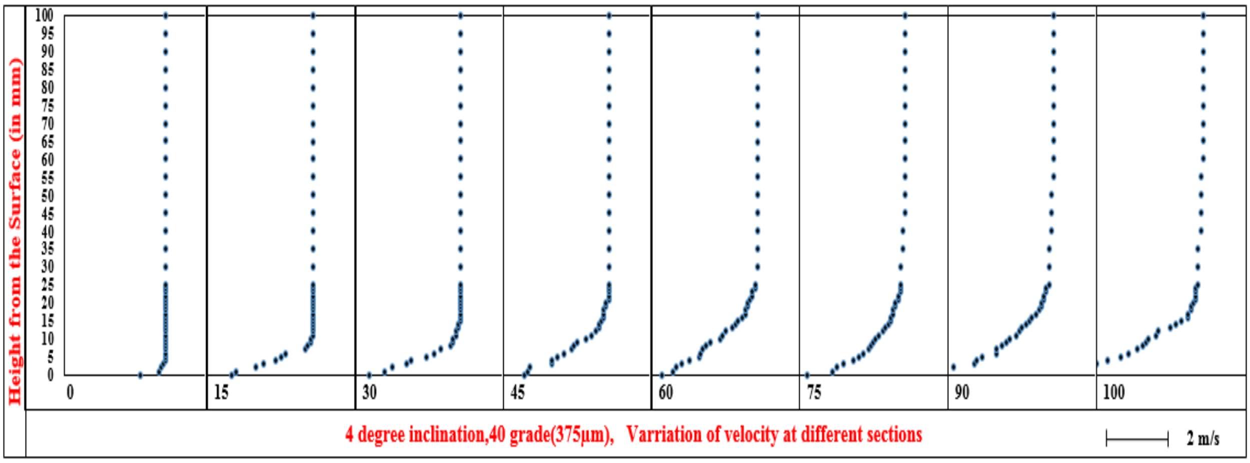


Fig. (4.2.3.a) variation of velocity in 4°inclination for 40 grade (375µm)

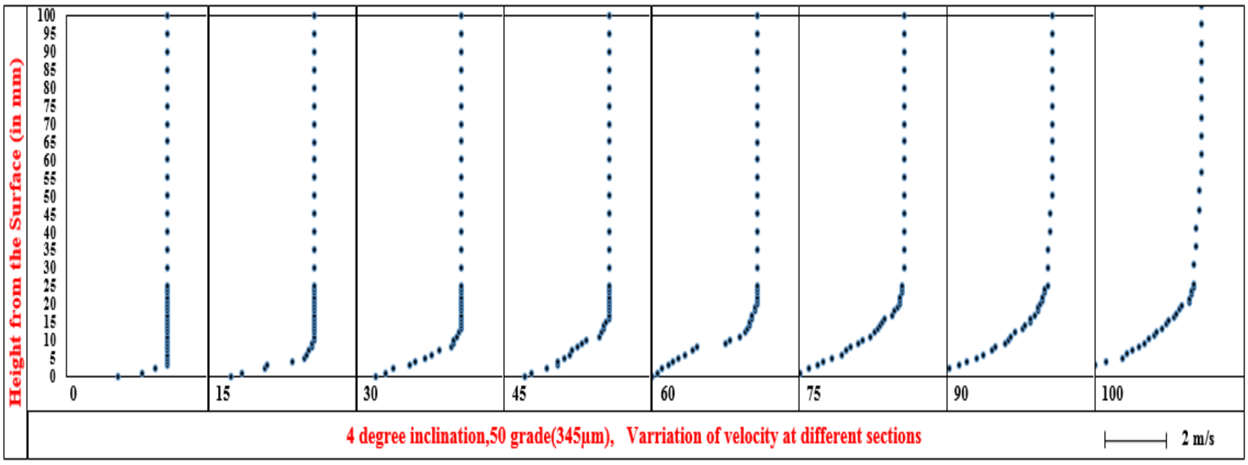


Fig. (4.2.3.b) variation of velocity in 4°inclination for 50 grade (345µm)

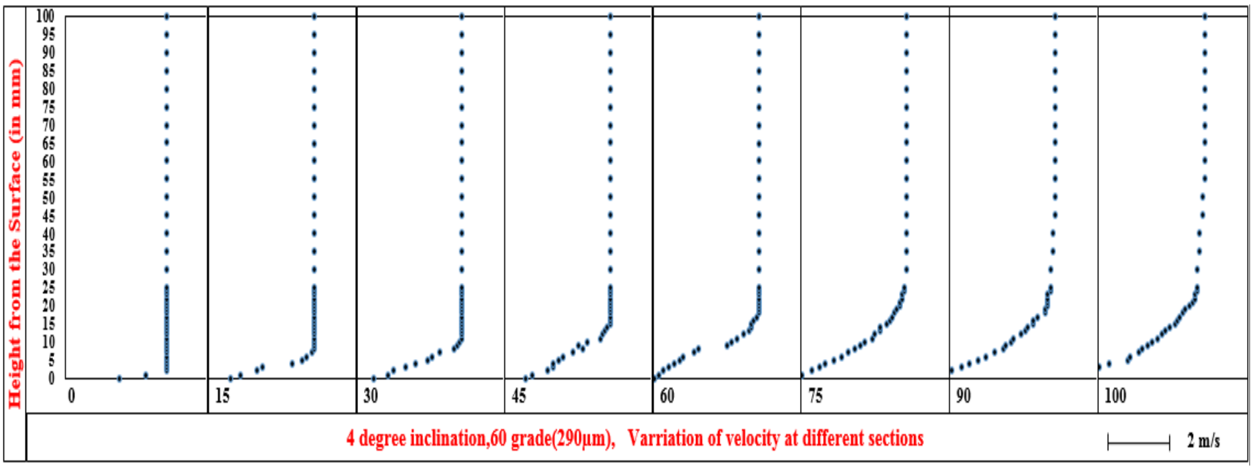


Fig. (4.2.3.c) variation of velocity in 4°inclination for 60 grade (290µm)

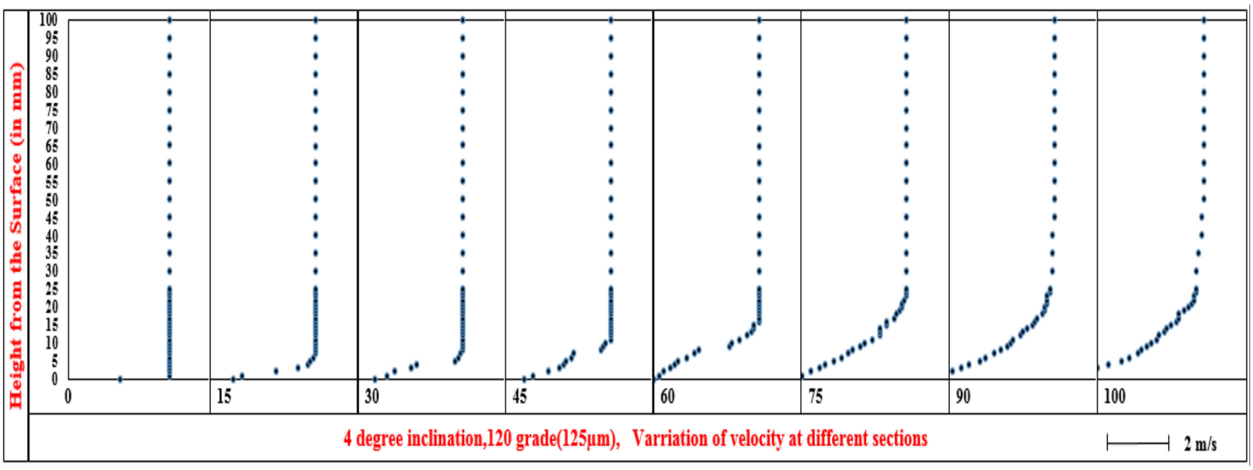


Fig. (4.2.3.d) variation of velocity in 4°inclination for 120 grade (125µm)

4.2.4 Variation of velocity profile on 40 grade (375µm), 50 grade (345µm), 60 grade (290µm), 120 grade (125µm) roughness plate with 6° inclination from the horizontal.

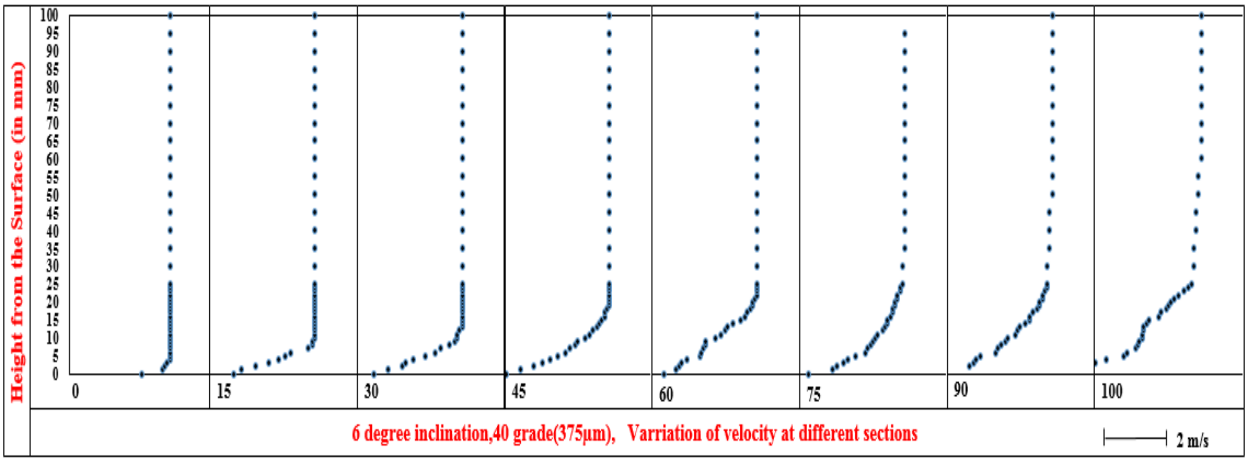


Fig. (4.2.4.a) variation of velocity in 6°inclination for 40 grade (375µm)

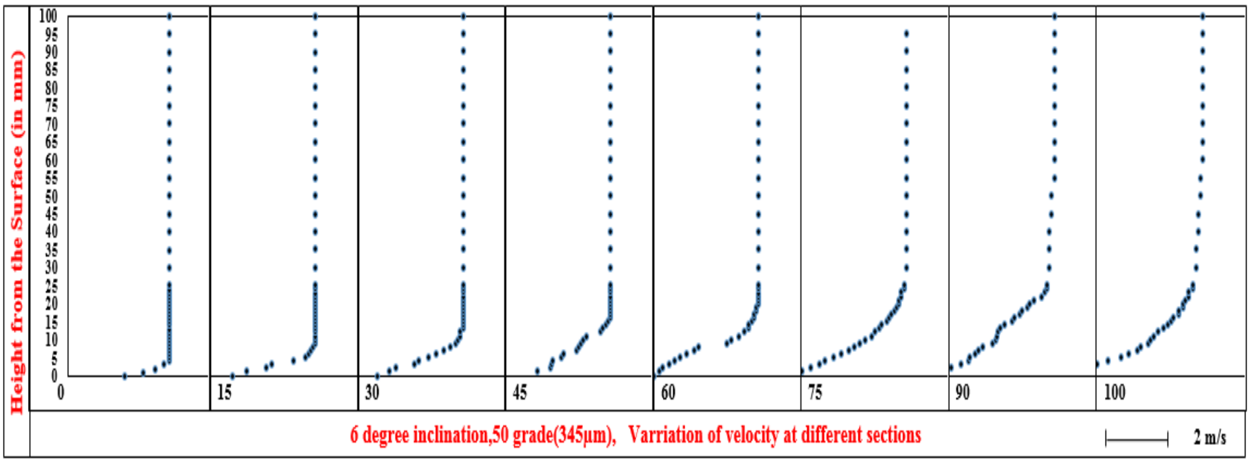


Fig. (4.2.4.b) variation of velocity in 6°inclination for 50 grade (345µm)

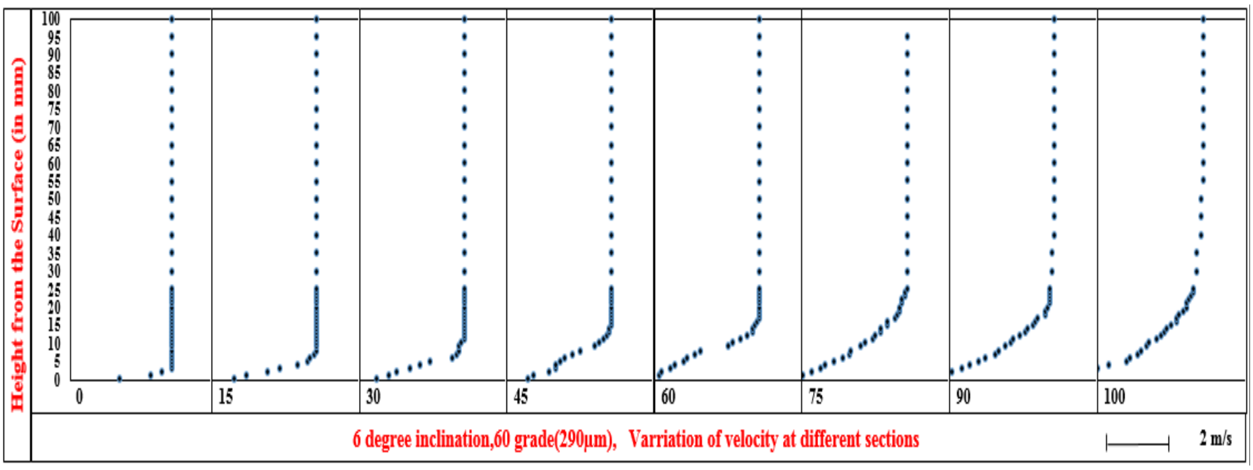


Fig. (4.2.4.c) variation of velocity in 6°inclination for 60 grade (290µm)

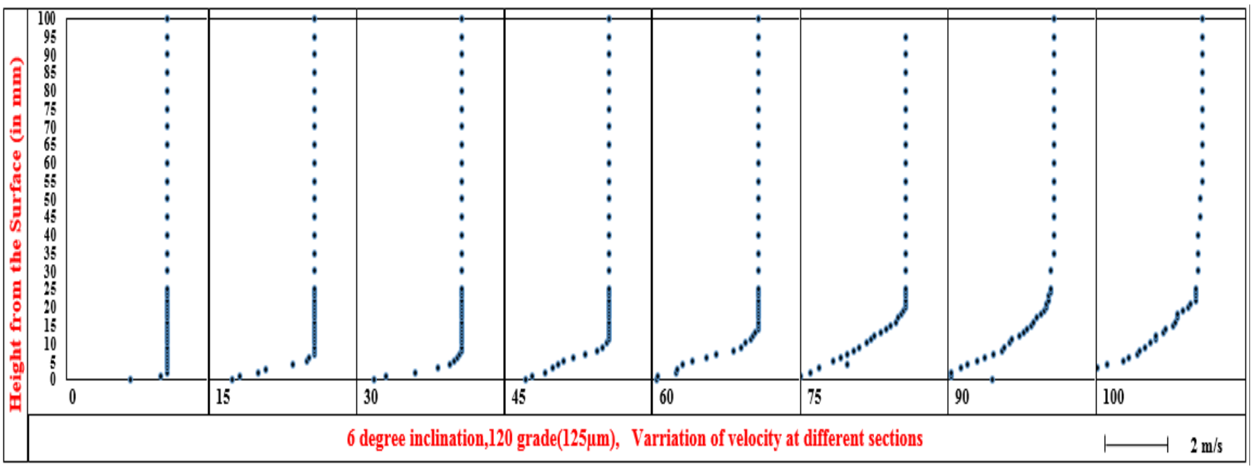


Fig. (4.2.4.d) variation of velocity in 6°inclination for 120 grade (125µm)

4.3: Effect of roughness on velocity profile

Effect of roughness on velocity profile with constant inclination and constant section. Here we take two sections of laminar flow and two sections of turbulent flow into consideration to know the proper effect of the roughness on velocity profile.

According to the laminar flow here observations with the section of 15 cm from the leading edge and 30 cm from the leading edge. Like that observation of the turbulent flow is taken for the section of 75 cm and 90 cm from the leading edge.

4.3.1: Effect of roughness on velocity profile with 0° inclination from the horizontal:

For Laminar flow region -

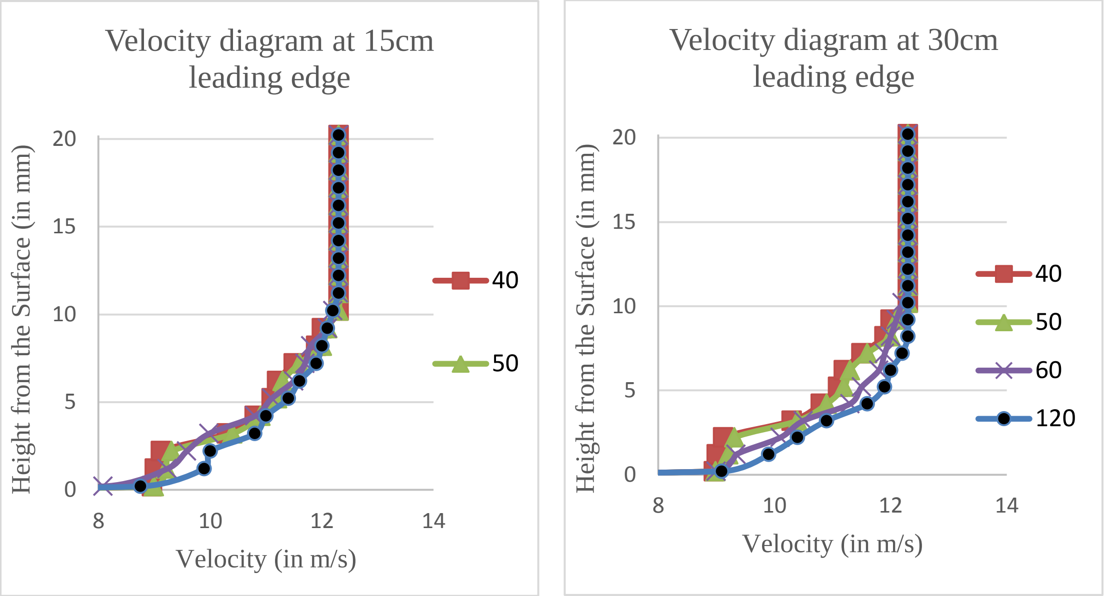


Fig: (4.3.1.a) Effect of roughness on velocity profile with 0°inclination at two sections

For Turbulent flow region -

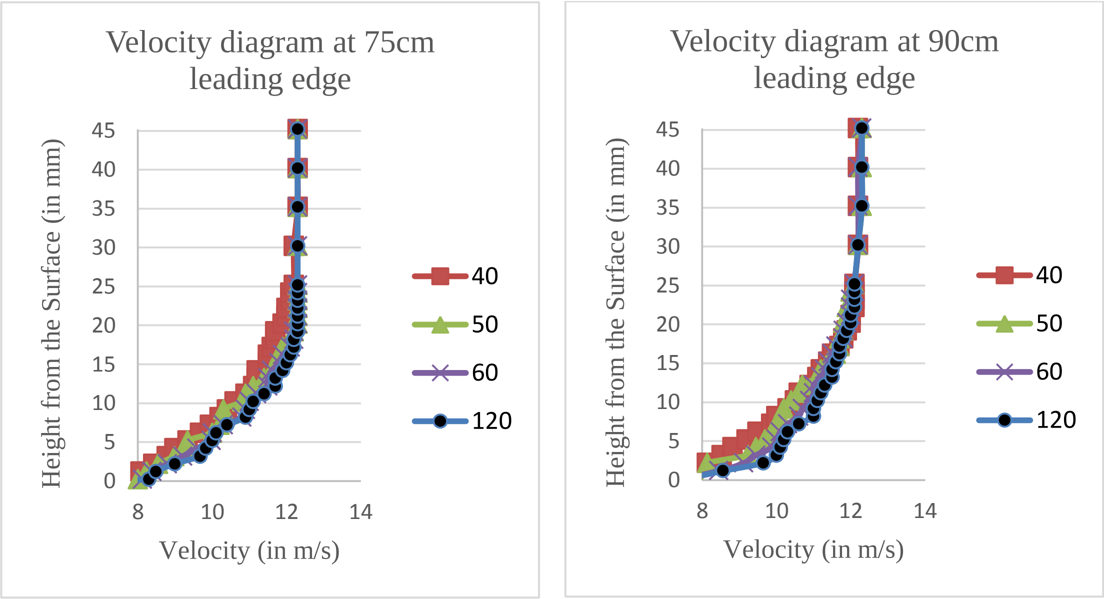


Fig: (4.3.1.b) Effect of roughness on velocity profile with 0°inclination at two sections

4.3.2: Effect of roughness on velocity profile with 2° inclination from the horizontal:

For Laminar flow region –

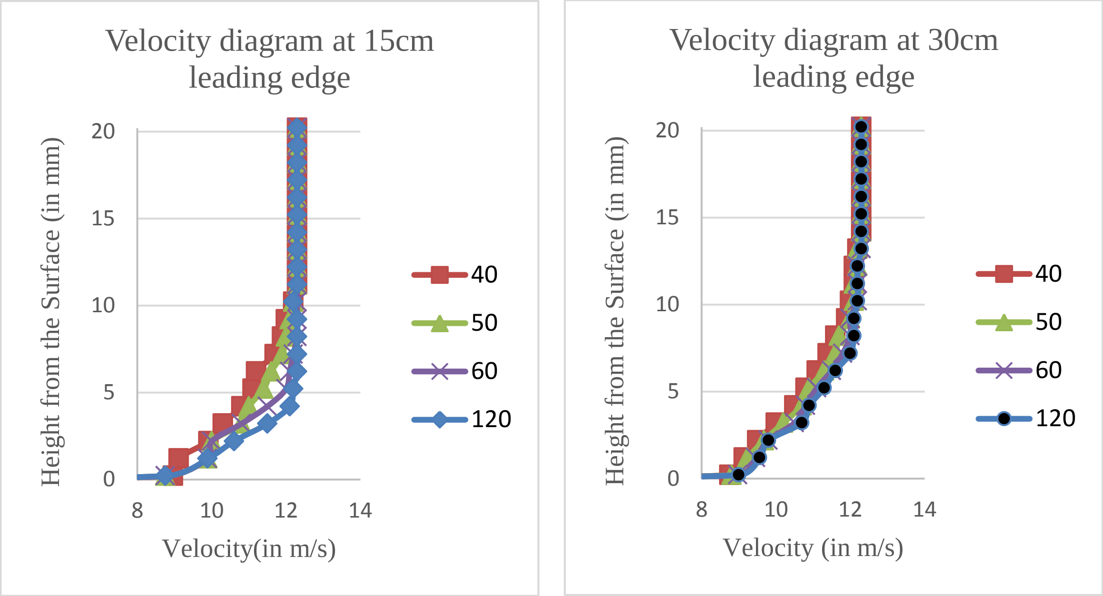


Fig: (4.3.2.a) Effect of roughness on velocity profile with 2°inclination at two sections

For Turbulent flow region -

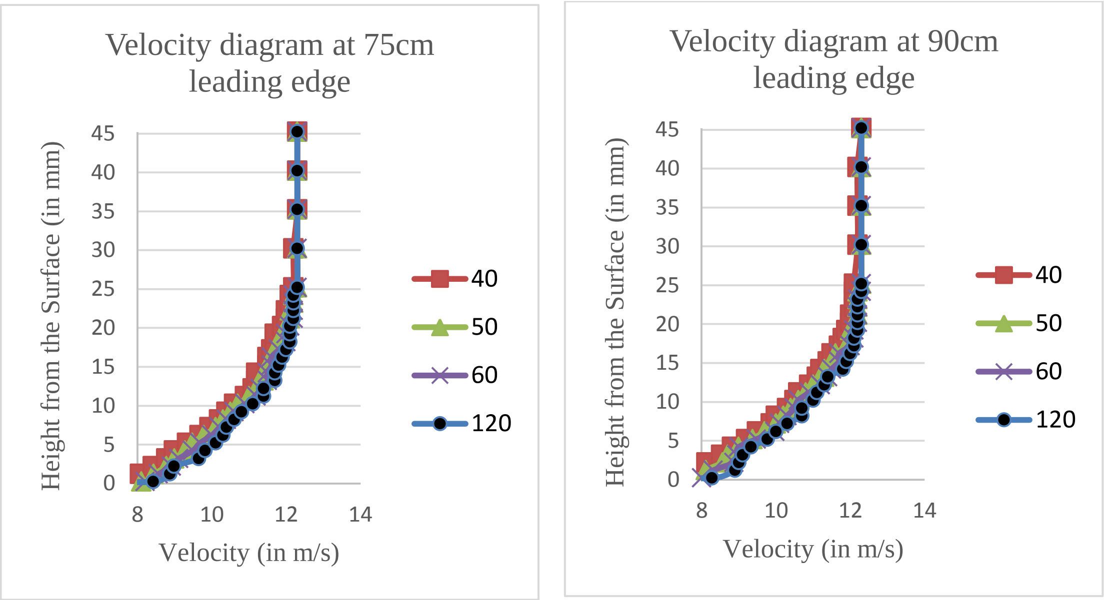


Fig: (4.3.2.b) Effect of roughness on velocity profile with 2°inclination at two sections

<u>4.3.3: Effect of roughness on velocity profile with 4° inclination from the horizontal</u>:

<u>For laminar flow region</u>:

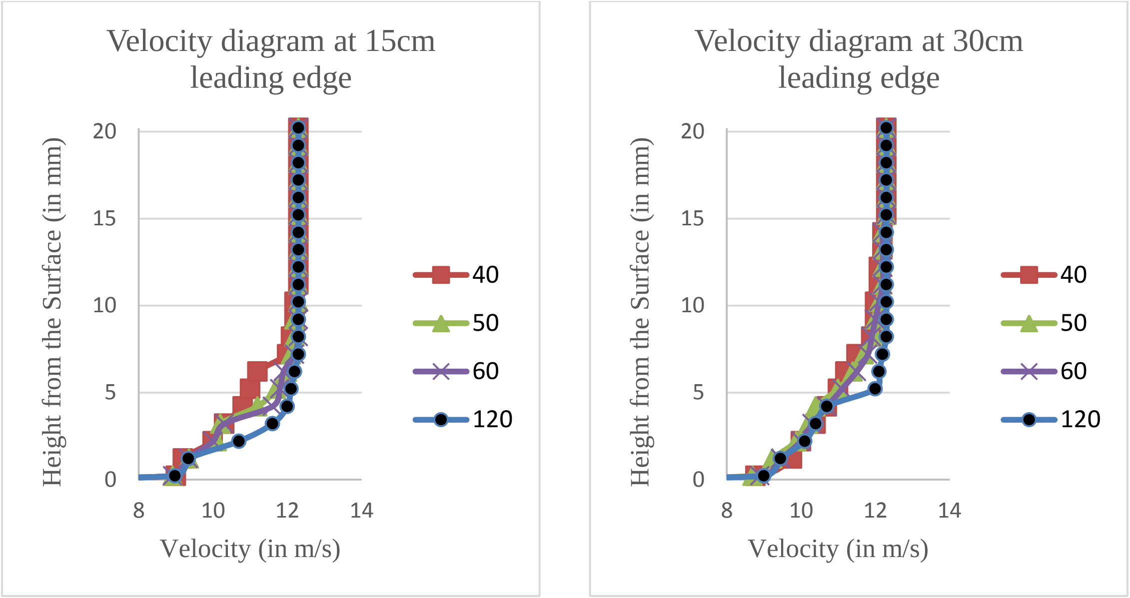


Fig: (4.3.3.a) Effect of roughness on velocity profile with 4°inclination at two sections

<u>For Turbulent flow region</u> -

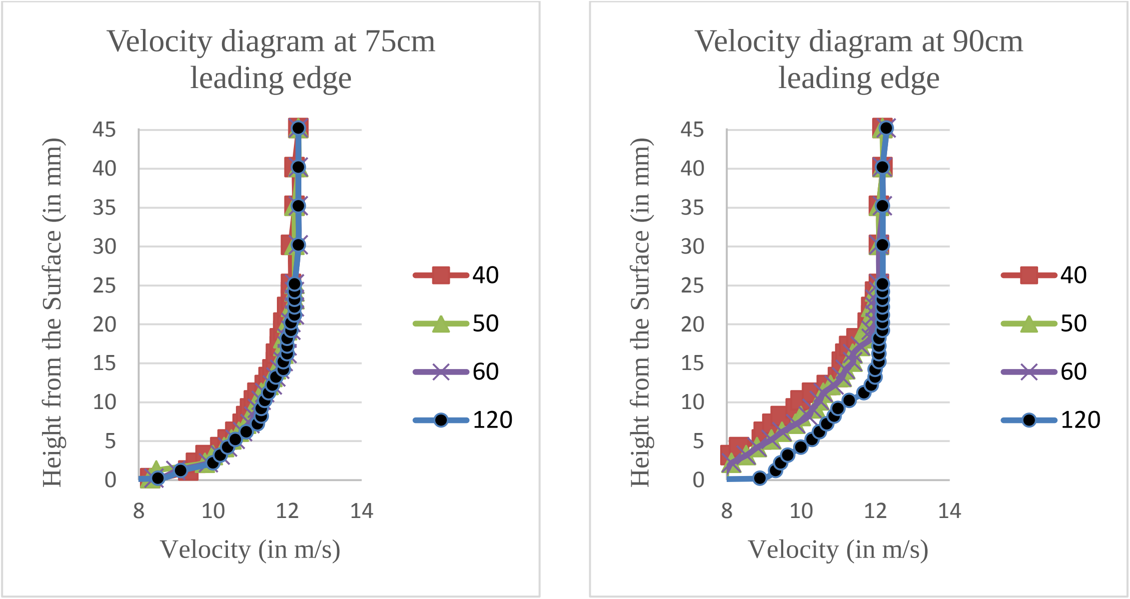


Fig: (4.3.3.b) Effect of roughness on velocity profile with 4°inclination at two sections

4.3.4: Effect of roughness on velocity profile with 6° inclination from the horizontal:

For laminar flow region:

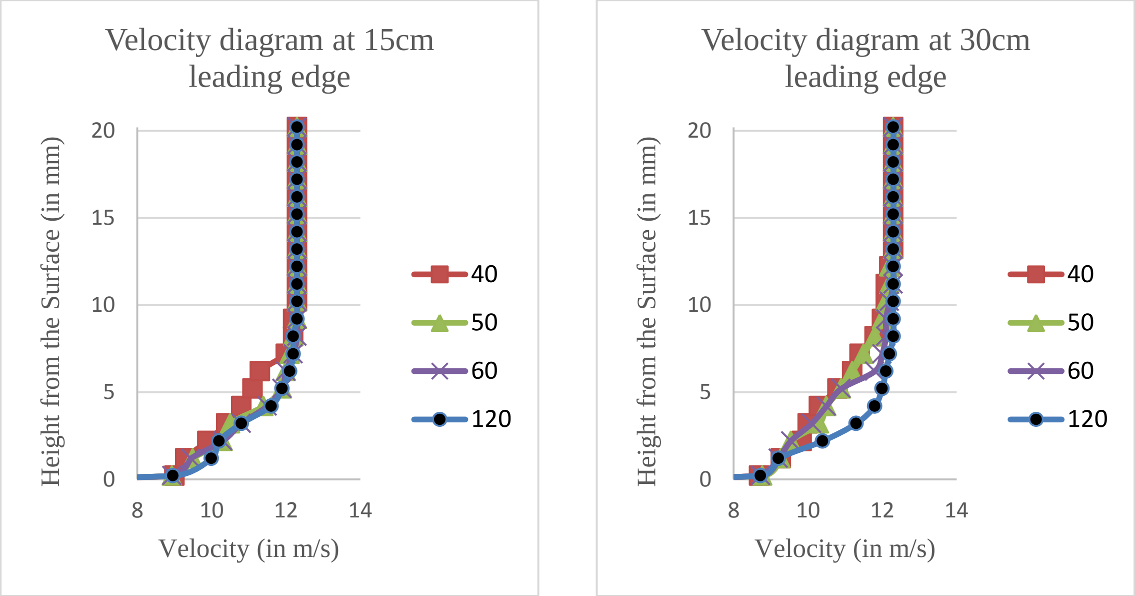


Fig: (4.3.4.a) Effect of roughness on velocity profile with 6°inclination at two sections

For Turbulent flow region –

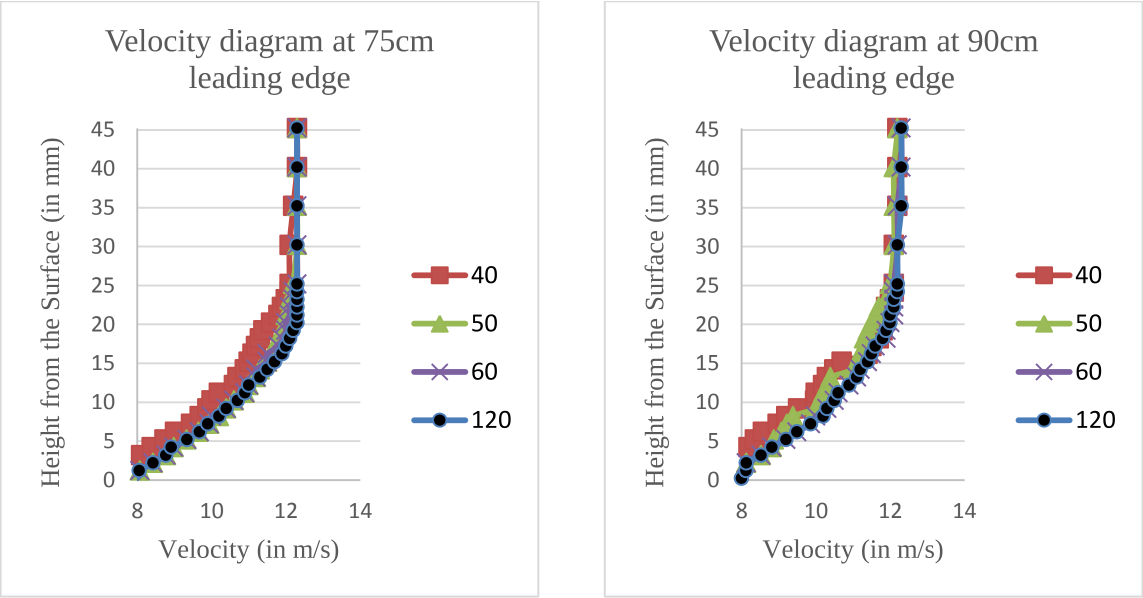


Fig: (4.3.4.b) Effect of roughness on velocity profile with 6°inclination at two sections

4.4 Effect of inclination on velocity profile

4.4.1 Effect of inclination on velocity profile with 40 grade (375µm) roughness:

For Laminar flow region-

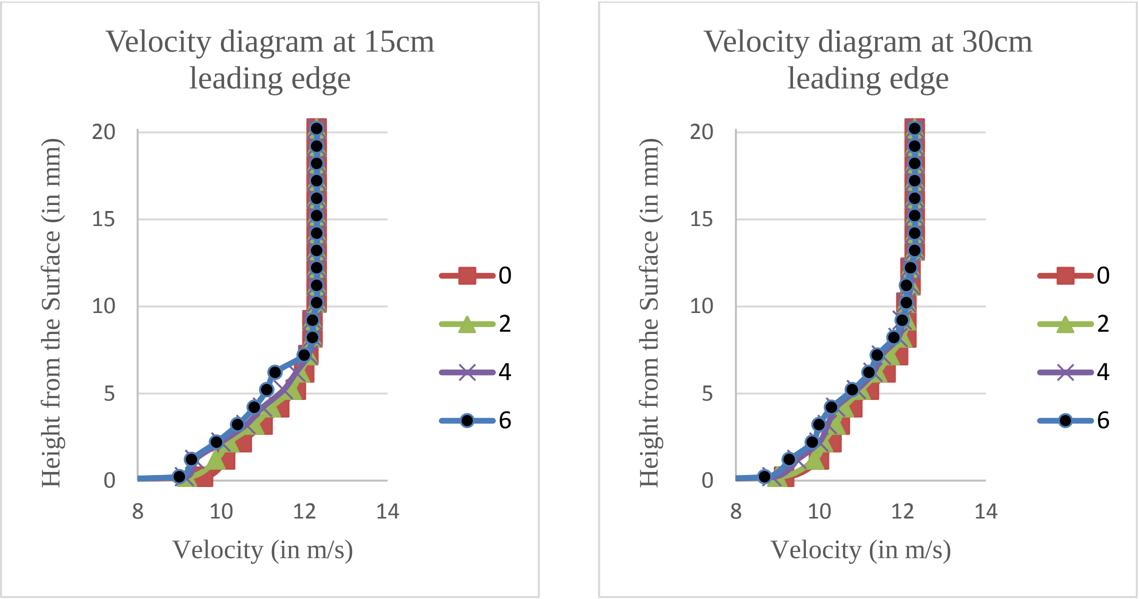


Fig: (4.4.1.a) Effect of inclination on velocity profile with 40 grade (375µm) at two sections

For Turbulent flow region-

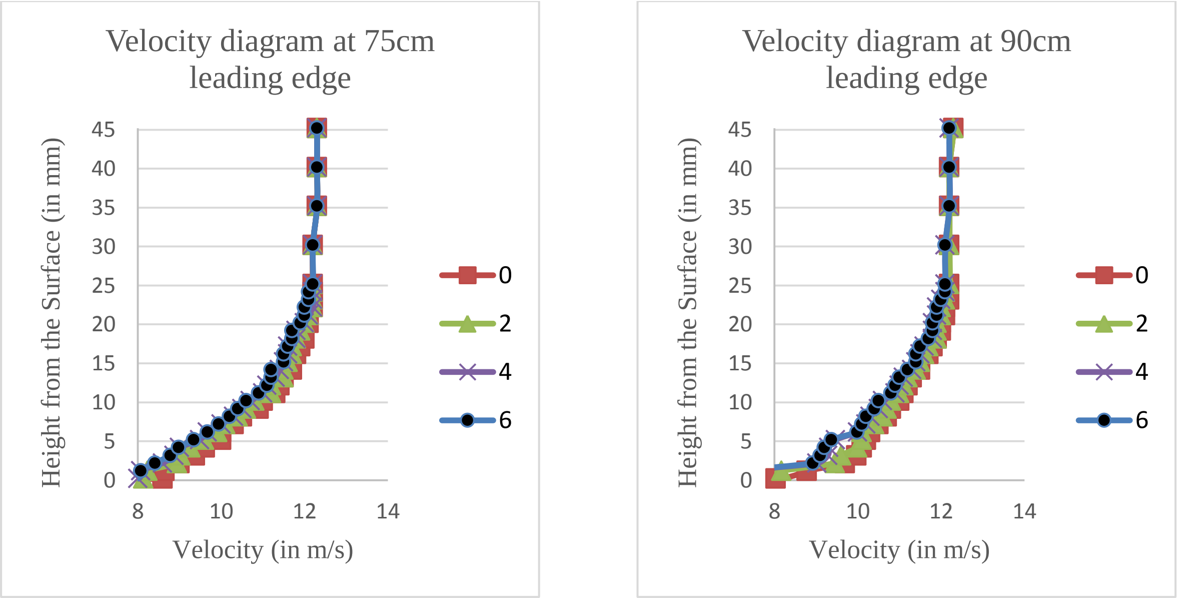


Fig: (4.4.1.b) Effect of inclination on velocity profile with 40 grade (375µm) at two sections

4.4.2: Effect of inclination on velocity profile with 50 grade (345µm) roughness:

For Laminar flow region-

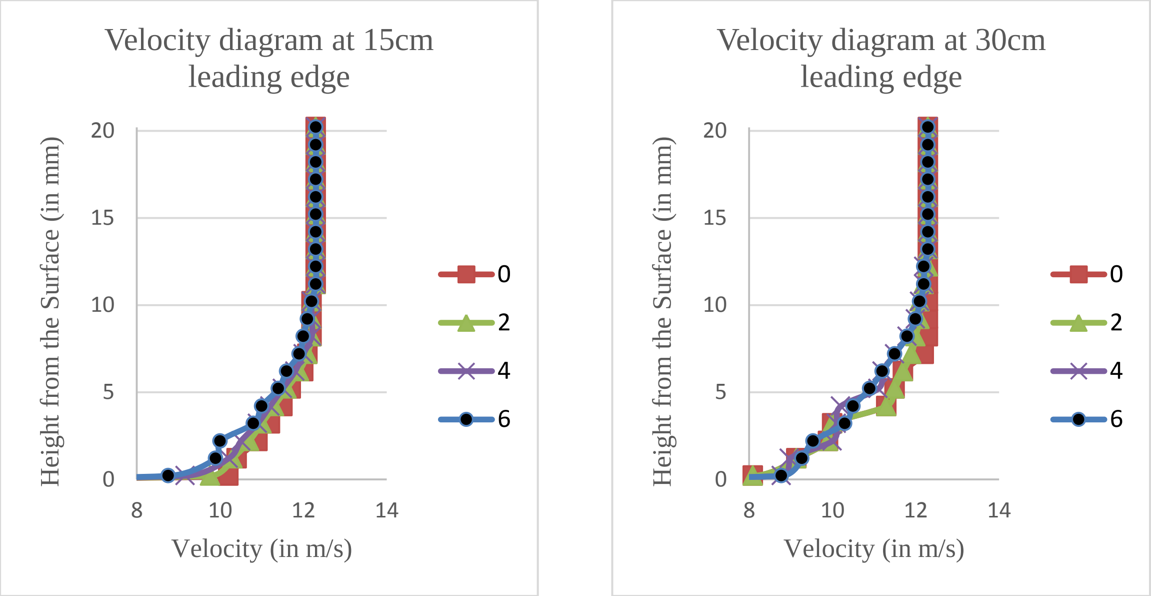


Fig: (4.4.2.a) Effect of inclination on velocity profile with 50 grade (345µm) at two sections

For Turbulent flow region-

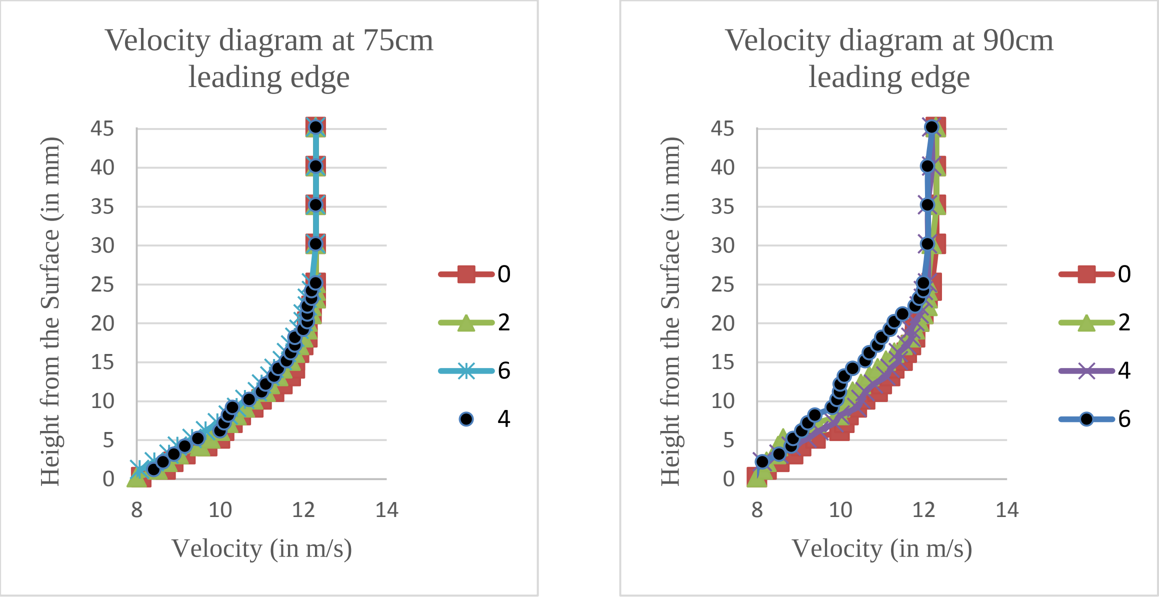
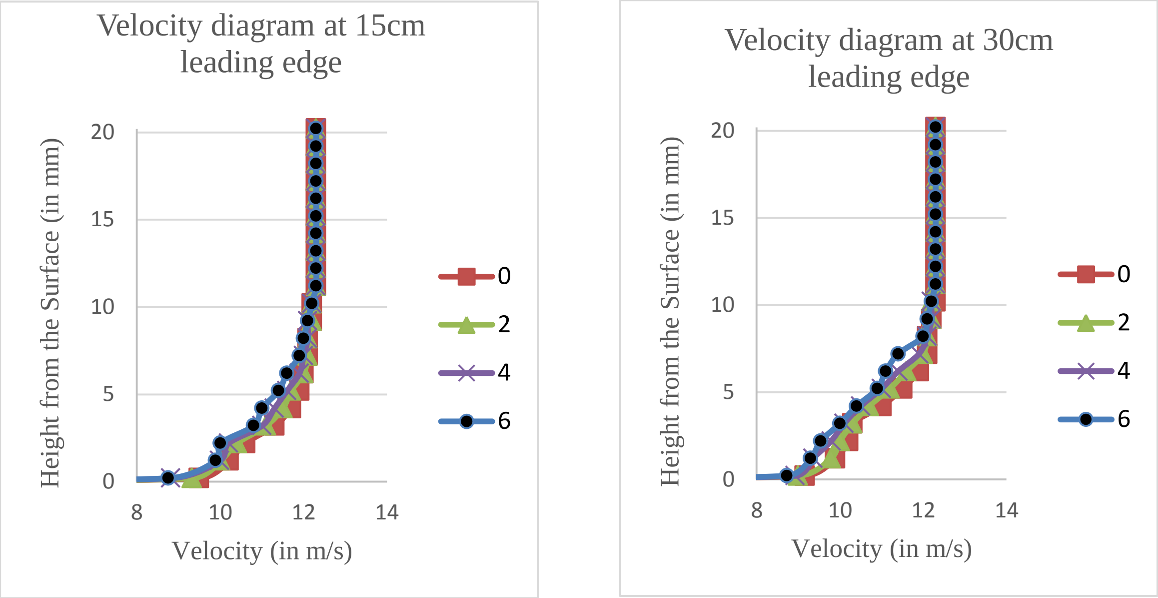


Fig: (4.4.2.b) Effect of inclination on velocity profile with 50 grade (345µm) at two sections

4.4.3: Effect of inclination on velocity profile with 60 grade (290μm) roughness:

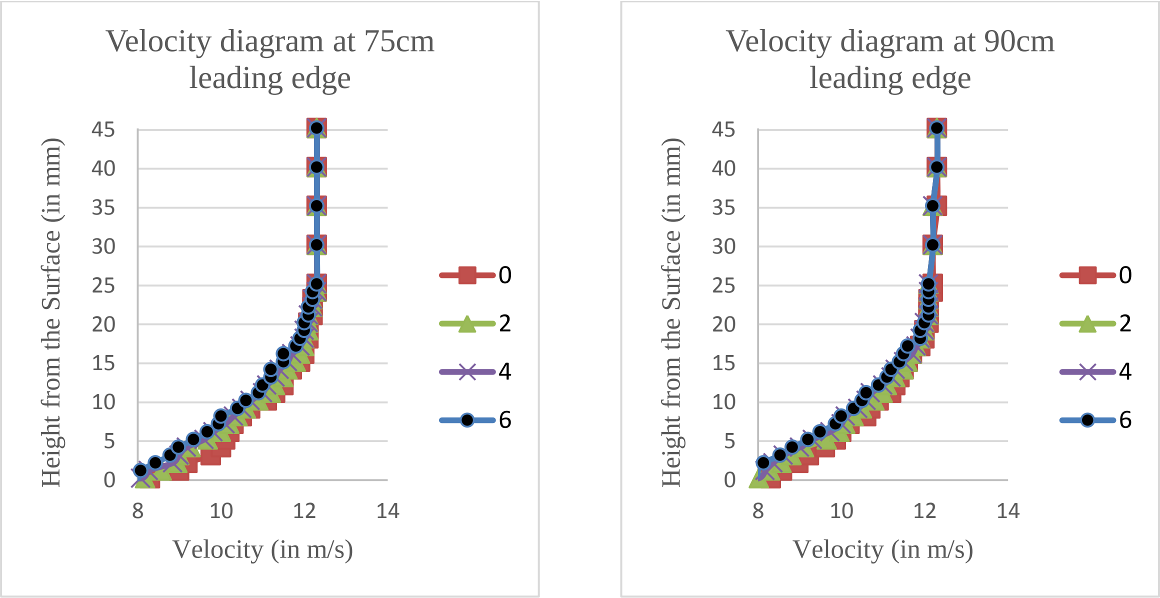
For Laminar flow region-


Velocity diagram at 15cm leading edge

Velocity diagram at 30cm leading edge

Fig: (4.4.3.a) Effect of inclination on velocity profile with 60 grade (290μm) at two sections

For Turbulent flow region-


Velocity diagram at 75cm leading edge

Velocity diagram at 90cm leading edge

Fig: (4.4.3.b) Effect of inclination on velocity profile with 60 grade (290μm) at two sections

4.4.4: Effect of inclination on velocity profile with 120 grade (125μm) roughness:

For Laminar flow region-

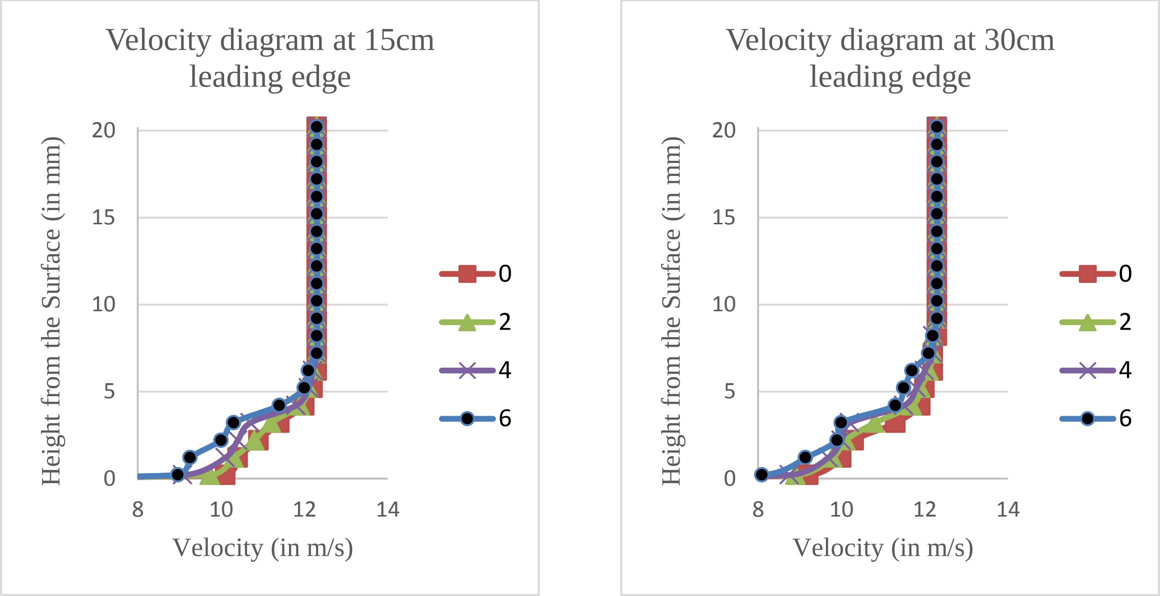


Fig: (4.4.4.a) Effect of inclination on velocity profile with 120 grade (125μm) at two sections

For Turbulent flow region-

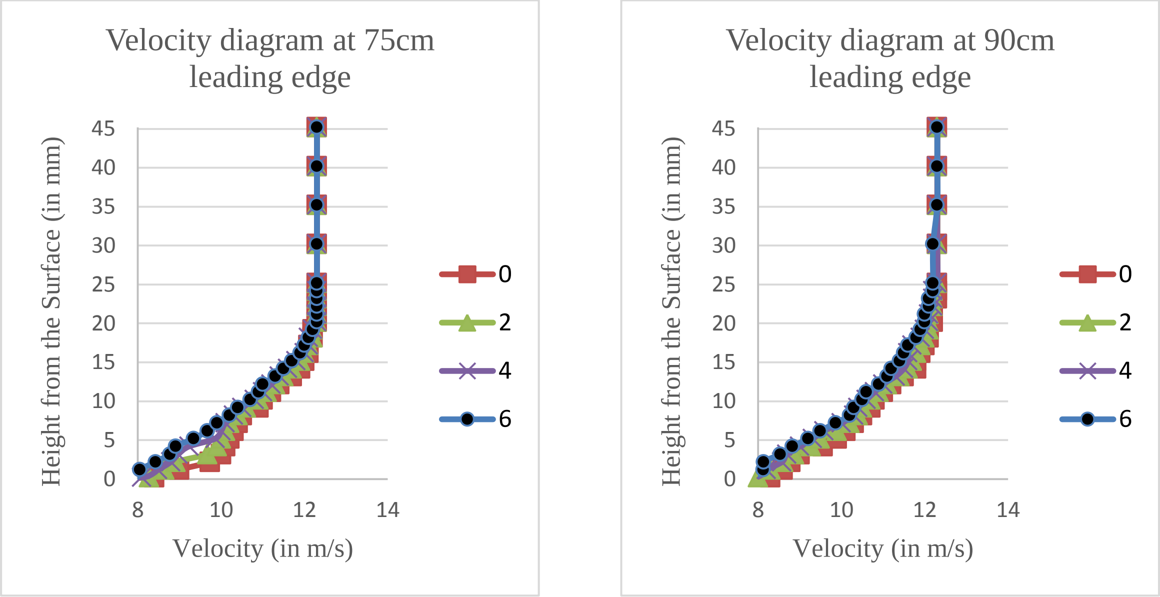


Fig: (4.4.4.b) Effect of inclination on velocity profile with 120 grade (125μm) at two sections

4.5 Effect of roughness on boundary layer:

Boundary layer is done by velocity profile curves with the help of different sections. As we are plotting the comparison curve for the effect of roughness and the effect of inclinations on velocity profiles for rough flat plate. We are also plotting the comparison curves for showing the effect of roughness and inclinations on boundary layers.

4.5.1: Effect of roughness on boundary layer with 0 degree of inclination from horizontal.

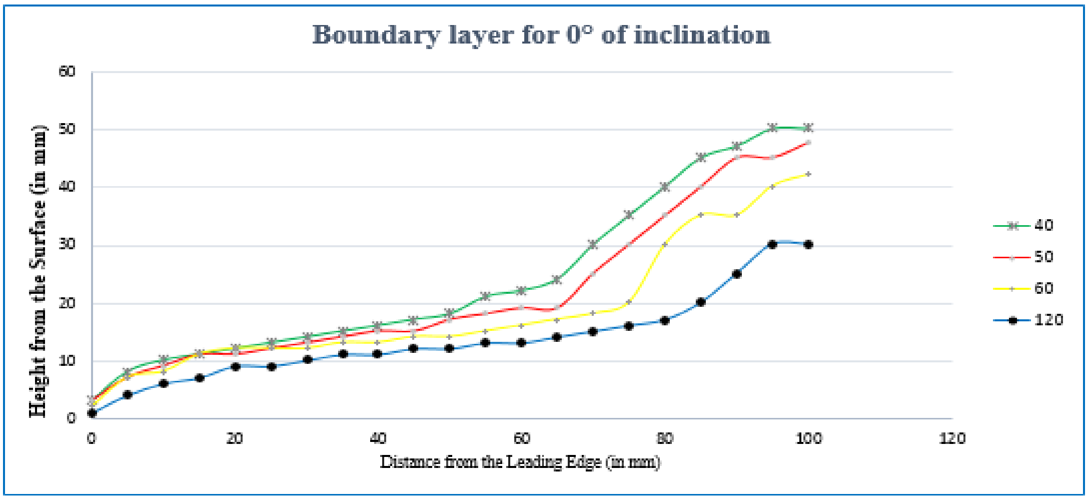


Fig: 4.5.1: effect of roughness of boundary layer with 0° inclination

4.5.2: Effect of roughness on boundary layer with 2 degree of inclination from horizontal.

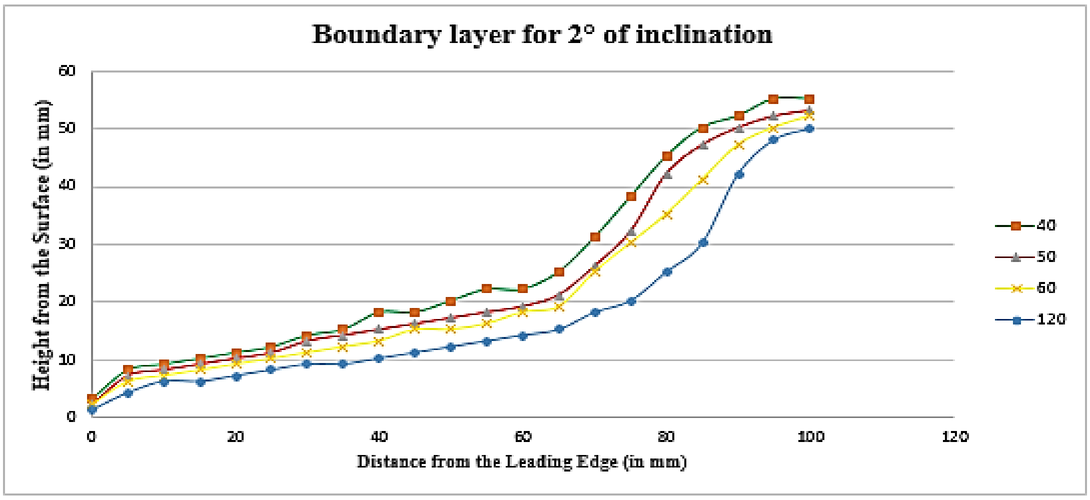


Fig: 4.5.2: effect of roughness of boundary layer with 2° inclination

4.5.3: Effect of roughness on boundary layer with 4 degree of inclination from horizontal.

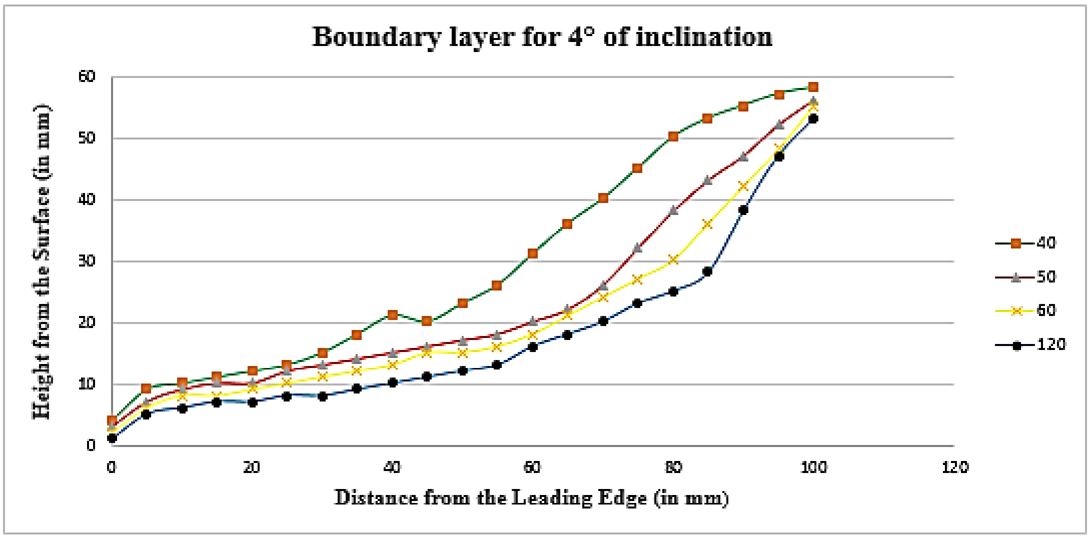


Fig: 4.5.3: effect of roughness of boundary layer with 4° inclination

4.5.4: Effect of roughness on boundary layer with 6 degree of inclination from horizontal.

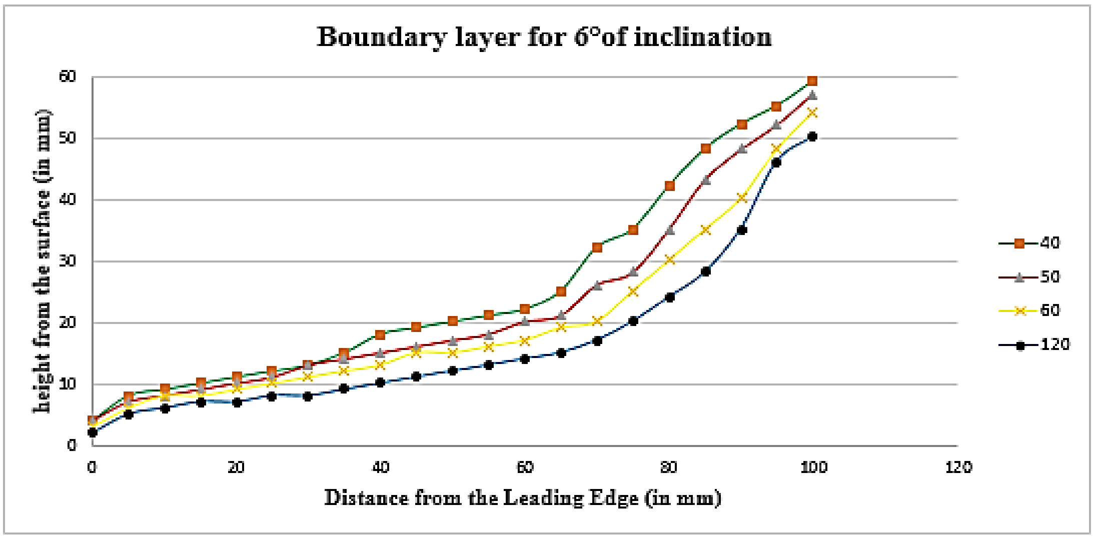


Fig: 4.5.4: effect of roughness of boundary layer with 6° inclination

4.6: Effect of inclination on boundary layer:

4.6.1: Effect of inclination of boundary layer with 40 grade (375µm) on rough flat plate.

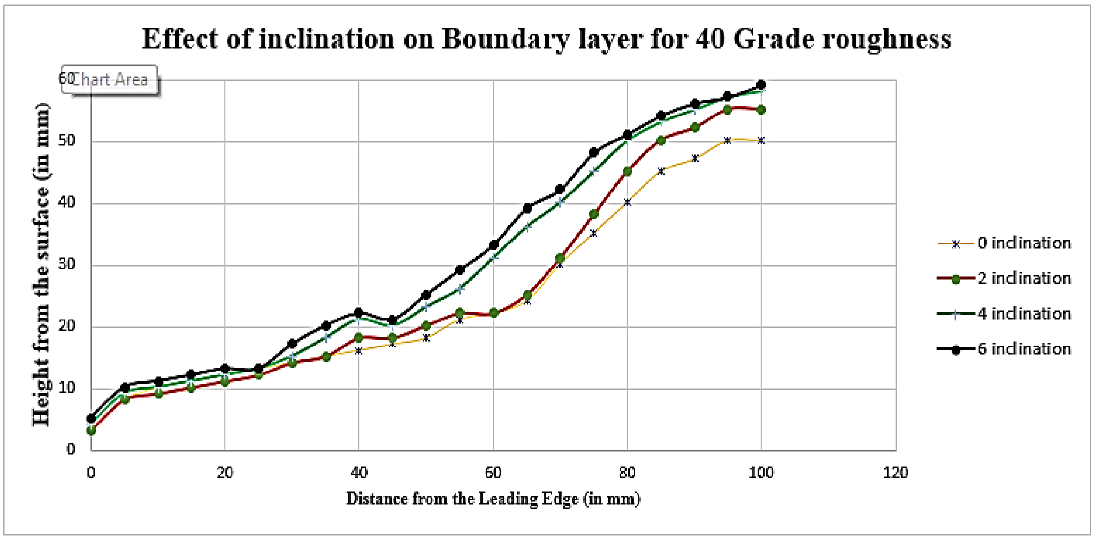


Fig: 4.6.1: Effect of inclination of boundary layer with 40 grade (375µm) roughness

4.6.2: Effect of inclination of boundary layer with 50 grade (345µm) on rough flat plate.

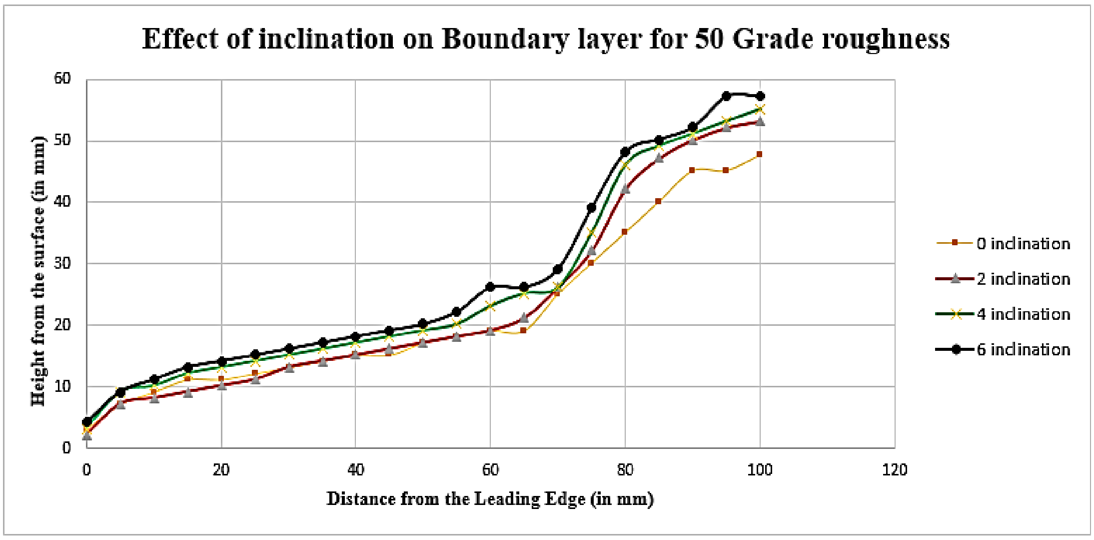


Fig: 4.6.2: Effect of inclination of boundary layer with 50 grade (345µm) roughness

4.6.3: Effect of inclination of boundary layer with 60 grade (290µm) on rough flat plate.

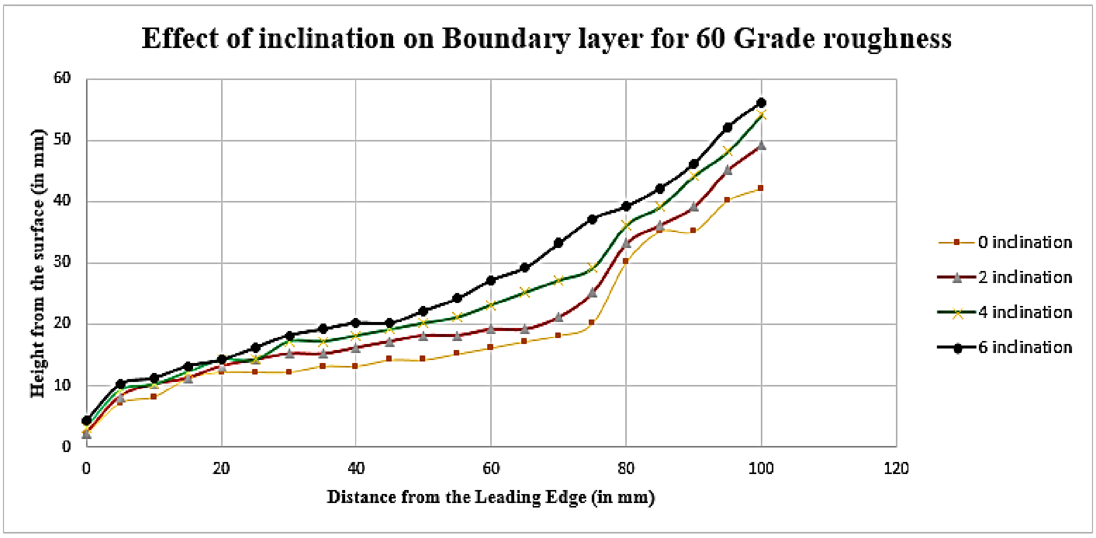


Fig: 4.6.3: Effect of inclination of boundary layer with 60 grade (290µm) roughness

4.6.4: Effect of inclination of boundary layer with 120 grade (125µm) on rough flat plate.

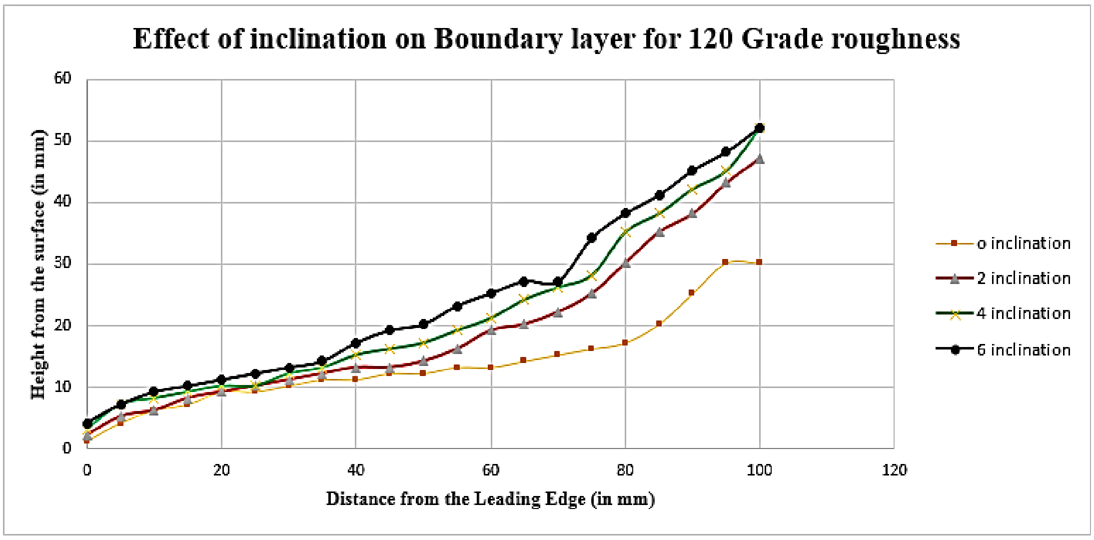


Fig: 4.6.4: Effect of inclination of boundary layer with 120 grade (125µm) roughness

4.7: TABULAR RESULTS FOR VELOCITY PROFILES FOR A PERTICULAR HEIGHT

4.7.1: Effect of inclination on constant roughness:

These are the results for 5 mm and 10 mm from the leading edge.

For the study of laminar zone we are taking two sections 15 cm and 30 cm from the leading edge. Here we are mentioning our result with 40 grade (375 µm) roughness flat plate.

Table no: 4.7.1.a (Laminar zone)

Section from the leading edge	Roughness in grades(in µm)	Inclination in (degree)	Height In (mm)	Velocity In (m/s)
15 cm	40 (375 µm)	0	5	11.9
15 cm	40 (375 µm)	2	5	11.6
15 cm	40 (375 µm)	4	5	11.2
15 cm	40 (375 µm)	6	5	11

Table no: 4.7.1.b(Laminar zone)

Section from the leading edge	Roughness in grades(in µm)	Inclination in (degree)	Height In (mm)	Velocity In (m/s)
15 cm	40 (375 µm)	0	10	12.3
15 cm	40 (375 µm)	2	10	12.2
15 cm	40 (375 µm)	4	10	12.2
15 cm	40 (375 µm)	6	10	12.1

Table no: 4.7.1.c (Laminar zone)

Section from the leading edge	Roughness in grades(in µm)	Inclination in (degree)	Height In (mm)	Velocity In (m/s)
30 cm	40 (375 µm)	0	5	12.1
30 cm	40 (375 µm)	2	5	12
30 cm	40 (375 µm)	4	5	11.7
30 cm	40 (375 µm)	6	5	11.6

Table no: 4.7.1.d (Laminar zone)

Section from the leading edge	Roughness in grades(in µm)	Inclination in (degree)	Height In (mm)	Velocity In (m/s)
30 cm	40 (375 µm)	0	10	12.3
30 cm	40 (375 µm)	2	10	12.2
30 cm	40 (375 µm)	4	10	12.1
30 cm	40 (375 µm)	6	10	12.1

From the above table no 4.1.a and 4.1.b shows the effect of inclination on a particular height for a particular rough flat plate, it is decreasing with increasing the inclination.

Like laminar flow work on turbulent flow has been done. Tabular representation of the analysis gives us a actual figure that which inclination gives better result of the velocity profile.

4.7.2: Effect of roughness on constant inclination:

These are the results for 5 mm and 10 mm from the leading edge.

For the study of laminar zone we are taking two sections 15 cm and 30 cm from the leading edge. Here we are mentioning our results with 2 degree of inclination from the horizontal.

Table no: 4.7.2.a (Laminar zone)

Section from the leading edge	Roughness in grades(in µm)	Inclination in (degree)	Height In (mm)	Velocity In (m/s)
15 cm	40 (375 µm)	2	5	11
15 cm	50 (345 µm)	2	5	11.2
15 cm	60 (290 µm)	2	5	11.5
15 cm	120 (125 µm)	2	5	11.8

Table no: 4.7.2.b (Laminar zone)

Section from the leading edge	Roughness in grades(in µm)	Inclination in (degree)	Height In (mm)	Velocity In (m/s)
15 cm	40 (375 µm)	2	10	11.9
15 cm	50 (345 µm)	2	10	12.2
15 cm	60 (290 µm)	2	10	12.2
15 cm	120 (125 µm)	2	10	12.3

Table no: 4.7.2.c (Laminar zone)

Section from the leading edge	Roughness in grades(in µm)	Inclination in (degree)	Height In (mm)	Velocity In (m/s)
30 cm	40 (375 µm)	2	5	11.3
30 cm	50 (345 µm)	2	5	11.4
30 cm	60 (290 µm)	2	5	12
30 cm	120 (125 µm)	2	5	12.2

Table no: 4.7.2.d (Laminar zone)

Section from the leading edge	Roughness in grades(in µm)	Inclination in (degree)	Height In (mm)	Velocity In (m/s)
30 cm	40 (375 µm)	2	10	12
30 cm	50 (345 µm)	2	10	12.2
30 cm	60 (290 µm)	2	10	12.3
30 cm	120 (125 µm)	2	10	12.3

From the above table no 4.7.2.a and 4.7.2.b shows the effect of roughness on a particular height for a particular inclination of flat plate from the horizontal, velocity is increasing with decreasing the inclination here.

Like laminar flow work on turbulent flow has been done. Tabular representation of the analysis gives us a actual figure that which roughness gives better result of the velocity profile.

Experiments are carried out to examine the effect of velocity profiles on boundary layers, when roughness is varying with inclination. What are the effects on boundary layer with different roughness and different inclinations .With the help of fig no.4.6.1 to fig no 4.6.4, we can clearly see the effect of inclination of boundary layers on a particular rough flat plate . Based on analysis and discussions of the experimental investigations certain inferences can be drawn.

- From the fig no 4.5.1 to fig no.4.5.4, shows variation of boundary layer gives a better understanding of that how roughness drawn important role in the field of designing. For a constant inclination either its 0 degree of inclination from the horizontal or 2 degree, 4 degree. And 6 degree provides us right effect of roughness.
- As roughness increases from 120 grades to 40 grades boundary layer thickness is also increasing.
- From the fig no 4.6.1 to fig no.4.6.4, variation of inclination with the constant roughness of the flat plate. Here it would be 40 grade, 50 grade, 60 grade, 120 grades.
- As inclination is increasing for a constant roughness then boundary layer thickness is also increasing. Here in this experiment 100 cm of long flat plate is placed in low speed wind tunnel because of proper comparison of dependent variables on the boundary layer.
- In all our results we are dividing the longitudinal length of the rough flat plate in to 20 equal sections and take velocity readings at every section until it is not reaches it’s free steam velocity.
- For showing the effect of laminar to turbulent it is important to take a long plate.
- After calculating the Reynolds number at each sections, we are showing here two sections for laminar and two sections for turbulent flow for the velocity profile.
- Effect of velocity at a particular section will give the effect of roughness considering constant inclination for creating negative pressure gradient.

CONCLUSION

Intensive literature survey has been carried out to study the boundary layer study with the help of velocity profile. From the literature review, it is found that boundary layer analysis depends upon the parameters like, roughness, inclination, height from the surface or solid body or solid wall. The results from the method opted here to observe the readings by putting the object in the working section indifferent –different manners. For the analysis point of view we make comparison curves between the inclinations and between the roughness. For the present experimental work, based on some experiment to investigate the pattern in the graph. The following are the results from present experimentations.

- There were some plugs prominent down from the velocity profile to boundary layer. In the longitudinal direction velocity distribution occurs at 20 different points with equal spaces. Flow is varying from laminar flow to turbulent flow. It is very important to pick observations from surface to the point where velocity reaches to the free steam velocity. It is observed that in all cases of height, the velocity is increasing from surface to the boundary layer point for every sections.
- According to the effect of roughness for velocity profiles all other parameters have taken constant like inclinations, section of the plate in the longitudinal direction. As roughness is decreasing slope of the velocity profile curves is also decreasing.
- For the study of tabular form of the result, for a particular depth, at a fixed cross section effect of roughness is discussed that for a particular inclination velocity is increasing.
- There are some effect on inclination for velocity profile, taken all parameter constant and vary only inclination, as you decrease the inclination from 6degree to 0 degree curves getting steeper slope.

- For the study of tabular form of the result, for a particular depth, at a fixed cross section effect of inclination is discussed that for a particular roughness velocity is decreasing.
- Boundary layer effect of a rough flat plate with different – different inclination gives a results that if the inclination from the horizontal is increasing boundary layer thickness is also increasing.
- Effect of roughness on boundary layer with different –different roughness gives us a nice understanding that increasing the roughness of the flat plate, increasing the boundary layer thickness.
- Effect of the velocity profiles in the transverse direction is remains same.

SCOPE FOR FUTURE WORK

The present work generates a wide scope for future investigators to search many other aspects of the boundary layer analysis. In this work free steam velocity has been taken constant, take it as a variable and plot different kind of curves. The equations for a model will be developed. Further study is required to investigate the flow properties and develop models to predict the boundary shear, velocity distribution, and energy loss having different shape and geometry. There are some simulation work in fluent like software could be done in this results. With the help of dimensional analysis we can produced a mathematical model which can predict the boundary layer data for some design as per the requirement.

SCOPE OF THE EXPERIMENT

These are some variables with the help of this, in this area have a great scope of investigation for the mathematical model and equation for the model.

Table no. 5.1: Scope of the experiment

Free steam velocity	**Roughness**	**Inclination**	**Section from leading**	**Height from surface**	**Local velocity**
Constant	Constant	Constant	Constant	Variation	Observation
Constant	Constant	Constant	Variation	Constant	Observation
Constant	Constant	Variation	Constant	Constant	Observation
Constant	Variation	Constant	Constant	Constant	Observation
Variation	Constant	Constant	Constant	Constant	Observation

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