Advanced Hydraulics
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Module - 1
Open Channel Flow
Lecture - 1
Introduction-Advanced Hydraulics
and Course Structure

Good morning to all of you. Welcome to the course on advanced hydraulics, this is a part of the NPTEL phase two project; it is a post graduate course in civil engineering. The target audience for this course are the post graduate students in various disciplines of water resource engineering in civil engineering throughout India. This course may also come under some of the post graduates program in other disciplines like mechanical engineering even chemical engineering as well, but mostly in our course we will be dealing with the civil engineering aspects.

So, before starting the course let me introduce myself, I am Suresh Kartha Assistant Professor in Department of Civil Engineering IIT, Guwahati. This course aims for introducing or giving advance level of knowledge to a student who have undergone their basic degree in civil engineering.

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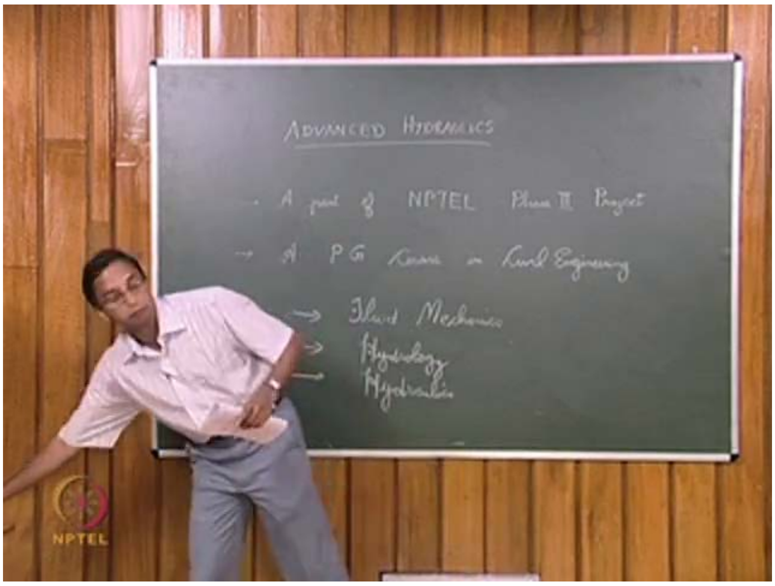

Before undergoing a course on advanced hydraulics, it is expected that the target students should have a basic knowledge on fluid mechanics. He or she should also be good in hydrology as well as he should have been introduced some of the concepts on hydraulics.

In our course here we will be dealing at an advanced level, where a graduate student has to conceptualise the various theories and aspects in the engineering as well as the physics behind the fluid flow. Well before starting the course you should be aware of the historical background of hydraulics. What do you mean by hydraulics? The word hydraulics it is developed from the Greek word hydraulikos. This particular Greek word it has meaning or has in its root two words hyder, excuse me it is o here, hydro and aulos.

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The word hydro refer to water and the word aulos refer to pipe. So, it is well correlated now that is, the flow of water or water related to pipes, that means something where water is flowing. These two combinely led to the word hydraulikos and subsequently in the English language the hydraulics term is adopted.

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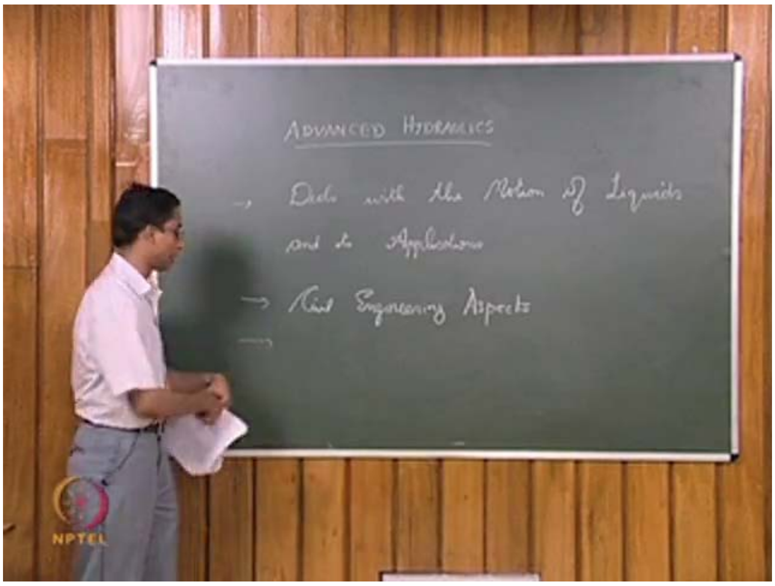

According to the definition of hydraulics it is that branch of science that deals with the motion of liquid and its applications. If you carefully go through this particular definition that is, this word hydraulics deals with the motion of liquids and its applications; you may see in various engineering fields these particular aspects occurring. Whether it is the river flow, whether it is the channel, flow, whether it is the motion of liquid where hydraulics jacks are applied, whether the motion of liquids in coolants, whether the motion of liquid in distilleries, whichever subject you take you will be dealing with motion of liquids, and all of these comes under the term hydraulics. And if you try to give a scope of all of these things, it is beyond our reach in this particular course on advanced hydraulics to cover all the aspects on hydraulics. We will be dealing mainly with the civil engineering aspects of hydraulics.

So, let us introduce the concept and introducing the concept, first we have to have a historical background on the subject. How hydraulics was developed from the age old days onwards? Mankind, if you see the historical mankind development and all, mankind started forming settlements at various locations, and mainly these settlements were along river banks or some of the water bodies. Subsequently, their settlements enlarged water became a scarce quantity or a more priced quantity. People were required to have water at their source, they started thinking of that, from the source of water they started drafting the water to their settlements. These let to the hydraulics of the ancient mankind.

If you go through them, you will see that they did not study it in scientific way or like that. They may not be knowing the scientific principles; how water can be drawn into their regions and all, but still they adopted those techniques. It was an art for them, we will be seeing how they did it. As the scientific knowledge started developing, you may see some of the scientist studying more aspects on the motion of liquids.

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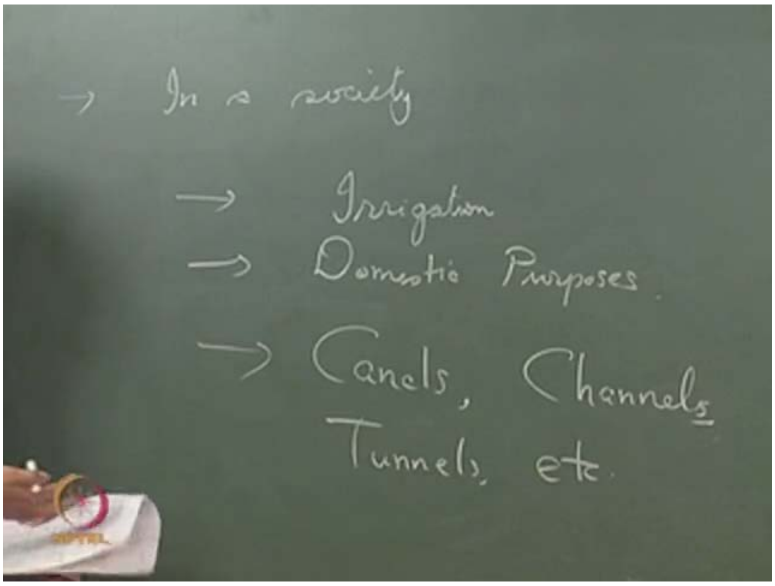

Let us see some of the historical developments. In a society people started using water for irrigation, domestic purposes and various other needs etcetera. To draw water to their location they initially started creating small small ditches, boreholes, holes, ponds etcetera. Subsequently, they intended to transfer water from one water body to another water body. They create a canals, channels, tunnels, if you go on you can list many number of items related to this.

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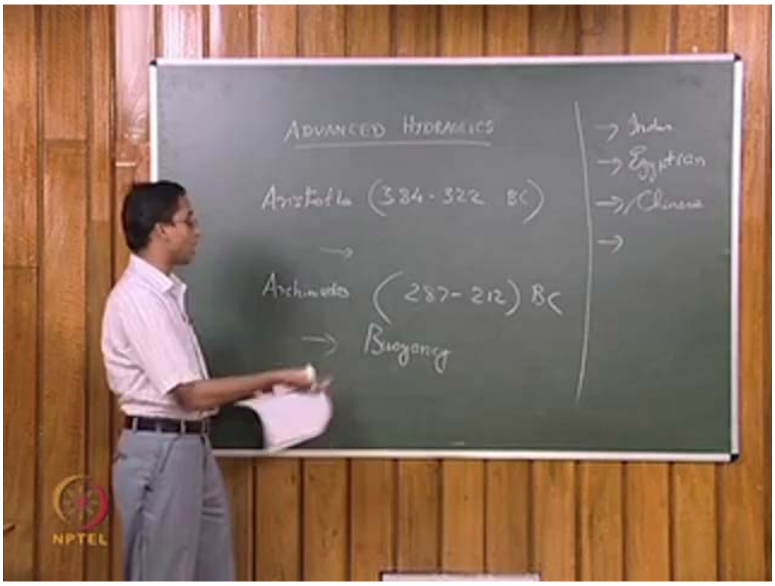

The mankind, if you start from the Greek development scientists like Aristotle, in the year 384 to 322 BC, he studied something related to the flowing of matter. When the body if it is if it is in a motion he assumed that surrounding that body there is some matter that is flowing and correlated with something related to the fluids. Archimedes, it is a well known theory from Archimedes that is still widely used, most of you are familiar with that. He developed the theory on buoyancy, he worked on several aspects of fluid flow. Still, if you see you may have other civilizations also in the historical this thing; you have Indus valley civilization, you have Egyptian civilization, Chinese. Further, if you extend you may see several type of civilizations that has used different type of drainage network, different type of fluid structures, fluid flow structures so that they can allow fluid from various sources to their locations or transfer water from their location to some other sources, as well as. After the knowledge of scientific scientific knowledge during the BC's, subsequent documentation of scientific development in hydraulics is not that noteworthy or it has not been documented also, we can say like that.

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Still it was following the form of art that is, hydraulics was still extended as a form of art. People through their intuition started building hydraulic structure, they developed the structures, they constructed canals, they constructed channels, they flow water from one location to other etcetera. The exact scientific principles were still inconclusive to them. From the year 1000 AD’s onwards, especially in Europe several universities were established. During the establishment of these universities and in subsequent studies conducted by the faculties, the students in these universities people have started knowing the mechanics of fluid flow. They started to interpret fluid flow in a scientific manner that was not there in previously documented researches of hydraulics.

How they started the things? If you go from universities of university of Paris, university in other Italian universities, Spanish universities and all, there are several studies on mechanics of fluid flow from the second millennium onwards.

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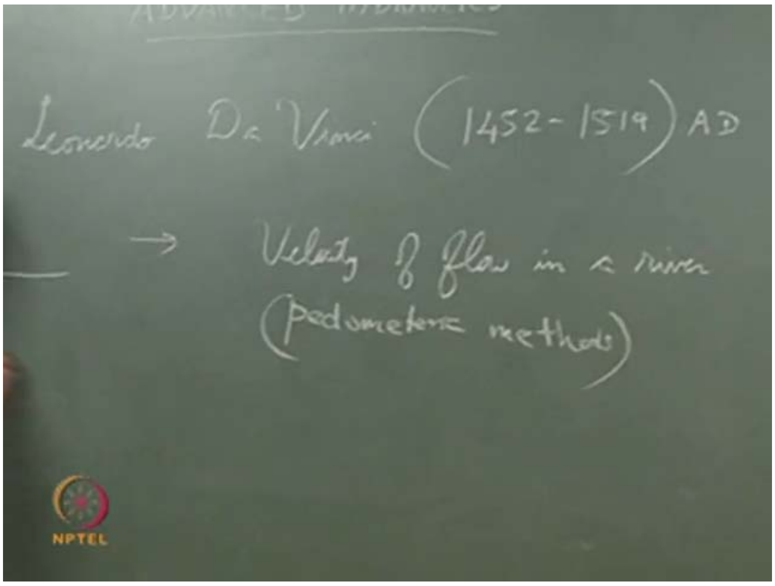

One of the prominent scientist that come into picture during these eras are Leonardo Da Vinci. He is the world famous scientist, he had done research in many mechanical aspects, many mechanics on the motion of objects relate, related to earth. He is one of the profounder in fluid mechanics, we can say like that. He has measured a flow of velocity, flow or he has measured the velocity of flow in a river using his own methods that is, pedometric methods.

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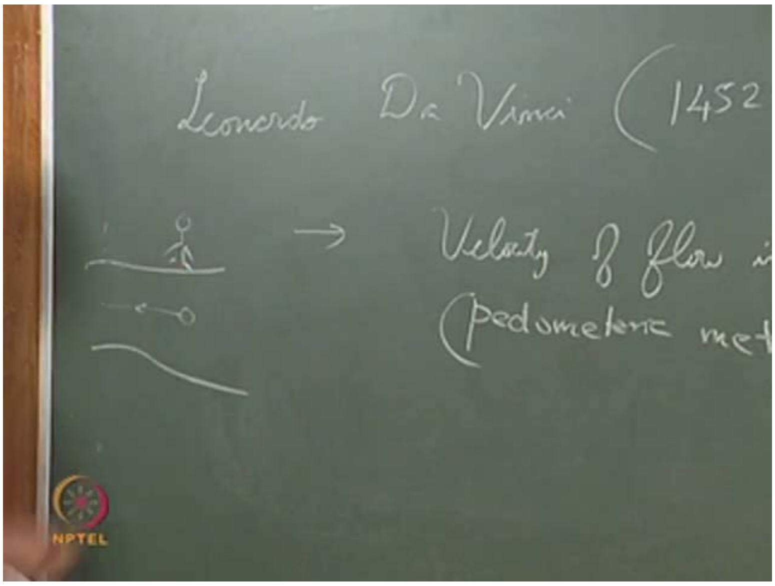

That is he stood near the banks of a particular river and he walked, he put some object on the water, on the river, this object started moving in this direction, the direction of velocity and he also started moving at the same pace, and at a stretch, certain stretch he observed the distance he moved and the time he took, and he subsequently interpreted the velocity of the river water there. That was quite intuitive and at that age, during that particular time it was one of the big findings.

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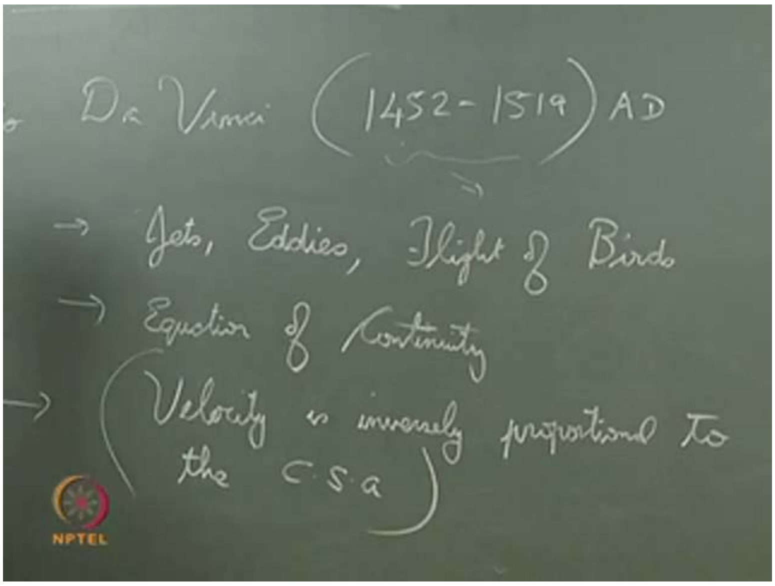

He has also developed knowledge on, he has studied on jets, he has studied eddies, he even observed the flight of birds. On various aspects he studied the mechanics related to the flow of liquids or flow of air as well. He was the main scientist who obtained or who found the continuity equation of continuity. The continuity principle he suggested in such a way that velocity at a place is inversely proportional to the cross sectional area of the location. That is also one of the most important findings from this particular scientist.

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Next scientist who comes into our picture, who had a profound influence on the hydraulics is Galileo, from 1564 to 1642. So, he has conducted various experimental studies, he was a man of experimentation. He observed the motion of objects, especially in fluids, how a particular object if it flows through fluid or it moves through fluid, how the, how its motion gets affected due to the presence of fluid and all. He has studied some some of them. Even the effect of gravity was was identified was Galileo, but the gravitational acceleration quantity and all was not discovered during that time and all.

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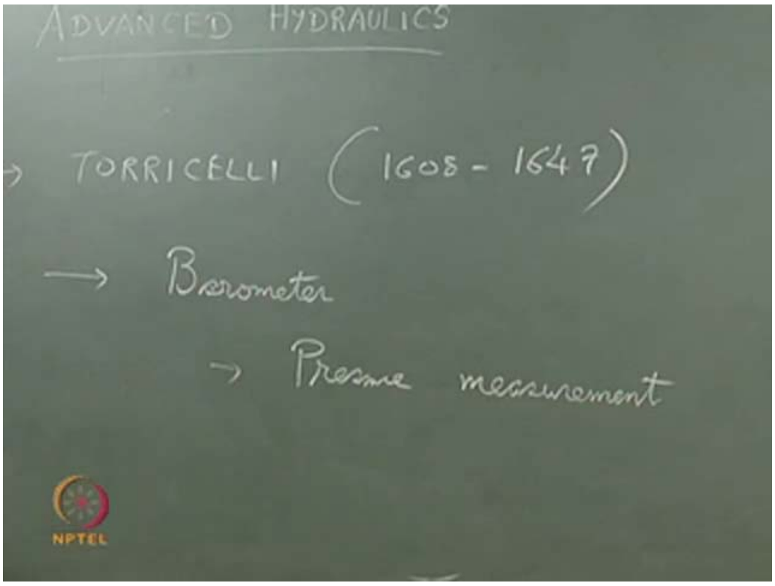

His Galileo’s student Torricelli, he had several students, he had, Galileo had developed him a school of scientist, you can suggest a school of scientist. Torricelli is one of the scientist, in some 1608 to 1647, who developed barometer. And you know barometer is one of the most important instruments where you can measure pressure of liquid or pressure of air, whatever it be, to measure pressure measurement instrument.

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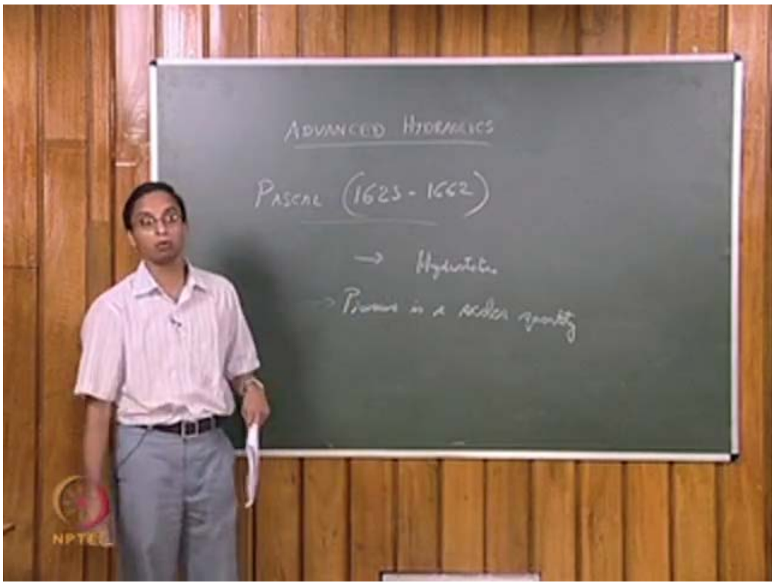

Subsequently other scientists who will be coming into picture are who studied on hydraulics; Pascal, he is a noted scientist in this area, in the field of hydraulics. Not only in hydraulics, you have already studied in mathematics his theorems and all. So, in hydraulics also his contribution is significant and still in his young age, I mean still in his short span he has contributed significantly in the field of hydraulics, such a way that in hydrostatics, here especially in hydrostatics and all. He observed pressure, which is the most important quantity in any fluid flow analysis.

Pressure is a scalar quantity, to understand this phenomenon it is not that easy or it is not that visualisable, we have to try to import from our mind, how pressure is a scalar quantity? If you say at any location, if I say at this particular point the pressure is not having any direction, it has only a magnitude. This pressure say if at this location it has a particular magnitude, say pressure is not in this direction or it is not in that direction or it is not in this direction, nor this direction or it downwards it has simply a magnitude.

Now, the effect of pressure will create force on any planes whichever you are taking into considerations that is the feeling you need to understand, that pressure is a scalar quantity. And that is pressure is independent of direction, this finding was done by Pascal, which is one of the most important findings in fluid mechanics.

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Of course, we cannot forget Issac Newton. He has contributed in almost all fields of science, physics in almost all physical, all the things in physics he has contributed. Issac Newton who lived from 1642 to 1727, he was the first scientist who studied and proposed gravity.

So, when he identified the gravitational constant or acceleration due to gravity, subsequently he studied them in hydraulics and tried to interfere, infer how the fluid motion is also affected. He introduced the concept of principles of momentum and you know that still in the twentieth century or still in the twenty first century, we are using principles of conservation of mass, principles of conservation of momentum and all, to analyse any fluid motion anywhere on earth.

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Next, scientist who comes into picture is Leibniz, he is a noted calculus man. You have studied Leibniz rule or Leibniz application in various calculus. The same calculus methods are used in the hydraulic problems as well and he has studied those aspects also, which are very important in fundamental in hydraulics. You can see the next scientist which we are going to study, Leonhard Euler the scientist who we are all in depth for. He is the main scientist, you can say even after Issac Newton he is the most important scientist in fluid mechanics. It is his approach, his studies on various aspects that are still in use, we have seen see he has introduced the concept on Eulerian analysis.

He has worked out on equations or he has worked out on acceleration flows and all, you have seen Euler’s equation of motion. So, all these things are developed by Leonhard Euler and still we are using Euler’s equation of motion in many fluid flow problems. What is meant by Eulerian analysis? How you came into the Eulerian analysis for any fluid mechanics related issues?

The Eulerian approach means rather than tracking a particular particle and its movement, if you are able to track a particle or if you are able to understand a property in it throughout at a particular location that is more suitable for fluid mechanics, that is how the Eulerian analysis has reached. That is for example, in a particular stretch of river, if you take a fluid particle and if you try to analyse its movement, it may be quite difficult because fluid it is the micro particles and all to observe the moment of micro particles in them in fluid and all, it is quite difficult and quite tedious. Rather than that if you take any particular cross section and try to identify say velocity at this cross section, at various time at this particular cross section that will help you to understand the discharge through that section, and such an approach is called Eulerian approach in analysing the fluid movement. If you see that till now we introduced some of the scientists who have worked on hydraulics.

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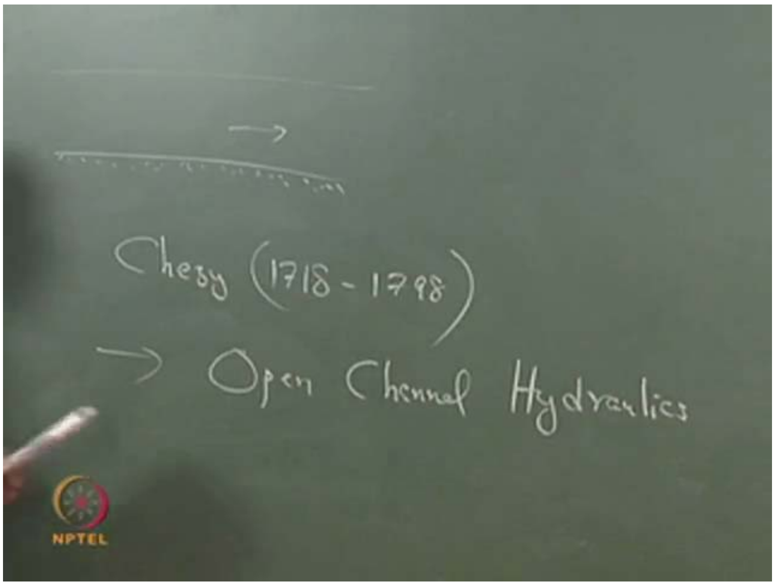

It is quite natural when a fluid on its flow along a bed it may be it may be resisted by the bed, the scientist who have a studying of previously to the previously to Euler and all, they were not able to analyse the effects of the bed on resisting the fluid. The scientist Chezy in 1718 studied extensively on these aspects and observed very simple relationship, how the resistance bed can create resistance to the fluid flow and analyse them. This is one of the main findings in open channel hydraulics, subsequently many studies were conducted in these aspects.

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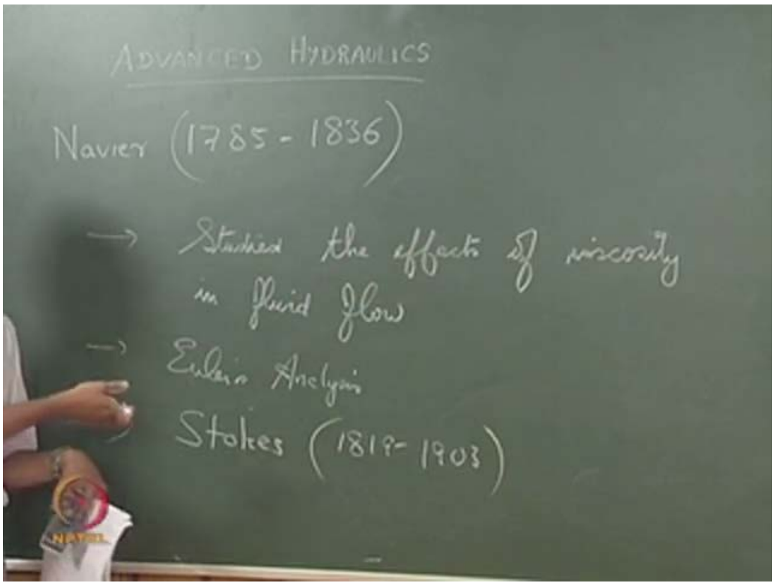

Another scientist who is well known in fluid mechanics is Navier, from 1785 to 1836. He is extensively studied on the fluid flow, studied the effects of viscosity, studied the effects of viscosity in fluid flow. He also extended the Euler’s analysis, euler’s analysis on fluid flow, incorporated the effect of viscosity on those analysis and extended the study, this was also an important finding. If you see that subsequently in the next few or in next century, may be some years after another scientist called Stoke’s, Gabriel Stoke’s, he extended the Navier Stoke’s or Navier’s studied on effects of viscosity in fluid flow, he formulated them.

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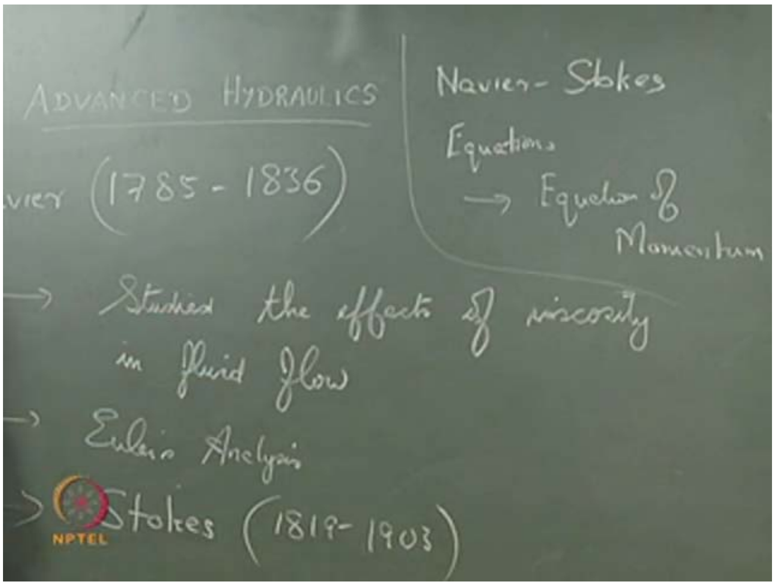

That created the well known Navier-Stokes equations on fluid flow, this is mainly the equation of momentum. In fact Navier-Stokes equation in a cartesian or in a three dimensional system, it consists of three momentum equation and one equation on continuity. Any fluid flow problem till now, it is being solved using Navier-Stokes equation, it is one of the most generalised form of fluid flow equations, and we well be using them or we especially the students on fluid mechanics they will be extensively working in navier-stokes equation. And we will be dealing partly or the part of those equations which are very significant in hydraulics or free surface flow.

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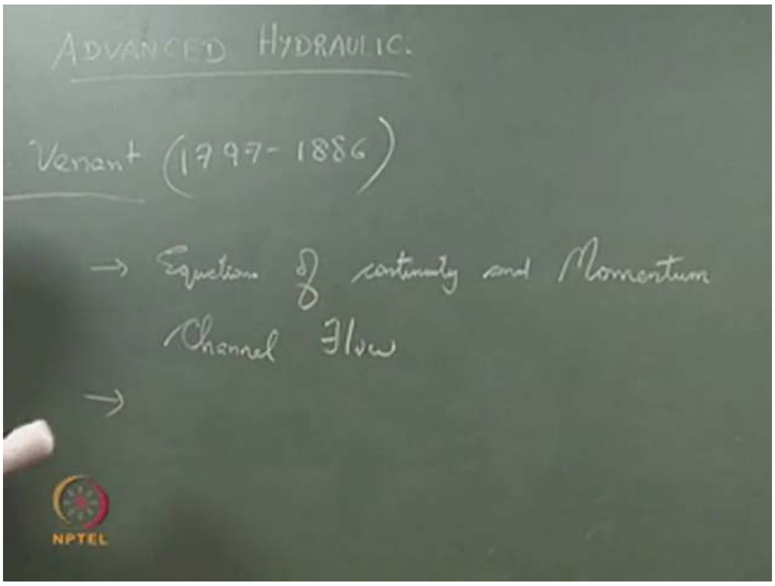

You might have heard about Saint Venant, another noted scientist. He has developed equations of continuity and momentum, especially for channel flow. They are still in equation for any river flow or any river engineering courses and all you will be still studying Saint Venant equation.

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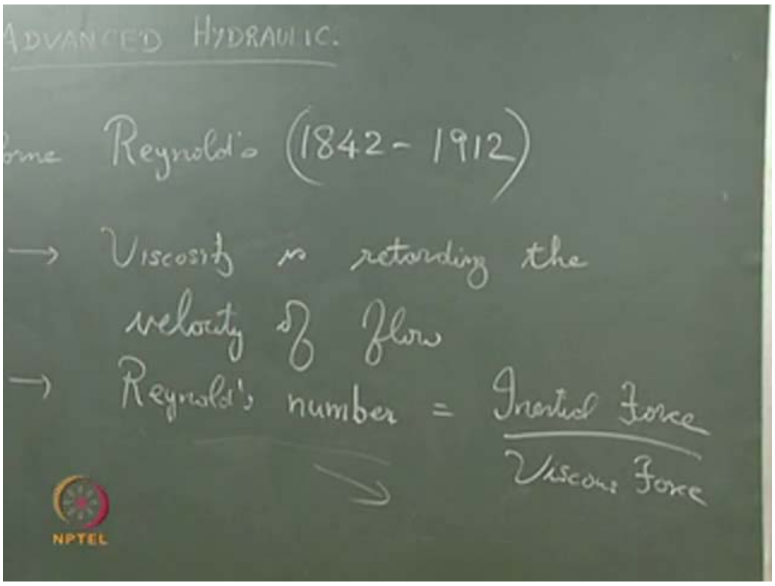

The next scientist who is much much familiar to most of most of the students here, Osborne Reynold's from 1842 to 1912 studied how viscosity is retarding the velocity of flow. Conducted several experiments of on these aspects, studied the effects, observed and obtained a quantity called Reynold's number. Reynold's number is the ratio of inertial force to viscous force, it is the ratio of inertial force to viscous force. If a fluid is moving with an inertial force with a velocity V and if there is a viscosity or in there is a, if the fluid is having some viscosity, that viscosity may retard the movement of the fluid and that quantity he visualised in a dimensionless form, and developed the number called Reynold's number.

This number is still widely used to classify any fluid flow, whether it is laminar fluid flow, whether it is turbulent fluid flow, whether it is a transitional fluid flow and all. We will suggest that this is also one of the most important findings in fluid mechanics. As we are dealing with hydraulics, especially with open channel hydraulics and another dimensionless number that you will come into account is Froude number.

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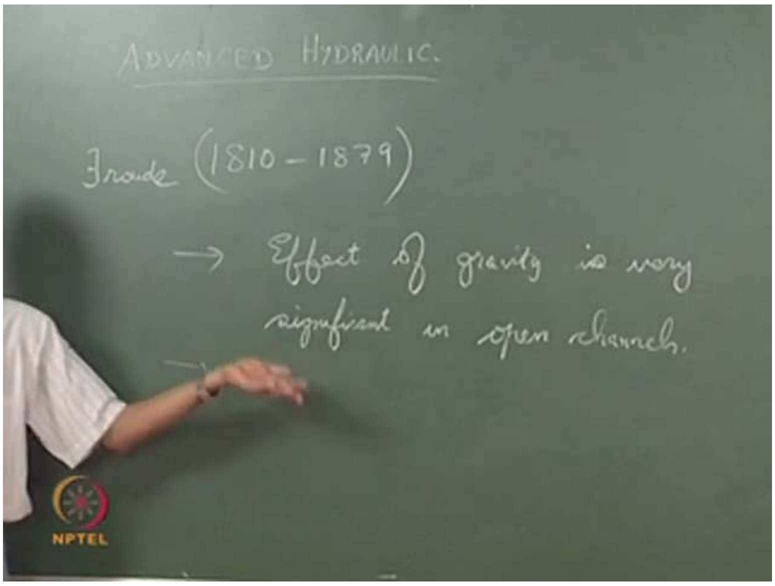

A scientist called Froude, he studied on various fluids flow in channels, especially in open channels. He observed that the effect of gravity is very significant, effect of gravity is very significant, open channel flows.

This again is one of an important findings, most of the open channel and flow analysis are based on Froude quantity or Froude number, which we will be defining it later in our theoretical classes and all. So, these were some of the historical developments of hydraulics. As in our country how the historical development of hydraulics has occurred also, we can briefly go through them, not extensively as it was done till now, but we will see that hydraulics or part of hydraulics, it was there from the age old Indus valley civilisation itself. You have seen canal networks, drainage networks in those civilizations also.

So, we can say our people were quite capable in hydraulics also. Our country may be pre independence as well as post independence they have work extensively in hydraulics area, there are lot of hydraulic projects related to this. If you see one of the noted contributions are, when Roorkee university was established in 1850s, the main objective of the university was to contribute to the water resources development of that region.

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As river Ganges was flowing nearby, they worked extensively, the particularly Roorkee university worked extensively in obtaining or in designing various type of hydraulic structures, hydraulic parameters. They have developed canals, hydraulic structures, intuit in their own way and that became a part of development throughout India also, which theories were subsequently used in many parts of India.

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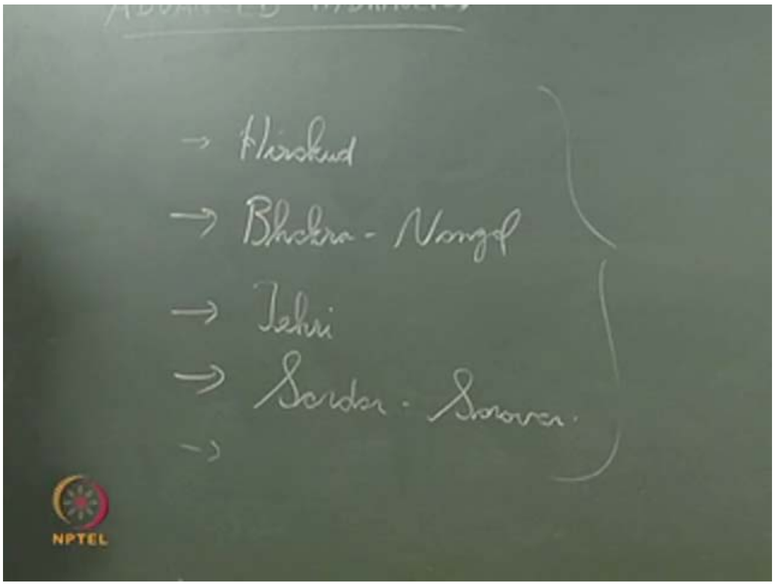

In the post independence area, in post independence era also you have seen very good hydraulic projects like Hirakud dam, Bhakra Nangal dam, Tehri dam, Tehri project, Sardar Sarovar project. I am not listing all of them here, but still some of them you can say even in canal networks the Indira Gandhi canal network in Punjab, in Rajasthan and all you have, you may see them extensively. So, for any person who are interested to work in hydraulic projects and all, they should have some basic knowledge on hydraulics and they should know how to design those things, hydraulic projects or hydraulic related matters.

In our course we will be teaching the theoretical knowledge on the various flow aspects in open channel, especially in the open channel hydraulics. As we mentioned that the hydraulics comes in various engineering fields and ours is the free surface flow. We will be dealing with hydraulics related to free surface flows. So, by describing this historical background, let us come into the course, its duration, its course contents.

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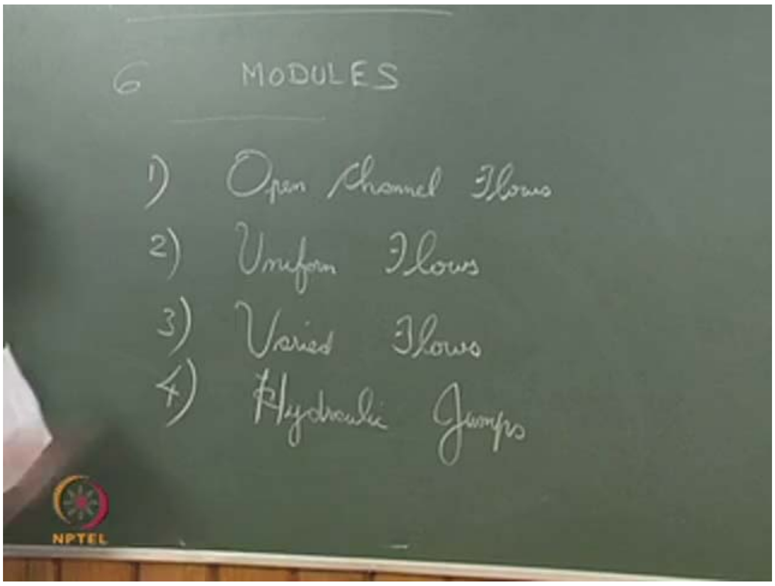

This particular course, it has 6 modules, in our course here there are 6 modules. The first module is on open channel flows, our second module is on uniform flows, third unit is on varied flows, fourth unit is on hydraulic jump, fifth unit is on flow through non prismatic channels, and the final sixth unit is on turbines.

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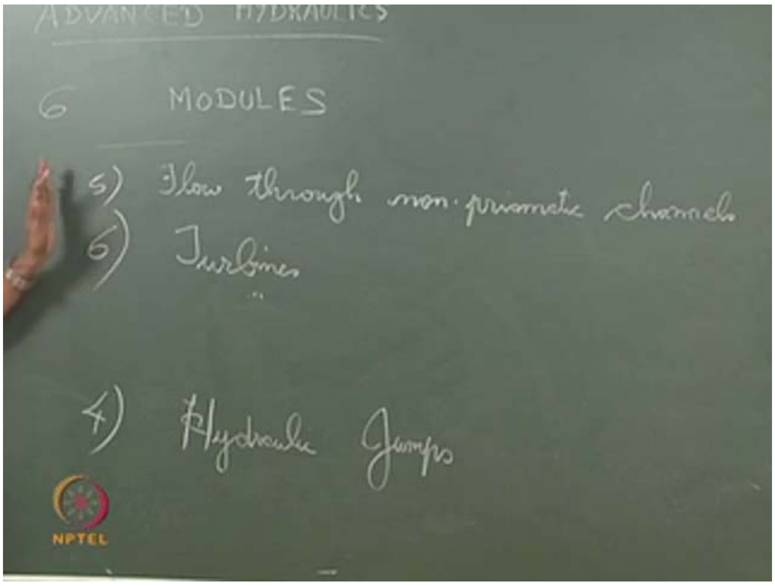

So, if you observe all of the units here or all of the modules here, you will see the final unit or final module on turbines. This is more related to the mechanical engineering aspect and all, but as this course is on advanced hydraulics, we surely felt this also should be a part of this course curriculum. A student after undergoing this course, may be first he will be put in some hydraulic projects and all. Definitely he need to understand the theoretical background on turbines and how the open channel flows affect the turbines and all.

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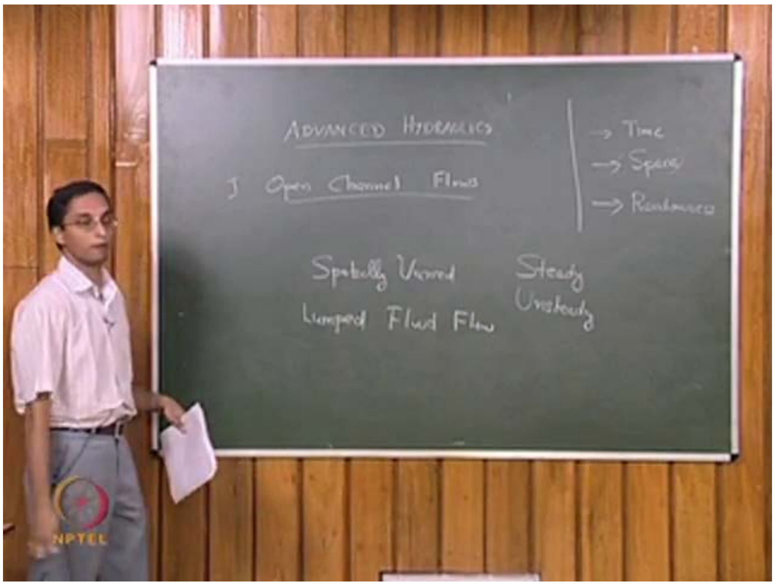

We will see how of them, we will consider each unit now, we will see in each unit what are the contents that we will be going to dealt. The first module is on open channel flows. You know any fluid flow fluid flow can be classified based on the following parameters; time, space and randomness. That is, any fluid parameter, any parameter for the fluid flow they can be characterised with respect to time, space and randomness. All these three quantities are independent to each other. If a fluid parameter, if it is not varying with respect to time then that parameter or that aspect is called steady. Most of you have heard about steady flow and all, steady fluid flow.

So, the steady fluid flow aspects come from the parameter velocity, which is not changing with respect to time. If that quantity velocity, especially in hydraulics if velocity changes with respect to time, then such type of flows are called unsteady flows. The next quantity that is coming into picture is space. If a fluid parameter, if it is varying with respect to space, it will be spatially varied flow. If that same parameter, if it is not varying with respect to space, it is called non spatially varied flow or it will be also called lump flow. We can consider in hydrology, especially in hydrology and all most of the students might have heard about lumped fluid flow and all. The thing is that the entire quantity it is not varying with space and it is lumped into a single parameter and such quantities are called lumped fluid flow.

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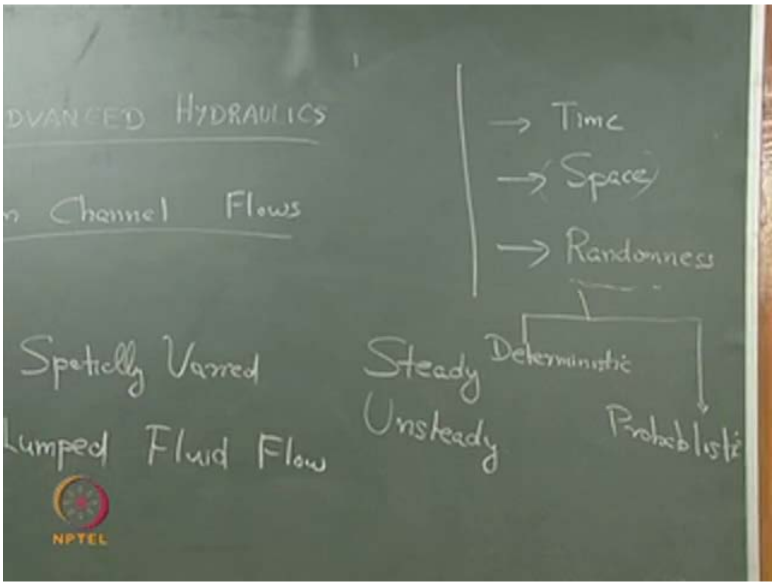

The next parameter, randomness or next quantity this will determine whether a fluid flow is deterministic fluid flow or whether it is probabilistic fluid flow. In our analysis we will be dealing with only these two parameters; time and space for various fluid flow aspect. The randomness is not taken into consideration, well that can be dealt in higher researches and all. So, the open channel flows can be classified using those parameters mentioned above.

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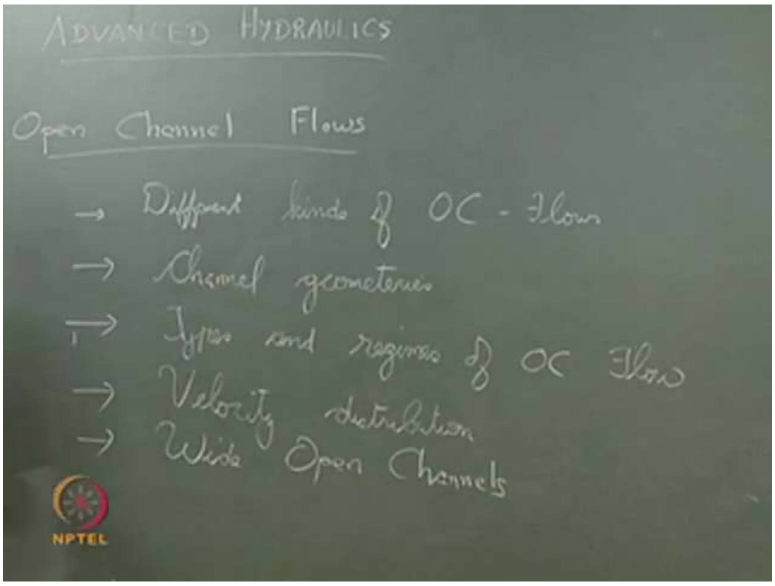

We will be dealing with different kinds of different kinds of open channel flow open channel flows, we will be dealing with channel geometries then we will be studying on the types and regimes of open channel flow. You will also be studying the velocity distribution, you will also study flow in wide open channels, you will also study constant of specific energy.

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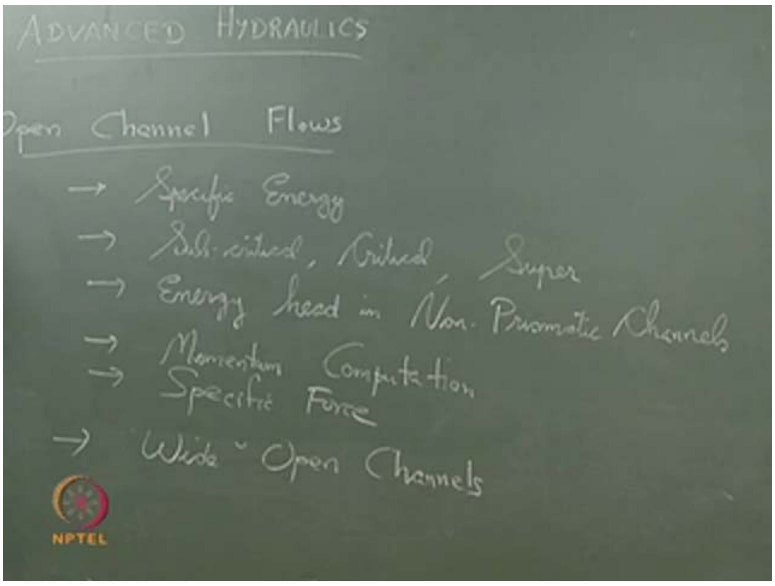

The subcritical critical and supercritical flows, how to compute subcritical flow, that will also be deal, how to compute critical, how to compute supercritical flows, all these things will be covered. You will also be introduced on how to compute energy head in non prismatic channels? You will also see momentum computation, specific force, all these components will be dealt in the first module, open channel flow. Our intention is to cover the first module in approximately 6 to 7 hours.

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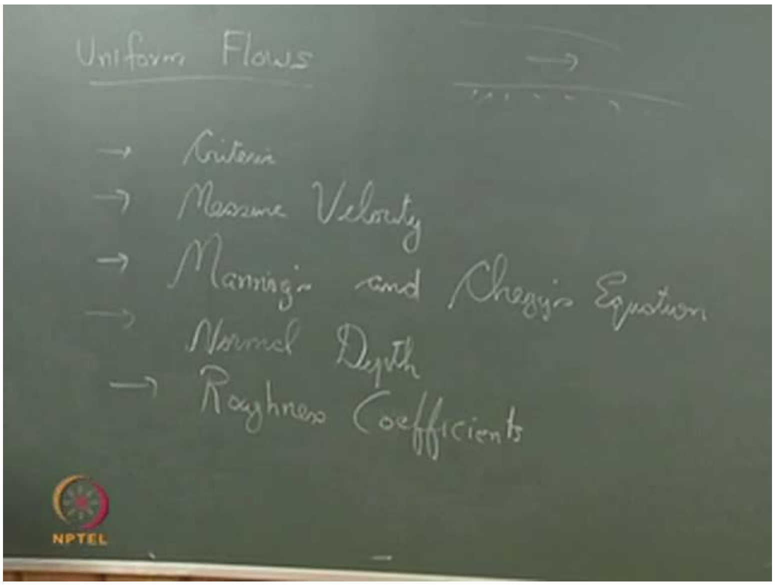

The second unit talks about uniform flows. We have seen any flow parameter that can be varied with respect to time, space and randomness, you have already seen them. So, uniform flow is that quantity where the flow is not varying with respect to space. Say if you take the velocity as a parameter, velocity you say it is uniform for a particular stretch of the channel, if the velocity is same for the particular stretch of the channel that flow is called uniform flow. It is not varying with respect to space. What are the different quantities or different things we need to study in uniform flows? You have to understand the criteria to decide which is an uniform flow. You should also know how to measure velocity in uniform flow. You have to study Manning's and Chezy's equations, we have described about scientist Chezy a few minutes ago. We suggested how he developed some simple relations to identify the resistance of fluid flow due to the bed, due to the bed, how the bed is influencing the fluid flow in a channel and all, he had studied and developed some simple relationship.

So, these quantities they are coming in uniform flow, we will see them. You have to identify what is normal depth, you have to identify its velocity, you have to determine roughness coefficients, you have to determine economical sections, also identify composite roughness coefficients.

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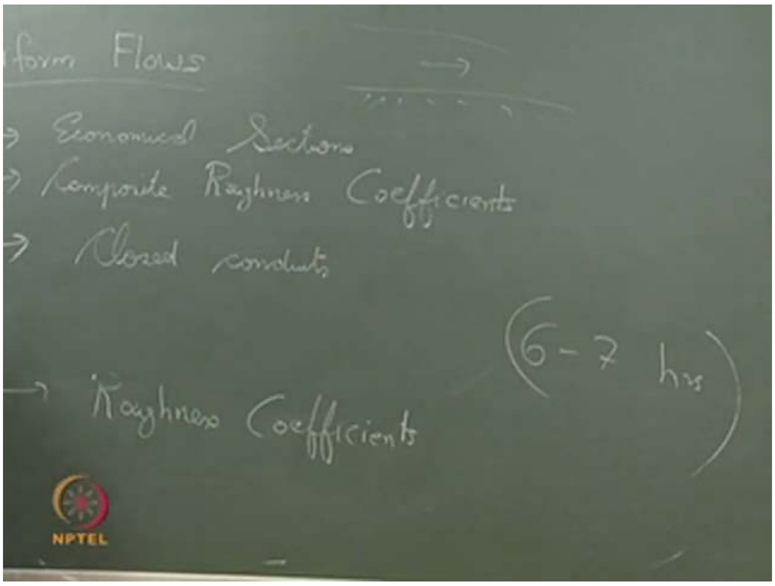

You also required to do analysis on closed conduits, how the uniform flows are there in closed conduits and how you can approximate them with open channel flow? We intend to cover this module also in 6 to 7 hours, depending upon our speed of and progress we will be delivering the lecture appropriately.

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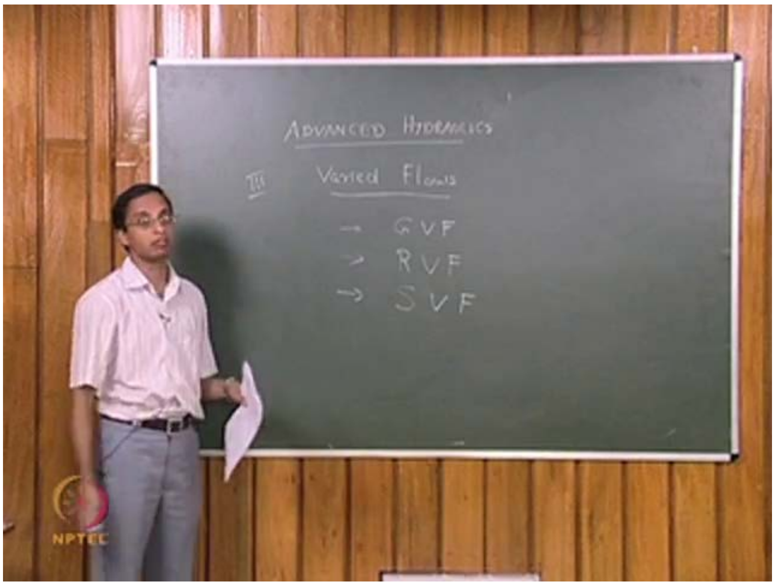

The next module is on varied flows. Varied flows means the quantity that is varying with respect to space. You have precisely different type of varied flows, say a gradually varied flow. I am writing it in short here. You have rapidly varied flow, you have spatially varied flow, different type of varied flows are coming into picture. So, what are the quantities you need to study here in varied flows? How the varied flows are occurring in nature? You have to identify them; you have to study that because it is especially required in the design of hydraulic projects.

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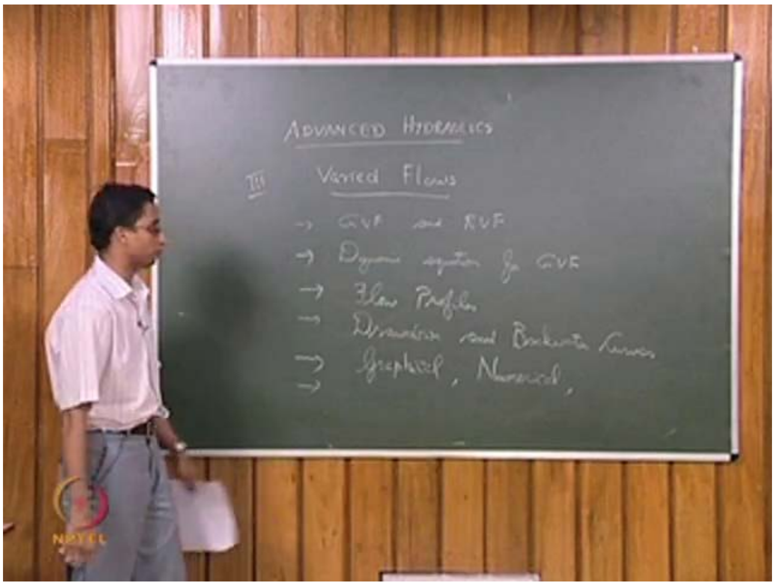

So, you need to understand the difference between gradually varied flow and rapidly varied flow. You have to use the dynamic equation for gradually varied flow computation, you also need to understand what are the assumptions and characteristics. You also required to understand flow profiles, what is meant by draw down and back water curves? You will also be taught on various methods of computing flow profiles, graphical integration, some of them are graphical methods, numerical methods, direct step methods. Then you can also use dynamic equation for spatially varied flow, you can if there are some analytical approach that can also be employed here, and we will see, because there are may be limited analytical solutions to gradually varied flow computations and all. We if if possible we will go through them also. You also need to introduce the dynamic equation for spatially varied flow.

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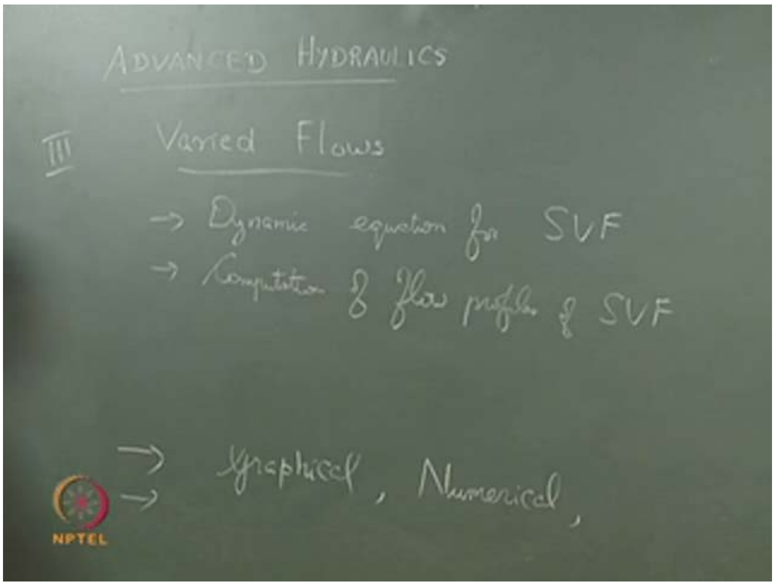

You can also go through the computation of flow profiles of spatially varied flow using numerical methods. Again numerical methods we will see some of the numerical methods that can be used for the following things. And as you know numerical methods is one of the most important tools, which has simplified the life of engineers considerably.

Using numerical methods you can solve almost all type of partial differential equations, all type of partial, you know that the partial differential equations are the governing equations for different type of fluid flow problems. You can solve them using the numerical methods by approximating the partial differential equations in a simplified manner. We will see them in the next time or in a detailed way when the appropriate lecture hours arises. Next comes into our picture, in this particular third module we are going to take approximately 8 to 9 hours. So, both the uniform flow and varied flow they are steady flows, please note that, they are coming in steady flows.

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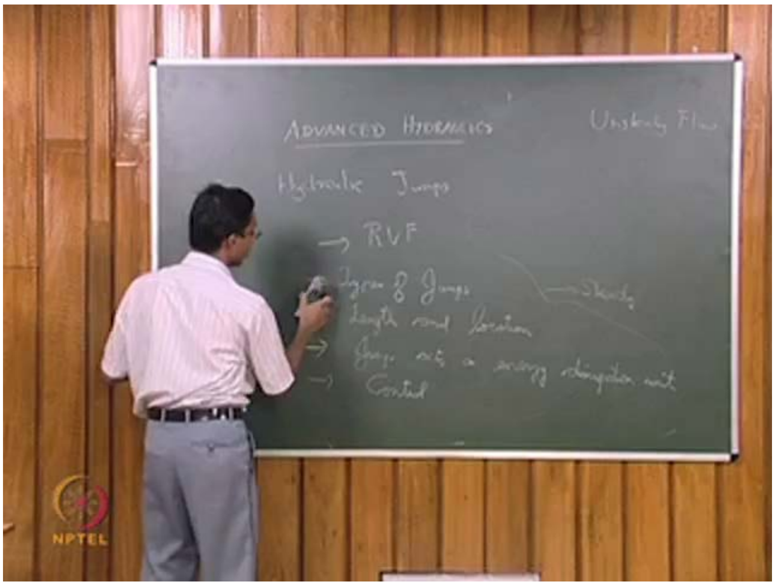

So, next module we are going to consider is hydraulic jumps. This is a particular type of rapidly varied flow. How this is occurring? Those things you have will be taught in the class. The different types of jumps, its characteristics, length and location, how jumps act as energy dissipation unit, how you can control hydraulic jumps, these things will be studied here. Some of the hydraulics jumps you will be considering as steady flow and some of the hydraulics jump will be unsteady flow, especially the quantity called surges and all which will be taught in this unit.

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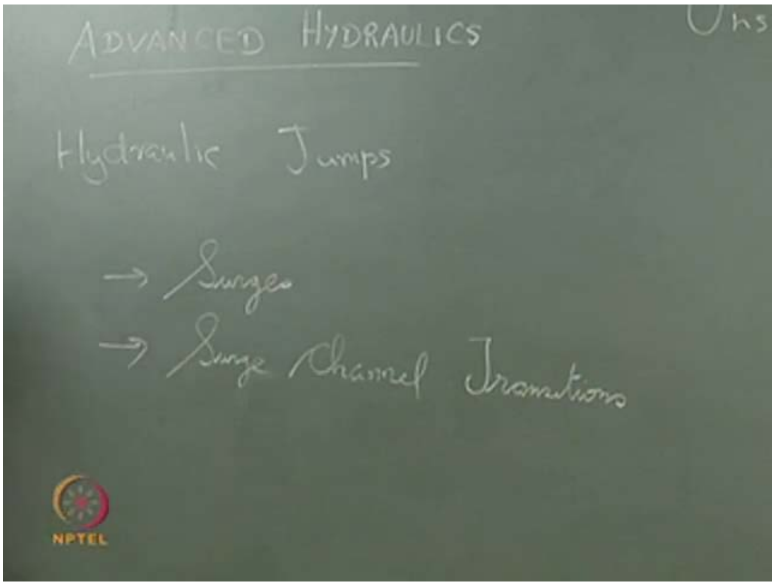

How the surge channel transition occurs. So, this particular unit we intended to cover in approximately 7 hours.

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Our fifth module is on flow through non prismatic channels. So, here there will be studies on how the sudden transition affects, sudden transitions in the channel flow how it affects, how the sub critical flow occurs through sudden transitions, flow through culverts, bridges, bridge piers, some of the flow around some of the obstructions, flow in channel junctions. Some of the things will be dealt in flow through non prismatic channels, as it is mentioned or as it you are aware of that non prismatic channels are found everywhere in the nature, all the rivers, all the natural drainages and all they are non prismatic in nature. So, how these things affect the natural flow and all will be dealt here. We are approximately giving 5 hours of lecture to this portion.

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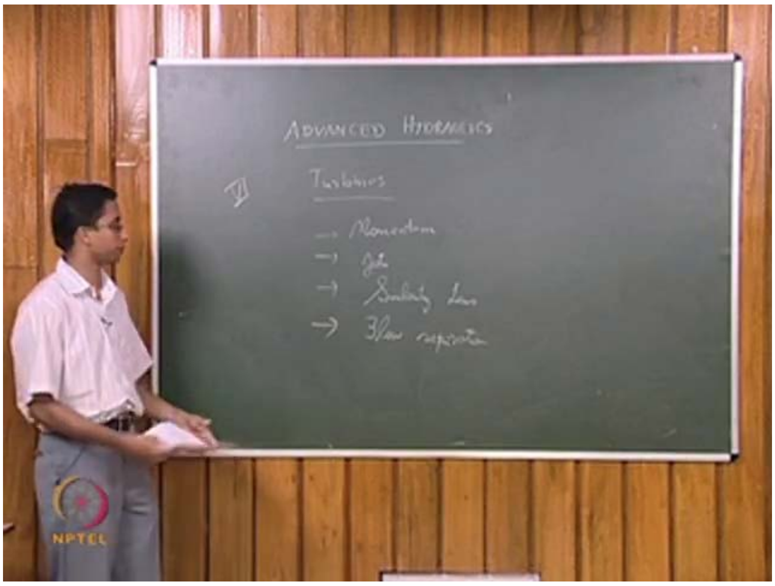

Our final module is on turbines. So, in this module you will be taught on the momentum principles; how you need to apply momentum principles in turbine related problems. How when a Navier-Stokes equation or the Reynold's transport theorem has to be applied, when turbines or generators or pumps are involved? You have to see the impact of jets, impact of jets on planes and curls. You have to classify turbines; what are the radial flow turbines, what are the axial flow turbines, what is meant by impulse and reaction turbines.

We will also teach you on draft tube and cavitations, you will also be taught on similarity laws. You will also be taught on centrifugal pumps; what is the minimum speed to start the pumps, what is meant by jet and submersible pumps, what is meant by positive displacement pumps, reciprocating pumps. How the flow separation affects turbines, what is meant by cavitation, because these features are very much in affecting the turbine or the power generation in any hydraulic projects related to power generation, turbines are coming into picture.

So, these quantities are to be studied in a significant manner. So, going through this introduction, let us wind up this first lecture. We will be going in detail in each of the modules from next class onwards. The next class in this course curriculum, it will be having some 50 minutes of lecture and we will be having a 5 minute quiz on each of the topics. So, when you come to the next class whatever has been taught to you based on today's lecture and all, there will be some 2, 3 minutes of quiz related to them as well.

Thank you.