**Hydraulics**
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**Module No. # 06**
**Canal Design**
**Lecture No. # 05**
**Unsteady Flow: Waves and It is Classification**

Now, we are talking about unsteady flow in open channel. So, when we were discussing say open channel flow classification there itself, we did mention about unsteady and steady flow. There are different classifications we gave and out of all those classification one classification we made that was the classification based on variation of flow parameters with respect to time. And when the flow parameters were not changing or when the flow parameters do not change with respect to time, then we refer that as a steady flow.

So, whatever depth we are getting at a particular section or maybe say a different section, this depth at different section will not change with respect to time. Maybe, it is gradually varied flow that is the depths are different in different sections, but that is remaining as it is with time, with time it is not changing. So, that sort of flow we were considering under steady flow and have discussed a lot on steady flow till now.

And then, when this depth are changing with respect to time, say at a particular section this is the depth we are having, in the next movement we are having another depth. So, that sort of change when occur then that is coming under unsteady flow and our discussion, today's discussion is on unsteady flow.

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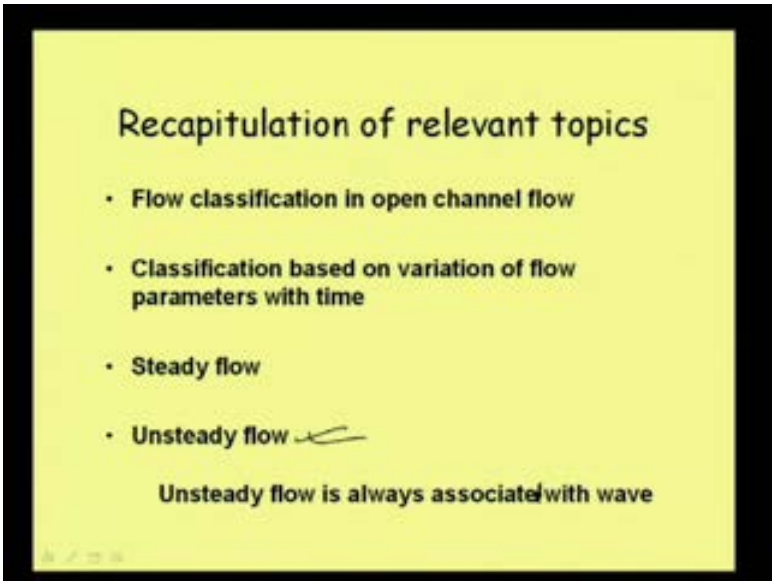


Well and when we talk about unsteady flow, when the thing changes with respect to time, generally it is an associated always with wave, it is unsteady flow is always associated with wave, associated with wave, well. Now, why this is important for us to discuss unsteady flow when we talk about wave? Now, these wave can cause … I mean see people started discussing on some of the topic or started working on some of the topic, when we find that yes it is creating problem to us, this is one reason. And another is that yes, sometime we try this is there, if we study further more in that then we can utilise this for our need and for the betterment of the mankind.

So, that way we start our, say we we start our working on a particular topic. Like this wave, that is the unsteady flow where wave is the one of the important aspect or it is always associated with that, now as we understand that wave sometimes can create lot of problem to us, as well as by we can use these waves for harnessing energy, also from that, like tsunami wave created lot of problem. Now, this is a very popular topic known to all, similarly if the dam fails it can create lot of waves, so like that this is becoming more important for us.

Then, these are the waves, well and we will be discussing first today basically what the waves are and when we just simply say wave. Well, that is known to all in our day to day life, we encounter those waves, but well, but technically we need to understand what wave is and what are the different type of wave that we need to understand.

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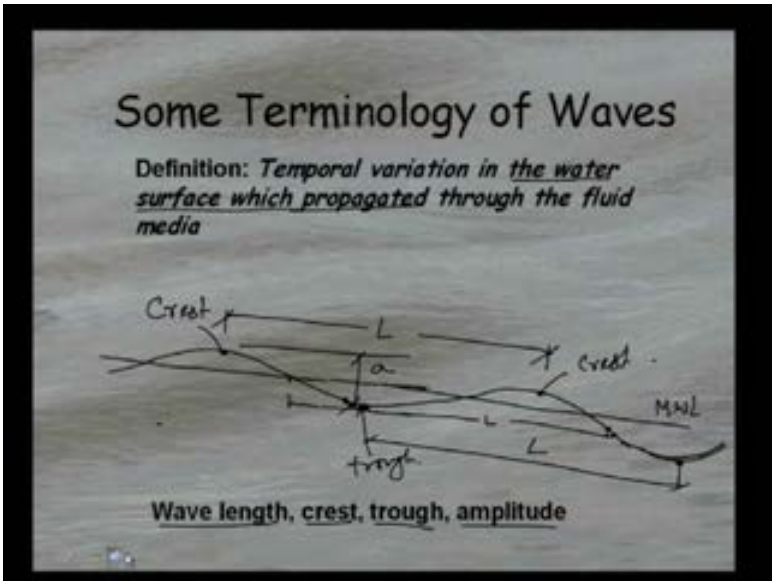


So, as a definition first we need to go, we need to understand some terminology of the wave. Well as a definition we can say that temporal variation in the water surface, which propagated through the fluid media or which propagate through the fluid media is called a wave. Well, so wave is generally always it is propagating, it is propagating through the fluid media and here temporal variation means variation of the surface generally is visible here. So, we normally understand that temporal variation of water surface, so this variation of water surface is propagating.

So, in fact, here one important point that we need to understand that we are talking about the propagation of water surface, whether the actual water is propagating or whether water is really transferring from one point to another point is not coming. By wave we mean that there is temporal variation in the surface, like that you can see here that these are the variation in the surface and this surface variation is propagating and that is what these wave.

We are not concern whether water itself is moving from this point to that point or not. Of course in many case water might be moving, in some cases water may not be moving or the mass actually may not be moving or may not be transferring basically. Well, then we need to know about some terminology, that we can see about a wave, we need to know some of the terminology, of course we have learned about this terminology perhaps from our very preliminary classes, but still let us repeat so that sometimes still we may have some confusion about those terminology.

Well, one term we are popularly using is wavelength, well. So, if I draw the wave, well, let me draw the wave on the wave itself, just one line, say if this is the wave I am

drawing and as you can see in the photograph also that this is one of the height highest point of the wave and this is say lowest point of the wave. Well, in my diagram this is the lowest point of the wave and then if this is the wave, then what we mean by wavelength, what we mean by wavelength.

So, this point and then another term, this is crest of the wave and trough of the wave, well, this is called the highest point is called crest of the wave, these are crest of the wave. And this lowest point that we refer as trough of the wave, then what is mean by wavelength, is basically we can define is the distance between the crest to crest, but of course, the real definition should not be like that, that it is not basically the distance between crest to crest.

If we take this as trough and there is suppose another trough on this side, well I do not have space that much, but suppose this is another space then trough to trough distance is also wavelength. And if it is a symmetrical wave then this will be same, this will be same and that is why by wavelength we defined that it is a distance from corresponding points we can say, corresponding point. Even if we start from here and then if we go to suppose after one cycle we are going there and then this corresponding points if I join, this distance is also say we can consider as wavelength, this can also be consider as wavelength.

So, it is basically corresponding distances between the two say consecutive points, consecutive crest height that we are getting and then this we can define as wavelength. And then amplitude, what is amplitude, amplitude of the wave? Well, we can draw a line like this actually, which is in fact is the say mean water level, mean water level, when wave is forming, well it is not necessary that always this I mean mean water level will be at the central point, it may not be always like that. But sometime that wave can go above the mean water level, but suppose it is the mean water levels, then by amplitude, say we called this as the amplitude of the wave, this is the amplitude of the wave. Well, then with this a very basic definition of some of the parameters of wave that our terminology of wave. Let us proceed to the discussion that how we can have different types of wave or on the surface of water how we can have different types of wave.

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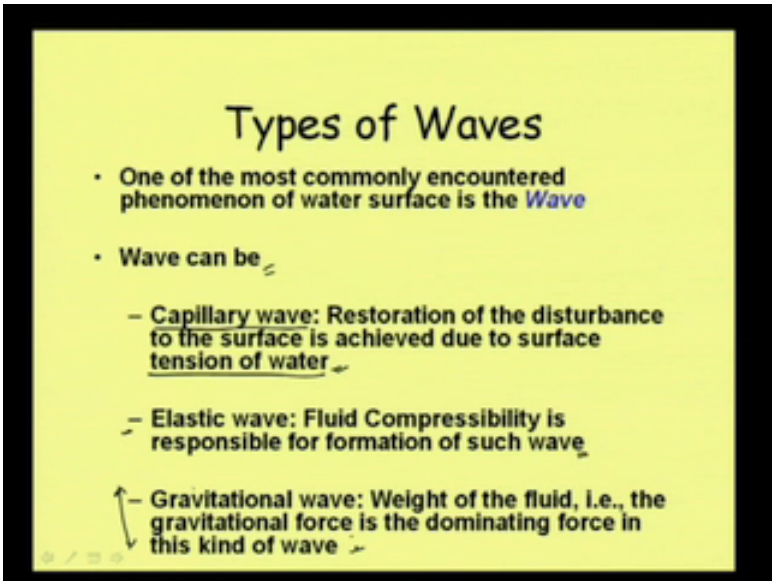


Well, one of the most commonly encounter phenomenon of water surface is the wave, I read every day when we are travelling over the wave, then when we are travelling over the say water, we find that even a boat is creating wave, which is also wave. So, that way different situation we see waves, but the wave can be, some of the wave importance we are talking about here is the capillary wave one of course. This capillary wave is very small in dimension and this capillary wave is... why it is called capillary wave?

So, when we create any disturbance, somehow if the water surface is getting disturbed then from its normal condition, then this will be some force will try to restore the water surface to its original position. And in case of capillary wave, the surface tension force is the force which restore or which try to restore it to its original position. So, what we can see that in capillary wave restoration of the disturbance to the surface is achieved due to surface tension of water and these are what the capillary wave, we get ripples in water, these are basically capillary wave, it is a length wavelength, is very small again centimetres, very small centimetres. And then then we can get another type of wave that is called elastic wave.

Now, of course, in case of water, if the fluid is considered as compressible, then only we can have this elastic wave. And in normal surface condition, say we do not get that as elastic fluid, but of course, in some cases when there is important we need to consider that fluid compressibility.

So, fluid compressibility is responsible for formation of such wave, rather formation means it is trying to restore, then again it will become, the because of compressibility if

it is, this wave is forming, then this elastic force will try to restore it, then again this will be disturbance will be coming. So, like that when this wave is forming, that we termed as elastic wave.

Well, then, when the wave are of larger size, waves are say length of the wave is increasing little larger, the height will also automatically increase to some extent and then this surface tension force cannot restore those things. Or in that case, when height increases its weight of the wave, become more significant and this governs the entire wave formation and then restoration.

So, that sort of wave we term as gravitational wave, so weight of the fluid, that is gravitational wave, the weight of the fluid that is the gravitational force is the dominating force and that kind of wave we refer as gravitational wave, Well. And for our discussion we will be concentrating all on this gravitational wave, well.

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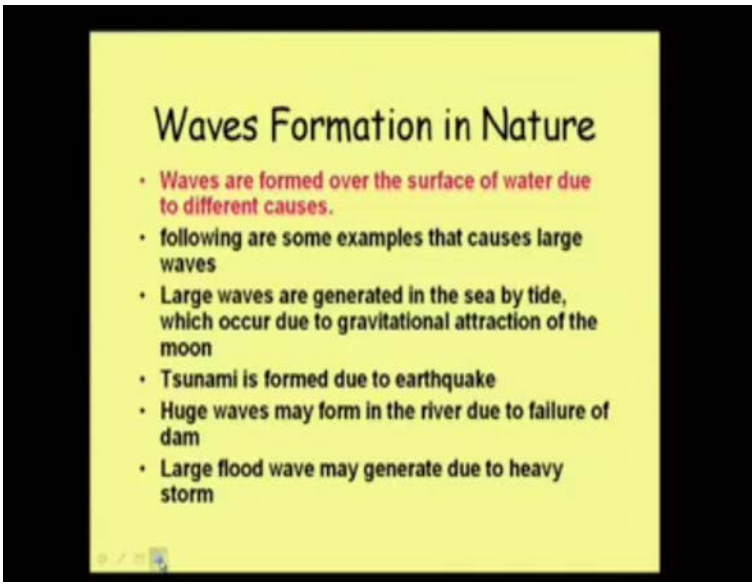


Now, as I was discussing at the beginning itself that we are interested for the wave because in nature, naturally also we are getting wave and because of some of our activities we are getting wave in the water. In the sea we are getting wave, in the rivers we are getting wave and these waves create many a time problem to us or sometimes we get, we can utilize this wave for our betterment again, just the river stream, you can harness energy from this high waves, sometimes tide.

So, now, let us see that waves that are formed and due to different causes and particularly, we are mentioning some of the large wave that we get. Well, following are some of the example that causes large wave, these large waves are generated in the sea

by tide, which occur due to gravitational attraction of the moon that is known to almost all I mean from school level itself and we know how the tides are forming.

So, this is what the tide creates some wave and that waves move, in the as stratus wave move into the back water also and we can see this sort of wave. Then tsunami that did not be mentioned, now it is very popular term and known to all that it is a kind of wave that it is initiated by a earthquake, if it occurs below the sea level, sea water that is on the bed and then it can give rise to some high waves. And if it propagates into the earth surface, I mean towards the bank or say towards the land, I would like to say because bank is not the term that we use sea towards the land, then near a land it may become very ferocious and it can cause lot of damages, so this is what one wave. And then say huge wave may form in the river due to failure of dam.

Well, now, dam is constructed to have better utilization of water, because that is known to all that with dam we can have lot of benefit and dams are serving well. Of course, some opposition towards the dam is also there, because that it abstract the natural flow, so environmentally it is got some problem, well. Now, we are not going to that controversy, but when this sort of dam if fails, then huge wave start forming, that means all the water will be just moving, rushing down into the I mean downstream area and sub merging all the things that is lying in the downstream.

So, that way it can be, if that it will depend on the size of the dam, if the dam is very large size say 300 meter high dam, then the wave formation or wave that will form under downstream will also be a very large size, may be 15 meter high wave will be flowing. So, that means, say 15 meters means, you see that it will be a say three to four storable, then like that it can move.

Well, so these waves, here first say steady on this then break way we have started, when there was a treat, there was a treat that well during second world war, there is treat that some dams can be failed and then and this can this may be one strategy of causing damage to the downstream area by the enemy.

So, enemy can put bomb and then this way can they will generate huge wave by that process causing distraction to the reservoir, which were constructed for benefit of the people. And in that context people were interested to know, scientist were interested to know, planner were interested to know that at what time this wave will reach, which place, how much will be the depth, what will be the submergence and that lead to the steady of then break way analysis.

So, this is one where we can have large wave, then again we can have large flood wave, this is occurs and then then break way also a flood wave, but we can have large flood wave may generate due to heavy strong. Generally we may not have that feeling that well heavy strong, say thunderstorm is occurring in catchment and if that catchment is hilly catchment, suppose very steep slopes are there, then all these wave, all these water may accumulate quickly and huge amount of water might be flowing or may flow into the river within a very short time and causing huge wave. And this short of unsteady flow with generated from thunderstorm or that we call cloud burst, from that if it occurs then it can cause great damages.

In fact, in the north eastern part of India one one storm from Meghalaya that came and a in a storm about 200 people washed away, about 200 people were washed away, from an area which is lying under western part of the Assam. So, that way this sort of wave can also cause lot of damages, well. And these are some of the cases I have just put, which are of course natural and of course artificial when we talk about the dam break case. And sometimes, we in some channels, suppose we have gate and suddenly if we open the gate, suppose on the gate we are storing water on the upstream, then if we suddenly open the gate, the water will be moving with some wave formation.

So, that way also we can get wave, that is manmade wave or we can create wave like that. Well, with this some understanding where we can have wave and how this is important or steady of this unsteady flow why it is important. Because, we need to know how these wave will be moving and to take care that, is if it is coming, if it is trying to do some devastation, how to take measures to just avoid those devastation. So, that analysis is required and that is very much important for hydraulic engineers and that way we need to study this wave in unsteady flow. Well, then, let us see how this gravitational wave we can classify.

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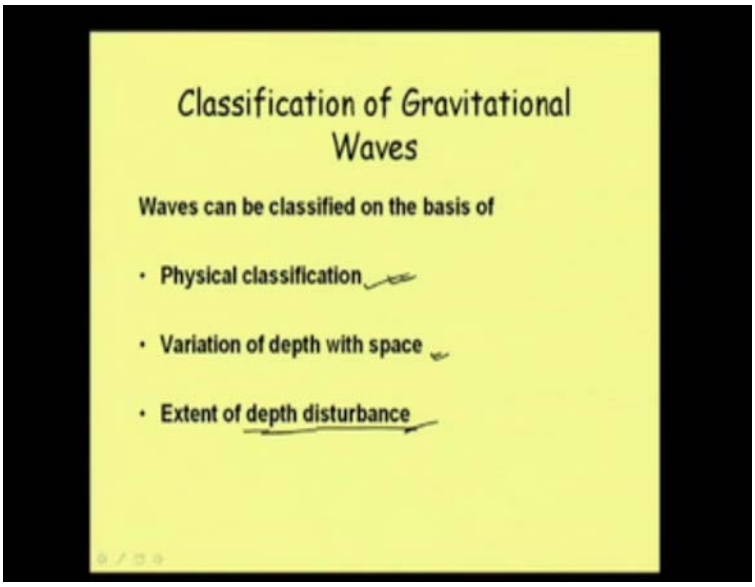


So, wave can be classified on the bases of first is physical classification. Well, by physical classification we mean that based on a shape and say how the wave looks like, that way also you can classify. Then, whether it is say higher than the normal water level, whether it is lower than the normal water level, so that way also we can classify.

So, on different basis, following different basis, we can classify it on the basis of physical classification. And then again type of wave, sometimes we find that waves in a particular wave, the mass is not moving, but we are having a wave like in the sea, we are having that mass is not exactly moving and then so average movement of mass is zero, but in some cases like then break way then mass itself moving rushing down.

So, that consideration also we can classify, so that way from different way we classify the physical classification. There will be some sub classes, will be coming later and then the variation of depth with space that is also one way of classifying that is how quickly the depth is varying. A variation of time is not considering here, because otherwise also we are talking about say variation of time, it is the whole it is unsteady flow, but in a unsteady flow also how this depth, so wave means there will be variation of depth on the surface.

So, how quickly these or within what space limit this variation is occurring, if it is suppose very surf change, then we can say that there is a wave front and if it not a surf change then will be finding a smooth variation of wave, so that way also we can classify it and more distinct you'll be discussing that of course. Then in some case of wave this is say extent of depth disturbance, well by this what I mean is that depth disturbance means up to which depth. Say wave is forming on the surface, then up to what depth this is

causing disturbance to the entire flow, so based on that also we classify the wave. Well, let us see one by one what the classes are, first we are talking about physical classification, that oscillatory wave.

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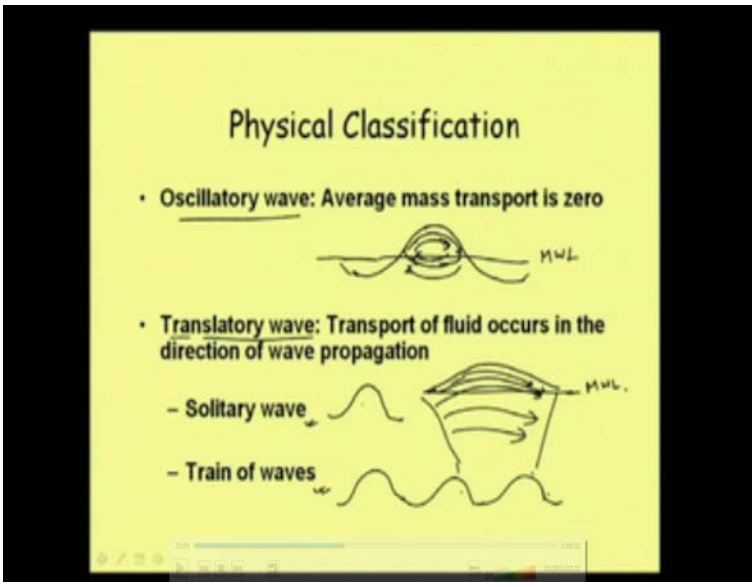


Now, in this oscillatory wave, say if this is a mean water level, if this is a mean water level, then the wave is forming like this, wave is forming like this, there will be a crest and trough of course. And then what is happening to the water here, these are basically moving like this, at the crest it is trying to move like these, but when it is going to the trough then trough part is moving like this, that means from this side water is moving like this. In fact, we will be getting ultimately a circulating flow like this, that is this part it is going like that and this part is...

So, basically the water is circulating or it is just moving in this form and net mass transform transferred from this portion is not that significant. So, net mass transport can be considered as zero and this sort of wave are called say oscillatory wave. In sea we get this sort of wave, sea is one example of this sort, we can have another place also, but this is one example.

Then another type of wave is called translatory wave, translatory wave here. Say, say this is the mean water level, then wave will be, water will be moving, when it is moving like that water will be moving this way. And suppose this is the wave I am drawing and then water is moving like this. Suppose this is the wave portion let me draw and then we can see that this is the water is moving in this way. And then this depth will be higher than the say mean water level or say water level, normal water level here and then it is moving like that.

And here what is happening the entire mass is moving from this point to the downstream point, well, that sort of wave we called as translatory wave. Like the wave as we are discussing in then wave flow as water is moving down and that we refer as translatory wave of course. Some more classification is there and in translatory wave we can have solitary wave and we can have train of waves.

Well, by solitary wave when we have a single wave then we call this as a solitary wave and then when we have trains of wave. Say, this one wave, then another wave is coming and another wave is coming like that, when we get then this sort of waves are called, that is one wave is followed by other then it is called a train of wave. Well, for many of our analysis purpose we sometimes form solitary wave and then we analyse how we can derive the different relationship between this wave height and all, well.

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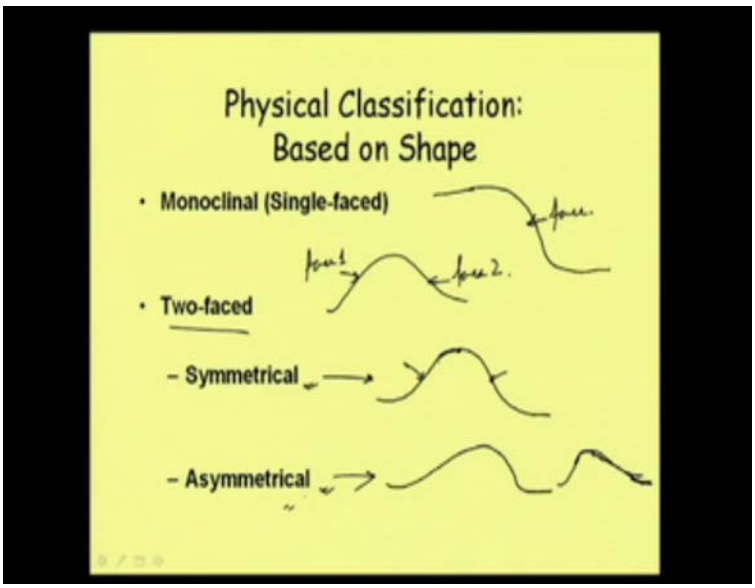


Then, let us see again we can classify this sort of wave based on its shape, well. Shape, say one type of wave we call as monoclinal, that is single faced wave. Say, water is coming like that and it is going like that, this is also a wave and this has a single face, this is the face of the wave, we are not having two faces here, so it is a single face. So, that sort of wave we also get.

And in many cases when we start this wave when we get a wave by say opening the gate, then we get this sort of single faced wave. And then we can have two faced wave like that, here we have this is one face and then this is another face, face one, say face two, we have two face well. So, in two face wave again there can be symmetrical wave or there can be asymmetrical wave, well.

Now, what is mean by symmetrical wave when we get a wave of this type. That is it is raising, this is ascending part and this is a descending part and we have a peak here, so this slope of ascending part, slope of the descending part and the peak. I mean on the others both side of the peak, the ascending part and descending part, these are symmetrical. So, this sort of wave we call as symmetrical wave, but many a time we may not get this sort of symmetrical wave, well, we can have a wave of the type that ascending part is raising gradually and then it is coming down very steeply.

So, when we get this sort of wave, then it is called as asymmetrical wave. So, here, you can see that it is rising steeply, then it is coming down very sharply, so rising flatly and slowly it is raising and then it is coming down steeply. So, that sort of wave, it can be in a other way also, I mean it can raise steeply and then it is suppose falling down in a very flatter way, so this is also possible, I mean just when it is not symmetrical then we refer it as asymmetrical wave, well.

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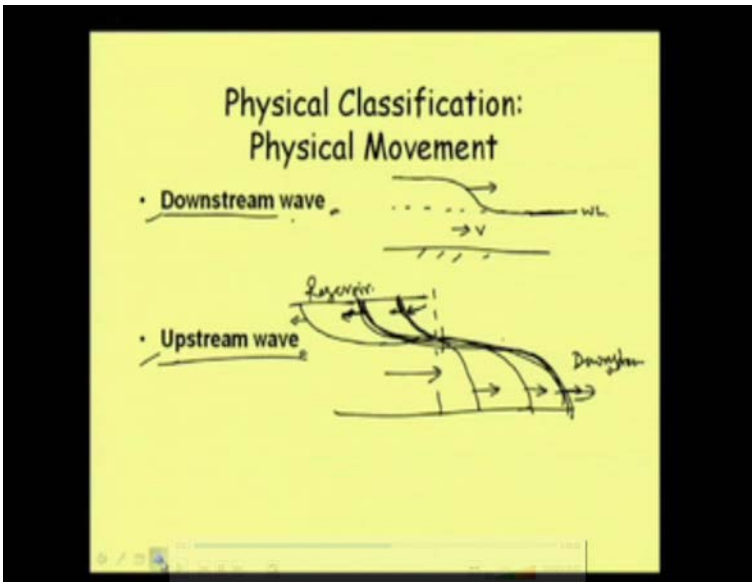


Then, say another physical classification we generally draw and this is of course important for some of our study and that we call as a downstream wave and upstream wave. Well, not necessarily though generally a feeling is there in our mind that when water is moving in a particular direction, wave will also be moving in that direction. The wave when it is moving, well, but it is not necessary, wave can sometimes move in the opposite direction to the movement of the water. Actual water is moving suppose in downstream direction and the wave is moving in the upstream direction that can also be possible.

So, when we see that the wave is moving in the downstream direction, well I can give you some example, then it is called downstream wave and when it is moving in upstream direction, then it is called upstream wave. In general, say water is moving like this and then it is the bed, say water is moving in this part, say this is the normal level and then water from some cases or it is coming like this and then it is moving like this. So, earlier it was moving like this, then this wave is, this is the water which suppose is velocity V, it is moving and this wave is coming and this wave is also moving in the downstream direction like the flood wave. Same flood, suppose this was the wave, water level, this is the water level and then if flood has occur, so flood water is coming and it is increasing the level of water and this wave is moving over the normal level of water in the river and this is moving in the downstream direction.

So, this is called downstream wave, but in some case the wave may be moving in the upstream direction, suppose say this is this is water was following like that, water was following like that and say suddenly we have closed this part, suddenly we have closed this part and then water will be moving in this way then it is going like that, sorry it is going like that. Say gradually it is this, wave is moving in the, sorry it is also a becoming a upstream wave, I will I will give one another example, like say let me take one example of dam failure. Suppose we are storing the water here and then there was a dam and suddenly we are removing this dam or this dam has failed, then, well if I remove of this dam, now say this axis I am drawing, what will happen? That water will be getting released like that and it I moving this way.

Then in the next movement water will be coming this way and then it is moving this way. Now, this part is also a wave that is this wave is moving in the upstream direction. See water is moving in downstream direction, that is what the point, water is moving in the downstream direction, but this wave is moving in the upstream direction, this is moving in the upstream direction. In a next movement, say it is continuing next movement, it can be coming up to this point. So, here this wave is moving in the downstream in the upstream direction, so this is what is called upstream wave.

Well, but of course, when a dam fail, that is the wave that moving in to the reservoir, the wave that is moving into this is what the reservoir side, this is what the reservoir side and this is what the river side, river side means I would like to say it is the downstream, downstream. So, when the wave is moving into the reservoir, water is just, ah the wave is forming that wave that is moving into the reservoir are the upstream wave. But of course,

the same water we are having this wave which is moving into the downstream side, these are again downstream wave.

That means, by this what is clear that although we are classifying this as downstream wave or upstream wave, but in real field we can get a surface which may contains say this is a surface we are getting. We can get a surface which may contain or one part of the surface may be containing a wave, which is moving upstream and then other part of the wave this is containing a wave which is moving downstream. So, not necessary that we will be getting one downstream wave or one upstream wave, we can get in combination as well.

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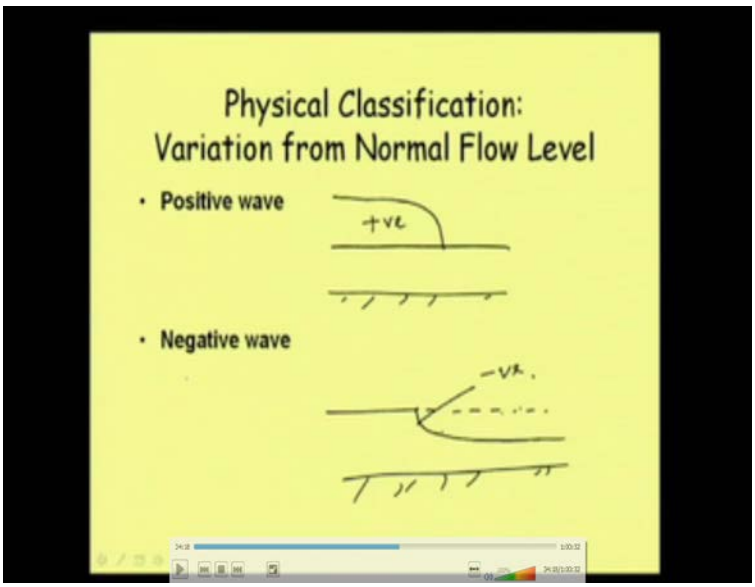


Now, there is another classification, we make as positive wave and negative wave, well. So, what you mean by positive wave, say our normal water level is this one and then if the wave height is greater than the normal water level, so then it is a positive wave, then it is a positive wave. But if suppose this is the normal water level, this is the normal water level and somehow we have block this one and just I was drawing in the just previous slide, that if I block this one, then water in this side a partially block or something has happen which is created the wave like that and it is moving in this direction.

So, this sort of wave which is actually lower than the normal water level is called... and it may be moving upstream, downstream, it does not matter, but when it is less than the normal water level, then we called this as a say negative wave. So, we can have positive wave as well as negative wave, and if we refer to our earlier diagram then we can see here. That in case of this fluid wave, when a dam break case we were discussing, then

here say negative waves is moving in the upstream direction, because it is negative, it is normal water level is this one, was this one reservoir and the level is lowering here because of the wave movement.

So, here, we are talking this as negative wave moving in the upstream direction and here say our earlier water level may be zero or may be that we have some amount of water here earlier, but still when the wave is propagating on the downstream, the depth is increasing.

So, here, we will say that the positive wave is moving in the downstream direction; here we are talking as negative wave moving in the upstream direction. So, I mean, again why I am emphasizing this point that although we are giving name as downstream wave, upstream wave, positive wave and negative wave. In real situation, there can be always we need to explain or we need say what type of wave it is, in that case we need say in combination, this is a negative upstream wave, this is a positive downstream wave like that. So, So, that what we have discussed where the classification of wave based on its physical characteristic. Well, then we can make another classification this is variation based on variation of depth with space.

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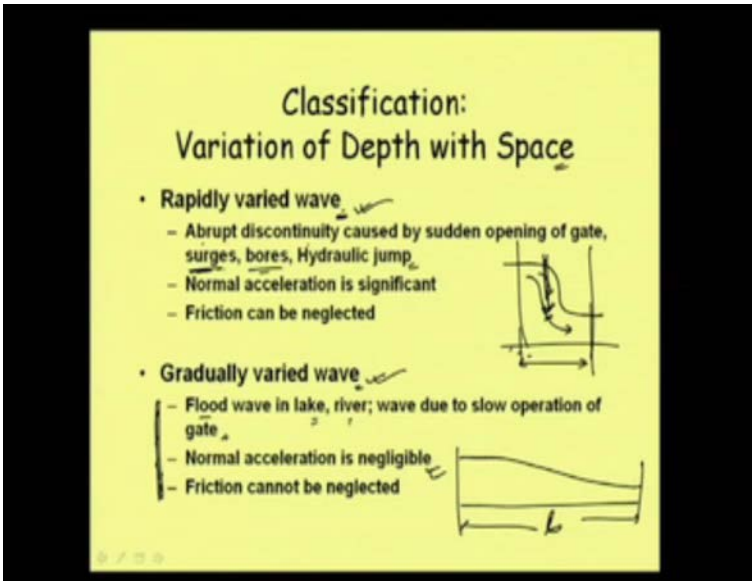


And there we make the classification as rapidly varied wave and gradually varied wave. Now, we have already discussed a lot on rapidly varied flow and gradually varied flow.

So, In fact, in reality we need not have much confusion about these two different types of flow, when it is unsteady flow, then we are getting this as wave and then we are talking this as rapidly varied wave and gradually varied wave. But what are important point that we need to still mention it in this part is that rapidly varied wave it creates abrupt

discontinuity by sudden opening of gate, this is we can create, but in some other situation also we can have rapidly varied wave, not necessary that always will have to have a gate, it is nothing like that, but just this is an example.

That when we create a wave, that we get where the sudden discontinuity or abrupt discontinuity by sudden gate opening, that sort of waves are coming under this rapidly wave form, these are surges we can have, we can have bores, surges are nothing but a discontinuity, a discontinuity like that. These we call as surge and then bores, that is during tide, that is in a story when this sort of surges occur in a story in the during tide then we refer this as bore. And then hydraulic jump we have discussed already, this is also one kind of say rapidly varied wave.

Well and then in this sort of wave this normal acceleration is significant, as the water is moving this way, because water will move in this way, so normal acceleration, acceleration in this direction acceleration in this direction is wide significant, we cannot neglect. When we are analysing these wave portion, then we should not neglect this acceleration in the vertical or normal direction, I will not say vertical, because it may not be vertical when we are drawing horizontal, then only it is vertical.

So, this, but if it is steep slope, it can be in this direction, but that I mean normal acceleration is significant here. And these sorts of waves are forming in a very small reach of the channel like hydraulic jump; the length where it is forming that is very small. So, the frictional resistance in the entire formation or the entire analysis of this wave we can neglect. So, what I want to emphasis at this point, that we have two type of wave, one is rapidly varied wave, another is gradually varied wave. And when we will be dealing these waves mathematically, when we will be trying to model this wave, then we need to understand the physics behind it. And in that case we need to know that physics, when we are making some assumption in the process of simplifying the entire physical process and so that we can represent it by mathematical equation in that case we should not neglect the vertical or normal acceleration here, but at the same time we can neglect the frictional resistance offered through the wave by the side in the bed, because the length is very small.

On the other hand, when we talk about the gradually varied wave, then it is say wave like that flood wave in lake, then in river or say wave due to slow opening of gate, again that we can generate. In a laboratory, in fact, if we open the gate slowly, then we can get this

sort of wave, in a channel we can block the water by gate, then we can have generated some height there. And gradually if we open, then we will be getting a wave of this sort and similarly, if we close it gradually, then also we will be getting this sort of gradually varied wave. And in gradually varied wave, the wave will be like this, in the gradually varied wave will be like this. And here, the vertical acceleration, normal acceleration is negligible, that is there we can neglect a normal acceleration, but the length of the entire wave portion will be quite large and a such we should not neglect the friction in our analysis.

So, friction cannot be neglected, but normal acceleration can be neglected when we will be representing this wave mathematically. And this gradually varied wave is very commonly found in when flood comes and then say flood routing when we do, then this sort of wave we follow.

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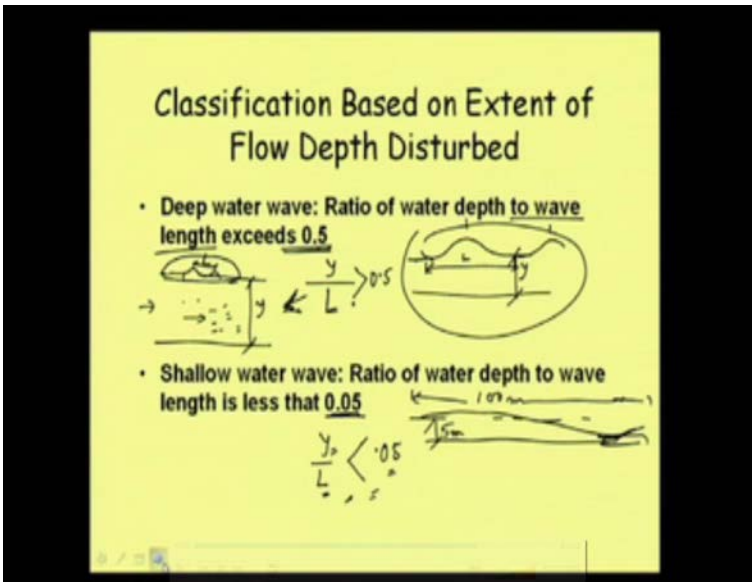


Well, then we can make another classification, so that is what the classification based on extent of flow depth disturbed, flow depth that gets disturbed basically, well, so flow depth get disturbed. Now, what we can see, you can concentrate in the slide that when we write say depth water wave, the ratio of water depth to wave length if it is exceed the value 0.5, if it exceed the value 0.5, that means if we have a wave like this and say depth of water is y here and say length of wave mean as you know say there, we can have the length of wave like that. Or say from crest to crest if we measure, say from crest to crest

we can measure or say from trough to trough if we measure and this is the say length of the wave. Then if this length ratio of the depth, water depth to the wave length, say water depth is y and wave length is L, let me write capital L to represent the wavelength, then this value if it is greater than 0.5, if it is greater than 0.5 and then generally it is termed as deep water wave.

Now, let us just see what we mean by depth, that means, here of course, in my diagram this y is smaller and this L is larger, but when we are actually talking about deep water wave, it will be like this means, this wave will be very small like that and depth is very high say y and wavelength may be this much. If I draw another then wavelength is this much.

So, this L by y is very small, this is the actual case not this one, because this is just I tried to show what is y and L, but this part is the representation of the this particular situation. Now, you can see when we have this sort of L size and y size, then the this wave formation will be disturbing the surface portion only, the entire water depth will not be disturb.

So, this part of water is flowing as it is this wave is coming in the surface, it is disturbing the surface and it is moving over the surface, so it is not disturbing the entire depth of the channel and that sort of wave is call deep water wave in sea, we get this sort of deep water wave. That means, water depth should be much higher, of course it is again relative much higher means we cannot say that this should be this much meter or something like that, relative to the length or wave length of the wave, the depth should be comparatively larger, then we can have shallow water wave.

So, what we mean by that, that ratio of water depth to wave length is less than 0.5, about say 0.5 and then we refer this as shallow water wave. So, what is that y by L should be less than 0.5, of course there is a range or gap in between, we may put on this side, if it is towards that, if it is towards this, we can put in that side. And exactly of course, this barrier is been put and in nature we can have anything in between, but this y by L is larger, means it is less than this value, means length of the wave is much larger than depth of the wave.

Length of the wave is much larger than depth of the wave, length of the wave is much larger then depth of the wave, like that if we have a wave of this type, this type and then say we see that this length of the wave is suppose 100 meter and then, say depth is of course as per our sketch if it is 100 meter. Then say depth is depth is say 5 meter, then

we are finding that this water, when it is propagating it is disturbing the entire flow depth and because it is coming here, we can see just near the bed and then it is creating disturbance to the entire flow system. And then say if it is less than that even this will give you a value of say 0.05, but it is say less than that, then this will be referred as shallow water wave. Means in shallow water wave the entire flow depth is getting disturbed.

So, for many of a analysis purpose we use this concept and sometime depth average things also we take the velocity and all this thing, as entire thing are getting disturb. So, velocity at a point means we can take average depth, average velocity of the particular section and that way we can carry out the analysis. And in then break analysis and of course, again in the same wave form we can see that are the front there may be steep steep surface which can be falling under say a in a different category, but in the other part, which where we have this sort of condition, then we can consider this as shallow water wave. And generally those wave in rivers we get shallow water gradually varied flow wave and we carry out the analysis, we make the assumption in our development of the theory and we study it in that form, well that way we can classify the wave in a different way.

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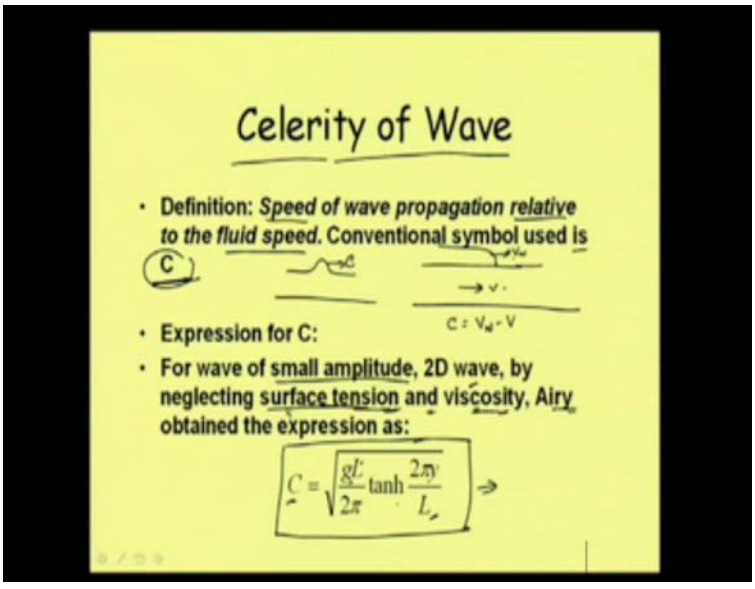


Then, we need to know about one new term, of course we are referring to this term earlier also, when we were perhaps discussing super critical and sub critical flow, at that point also we were referring to this. And particularly, when we were discussing control section or effect of control section on the water, where suppose in sub critical flow where

the control will be there, when we discussing that part earlier, then we refer to this particular term that is the celerity.

And in wave steady, we need know or when wave steady means, basically we are talking about unsteady flow steady, in an unsteady flow steady, we need to know clearly about this term celerity of the wave. Well, that definition wise we can say that it can be referred as speed or wave propagation relative to the fluid speed.

That means, fluid may be having a speed already, suppose the water is moving with some speed, water is moving with some speed V and then there wave is coming, then this wave may have some absolute speed, wave may have some absolute speed. Say, it is coming with the V W speed, wave speed, but the water is also moving with a speed V, then what will be its relative speed? That is basically say V W minus V will be its relative speed, speed of the V W or speed of the wave relative to the speed of the fluid media or say water media, we can call as p w minus p and that is basically called as C.

So, speed of the wave with respect to the speed of the media over which it is flowing and then it is called sea. Now, if we see or we create a wave in a stationary fluid, say water is standing may be in a tank we are taking water and we can generate a small wave by just moving a paddle, just one strike of a paddle will create a wave.

So, that sort of a wave if we create, then say we are getting a wave and then it is moving, hence this part of water otherwise in static condition, then this wave speed suppose whatever we get this wave speed, whatever we get this will be the relative speed. And in in that case, absolute speed and related speed become same if the water is not moving otherwise.

So, that is how we defined, but as per definition it is a speed of propagation of the wave and the relative to the fluid speed. And the conventional symbol that we use is C, so C is the conventional symbol that we use for representing celerity of wave. Well, now the important point is that what will be the expression for

C, what will be the expression for C. Well, that that study, in fact if we try to go into detail, we need to go much deeper, but that is beyond our scope, but still we will be just discussing some of the very preliminary things of these expression how we can derive. And this how finally this expression can help us in many computational works that will be trying to see. And an expression for C, for wave of small amplitude, that was done for small amplitude, as we know what amplitude we mean. And to the wave, there is we know what is this sort of wave and then by neglecting the surface tension, by neglecting the surface, two D means two dimensional, we are talking about it is moving like this, I

mean this wave is vertical and then in the along the flow it is moving, so this we refer as two dimensional wave.

And by neglecting the surface tension and viscosity, because surface tension force sometimes for gravity wave this becomes very insignificant, so we neglect that. But many a time this is of course we should keep in mind that when we are analysing the theory of gravity wave, if we do it in experimentation level in laboratory, then if the wave heights are becoming significantly smaller than that of the actual wave in the field, then the surface tension force may become sometimes dominating. But, here of course neglecting this surface tension force and the viscosity again say elastic condition we are neglecting, so viscosity is not coming here, internal friction that is not coming.

So, that way neglecting the surface tension and viscosity airy, he obtain the expression as say C is equal to root over g into L, L is the wavelength of the wave divided by twice pi and tan h of say two pi y, this is the again depth the of the flow and then this is the length of the wave. Well, we are taking this directly and the derivation of this we are not bothering at this movement and this is of course will require lot of elaborate study. But we are taking this expression directly that C can be expressed in this form. Now, this expression again, when we are talking about this expression, in this expression we are neglecting surface tension in the derivation of this expression, we are neglecting the viscosity and these are valid for small amplitude wave well. So, this point we should remember, but this is the expression for wave and this is used for many of our purposes.

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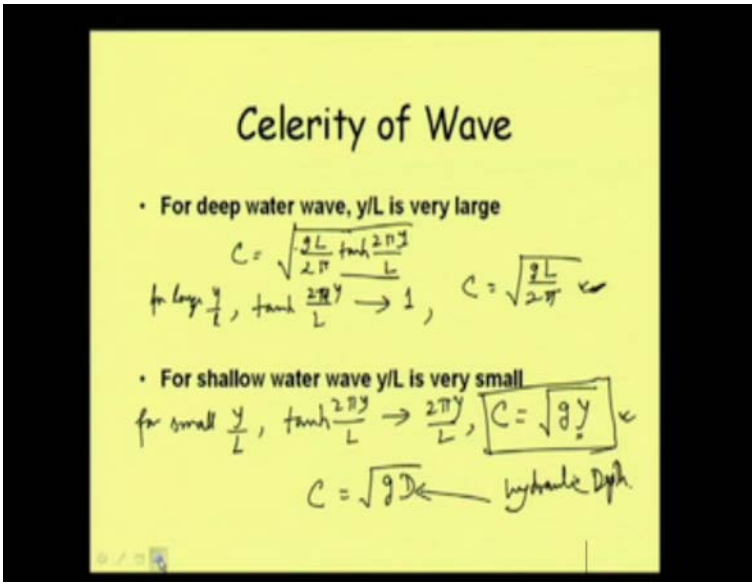


Now, we can see that how this expression will take different shape for say deep water wave and shallow water wave, well. Say for deep water wave when our y by L is very

large, then we can see the expression we have drawn that C is equal to root over g L by twice pi and tan h of say twice pi y by L. Now, when our y by L is very large, y by L is very large for large y by L, this tan h twice by y by L, this expression become equal to 1. So, that gives us a simple expression, that twice pi y by L, this tends to one. And then if it tends to one what we get? That C tends to or C become equal to..., rather now we can write that C is equal to root over g L by twice pi. Fine, then for shallow water wave this y by L is very small, so when y by L is very small for small y by L, then what will happen to this value, that is tan of very very tan h of very small quantity that will become the quantity itself.

So, what will happen, that tan h twice pi y by L is becoming almost equal to twice pi y by L and that leads to, see if it is for twice pi y by L, L L get cancel pi pi get cancel and then what we will get, that 2 2 get cancel, y will be remaining, g will be remaining and what will get the C is equal to root over g into y and that is a very popular expression, that is a popular expression. This is when applicable for deep water wave like sea, this is applicable for rivers and this is application for rivers.

And if the channel is, if the channel is not prismatic, so in case of non prismatic channel, then we can have C is equal to, because why we cannot use directly, then we can write root over g D, where D is the hydraulic depth, where D is the hydraulic depth.

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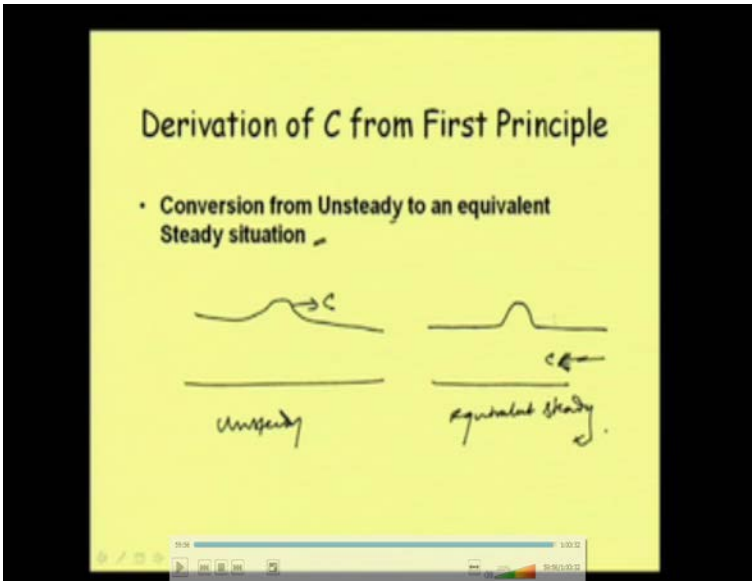


So, this is what the expression of celerity and what celerity we have understood, but now this expression C is equal to root over g y, that we can derive from the very first principle. From the very first principle means if we start from the continuity equation and momentum equation, then taking a wave we can derive this expression. Of course, as we

have already discussed that this expression is coming from the consideration that a is very small, that is the amplitude of the wave is very small, so when we will be deriving we will also have to take that amplitude is very small and then we can use our first principle and then we can try to derive these expression.

And for that, for derivation of this sort of expression what we do, that conversion of unsteady to an equivalent steady situation, generally for say analysing a unsteady flow situation, that is when depth is changing with time at any point, then it become little bit difficult, I mean how we will tackle this point. So, what we can do, we can just change that to an equivalent steady condition.

For example, say I can give you a practical example, say now morning walk, evening walk these are very habit of the people, now we do not have space to move and that way what we do, we move on a walker. And then, it is just simulating your walk system, say you are walking, we are walking on the walker and then the belt over which we are walking is when we are walking the belt is moving in the opposite direction.

So, though we are walking we are not moving forward, as if our condition is not changing we are in the steady condition, we are not changing our position, we are in a steady position, how we are achieving that? that we are walking, but the bed or the belt over which we are walking is also moving in the opposite direction.

Now, suppose a doctor want to analyse some of the things, say I do not want to go the medical science, but say when we try to analyse suppose a heart problem, say how this person will behave when walking then if the person is really moving, then doctor will find it difficult to analyse. So, what he will do he will put him on a walker and then a belts, so belt will be moving on the reverse direction and the person is walking, so the person is remaining on steady position, static position and it become convenient for the doctor to study this person how he will behave during the situation when he is walking.

So, similar situation we can create in water also, say when a wave is actually moving with a speed C over a may be a over steady water or over a static water. Suppose this velocity is 0, but it is moving with a speed, then if we try to observe this is moving, so rather than that what we can do, just like the belt, to the water we put a reverse velocity C and then we consider that this wave is in static position. We are just providing rivers velocity C to the fluid media and then this wave which was suppose to move with a speed c will now remain in steady position. So, this unsteady case we can just analyse by considering this as an equivalent steady case. Well, in the next class, we will see how

from considering this equivalent steady state, we can analyse and we can see in a very simple term the expression for C we can derive. And then, gradually we will be moving on to other more important topic of unsteady flow; so thank you very much.