Coastal Engineering

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Module - 5
Breakwaters
Lecture - 3
Breakwaters – III

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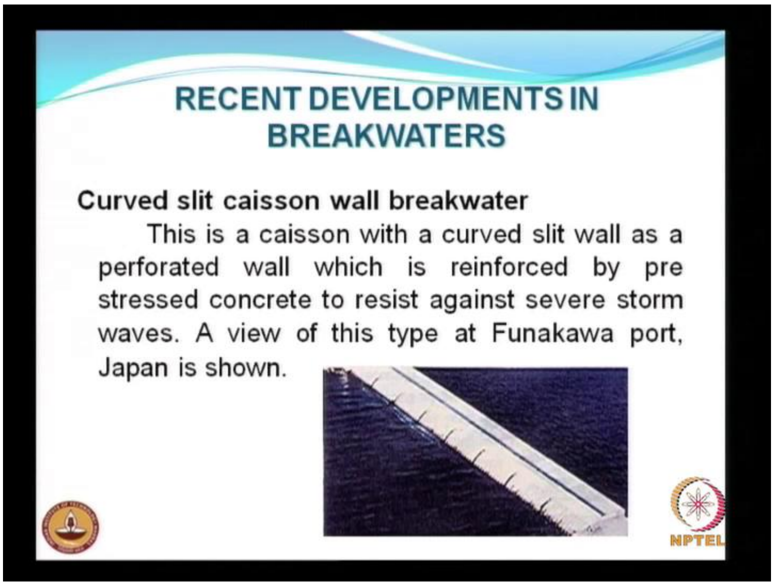

So, today we will get started with some of the recent developments in breakwaters. As we all know, at least all of you, most of you, will be knowing that what we have been dealing with is, with the rubble mound breakwaters. I have already told the most widely adopted breakwaters along the Indian coast are the rubble mound breakwaters and to certain extent we also have the composite breakwaters. So, the Marmugoa port was initially a vertical composite breakwater, in order to enhance its stability, they have converted this vertical composite breakwater into a horizontal composite breakwater by putting in some boulders on its seaside. We will look into the details of some of the experimental study in order to assess its stability later.

So, although we have not, there is not much of many types of breakwaters which have been tried over in India. We still have to look at some of the other types of options; other options we have in the case of breakwaters. These are all mainly deals with, mainly depend on the need; the specific need and also the type of water depth you are looking at for example, some of these concepts maybe for large water depths, maybe 20 meters or so. So the concept as I have said, any breakwater would look into the possibility of reduction in the energy, incident wave energy, either by losing its energy while it is running over the surface or losing its energy while it is propagating through some kind of permeable medium.

So, this is the idea. Most of these things you also know that, the energy in the waves are concentrated near the surface. So, the attempt should be to absorb the energy or I mean to destroy the energy closer to the surface. With this concept in mind, so, all this, although I have said recent developments, it is not really recent developments. These developments have started from mid 90's and still there are, some of them are in conceptual stage. Some of them have been already installed. So, this is a curved slit caisson type breakwater, wherein you see a curve here.

So, you see a curve here and this is the walkway and then, you have slits over this. So, this is, you know already what is the purpose of such thing. So, this is, the energy is dissipated when it is trying to move over the curved surface. That is obvious and then, and this is of course, resting on it. It can be resting on piles or it can be resting on, it can still serve as a composite breakwater, a vertical caisson.

So, only the curved surface will be near the coastal surface and then, you can still have the; anyway, the lee side will have a vertical phase. It can have vertical phase, wherein you can have the berthing of vessels.

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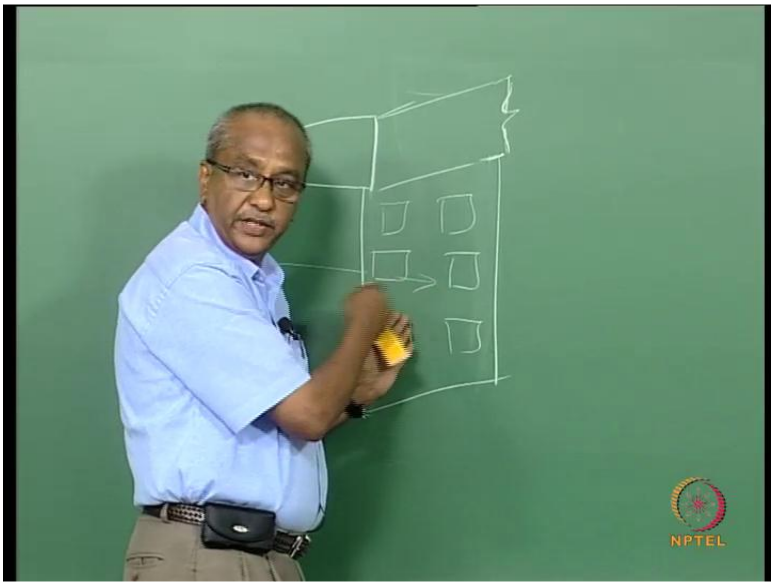

So, even on the lee side, you can have a situation if; so, this is, so, if this is the type of surface. So, on the lee side, you will have the berthing of vessels. The concept is, either this whole thing can be solid structure or it can be on piles. It can be on piles. You understood? So, piles spaced at regular intervals. So, if this piles are placed at regular intervals, what will happen? The current or the current will move through the piles. Particularly, when you have an environment dominated by long shore sediment transport, so, you know that we have already seen case studies, where if you have a solid obstruction, a littoral barrier, the movement of sediment is arrested and on the up drift side, you have deposition and on the down drift side, its erosion.

So, that can be avoided if you have a pre passage of the sediments. So mostly, the bed, if it is particularly in case it is dominated by the bed load. You understood? So, this is one advantage. So, either it can be like this. Or now, there is a problem here. If you are going to have it instead of piles, if you are going to have a solid obstruction, so then, that would result in the imbalance in the shoreline stability. Number one. The other one is, if you are having on this side of the harbour, then this is going to act as a vertical wall and that is going to reflect energy.

So, in order to avoid that, there are other possibilities. Suppose, if I consider this not as a pile, as a solid obstruction, then there are possibilities of having creating some kind of, converting it as a permeable medium, so that, you can have the waves water gushing inside and outside. Then, the energy is getting dissipated, so that, you do not have reflection inside the harbour. So, these are all some of the concepts, which you can think of while designing such kind of breakwater.

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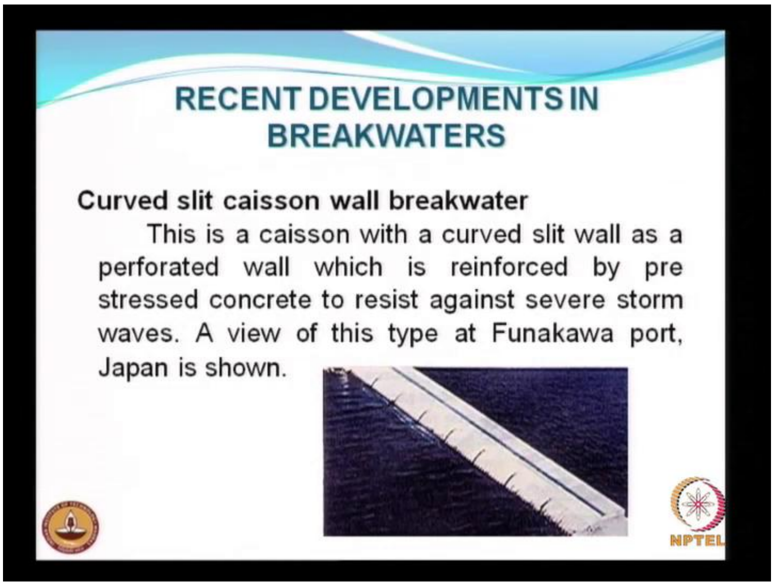

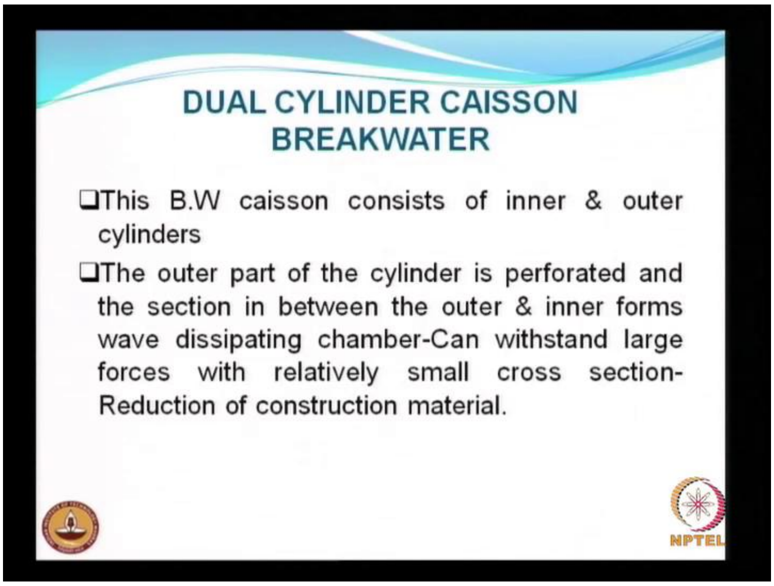

So, this view of this type has been installed, has been available, has been constructed in Funakawa port, that is in Japan. Most of the breakwaters, which I will be showing are in Japan. Then, this is a bit quite popular concept, wherein it is dual cylinder caisson breakwater. Dual cylinder breakwater; this breakwater caisson consists of an inner cylinder and an outer cylinder. The outer part of the cylinder is perforated.

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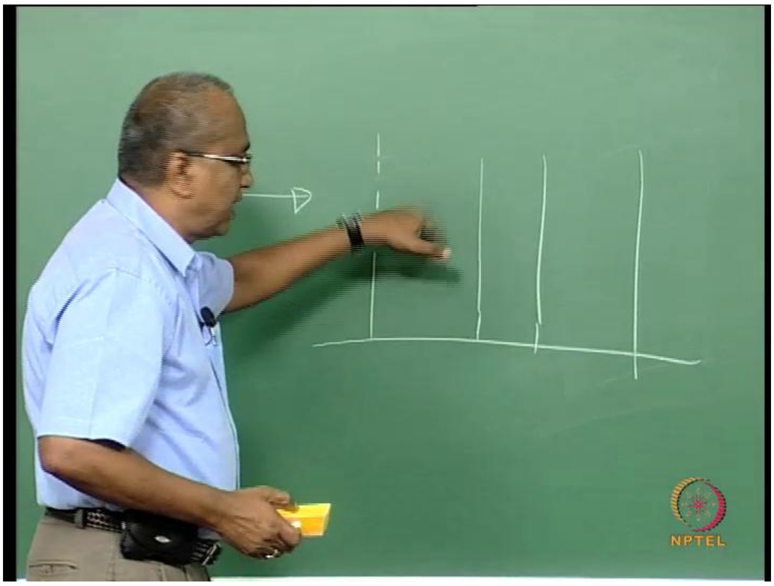

So, you have an inner cylinder and you have an external cylinder. The idea is, when the waves are coming, as I said, if there is some kind of porous medium, permeable medium, then there is no problem you see. So, the water will get inside and then, this will get oscillated. So, the energy will be dissipated. Because, once it has entered inside, then the oscillation will take place and then, the energy will get dissipated. You understood?

So, the outer part of the cylinder is perforated and the section in between the outer and the inner forms a wave dissipating chamber. It can withstand large forces with relatively smaller cross section and reduction of construction material, because you are avoiding this area. You are not putting any material right. But still, it is going to be a gravity type structure.

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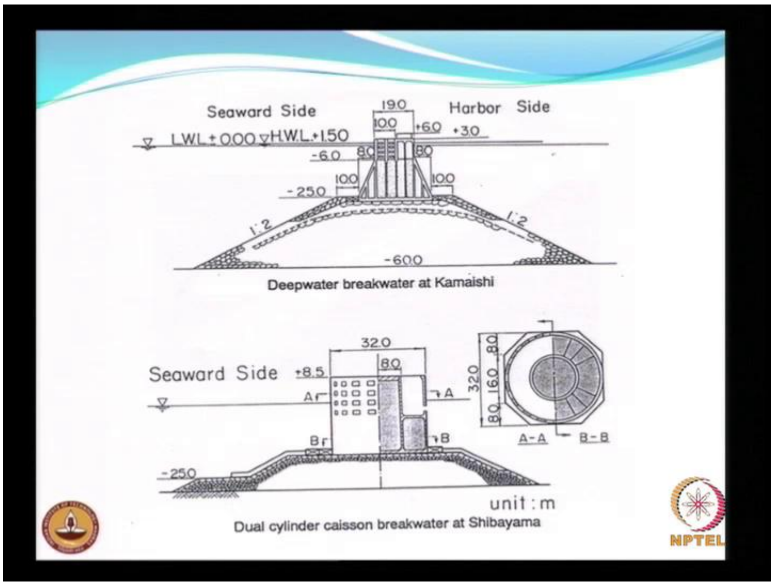

This quite a popular structure, wherein you see that, this is the kind of structure you can, it is of course, a vertical composite breakwater. So, this is the inner cylinder and this is the external cylinder. You can have, it is having the perforations and the perforations can be only near the free surface, where your force is going to be dominating; the force due to waves. So, this perforations will take care of the dissipation of the wave forces. On the lee side, you do not need any perforations because, there is not and in case, if you are suspecting some kind of waves inside the harbour, you can still go in for perforations on this. But, this has been constructed in Shibayama. That is again in Japan and this has been reported to be quite a promising breakwater.

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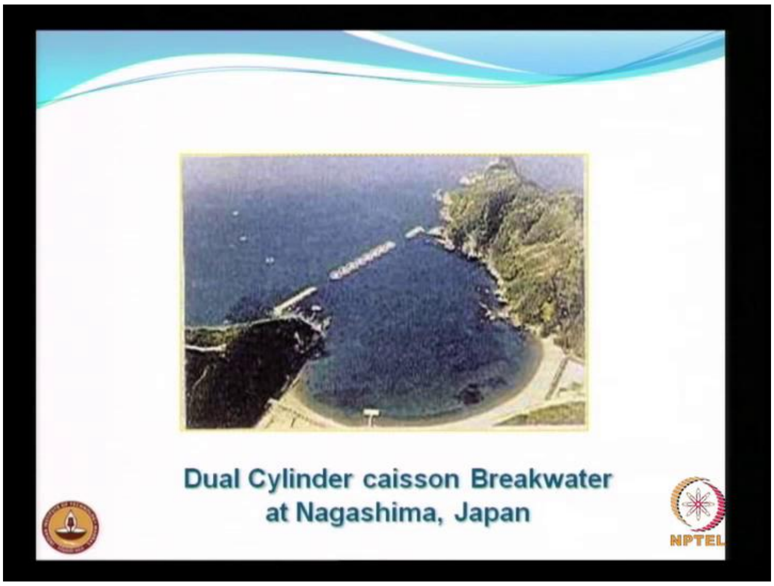

This dual cylinder caisson breakwater has been installed in Nagashima that is in Japan. So, look at this. This is excellent area for the formation of a harbour. Maybe, a harbour or a small mariner or maybe a fishing harbour. It depends on the need and also, when you want to develop a port or a harbour, you need to look at the inter land facilities, because you need to have sufficient land available. So, all these things also would decide and also the marine traffic. There are so many other. All these aspects should be covered, would have been covered under port and harbour structures. So you see that these harbour breakwaters are put here and then, you have an entrance. So, this is going to be a calmer basin for the operation.

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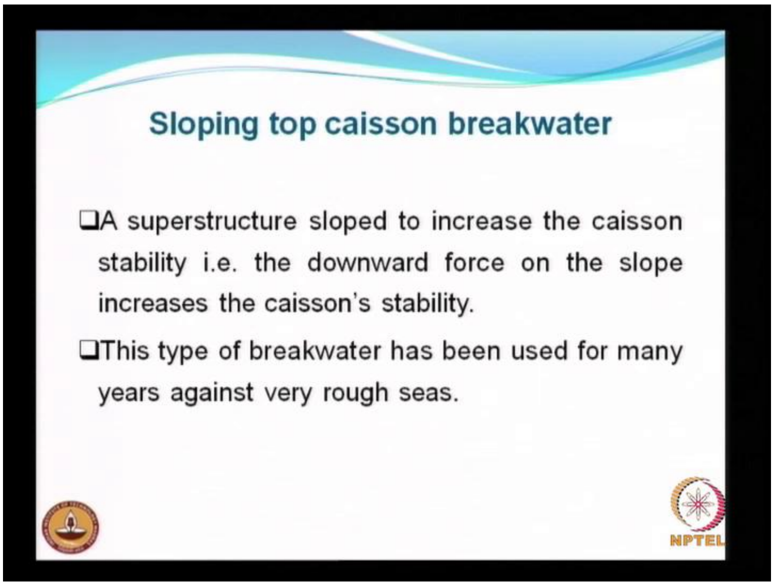

Sloping top caisson breakwater; a super structure sloped to increase the caisson stability. That is the downward force on the slope increases the caissons stability. This we have already seen earlier, when I was explaining about the vertical caisson breakwaters. So, this type of breakwater has been used for many years in against very rough seas.

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So, the concept looks like this. The breakwater looks like this. You have a sloped wall and you have, this is similar to a crown wall, but inverted. You understand? Crown wall will normally have a vertical phase.

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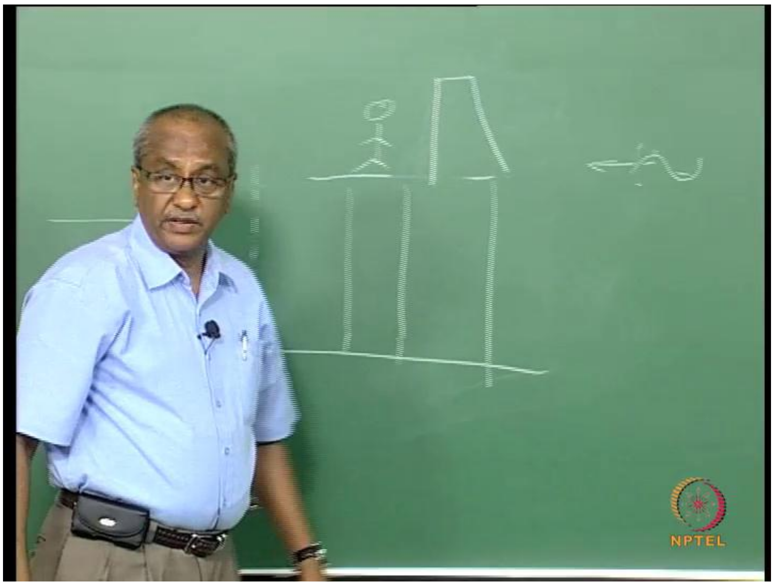

On its side, on its, so, when you have a crown wall, if this is the waves, normally, the crown wall will be like this and this will be your slab; walking slab. But here, it is reversed. So, what will happen? When the waves are moving, you have a, it has to ride over the sloping surface. So, that can reduce. So, this shape is very very important. Later, we will see that, we have done some experiments looking at the shapes.

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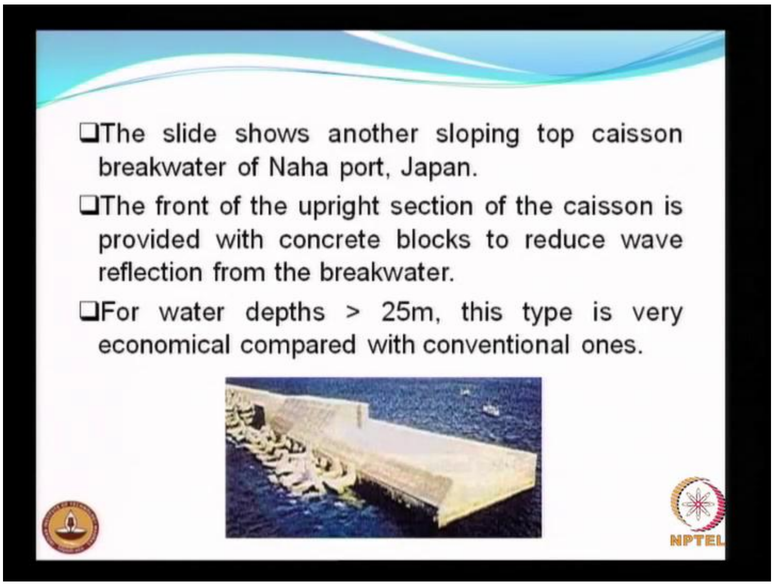

This has been installed in Hitachi Naka. That is in Japan again. The slide shows another sloping top caisson breakwater in Naha port in Japan, wherein the upper, the front upper right, upright section of the caisson is provided with concrete blocks to reduce the reflection from the, so, this is an added, so on the seaside, if you want to put, do some kind of extra additional dissipation, if you want to have, you can always have some kind of a rubble mound structure here. Later, we will also see some of the, we will work out some problems without this rubble mound at the base, what is the force and with the rubble mound base, what is the kind of reduction of force you have on the caisson.

So, we will work out some examples later. So, in this way, this is going to be helpful, having rubble mound near its toe and also it is going to act as a additional, I mean take care of the toe erosion. If water depths are greater than 25 meters, then this type is quite economical with conventional ones. See normally, as I said, if the water depth is greater than 20 meters, itself going in for conventional rubble mound breakwater is not so advantageous because, the volume of material you need is quite huge. The base width of the breakwater is quite, is going to occupy a larger area over the sea bed.

So, offshore breakwater, this is a typical caisson. A caisson, I mean a typical caisson, but, it is a trapezoidal section. Trapezoidal section similar to your conventional breakwaters and it can be used. They have adopted for, where the water depth is greater than 25 meters and relatively if the foundation is, the soil is relatively weak, probably you can think of using this. Again there is drawback in this, because your base width is going to be high.

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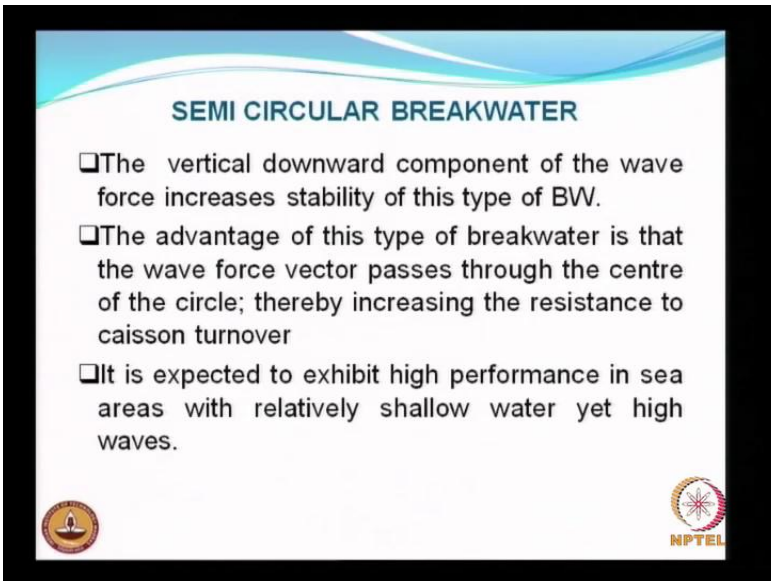

Semi circular breakwater; semi circular breakwaters is quite very efficient kind of breakwater. So, you have breakwater like this. The vertical downward component of the wave forces increase the stability of this breakwater, because it is, this is again a semi, I mean a gravity structure. So, the advantages of this breakwater is that the wave force vector passes through the center of the circle, thereby increasing the resistance of the caisson turnover that is mommat. So, it is expected to exhibit high performance in sea areas with relatively shallow water, yet exposed to higher waves.

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So, this is a typical semi circular break water. It is in Miyazaki again in Japan. So, you see that the surface of the breakwater is perforated. So, you can have impermeable, the whole surface being impermeable or the seaside alone being permeable or the whole thing can be permeable. So, all kinds of possibilities are there. Depending on your need or the requirement, you can adopt the kind of breakwater you are interested in and the porous, the permeability is again to enhance the dissipation of the energy. But there are some problems. Whenever you deal with the porosity, I have been mentioning about the porosity porous breakwater. Whenever you mention about this, you have to have some kind of a regular maintenance because, the holes can slowly get clogged, but the radius can be reduced. But you can easily; maintenance is not that difficult, but, it has to be done.

So, instead of just dissipating wave energy, it can be used as conventional usable energy. That is, we have always been talking about dissipation of energy. Because, when we are talking about breakwaters, we are talking only about dissipation of energy. But, there are other concepts. When the energy is available in the ocean waves, why cannot we make use of it? Is it possible to extract energy from the ocean waves? Yes, it is possible to extract the energy from the ocean waves. There are some well established concepts. Although there a number of concepts, I will not go into the details of all these concepts. But, I will just touch upon only the most popular concept, which is the oscillating water column device. So, one thing is, on the sea side, you can make use of the energy convertor and on the lee side, you can use for berthing of vessels.

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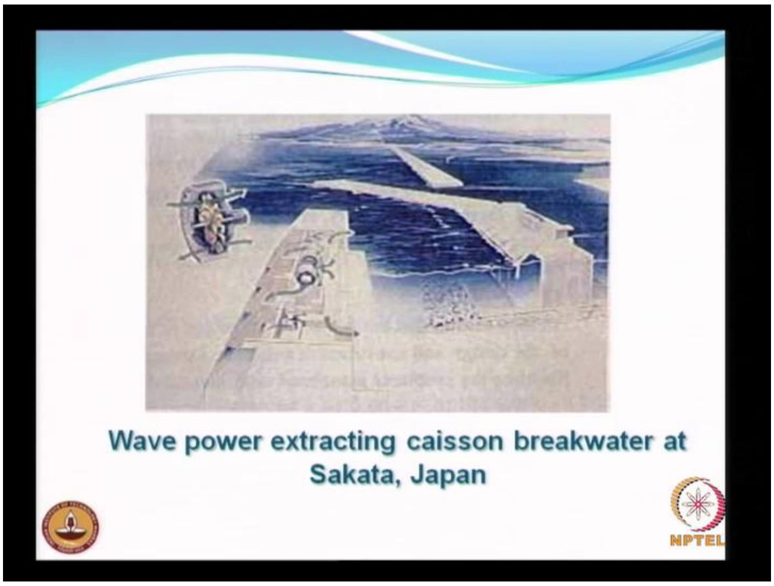

So, breakwater can be used for extracting. This is in Sakata, and that is in Japan. So, you see that this is a caisson breakwater here and on the lee side, this is the harbour side. So, this is the sea side.

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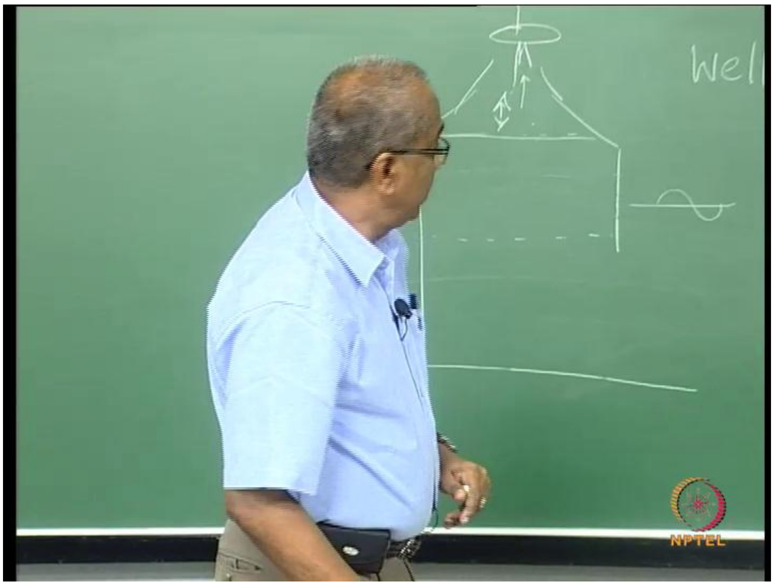

When the waves come inside, the there is an; so, when the waves move inside, so, there is an oscillation in between this area. So, here the water level can be oscillating between this and this point may be. So, it can be oscillating within in this chamber. When it is oscillating, you see that there is an air column above this water depth, water surface. There is a water column, air column, which is going to oscillate according to the oscillation of the water level inside this chamber. So, this is what is called as oscillating water column.

So, this oscillating water column allows the air inside this chamber to oscillate. So, there is a kind of a motion. If you have a turbine here, that can be made to rotate and this rotating of this turbine with this, we can get your energy. It can be converted into useful electrical energy. The concept is quite straight forward. It is not so difficult. Only thing is, there are a lot of work, which has been done in optimizing this chamber etcetera, because you need to tune the system, because this oscillation is going to be a function of mostly the frequency of the wave.

If there is a site, where the frequency of the waves do not change much, then this is not found to be quite useful because, it is very easy to tune the system, because this length, all these things, everything depends on the wave climate. Also in a ray, in an area where you have a wide range of wave characteristics, sometimes it may be a problem. The efficiency may not be so good. So, then you see that when there is a rise in the water level, this will be moving upward. But, when there is a fall in the water level, this will be moving down. So, then the turbine will be rotating like this and then again, it will be rotating like this. Then, energy released is energy absorbed. So, what they should do is, they should, irrespective of the motion of the air column, irrespective of the direction of the motion of the air column, the turbine should rotate in the same direction. That was quite a big challenge when this concept came into being.

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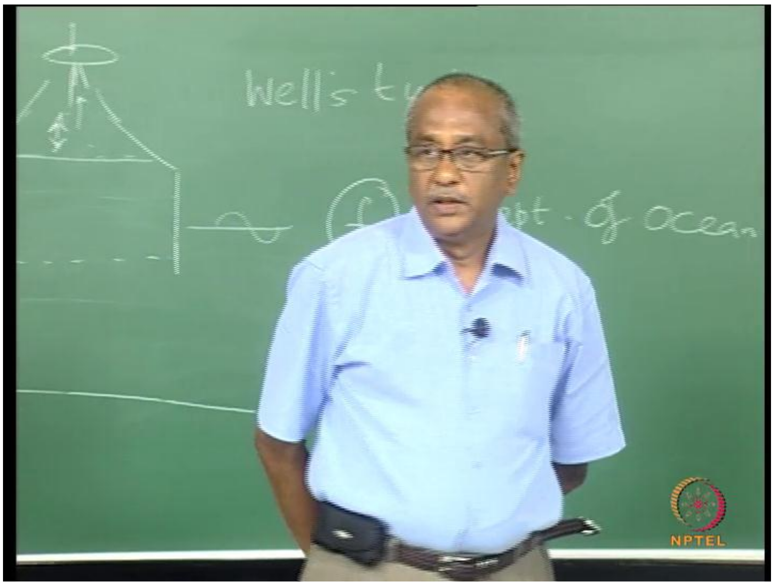

That time they came out with what is called as wells turbine. So, you can google and see about the details of a wells turbine. So, irrespective of the direction of flow of the air column, the turbine will rotate in the same direction. This helps in generating your electricity irrespective of which, whether the trough is inside the chamber or the crest is inside the chamber. So, what are all the parameters you need? This parameter, this opening and then how you have this, whether it has to be streamlined, all these parameters need to be looked into.

There are number of studies, which we have in the department of ocean engineering. In our department, we have done a lot of work on this aspect. In early, starting from mid 80's, going all the way to, maybe it was running up to about end of 90's. So, mid 80's to end of 90's, we had lot of work being done on major projects concerning this wave energy.

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So, this is what is shown here. This is after a lot of studies in the in our department. We had gone in for development of a wave energy caisson in the field and this is in Vizhingham harbour that is in along the state of Kerala coast. So, there is a harbour already that was in existence. So, they just wanted to use this location. So, the caisson was cast on the beach and then, towed in a water depth of about 10 meters and it was installed.

So, construction was done in a calmer area and then, it was towed and then, it was installed. See, actually this caisson can also form as an integral part of the breakwater. So, you can merge the breakwater for certain portion of the, merge the owc caisson for certain portion of the length of the breakwater.

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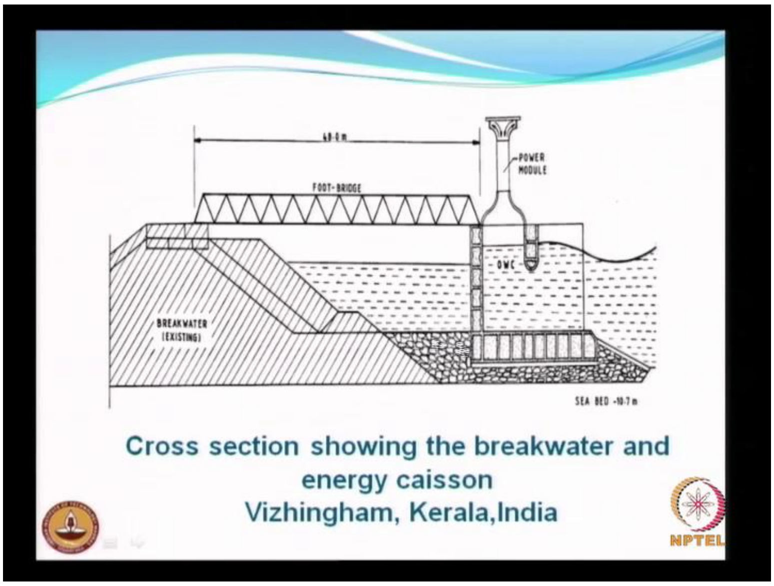

So, this is how it looks. So, this is the existing breakwater. So, this is the caisson. So, you have the oscillating water column. This is the lip wall and you see, this is harbour wall.

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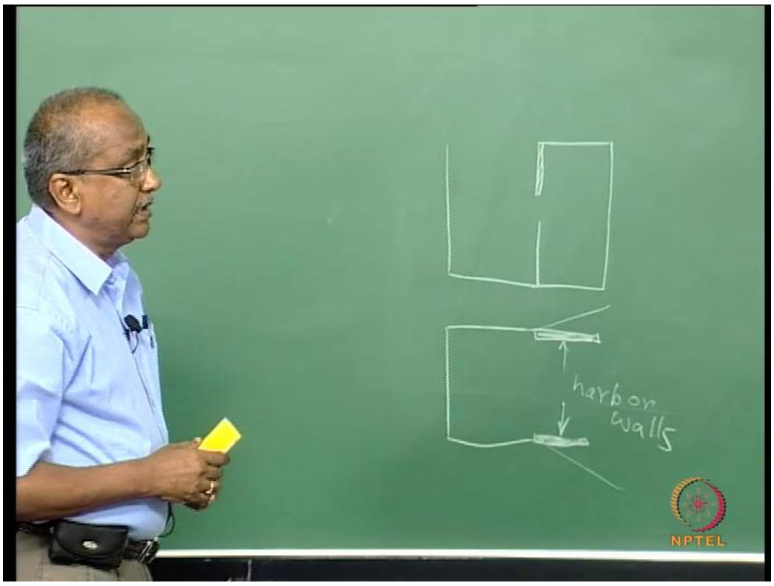

So, it will be, the section looks like; so, this is your lip wall. So, that is in plan. So, these are called as harbour walls or guiding walls. So, this concept was introduced by the Norwegians, where they tried to look at different configurations, whether it has to be like this or it can be like this. So that, when it is like this, then you try to focus the energy and then, allow the entire energy to get inside the oscillating water column. You understood?

So, these are all some of the concepts and there you see the harbour wall being installed. Harbour wall that has been constructed. So, you have the power module right here. In order to access the caisson, they had a bridge. All these things are in existence and it was a proven model. This was only for demonstration. That is, this was supported by the then department of ocean development, government of India. So, this was completely done by the department of ocean engineering and the funds were from department of ocean development. This project as a demonstration project, it still stands there and it has been proved.

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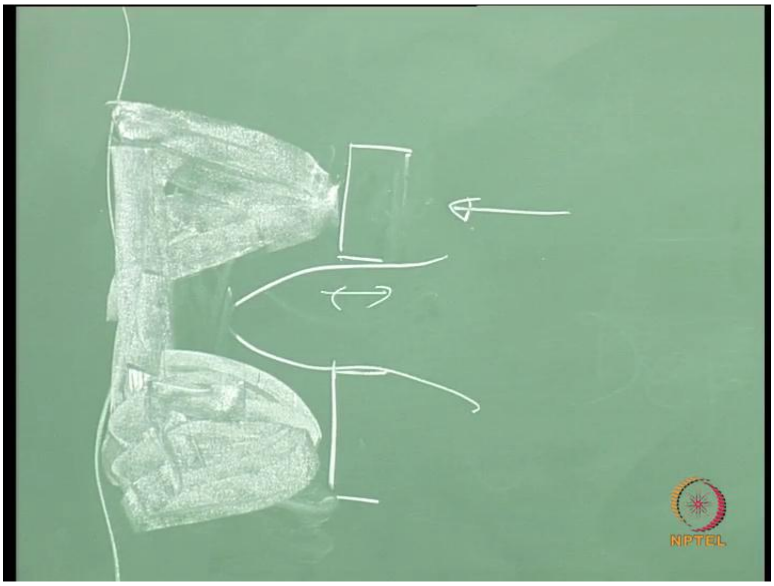

So, having seen some of the applications of the breakwater, before I get into the design of rubble mound breakwater, what I would like to tell you is, now we have seen that, if you have some kind of a breakwater; so, this is the shoreline, right. Earlier, we have seen that, if you have the detached breakwaters, the detached breakwaters serve as an excellent coastal protection measure. So, you have a beach build up. The lost beach is obtained. So, instead of having it as a breakwater, you have energy caissons here. So, 1,2 like this. But, the distance between the breakwaters and the distance between the shoreline and the breakwaters, all these things have to be followed based on the design principles of design of offshore detached breakwaters.

But, only thing is, instead of this being, because when you construct a rubble mound breakwater, what is going to happen? The energy is going to be dissipated by, may be about, 40 percent of the energy is getting dissipated, because it is going to be a sloping wall; a sloping structure occupying a larger width.

Now, instead of that, you have a breakwater something like this. Then, what will happen? The advantage is the width of the structure is less. Then, I am trying to use this for enhancing and for absorbing the energy. So, there is no reflection in front of the structure. The entire energy is absorbed and then, through the phenomena of diffraction, you will still have the beach formation here. Then, there will be some like this. On the lee of the breakwater, you expect a more of energy and to be more sediments to be deposited. It might come like this. Something like this.

So, because of the diffraction, you may have some certain amount of erosion taking place. But, that will be compensated once you have the tombolo or the salient formation that is taking place. But, at the same time you can use this energy for coastal land. So, this particularly may be more effective for islands. So, in islands it may be very difficult for you to get the rubble mound stones. So, you can rely on precast structures. So, this can be constructed in small small modules. All these things are possible.

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So, we are likely to take up this as a major project with the Norwegian institutes. It is going to be supported by and our department will be actively involved in this project. Now, this is just a passing remark and then, but the concept looks very promising. So, at one point, so, that is with one go, you are trying to arrest your answer to your coastal erosion problem and at the same time, you are looking at extraction of energy from the ocean waves and also, this is quite useful for locations in remote islands etcetera.

So, now I will go into the design of rubble mound breakwater. Design of a rubble mound breakwater is not so difficult. It is quite straight forward using some set of formulas and using some guidelines that has been given in number of manuals. So, number of books also will provide this. So, I do not want to design breakwater here, because you can definitely do that your own, but, I will try to touch up on the design principles.

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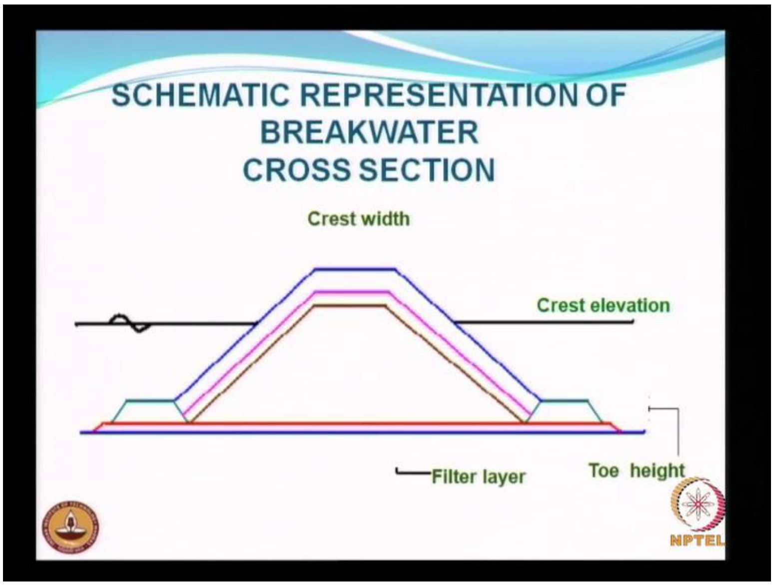

Schematic representation of the breakwater; cross section looks something like this. The components are, you have a filter layer, that is to prepare the bed of the sea bed and then, you have a core layer. The core layer is this brown color and then, in between the brown and magenta color will be the secondary layer and then, you have a core layer. Sorry, you have a armor layer on top or it is also referred as a primary layer. So, what is the purpose? The larger, the top most layer will have more permeability. Then, the permeability will be reducing and then, the core will be having very less permeability. So, that is, this allows the gradual dissipation of energy.

Now, you look at the toe section. The toe can be extended like this. Either the, there are different waves of looking at the toe. There is a kind of guidelines for determining the, I mean the designing the toe, because toe is something like a heart for human being. Usually, the width of the toe can be around 3 meters, minimum of 3 meters and the depth of the toe can be around 1 meter to 1.5 meters. So, these are all guidelines. But, we will get into it slowly.

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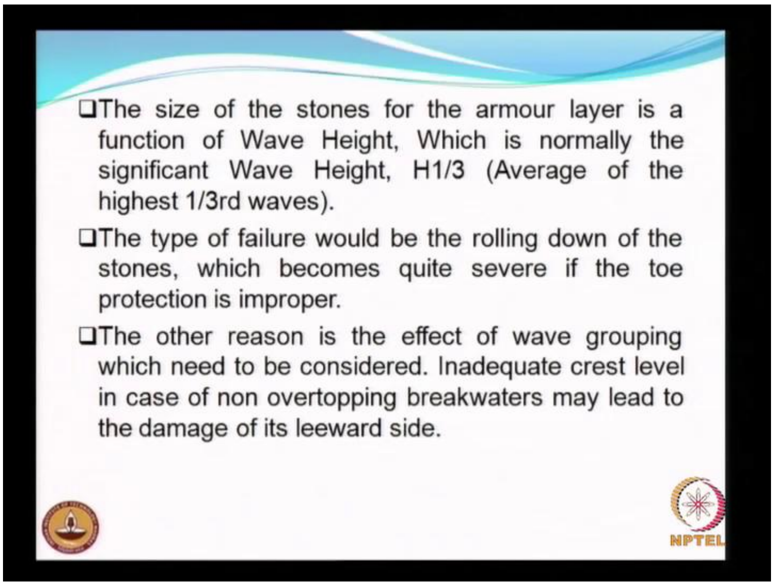

So, the size of stones for the armor layer is the function of wave height, which is normally the significant wave height, average highest of the one-third waves. What do you do when you do not have any climate? Suppose, if someone is coming and asking you to design a breakwater for a fishing harbor.

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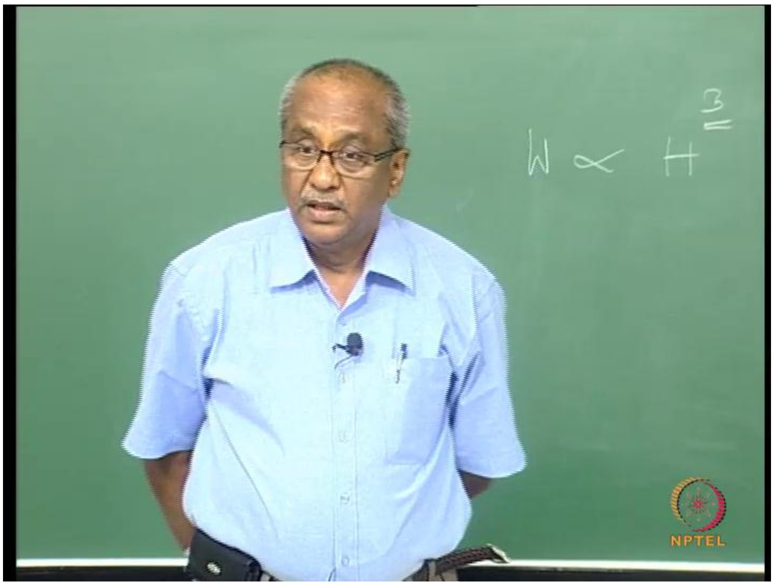

See, as we will see very soon that, the weight of the, stone weight of the armor layer is proportional to d h cubed. Any small variation with the wave height is going to increase your wave height weight of the stone tremendously. Once, the weight of the stone is going to increase, naturally, the cost of the breakwater is also going to go up, but, may be the safety is also increasing. But, I do not think you would need to, you would be interested in dumping so much of money inside the ocean. So, what you do need to is, this careful assessment is important. So, I will just spend couple of minutes on this because, this is where we have lot of problems.

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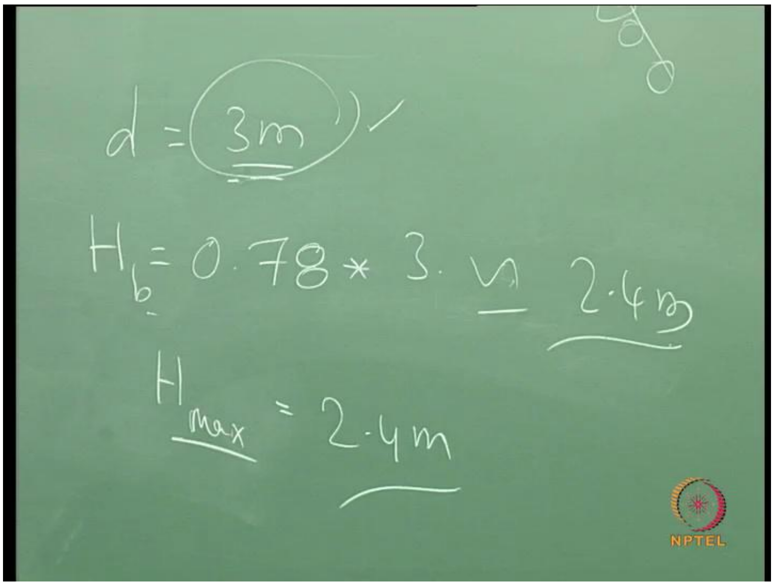

Because, when you want to have a breakwater going up to about 3 meters water depth, so, and you do not have any data and how do you design this. The best possible approximation would be 0.78 times water depth is what? 0.78 times 3 meters is how much? Say around 2.4 meters approximately. Approximately, let us say it is about 2.4 meters. So, I call this as, although this is H b, I call this as, this is something like maximum sustainable energy. When I say 3 meters, this includes all the storm, surge etcetera, for example.

So, the person who wants to have a breakwater, may say that the water depth should be 3 meters, maximum water depth for up to which the break water has to run. Then, you should make sure that all the levels are taken care. That is, three meters, does it include the storm surge also? In tsunami prone area, if you want to include that also, give an allowance. So, that level has to be decided and that is site specific. So, on the assumption that you have included all those levels and water depth comes to about 3 meters, then your breaking wave height or the maximum sustainable wave height, I would say is approximately 2.5 meters or 2.54 meters. But, the other, but, you design the breakwater only for the significant wave height. You do not design the significant, I mean the breakwater for maximum wave height. Why you do not design for the maximum wave height? Because, there is nothing like catastrophe, something like immeria or sudden failure.

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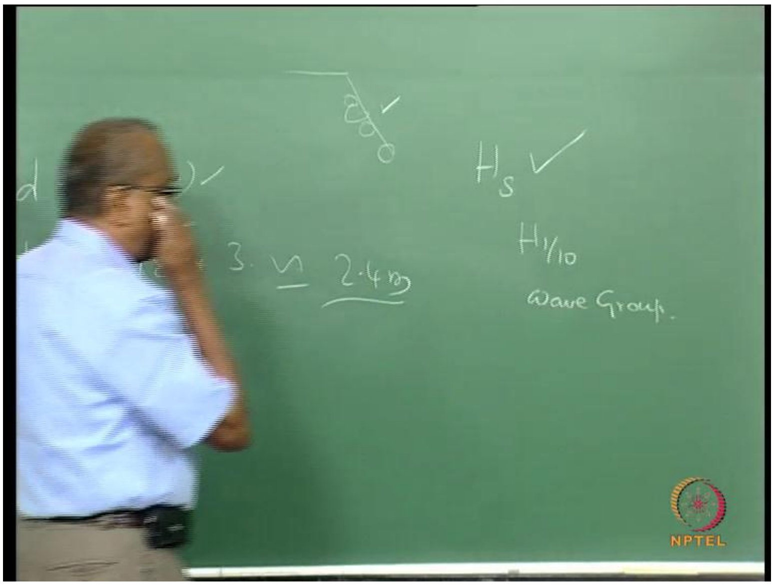

At the maximum, when you are talking about rubble mound breakwater, it will be some displacement of the stones. When you design the breakwater, you design the breakwater for the significant way, that is good enough when you are designing because, at the maximum, there will be only dislodging. Even if it is dislodged by 1 diameter, beyond 1 diameter, still you have enough opportunities to re habilitate the structure and bring it back to its original condition to some extent.

So, this kind of fee possibility is there. So that means, it is enough you design for significant wave height. So, I would say that significant wave height is good enough. So, we will keep this story here that significant wave height is alright. But, I have to touch upon 1 by 10 and wave groups. I will just list about this and then, we will go into the design. So now, you see that the breaker wave height or the h max is approximately 2.4 meters.

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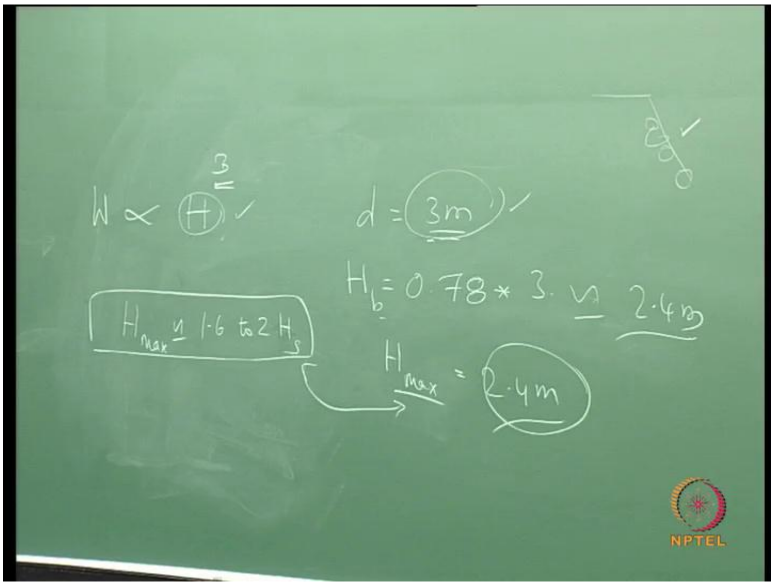

So, if you look at my lecture on random bills given under Wave Hydrodynamics, there I would have said that the h max is approximately 1.6 to 2 times H s. So, the assumption here is that, the wave heights follow an array distribution. The assumption is only, one of the assumptions is that, the wave heights follow an array distribution and if it follows an array distribution, that h max is close to this. So now, you have your h max. So, using this relationship you can decide your H s. You understood?

This sounds more logical instead of trying to fix some arbitrary value, this have some logic in it and then, here again you have a range. So, either you can keep it and take the average as 1.8. May be 1.8, that should be alright to take care of your; so, this is one way of arriving at the wave height that could be used for the design of breakwater.

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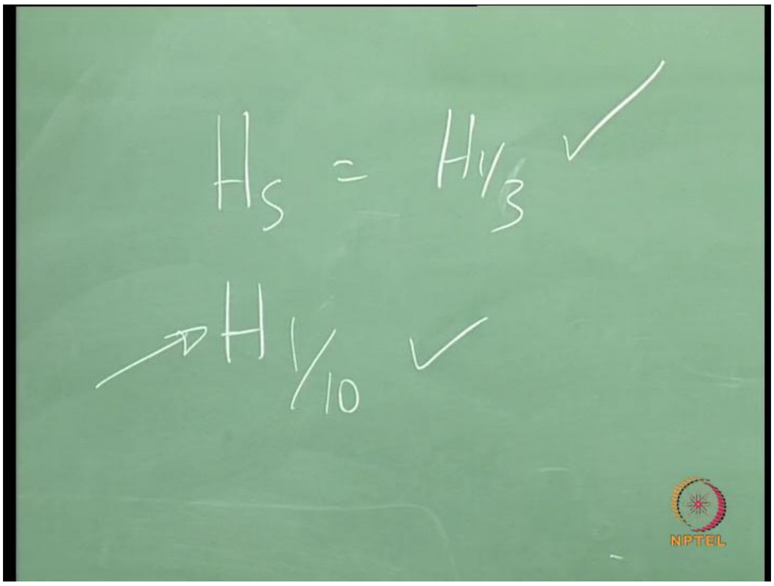

But, when you design a breakwater, but, there is still an argument weather H s is what? H s is something like 1 by 3, right? Average of highest one-third o f s. There has been some amount of failure in the rubble mound breakwater. So, they started looking at whether we can go in for h one-tenth. That is average of highest one-tenth. So, there is some kind of re rethinking whether we should use this or this, but, as of now, it is better to use h one-third.

Is it alright? Because that is more kind of more conservative. But then even if you design the breakwater for H s, there is one other important factor, which has resulted in failure of a rubble mound breakwater.

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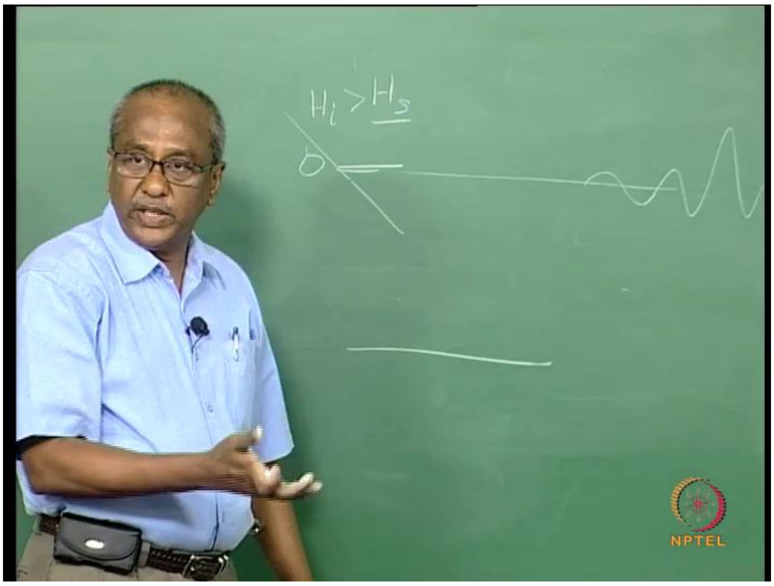

So, this is because, when you have breakwater and when you have the waves coming, when you have the random waves coming, so, it may be exposed to the action of H s. When a wave height, which is greater than H s, if h i is greater than H s, what will happen? It will go and hit the structure. So, the duration of this wave height, which is exceeding the significant wave height is less.

So, what will happen? The stone will get a jolt of sudden duration, but, it can get back to its original position or slight displacement can happen. So, this means that it can sustain to some extent, to certain extent to wave heights that is slightly greater than H s. But if this is approaching and hitting the breakwater at very short intervals with waves greater than H s, so it will go and hit. What will happen? That is the problem when you have; it can lead to the failure of the breakwater. So, that is, when it goes and hits the structure at very successive intervals with waves higher than H s, then we call it as the effect of wave groups. So, in such a situation the failure can happen. So, this needs to be considered when you are designing the breakwater. Is that clear? Any doubts?

In location where the accessibility is not there, say remote location, whether you can consider the h max for design of breakwater; whether it takes like…

No, that is what I am telling. I told you, at locations where you do not have any data, the only thing is you can get the bathemetry. So, bathemetry is known and you want to, based on that, you can design the breakwater for which you might need the wind climate or the wave climate. From the wind also you can get the wave climate. That is one way of looking at things and if you do not have any other thing for the design of breakwater, I am talking only about the, leave alone the layout of the breakwater, for design of breakwater, it is good you follow this method in absence of any other data.

My question is, after the design sir, whether we consider the breaker also. In extreme condition, there may be chance of failure. Do we have to re habilitate the things?

So, mostly I think it is, I mean yeah yeah because, there is, then in that case you have no other choice to go for the maximum wave height, which is going to increase the cost. But, even in that case what I am trying to say is, it is only precast stone or precast harbor unit, because, in island it is very difficult to get a rock for example. Then in that case, you have a precast armor blocks. So, you can always use that for rehabilitations. So, some of the projects they do have in stock. They always have some few armor blocks in stock, so that, this can serve as a buffer.

No sir, my way of question is, in remote locations we cannot get the logistics, say for example, cranes. So, during construction, we can bring the crane for 10 ton capacity or 20 ton capacity. So, once it is over the crane is also going. If there is any failure, single stone replaced. We have replace the stone and we have to bring crane. It will be…

No, that is, see those are all logistics. So, you want to have some kind of maintenance free. You invest more money, so, huge stone will be there. So, even in remote areas under extreme weather conditions, there is always a possibility. You understand? It depends on the type of logistics you are applying. So, I do not recommend use of the extreme way for design of breakwater, because you are unnecessarily going to dumped in so much of money into the breakwater.

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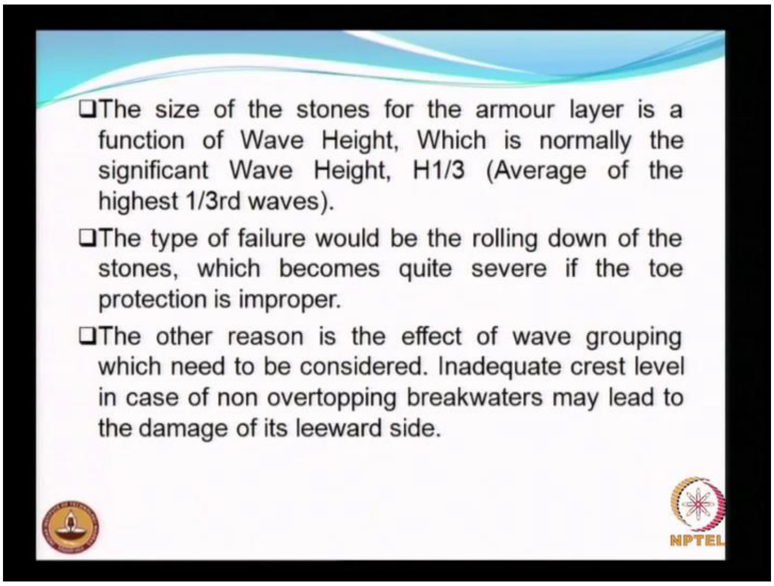

The type of failure would the rolling down of the stones, which becomes quite severe, if the toe protection is improper. So, that is what I am telling you. The toe protection is very important even in this extreme situation. See, very often, what happens is, people feel that what is on paper to put on field is quite difficult. That is what they have in mind. So, in a place like a remote site, you may not have sophisticated instruments etcetera. So, in that case, what will happen is and you are talking about crane. You may not have crane with sufficient boom, when you are trying to look at the toe and that is where they make a mistake. So, they do not realize the importance of the toe.

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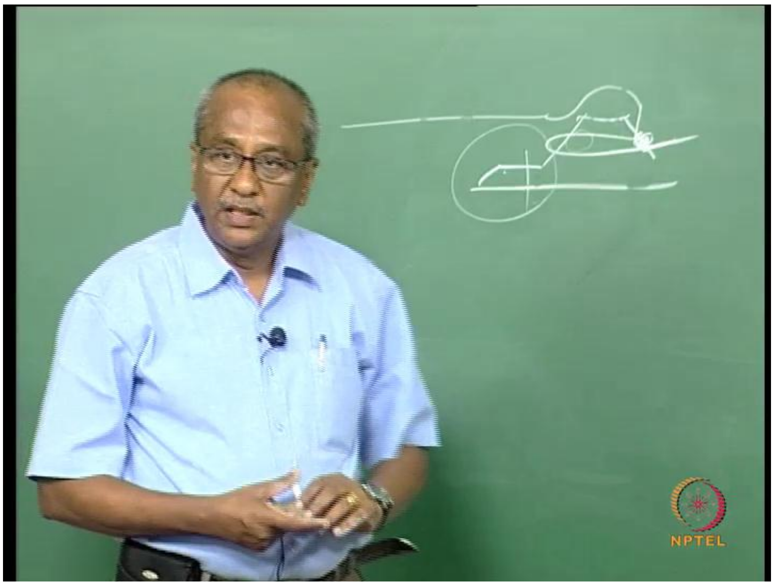

So, instead of going up to this distance on the sea side, they stop here and this will yield. Once this will yield, failure will take place. So, in fact, the size of the stone is of course, very very important. Instead of straight away increasing the weight of the stone, make sure that this is intact.

So, other reason is the effect of wave grouping, which I have already said and then, inadequate crest level in case of non overtopping may lead to damage of the lee side. This I have already covered. So, when you have the over topping taking place, so, you will have the removal of the material on the lee side and then, that can give way and then, the whole thing can breach. We had a similar situation in one of the breakwaters in Kerela, where a breakwater completely breached at two sections. When we looked at the physics behind it, what was clearly revealed was the in sufficient crown, the insufficient crust elevation as well as they did have the crown wall, but, that was not sufficient enough. So, there was an over toping and that led to this kind of a failure.

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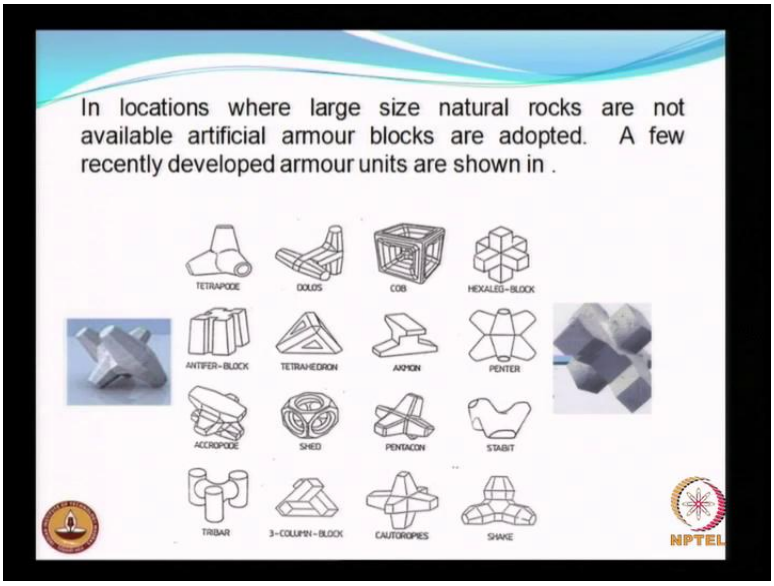

In locations where you do not have large size natural rocks, so, we go in for artificial armor blocks. I told you, suppose if you work out the size of the stone, you land up with say 12 tonnes. Can you transport 12 tonnes here? I know there are some breakwaters there; 34 tonnes, single rock. Breakwaters do have rocks with 34 tonnes, but, in our case, it is not easy to handle greater than 5 tonnes. On single piece, it is very difficult and it also depends on the quality of rock you get from the quarry.

So, and it is more convenient that you have a pre cast units, for instance remote islands. So, the first well known one was the tetrapods. As you can see here, it has 4 legs and then the dolors, that is, it has a trunk like this and then, you have the two things. So, it is right angle to each other. Then there are other things, which are hexaleg block, antifer block and so many things. So, tribar and then are hich block and core lock and core lock 2 and so many things have come into market. Some of these amour blocks do have royalty on that. So, you cannot just like that fabricate and then install. It is a problem; but now, tetrapod being very easy, they have adopted in number of projects even in India. It also takes care of whether it is two layer blocks or a single layer blocks. So, for example, tetrapod is a two layer block.

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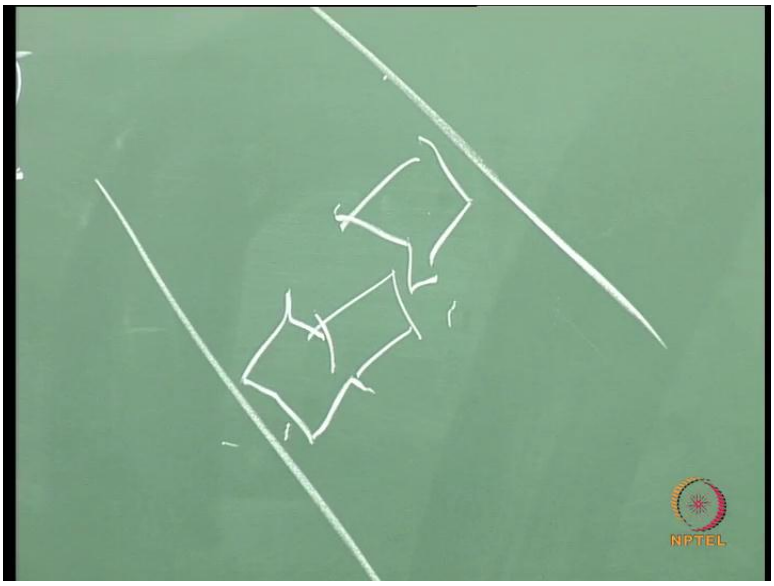

So, you need place two tetrapods one above another. So, this will be the, you need to have atleast 2 blocks in one height and this is single double layer. Mostly all these things are double layer; some of the things or some of the, see for example, accropode. Accropode is a single layer structure. So, only one single layer will be there. But, there are some merits and demerits with each of these blocks.

So, each of the blocks, once it is manufactured they come. From commercial point of view also, they try to compete with each other and try to say that this better than other and this the best etcetera. So, you need to look into what exactly need. You have number of options in the market.

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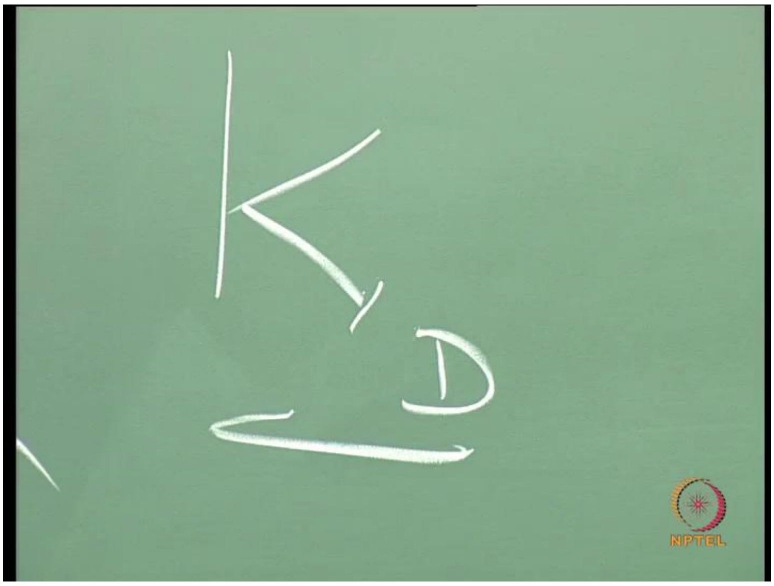

So, we have done in our department, whenever you go in for whichever kind of stone, always see you the characteristic of the blocks depend on one single value, which is called as K d.

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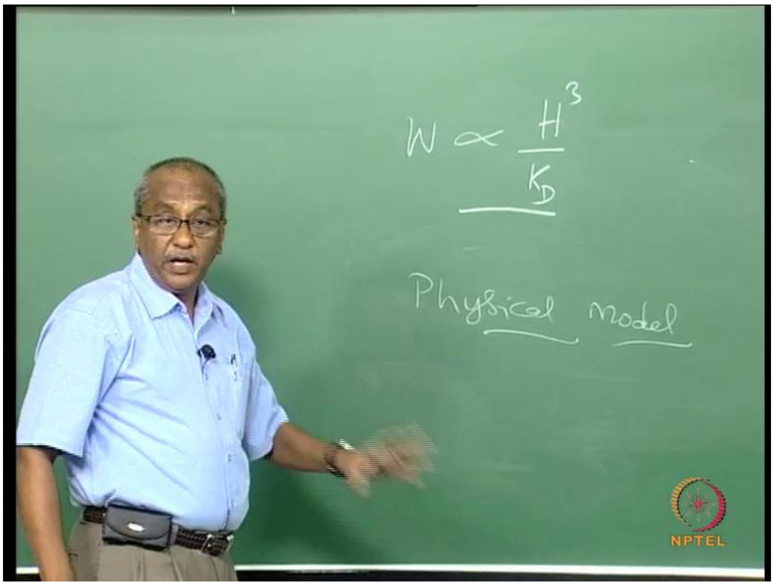

This is nothing but, the stability coefficient. The stability coefficient is very important. If the stability co efficient is very high, then the weight of the stone will be less. For example, weight of the stone will be directly proportional to h cube divided by K d. Which means, higher the value of the K d, then the weight of the stone will reduce. So, this is property of each of this and this K d for any particular armor unit is usually done by, has to be done only with physical model studies. That is why physical model studies is very important in field of coastal engineering. Not only for stability of armor units, there are so many other associated kind of problems. So, herein you see that we have subjected to cubes and then, this is tetra pods. The stones when you are doing the physical modeling, you need to verify how it performs as a trunk when it is put as trunk and how it performs when it is used performing the head of the breakwater.

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So, here you see the trunk portion dolos, and with head portion. Then, this is another core loc and tetrapods for the head and this is for the trunk; so, will be having a detailed look when we look into the aspect of physical model later.