

Coastal Engineering
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Module - 8
Physical Modelling
Lecture - 1
Physical Modelling of Coastal Structure – I

Now, this lecture module will be something about the Physical Modeling in Modeling in Coastal Engineering in general, dealing with a mostly coastal structures. And we will just looking into some of the aspects, why model testing? Problems that cannot be addressed by analytical or numerical modeling.

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WHY MODEL TESTING?

- > Problems that cannot be addressed by analytical or numerical models
- > Non linear effects, such as wave breaking, flow separation and overtopping of breakwaters are mathematically complex
- > Prediction equations for a given problem, usually has empirical coefficients that need to be derived from tests
- > To understand the underlying physics behind a problem, eg: wave transmission past a barrier

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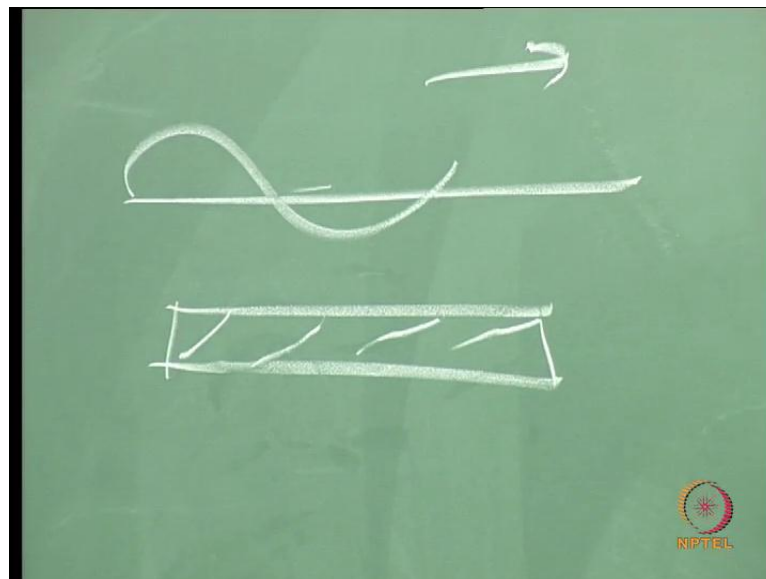
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Naturally you have to resort to physical modeling. Non-linear affects such as wave breaking flow separation and overtopping of breakers or overtopping over break waters are mathematically extremely complex very difficult. Prediction equations for a given problem usually has empirical coefficients that need to be derived from tests, there are number of empirical coefficients. For examples, we have also seen in the long shore sediment transport proportionality constant, sediment transport to the immersed weight of the sand.

Now, how do you get that proportionality constant may be you do some experiments or you do some field studies only then you can get some proportionality constant. In fact, how did you get the k_d value for your breakwater, that is also based on experimental experimental studies. So, then to understand the underlying physics between the behind the problem; for example wave transformation pass a barrier. So, you have a barrier you have the wave transformation passed a barrier, what is the physics behind it.

Now in order to understand the physics behind the any problem you also have the flow visualizing techniques, flow visualization techniques where you can under you can also look at the orbital paths.

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So, when you have flow taking place a waves moving in this direction and then in the wave flume you want to have submerged breakwaters plate breakwater for example, just an example. So, without the submerged breakwater you can look at the orbital velocities, for a given particular wave condition.

So, you have that picture, now you put this at different locations different lengths then you see the distorted movement of the orbital practical orbital motions. So, all these things can be such information can be obtained when you want to when you have flow visualizations techniques. So, this has to be, so flow visualization techniques have become very popular tool to understand the basic physics.

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CRITERIA FOR MODELLING

- Geometric similitude - flow field and boundary geometry be of same shape in model and proto
- Kinematic similitude - ratios of corresponding velocities and accelerations be the same between model and proto.
- Dynamic Similitude - similarity of forces acting in corresponding fluid must exist.

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So, these are all some of this aspects which you would have already done in your undergraduate course. So, criteria for modeling geometric similarity, then kinematic similarity and the dynamic similarity in the geometric flow field, and the boundary geometry be the be of the same shape in the model and proto.

So, you adopt geometrically, I mean scale ratio and then in the case of the kinematic similitude the ratios corresponding to the velocities and acceleration be the same between the model and the proto. And finally, the dynamic you consider the similarity of forces acting upon, acting on structures or fluids corresponding that must exist.

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CRITERIA FOR MODELLING

Deep water:

- There is always a certain chance, that any extreme design condition will be exceeded

Shallow water:

- wave height at the structure are limited to breaking conditions i.e. high water level becomes the most important design parameter

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Now, criteria for modeling in deep waters and shallow waters; in deep waters there is always a certain chance that any extreme design condition will be exceeded, so the in deep water that can happen. And in the case of a shallow water wave height at the structure is limited by the breaking wave conditions, high water level becomes the most important design parameter in the case of shallow water studies.

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FEW COMMONLY ADOPTED NUMBERS

Dimensionless number	Definition	Remark
Froude number	$V/(gL)^{0.5}$	(Inertia/gravity) ^{0.5}
Reynolds number	$\rho vD/\mu$	Inertia/Viscous
Strouhal number	f_s /Du	Vortex shedding frequency
KC number	uT/D	Period parameter
Ursell number/parameter	HL^2/d^3	Depth parameter
Cauchy number	Pu^2/E	Inertia force/Elastic forces

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So, some of the commonly adopted numbers, why are we using this numbers when we say that Froude number is, so much Reynolds number. So, much we understand whether

what kind of flow it is; so based on the value of the Reynolds numbers we can always understand whether it is a laminar flow or a turbulent flow etcetera and K C number. See, K C number if you look at K C number is nothing but the Keulegan carpenter number when you look at the Keulegan carpenter number if it is much higher, much layer I mean may be 10, 15 etcetera.

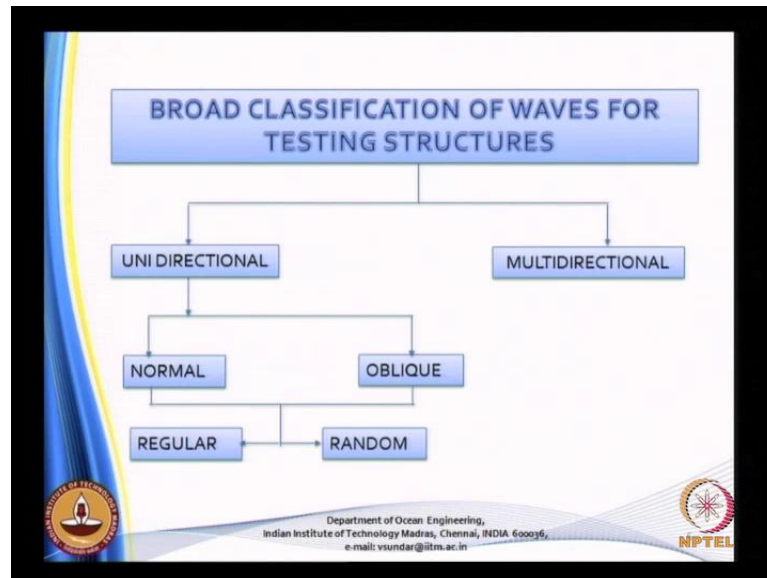
You know that drag component is slightly dominating slowly started dominating at if the K C number is exceeding 50, you know that they drag Comedent component is dominating more. And if the Keulegan carpenter number is quit less then you see that the drag component is becoming negligible.

So, all this kind of information can be obtained by using the some of these parameters dimensional numbers. So, for example the Froude number is given here I will not take much time because all these aspects are known to you this is the remarked inertia verses gravity. Whereas in the Reynolds number it is the inertia forces versus the ratio of the inertia forces to the viscous forces.

Then this is the Strouhal number vortex shedding frequency etcetera; then Keulegan carpenter number is also called as the period parameter and this is given by $u_{max} T$ by D u_{max} is the horizontal maximum water particle velocity, T is the wave period. Then Ursells parameter is H into L square that is the wave length square is divided by D cube, this parameters very widely used for categorizing the type of waves particularly in the shallow waters.

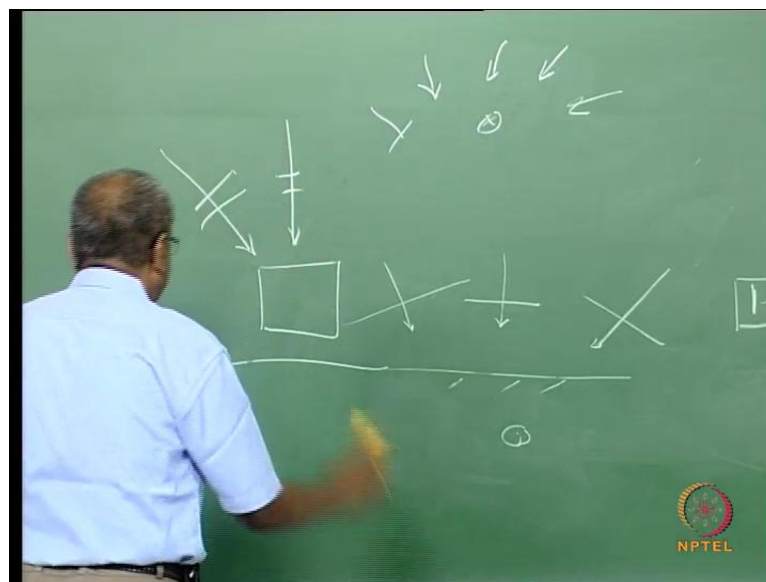
So, Synadel is the one such type of the waves which is approximately set to represent tsunami, which we will see later. Then finally, you will be have having Cauchy number this is the general the wide range of a parameters, which are used in the field of coastal engineering or ocean engineering.

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So, broad classification of waves that are used for testing structures. So, there are broadly you can say that the structures are exposed either to unidirectional waves or multi directional waves, what is meant by unidirectional waves.

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For example, if you are standing near the coast and then when you look in to the ocean what do you see you see either the waves are coming in this direction. Or the waves are coming in this direction or you see that the waves are coming in this direction, this is

what you observe. And you will most likely you will see that there is well defined more well defined wave direction, so that means, this is a unidirectional waves.

May be it is coming from this direction for some during some time or maybe it is coming from this direction. So, in this case this is unidirection can you generate unidirectional waves in the flume yes what you generate in the flume is you will have wave maker and you will have an absorber, what you generate here is only the unidirectional flow unidirectional waves.

So, it has only one wave direction, but if you go further deep into ocean when you are in a ship in the ocean you will not have a well defined direction as you can see here; for the simple reason the waves are coming from different direction at this location. So, that means, structure in the deep ocean is going to be subjected from waves from different direction, so this needs to be studied.

So, when you put a breakwater in the offshore it is not, so easy you have to consider all the directions, when you put a break water here when I know that this is the predominant wave direction I orient my structure like this. So, all these things need to be studied. So, under the unidirectional waves you can have normal when you have structure like this for example, let me let me say the that there is a structure like this is normal angle of incidents.

Suppose, if this structure the same structure is installed like this then you see that the wave direction is different. So, if you have structure like this, if the wave is coming in this direction it feels a force, but when it comes in this direction the force is different, the force in general is going be the function of the projected area. So, this again under this is well defined single direction, but it has not normal to the structure, but it is inclined.



So, it is oblique wave of oblique angle of incidence. So, again under this you can have either regular waves or random waves multi direction waves is a different category all together. Although it is meant for offshore it also important when you are dealing with coastal environment, there are some structures where it will be the direction effects can be felt is that clear, all of you are with me.

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REGULAR WAVE TESTS

- Testing of Coastal and Offshore structures in hydrodynamic laboratories with regular sinusoidal waves had been the normal practice for several years.
- In the case of regular wave tests, the design wave is represented by a wave period and a wave height.
- The main reason for such tests is that the approach is simple in the design analysis and the determination of the response due to extreme wave conditions (as against a design sea state) is easier.
- The wave-structure interaction phenomena can be well understood with a regular wave test. (Flow Visualization)
- If this method is employed, the structure has to be tested for several waves of different amplitude and frequency and the structure has to be designed for the worst loads, it experiences.

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Now, regular wave test, testing of regular testing of coastal and offshore structures in hydrodynamic laboratory with regular sinusoidal waves has been a normal practice for several years. So, it is very, very simple because you have a tank, you have some mechanism where in the wave maker can be moving up and down like this or you can be moving in this direction.

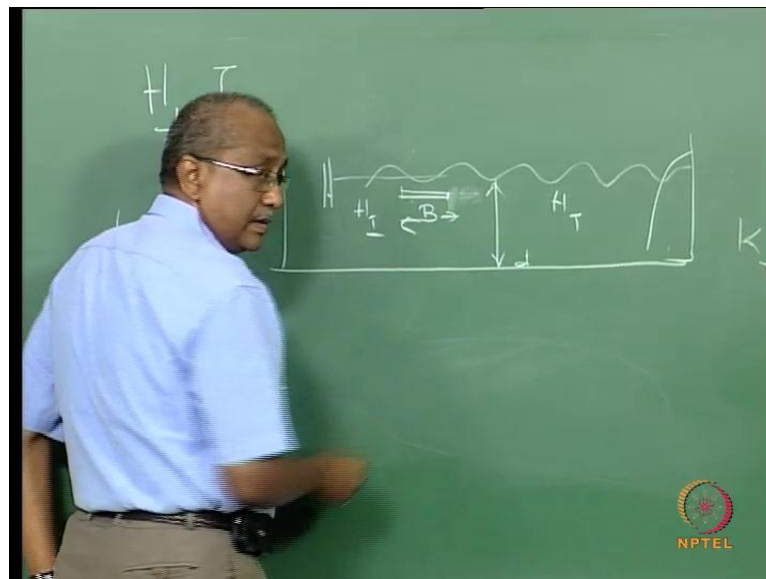
So, once it is moving the water surface is subjected to oscillations depending on the motion of the wave maker. So, this wave maker initially it was not connected to the computer, but now these days all wave makers are controlled by a computer. (Refer Slide Time: 11:17)

A hand-drawn diagram on a green background. On the left, a rounded rectangle contains the letters 'H' and 'T'. 'H' is on the left and 'T' is on the right, with a comma between them. Below this rectangle is a horizontal line. To the right of this line is a small 'd' with a horizontal line underneath it, representing a wave profile. In the bottom right corner, there is a small NPTEL logo.

So, in case of regular wave test the design wave is represented by a wave height and a wave period of course, in a given water depth. Although depth is a parameter I am not including here, I am talking only about the characteristics of waves. So, in which case you need only two parameters to describe the wave, the main reason for such test is that a approach is simple. In the design analysis and determination of response due to extreme conditions as against the sea state is quite easier.

So, for example, if you want to have test how a structure behaves for example, floating body, how it behaves under an extreme wave condition. So, it is easy for us to consider only that extreme condition and see how the response of the body looks like, why extreme condition even for simple condition wave condition how whether the heave is more or whether sway is more. Whether there is any role taking place all these things under what frequencies the role can be more dominant; all these information can be understood very easily when you are considering regular wave test.

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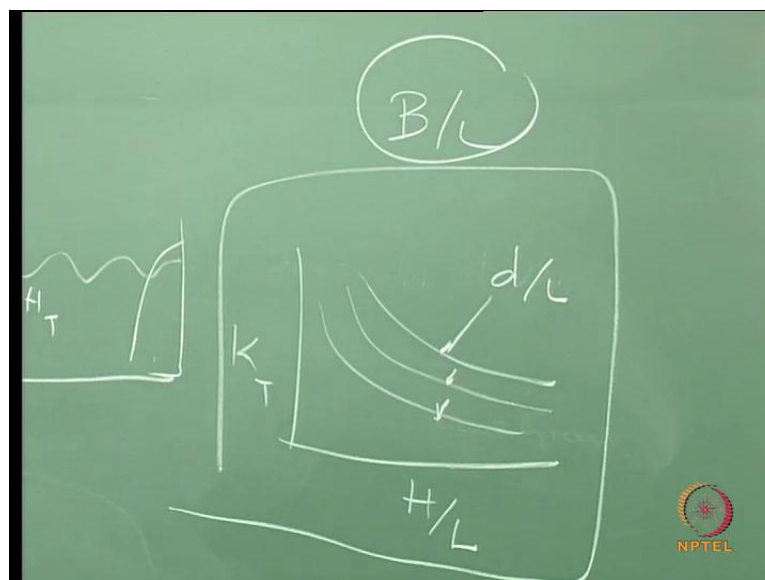


Or for another example is if you want to have a horizontal break water again. So, you have fixed the wave width and the wave maker is here now you generating the waves. So, you can easily you want to know for what should be the length of this for better attenuation that is the wave height on the le side should be much less compare to the sea side, then what could be the length of this.

So, what you do is you fix initially you have length this much length, then you do the test for the number of wave amplitudes and wave frequencies and then get the wave height here wave height here. The ratio of wave height here to wave height here is, the wave height here is for example, is H_T and this is H_I , then we have K_T that is the transmission coefficient as H_T by H_I for an efficient break barrier this should be K_T should be as less as possible.

So, which for which I will consider I will consider different criteria or different range of wave height, range of wave period do the test and then represent the results for example, this for particular water depth say.

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The best way of presenting is may be K_T by H by L for different d by L how it looks like, so this for different d by L . So, here L , but then B is missing may be this set of result is for a particular B by L . So, I do the test for number of B by L to try to find out what is the kind of variation I get and for which the least K_T is arrived, then I can say that is that could be the possible optimum kind of structure.

Then I take it for further test may be subjecting it to random waves etcetera, even the multi directional wave etcetera you understood. So, initial kind of detail investigation you can try to use the regular wave test to assess the performance and then you take it from there for random base or multi directional waves.

So, this I have already said the 4th point that is the wave structure interaction phenomena can be well understood using regular wave test that is flow visualization. If this method is employed the structure has to be tested for several waves and different frequencies and amplitudes and structure has to be designed for a worst loads it experiences. So, this just now I explained in terms of efficiency or efficiency of the structure I explained, now this point is with references to the loads that is all is that clear any doubts.

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RANDOM WAVE TESTS

- ❑ Random wave tests are recommended, since such a wave simulates large number of harmonic components and its effect can be studied within a short duration, thus saving considerable testing time.
- ❑ Combinations of frequencies may give rise to higher order excitations due to coupling mechanisms.
- ❑ In many cases, knowledge about these non-linearity may be limited and tests with random waves is the only way to study them.
- ❑ In the case of random wave tests, the design wave environment considers a wave spectrum (energy spread over a frequency band).
- ❑ A suitable wave spectrum model could be chosen representing an appropriate power spectral density distribution of the wave surface elevation at the site under consideration.

❑ Wave groups

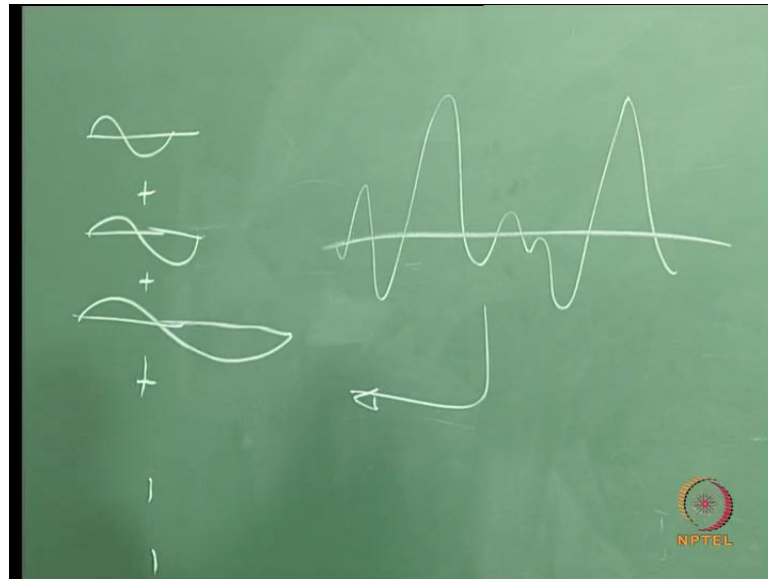
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Why we are doing regular waves see remember ocean waves are never regular you cannot it does not have any meaning because ocean waves is not a regular wave, but it is only a simplified mathematical concept that we assume and this become handy for us. To find out the response or the forces exerted by waves of a particular frequencies and wave height. Because when you work with the random waves which his more close to the real ocean then what do you see you finally split into frequencies and amplitudes.

Please look into the lecture of mine on random waves, there I have explained what again the same all these things I have explained there. So, if you want to have under wave dynamic course you can just verify all those things again. So, combinations of, so now, random wave test are recommended since a such wave simulates large component of harmonic components.

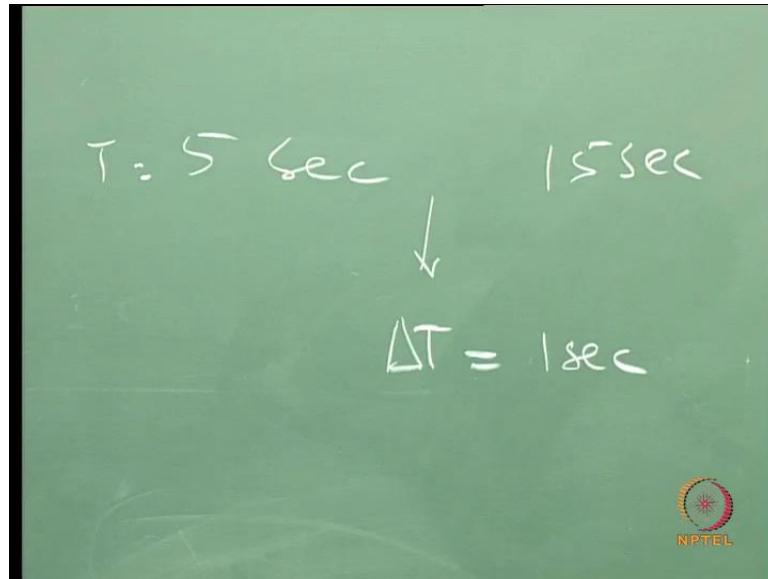
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So, for example, the ocean wave is a random it is something like this, but finally, how to do you get this it is by super position of a number of sinusoidal components. So, what do you mean by super position of sinusoidal components. So, this plus this plus this n number of components when you super pos you are suppose to get this kind of a this one. Now, if this is the measure time history then what do you do with this you need to split into number of sinusoidal components to understand the forces or response for different frequencies.

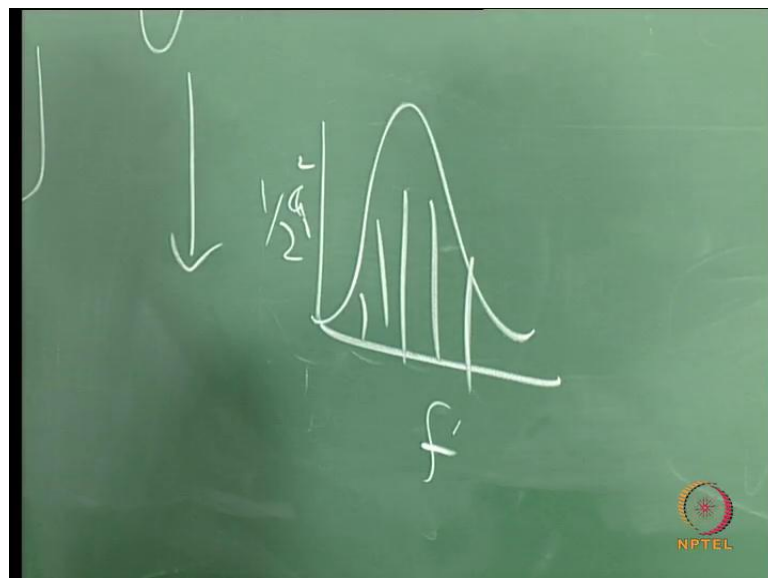
So, if you want to study the forces on a structures if you do not have random wave facility what you do, you use only a regular wave facility because if the wave maker is not capable of the generating the random waves. Then you use that only the wave maker can generate only regular waves then use that wave maker, then you have to do the test a number of times in order to complete a range of frequencies.

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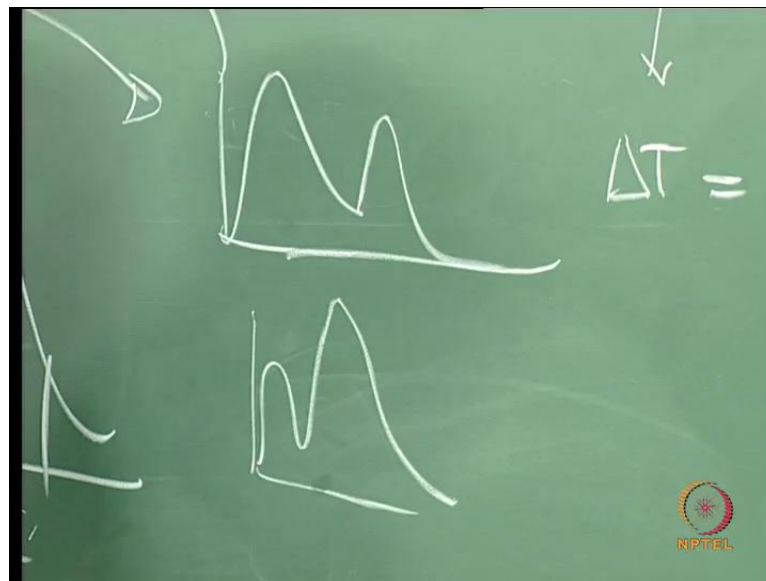
For example, in the field it is ranging from 5 seconds to 15 seconds. So, you need to the wave period you need to cover and may be you use delta T of the 1 second and then take, so much of time in continuing continuously doing all the tests you understood, whereas in the case of random waves only once you need to operate the wave maker the signal is come given to the computer, then it will oscillate as per the computer. And then you have a random time history, the test is over because when you have got this you can split into a number of sinusoidal component.

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And you can understand that is in the form of spectra you have frequency and this is half amplitude square be it force or whatever it is. So, I get for each frequency which you need to do it for a long time, if you do not have facility that can generate random waves. So, that is one important thing combination of frequencies may give rise to higher order excitations due to coupling mechanisms. So, all these things are you can work with, so many other kind of a facilities you can artificially create higher frequency component, when you are doing the experiments.

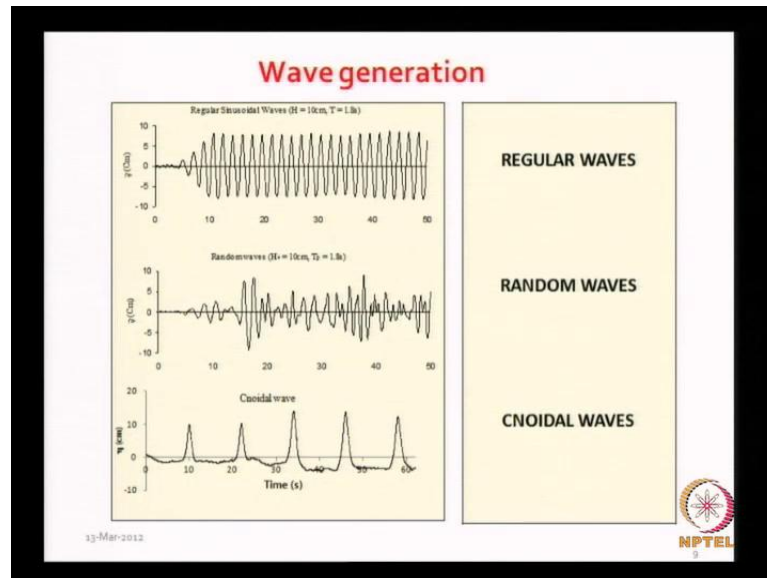
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So, you can have simulated time history see for example, there is way to simulate such kind of the time history or you can also simulate time history, which is representing this kind of a spectrum all these things are possible. In many cases knowledge about this non-linearity may be limited and so the test with random waves may also be may be the only way to study them. So, in the case of the random wave test the design thing is design environment is based on your spectrum, instead of having only wave height and wave period it will have the spectrum coming to picture.

So, the spectrum will be, the spectrum can be in the standard spectrum like Scart Johnswab a Brushnider etcetera. A suitable spectrum model could be chosen for representating the a appropriate power power spectral density function. So, this depending on the site where you are talking about, you can choose particular standard spectrum for simulating your portion waves is that clear.

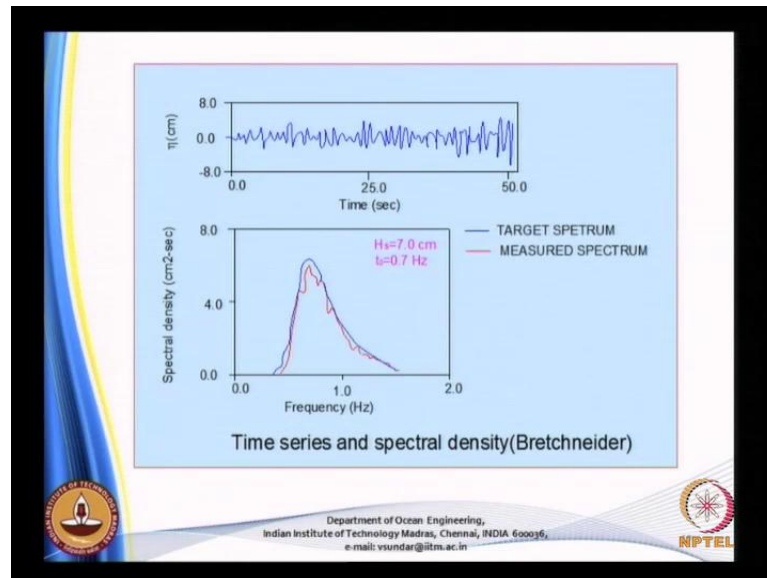
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So, these are some of the typical waves that are that have been generated in our wave flumes. So, for the kind of facilities what we have in the department of ocean engineering IIT madras, you one can visit the department website or you can also look at the some of the lectures which I have given under wave hydra dynamics course.

So, this is typical picture showing the generation of a regular wave the middle one is for random wave and the bottom one is for cnoidal wave. Cnoidal wave you see that it is a very flat rough with very sharp crust, this is more or less representating solitary; solitary waves and cnoidal waves more or less represent the characteristics of tsunami. But it is not 100percent true, but to some extent it is still can be accepted.

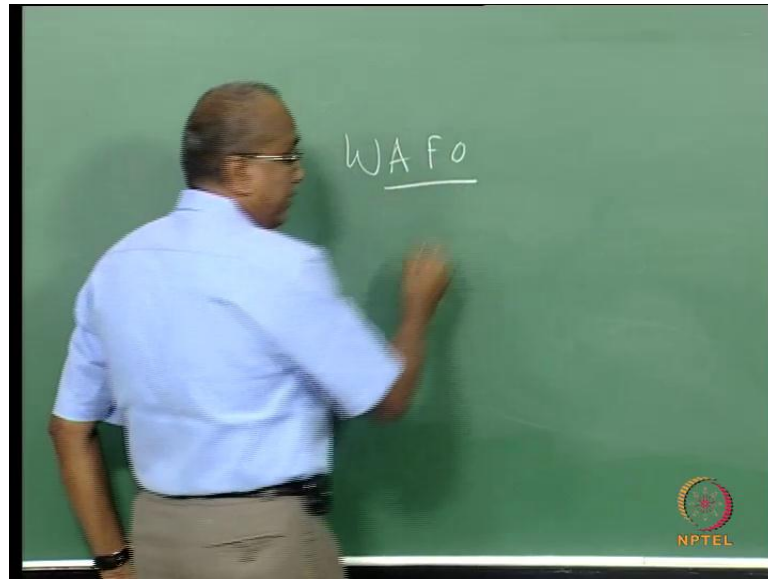
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So, when you are generating a random wave. So, the what you do is you simulate the wave in such a way you simulate this is the target spectrum may be the blue is the target spectrum may be generating you want to generate a time history in the tank they would follow a Bretschneider of the spectrum in the instance. So, there is the way to do that and it is automatically done and you can either use it as a black box, but even if you want to use it as a black box it is always better you understand, what is meant by Bretschneider spectrum.

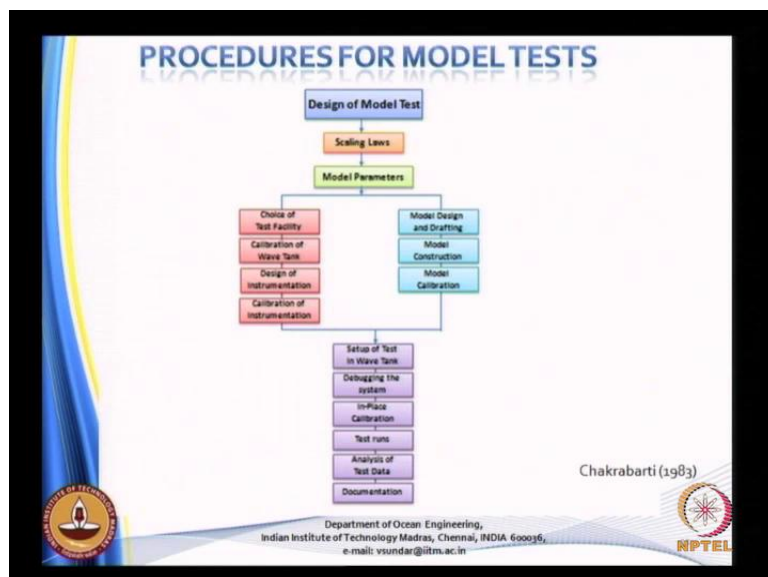
And when you want to use the Bretschneider spectrum or any other spectrum for that matter. And then when you this the target spectrum and now the computer will generate the time history, signal for driving the wave maker. Once the wave maker is driven then you are measuring in the tank and once you have measured the time history the displacement or the random time history wave elevation in the tank that you try to subjected to spectrum analysis software.

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And WAFO is one software available under matlab where you can use for getting the spectral density and then once you get the spectral density try to match it what you have. So, this is only to confirm whether you are generating the time history that follows a standard spectrum are able to understand. So, all these things are possible and we do have a such kind of facilities here.

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Procedures for model test; so you have to design the model test then apply a scale law, then you have to select the model parameters then choice of the test facility has to be

chosen. Then calibration of the wave tank, calibration design of instrumentation, calibration of instrumentation. So, all these things are extremely important then you look at one is the test facility and other one is the model design and drafting model construction model calibration.

Then all these things then it goes in to the test set up in the wave tank, then you need to debug the system in case and then do all the test runs. And then once you do the test runs analysis analysis has to be carried out with the test runs and then once you are through all these procedure then you document. This is very nicely elaborated by professor Chakrabarti in his books of hydrodynamic of ocean structure published in 1983 and it has been revised also. So, you can just have a detailed look into his book.

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SCALING OF COASTAL STRUCTURES

Scaling procedure

For coastal structures such as seawalls and groins, a model scale of 10-50 will be agreeable or it may vary with the characteristics of site, purpose and the available testing facility

Froude's model law
BASIC MODEL SCALE - λ

- acceleration scale 1:1
- length scale 1: λ
- time scale 1: $\lambda^{1/2}$
- force scale 1: λ^3

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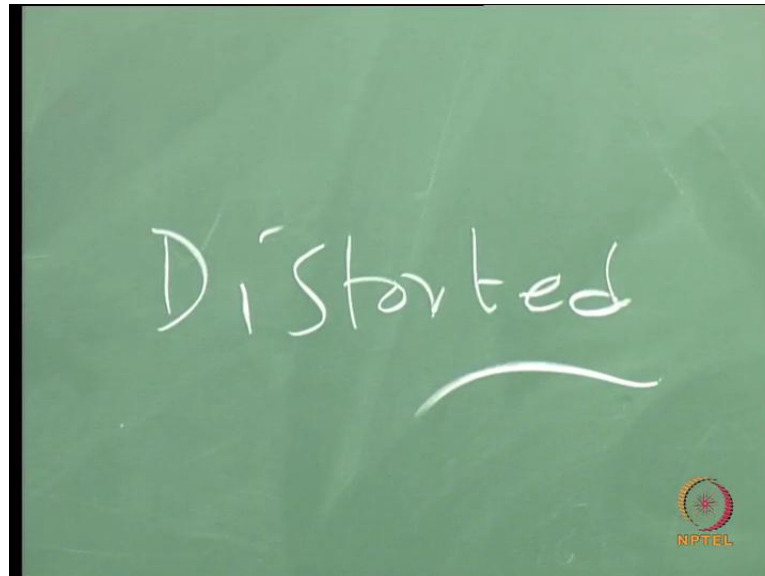
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So, scaling of coastal structures scaling procedure for coastal structure such as sea wall or groins a model scale of a 10 to 50 will be agreeable or it may be varying, it may vary with the characteristics of the site purpose and available test facility. When you are dealing with the large coastal model when you are dealing with the large coastal model then we use what is called as the distortable model.

So, when you have a large basin and when you want represent a 3 kilo meters stretch of the coastal 5 kilo meters of the stretch of the coast in the lab; then you have to simulate also the water depth water depth may be 5 5 meters, so how do you do that. So, you

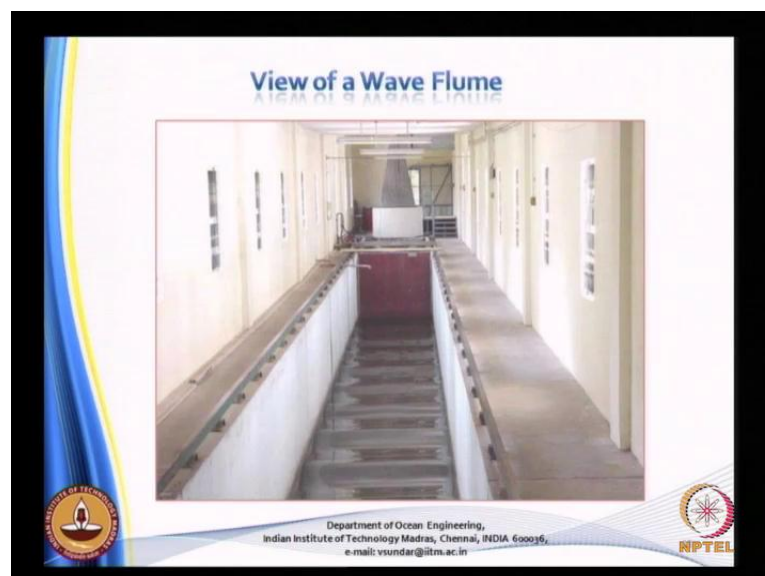
cannot have a undistorted model, so you need to going for a distorted model. So, you use different scale ratio or the horizontal scale and for the vertical scale.

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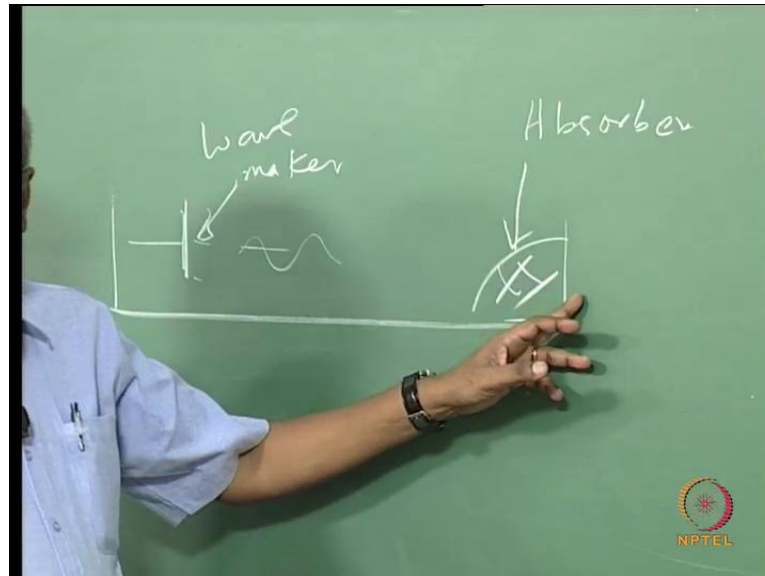
So, this is called as distorted scale, if you want to have more details about the distorted scale you need to look into some basic books what is meant by undistorted and distorted model. Froude models are the basic model scale if we have it as 1 is to lambda then you have length scale 1 is to lambda then the time scale is 1 is to square root and the force scale will be 1 is to lambda cube.

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So, this is flume view of a flume, which shows that on the other end we have what is called as wave maker or wave absorber.

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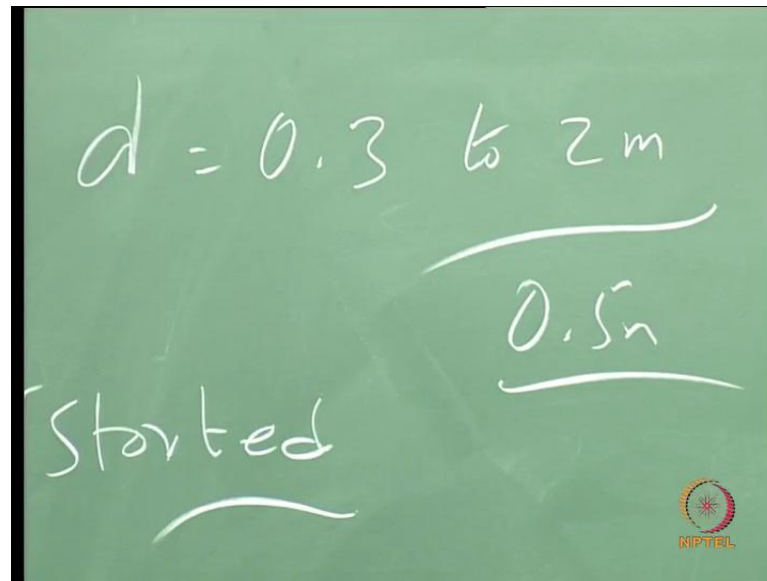


So, you have a tank usually you have a wave absorber, wave maker this is the wave maker and this is the absorber. What is the function of wave maker you know because it is either moving up and down or in the horizontal direction it will generate the waves in the tank. But the waves the wave absorber is now absorbing the incident waves, because what do you see when you go to the ocean, what see in the ocean is the waves are coming in front of you breaking in front of you.

And then you have only in the gentle operation then again the new way is coming. So, whatever wave is generated it loses all its energy before it reaches the coast, when it reaches the coast. So, what you have in the ocean is break progressive waves and that is what you going to generate in the flume. So, unfortunately I have not shown the absorber is not shown here, this is a wave maker which can operate for different water depths generating a wide variety of waves.

So, there are wave makers which are very simple, which can operate only which can generate only regular waves or there are sophisticated wave makers for instance this wave maker can operate both for very shallow water it can operate for water depth from 3 meters 0.3 meters to as high as 0.2 meters.

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That is it can work in water depth ranging between 0.3 to 2 meters water depth, producing the waves of even put to about 0.5 meters in given water depth. So, it is quite and the entire thing is controlled by the computer.

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STABILITY

The armour layer of breakwater designed with Hudson's formula has to be verified for its stability against waves in the laboratory

Hudson's stability co-efficient $K_D = \frac{\gamma H^3}{W \left(\frac{\rho_c}{\rho_w} - 1 \right)^3 \cot \alpha}$

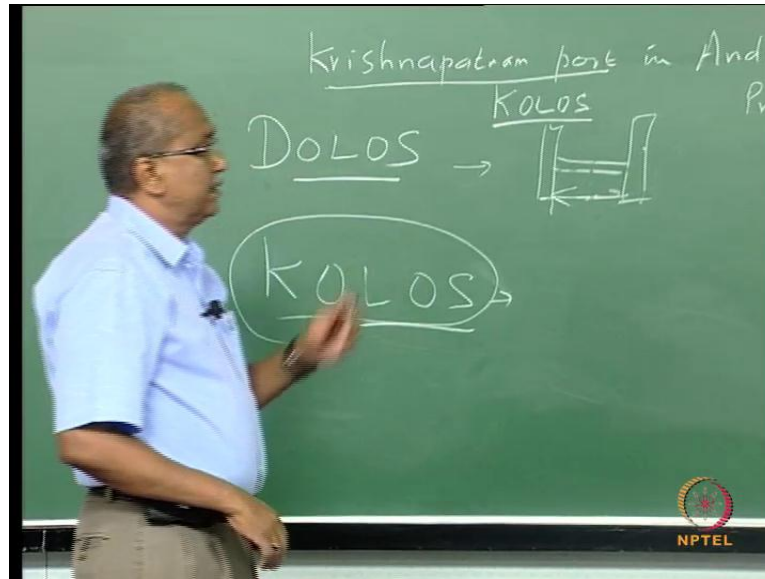
H = Wave height
 ρ_c = concrete density
 ρ_w = water density
 α = structure slope angle
W = weight of a KOLOS
 γ = unit weight of KOLOS unit

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So, now, let us look into the how these make use of this some of these models or facilities for testing the break water stability. So, the stability of the breakwater as you know this controlled by the Hudson's formula has to be verified in the lab. So, these things I have already explained earlier, now there is we have seen DOLOS.

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So, what we have done is we have recently introduced a name called KOLOS what happened was this DOLOS which was used you had I am not, so good in drawing. You heard 3 legs this leg was quite long, because of which there was lot of shear failure. So, the performance wise as an interlocking, and other aspects this was good, DOLOS was good, but individual unit it was having a problem.

So, we changed the dimensions of the KOLOS DOLOS and we have called this as KOLOS and this is new armor unit done by our department along with Krishnapatnam port company. So, they have a come up with the idea and we did all the test and also assessed it is stability quotient and this has been installed in Krishnapatnam port already it has been installed Krishnapatnam port in Andhra Pradesh.

Probably just to use KOLOS try in Google or you can also try with this in the Google to have more information about this aspects. So, what I have taken is I think I have taken the KOLOS as an example for showing you the demonstration of stability test let me seen what I have done.

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TESTING PROCEDURE

$$\% \text{ Of Damage} = \frac{\text{No. of armour units displaced}}{\text{Total No. of armour units placed}}$$



1. P - Unit seen to be rocking, but not permanently displaced
2. Q - Unit displaced by upto 0.5 D
3. R - Unit displaced between 0.5 and 1.0 D
4. S - Unit displaced by more than 1.0 D

Where D is the equivalent diameter of the armour unit.

5. Damage level = P+Q+R+S

The performance of the armour layer is continuously monitored by an underwater video camera.

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So, testing procedures percentage of damage is number of units displaced by total number of units. So, when you place the no total number of units are known to you the total numbers of units is known to you, then number of units displaced that you need to measure either you do it physically going and standing near the section or you can have camera mounted in the control room both facilities, we have both we both methods we adopts.

So, P is there are different 4 categories P is unit seen to be rocking, but not permanently displaced its only rocking, but unit displaced by about 0.5 times the diameter of the structure when I say diameter width of the structure may be. Then you R is a unit displaced between 0.5 and 1 D and S category is more serious that is displaced totally by 1 diameter. So, the total damage level is P plus Q plus R plus S.

So, we look at continuously look at the section. So, the section will be occupying the whole entire width of the flume most of the time and then we calculate the all this category, how many stones are moving how many are rocking, how many has displaced by point D, how many has moved by 1 D etcetera. Add them together and that is going to be your total damage level and the permissible damage level is 5 percent as I have said.

So, percent of damage is given there, so each of the category you have to assess the percentage of the damage, add all of them together that will give the total damage and that should be less than 5 percent.

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MODELLING OF BREAKWATER

BASIC MODEL SCALE - λ

wave heights - λ

wave periods - $\lambda^{1/2}$

The weights of individual units - λ^3 .

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NPTEL

So, the performance of the this I have already said, basic model is the wave height and this I have already explained to you.

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Cubes

Cubes

Tetrapods (trunk)

Accropods

Tetrapods (head)

Dolos (trunk)

Dolos (head)

Core-Loc

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What we have done earlier is on cubes, cubes, Tetrapods trunk, Accropods, Tetrapods head section, DOLOS trunk sections, DOLOS head sections, Core loc. Then KOLOS also we have done and there are some many other models which I have not shown here.



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'KOLOS'
artificial armour units

➔ **KOLOS**

- Modified version of DOLOS armour units.
- Re-designed the DOLOS units by reducing the distance between the vertical arms
- Reduced susceptibility to fail at the junction of the horizontal and vertical arm due to wave action.

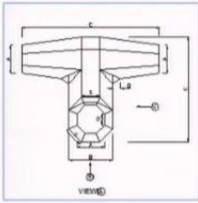
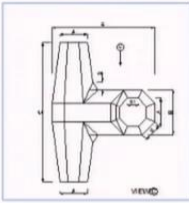
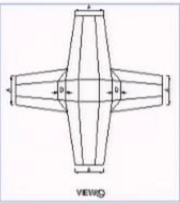



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So, this is the KOLOS armour units modified version of DOLOS re-designed the DOLOS units by reducing the distance between the vertical arms, that is the distance between these two arms or reduce in the case of KOLOS. Reduced as the reduced susceptibility to fail at the junction of the horizontal and vertical arms due to... So, these are the junctions which are which most often the most of the breakage of the units we see this is the location, which is very vulnerable for breaking and that is the reason we reduce the length.

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'KOLOS'
Dimensions


WEIGHT (tonnes)	12	8	5	4	2
VOLUME (m ³)	5.0	3.33	2.083	1.667	0.833
A (m)	0.659	0.576	0.493	0.457	0.363
B (m)	1.055	0.922	0.789	0.732	0.581
C (m)	3.297	2.881	2.465	2.287	1.816
D (m)	0.188	0.164	0.141	0.130	0.104
E (m)	2.473	2.161	1.849	1.715	1.362
S (m)	0.439	0.383	0.328	0.304	0.242
S1 (m)	0.274	0.239	0.205	0.190	0.151


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And lot of investigation has been carried out here, some of the details are proved here I will not go into all this details, because it gives the volume A what is the size of different parameter for example, C this is in meters. Then we have the weight in terms different weights. So, starting from if it is 12 tons, 8 tons, 5 tons, 4 4 tons, 2 tons, then you have the volume of concrete occupied and here gives all the lengths of the each sides each of the sides you to locate from this.

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'KOLOS'
Establishment of stability coefficient
(breakwater trunk and head sections)



Breakwater sections with trunk slopes 1 in 1.5, 1 in 2 and 1 in 2.5 armoured with KOLOS



Breakwater head section with slope 1 in 1.5 armoured with KOLOS

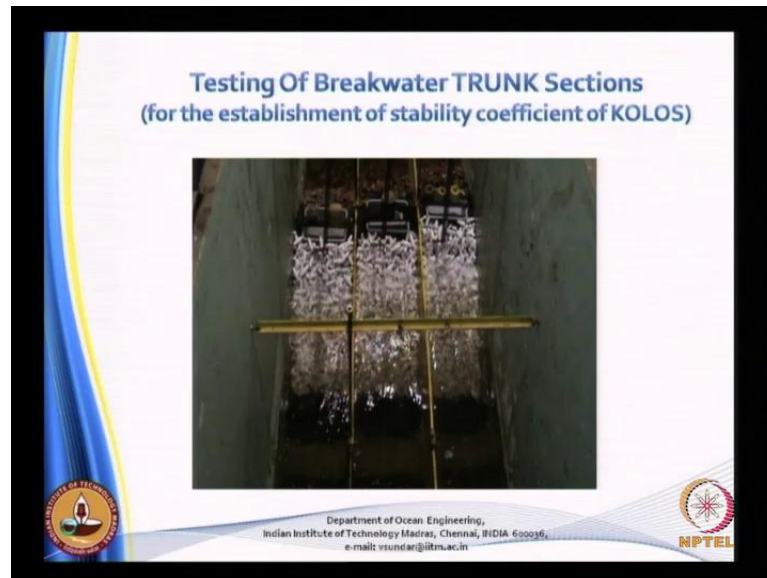
Trunk Slope	Hudson's stability coefficient for trunk (K_D)			Trunk Slope	Hudson's stability coefficient for head (K_D)		
	Zero Damage	Upto 0.5% Damage	Upto 1% damage		Zero Damage	Upto 0.5% Damage	Upto 1% damage
1 in 1.5	23	32	35	1 in 1.5	6.5	8	-
1 in 2.0	19.5	27	-	1 in 2.0	4.5	5	-
1 in 2.5	14	23	-	1 in 2.5	3	3.5	-

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And then now you see that establishment of the stability coefficient for break waters section both trunk and the head section. So, breakwater sections with the trunk slope it is here. So, we have partitioned the flume into three compartments one one this is one compartment, this is another compartment, this another compartment. The total total width of the flume is 2 meters. So, we try to vary the different sections, we adopt different section the different compartments, and we can simultaneously check for example, here may be we have tested the three sections here at one one go.

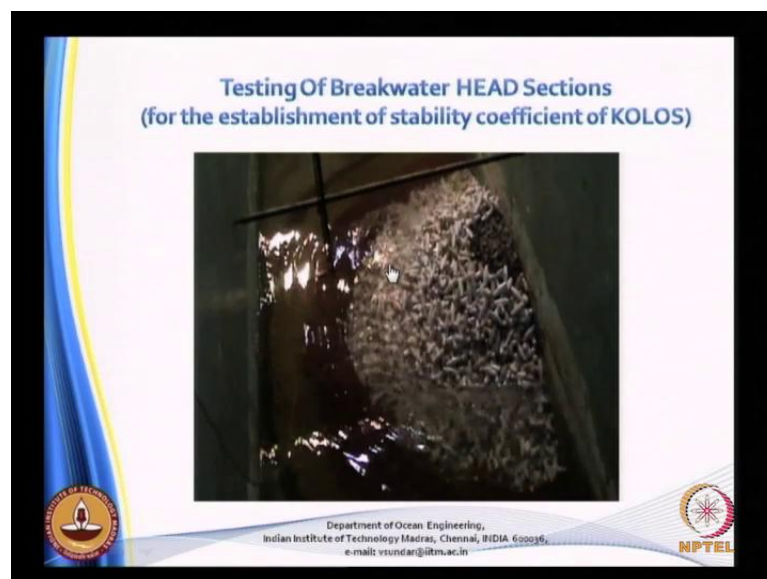
And then these are all after the series of test we try to find out what is the kind of the stability coefficient I will not go into the details of how the stability test is done. So, this I will leave it to you have to look into the general I mean again in to literature or you can write to me or contact me for the details of the test. So, this is how it is after the test we get the stability coefficient after detailed test.

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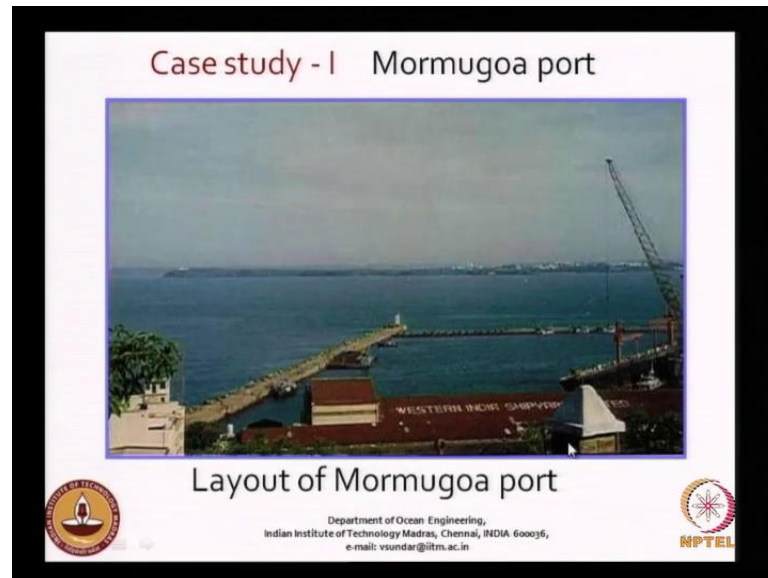
So, now, you can see unfortunately it is not, so clear. So, this, so this waves are moving and hitting the structure the subject is structure for about thousands waves and continuously cumulative the action of the waves. And then we try to find out what is the damage while doing the test we try to find out what is the how much percentage, how many stones are rocking, how many stones are displaced etcetera, as I have said earlier. Then add up the whole thing and try to find out what is the total percentage damage and the through which, in fact, you get the stability coefficient.

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So, this again for the head of the section, so you see that this is the width of the flume this the width of the flume this is the head of the portion of the head of the structure. And then we allow it to generate and then try to find out what is a criteria, what is the K D value for the head. So, this takes although the test are not, so complicated the test takes lot of time.

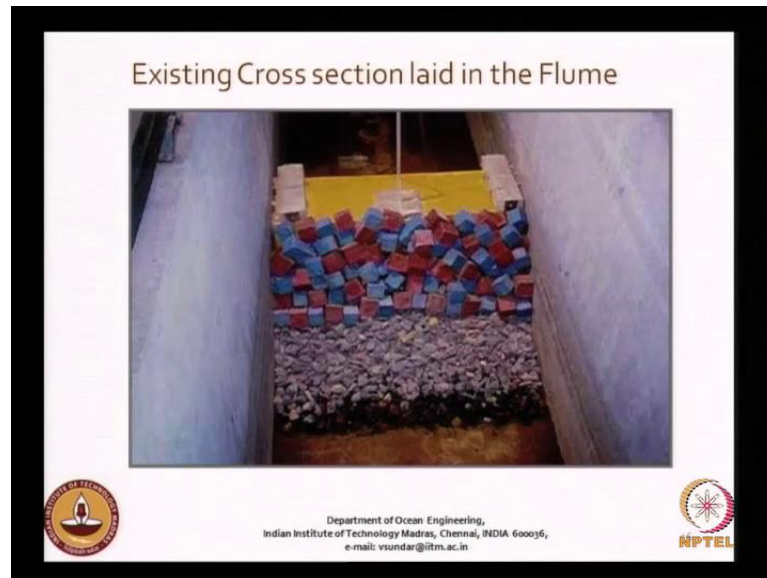
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So, next I will just look at this case study which may be quite interesting this is for the Mormugoa port, which we have said that it is one of the one structure, which has the initially the breakwater was vertical composite break water, which was later converted into a horizontal break water horizontal composite breakwater.

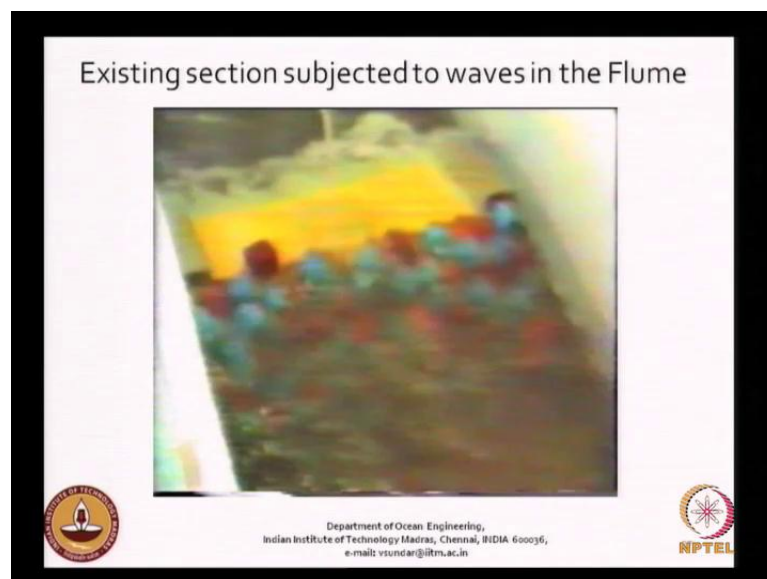
So, I am talking about this is a layout of the breakwater. So, this is the main breakwater and this breakwater on the sea side this is the open sea on this side a the stones, where dislodged. So, initially this was only a vertical breakwater.

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So, what we did was we just modeled this structure that is this is the existing structure. So, we have modeled here and this blue and blue and red co color they indicate one is 18 ton and another has 12 ton.

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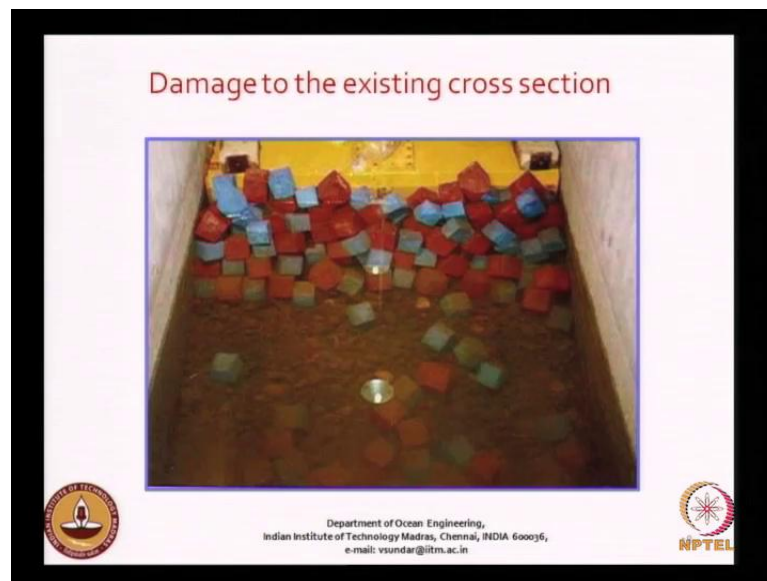


And then we did the first we modeled the whole thing in the flume and then. So, we did the model studies and you see that this is only a portion of the a test where we have just removed, where we have just shown only the portion where that stone is being moved.

So in fact, even that blue colored stone also moved and then it fell onto the other side for example, it you see that it is being pushed.

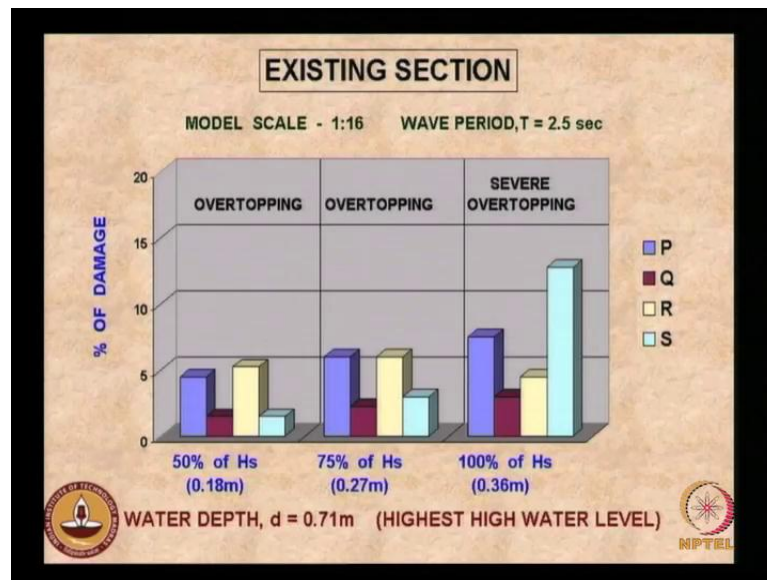
So, that fell on other side, so we were really very happy that we were able to really simulate, what was happening in the ocean? And I will just let it come I think. So, this all these tests were done in our department in the two meter wide wave flow.

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So, after the test we found the kind of disturbance that has taken place and we tried to match this with the what happened in the field, but that we could not get I mean close comparison and all. But we the kind of disturbance we noticed in the lab, so also seen in the field, but it cannot it would not be compared it is not. So, easy to compare then what did we do.

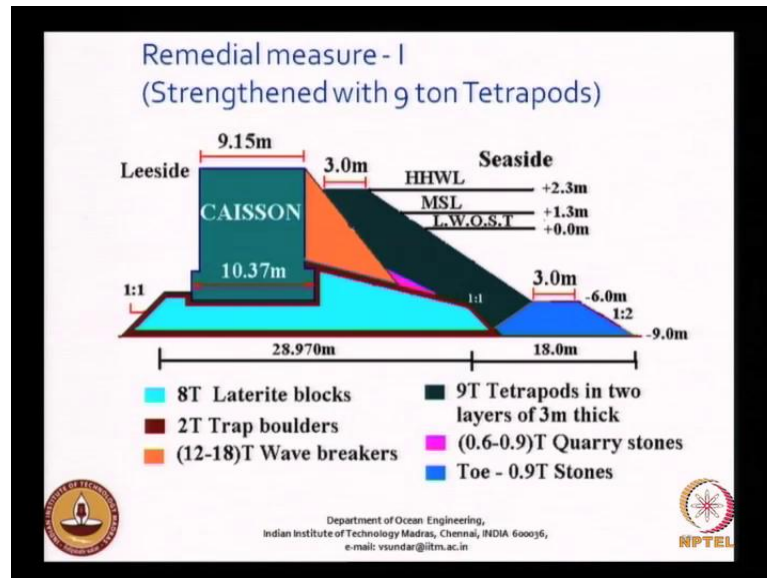
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So, we did the I mean the existing section. So, you see that under we had plotted here 50 percent of the wave height, when you do the test what you do is we first subject the cross section to 50 percent of the significant wave height. Then we slowly increase the wave height to 75 percent of the significant wave height, then we increase it to 100 percent of significant wave height. And in fact, we follow it for some of the sections by additional 25 percent more than 100 percent of the significant wave height, so as to ensure that the section is quite safe.

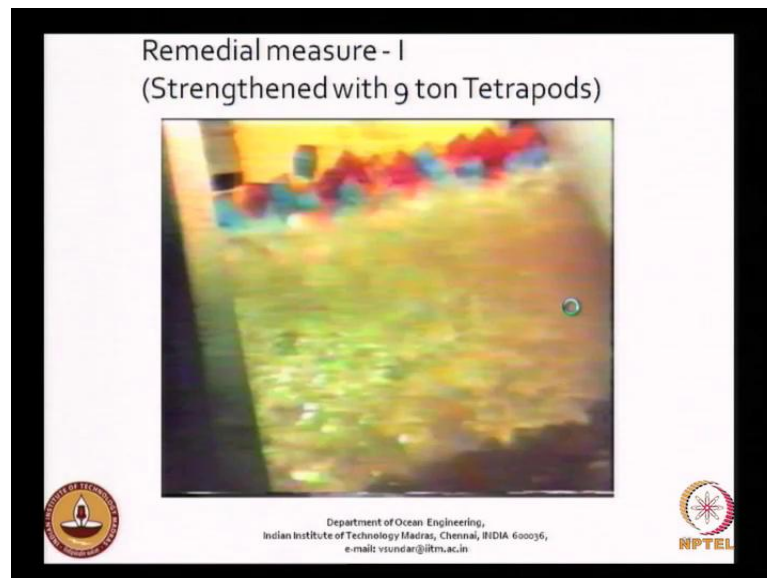
So, ea each time when we do we see that the P cat the S category is here S category is the complete dislotchment the total dislotchment more than 1 diameter you see that when you keep on increasing the S category keeps on growing. So, this is not much of importance for us, but even for a 50 percent of thing itself see for 75 percent of the wave height itself is more than 5 percent. So, the cross section is not safe is that clear, because as I said 5 percent damage is tolerable if it is more than that it is not possible.

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So, we continued the idea was to have an extra layer of tetrapod as shown here 9 ton tetrapods in two layers, and this was suggested with a strong toe for these 3 meters.

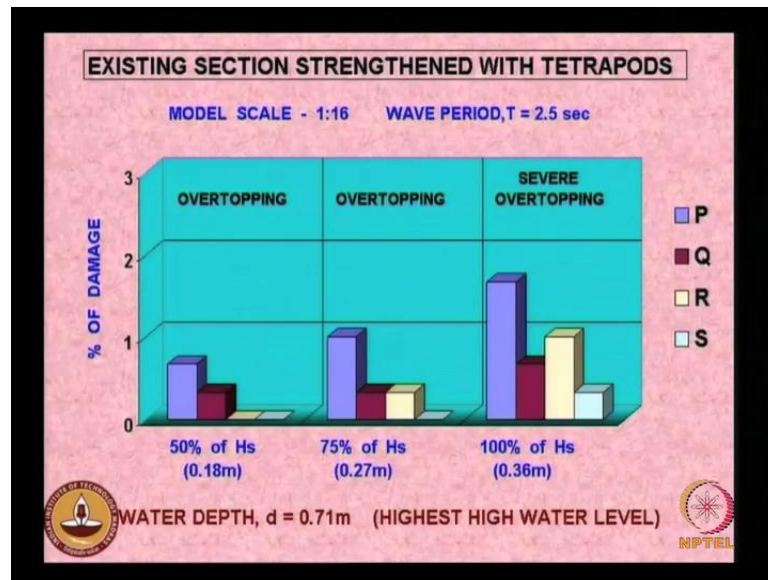
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And then we did the test and when we did the test the structure was quite stable the armour layer that is the tetra pod was quite safe no problem. But you see that again that problem of one or two stones that was moving persisted in one particular (()), that is only one stone was removed in this case, but the stability of the tetra pot was the armour layer was quite.

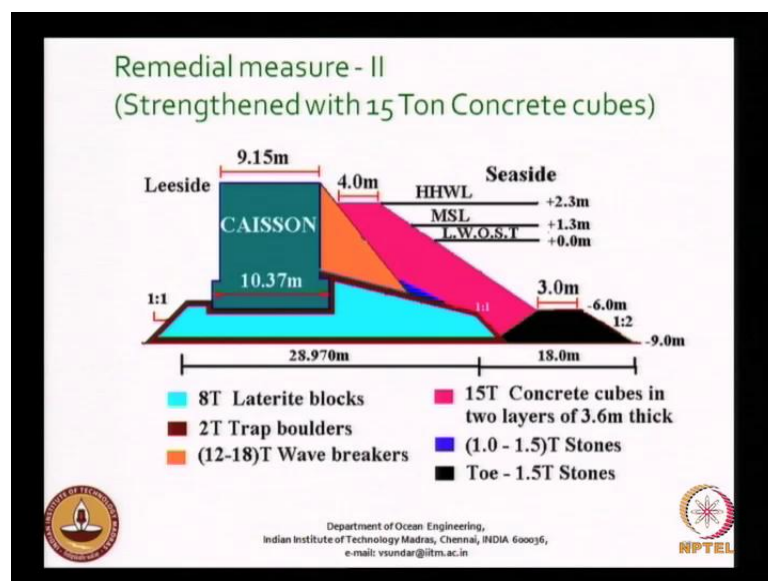
So, this was one of the solutions which we had given, but then the authority is concerned they suggested that me we it is better we have instead of tetra pods why not you think of having cubes. So, naturally when you go in for cubes the interlocking capacity is not. So, good compare to the tetra pod, because cube is just saw something like this no it can slip.

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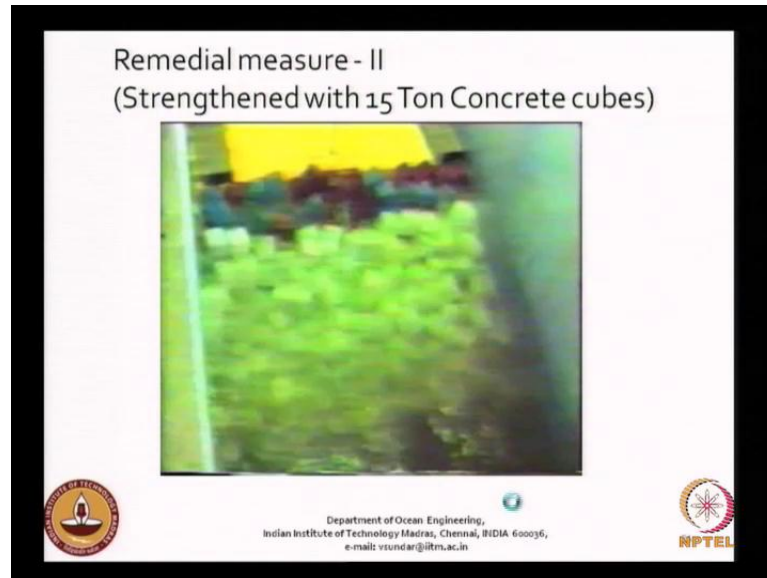
So, naturally the weight of the cube has to be more, in which case we had in the case of tetra pods you look at the damage criteria it is much below 5 percent.

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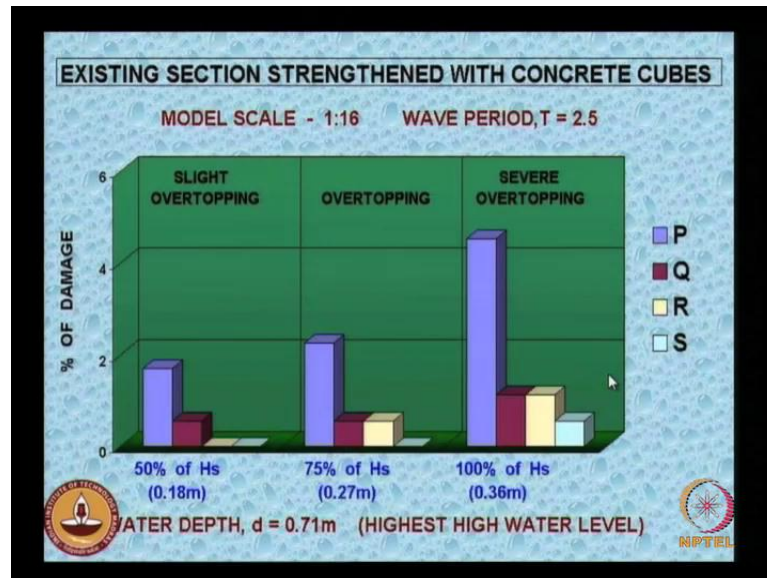
But then since the authority is concerned wanted us to use concrete cubes then we adopted 15 tons concrete cubes in 2 layers as shown here and then re did the experiments.

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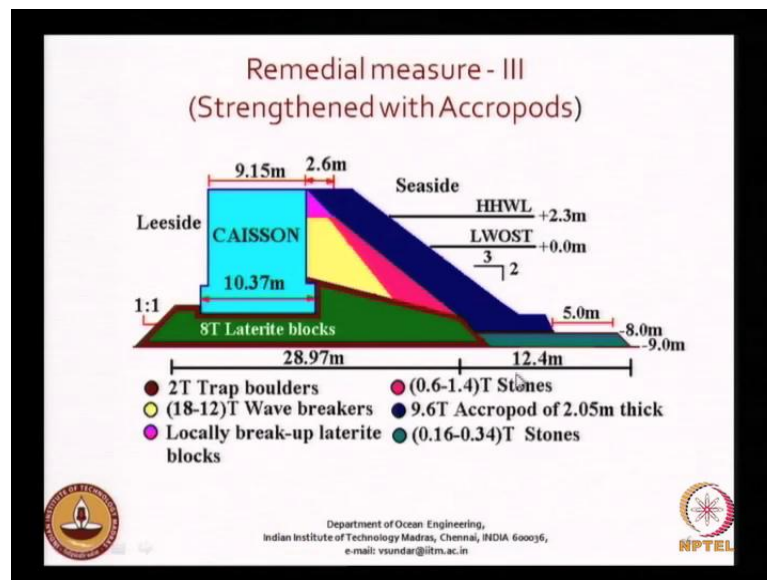
So, when we did the experiments then this this layer was also found to be quite stable we also did the test with accropods this was one of the major projects we did earlier concerning the stability of breakwater how to enhance the I mean, how to re habilitate the existing breakwater. So, important breakwater and you see that this is how we do the test I will allow the, is it clear.

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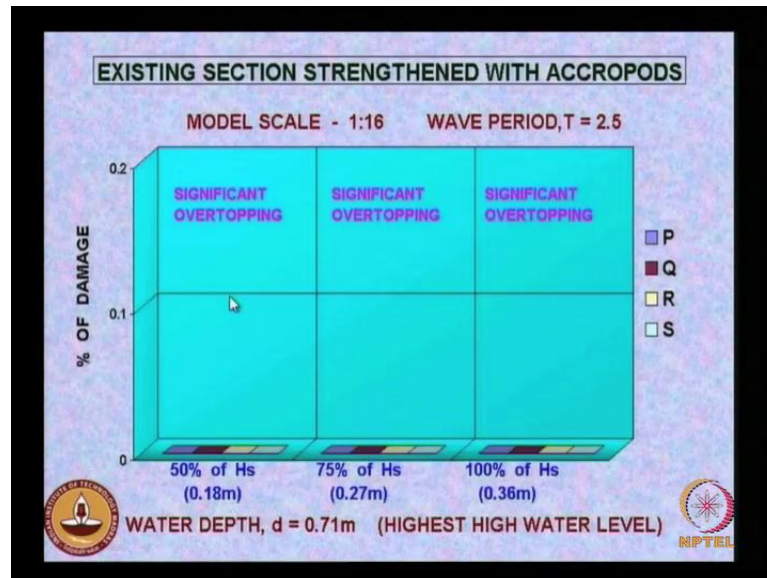
So, you look at the only the rocking is dominant, but this section is quite stable. So, we said that both the sections either with cubes or tetra pods can be considered, because although we did the accropods as shown here.

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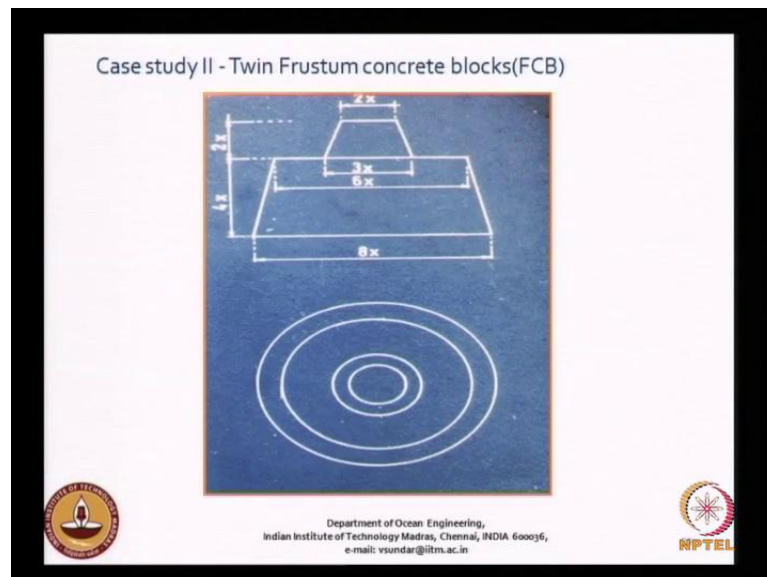
This is a single layer accropods it was found to be quite, but then there are there were other problems because skilled labor is lee needed all those things. So, they decided for either cubes or tetra pods, but the project is yet to be implemented.

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So, in the case of accropods you see the layer was the armor layer was something like stand still not no rocking also, because it is glued on to one one to another. So, but then this also had significant over topping, but although significant over topping was there on the lee side there was not much of damage.

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So, I will stop with it and then we will look into the next studies later.