Physics of Renewable Energy Systems
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Lecture – 15
Introduction to Hydroelectric Power

Hello, I hope you have completed the assignments and you have also understood the first three modules. Today we will start the next module, that is based on hydroelectric power. Till now, we have discussed on solar and wind-based energy systems, which are going to be very useful for India. But if you look around, you will find that hydroelectric power is an intrinsic component in the current energy landscape of India.

And it is expected that this renewable based unit will continue to play an important role in future also. And therefore, it is very important that we also understand the operation and functioning of hydroelectric power stations and where this technology will head towards in future.

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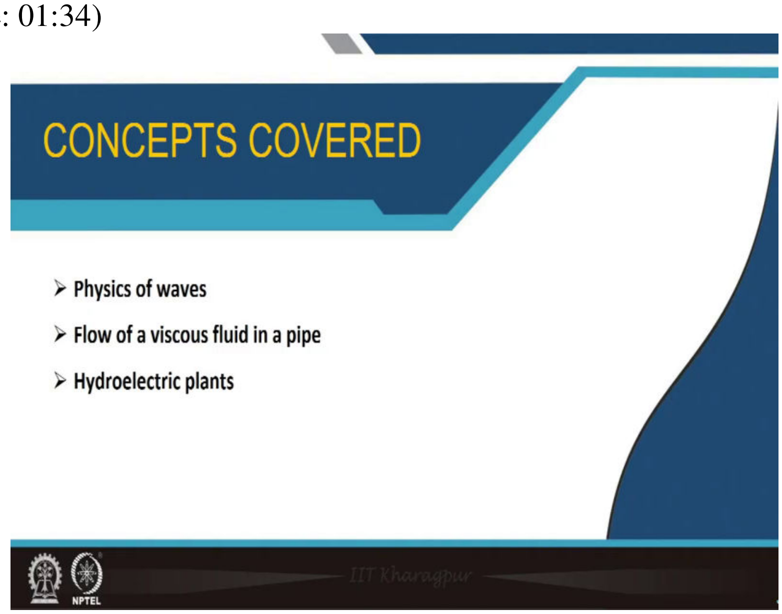

So, in today's lecture, we will again ask the fundamental question, which topic of physics is important to hydroelectric power? You will find that, physics of waves or what you have been talking in terms of waves or wave equations, play a critical role in defining the extent to which you can use the water energy. Along with this, we will continue to use the concepts of fluid mechanics, which we discussed in the previous module.

And today, we will just give you a very brief introduction towards the hydroelectric plants and the details about the hydroelectric plants will be discussed in the next lecture. So, these are the three main concepts, which will be covered.

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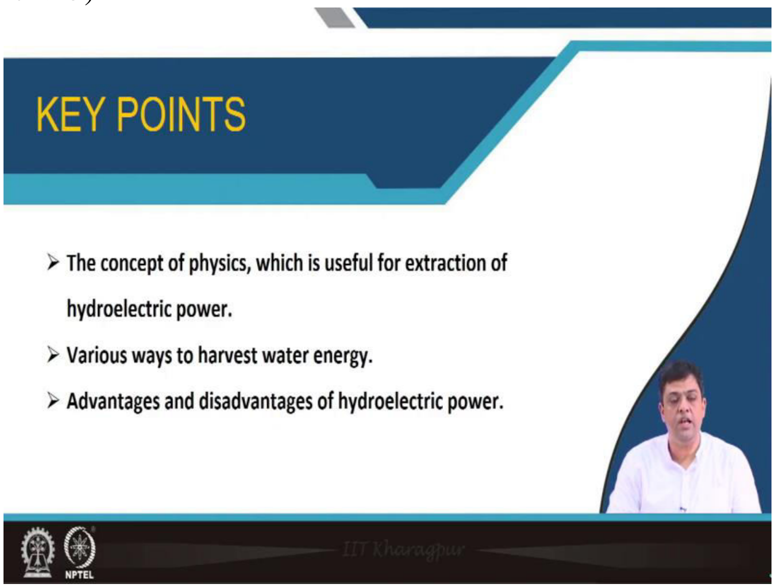

And you will be able to understand, the relevant points of waves and wave equations, which are going to be commonly used in the topic which we are going to discuss. You will also be able to defend the statement that, there are various ways to harvest water energy. And finally, we will also try to give you the advantages and disadvantages of hydroelectric power.

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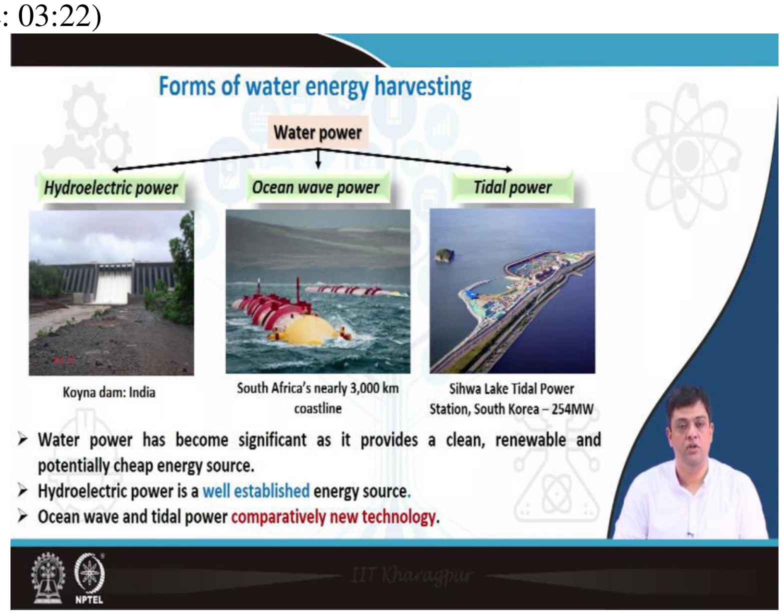

You will see, that water power can actually be extracted from various strategies. You can have hydroelectric power from the construction of dams, you can use the energy in ocean waves and you will have different protocols to extract the water power using ocean waves. And finally, there are waves by which you can also extract power from tidal. As you have seen all around, water already become a significant source of power, and it is used in various forms.

It is a typical renewable base systems or source, it is clean and if used efficiently, it can also act cheap and economically viable energy source. In India, hydroelectric power is a well-established energy technology. But now, ocean wave and tidal power are coming to the forefront and in coming years, you will find that these two technologies will also become important to our country.

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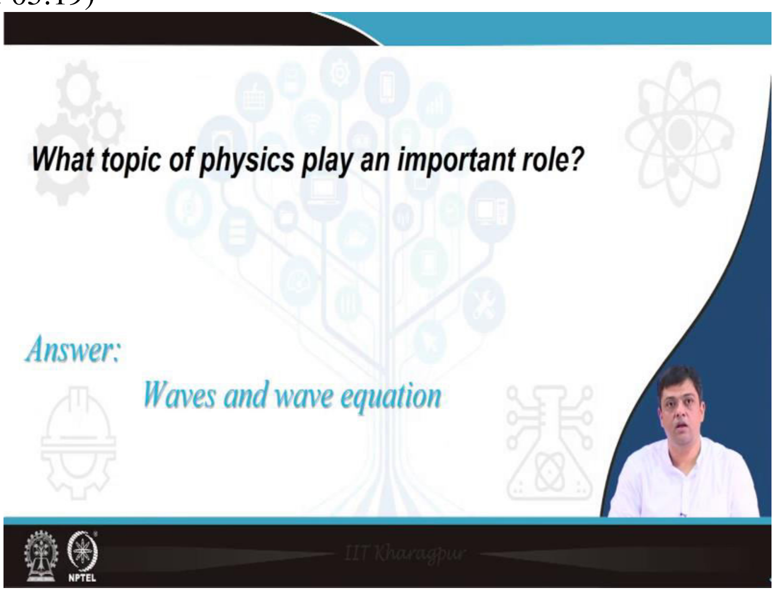

As I said, let us ask the basic question, what topic of physics play an important role in this module? And the answer is, the topic is waves or wave equation. So, very quickly let us revise your first year B. Tech or first year bachelor's degree topic, and revise the concepts which will be useful to us.

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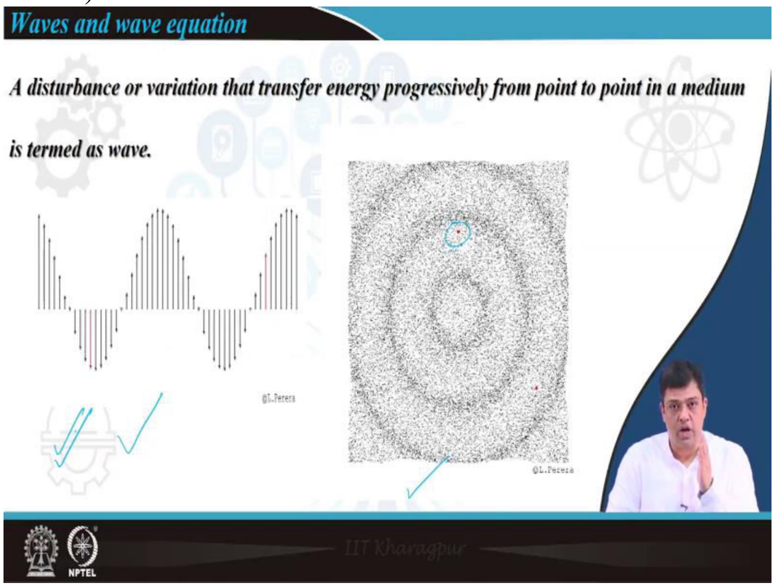

What is a wave? How do you define a wave? A wave is primarily variation or disturbance, that is traveling. So, a disturbance or variation that transfers energy progressively, from one point to the other in a medium is termed as wave. This is a one-line definition which I have used in this slide. But, some where you will find that wave can also be defined as a traveling disturbance is called as wave.

This definition is as good as the one which is written in the slide. You have understood two types of waves, the transverse or the longitudinal wave. If you see, the red spot, this is moving along the direction of the disturbance. So, it is longitudinal wave, whereas in the case given in the left-hand side, the variation is in the transverse direction than the direction of the wave. So, transverse wave and longitudinal waves.

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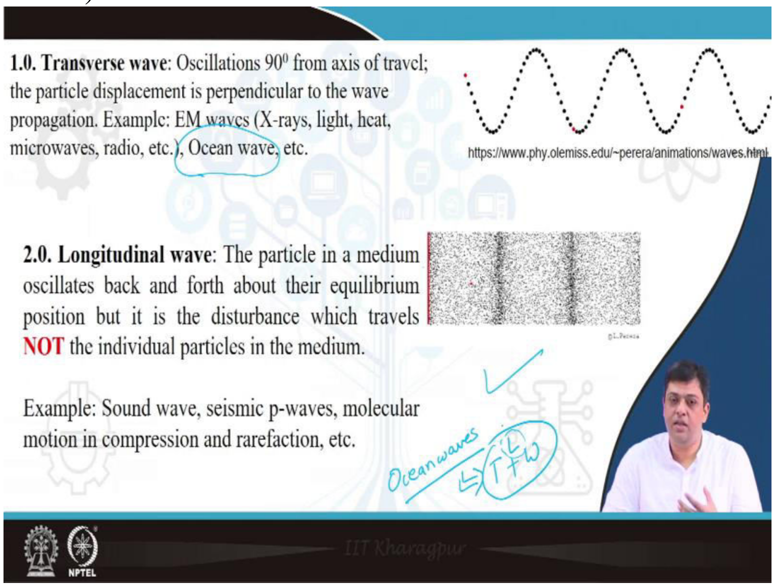

Just to give you a very quick revision, transverse waves, what are those? There are oscillations which are 90 degree from the axis of travel. The particles are displaced perpendicular to the wave propagation. And typical examples are EM waves, we have seen x rays, light, heat, microwaves, radio waves. I have mentioned ocean wave here, but when we reach this point, you will find that understanding ocean wave is not very trivial, it is a non-trivial exercise.

Because ocean waves have both the components, longitude none as well as transversal. And the second type of waves, which we have are the longitudinal waves, where the particle in the medium is oscillating back and forth, about their equilibrium. But, it is the disturbance, which travels along the direction of the wave propagation. And, but not the individual particles in the medium. And typical examples are sound waves, systemic waves, molecular motions in compression and rarefaction and few others.

Again, you will find that ocean waves when we start talking about ocean waves, they will actually be a combination of transverse plus longitudinal waves. So, you will see, that generally they are defined in terms of in the group of transfers wave, but there is an additional understanding which comes in, that there is longitudinal component also. And therefore, extracting power from ocean waves is slightly more involved.

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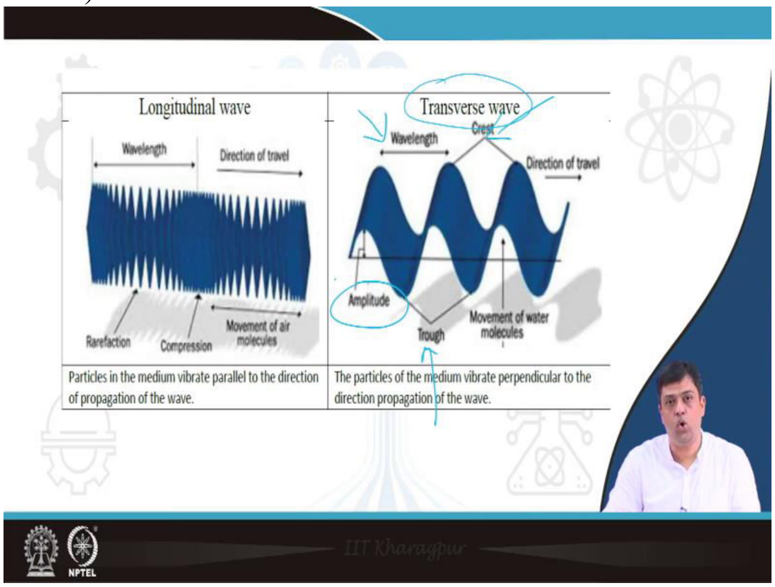

Some very quick term revisions, so, you have ready fractions when the particles are, two things can happen when the particles either they come very near or they are far away. So, if particles come very near to each other, while they are vibrating, that is compression. And if they are going far further away from each other, then it is rarefaction. For transverse waves, you have the component the terms wavelength, crest, trough and amplitude which are critical. And I am sure that all of you understand these terms very clearly.

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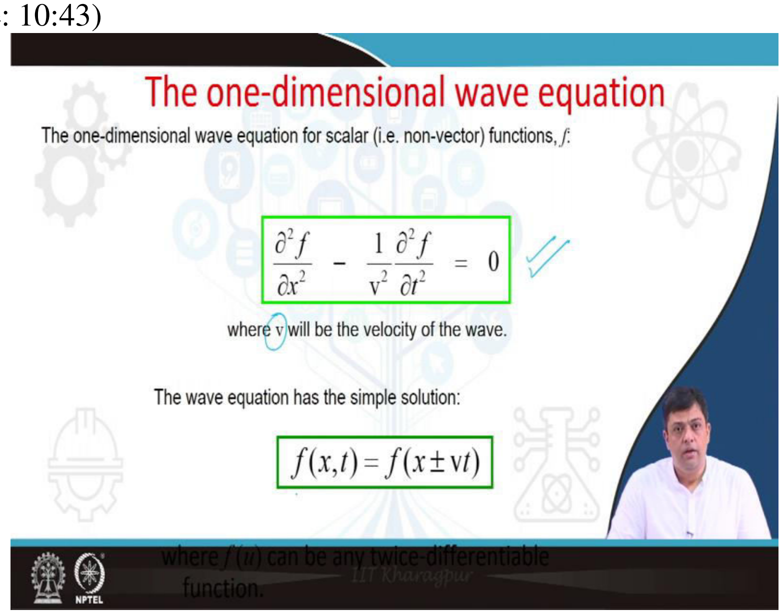

So, if I quickly write the one-dimensional wave equation, let us say for a scalar non, that is non-vector function f then it is given by deba 2 f by deba x square minus one by v squared deba 2 f by deba t square is equal to 0, where v is the velocity of the wave. And has, this equation has a very simple solution which is that f(xt) is equal to f(x plus minus vt). So, you have already understood this in your first-year physics.

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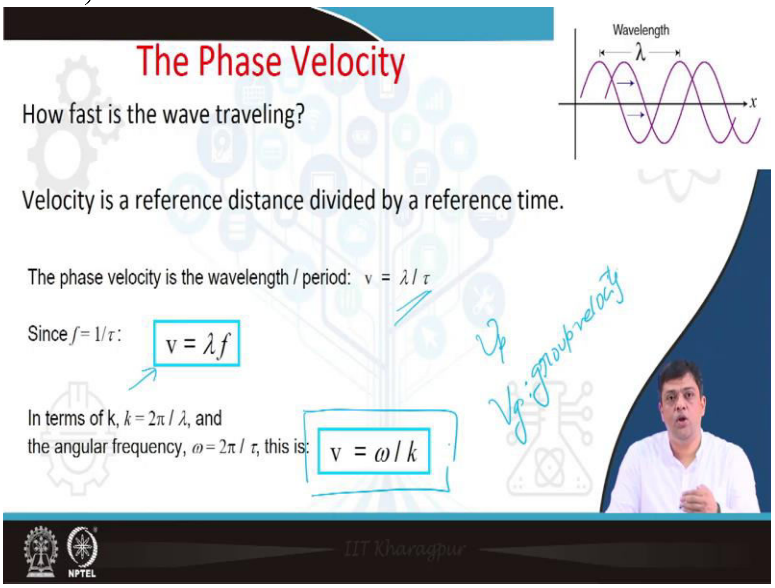

There are two more concepts, which should be very clear to you. The phase velocity and the group velocity, what is phase velocity? If I ask you the question how fast the wave is actually traveling, then you will be giving me answer in terms of the phase velocity. And if you have to define the phase velocity, this is lambda by tau. So, the reference distance divided by the reference time.

I know frequency is 1 by tau, and therefore, phase velocity, you will see that in the subsequent slides we will be defining phase velocity as v_p and the group velocity as v_g. But, in this slide, I have just used the term v for keeping the discussion simple. We know, f is equal to 1 by tau and therefore, v is equal to lambda f. In terms of k, where k is 2 pi by lambda and angular frequency omega is 2 pi by tau we have v is equal to omega by k.

So, this is phase velocity. This is the mathematical expression, which we have seen. in coming few slides, I will try to explain the whole concept with few animations and I hope things will become a bit clearer to you.

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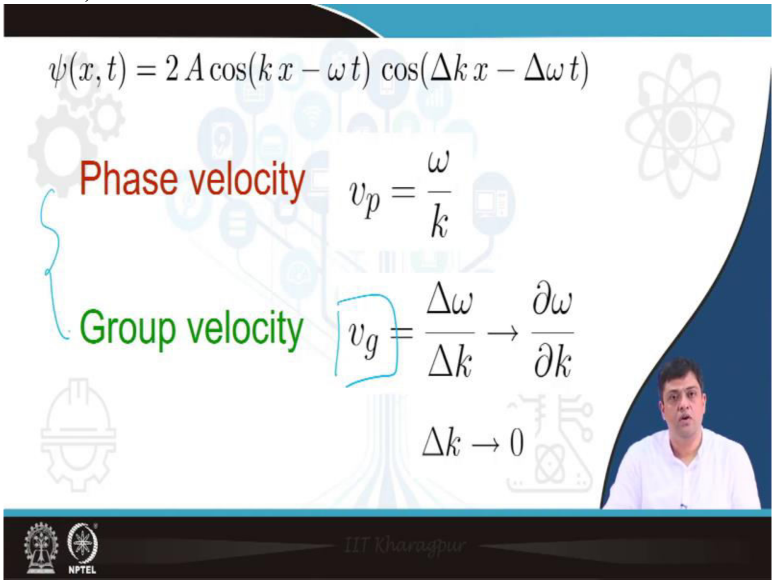

And what is group velocity? Group velocity is del omega by del k, if del k tends to 0, then it is theta omega by theta k. So, these are the two terms which are routinely used while we discuss about the wave and its propagation.

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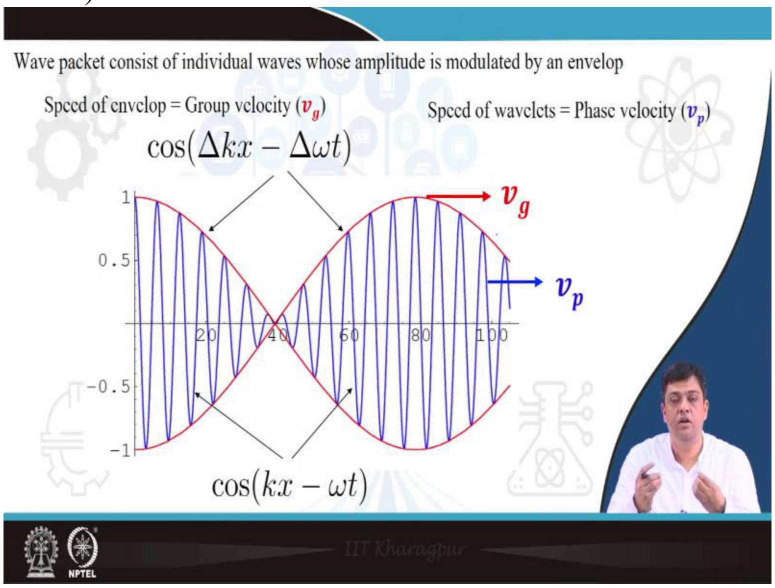

So, two things if you look into this figure, you have two concepts one is the envelope. So, if there is a way which is moving, if there is the propagation of particle or vibrations, then the particle is vibrating what, what you see is not the vibrating particle it is the envelope which you see. So, there are two things, one is the envelope shown here in the red solid line.

While there is the second component that is the wavelets, which are actually being generated or the these are the wavelets which are propagating. And these are shown in the blue solid lines. So, two concepts envelope the wavelets. And they can have slightly different values. Let us see what I mean by this point.

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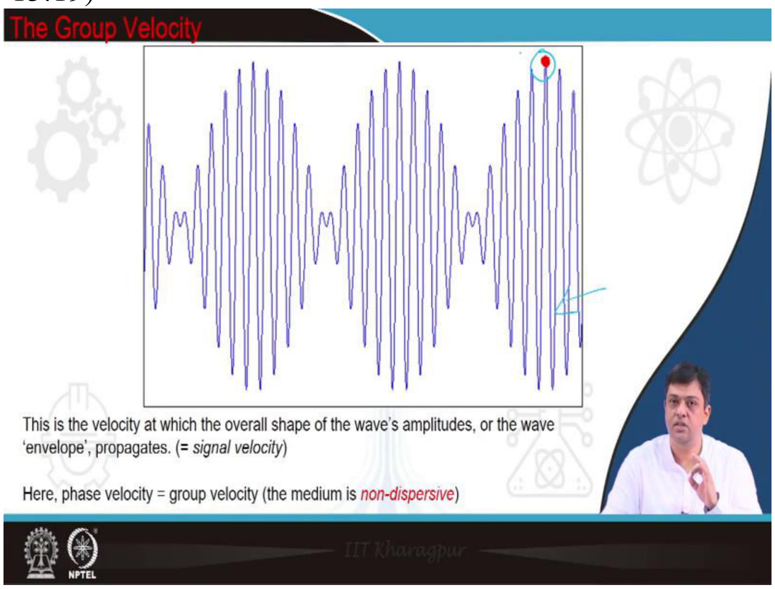

So, if you look into the red dot, which is given it is the motion of the envelope. So, you see, there is a red dot, which is actually propagating and you have its propagation along the wave. But, you, you also see these small wavelets. So, if you see these small wavelets, how are they moving? Are they moving in the same direction or with same speed as that of the spot or they are moving in two different directions or do they have different values? In case of a non-dispersive medium, you have phase velocity equal to group velocity, this is what you always talk about.

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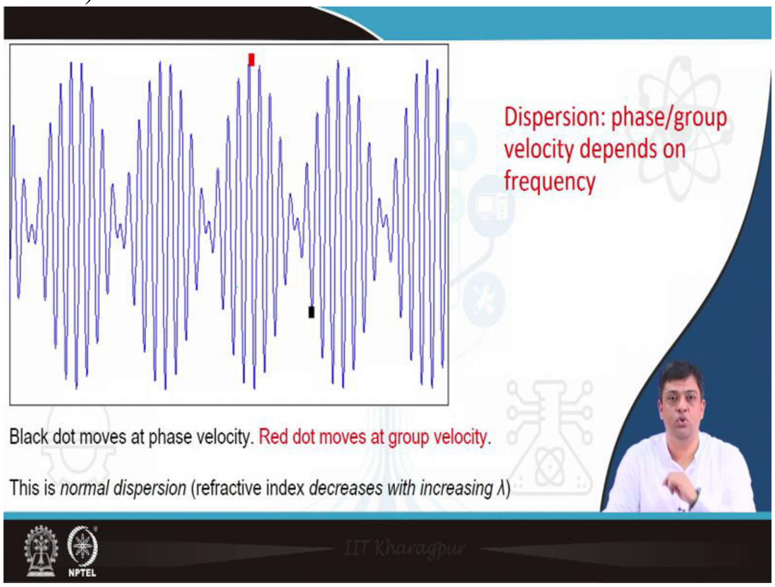

Let us say, what happens in terms of your phase velocity and group velocity when plotted together. The black spot is the phase which is moving, while the red spot is the group velocity. So, you see, you have the movement of phase and the movement of the envelope. So, the movement of the envelope gives you the group velocity. Whereas, the movement of the point, if you monitoring its motion, then it gives you the phase velocity.

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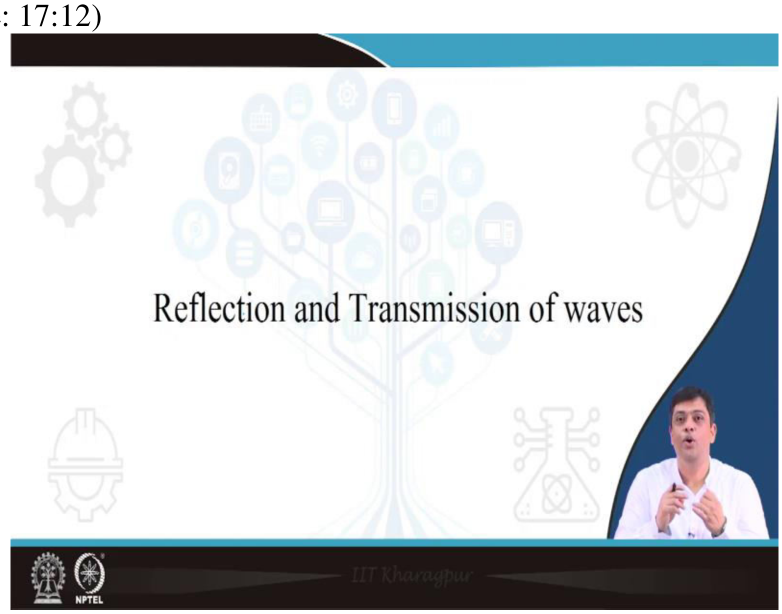

Now, we have discussed about the wave, what is wave, what is the typical wave equation which we write we have taken the one-dimensional case will give you the forms of 2a, 2d and 3d bit later. We also talked about the motion. Now, if you remember in the previous module, what did we discuss? That there is the motion and you have an obstacle. If there is an obstacle, then you try to extract power from the incident fluid interacting with this obstacle.

This is what we had discussed right from the beginning when we started talking about the fluid mechanics concept, and the interaction of fluid with a stationary wall or we had also talked about in terms of windmill blades, I hope you have understood those concepts. So, let us talk about those concepts once again. Now, you have a wave which is inter reacting with an obstacle. Now, if this is happening, you will see that there are two additional factors, which come into picture. These are reflection and transmission of waves, owing to what? Owing to the appearance of an obstacle in the path of the wave.

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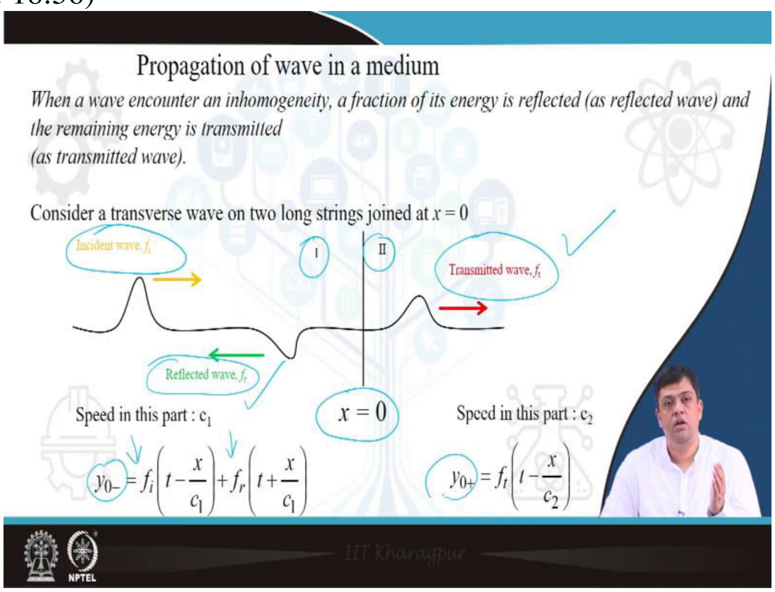

So, let us talk about this case. You have an incident wave f_i, so, this wave is moving smoothly. So, if there is no obstacle this wave continues to move without any trouble. I have just taken a case of a string or you can just extend this discussion to any other wave. Now, I have an obstacle placed, let us say at x is equal to 0. Because of this obstacle, you will have a wave which propagates beyond this obstacle, that is called your transmitted wave.

And there can be some reflected component and that gives rise to your reflected wave. So, I hope you are understanding. You have two regions, one and two at the boundary, you have the obstacle wave traveling from region one towards region two. When there is an obstacle, you have the appearance of a transmitted wave and a reflective wave. So, the speed of this wave in region one, let us say c_1, region two c_2.

So, you can write the equations as the one, which is reflected y_0 minus as f_i(t minus x by c_1) plus the component that is f_r into (t plus x by c_1). So, you take into consideration the reflected component and the incident component. And in the other case, you only see the transmitted wave and therefore, you have the equation which is much simpler and you write f_0 plus as ft(t minus x by c_2). So, you write the wave equations.

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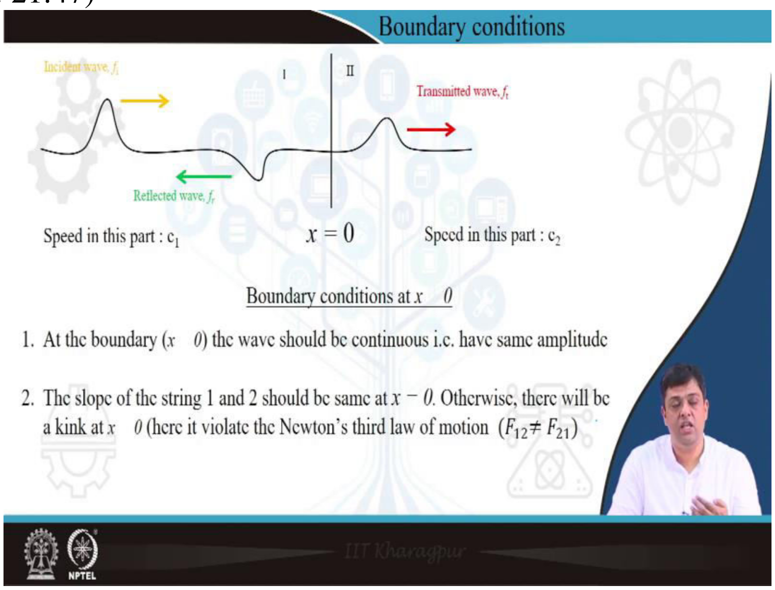

The moment I said that at x is equal to 0 there is an obstacle. So, at this point, we are going to define the boundary conditions. What happens on the left of this and what happens to the right of this obstacle and what is happening at the interface. At the boundary x is equal to 0, the waves should be continuous. That means, it should have the same amplitude. The slope of the string 1 and 2 should be same at x is equal to 0.

If there is some change at x is equal to 0, then you will have the violation of Newton's third law. And that is not allowed, because we see and we have discussed in the previous module also, that fluid mechanics and the related topics we believe certain laws are fundamental and cannot be violated.

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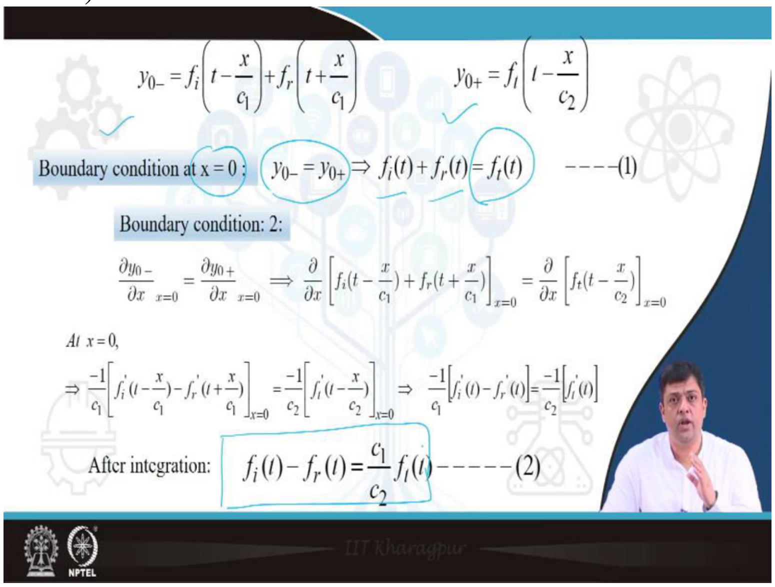

So, knowing these boundary conditions, you can solve the two equations which were given earlier. Boundary condition number one, at x is equal to 0, the two components are same and therefore, f_i t plus f_r of t is equal to total f. Using boundary condition two, you will find the relation which you obtained is the f_i of t minus f_r of t is equal to c_1 by c_2 ft of t. This is the two relations which originate because of what? Because of the boundary conditions.

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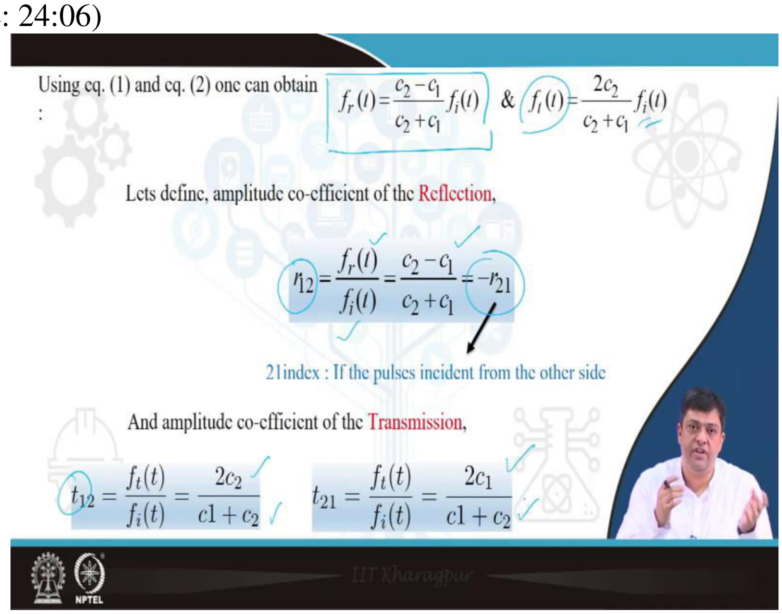

And using these two equations, you straight away obtain the terms f_r of t is equal to c_2 minus c_1 by c_2 plus c_1 f $_i$ of t. And f t of, which is a function of time is equal to 2 c_2 c_1 plus c_2 f_i, which is also a function of time. If you define an amplitude coefficient of reflection, let us say r_{12}, r_{12}

means, wave propagating from one towards two regions. Then If you define this coefficient as f_r t by f_i of t, you get this coefficient is equal to c_2 plus c_1 upon c_2 plus c_1.

And because of the boundary condition, which I discussed earlier that the relation should hold good at the boundary, you get that r_{12} is equal to minus of r_{21}. That is, if the pulse is incident from the other side. Similarly, you can define the amplitude coefficient of the transmission and you will obtain the amplitude transmission of transmission t_{12} is equal to 2 c_2 c_1 plus c_2. Why? In terms of the wave, the pulse traveling from two to one then you get 2 c_1 c_1 plus c_2. So, you have two components, the coefficient of reflection. What component gets reflected? that is what it is indicating and also the coefficient of transmission.

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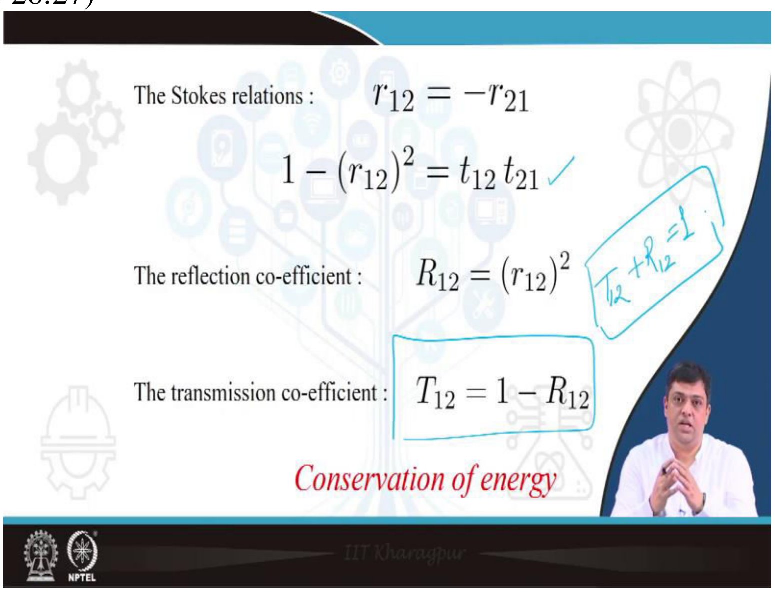

Once again using Stokes relation, we have already seen that r_{12} is equal to minus of r_{21} and that gives us 1 minus r_{12} whole squared is equal to t_{12} into t_{21}. Now, the transmission coefficient can therefore, be written as t_{12} is equal to 1 minus r_{12} or t_{12} plus r_{12} is equal to 1. And that gives us the relation which also fulfills the requirement of conservation of energy. So, please remember that, whenever you have a wave hitting an obstacle and if there are reflection and transmission coefficients, then although the energy will be distributed in these two components, but the total energy will remain conserved.

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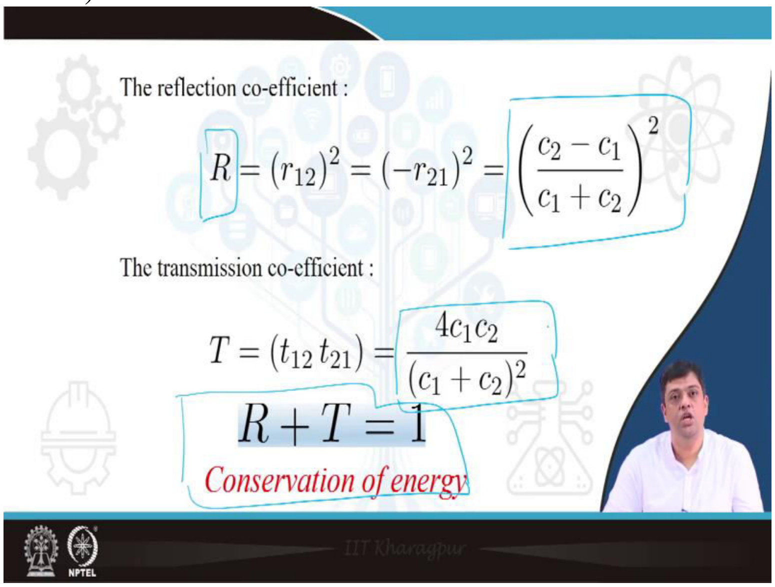

And this is what I have just discussed in words. And you can then again write the reflection coefficient r as c_2 minus c_1 by c_1 plus c_2 whole square. And the transmission coefficient will be obtained as 4 c_1 c_2 by c_1 plus c_2 square. And if you have this, then you obtain r plus t is equal to 1. And that is the condition which is for conservation of energy and we have discussed that this should be maintained while we talk about the motion of fluids.

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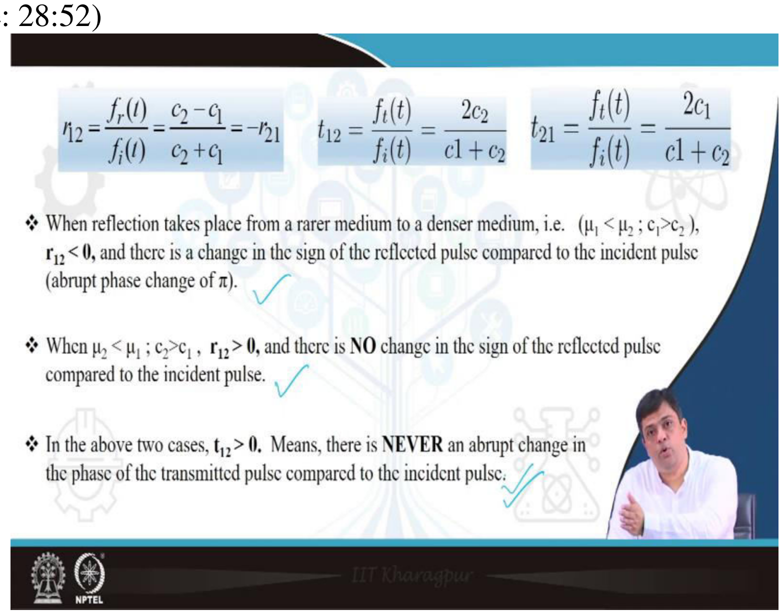

And if you have reflection that takes place from rare medium to denser medium, that means, mu $_1$ is less than mu_2, then c1 is greater than c_2. In that case, r_{12} is less than 0. And there is a change in the sign of the reflected pulse compared to the incident pulse. In other words, there is an abrupt change in the phase, if you are moving from a rarer medium to a denser medium. In case when mu_2 is less than mu_1, c_2 is greater than c_1.

Then you have the reflection coefficients which are more than 0 and there is no change in the sine of the reflected pulse compared to the incident pulse. And in the above two cases, which we just mentioned, the transmission coefficient, which we are talking about will have the value t_{12} is more than 0, what does it mean? It means, there is never an abrupt change in the phase of the transmitted pulse compared to the incident pulse. That you should remember that the if there is an obstacle, then also it does not induce any sudden change in the phase of the wave, which is propagating beyond the obstacle.

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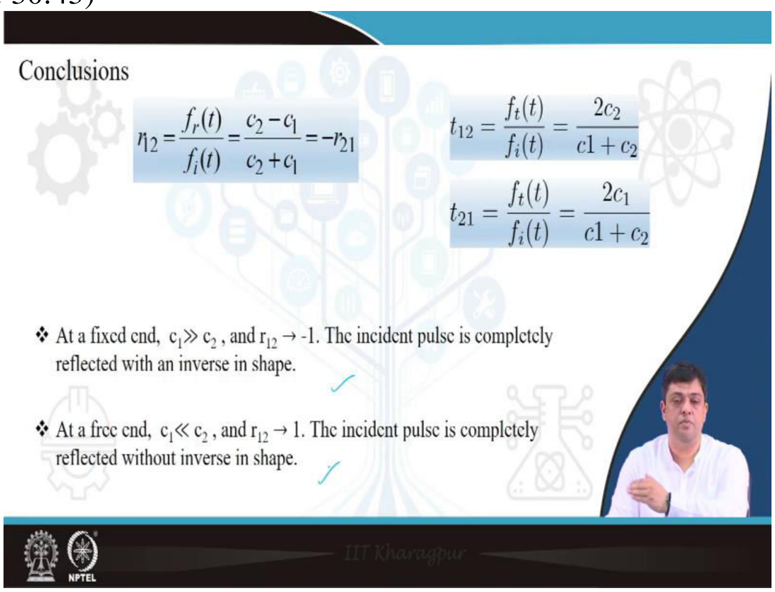

And, the same things are once again given in this slide. And why I am repeating this slide is that you should remember these formulas and these two concepts clearly. Because they will be extensively used in future discussions and they will be mentioned in different ways. While I believe that you have already understood the origin of these two terms, sometimes I talk in terms of reflection, sometimes I will talk in terms of transmission. But you should understand once I have given you the reflection coefficient or the percentage which is getting reflected, then the transmission is what? 1 minus of that or 100 percent minus the percentage of the reflection which I may discuss a bit later.

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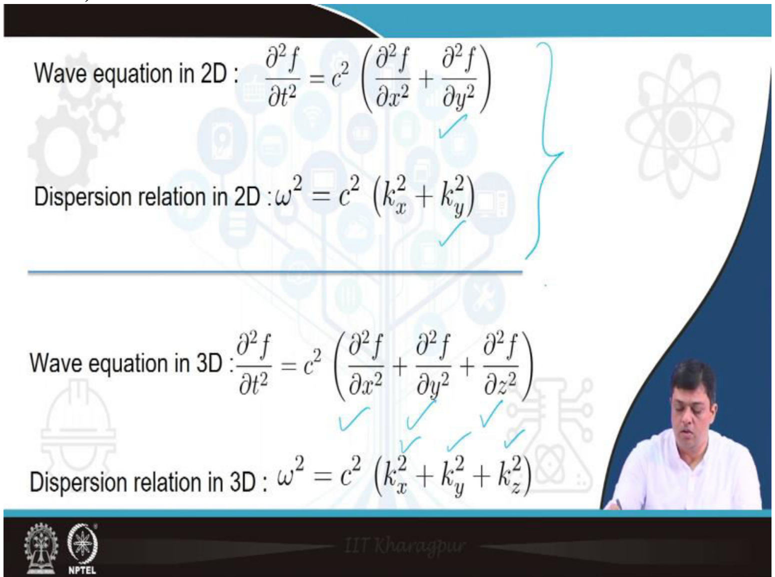

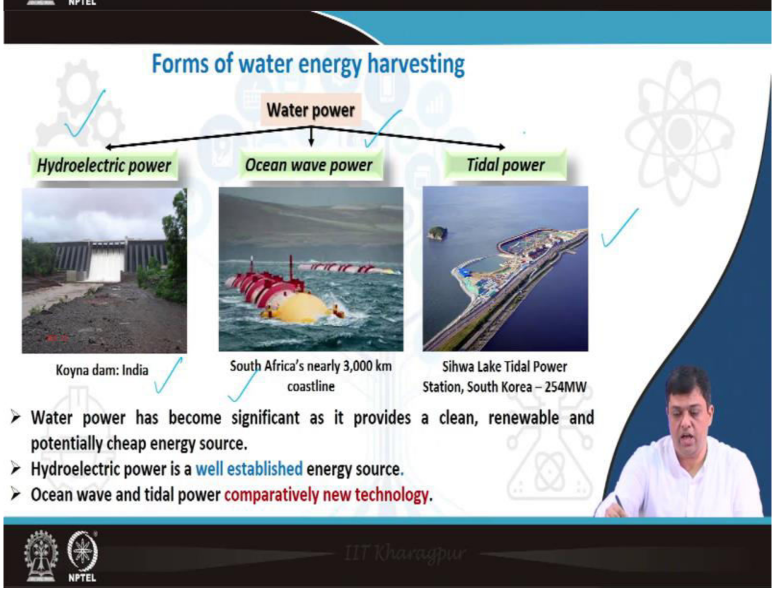

Till now, we discussed with you the one-dimensional wave equations and we have also discussed the dispersion relations in 1D. Similar to that, you can write two-dimensional wave equations or dispersion relations in 2D or 3D. If you have to the wave equation in two dimensional, there is an additional component which comes into picture. Earlier case, we were only talking in terms of x, now, you have the coordinates y also which will come into picture. And when I start talking about wave equations in three dimensional, then you will have the components x, y and z all coming into picture. And similarly, if I write for omega, you will have the components k x k y and k z coming into picture. So, these are the relations in 2D and 3D.

Now, that we have discussed about the waves and how they propagate, let us see what are the typical ways by which you are seeing the flow of water. One is coming in from reverse, which are originating at height and then flowing down. So, originating let us say at the top of a mountain or hill and then flowing down the direction of planes. Or you have the water which are showing propagation in ocean. And then you have tides, and seeing all these three, there are three different forms of harvesting this water energy.

If you are using the concept of inducing an obstacle in the path of wave or water, which is coming from height and flowing towards the plane, you lead to the origin of dams. Typical example is given here is like the Koyna Dam, which is in India. If you are using the propagation of the wave and making the oscillation about the equilibrium point or slight longitudinal motion also, then you can have ocean wave power.

And if you are allowing the tides to move towards inland, store them into a reservoir and increase the height of these water level in a reservoir. And then induce a condition very similar to a dam, then you can have the extraction of water energy in water converters which are using tides. This will also be discussed in detail in subsequent lectures, I am just introducing the forms of water energy harvesting. So, you can have hydroelectric power, you can have ocean wave power or you can have tidal power.

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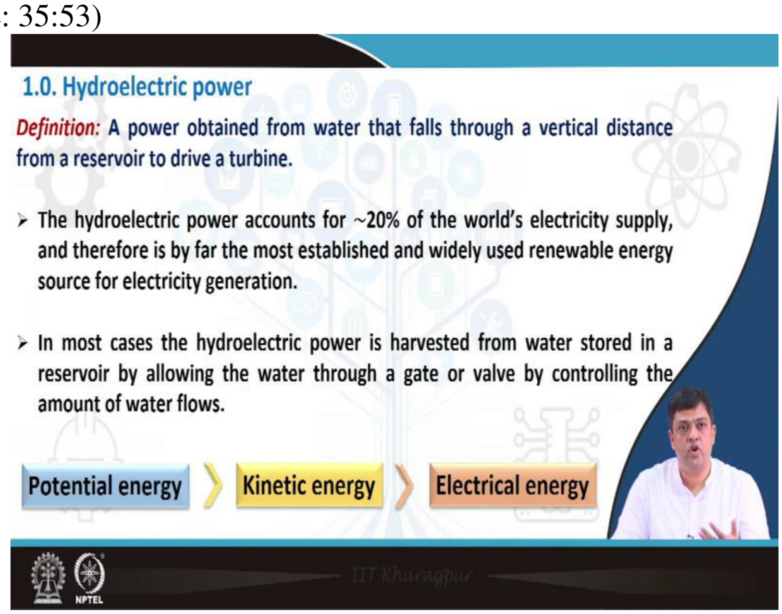

How do you define hydroelectric power? Hydroelectric power is obtained from water that falls through a vertical distance from a reservoir to driver turbine. So, from height, the waterfalls and the turbines are made to operate. And then you convert this energy into electricity. As of now, the hydroelectric power concept is well known and extensively used and already accounts for approximately 20 percent of the world's electricity needs.

As a result, it is far more established and an accepted form of renewable based source. And in most cases, you will find that the countries are continuing to make newer dams with newer designs and novel modifications. So, that the limitations of the dams which are constructed to extract the hydroelectric power, can be limited.

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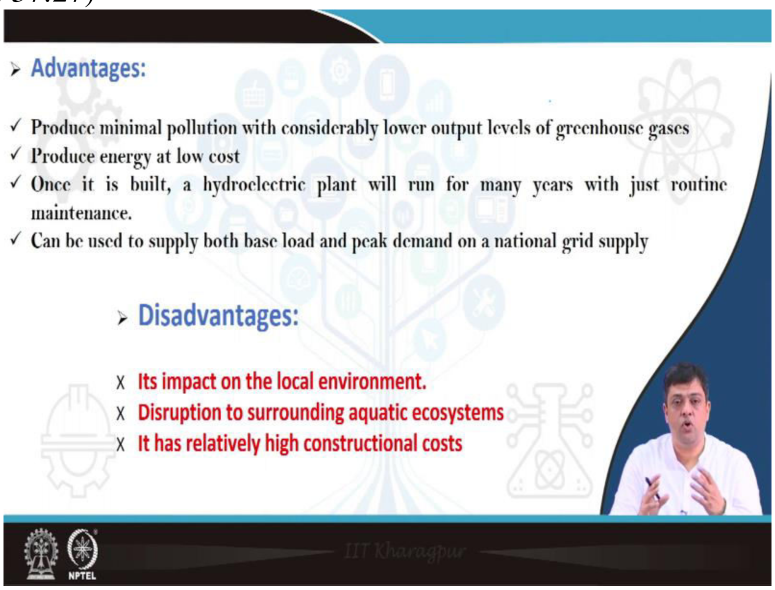

As I said that, they are making newer dams with novel modifications. So, as to limit the disadvantages, what disadvantages? See, when you are constructing a dam, it has very serious social impacts. It has very serious environmental impacts, because, where you construct this reservoir, you are going to displace the local habitat. Along with that, the environment of that place will change.

So, this if you can reduce, the impact on the local habitat on the or the environment, then the advantages are huge. If you can also reduce the construction cost, not the operating costs, because once constructed, the operation of these hydroelectric power is quite feasible and economically viable. But, while it is being constructed, it has very high cost. So, the capital cost is quite high.

So, if these limitations can be addressed, the advantages are quite a few. Because it is typically a renewable source, it is can be treated as a continuous source, the downtime is quite limited. And once constructed, it can operate for many years with minimal but routine maintenance requirements only. And it can be used to supply both the base load and peak demand and can be directly connected to the National Grid. So, there are a large number of advantages, if we are able to counter the disadvantages. This is what we are going to discuss in the next lecture onwards.

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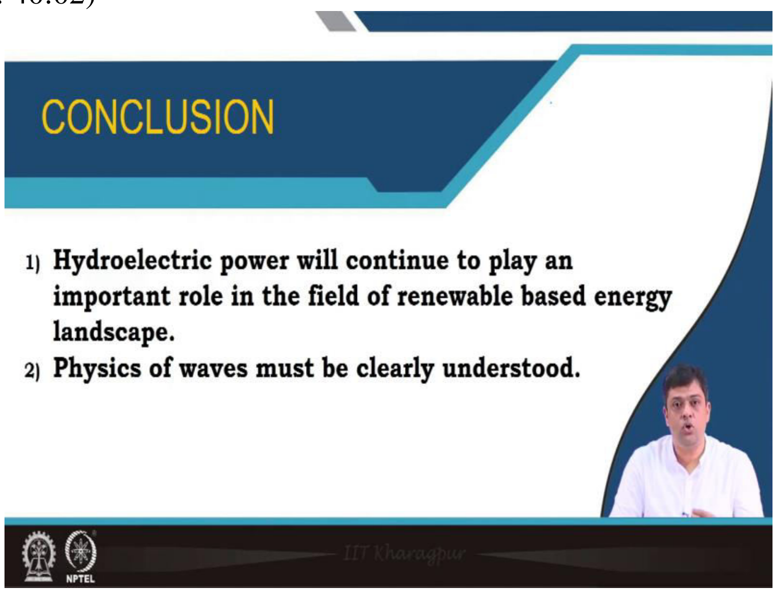

So, I hope in today's lecture, we have given you a glimpse and also tried to convince you that hydroelectric power will continue to play an important role in the field of renewable based energy landscape in India, provided we are able to counter the limiting or disadvantages that are associated with it. And physics of waves play a critical role in the whole topic and must be clearly understood at this point, before you go to the next topic, otherwise, you will not be able to understand the.

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References which I followed in today's lecture. And I hope you enjoyed this introductory lecture on hydroelectric power. And from the next lecture, I will start talking to you about the construction of dams and water converters. And I thank you for attending today's lecture.