Coastal Engineering
Prof. V. Sundar
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module - 7
Scour Under Marine Structures
Lecture - 1
Scour Under Marine Structures

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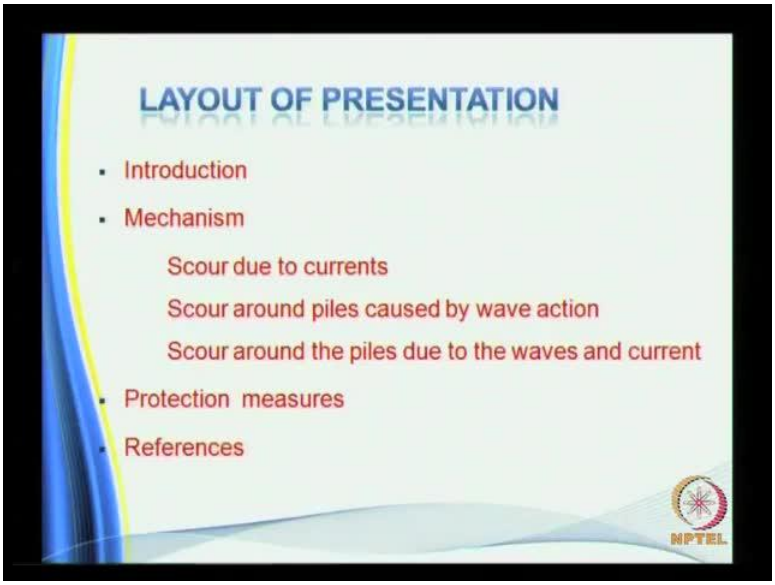

So, today we look at the details on scour under marine structures. The layout of what we are going to discuss in the class, I will get started with the introduction move on to mechanic mechanics of scour. In general I will cover the scour due to flow that is due to currents followed by scour under around piles due to the propagation of waves, then later due to the combination of currents and waves. Then this will be followed by protection measures, some of the suggested protection measure which we have already, which have been already implemented. Then there will be some references from which some of this material has been taken. So, this is a kind of the kind of organization of the lecture on scour.

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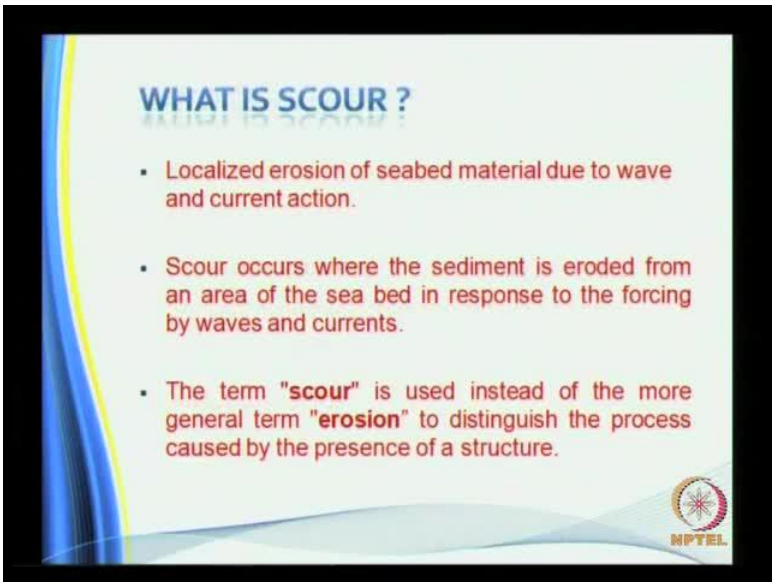

Let us see what is scour? It clearly says that, localized erosion of seabed due to waves and are current action. Scour occurs where the sediments is eroded, I mean the bed of sediments is eroded from an area in response to the forcing of forcing due to waves and currents. The term scour is used instead of the general term erosion to distinguish the process caused by the presence of a structure. So, we should clearly distinguish between what is scour and scour and erosion. Erosion can happen without any obstruction for example, a seabed is there, I mean the beach slope is there, during a storm the entire beach can get eroded.

That is an instant kind of erosion or a continuous propagation of waves over the beach can slowly and gradually it will be removing the sand. So, there is, there may not be any cause for this erosion except that the waves are hitting the coast and the coast is the beach is being removed, the beach material is being removed. So, this basically depends on the forces from the waves and also the sediment characteristics. This we have clearly seen under the coastal erosion and protection lecture.

Now, scour is different. Scour takes place certainly when there is an obstruction. Simple example is you go to the beach, stand on the beach, water comes and then when it is when the down wash is happening initially you have the wave run up which will pass your feet and then when it is getting back you see that the some amount of sand is removed from the toe, from your toes or from your feet. So, from the toe near the toe the

depth of the hole that is been created will be slightly higher. So, this is the classical example for knowing the physics of scour. So, that clearly indicates that it has something to do with the size of the obstruction and also the characteristics of the flow and the characteristics of sediments.

So, remember that the scour takes place when there is an obstruction. What are all the locations where you can usually have scour? You see bridges, piers, if you happen to cross, if you happen to see the bridge piers when there is not much of flow in the river. You can easily see that around the piers, pier near the, near it is where it is touching the bed river bed you will see the dumping of stones. This is called as in general they call it as rip rap protection for scour. Then near the dams, near the toe of the spillway there you will have protection. So, all this things some way or the other it is meant to take care of scour because of the velocity gradient that is going to remove the material. Is that clear?

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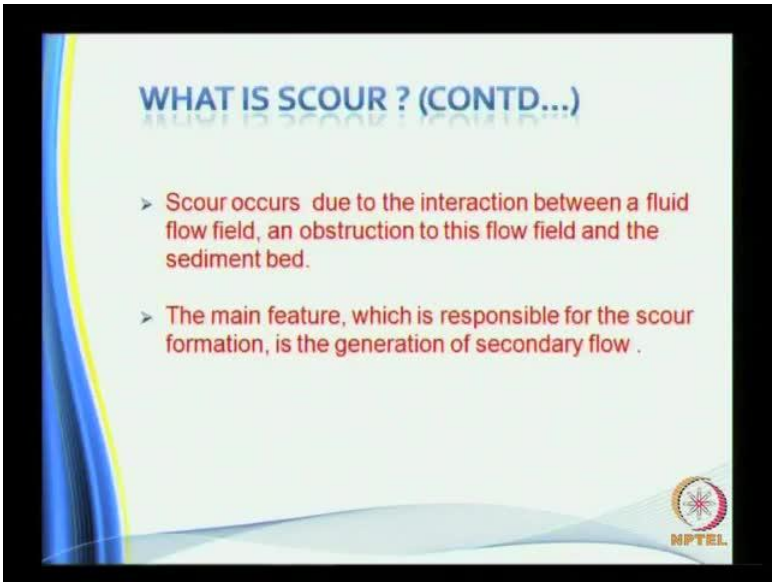

So, now scour occurs due to interaction between a fluid flow field an obstruction to this flow and sediment bed, this is what I have just explained. The main feature which is responsible for the scour formation is the generation of secondary flow. So, later we will see what is meant by primary flow and secondary flow. The primary flow is the normal flow and the secondary flow is cost because of the flow as well as the flow due to obstruction. That is flow which is (( )) over the structure and due to some kind of a flow

due to the presence of the structure. These two kinds of, these two flow interact causing a kind of a secondary flow.

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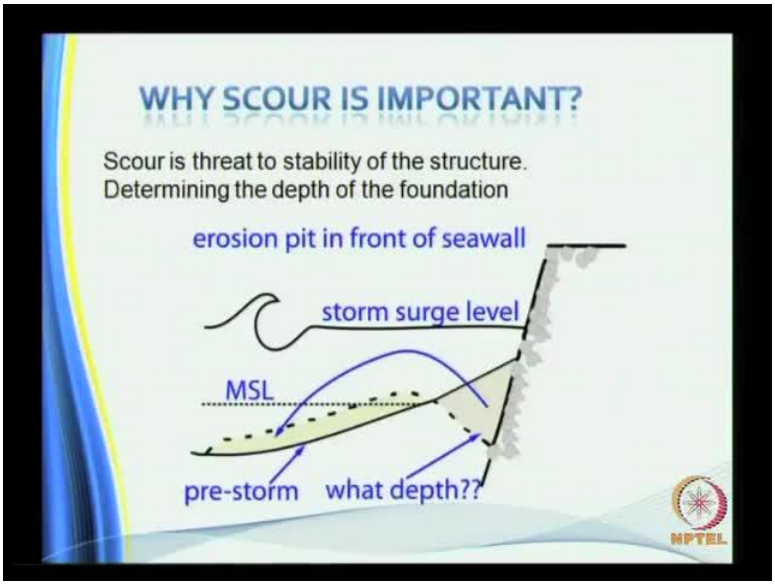

Now, why is scour important? Scour is threat to stability of structure determining the depth of foundation. Now, here you see a sea wall and under the normal circumstances what happens and you can have, you will, the structure near its storm is likely to experience, lightly likely to experience scour and this is where you are supposed to take care.

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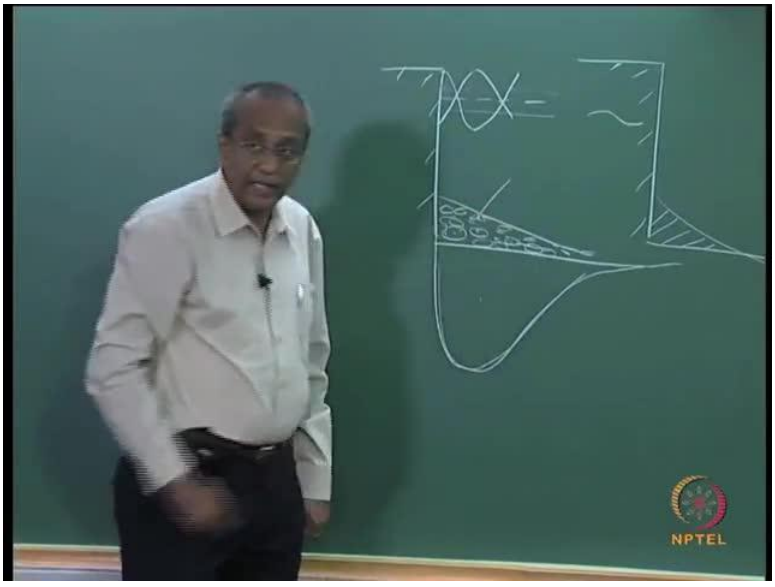

As passing remarks we have I have already indicated whenever you have structures you will have to protect the toe of the structure be it wall or a pile etcetera. So, if you do not give this what will happen? You will have the same, you will have the depth of the scour taking place. Depth of the scour takes place because in the case of let us examine in the case of a vertical wall. If the wall is not there the still water line will be somewhere here the main sea level, but when the wall is there then the still water level itself will go up by certain magnitude which I have discussed when I spoke about wave forces on wall types structures.

When the depth increases naturally because of this vertical wall you have the reflection reflected waves. So, you have the reflected waves the wave height will be double the wave height of the incident wave, you know that. When the wave height is large naturally particle velocities near the structure is going to be large. So, the difference in the velocity is going to be felt all through depending on the magnitude of the incident wave characteristics you are going to have a scour taking place. If you do not, so it is a primary requirement that this is not allowed.

So, in order to make sure that this is not allowed the flow field has to be dissipated. So, you have a hard mattress, you prepare something like hard mattress in the form of maybe gabions or natural stones preferably with over a slope. So, that the flow field gets diverted and it does not create create the scour. So, this is an essential requirement that is scour protection for structures.

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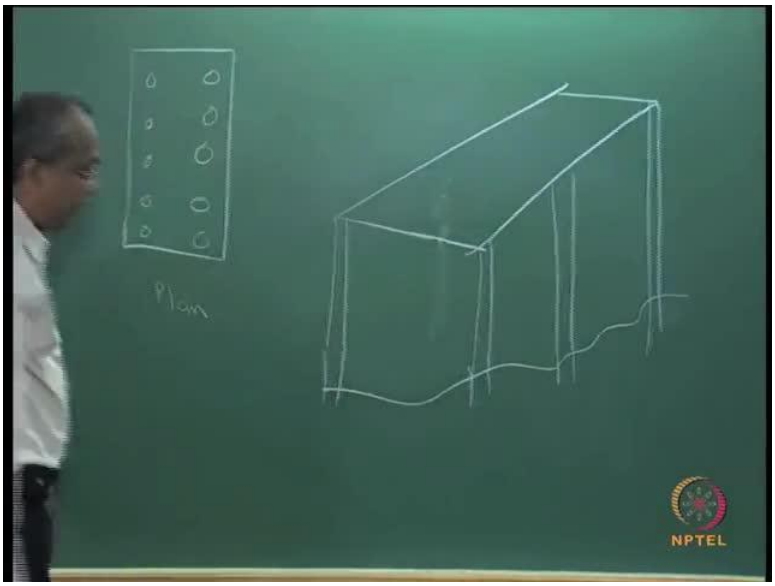

Now, another example, for example, I, we have we are supposed to construct a jetty and this jetty this is in plan. So, this will be let us let us say that it is supported on piles. How deep the piles have to go beneath the sea bed that is very important. For example, this is constructed along a river you say, say it is constructed along a river. What are the information's you need?

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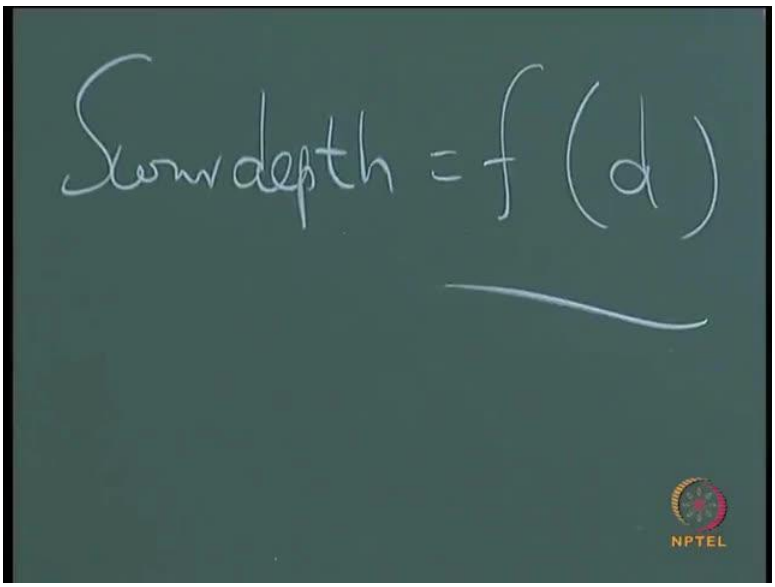

Basically, this scour hole or this scour depth, scour depth will be a function of water depth for sure, apart from the other enforce, forcing variables. So, for the water depth

which we are talking about and for the in inflow discharge characters velocity etcetera you need to know what is the approximate, I mean what is the kind of scour depth you can anticipate.

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In coastal waters some some they use twice the water depth can be treated as the scour depth. Whatever may be if this cover depth below the sea bed for example, you estimate as 10 meters or may be 20 meters or 10 meters or 5 meters, whatever it maybe. For sure your pile has to extend the scour depth, preferable and also you need to have the scour protection. Just imagine you are constructing a structure and your pile has not gone, this is only 10 meters, for example this is only a example and we have not given any, no scour protection is given, the structure has been constructed. What would happen?

When there is a scour hole later you will see that the scour hole is maximum in the vicinity of the pile and this is the pile. Now, this much of sand is removed, this is your pile, what will happen? The pile will be suspended because the sand around the pile has been removed due to local scour, this is called as local scour. Once this is removed one pile still the structure may be able to withstand. Suppose, if you have the row of piles then you will see that the entire thing will collapse and then the scour is, the flow will get diverted and then some of the piles intermitted five piles also can be removed and slowly the entire structure can go into the river.

Now, you see the importance of understanding the scour phenomena and also looking at the possibilities of protecting the structure against scour problems. Is there any question? Is it okay? You are alright? You understood.

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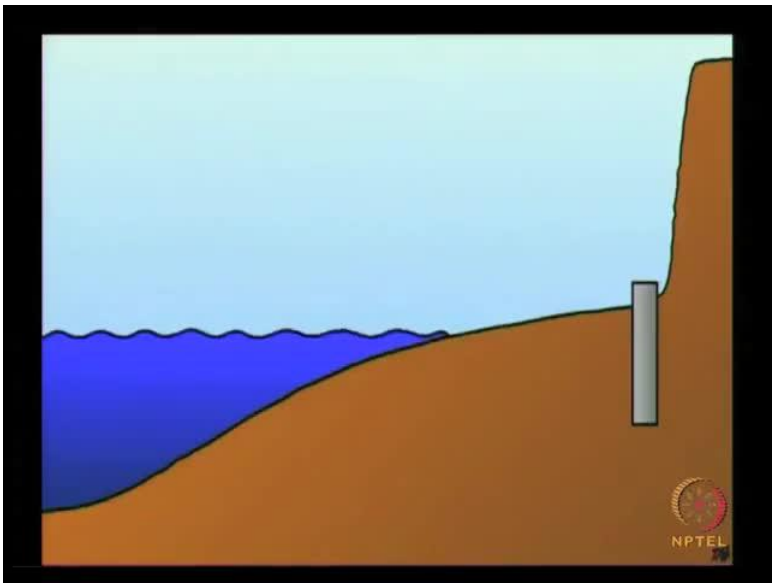

So, look at this animation of whatever I was, I had discussed. You have a structure and you have a flow taking place and hitting the beach initially. So, after hitting the obstruction the flow is getting back and when the flow is getting back it will pick up the sediments and remove it towards the ocean. That is in the event you do not have any scour protection. If there is any scour protection this down flow will not be removing any sand because you have a, an obstruction, you have a protection measure there.

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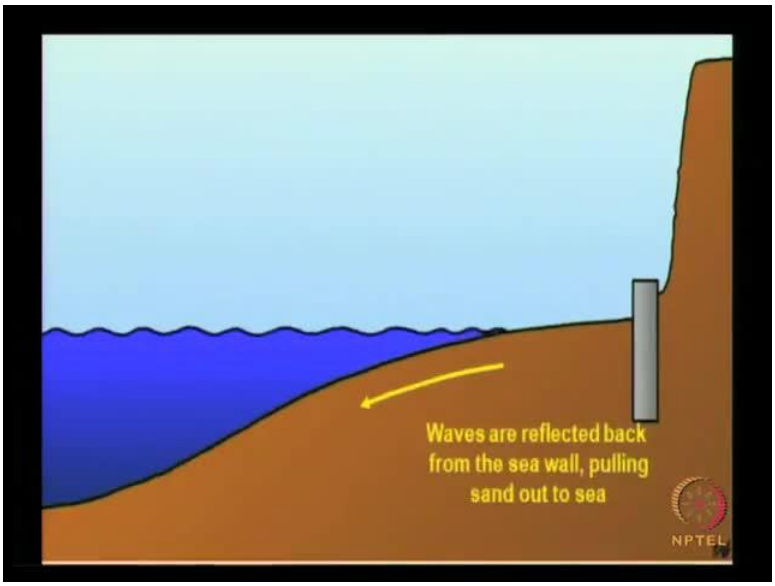

So, waves are reflected back from the sea wall pulling the sand out to the sea. This is what I had been explaining.

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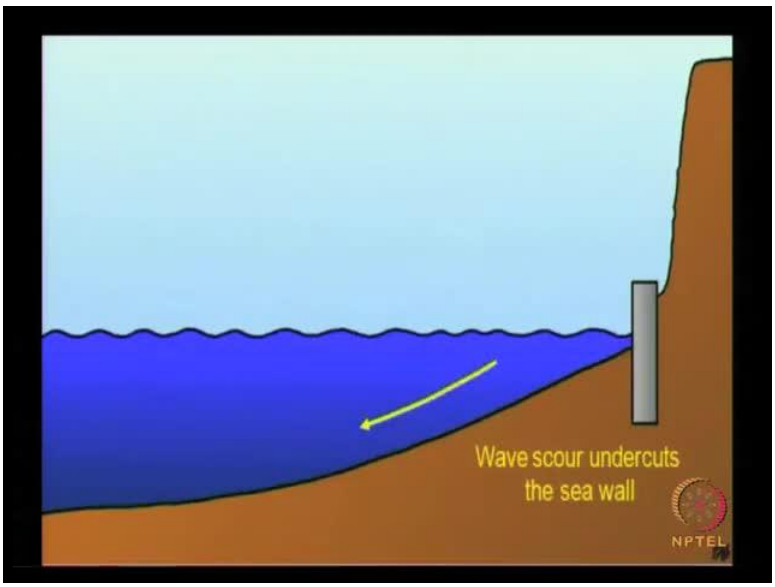

So, now waves scour undercuts the sea wall. So, earlier you saw the level of the sea bed somewhere here.

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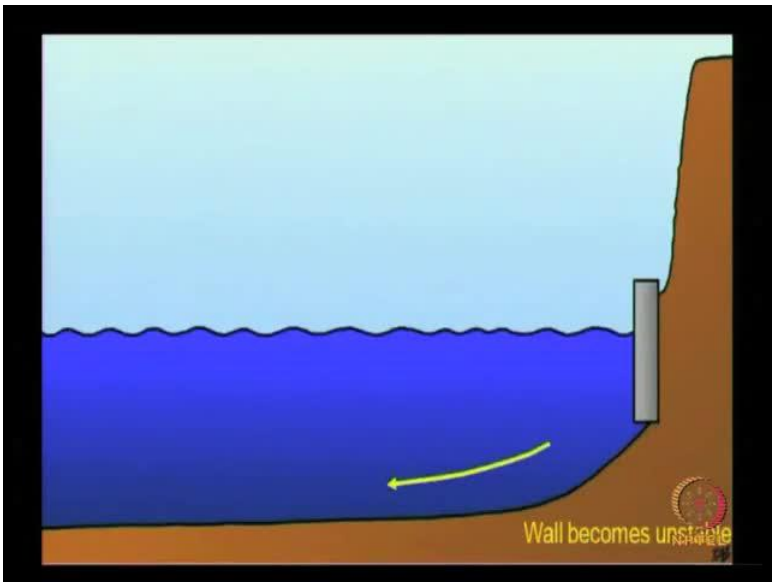

As time progresses you see the level of your sea bed in the visibility of the wall that is because of the under cutting the sea wall by the waves and still you do not take any proper measure in protecting it, the process of scour will continue, so erosion of or scour of the sand will take place. Then until it has removed even the founding level of, it has the founding level of the structure is now seen here. So, when it goes below the founding level the wall becomes, the structure becomes unstable.

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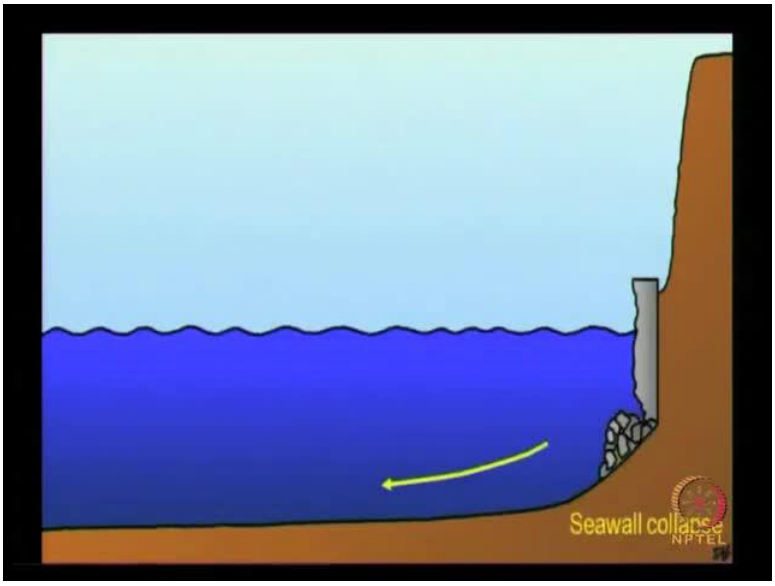

And then the sea wall is likely to collapse. So, there earlier I explained with an example of a pile. The pile will start hanging. Here, if it is a structure the whole structure can collapse.

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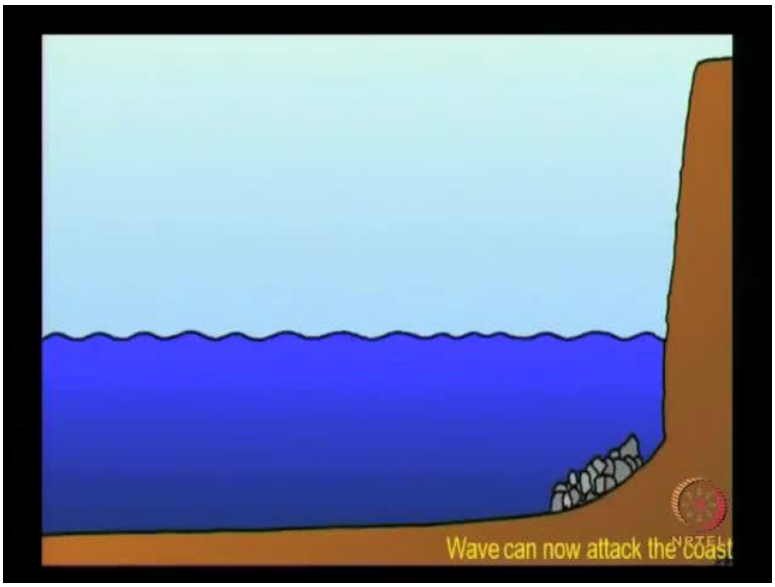

The whole structure may not be collapsing maybe at parts looking wherever you have this type of instability there is a possibility that the wall itself can disappear completely.

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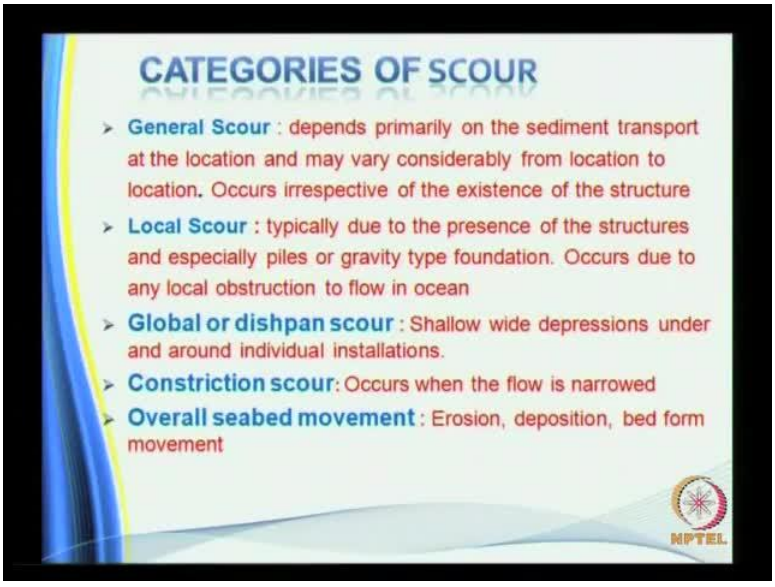

So, that explains to some extent the importance of scour of knowing what is scour. Now, when you look at the categories of scour we have broadly five different categories.

Although we have five different categories we may not be using all the five and the most frequently used categories are the general scour and the local scour. So, general scour depends primarily on the sediment movement at the location and may vary considerably from location to location. Occurs irrespective of the existence of the structure, please do not confuse, do not get confused between this general scour and erosion.

Erosion is something different. This general scour is when you when the flow is taking place there can be even sea bed ripples that is being formed. Sea bed is always not smooth as you may think. So, there may be some locations, local locations where there can be general kind of movement of sand depending I mean removal of sand and then the sea bed can have some kind of a depression and this of course, depends varies from location to location.

Local scour, typically due to the presence of structures and especially piles or gravity type foundations, it basically occurs due to the local obstruction to the flow. Wherever you have large obstructions you can have large or small obstructions, you can still, you will still have, you will have scour and this is called as local scour that is in the vicinity of the structure itself. Then global or dishpans scour. These are shallow wide depressions under and around individual installations. These are very shallow, but wide depressions.

Then constriction scour that occurs due to the flow being narrowed not very common, then overall seabed movement that is erosion deposition or bed form movement. See, the overall said movement and the general scour more or less fall under similar kind of categories.

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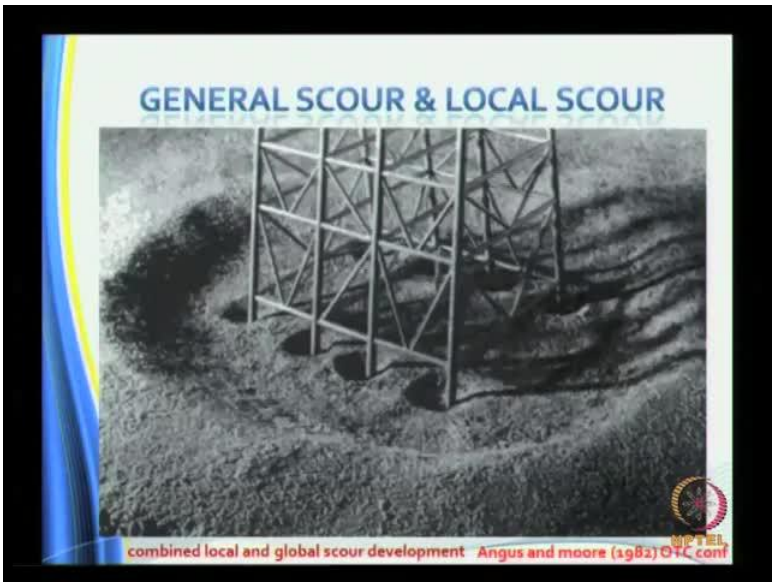

So, this picture clearly illustrates that has been presented in the off shore technology conference in 18 1982 by Angus and Moore, this is an excellent photograph showing an, giving an explanation for the difference between general scour and the local scour. General scour all these thing is called as general scour. Local scour or the ones which are occurring just in the vicinity of the obstruction that is in this case, it is a pile. This is a typical formation of general scour and local scour in the presence of an off shore structure.

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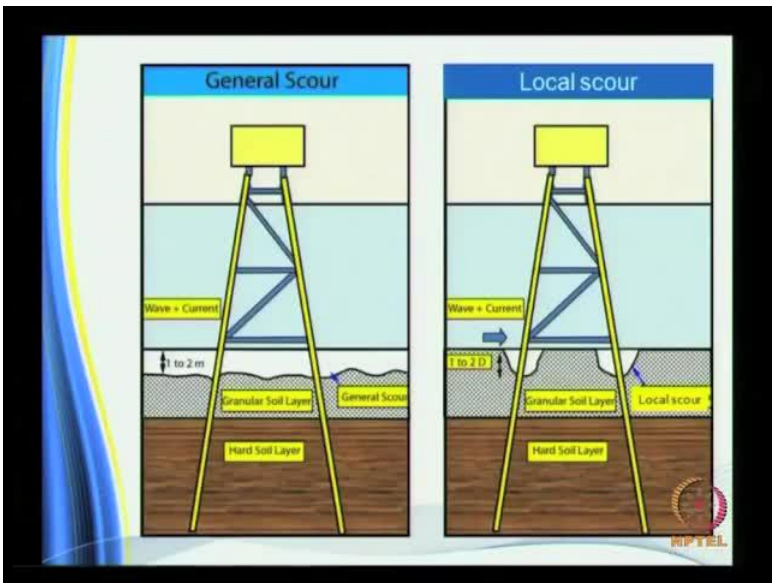

So, again pictorially it can be represented as you look at the general scour here. This is the general scour which we have seen with the earlier photograph and you see that the local scour can be something like 1 to 2 times the diameter. These are all only empirical, I mean thumb rules.

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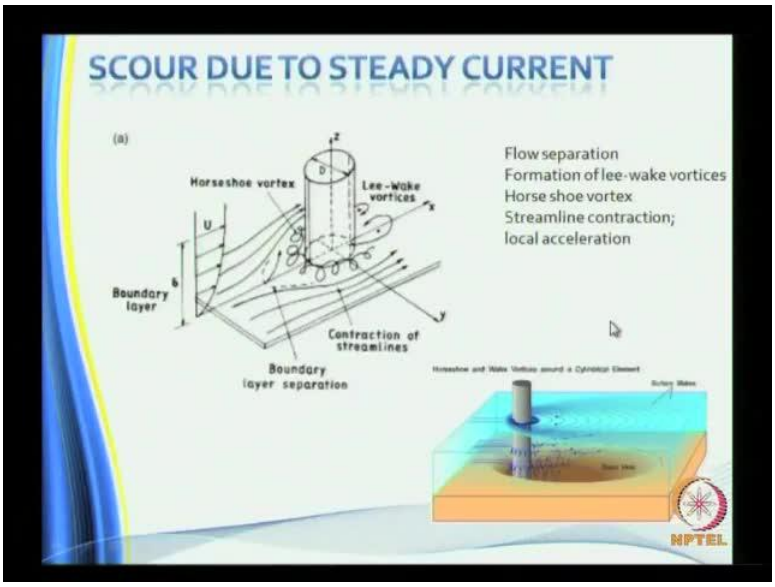

Now, we move on to scour due to steady current. The scour mechanism is the same weather it is steady current or waves or combination of current and waves. The basic physics remain same, it is only the magnitude of all the flow field that occur in the vicinity of the structure which dictates the intensity or the magnitude of this scour hole or and also the extend of this scour. So, the physics contains of flow separation, formation of lee wake vortices, formation of horse shoe vortex, then streamline contraction and then local acceleration.

What exactly happens is when you have a flow taking place in the direction as shown here and you have a presence of a structure, we take a pile it is obvious that the flow separation will take place, the on the lee side the wake vortices will be formed, the strength of which depends on the characteristics of the flow as well as the dimensions of the structure. The streamlines here would contract, there is a kind of horse shoe vortex which is formed here, as you see here in addition there will be local acceleration because of obstruction to the flow and there is a large pressure gradient here which is going to

create a flow taking place from this location, approximately this location towards the direction of flow field, towards the direction of flow.

So, you have a main direction here and because of the obstruction you have a kind of a return flow. So, these two flow fields start interacting with each other and you know that this flow and this both are in opposite direction and that is going to create vortices again and that is going to enhance the sheer stresses at the sea bed. When the sheer stresses exceed a certain limit that is been task sufficient sufficient sufficient driving force it will remove the sand and it will transport. So, in addition there is pressure gradient also along the cylinder or a pile. So, which is going to create a scour hole in the vicinity of the structure and then you also have a scour.

This scour will be propagating as shown here. This is the depth up to which this scour hole goes, is called as local scour depth whereas the other aspects we also used what is meant by general scour depth. So, this local scour depth is extremely important for the design of the structures. So, the aim of the engineers who are working in the design, they calculate the local scour depth based on number of empirical formulae's and this depth is utilized in order to fix the bottom of the piles, founding level of the piles. Is that clear? So, if you want to have further explanation on this it is not so easy, it is a bit complicated you need to refer to a number of books which are given under the reference, is that clear? I will also show you animation.

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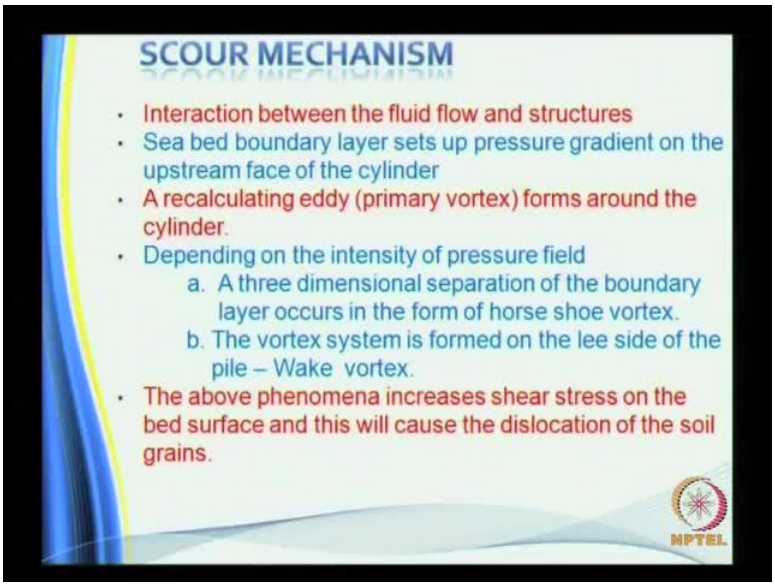

So, scour mechanism what I have covered I am just putting it here, interaction between the fluid flow and the structure, sea bed boundary layers sets up pressure gradient on the upstream face of the cylinder, a recalculating eddy primary vortex forms around the pile, depending on the intensity of the pressure field three dimensional separation of boundary layer occurs and this is in the form of a horse shoe vortex. The vortex system is formed on the lee side of the pile and which is called as wake vortex.

The above phenomena increases the shear stress on the bed surface and this will cause the dislocation of the soil grains. So, the shear stresses as well as the grain size is extremely important. So, even if shear stresses exceed and if you are now protected it with huge rocks, this is not going to lift the rock, stones, it is going to be in its position, but there are situations where scour can go so deep. So, you need to be very careful. I would like to recollect recollect one thing.

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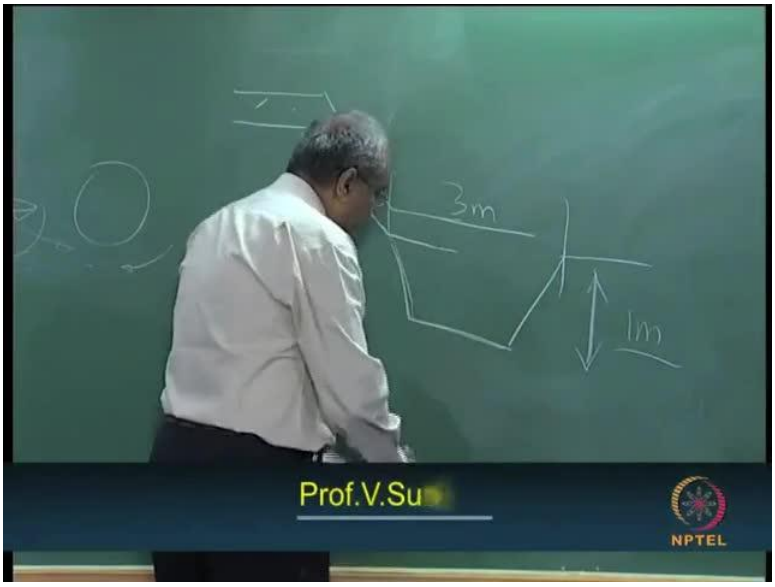

In the case of breakwaters, in my lecture on breakwaters you have I have explained about exposed toe and excavated toe. Remember, so you excavate some material and approximate thumb rule is 1 meter deep and the toe width is approximately 3 meters.

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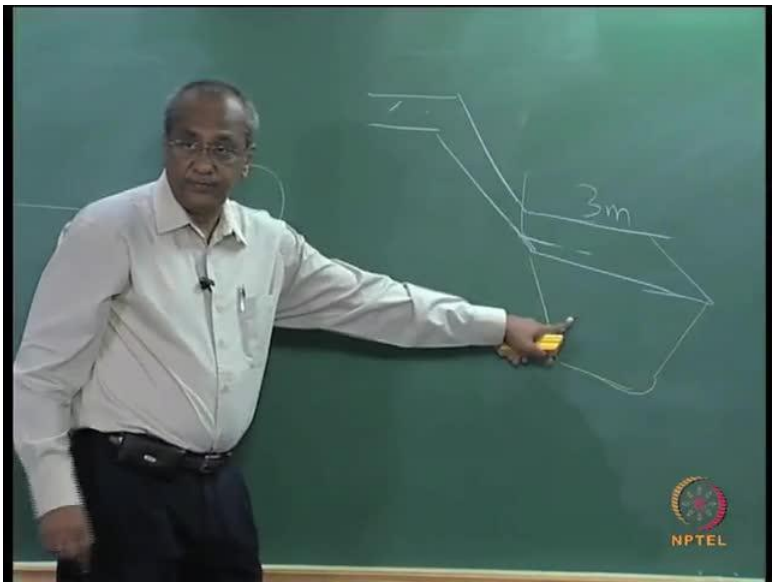

Either you have it like this or you have a, or you have an exposed toe. This is an exposed toe and whereas you can also think as an ex excavated toe, if you do not have this.

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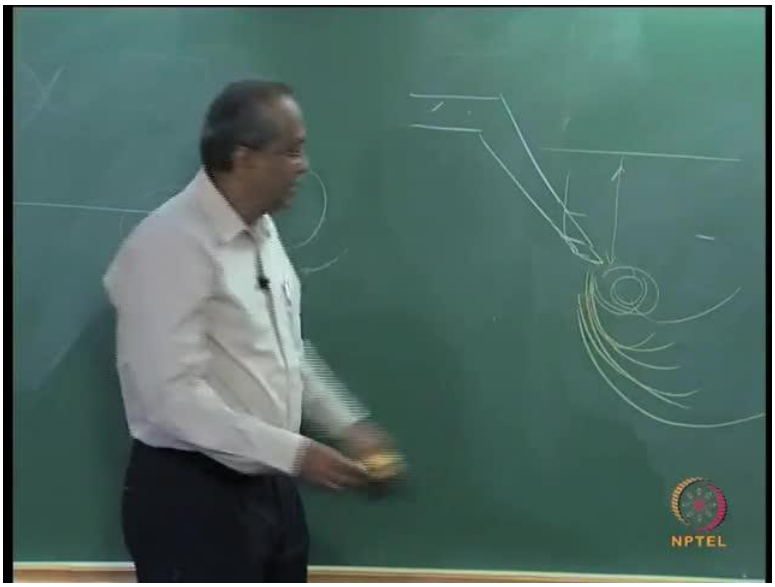

Now, you leave it as it is. So, large obstruction to the waves, so what will happen? The pressure gradient etcetera all this will take place the sand will be removed. Now, you see that this portion is almost like suspended. So, what will happen? You lose this portion and once you lose this portion you will also lose this portion. The entire breakwater can

go. Now, you have I have explained you the example of vertical wall, example of vertical pile and an example of breakwater. So, all this places scour is scour protection is extremely is of paramount importance. So, horse shoe vortex I will just take 2 minutes.

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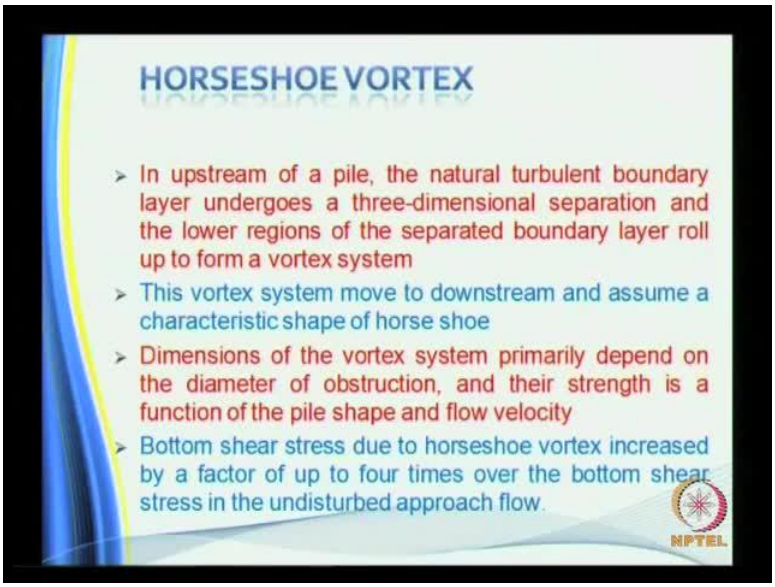

Just 1 minute on this. In the upstream of a pile the natural turbulent boundary layer undergoes a three dimensional separation and the lower regions of the separated boundary layer roll up to form a vortex system. This is what I am repeating, what I have told I am just repeating. Only thing is I did not mention it is three dimension, but it is three dimension. So, this vortex system moved to downstream and assume the characteristics of the shape of a horse shoe and that is the reason why they call it as horse shoe vortex. Dimensions of the vortex system primarily depend on the diameter of obstruction and their strength is a function of a pile shape as well as the flow velocity.

Finally, bottom shear stress due to horse shoe vortex increased by a factor of up to four times over the bottom shear stress in an undisturbed approached undisturbed flow. So, these are all some of the important things.

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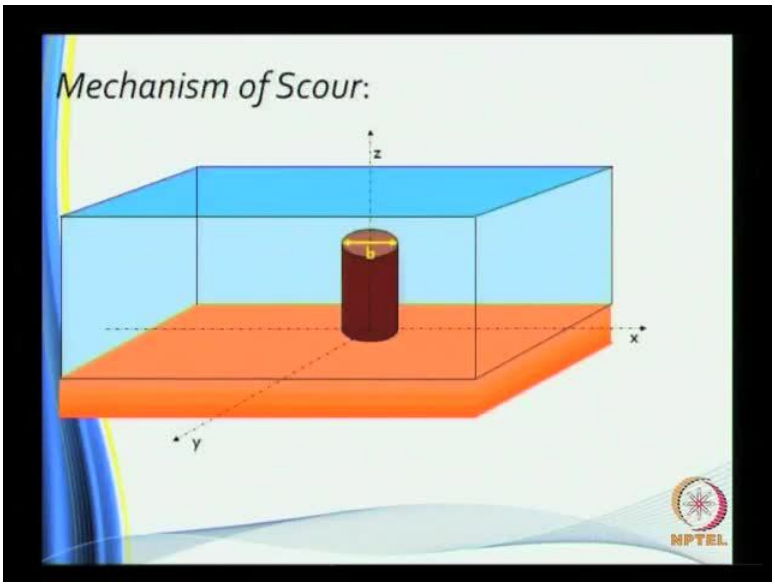

Now, let us, whatever I have explained still if is not clear I suggest read some books in order to familiarize yourself the basic mechanism. Now, you have an obstruction.

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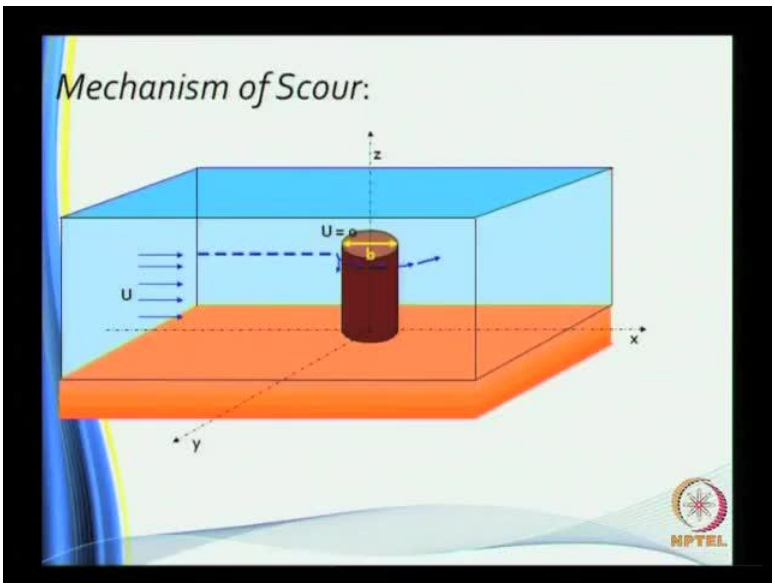

Now, flow is taking place. Now, the flow reaches the obstruction. Now, you see the diversions of the flow field or the flow separation. So, that is what happens, the flow separation takes place.

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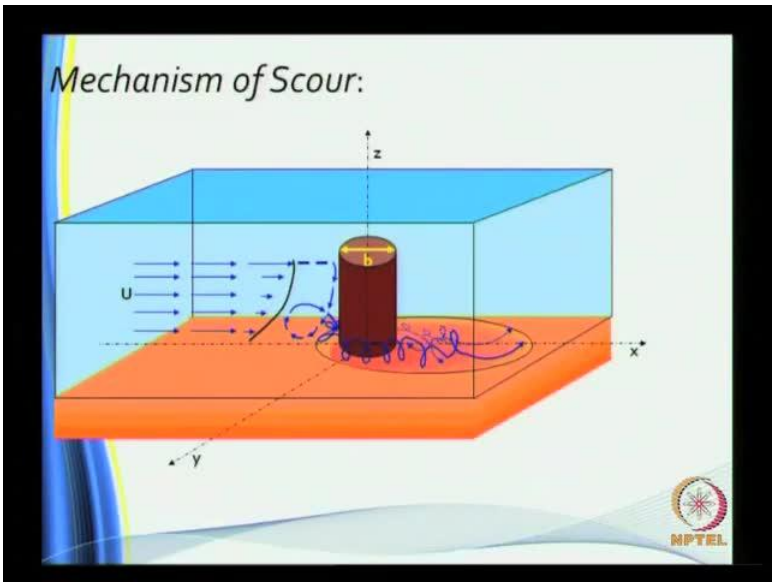

Now, there is a flow towards the sea bed also because of the gradient, pressure gradient and when it goes down, it generates also in the the vortices and this is how it will look like and this in combination with the return flow you will have the kind of horse shoe vortex that is being formed. The scour in the vicinity of the pile will be deeper.

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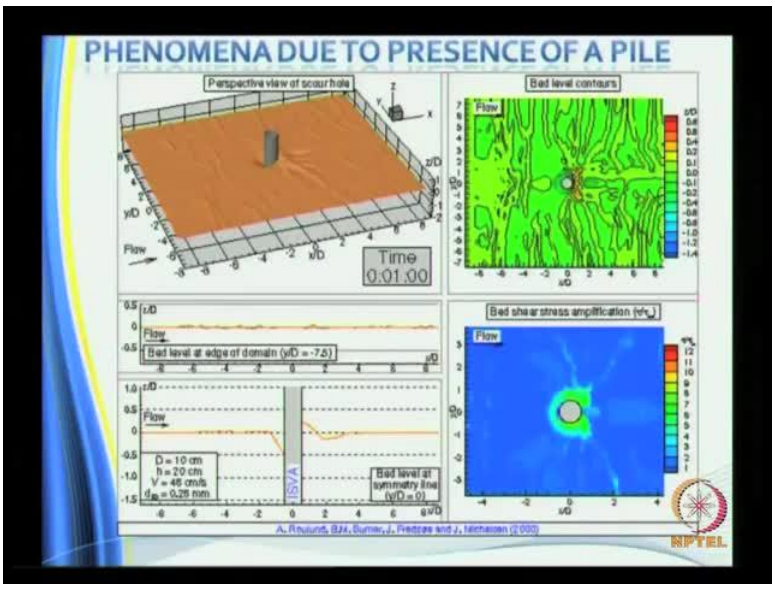

So, now this is yet another animation wherein you see a pile thanks to Sumar, Fredsoe all these people who have provided this information. They are all from Denmark and this animation was published in 2000. This is an excellent admission which shows the basic

phenomena of scour. The top one shows the graphical the graphical the animation how it takes place, this is only the flow field which you are seeing, flow is taking place. Then now here is the here is a sea bed level contours how the sea bed contours are changing.

Now, this is the bed level at the edge of the domain for example, here you see that there are some, the flow taking place now you see that what is happening here, the bed level so slowly you see the depression taking place and this shows the bed stress amplification when it is greater than 1, you will have the ratio between the shear stress and the critical shear stress, you will have the scour taking place and this is the different color shows the magnitude of the ratio of the shear stresses, that is the relative shear stress I would call it. So, this shows that the scour is taking place on a continuous basis in the vicinity of the structure, is that clear?

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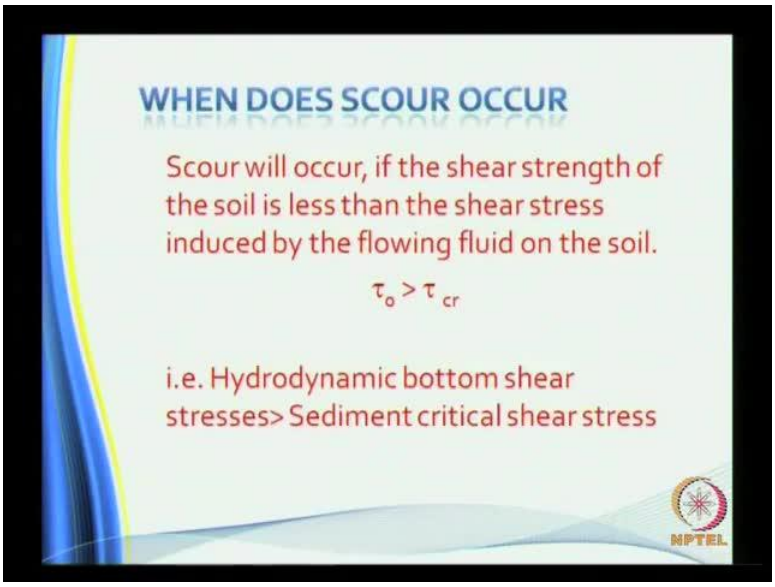

So, when does scour occur? Scour will occur if the shear strength of the soil is less than the shear stress induced by flowing fluid. So, hydrodynamic that is hydrodynamic bottom shear stresses is greater than the sediment critical shear stress. So, when the hydrodynamic shear stress is greater it will remove the sand from a, from the bed and it will transport. Is that clear? Now, where does scour occur? We had seen earlier here and there that is we saw a typical example of a wall, pile, breakwater etcetera, but in a coastal environment in general let us examine what are all the locations where you can anticipate scour.

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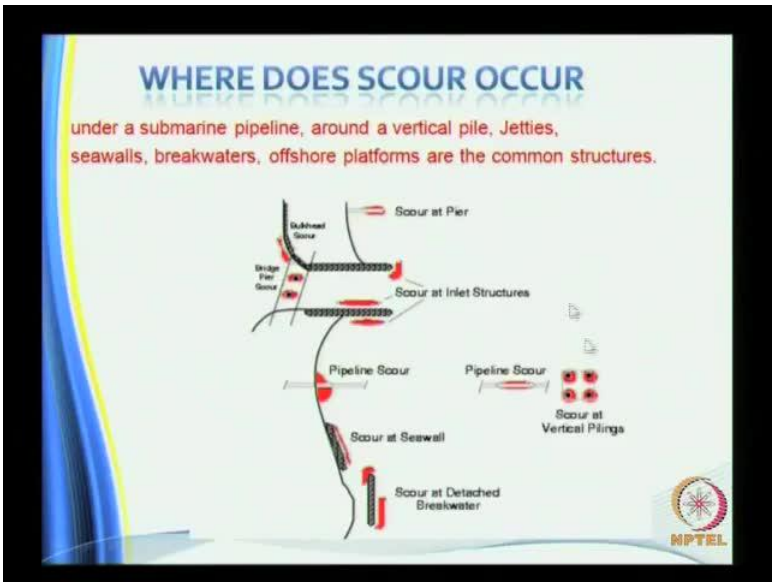

For example, you have a bridge here and you have a, an estuary. Usually you have blockage of the mouth sandbar formation for which you go in for training walls. Maybe here you have a bulk head, in order to retain this sand, retain this earth and you see that there is a bridge also here. Bridge has piers supported on piles or piers. So, this is going to be an active zone of scour. Bulk head is there at its toe you can anticipate scour and also this location is the location where the velocities is expected to be higher. So, you can anticipate more scour here near the tip of the wall.

In fact all along the wall you can anticipate erosion, but this also illustrates one aspect that if the sand is in this direction the littoral drift is in this direction. You have an advancement of the shoreline and hence there may not be any scour here, but scour can be anticipated at the near the head of the training wall. On this side you can anticipate because it is there is not much of deposition taking place both the hence of this training wall you can anticipate erosion because of the flow taking place here and the flow and due to the wave action on this side you can have, this is the flow due to waves, due to the river flow as well as to the tidal ingress.

If you for example, if you have a pipe line for drawing sea water for various purpose, you can have you might experience the pipe line may have a scour taking place or if this pipe line in this deeper waters you can have pipes scour. How do we protect all this things? I will just give some basic information's and suppose if you have structure, off

shore bridge or off shore structure you can have, you will, these structures will experience scour, the sea wall connected along the shore can have scour, detached breakwater can have scour and not only that during the ingress of the tsunami a number of buildings collapsed because of the return flow.

You know what is the order of velocity we were, with what order of velocity the tsunami approached the coast. So, much of water went inside the land and when it it has to return back it returned with greater velocity. When it returns with a greater velocity what happens? It feels the obstructions like your buildings, coconut trees, all kinds of obstructions. Wherever there are free obstructions small house, it obstruction, so you will have the scour hole taking place, unfortunately the if the foundation of the house is not so taken deeper the scour hole can lead to, has lead to instability of the wall, the instability of the building and the building has collapsed. So, many trees fell down. These are all because of scour only. Is that clear?

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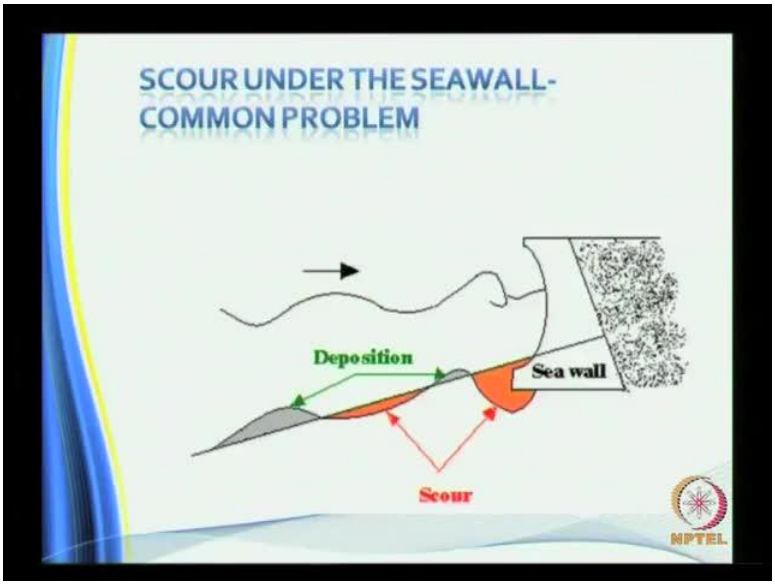

So, this is a scour under sea wall a common problem. This is basically due to the propagation of the waves, a striking the sub structure. So, initially what will happen is when you have an obstruction the sand will be removed here? Where will be the sand removed and where will it go? It will go and create a kind of sand bar, you understood and this sand bar may be a bit dynamic, it depends on the location, but this sand bar itself can form as another obstruction and that obstruction itself can create erosion and when

this sand is removed that will form another small hump in its on its sea side. So, you can have alternate dips and this varies from location to location, but this is a kind of a general phenomena which can, which is likely to take place. Is that clear?

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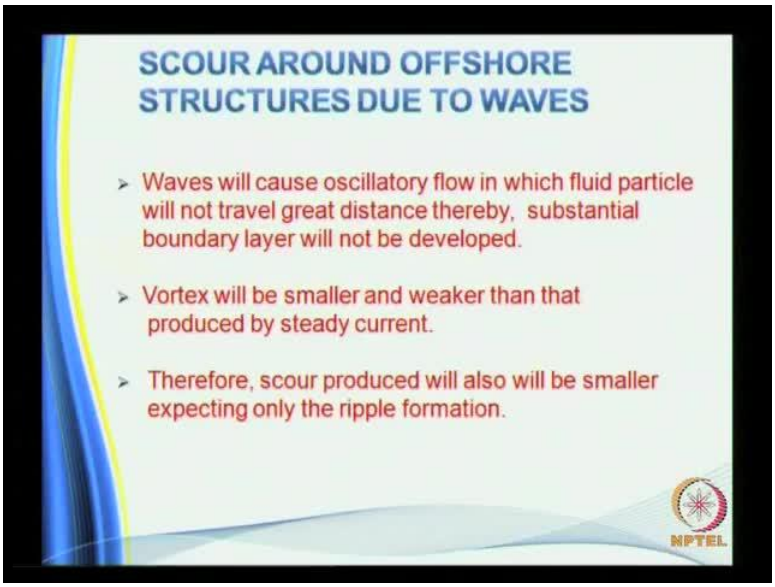

Now, scour under offshore structures due to waves. Waves will cause oscillatory flow in which the fluid particle will not travel great distance thereby substantial boundary layer will not be developed. Because it is oscillatory flow whatever transport is taking place it is likely to be only due to the mass transport velocity. Otherwise its only a an orbital velocity movement. So, in which case the vortex will be smaller and weaker than that produced by a steady current, therefore, scour produced will also be smaller, but you may you can anticipate ripples on the sea bed. So, these ripple formation can be with or without structure. With structure in the presence of structure the scour will be more, but otherwise you can have the ripples on the sea bed.

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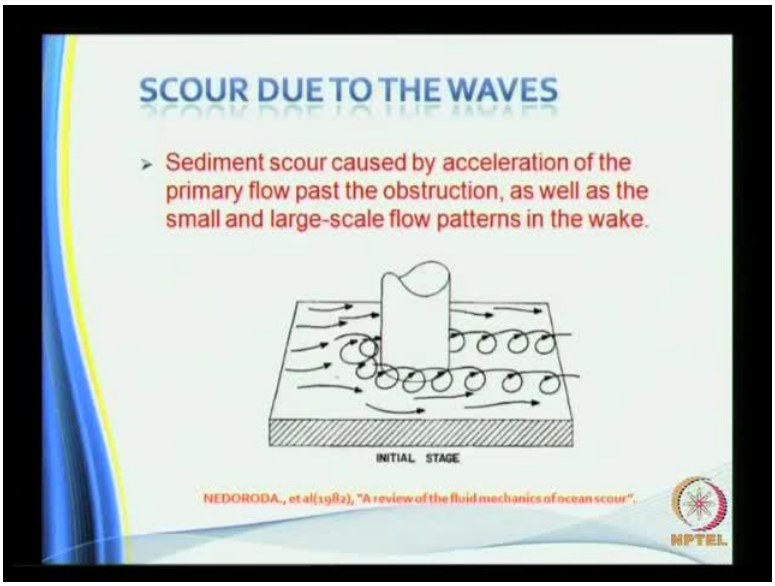

The same phenomena will hold good sediments scour caused by acceleration of the primary flow past the structure, structure as well as small and large scale flow patterns in the wake. The similar kind of vertices will be generated. The same phenomena of shear stresses, hydrodynamic shear stresses exceeding the sea bed stresses which will remove the sand particles for a complete detail of this you may look at the references given here. So, he has discussed the details of scour under this.

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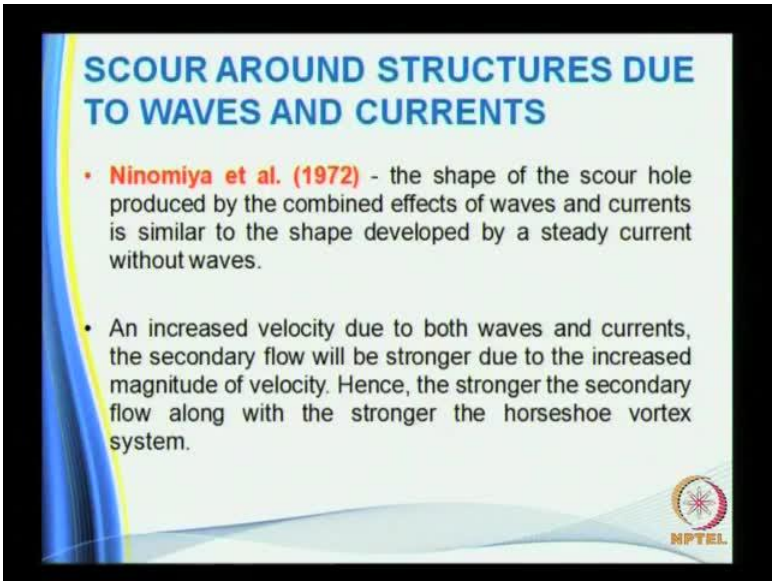

Scour under structures due to waves and currents. The shape of scour hole produced by combined effects of waves and currents is similar to the shape that is developed due to steady currents without waves. An increased velocity due to waves and currents, this again depends on the directions, direction in which the wave is moving along with the current, you can have different scenario, wave moving in this direction, current moving in this direction or there can be an oblique angle or both can move in the same direction. For the details of this please refer to the lecture material on wave deformation.

An increased velocity due to both waves and currents, the secondary flow will be stronger due to increased magnitude of the velocity hence the stronger, hence the stronger the secondary flow along with the stronger or to horseshoe vortex system. So, if you have the secondary flow, secondary flow in fact is one of the most important thing because of the pressure gradient there is a secondary flow, there is a return flow which is going to be superpose or which is going to be driven by the primary flow. So, that is that kind of situation only is responsible for the creation of the horseshoe vortex system.

Now, the strength of the horseshoe vortex system system will depend on the characteristics of the flow which is going to be altered depending on weather only current is moving or only wave is moving or waves superposed on a current and if so is it in the same direction or is it in the opposite direction or with a oblique angle. All these conditions or criteria will will govern the strength and or the intensity of the scour I mean the intensity of the local scour as well as the general scour that takes place in the near a offshore structure. Is that clear? So, I will stop here.

So, now we just now we move on to the geotechnical considerations when we are addressing the problem related to scour under marine structures.

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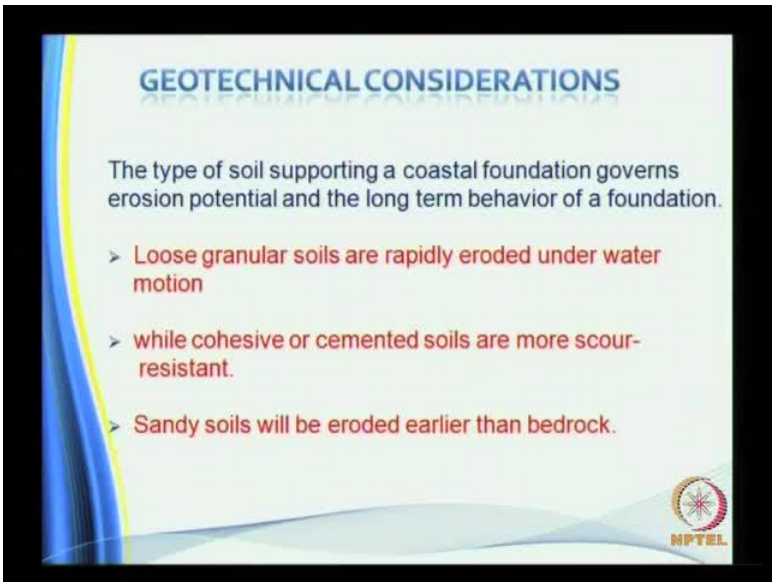

The type of soil supporting a coastal foundation governs the scour protection, scour or erosion potential and the long term behavior of a, of the foundation of that particular structure. Loose granular soils are rapidly eroded under the movement of water, flow of water, while cohesive or cemented soils are more scour resistant as we all know. So, that is one of the reason why we use natural rocks as scour protection. Sandy soils will be eroded earlier, not only earlier it will be eroded in more rapidly also compared to the other types of soil like bed rock etcetera.

So, sandy soil, sandy beaches, when you want to develop, in case you want to develop some, promote some kind of infra infrastructural facilities on a sandy beach then you better be watch out, on the watch out for the scour. Again there is a difference of scour and erosion. Scour is a kind of a local phenomena, more intensive with respect to the local, near the obstruction, but erosion can be felt over long distances. Next, soil properties, so properties of soil I mean I mean sediments which are very important in in the phenomena of scour, a scour is governed.

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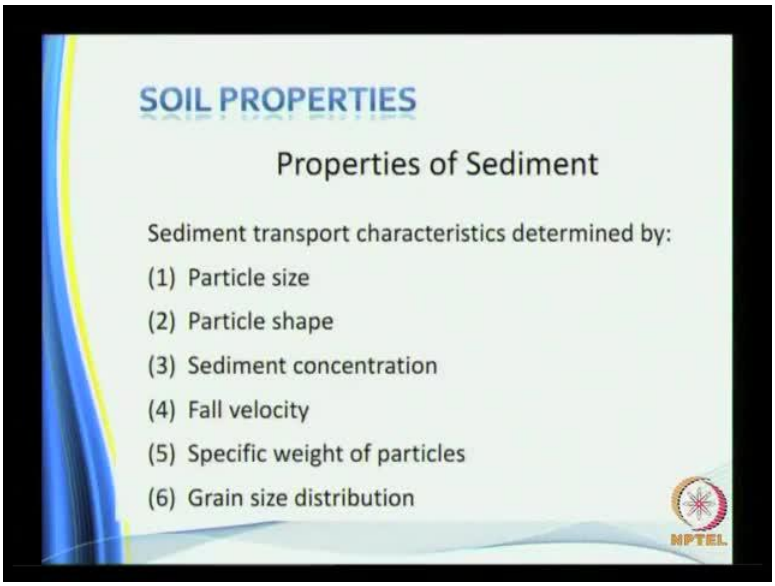

These are the characteristics of the sediments which control or govern the extent of scour. So, namely the particle size, particle shape, sediment concentration, fall velocity, specific weight of particles as well as grain size distribution apart from a few other characteristics. If you want to have detailed information on this you can go to my lecture on sediment characteristics wherein we have discussed most of the aspects and some additional factors also or you can refer to a number of references books given at the end of the lecture.

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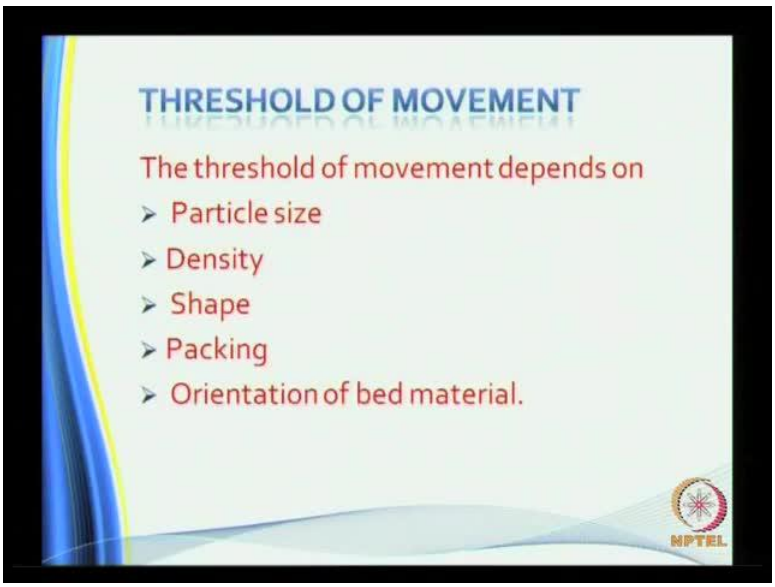

The threshold of movement that is where your hydrodynamics shear stresses exceed the sea bed shear stresses, that is going to depend naturally on the particle size, the density, shape, packing, orientation of the sea bed material all these factors they control the threshold movement that is the initiation of sediment motion. Under waves we have worked out a few problems also on initiation of sediment motion. So, look at the information's that have been discussed under the chapter on initiation on sediment motion.

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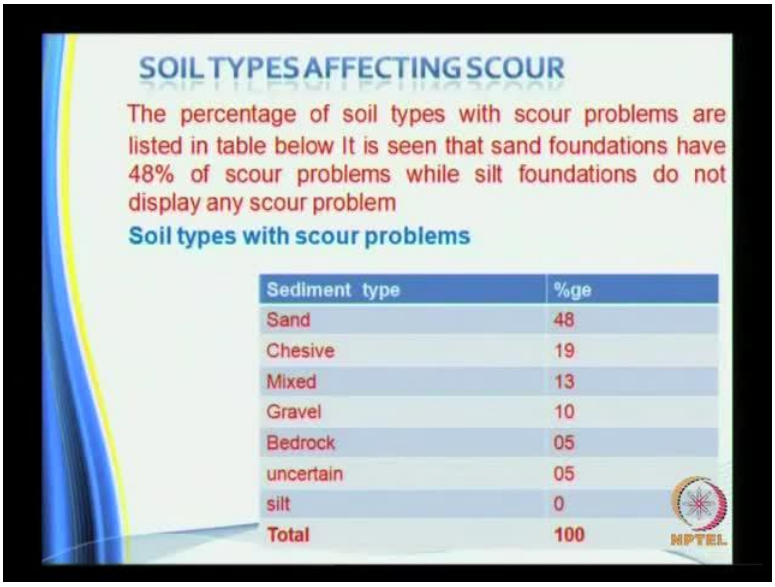

Soil types occurring, affecting scour. The percentage of soil types with scour problems are listed below. It is seen that the sand foundations have 48 percent of scour problems whilst silt foundations do not display any scour problem. So, percentage is given on the right hand side and the sediment size is given on the left hand side. So, sand has the maximum percentage. All these information's are available in the list of references that are given at the end of the lecture material.

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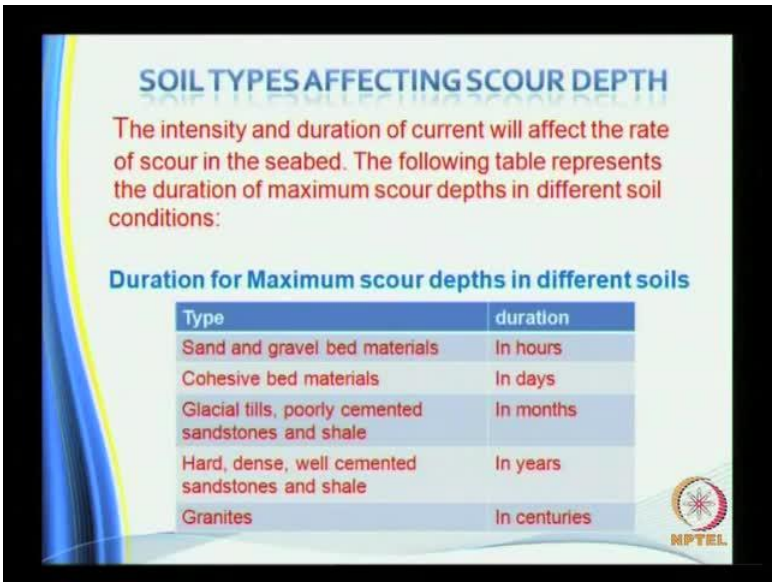

Soil types affecting scour depth. The intensity and duration of current will affect the rate of scour in the sea bed. The following table represents the duration of maximum scour depths in different soil conditions. Some of the scour depths which are used are local scour depth, ultimate scour depth, the ultimate scour depth is the depth beyond which almost like steady state once you reached. So, some of these information's can be had from number of references. I am not going to discuss about all those details. Duration for maximum scour depth in different soils are given here, sand and gravel bed materials in hours, cohesive bed in days, glacial tills, poor cemented sand stones in months, hard dense, well cemented sand stones in years and granites in centuries.

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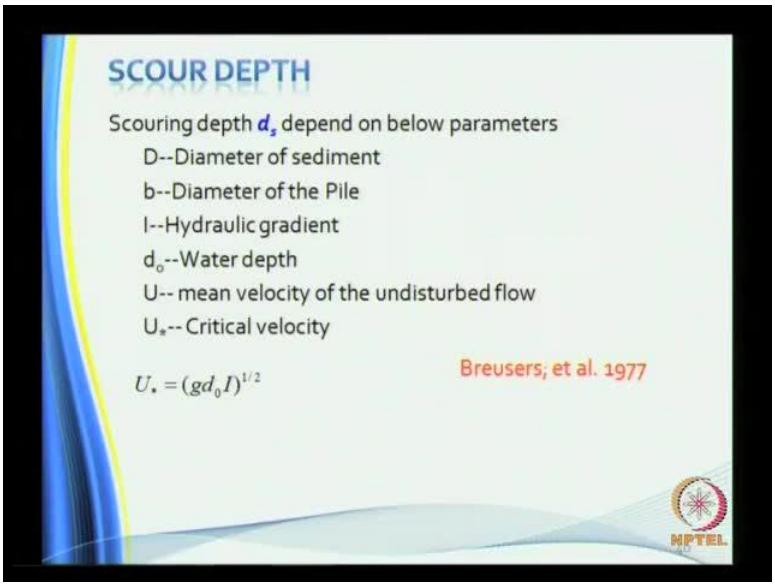

Now, scour depth depends on the following parameters, diameter of the sediment size I mean the grain size or the diameter of the sediment, diameter of the obstruction that is in this case we are considering a pile, hydraulic gradient I, d is the water depth, U is the mean velocity of the undisturbed flow and U star is critical velocity given as this expression g into d naught into I square root of this product as mentioned by Breusers, et al in 1977.

So, the critical velocity is represented as a form of the water depth as a function of water depth and the hydraulic gradient. The hydraulic gradient is going to be the driving force.

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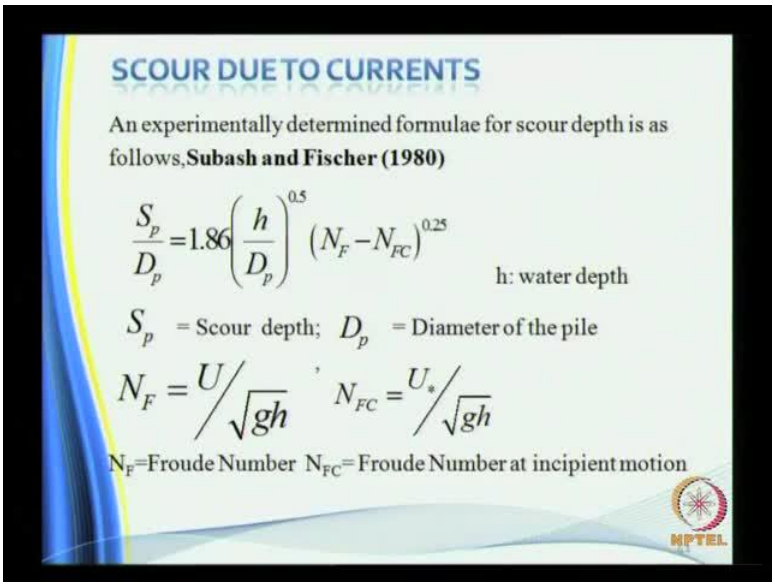

Now, let us look into the scour due to currents. Most of the expe, most of the empirical relationships that are available in literature as, are based on experimental work. The experimental work I mean in the laboratory is not so easy because modeling the sediment is not so easy. You can easily model the flow, but modeling the sediment is a bit tricky and it is not so easy. This is an equation or a relationship available for the prediction of scour depth as given here. S p is the scour depth, D p is the diameter of the pile.

This is given as a function of relative water depth h by D p and the Froude Number and Froude number at the incepiation, at the incipient motion which is governed by this is the undisturbed velocity with, for which you calculate your Froude number and the other one is based on the flow flow field at the incipient motion. So, once you are able to calculate all these variables if it is available to you. You can estimate, I would use rather estimate because all these things are derived from experiments and it is a, an empirical formula. Then sediment a scour depth (( )) under currents, so this is the, a relationship as given here.

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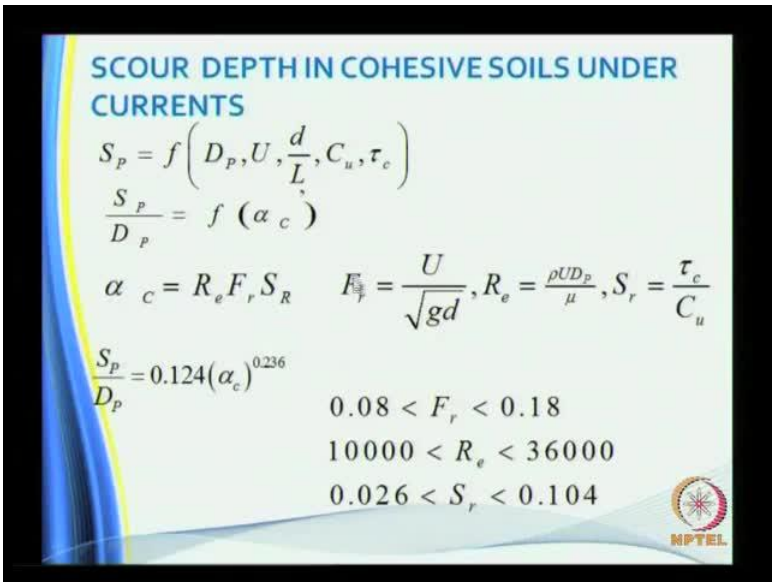

This alpha C is the product of these numbers and all these things, U is the velocity, d is the water depth and D is the, capital D p is the pile diameter, then tau C is the critical shear stress and all these variables are given to us. So, based on this you can estimate the scour depth under cohesive soils.

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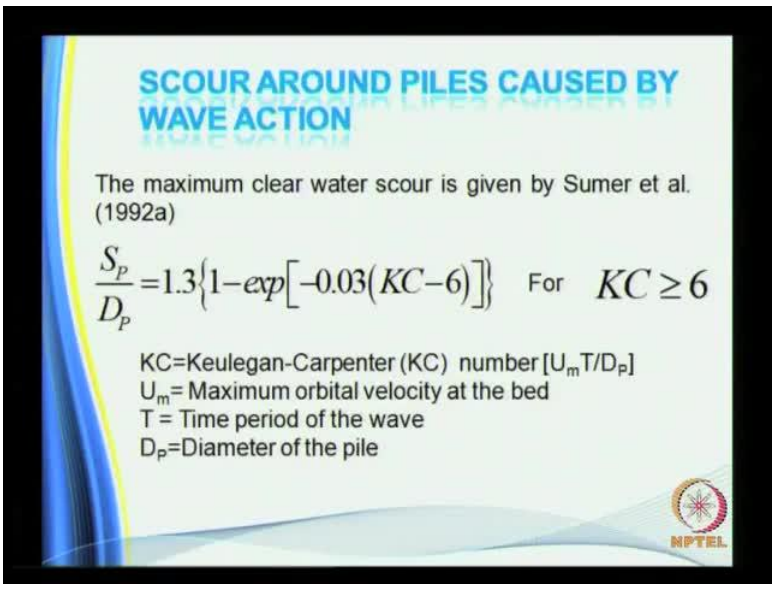

Scour under piles caused by wave action. This is basically a function of Keulegan Carpenter number. Keulegan Carpenter number is U max T by D. So, this equation is quite straight forward, but it is valid only for K C number greater than 6.

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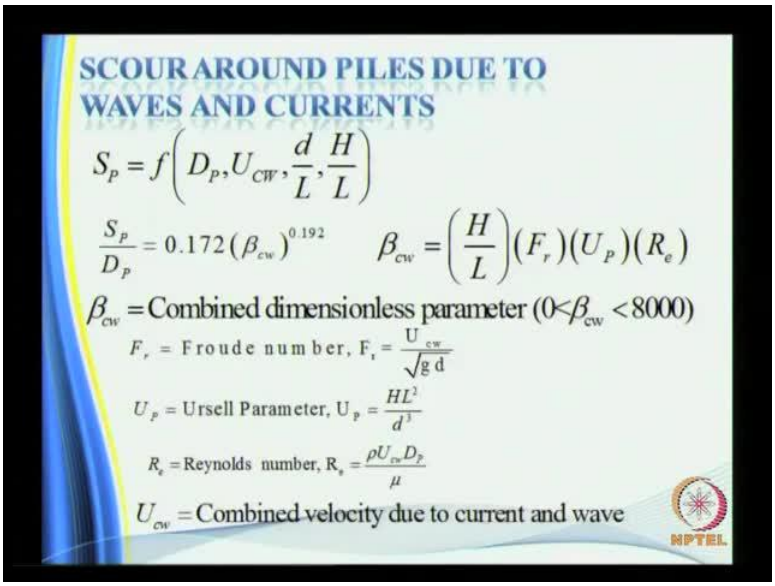

Scour under piles due to combined action of currents and waves. So, you have a beta parameter coming here which is controlled by this factor, where U p is Ursell's Parameter, this is Froude number, this is Reynolds number, this is wave steepness. Once you are able to calculate this then use this relationship to get the scour depths.

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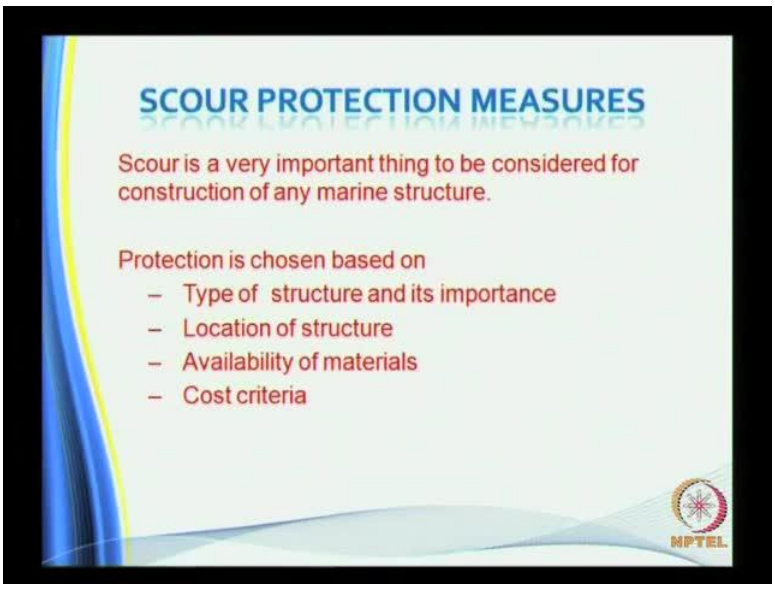

Now, we having seen some of the basic, starting with basic phenomenon of scour. We saw what are all the problems associated with scour, the importance of scour, the consequence of scour, if you do not consider the scour protection what will happen to the

structure? Then we looked at the combination of environment as far as flow is connected. So, you can have a steady current or waves, combined waves and currents etcetera and finally, we came up with we looked at the formulas for current, all these conditions, different conditions. We also looked at the different soil characteristics that are very important.

I am sure that this lecture should be starting as a base for you to, if you are interested in proceeding further in this area, this can form as a base material and of course, additional additional reading is very much essential in order to understand, in order to really do some kind of research or in the case of field application. Now, we will move on to scour protection measures as I said earlier is a very important aspect, that to be considered for the construction of any marine structure. Protection is chosen based on the type of structure and its importance. Location of the structure, availability of material, what kind of materials are available and finally, the most important is the cost criteria. We have a wide range of products that could be thought of, but a careful planning is needed.

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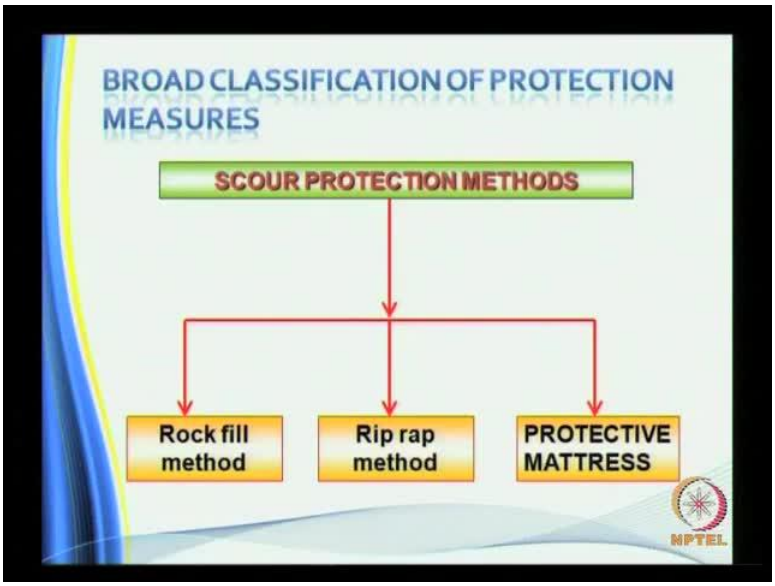

Broad classification of protection measures, the scour protections methods can broadly be be classified as rock fill method, rip rap method and protective mattress.

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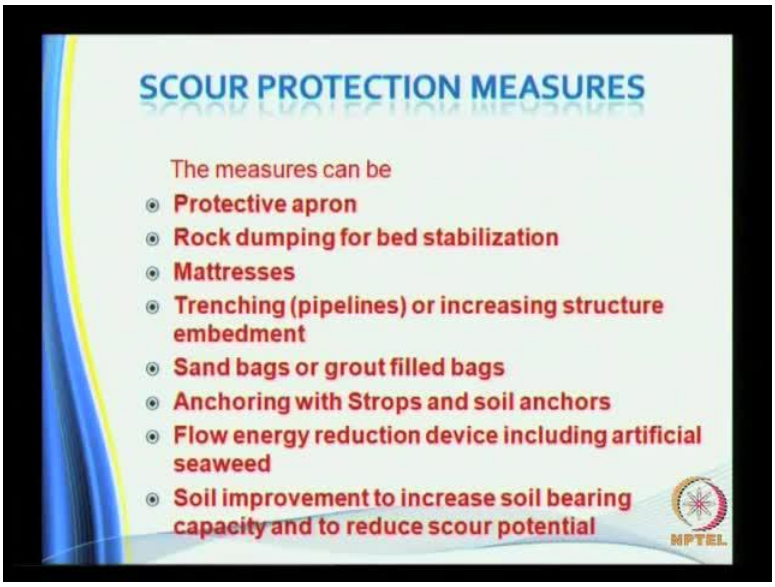

Scour protection measures. The measures can be actually the details (( )) I have presented the details here. It can be either protective apron, like the apron near the toe of the dam, rock dumping for bed stabilization, mattress, this mattress can be geosynthetic mattress. Look at some of the, look at the lecture on geosynthetic materials, application of geosynthetics in coastal engineering, that will give some information about the protections scour protection.

Then trenching this particularly is very important in the case of pipelines or and even in the case of, I would say even in the case of a breakwaters if you have excavated toe you need to have a kind of a trench wherein you can place your toe, although, difficult it is extremely effective then sand bags or grout filled bags. This is the most commonly adopted, it depends on the environment for example, if you have a location where you have lot of sharp corners, sand bags is not recommended procedure. Anchoring of strops and soil anchors, flow energy reduction device including artificial seaweed.

Now, there are some geosynthetic products where you can have seaweed growing. So, this is a, this can result in rich flora and fauna also. There are options, but naturally when you want to have more benefits the product is going to be costly. So, you have to decide what exactly you want. Soil improvement to increase soil bearing capacity and to reduce scour potential, these are all soil improvement studies, ground improvement techniques.

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So, there are variety of problems and methods also. You have on the top the types of structures. This I have taken from Richard Whitehouse from his book Scour on marine structures, around marine structures. Piles, pipelines, large volume structures, sea walls, breakwaters, jack up rigs, these are the variety of structures that are in existence in the marine environment, in the ocean or in the coastal zone. So, on this column you have the type of the method for protection. Protective apron for piles, large volume structures, seawalls and breakwaters. Rock dumping can be used for all, but of course, the size of the rock will be varying, then mattress can be for pipelines. In fact mattress is widely used for pipeline, pipelines widely used.

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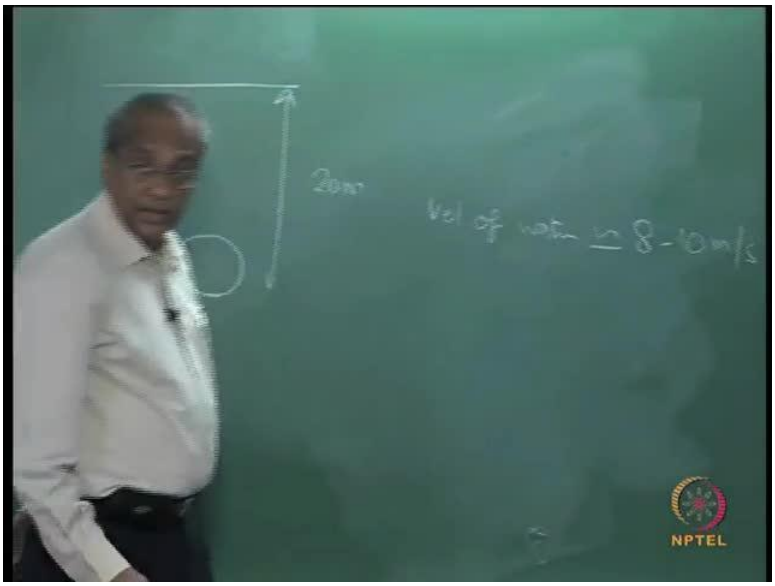

And in fact we had a very nice experience of lowering a pipeline in a water depth of 20 meters where the velocity of water was approximately 9 meters per second, 8 8 to 10 meters per second. This is somewhere in Gujarat, along Gujarat. So, you can imagine with this kind of a a speed the pipeline is resting on the bed and we need to have a protection for the pipe. Say, we looked at several, I mean options and finally, we went in for this mattress.

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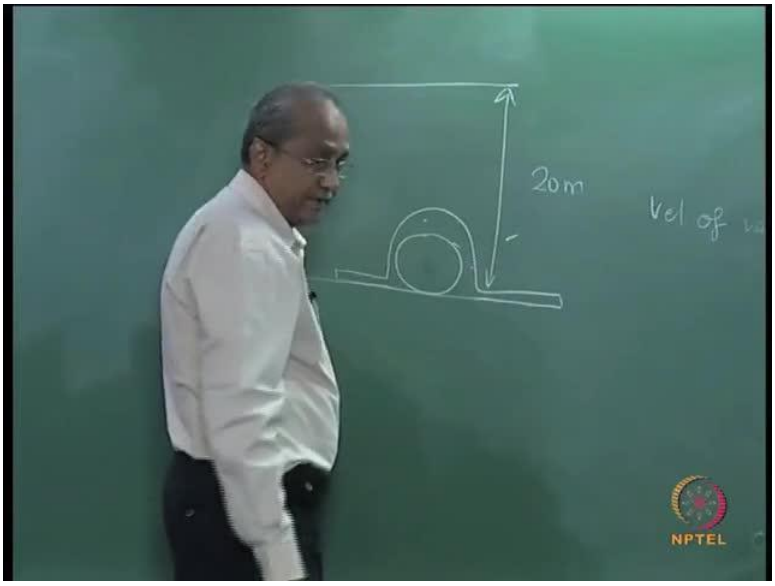

Unfortunately, I do not have any pictures on this so what what was the main problem is not even the anchoring, the main problem was dropping it and making it, keeping it in position because of the huge velocity involved. So, this has been completed and the pipeline is in its position without any problem for at least now may be about between 5 to 10 years. So, then sand bags there are several cases, in fact it is also used in the case of seawalls and breakwaters also, although it is not marked here. Flow reduction in all the cases we have then soil improvement scheme mostly piles, large volumes, seawalls etcetera.

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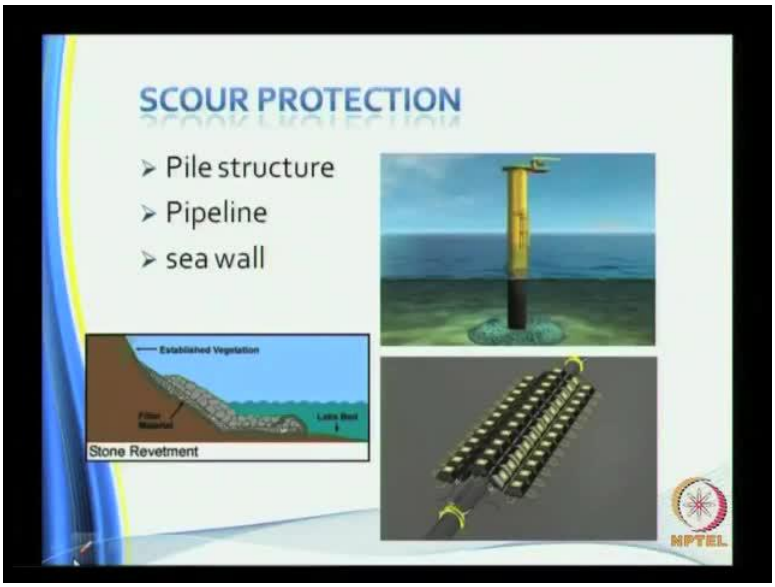

So, you see that there is a pile structure here, how we, how it has been protected. You see that this is the kind of protection. So, the width, a height all these things need to be calculated or you can have a stone stone revetment in order to provide, prevent the slope erosion or slop the scour around this and you can also have vegetation here which is strongly recommended. This is a, for the case of a pipeline, you have a kind of a mattress.

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This is application of geobags, offshore wind plants, wind energy plants which is gaining tremendous importance these days. So, when you operate when you go in for wind form this is one important area where we need lot of information, scour protection forms a basic necessity.

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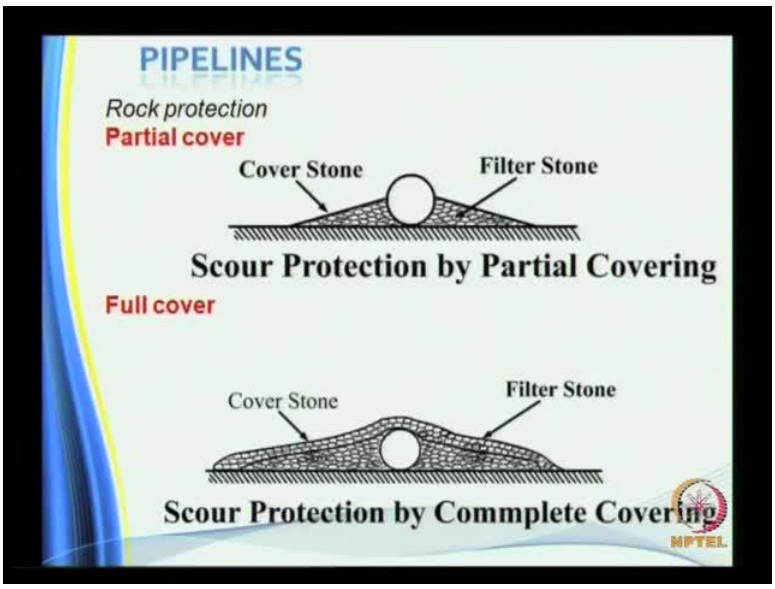

Then this is in case of a pipeline, this is only a partial protection you have you protect only this portion. Probably in deeper waters because if this kind of situation exists in

shallower waters the ship anchors etcetera might hit by chance. So, in case of mostly this kind of situation, this kind of protection is considered the whole pipe is covered.

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Protective mattress as I have said earlier, this is free prefabricated mattress used where less control over rock dumping. They are flexible and follow local bed contour. So, the, those are the advantages. So, synthetics it is also a fascine, this is another product which was, which has been mentioned in Herbich et al. So, filter fabric strengthened with geosynthetic mattress this is nothing but your natural your geosynthetic material and you have strengthening, so that it is very flexible you can cover it and use it for…

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So, this is another block mattress. A continuous array of concrete blocks held together by cable and then it is laid over the concrete block. See, for example, you look at this. This is to take care of end scour. So, this is vertical walled structures, seawalls as I have told you these are used by using gabions.

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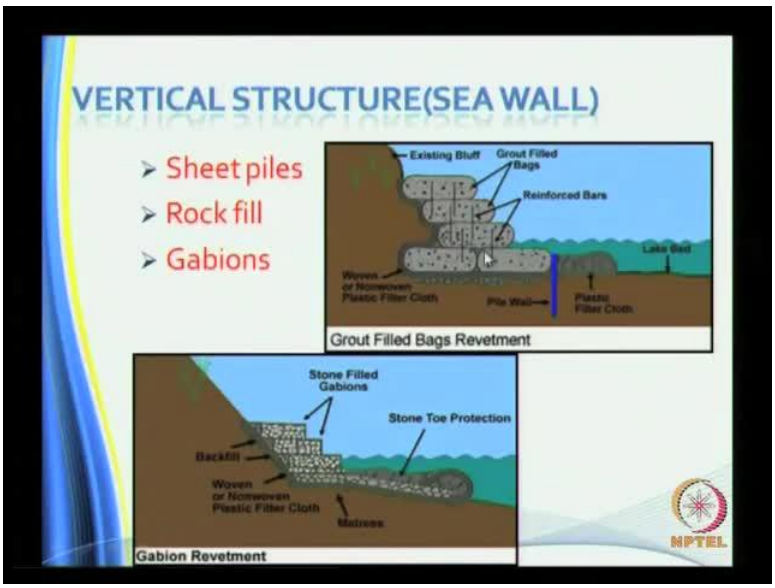

See scour and erosion, they are together in fact. There's a slight difference, but the effect is almost same, effect is loss of material.

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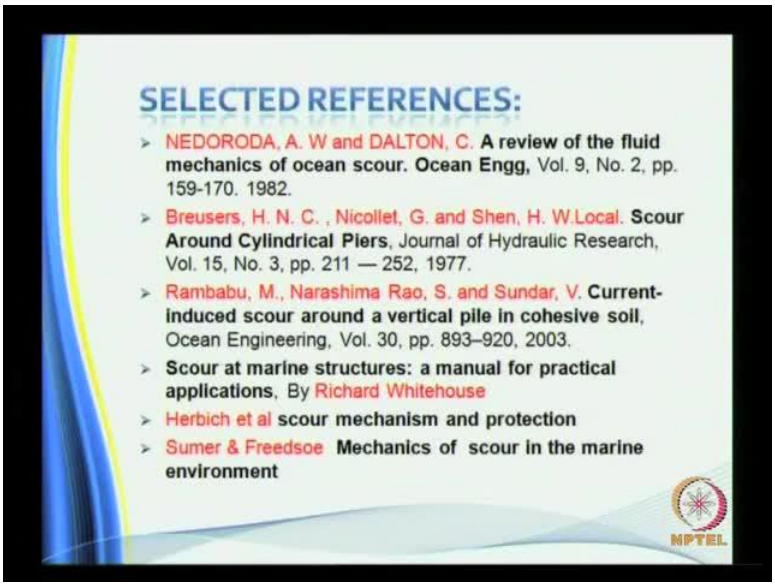

So, with this I will conclude and I would suggest like to list the books. All these all these references have provided some useful information on scour under marine structures.

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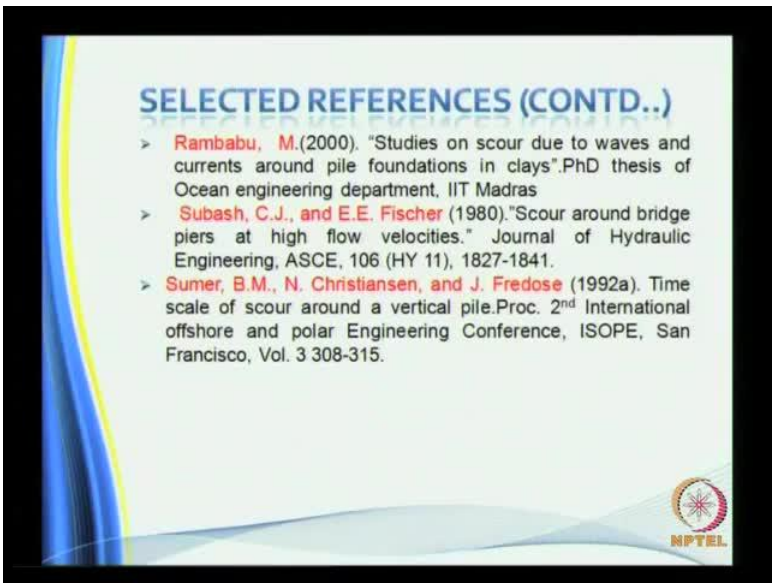

And these are all some of the references that I have used in preparation of this lecture and there might be some others also, which I might have missed.