Port and Harbour Structures.
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Module-3.
Lecture-12.
Design of Breakwater-Part 1.

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In this lecture we will discuss about the design of breakwater. This shows the Google image of Ennore breakwater, pair of breakwaters. Always Breakwaters are pair of breakwaters, with an opening for the vessel to enter here and this is the core berth. And here we see 3 small arms, these 3 small arms are for tugboats which are used to bring the vessel here. The temporary structure for iron ore terminal and from here we have the coal which is coming through this conveyor system and going to the thermal power plant.

And here because of the construction of the breakwater, there is advancement of shoreline from here to here, a sand deposition. So we will be discussing about the design of the breakwater in this lecture. So this shows the details of breakwater. We have to have certain glossary of terms, so whenever you build a breakwater, you have to mark 2 sides, one is on the sea, that is Oceanside, another is on the Harbourside. Then we have to show what is the crest, this is the crest of the breakwater.

This is your seabed level, what is the bed level, seabed level and we normally provide a bedding layer on the seabed. Then we have the core layer, then we have 2nd underlayer, 1st

underlayer, normal layer, so these are the various layers. And we have what is known as the design high water and then still water level, then we have this water depths, this is one of the main parameters for the design. Then we also have the toe, the toe has to be designed. We have the slope on the seaside, the slope on the Harbourside, these are the parameters.

And to fix the top-level, we have to have this height above the design high water, that head sea. So what we are going to design is the rubble mound breakwater for which we need to design a filter layer, core layer, toe layer and you may or may not have armoured layers, you may have only underlayers, you may have only one underlayer, 1^{st} underlayer or you may have 2 underlayers, then we have the armour layers. Main thing is to design this W, width of the armour stone, that is the main purpose.

For the design, what is required is the wave height for which we are designing, the input parameter is the wave height, the type of soil here and we have to find out armour layer. This also depends on the slope, whatever slope you are consuming, based on which your armour layer weight will change. For functional requirements you should know what is the width, the vehicle has to go, so maybe 8 metre may be required, that is based on functional things. It has various connotations, but we have radius tidal ranges, mean sealevel, lowest low-water spring, high water spring.

Still water level, they will use it for the mean sealevel. You know what is the tidal range no? Average of the tides will give you the mean sealevel. Design high water level is highest high water level + storm surge. The failure of the breakwater will take, if it at all it takes place, it will take place during a storm. During a storm, when a highest high water spring takes place, then there can be a damage. So the design water high water is the highest of high water + the storm surge.

For construction purpose we need the still water level. When you are building the breakwater no, typically you put a core layer, armour layer and all, it should be the armour player should be about the still water level for construction purpose. That is why Stillwater, Stillwater level is required because generally that gives mean sealevel, that is not used for design purpose, this is for some other purpose. What is your doubt, I did not get your doubt?

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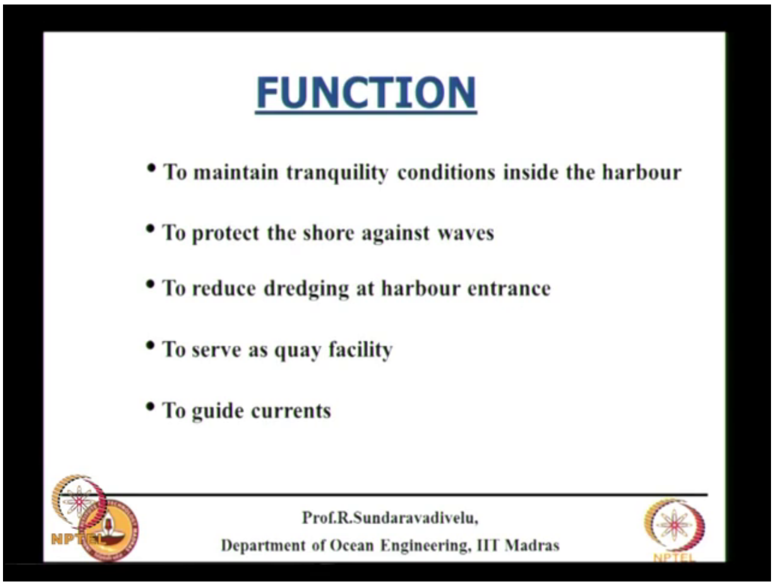

It is same. What are the functions of the breakwater, you have to maintain the tranquillity considered conditions inside the harbour, to protect the shoreagainst the wave, this also can be another function of breakwater, we call it as groins and to reduce dredging at harbour entrance. If you do not build the breakwater, the siltation will be more and dredging will be there, the entrance will be more. And we can also use the breakwater is a quay facility, then we can use it to guide currents, these are the functions of the breakwater. Rubble mound can be used as a quay facility.

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This shows layout of the breakwater, we always a pair of breakwater. And this is for a marina, in foreign countries we have marina where we have the pressure boats that are being used inside. We have to design typically 2 sections, one is called as the transaction, another is called as the head section. The difference between trunk and head is head section you will have slope on 3 sides, trunk section you have slope 2 sides, clear no. Because it is at the entrance, it is facing all the 3 sides, you have the slope, that is called the, you will have head section here, you will have head section here also.

And this trunk section, we have shown BB, CC, CC and all, so you will have different section, it is not that you will be providing, designing only one section. The water depth varies from 0 metre here, it goes up to 10 metre let us say, you will put 0 to 5 metre one design, 5 to 7 metre another design, 7 to 9 another design, 9 to 10 another design. It is not one water depth you have to design, you have to design it for different water depths so that you will get the economy. And another thing required is what is the direction of the waves, waves can come in different directions.

Normally we assume that the direction of the wave is perpendicular to the alignment of the breakwater, that will be the most severe condition, that is what we have seen, we have seen the direction is perpendicular to this breakwater.

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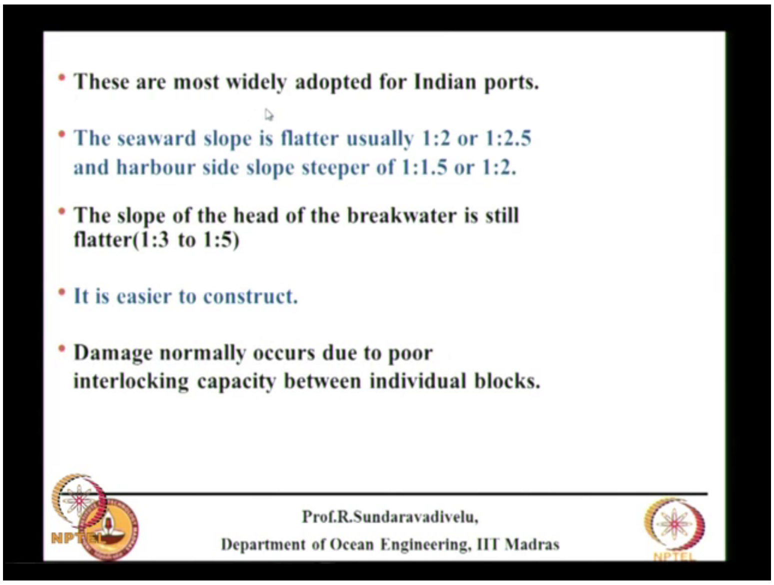

We will be concentrating more on rubble mound breakwater because this is the most widely adopted for Indian ports. Most of the ports, 99 percent most means, we have only rubble mound. I said there is a slope, Seaward look and the Harbourside slope, the Seaward slope is between 1 is to 2 or 1 is to 2.5 and Harbourside slope is 1 is to 1.5 to 1 is to 2. So in the 1st slide I have shown what is the seaside and what is the Harbourside. Seaside, the slope is flatter, flatter the slope, weight of the stone will be less, steeper the slope, weight will be more.

But in the Harbourside you do not have waves, only on the seaside you have waves, that is very provided flatter slope 1 is to 2 to 1 is to 2.5. Whenever you design any structure, all these things have to be used as a guideline, you do not put 1 is to 5 slope, you do not put 1 is to 1 slope. The structure will not only fail, you will be putting very huge size of stone, okay. When we want to design any structure, there are certain guidelines which you have to follow. In the head of the breakwater, the slope is still flatter, 1 is to 3 to 1 is to 5.

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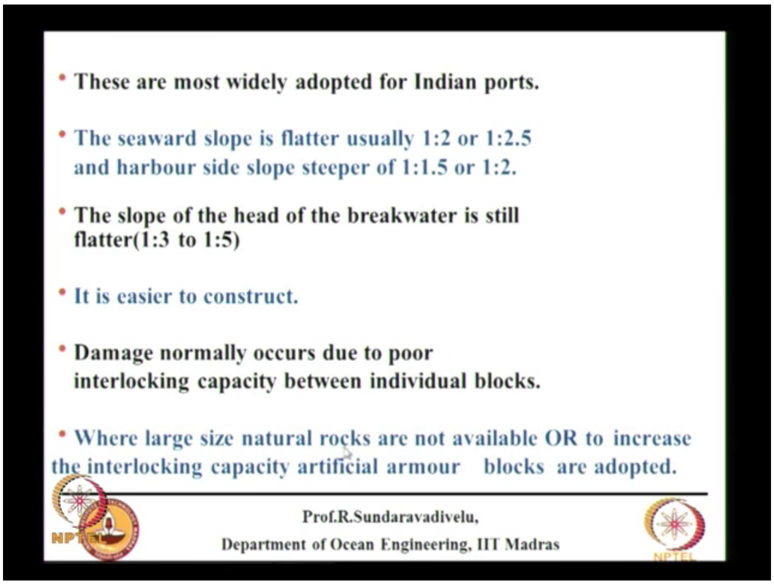

So this slope is 1 is to 3 to 1 is to 5, this slope is 1 is to 1.5, this slope is 1 is to 2, is it clear? This is the seaside, 1 is to 2, Harbourside 1 is to 1.5, in the head section it is 1 is to 3, 1 is to 3 means one vertical to 3 horizontal. Why do we go for this in Indian ports? Mainly because it is very easy to construct, not very difficult. But it takes a very long time, a breakwater construction will typically take more than 2 years for a greenfield port. So when the damage will take place, damage will take place due to poor interlocking capacity between individual blocks, this we will discuss.

We have what is known as the stability coefficient, the stability coefficient depends on the interlocking of the blocks, where interlocking of the blocks depends on the type of block we are using. If it is artificial armour units, interlocking is better, natural stone interlocking is not that good, still we can use natural stones. If it is available nearby, the cost is cheaper. So where large size natural rocks are not available or to increase the interlocking capacity, artificial armour blocks are adopted. Only these 2 conditions we use artificial armour blocks and even if we use the artificial armour blocks, we may use for 0 to 5 metres only natural rock.

After 5 metre we will start using the artificial armour blocks, it is not that throughout we will use the artificial armour blocks. Up to 5 metre water depths, natural rock as armour unit is more than sufficient. If the water depth is more than 5 metres only we need artificial armour units, there is another guideline. Up to 5 metre natural rock, more than 5 metre artificial armour if required.

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So use of natural material is a big advantage, especially when large quantity of trouble so than available near the site, this reduces the material cost. Material cost means the alternative to rock is concrete, concrete cost is very high. Who are all civil engineers here, what is the cost of concrete?

96 Rupees per KG.

Concrete in per cubic metre what is the cost? You are telling the cost of cement I think. Per cubic metre how much it is?

3000.

3000 rupees one answer, another answer? How many bags will go into concrete, one cubic metre how many bags will go?

I think 12,000 per cubic metre.

How much?

12,000.

I am not asking the cost, you are answering the previous question, 12,000 is very high 12,000 rupees is very high, I am asking how many bags or how many KGs of cement will go into a cubic metre of concrete?

350 KG 7 bags.

What is the maximum quantity of cement you can put in concrete?

60 KG per metre.

It is given in IS 456, latest version, maximum cement that can be put in a concrete, 450 KG per cubic metre. What is the weight of one bag of cement?

50 KG.

So 9 bags is 450, you should not put more than 450 KG of cement in 1 cubic metre of concrete. What is the cost of per bag, cost of cement per bag?

300, 250 to 300.

300 into 9 bags is 2700, so your 3000 rupees is coincidence itself. Typically it is about 4500 rupees per cubic metre if it is online. If you have to put the same concrete offshore, it will go up to 9 to 10,000 rupees per cubic metre. What is the cost of stone, quarry stone? Just guess,

this is 4500 rupees per cubic metre what will be the weight of one cubic metre of stone? 1 metre by 1 metre you put the stone, what will be the weight? How much? What will the weight of concrete, one cubic metre?

2400 to 2500.

What will be the weight of stone in one cubic metre? You told 3000, how it can be more than the concrete weight? Cubic metre concrete is 2500 KG per cubic metre, cubic metre stone means you are not dressing stone to one cubic metre, you are filling the stone, there will be voids, okay. Void ratio will be a much, suppose you fill the stone, 40 MM stone or 150 MM stone or 1 metre by 1 metre stone, you stack it, there will be voids. Voids are very important, your dissipation of wave energy takes place through the voids only. How much will be the void ratio?

What we are discussing for non-civil engineers is, if you take a container of 1 metre by 1 metre and put 40 MM size, that is about size material what we are using and we are putting it in that, there will be voids, much will be the voids? 5 percent, 10 percent, 20 percent, 30 percent, 40 percent? 30 percent is correct answer but it varies between 30 percent, 25 to 40 percent, depending on the size of aggregate. Smaller the size of the aggregate, the void ratio will be less, bigger the size, the void ratio will be more. But 30 percent is correct answer.

What is the density of stone? You said 1 point something, one point is totally wrong. 2.7? But we have in Tamil Nadu someplace where the stone density is 3.3, near Jinji and all, anybody from that place, Cuddalore, Jinji side? Nobody is here. Because we are doing some breakwater in Cuddalore, we are making the weight estimate using 2.65, it is normally used but this fellow has told 3.3, we never believed, finally when we saw, the density was 3.3, to the good-quality stone, normally it is exported to Japan. Where they put this stone carvings on cemetry and all, so it is polished so nicely.

Tamil Nadu there are some places where we get very good granite blocks, where the density is 3.3. Suppose it takes 2.65, take void ratio is 0.3, density will be 2.65 into 1 - 0.3, that is 2.65 into 0.7, so about 1.7. So one cubic metre will be 1700 KG. One tonne of stone depending on where it is available, is normally does not exist more than 700-800 rupees. So one cubic metre will be maximum 1500 rupees, concrete is 4500, so it is one 3rd cheaper. Which one is one 3rd cheaper, stone, that is why we go for this. Then we need smaller construction equipment, less environmental impact due to smaller reflected waves.

Stones are having very high void ratio, then creation of a natural reef, the slope of rubble mound breakwater provide a suitable place for sea life. When we go to the breakwater site, a lot of sea, the fishes, crabs and other things, they take it as a place for nesting and living.

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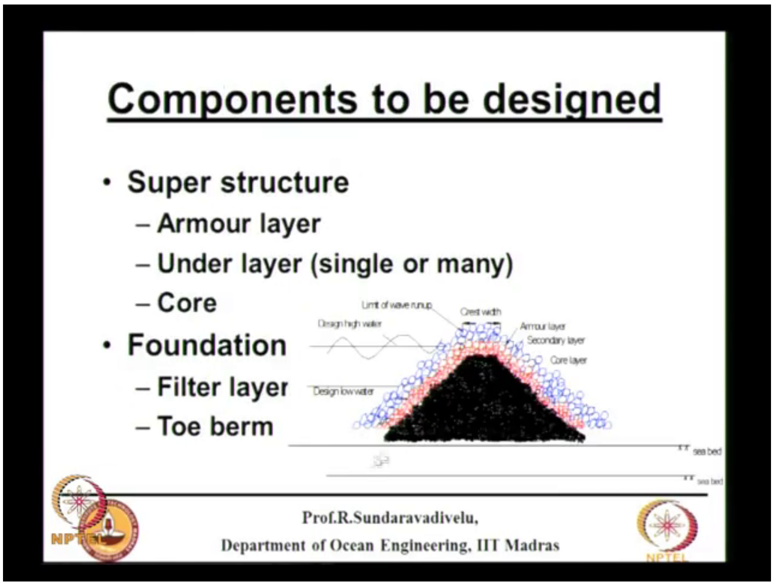

So we have the components to be designed, what is called at the superstructure, what is called as the foundation. Superstructure consists of an armour layer that is shown here, it shows the underlayer, single or many, it shows the core layer, then in the foundation you have the toe berm and filter layer, I think the colour has not come in this I think. Toe berm will be here and filter layer will be here. This is a classification, when you want to design, you should know what is the superstructure, what is the foundation. Superstructure design normally the influence of seabed properties are not much, whereas the foundation, it will be influenced by the seabed properties, that is why we classify between superstructure and foundation.

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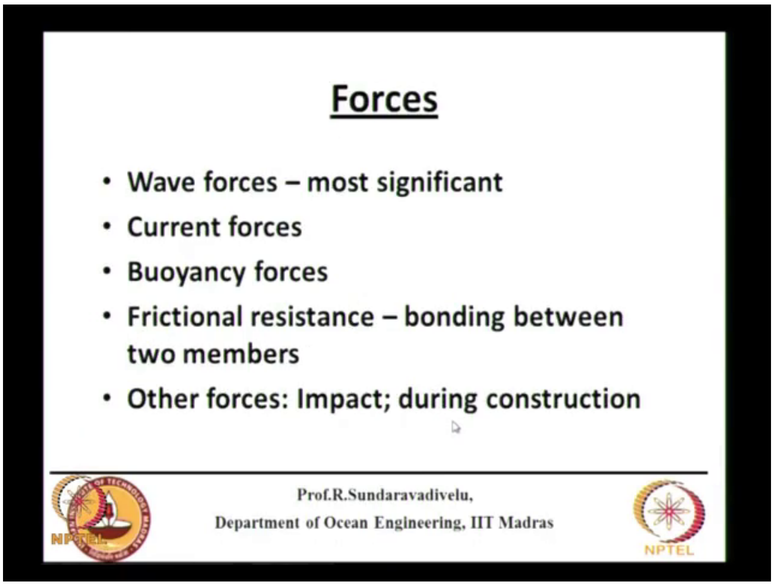

Superstructure design is mostly affected by the wave climate, foundation design is mostly by the seabed properties. So whenever we want to design, there are 3 components for the design, one is estimation of force, 2nd one is analysis, the 3rd one is design. A poor structure and better structure, optimum structure and expensive structure, mostly it depends on the force estimation. If the force estimation is not done properly, the structure will fail. Any place whenever there is a failure, it is mainly because of not poor design or analysis, it is mainly because of wrong estimation of forces.

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If they do not estimate the force properly, the structure will fail. So you have to concentrate more. In undergraduate, you will be concentrating more on design, if you want to become a professional designer, you should concentrate more on your forces. The significant force is the wave force, in addition you have to consider current force, buoyancy force, facial resistance, bonding between 2 members and other forces like impact during construction, these are the forces but mostly we will be using only the wave forces for the design.

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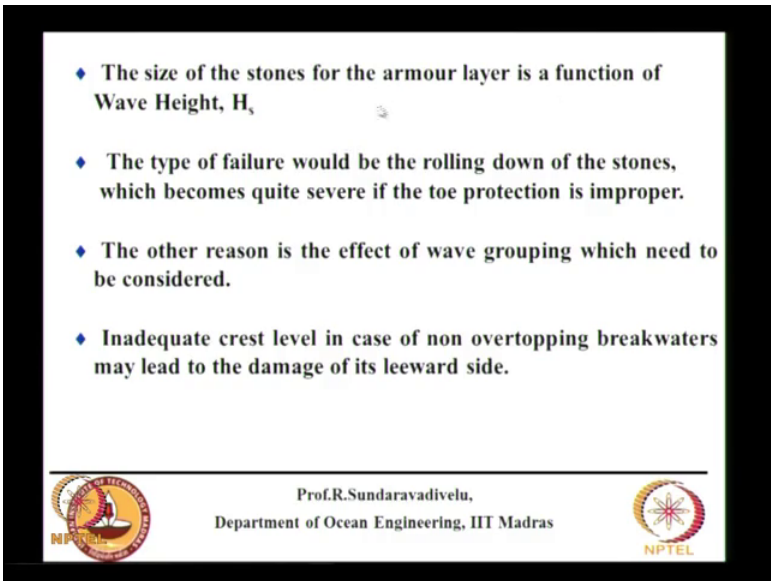

The size of the stones of the armour layer is the function of wave height HS, HS is the significant wave height. So if we know the significant wave height, the armour layer weight is a function of significant wave height. The weight of other underlayer, core layer and other things is a function of armour layer unit weight, the empirical formulation. So the armour layer we have the formula called Hudson's formula, that depends on HS, HS means cube of HS. So if we do not calculate HS properly, there will be lots of issues which you have to address. Either it will become unsafe or it will become very expensive.

What is the type of failure, the type of failure will be the rolling down of the stones which becomes quite severe if the toe protection is improper. When the rolling down of stones will take place, when the design wave height, what you have assumed, the wave height what has occurred in the storm is different, that is during the storm, if it has more wave height, then it is designed for, then there will be rolling down of stone, there will not be complete failure, there will be some rolling down of stones. But that also will become severe only few do not have the toe protection.

That is by toe protection is important. The other effect is effect of wave grouping which needs to be considered. So there is a breakwater which is done by very good designers, I forgot the name now, I think it is in France that has failed, everything was done properly, then they found out the problem is because of wave grouping. Wave grouping means the same HS, suppose about for a period of let us say about 5-10 minutes, waves are coming in a group same HS, then it will fail. I will explain the figure and tell you later what is this wave grouping, I will show the timeseries and will let you know.

And another thing is inadequate crest level in case of non-overtopping breakwaters may lead to damage of its leeward side. We have 2 types of breakwaters, one is called as overtopping breakwaters and another is non-overtopping. Overtopping breakwater means from the seaside the water will go on top of the deck and go to the other side, there is overtopping. We have designed non-overtopping also, so when you have a non-overtopping breakwater design and the water level spills over, there may be damage in the leeward, leeward means the Harbourside.

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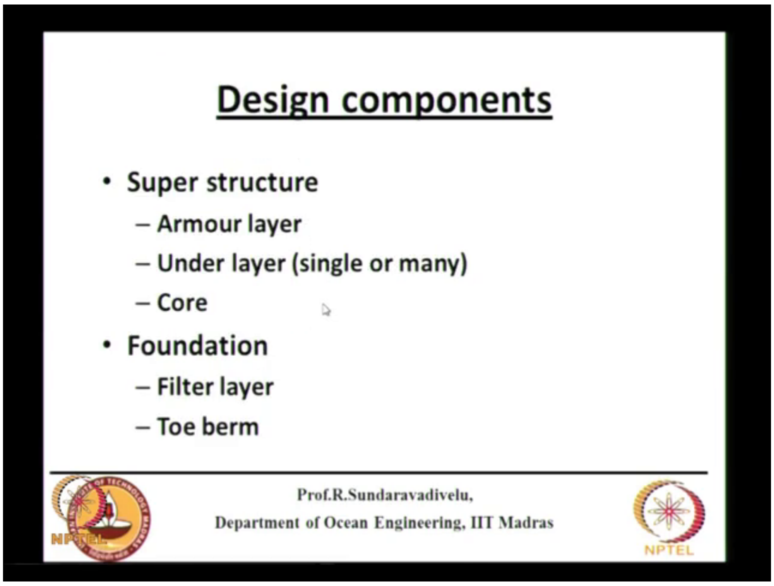

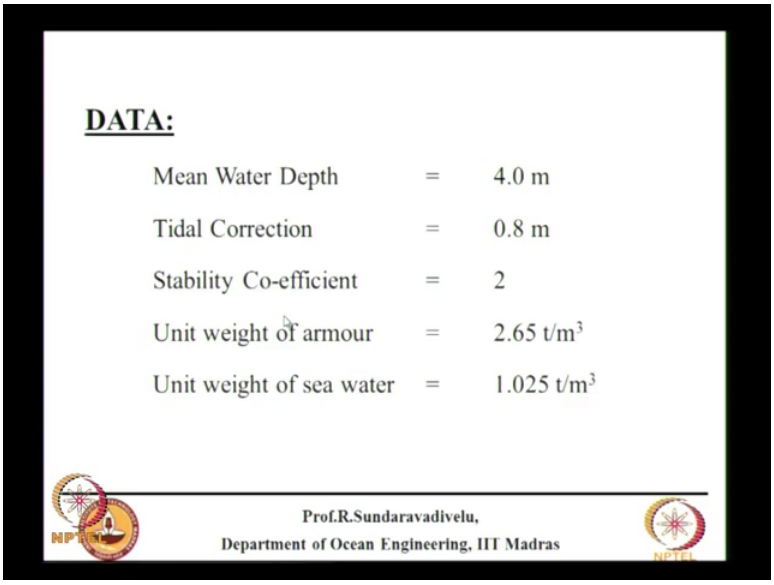

So these are the design components, we will see one by one how to design this. I will show you one typical example, I have shown main water depth, he was asking, this is from the Stillwater level, water depth is 4 metres. The tidal correction, it can be due to high tide level or it can be due to storm surge, we are giving it as 0.8 metres. This is the input data what is given for you in the design. Water depth is 4 metres, on top of 4 metre you have additional 0.8 metre of storm surge that is coming into place. We have the stability coefficient 2, this is for armour units consisting of rocks, this also data which is given to you.

If it is artificial armour, it can be 6, 8, 10, 12 like that, okay, this is the data which is given. Unit weight of armour is given as 2.65 tonnes per cubic metre and unit weight of seawater is 1.025 tonnes per cubic metre. What is the unit for force?

Newton.

Newton or kilo newtons. What is the unit for this unit weight, it should be kilo newtons per cubic metre only, but in design we normally use tonnes, so be familiar with this. Tonne is normally a mass unit, the 1000 KG mass is defined as a tonne but here it is a force unit. If you, some of you may go abroad, there is a use kips, what is k-i-p-s? You do not know?

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Kips is kilo pounds. Kips per inch square, that is what they have seen, material strength and all. So be familiar with the units, I am telling about the units because most of the people when they do the design, common mistake they make is they do not see the consistency of the unit. Consistency of the unit means if you get this formula substituted in this, the weight of the armour units will come in terms, you have to substitute properly units. If we use tonnes per cubic metre, water depth should be in metres, wave height should be in metres.

I have seen many people in the example they have given the wave height is in centimetres, they will directly substitute centimetre. So you be very careful, whenever any equation is given, whether it is a analytical solution or a semiempirical solution, it is more important in semiempirical solution, they should write what the unit in which the equation is valid. Sometimes some of the semiempirical equations are valid only in certain units. Analytical equations, analytical equations means it has a basis, from an equation it will be derived. M by A is equal to F by Y is equal to E by R, all of you studied that equation no, Euler's equation? That is analytical equation, from where you can get the stress, but the equation what I am going to show in the semiempirical equation for the breakwater design.

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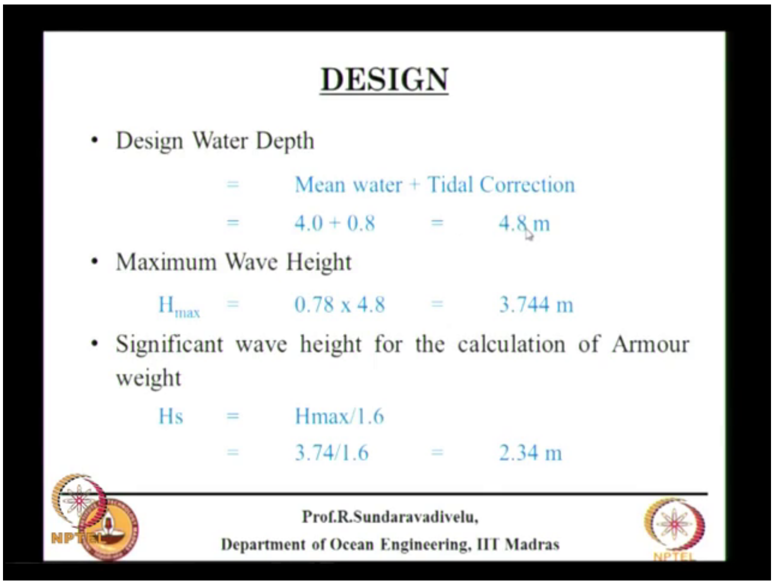

So these are the various steps, step-by-step design water depth 4.8 metre. Maximum wave height is, so you may wonder I have not given wave height here. All along I was telling, wave height is the commanding parameter for design, I have given a problem without wave height. So in this example if I ask the question, do not ask me sir what is the wave height, you are not supposed to ask that. Is it clear? There is a reason for that, I will explain in the next slide. Wave height is not given, do not ask in the exam. We have maximum wave height, that is 0.78 into water depth.

Ocean engineering students, you know what is this 0.7 inch?

Wave breaking criteria.

Wave breaking. If you go to the beach and when you see the waves, waves will be breaking. If we sail in a ship, go to mid ocean, you will see the waves without breaking, sometimes in the mid ocean also the waves will break. If you come to our department, there we generate waves in the basin, waves without breaking will occur, when it goes to the observer the other end, the waves will break. Okay. Wave breaking is by 2 criteria, one is depth dependent Wave breaking, what is the other one? One is based on the…? Other is?

Stiffness.

Wave stiffness. What is Wave stiffness?

HPL ratio.

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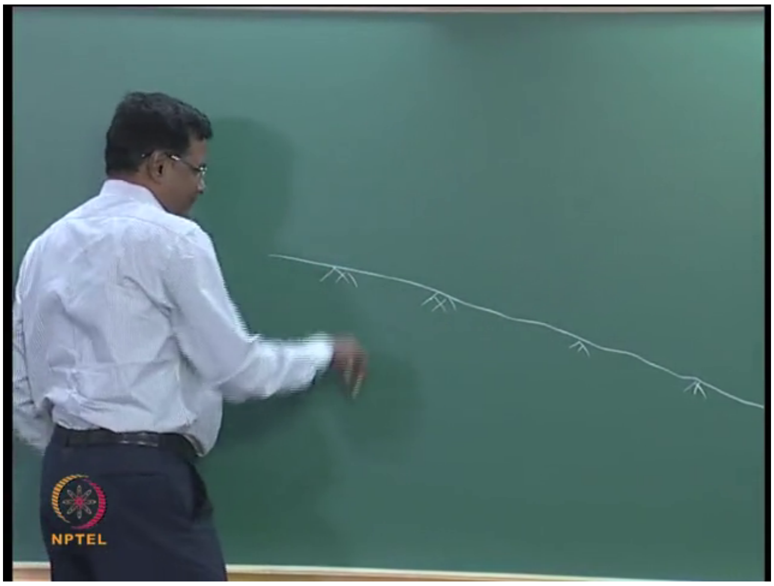

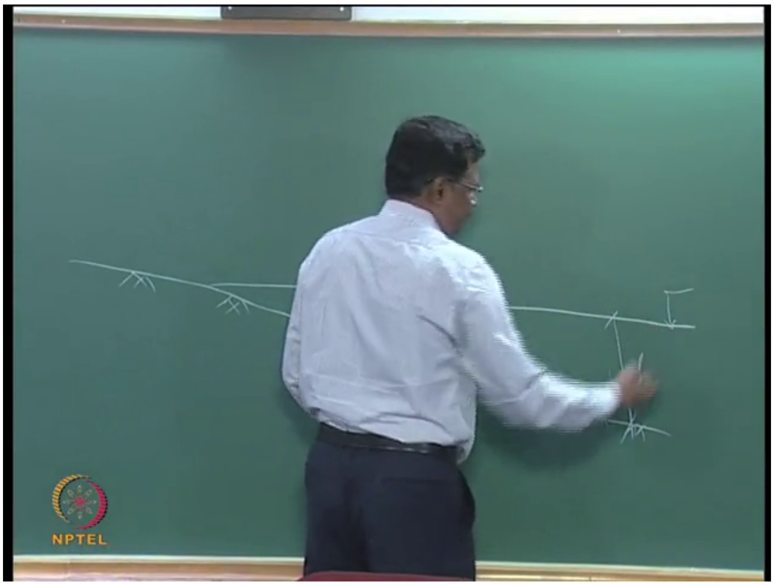

So I will tell you what is the wave now. This is the water line, that is the water line, so this level can be designed water level, so this depth is 4.8 metres. Your breakwater may start from here, we will go to 4.8 metres, stops. But we design for 4.8 metre, note off the value for the other places also. Right. There is a wave coming here, there is a parameter called as wave period and wave period I said it can be from 5 seconds to 20 seconds. Then we have this wave height, what can be the range of wave height?

Ocean engineering students, what will be the height of the wave? Minimum to maximum? Minimum, one foot is generally taken as the wave, we will get less than that also, okay, 0.3 metres to, what do you think will be the maximum wave height? How many are Ocean engineering students, raise your hands, 1, 2, 3, 4, that is all? How much? What will be the wave height in Bombay High, Placement you will not get, somebody will come in ask you what is the wave height in Bombay High. Where is Bombay high? Others know where is Bombay everybody knows, where is Bombay High? You do not know where is Bombay high?

You know what is Bombay High, you do not know? Gulf of Mexico you know? Gulf of Mexico you know, what is Gulf of Mexico? There is a gulf where we get the oil, India we get the oil from offshore field in Bombay High. It is near Bombay only but into the sea, Arabian Sea. What is the maximum wave height in Bombay High? See, there is a handbook by Chakravarthy, you see that, I think Bombay High is not given but it is given for many seas. North Sea you know, where is North Sea? Where is North Sea , where is it?

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But you are not ocean engineering, that is correct only. North if UK and Norway, that is called as North Sea, that is another field where we get the oil, maximum wave height is in North Sea only. It can go up to even 30 metres, Bombay High is 16 metres. Where is Godavari basin?

Bay of Bengal.

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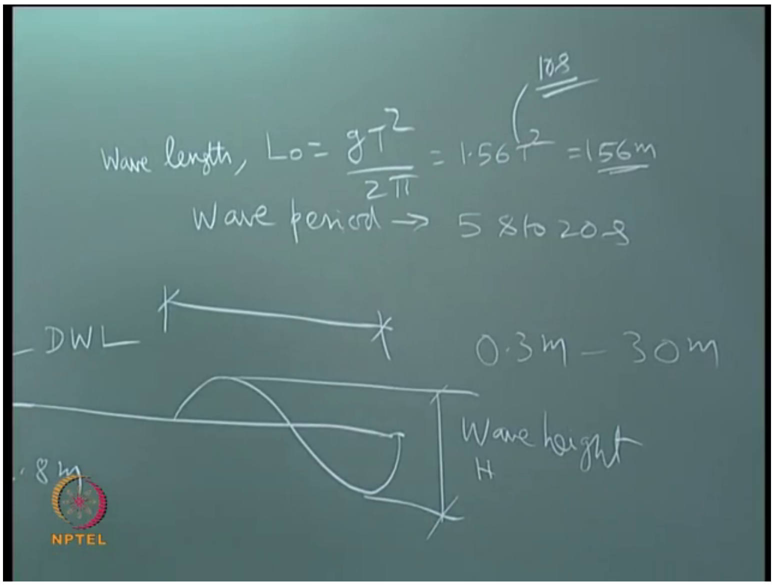

It is in Andhra only. Reliance field where is it, gas field? Krishna Godavari basin. We have Kaveri basin is there, between Pondicherry and Cuddalore where we get the oil. Eastern sides the wave heights are higher, about 20-22 metres it will go. So we have, this parameter is called as H. Based on wave period we get one parameter that is called as G is acceleration due to gravity, L is wavelength, we can call it L0, it is deepwater wave height, you can simplify as 1.56 T square. Suppose for 10 seconds wave, this will be 156 metre, if T is equal to 10 seconds, wavelength will be 156 metres.

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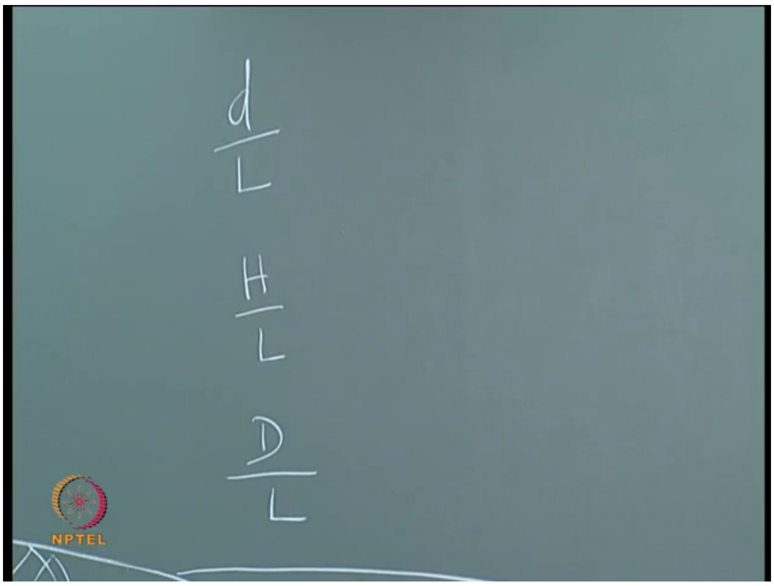

We have 3 parameters, nondimensional parameters, one is called as d by L, another is called as H by L, 3rd one is called as D by L, capital D by L. These are the 3 parameters, ocean engineering people might have studied this. What is the significance of small d by L? When is it called deep water?

Greater than 0.5.

Greater than…?

0.5. Suppose you have a pile supported structure here, you use it as a berthing structure, its diameter is D, what is the distinct significance of capital D by L?

Diffraction?

Diffraction, when is it, when does it take place?

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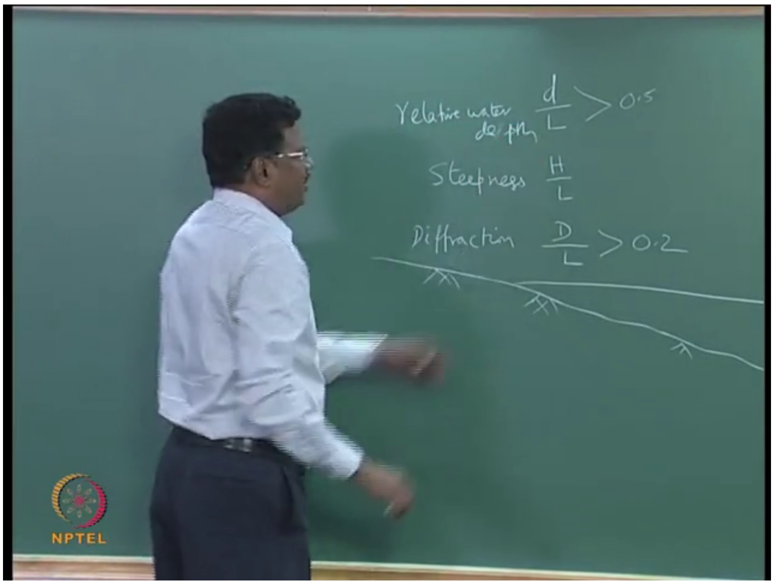

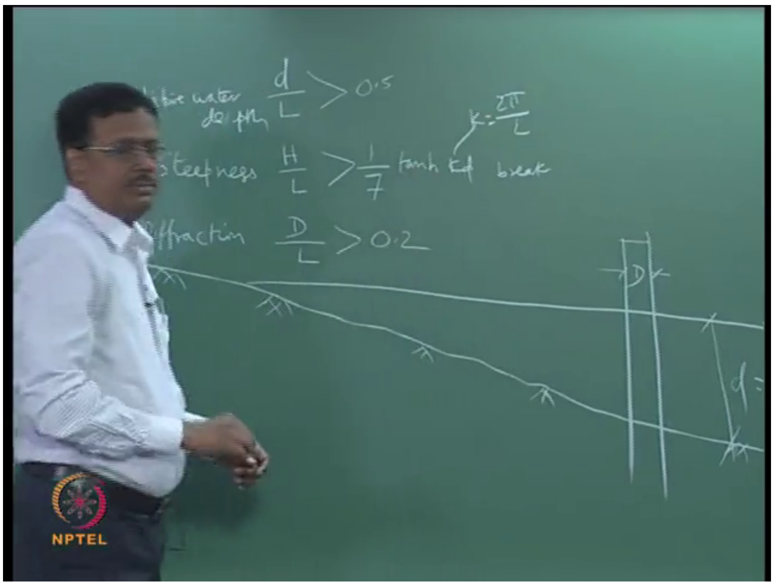

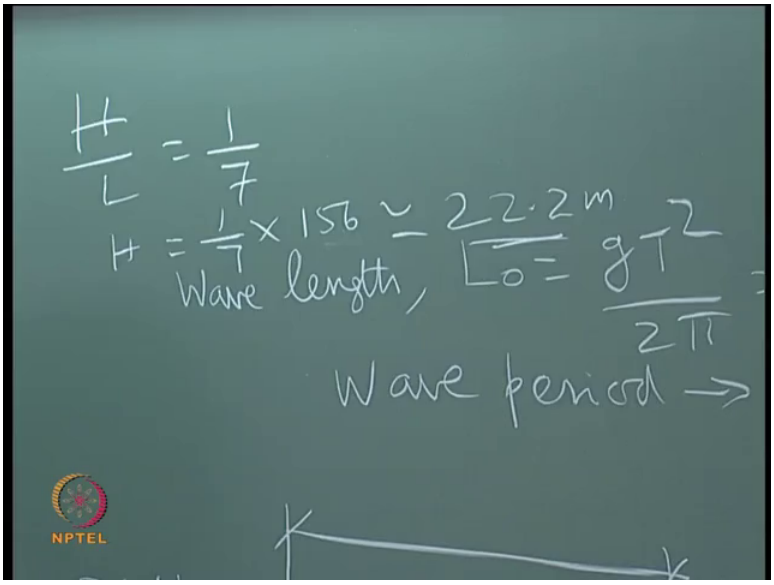

d by L less than d by L greater than 0.2. Then this is 0.15 also, if it is greater than 0.2 then diffraction will take place. For pile supported structure, it will not be in diffraction region, it will be in Morrison region, d by L will be less than 0.2. So this is called as diffraction parameter, this is called as steepness, what is this called, relative water depth. So if it is greater than 0.5 it is deepwater, then we have shallow water and things like that, that we will see later. Now here steepness we will see, what is the maximum wave steepness?

1 by 7.

1 by?

7.

If H by L is greater than 1 by 7 tan HKD, then waves will break. K is 2 pie by L, D is water depth. There 2 conditions of breaking, one is when the Wave stiffness is more than 1 by 7 tan HKD, tan HKD will be equal to 1 for deepwaters.

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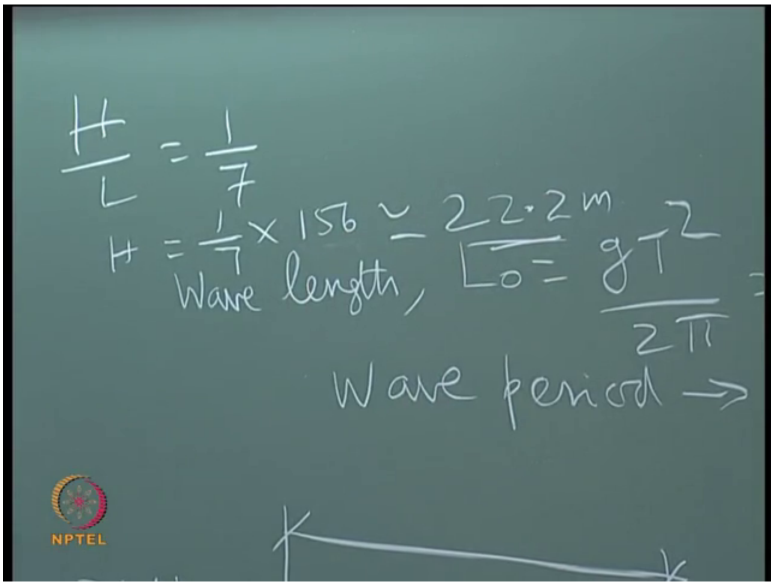

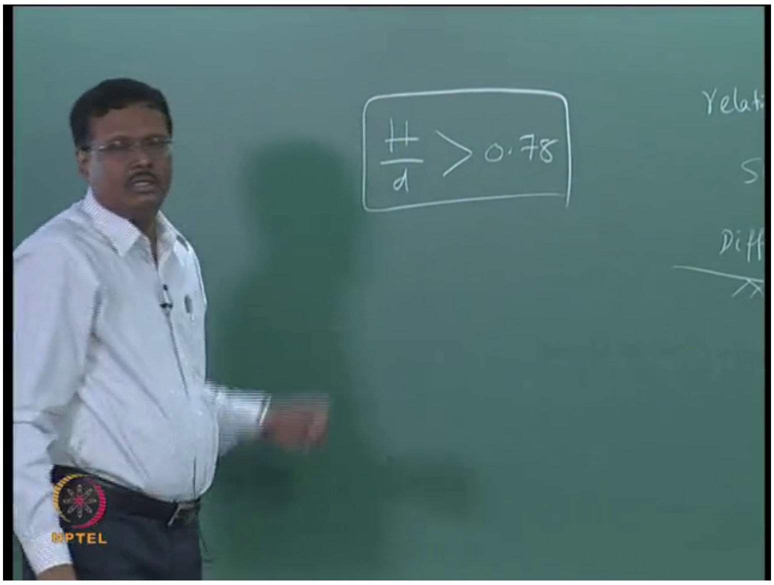

So for this wave, what is the maximum wave height it can have, H by L is 1 by 7, so H will be 1 by 7 into 156, so the wave height is, so the wave height is greater than 22.2 metres, the waves will break. Is it clear? A 10 seconds wave, when it is travelling, the wave height becomes more than 22.2, even in the mid ocean the wave will break. Wave break means it will break and it will generates smaller waves, like that. That is a wave breaking that takes place, it is in deep water by the water depth is more than 100, 200 or 300 metres like that. Now you have only this much water, 4.8, so for this the waves will break when H by d is equal to greater than 0.78. So if we have a 10 metre water depths, you can have maximum wave height of 7.8 metres only. Clear.

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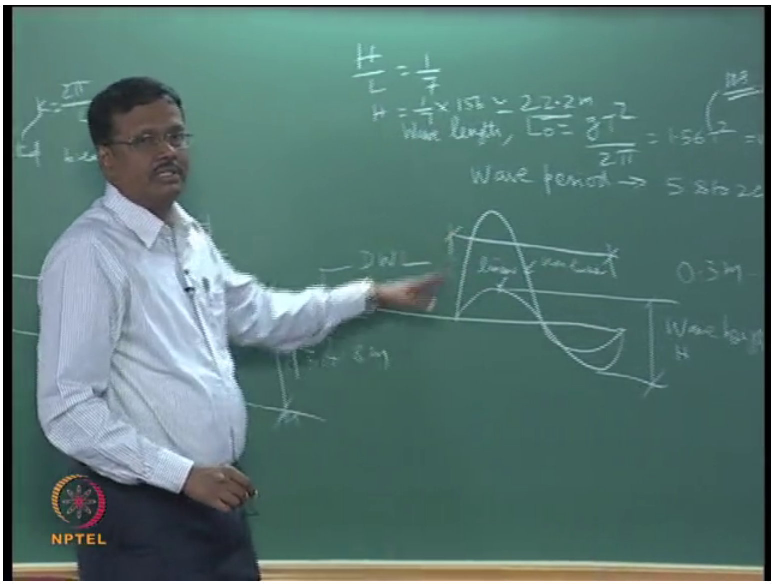

When the wave is breaking, before breaking the wave height will go like this. What is the difference between this curve and this curve? It is a linear wave, it is a non-linear wave. What is the difference, the crest height is about 70 to 80 percent of the total height, whereas in a linear wave, the crest height is equal to 50 percent of the total height. Before breaking what happens is the crest height increases to about 70 to 80 percent, then it breaks. When the wave is breaking on the structure, the force is enormous, is it clear, when the wave is breaking, the force is enormous.

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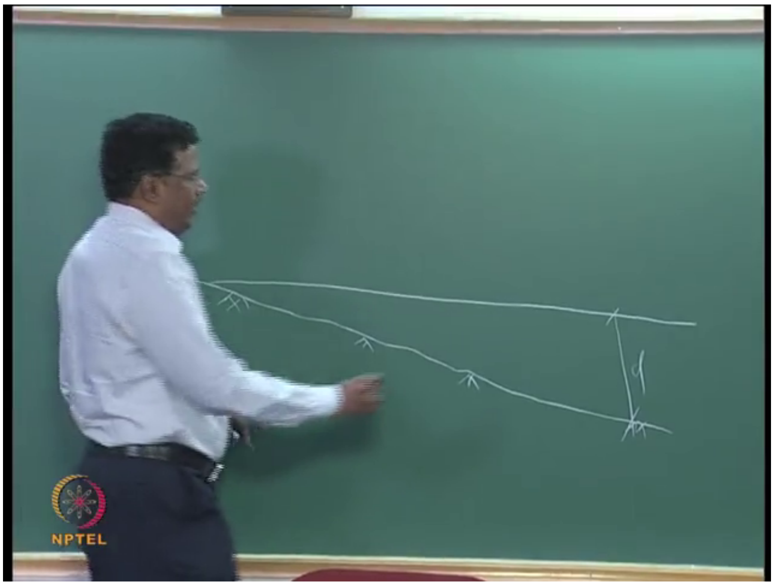

So this wave, what we are calling is H Max, significant wave height is H Max divided by 1.62 we put 1.8, sometimes they will say it is equal to 2 also. So what is that we are talking is, when a wave is coming, the waves will be coming something like this, you will have waves like this, different wave periods, wave heights and things like that. You take all the waves, you take an average, that is called as H average. You take the maximum of the wave, that is called as maximum, H Max.

Significant means, out of, let us say there are about 12 waves, you take 4 waves and take the average, it is called as the significant wave height. That is top one 3rd of the waves we take the significant wave. Do not take 12 waves and all, we have to take minimum about 500 or 1000 waves. If we take 1000 waves, top 333 waves you take, you take an average, that will be your significant wave. So the relation between significant and maximum wave height is given here, H Max by 1.6. The group of wave means something like this, the significant wave height comes like in a group continuously.

So here it is up, small, small, like that, but when a group of wave means waves heights of same size comes for about 2 to 3 minutes or 5 to 6 minutes, like that. Even if you have designed for HS, it would have failed. Normally it does not happen, the group of waves. So now we come to the problem, that is maximum wave height, significant wave height, so you can calculate 0.78 into 4.8, 3.744 by 1.6, 2.34 metres.

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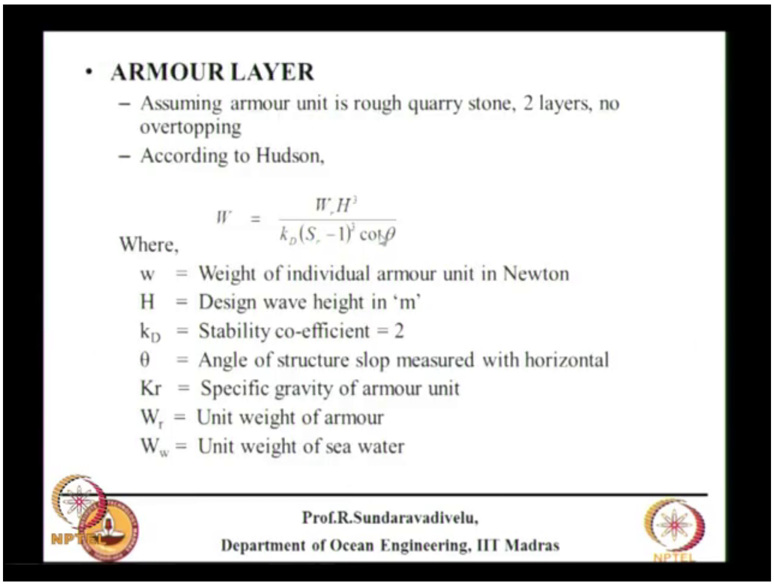

Then there is a formula by Hudson and another thing is, there is another criteria which you have to show. Assuming a unit is rough quarry stone, what is opposite to rough ? What is opposite to rough?

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I do not know that is why I am asking. I have something in between. What is opposite to rough? Do not say not rough and all, what is the opposite? Tell yah, you do not know what is opposite to rough?

Smooth.

Smooth you are telling, I also thought that, rough means, stone should, when you do not try to make it very smooth, rounded and things like that, do not use that. When you use for armour stone, do not try to cut the edges, like what you are doing for statue or for a temple, wall and things like that, you should not use like that. Clear no, it should be rough. We have to use 2 layers, this is very important. There are certain normal blocks where we use single layer, otherwise we have to use 2 layers.

Then this is the formula, W is the weight of individual armour unit, Wr is the unit weight of armour, H here, what we use as the significant wave height, KD is the stability coefficient which is given as 1, SR is given in the next slide I think and cot Theta, Theta is the angle of structure slope measured with the horizontal.

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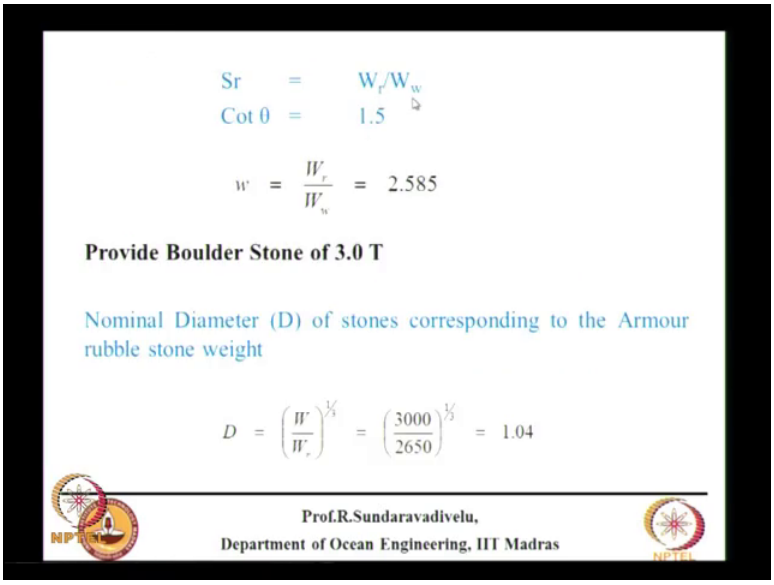

SR is Wr by Ww, Wr is the density of and Ww the density of water, that is why I have given in the problem water density. You substitute and get the weight of the stone as 2.585, in civil engineering we always round 2.585 to 3, we will not round 2.6 and all. So we use 3 tonnes stone. So with this we complete the class today, so you are calculating W, you substitute all the values here, I do not know what slope I have assumed, I think cot Theta is assumed as

1.8. I have given 1 is to 1.2, 1 is to 2 on the seaside but since the water depth is small, you go in for 1.5. Okay.