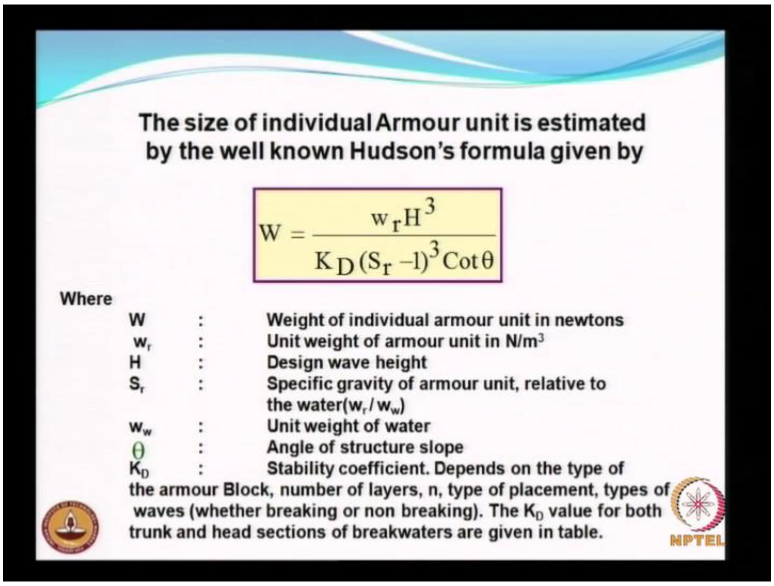
Coastal Engineering
Prof. V. Sundar
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module - 5
Breakwaters
Lecture - 4
Breakwaters – IV

(Refer Slide Time: 00:14)

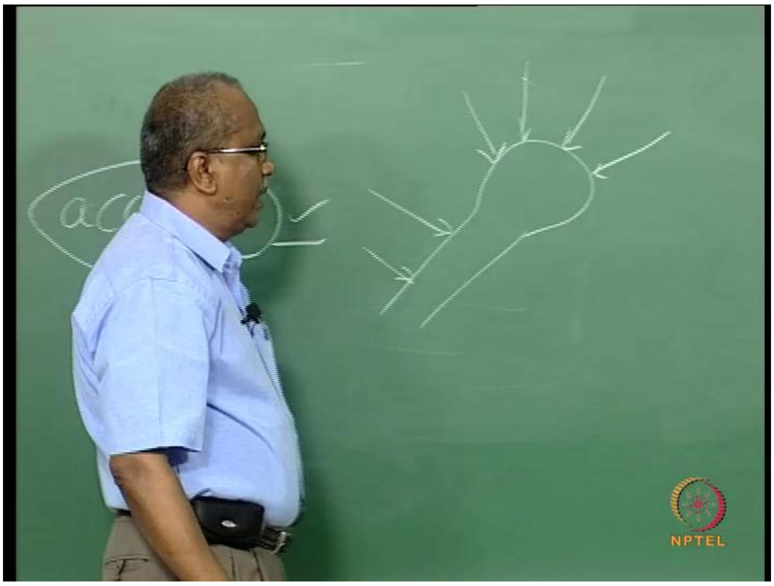


We will again proceed with the design of breakwaters, I will just explain about the design principles. The first and foremost requirement is the assessment of the weight of the stone that is needs to be used for the Armour layer. Once that is done, the rest of the things are automatic, in the sense you need to use some kind of a ratio for the secondary layer, core layer, etcetera; ratio of the weight of the stone which you have determined for the primary layer. So, here, the weight of the stone individual armour unit in may be in Newton's. So, it is given by this expression, where W r is the unit weight of the armour unit; then H is the design wave height, which I have already explained to you, how to look at the design wave height, how to select the design wave height; then the specific S r is the specific gravity of the armour unit related to the sea water. So, that is W r by W do W; then W w is your unit weight of water, I mean the sea water; then, you have the angle of the structure slope. So, this is the sloping, slope of the breakwater.

Then, K D is the stability coefficient which depends on the type of armour block, the number of layers n type of placement, whether, type of placement, whether it can be random or in a regular fashion, I will explain about that later; then, type of waves that is whether it is breaking or non breaking. The K D value for both trunk and head sections of the breakwaters are quite different, and are provided in the table in the next slide.

So, before that, so number of layers I have already explained in the previous lecture. The type of placement, see for example, if you look at some of the stones like Tetrapod's; this can be placed in random. The only requirement is that it has to be placed in two layers, but you can just simply place it.

(Refer Slide Time: 02:22)

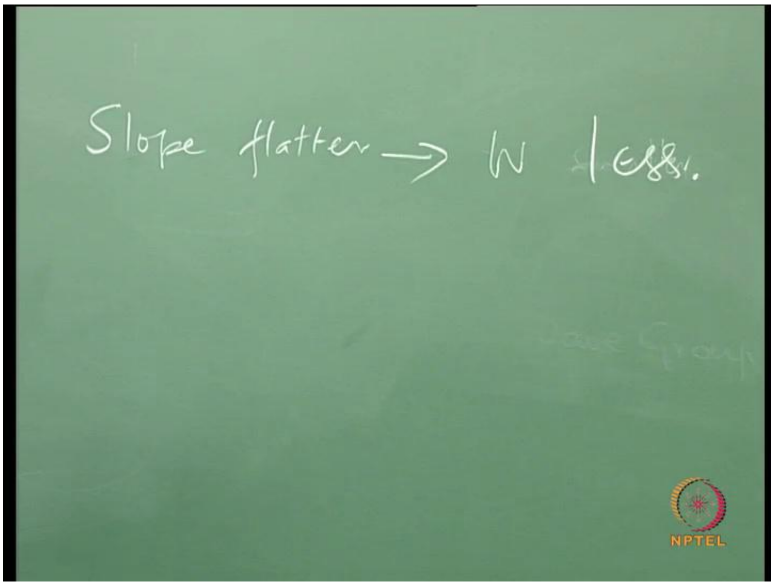


But if you look at the accropod, so, you cannot place this in random; it has to be, it has a regular way, a specific way of placing the armour unit; and, it is a single layer. So, if you do not follow the procedure laid down for placing the accropod, we are in trouble. So, so normally, it is up to the individuals or the people who want to have the breakwater, whether they want to go in for Tetrapod or accropod. So, there are a wide number of, a wide number of parameters which need to be looked into for allowing you, or for deciding on which armour unit you would like to use. Suppose, if you want to have accropod unit to be placed again in an island then it becomes a problem, because you need to have a skilled labour; skilled, I mean, a sophisticated constructional equipments, and may be someone who is quite experienced in placing procedures, etcetera.

So, in such cases, the usage of accropod may be a questionable, I am not single, I am not singling out, I am not, I am not try trying to discard accropod. Any layer any armour unit which has a specified method of placing has to be carefully looked into, if you are planning for a remote area for breakwaters. Whereas, the rubble mound, or natural rock, natural rock, or even the tetrapod is, just you need to know how it has to be fabricated; then, it is just going and putting it; only thing is, only guideline is that it has to be laid in two layers. So, this is very important.

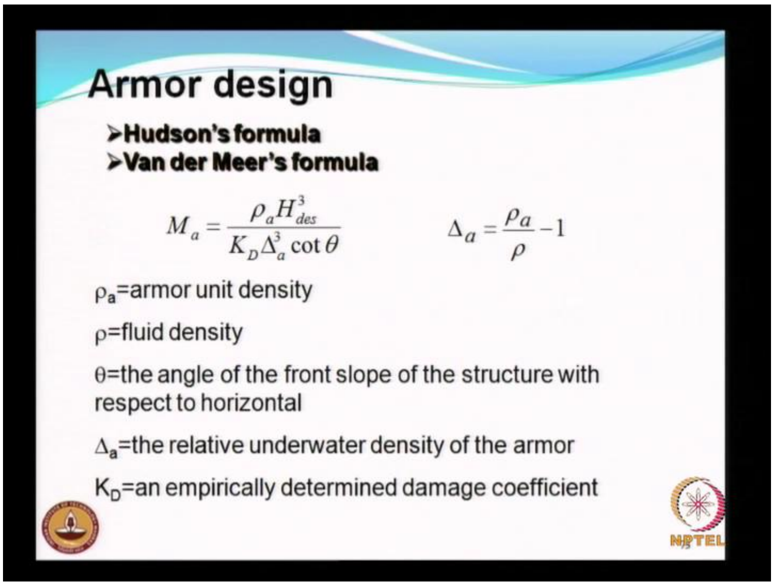
And, as I said earlier, you have the trunk and the head. So, trunk portion, normally the waves are approaching the trunk like this; whereas, your head is approached like this, the waves from all the direction. So, you have a flatter slope, which I have already explained. So, when you have a flatter slope naturally what will happen; see, you look at the, where the breakwater slope is coming here, called alpha.

(Refer Slide Time: 04:53)



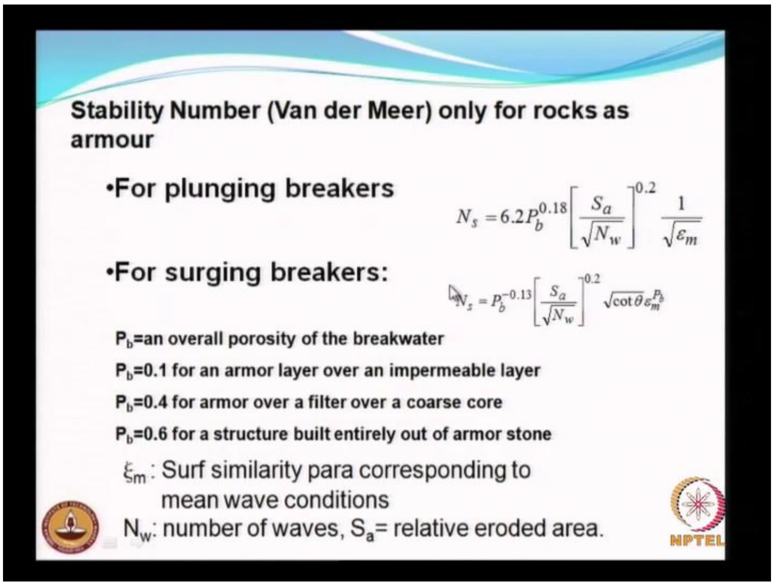
So, if the slope is flatter, slope flatter what happens? Slope is flatter; you, the weight stone can be smaller; the weight can be less and vice versa. If you want to have a steep slope, the weight has to be more. So this, some of this guidelines which you need to have in mind. So, if you have a, where in a location where you do not have, you have a moderate size of rocks, then, and you would like to make use of those rocks, then probably you can think of going in for a flatter slope. So, these are all some of the options which need to be considered when you are in the planning stage of thing.

(Refer Slide Time: 05:44)



So, you have armour unit, where Hudson's formula and Van der Meer's formula. So, where in here, in this case I have shown the expression for weight. So, here it is mass. So, I am putting here mass, and K D is usual thing, and then this relative density under water. So, this is given by this. So, this is what you have.

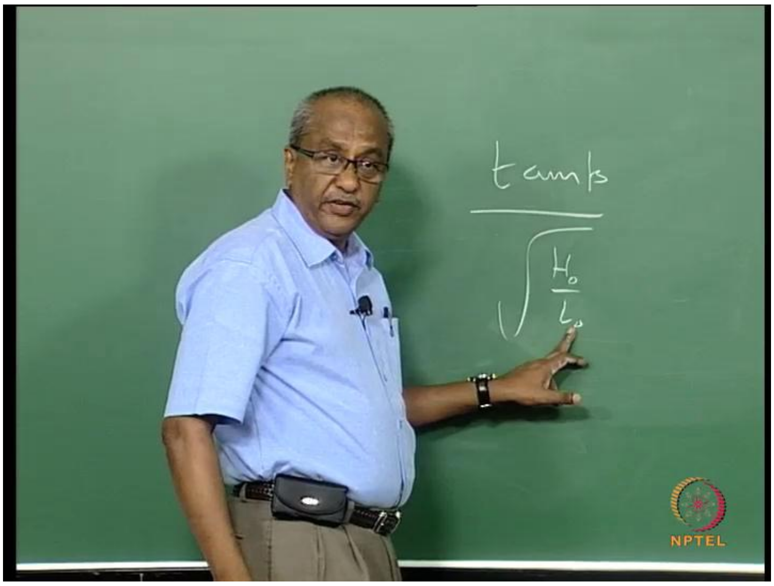
(Refer Slide Time: 06:12)



So, in the case of Van der Meer's formula; so, what he has done is, he has considered the type of breaking also into account. So, I suggest that you to refer to some of the books like the coastal engineering manual, etcetera, for other details, I am just giving only kind of introduction to this. Van der Meer's formula can be used for situation where you breakwaters are filled with rocks, are formed by rocks.

So, in such case, you have 2 equation, 2 equations or expression for the stability number which is given as your, for plunging breaker this is what you will have the stability number. And then, this is the, for the surging breakers. What will happen is P b is an overall porosity of the breakwater? P b equal to 0.1 for an armour layer over an impermeable layer; P b equal to 0.4 for the armour layer over a filter layer over the core coarse; then finally, you have for a structure built entirely out of armour stone, just dumping the stone, no core no secondary layer nothing. So, you have for a wide range of choices; you have the stability number slightly changing.

(Refer Slide Time: 07:46)



So, here, in this case, this surf similarity parameter, we have already seen, the surf similarity parameter is nothing but tan beta that is the slope of the structure divided by square root of; which means that in the stability number, in the earlier case, you see that there is no wave height, wave period coming into picture at all means at this formula. But in the Van der Meer's formula, this is accounted for; that is the wave period is accounted for; that is a major difference between the Hudson's formula and the Van der Meer's formula.

So, then, you can also consider this, the number of waves. So, number of waves normally when you use for, usually they consider for, as for 1000 waves. So, what does that mean?

That is cumulative affect or cumulative action of about 1000 waves. What is the status of the breakwater? It is very easy, in the lab, you have a breakwater formed by this procedure, you have arrived at the wave, etcetera, you have formed the breakwater. You have a wave maker at one end then you set the wave maker for a particular period for which it has to be adjusted, then subject the model for about 1000 waves. Look at the stability, the status of the structure. The status of the structure is intact then we say the structure is safe, stable. So, the number of waves, normally it should be taken as 1000. For details, please refer to the standard books as I have said earlier.

(Refer Slide Time: 09:17)

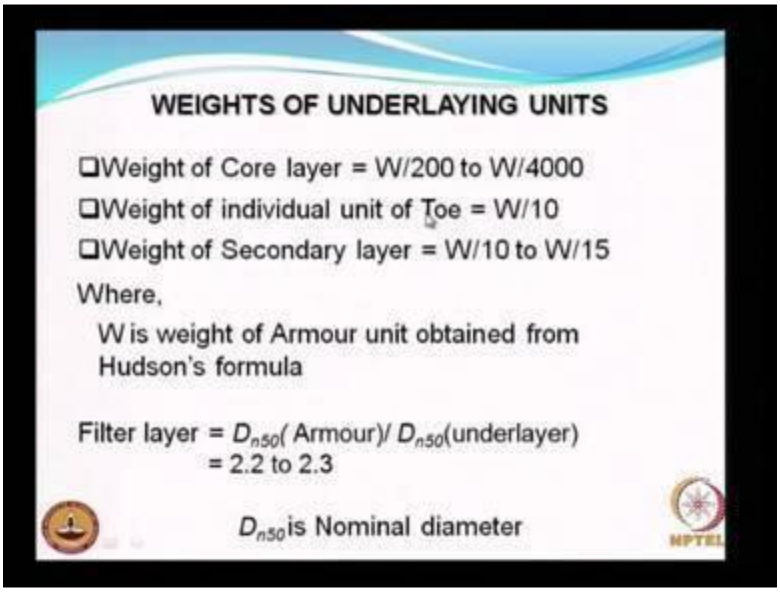
Suggested K_D values for use in determining armour unit weight[1].

No - Damage Criteria and Minor Overtopping							
Armour units	n	Placement	Structure Trunk		Structure Head		
			K_D		K_D		Slope
			Breaking Waves	Non-breaking waves	Breaking waves	Non-breaking waves	Cot θ
Quarrystone							
Smooth rounded	2	Random	1.2	2.4	1.1	1.9	1.5 to 3.0
Smooth rounded	>3	Random[4]	1.6[4]	3.2	1.4[4]	2.3	5
Rough angular	1	Random		2.9		2.3	5
Rough angular	2	Random	2.0	4.0	1.9 1.6 1.3	3.2 2.8 2.3	1.5 2.0 3.0
Rough angular	>3	Random	2.2	4.5	2.1	4.2	5
Rough angular	2	Special[6]	5.8	7.0	5.3	6.4	5
Parallelepied[7]	2	Special[1]	7.0-20.0	8.5 -24.0	—	—	
Tetrapod and Quadripod	2	Random	7.0	8.0	5.0 4.5 3.5	6.0 5.5 4.0	1.5 2.0 3.0
Tribar	2	Random	9.0	10.0	8.3 7.8 6.0	9.0 8.5 6.5	1.5 2.0 3.0
Dolos	2	Random	15.8[8]	31.8[8]	8.0 7.0	16.0 14.0	2.0[9] 3.0
Modified cube	2	Random	6.5	7.5	—	5.0	5
Hexapod	2	Random	8.0	9.5	5.0	7.0	5
Toskane	2	Random	11.0	22.0	—	—	5
Tribar	1	Uniform	12.0	15.0	7.5	9.5	5
Quarry stone(K_{RR}) Graded angular	-	Random	2.2	2.5	—	—	

Now, looking at the, suggest that the K D values, there are some of the new types of latest, latest armour stone is stone which might be, which might not be appearing here. So, this is from the old shore protection manual where you have the armour units; this is the number of layers. So, this is the type of placements, rather it is random or special type, for example, accropod is not there.

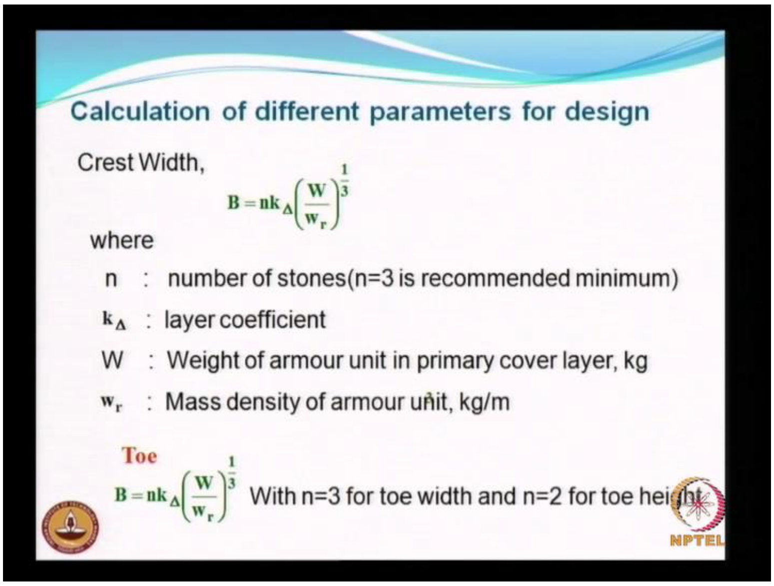
So, accropod, I think, you have to check into the literature for accropod; and then, you use this structure head and for, the structure trunk and structure head. The K D values for, if you want to consider the breaking waves, these are the K D values; and these are the K D values for non breaking waves and similarly for the structure. And see, for all these things, all this row is for a particular slope of the breakwater. So, you need to know the slope; and then you need to know whether you are designing for breaking waves or non breaking waves. For non breaking waves naturally your K D value is more.

(Refer Slide Time: 10:46)



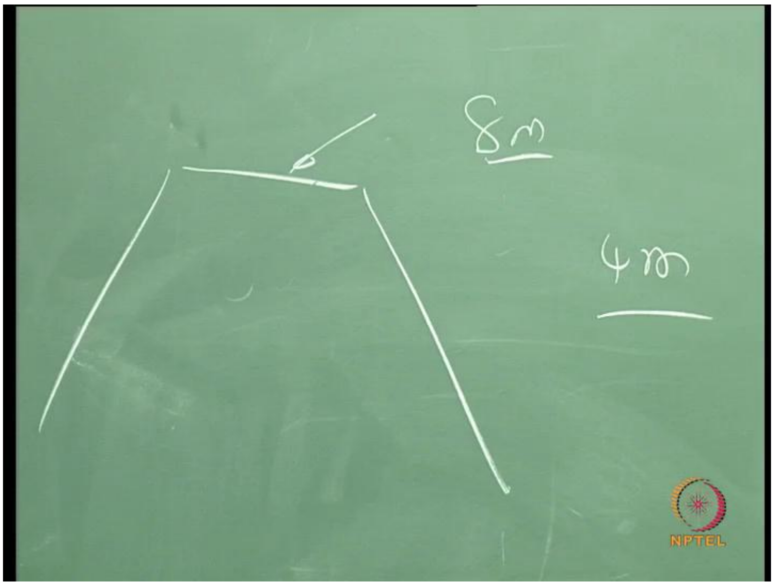
Now, once you have decided the weight of the stone, then weight of the underlying units can be calculated. For example, for the weight of the core, the weight can be varying between W by 200 to W by 4000; whereas, the weight of the individual unit for toe can be, toe can be around W by 10; and then weight of the secondary layer W by 10 to W by 15. W is the weight of the armour unit obtained from Hudson's formula, is that clear. So, that is what I said, once you calculate your weight of the stone then it is all quite straight forward. The filter layer can be D n 50 for the Armour layer divided by the under layer or the secondary layer. This ratio should be between 2 to, 2.2 to 2.3; these are all the guidelines which you need to take care.

(Refer Slide Time: 11:43)



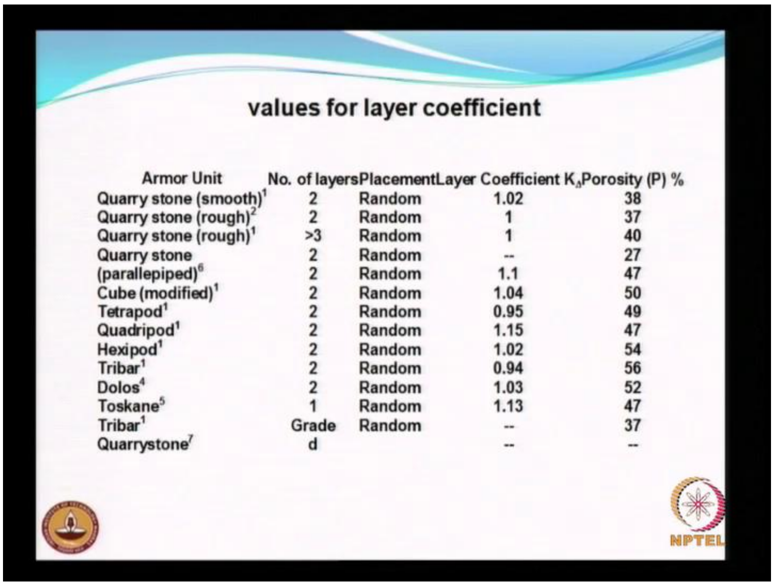
Now, calculation of the different other parameters. For example, the crest widths; the crest width of the break water.

(Refer Slide Time: 11:53)



Usually for commercial harbours, it is taken as 8 meters, and for fishing harbours etcetera, or minor ports they go in for about 4 to 5 meters. So, this is general guideline which you can use. But, the break water width can be calculated as shown here, where n is equal to 3 is recommended minimum one is; k delta is the layer coefficient, which we will see later; and then, W is the armour layer weight; and then, this is the mass density of armour unit. So, toe, for the toe, the width of the toe can be again calculated as shown here, for the, for the toe width; and n equal to 2 for the toe height, the same procedure you use. So, you can calculate the toe width. So, in general the toe width is kept as atleast 3 meters.

(Refer Slide Time: 12:55)

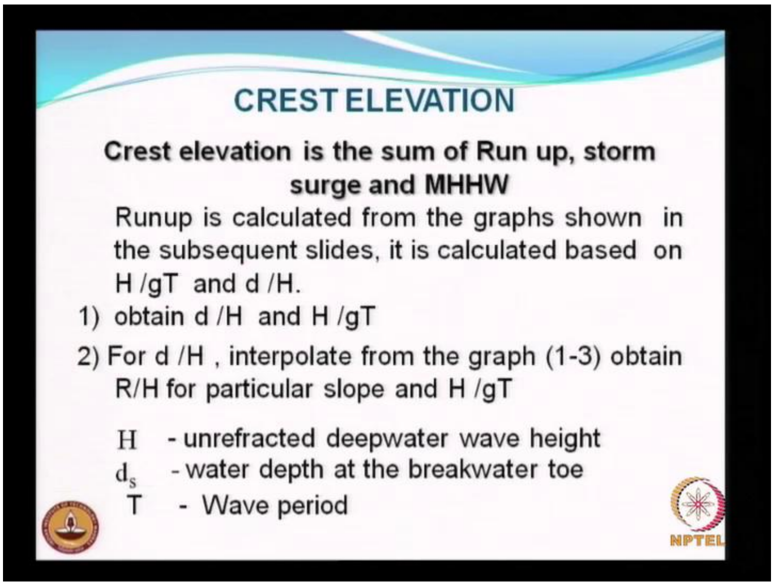


values for layer coefficient

Armor Unit	No. of layers	Placement	Layer Coefficient K_Δ	Porosity (P) %
Quarry stone (smooth)[1]	2	Random	1.02	38
Quarry stone (rough)[2]	2	Random	1	37
Quarry stone (rough)[1]	>3	Random	1	40
Quarry stone	2	Random	--	27
(parallepiped)[6]	2	Random	1.1	47
Cube (modified)[1]	2	Random	1.04	50
Tetrapod[1]	2	Random	0.95	49
Quadripod[1]	2	Random	1.15	47
Hexipod[1]	2	Random	1.02	54
Tribar[1]	2	Random	0.94	56
Dolos[4]	2	Random	1.03	52
Toskane[5]	1	Random	1.13	47
Tribar[1]	Grade	Random	--	37
Quarrystone[7]	d		--	--

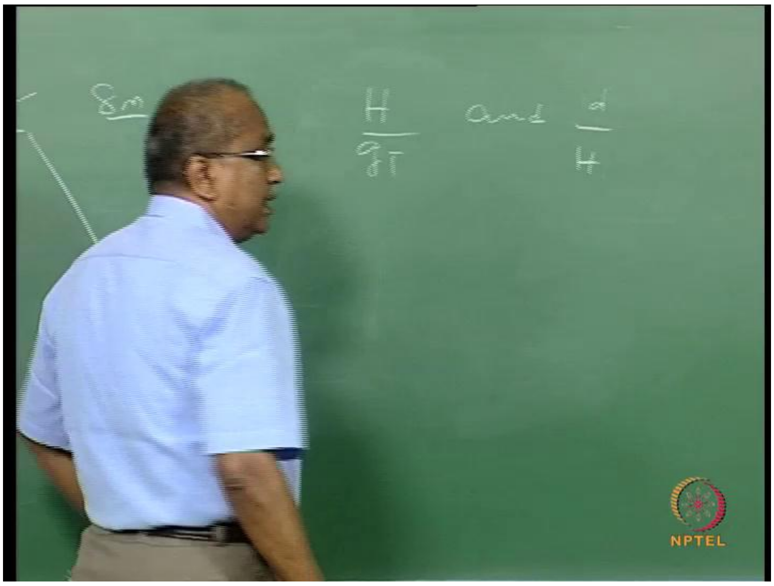
So, this layer coefficient can be obtained from this table, where you have the different cases, where you have the different types of armour unit; then the number of layers; then placement method; then this is the layer coefficient which is provided here; and then the percentage of, I mean, the porosity percentage is also given in the last column that would give you an idea concerning what is a kind of porosity you may expect when you use the different types of armour units. The most widely adopted stones are quarry stones, Toulouse, Tertrapods, then cubes, then core lock, then core lock, I think mostly these things, and I think you should look into the literature.

(Refer Slide Time: 13:58)



So, crest elevation. So, you understood the crest width and the toe width; there are some guidelines which you need to follow, and using; all this factors are, have been discussed. So, you have to calmly design the breakwater cross section. So, concerning the run up calculation, run up calculations are made using the graphs as shown in the subsequent slides. So, it has to be, it is calculated based on H by g T and d by H.

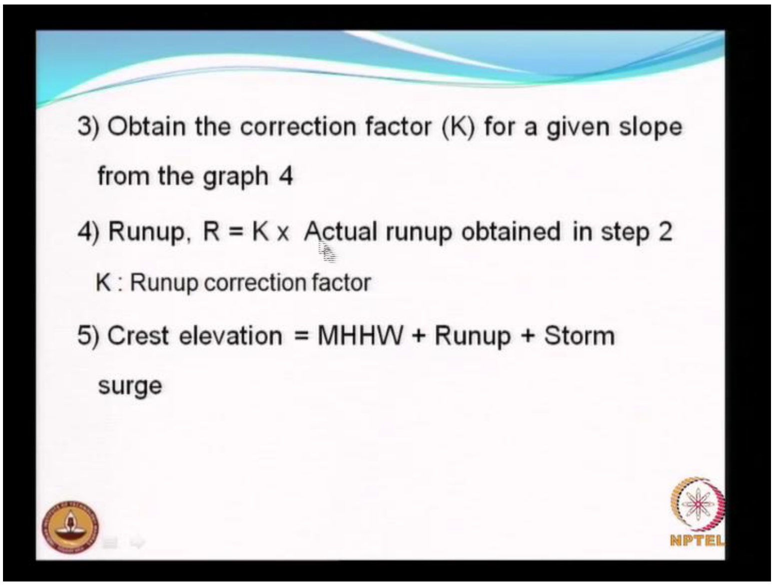
(Refer Slide Time: 14:29)



So, obtain a correction factor for a given slope that is some, this one; and then run up is, actual run up. See, for example, you get, you interpolate from the graph 1 to 3 to obtain

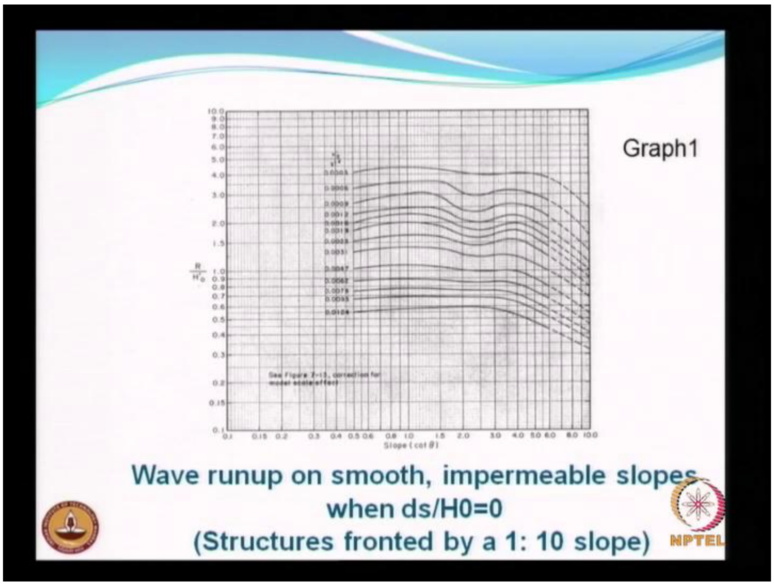
R by H; and so, for a particular slope, and this one. So, for slope is fixed, and for particular value of these values, you calculate your, a run up.

(Refer Slide Time: 15:04)



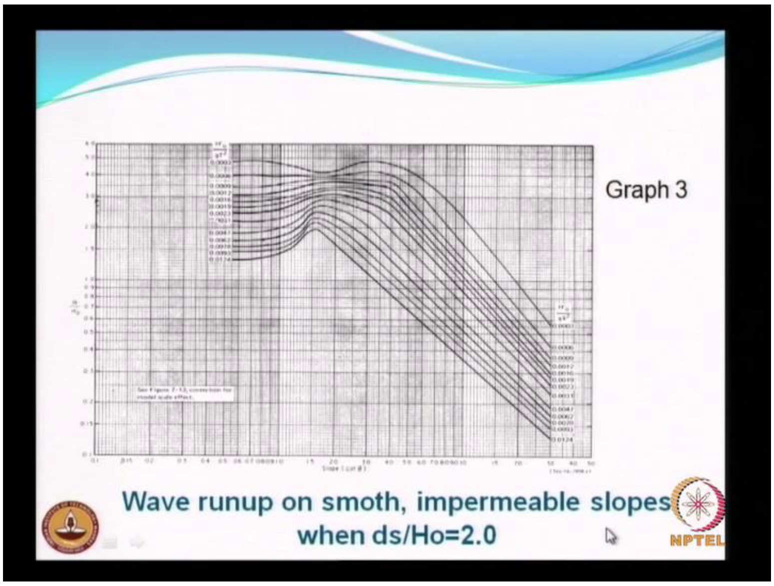
And then finally, what you do is, you get the run up value, but you adopt a correction factor K; and then, you have to add up the mean, the maximum highest high water, maximum high water, highest high water plus the run up as per the calculation plus storm surge; storm surge may be 1 meter, or it depends on the size 1 meter or 0.5 meter or whatever it is; and then you have to include what is the maximum high, highest high water. So, this is very important to decide whether you are going to design it, design it as a over tropic structure, or a non over tropic structure.

(Refer Slide Time: 15:48)



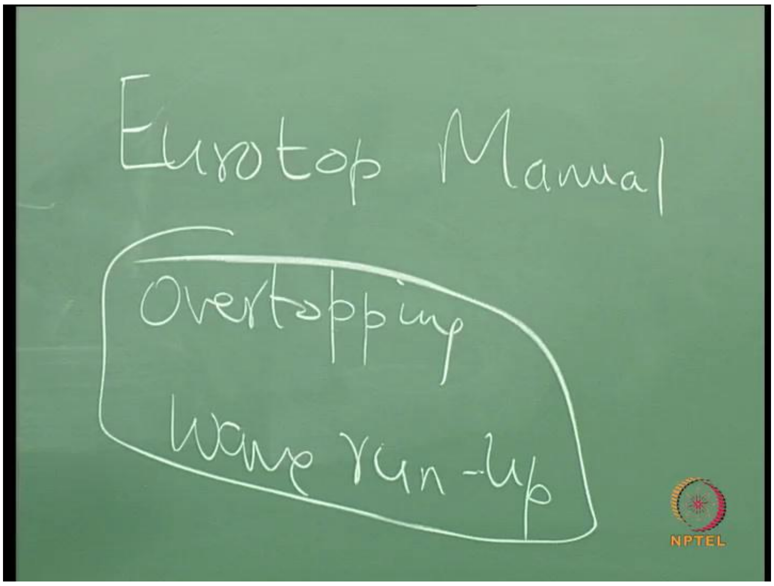
So, here is, it is. So, the wave run up for smooth impermeable slopes are given here; slope is given here. So, this is the H by g T square. So, this is R by H, H not prime. So, you can use this value. So, you calculate this parameter, and you know the slope. So, you can get this value.

(Refer Slide Time: 16:17)



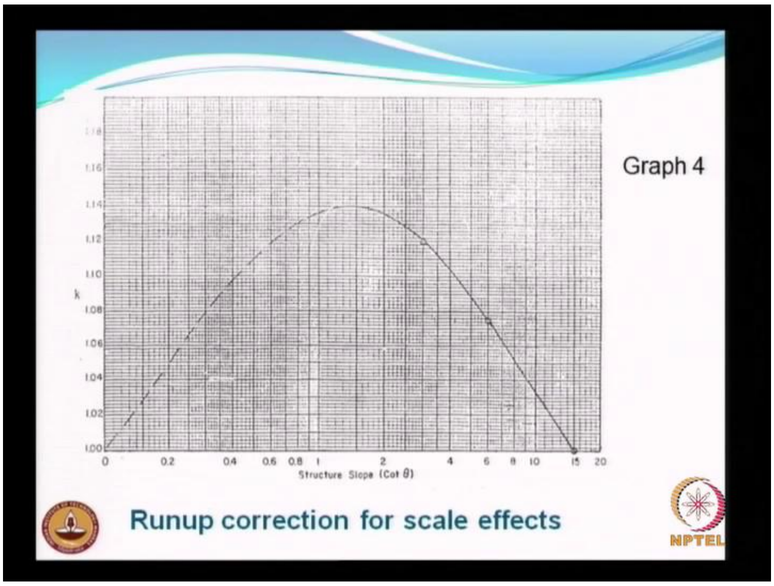
So, then, smooth and impermeable slope for 1 isto 10; and then, smooth and wave run up for, on smooth and impermeable slope for this factor ds by H naught equals to 2.

(Refer Slide Time: 16:30)



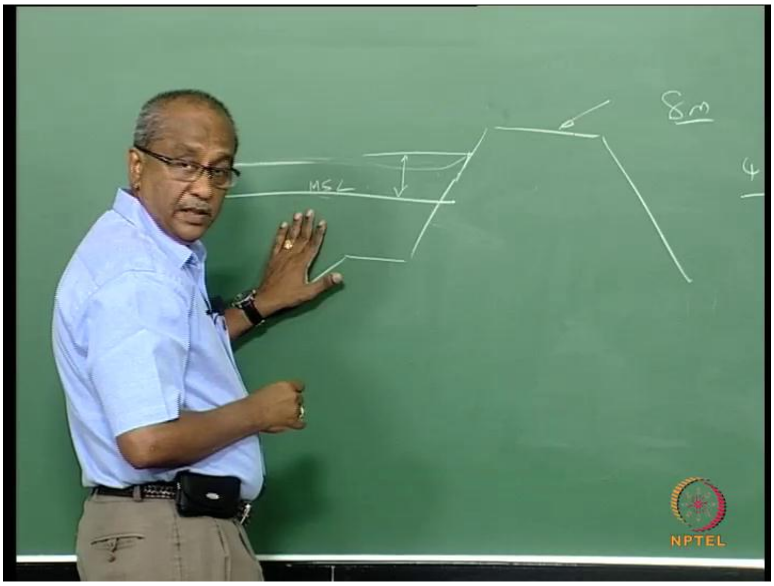
And, I suggest, there is one manual which is called as euro top manual, which is exclusively for overtopping and wave run up. So, if you try to Google it for this, you have a manual available; you can really download, which gives the latest information about, on this important aspect. So, I do not want to go into the details of wave run up. We have so many, there is major European project that was carried out to, for considering these two aspects. So, I suggest you have a look at it.

(Refer Slide Time: 17:21)



So, you also, once you calculate the run up from that then use the, for a particular slope you can get the correction factor which has to be multiplied by the run up, which you have evaluated based on the earlier figures and that run up has to added to the maximum highest high water line, high water plus the storm search that gives you the crest elevation.

(Refer Slide Time: 17:49)



So, this is the MSL. So, may be, this is the run up under MSL. But, then you have to add your maximum high water line and then you have to add the storm search, in order to get the crest elevation. So, this is, actually we have already seen the different kinds of layers.

(Refer Slide Time: 18:17)

So, this based on accropod. So, you have a secondary layer, I mean, a core layer, a secondary layer and the primary layer, wherein, in the case of accropod, it is only by a single layer. So, there is only one single layer which is, which is used to form the; so, you see only one stone is there. And, what we have also done some test with the accropod? The accropod is quite stable.

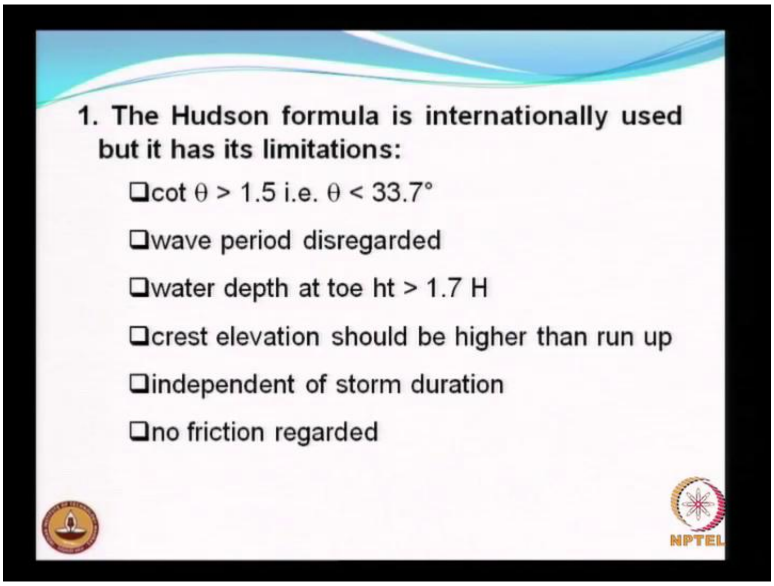
See this artificial armour units, they have very good interlocking capacity, when they are put together. So, for example, this has a very good interlocking capacity. But, it has a regular placing method that is the slight disadvantage. But this, and another problem with accropod, it is not a problem, it is a feature. The, another feature is the surface is not that rough as compared to, at accropods. So, when we did the experiments with Tetropod and accropods in the department, we found that accropod has slightly more reflection, sorry, less reflection, and then it has slightly more over topping.

Because, when you have Tetropods, it is placed in random, so, lot of friction is offered. So, the reflection is less, and so, the over topping is also naturally has to be less; and we found that it has to be less in the case of Tetropods.

(Refer Slide Time: 19:57)

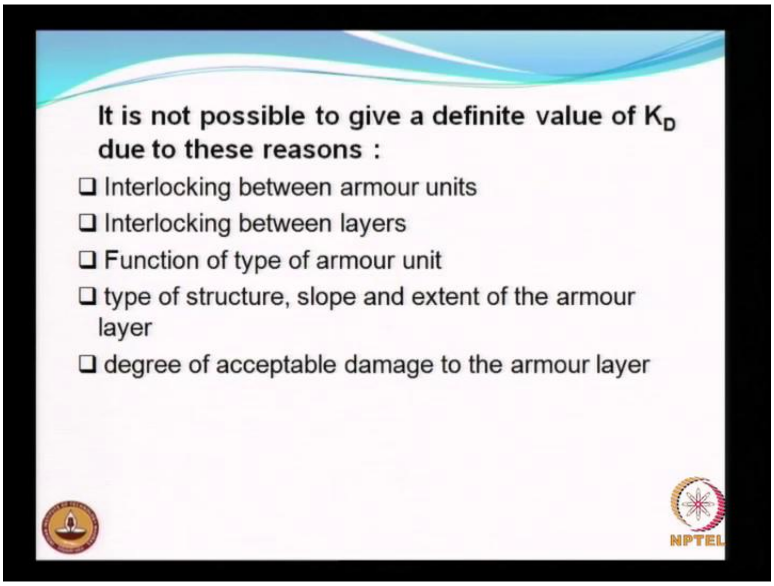
So, this, I am showing this, this is another type where you used Dolos. Dolos is, you refer to the earlier picture how it looks like. So, Dolos is shown here. So, just give me a second, so, I forgot to bring a model, so, maybe I show you the models later.

(Refer Slide Time: 20:27)



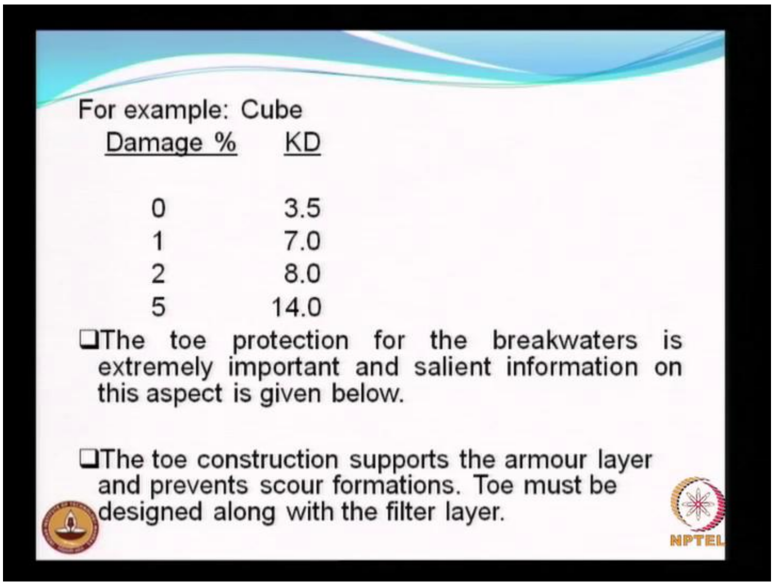
So, the Hudson's formula; let me have a kind of commentary on the Hudson's formula, because Hudson formula is widely used. So, although it does not consider the wave period, but still it is widely used. And, it incorporates all the other different, at which Armour unit also. So, you see that it has some limitation. So, for, that is one with respect to the slope; then the wave period is not considered; the water depth at the toe, at the toe if it is greater than 1.5 H; then the crest elevation should be higher than the run up, that is for sure; independent, so it does not consider the storm duration; and finally, no friction is regarded, it is, it does not consider the friction either; so, but it is an empirical formula, but still it is widely used.

(Refer Slide Time: 21:18)



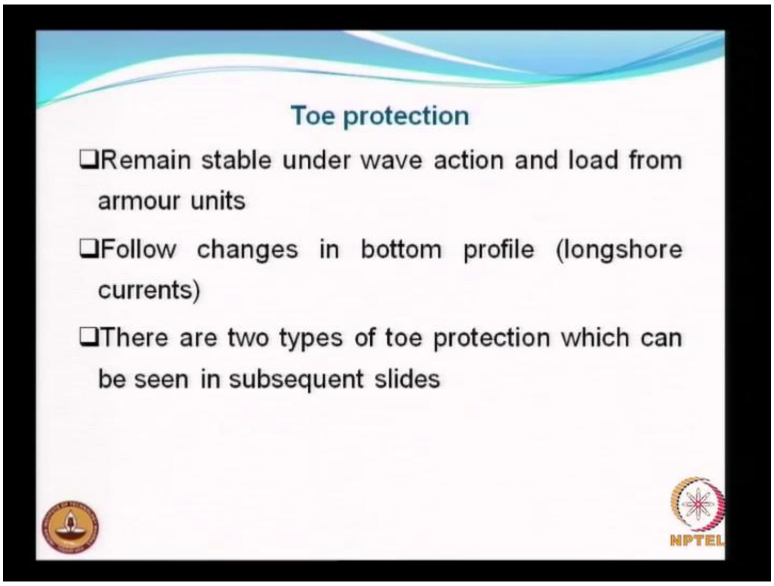
People say that it is giving slightly over estimate for the weight of the stone. But then, you can also argue whether the wave height, we are not using the max wave height, we are using only the wave height. So, there are some kind of discussion going on even now. But, it is still, inspite of all this things, we still use the Hudson's formula. And, so, it is not possible to give a definite K D value due to reason, because K D value is there in the Hudson's formula. But, you have to, have a, the K D value which have, will have to depend on interlocking between the armour units, between the layers; then function type of the armour units; and type of structures, slope and extension of armour layers; and then degree of acceptable damage. See normally, the acceptable damage, you can have a damage upto 5 percent, I will come to that later when we look at the physical modeling of breakwaters.

(Refer Slide Time: 22:30)



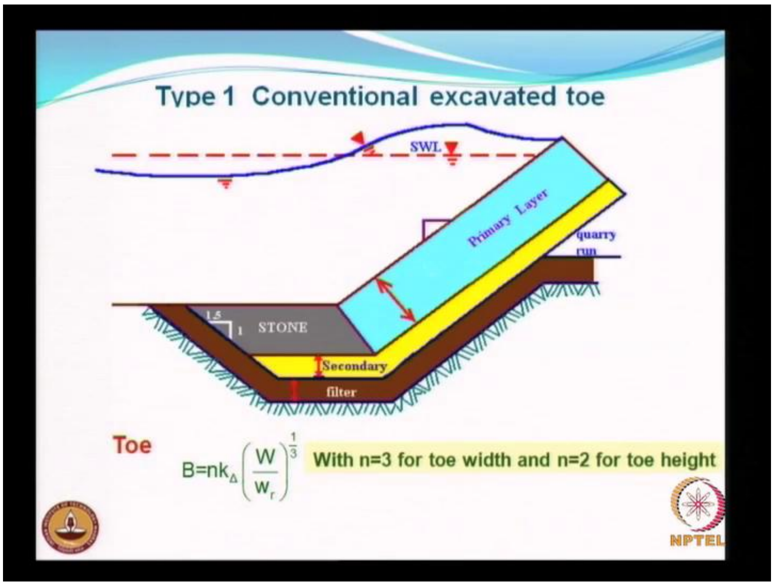
So, for example, in case of cube, percentage of damage, if it is 0.5 the K D, the K D will be, no, the percentage damage is 5 then the K D value can be upto 14. So, the toe protection is extremely important, and I will just move on to the next slide which shows the toe protection

(Refer Slide Time: 22:50)



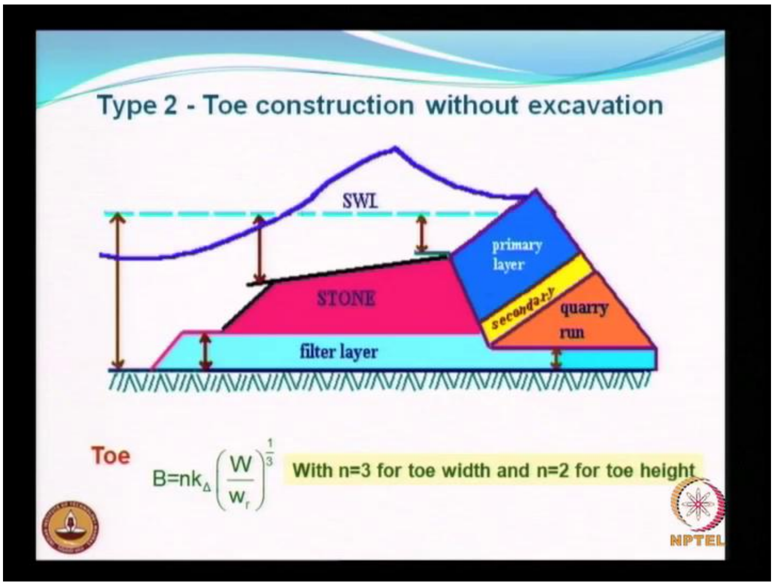
Toe protection remains stable under wave action and load from armour unit. Follow changes in the bottom profile that is due to long shore current, it has to take care of that, because it is, it can, changes near the toe, near the tip of the break water. There are two types of toe protection, and one is the exposed to and another is the excavated to.

(Refer Slide Time: 23:15)



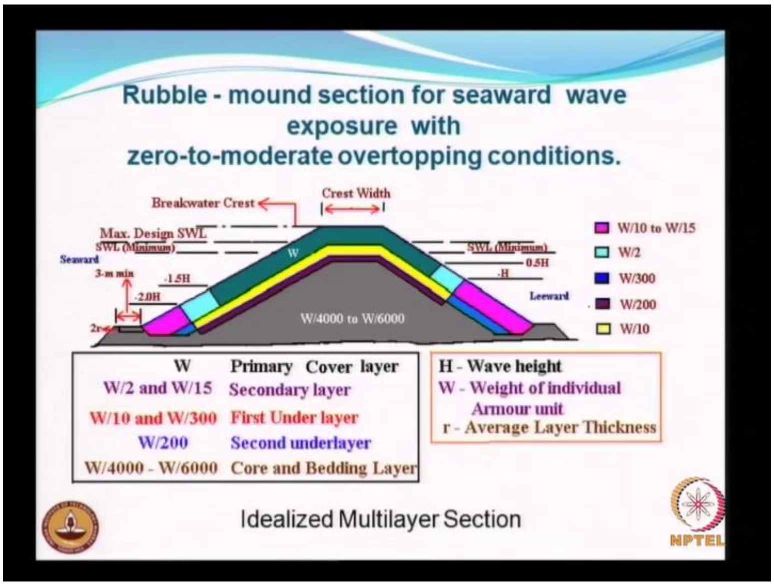
So, this is the conventional excavated toe; that is the big. Remove the sand and then build up it, as shown here. So, as you can see here, they built the whole thing. And then, these are the width n equal to, for toe width and n equal to 2 for toe height, as I have discussed earlier. So, this is the primary layer. So, you can run the filter layer, and then you can use the secondary layer can be run in to this; and this also be just primary layer stone itself, can be extended or you can use slightly less, but the width, if for sure it has to be minimum of 3 meters, minimum, minimum; many location they use 6 meters.

(Refer Slide Time: 24:04)



So, this is without any excavation. So, wherein, you have the, you have the primary layer, then the filter layer extended, then you have stones of either the primary layer or something in between the primary layer and the secondary layer, and again here the toe it has to be about 6 meters, but you have a conventional method of calculating the toe height and the toe width, is that clear.

(Refer Slide Time: 24:36)

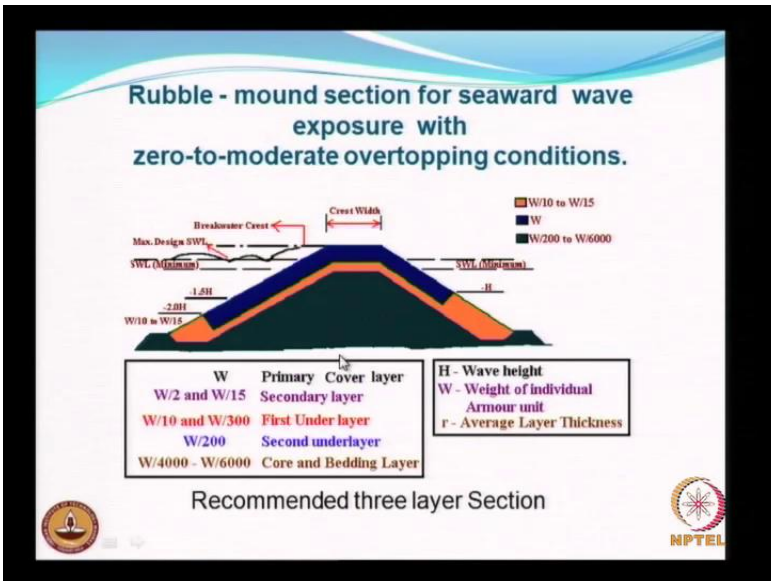


So, rubble-mound cross section for seaward wave exposure for 0 to moderate overtopping. So, this is to summarize what we have done so far. So, this is, may be the

W S to W 15; so this W that is armour layer; or sometimes this is not, this is not considered, this is, all this things considered as the W, and this all can be considered by W by 2. Instead of just this alone you can also consider this as W by 2 provided, but here you see that there is with zero to moderate over topping; suppose if you allow moderate over topping, then there may be some problem here and that is the reason why you have the W itself extending at least for certain distance on the least side.

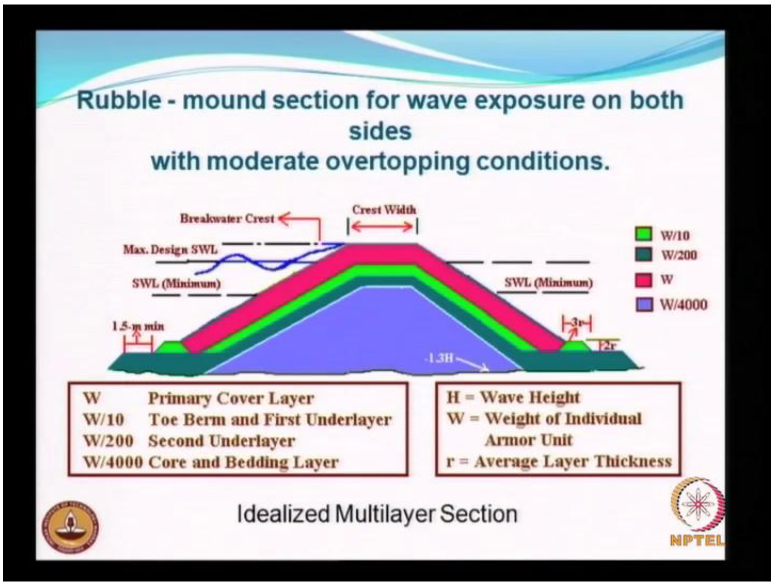
If there is no over topping allowed, then you can still replace this darker, the entire thing by W by, even W by 2, but not W by 10. W by 10, if you want to have, then it has to be far below, because when the waves fall under this, is the area which is quite important that is the distance of about minus H, minus the wave height from the still water line. So, if this, if this height is approximately upto this, is one wave height, then you can have beyond this W by 10; that is gives you an idea that beyond that the over topping cannot or may not have much affect, you understand. So, once you design it, it is always better you check with physical modeling before you go into the field. And, the core layer also worked out; all this things are, all this details are given in this.

(Refer Slide Time: 26:27)



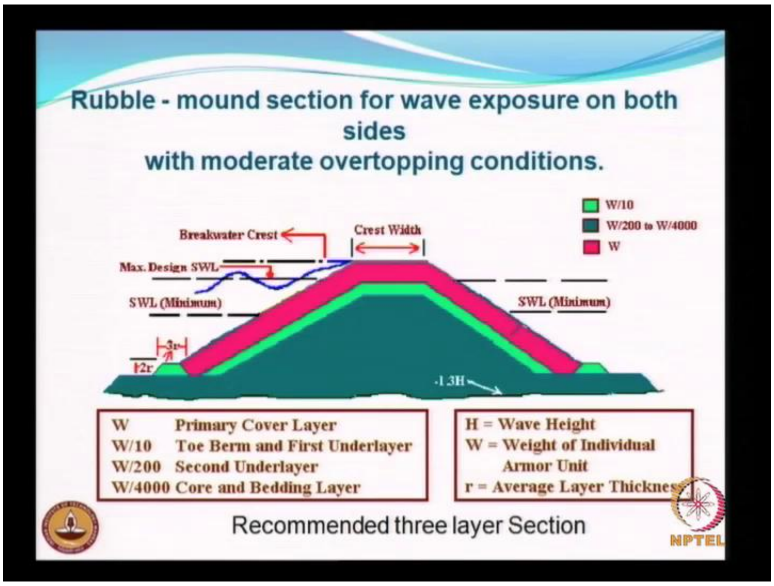
Next, this is the rubble mound structure 0 to recommended this 3 layer structure; this is another typical cross section, where you can use this as a base for your design of your breakwater. So, as I said, I have already indicated you, how to calculate W that is what is very important, because if you look at the cross section, it just you need to draw a picture, or only thing is you need to only have the weight of the stone; that is the only thing which is very important. So, looking in the figure, you can make the whole thing on your own, is that clear.

(Refer Slide Time: 27:03)



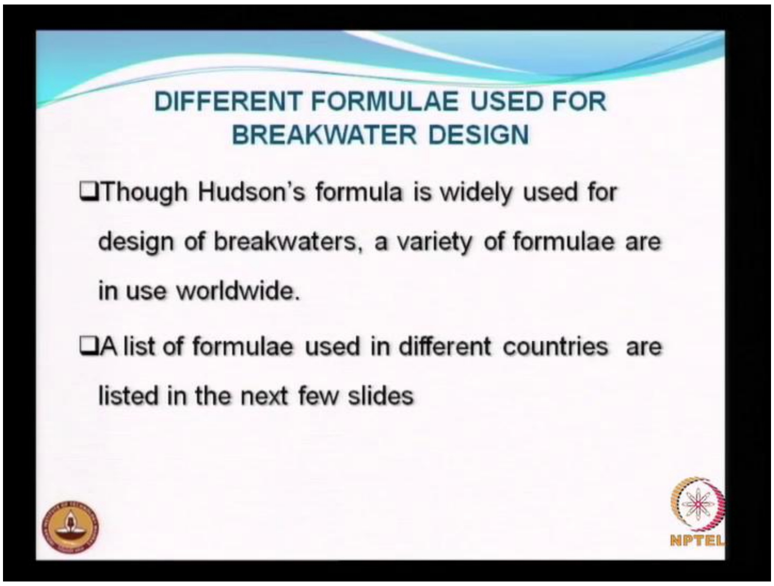
And, this is again for moderate over topping. And, this needs a lot of experience also, because there are, when do you consider the over topping, when do you do not know, it also depends on the importance of the project. There is certain projects you do not need to have, you should not have even a small degree of over topping; a certain significant over topping can be allowed. For example, there are some reef breakwaters; it will always be submerged. So, all these things you have to look into the details in some selected reference, which are given at the end of the lecture.

(Refer Slide Time: 27:40)



So, this is again with moderate over topping rubble mound wave exposure, so, all these things.

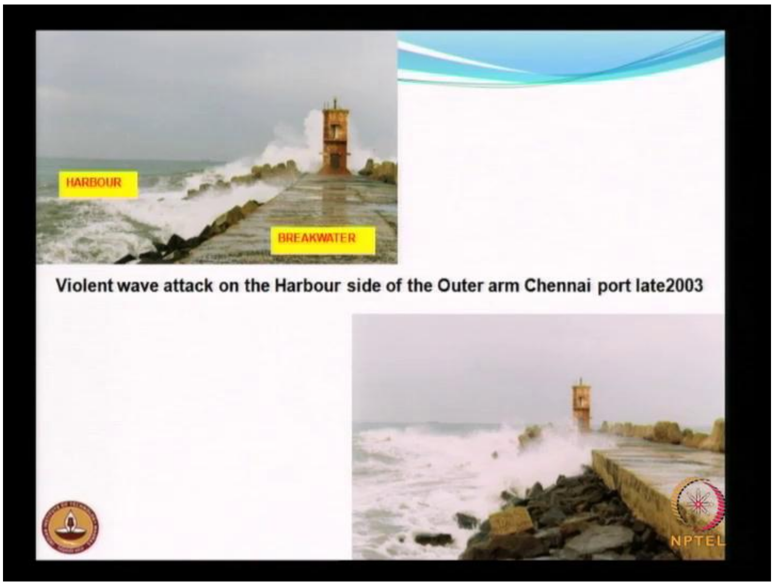
(Refer Slide Time: 27:51)



There are different types of combination which you can think of, you think. Again for, although the Hudson's formula is widely used in the design of breakwaters; a variety of formulas are available in literature; a list of formulas used, are given here.

So, this was, this has been used in Spain. So, this is used in United States; this has been used in France; Sweden, Norway; Soviet Union; So many formulas are there. So, it is all available in the lecture material, you can have a look if you are really interested in knowing more about the formulas.

(Refer Slide Time: 28:21)



Then you have the violent. So, this picture just shows Chennai harbor, outer arm, during one of the cyclones, when, during late 2003, the kind of over topping; and, usually there is not much of over topping, but during a cyclone you see what can happen. So, in fact, the wave reached till the top of this tower, I believe; but nothing happened, it is all intact. So, with that I complete the breakwaters studies.