Advanced Marine Structures

Prof. Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute Of Technology, Madras

Lecture - 5
Flow through perforated members -l

Welcome to the fifth lecture on module 2 on the course on Advance marine structures under the brace on NPTEL IIT Madras. I am now continuing to discuss on the fifth lecture, in the last lectures in this module we understood what would be the disturbance caused in the fluid flow by interference of members. You place the cylinders in horizontal directions, vertical direction, along the flow, across the flow. There are vibrations induced or disturbances caused in the vicinity on the member, what we have understood is a wake region. We have also seen there are secondary vibrations set in because of the vortex induction or the vortex shedding frequencies which can disturb and cause additional vibrationson the member and so on. We also see and understood that how these can be handled in the designer’s perspective. We will continue to see them as one of the important application in this lecture, to understand how the flow gets altered through a perforated cylinder.

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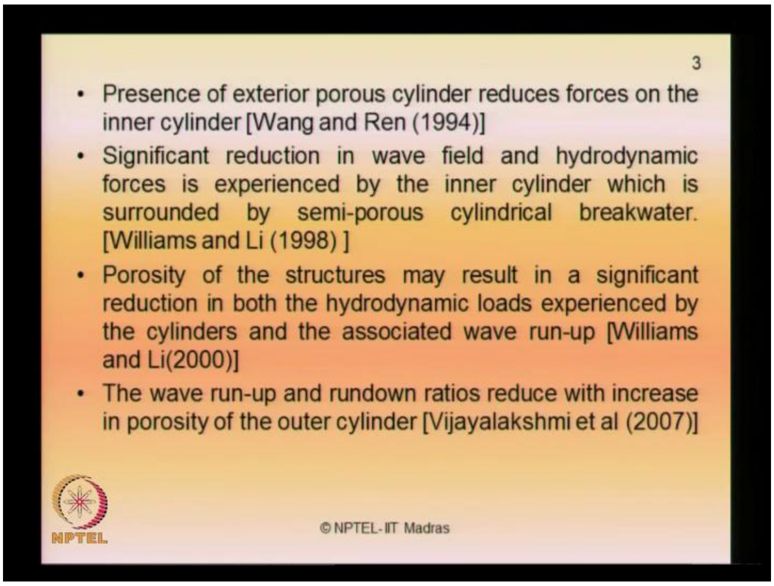

Presence of exterior porous cylinder reduces force in inner cylinder; this has been ascertained and verified by Wang and Ren. Whenever you have got an outer cover which is porous, over and inner cover or inner cylinder which is solid, there is a force reduction on the inner cylinder,I am talking about reduction on the inner cylinder. This has been verified and quantified by Wang and Ren.

There is also a significant reduction in the wave field and hydrodynamic forces experienced by the inner cylinderwhen it is surrounded by what we call semi-porous cylinder. This application is been tested in breakwaters by Williams and Li and they have quantified that there is a reduction in hydrodynamic forces on the inner cylinders, when they are covered by semi porous outer layers in breakwaters.

We have also seen that porosity which is nothing but, the ratio between the perforated area with that of surface area which is non-perforated which expresses the ratio, which we call it as a porosity ratio; the porosity is one of the important parameter which significantly influence the reduction in hydrodynamics loads experienced by the inner cylinder. And of course, it also alters the associated wave run up which is in the wake region of the cylinders, which has been also seen by Williams and Li.

It is shown that the wave run up and the run down ratio reduce with increase in porosity.But there is an upper limit for this, you cannot completely make the outer layer totally porous or totally pervious, then the effects get completely nullified. So there is an upper limit of this porosity which has been study and examined by Vijayalakshmi et al in 2007, and literature show that wave run up and run down ratio reduces with the increase in porosity. Based on this some studies have been initiated in the literature to carry out experimental investigations on an outer cover which is porous, which is covering an inner cylinder which is non-porous or solid. So there are different studies or different experiments conducted.

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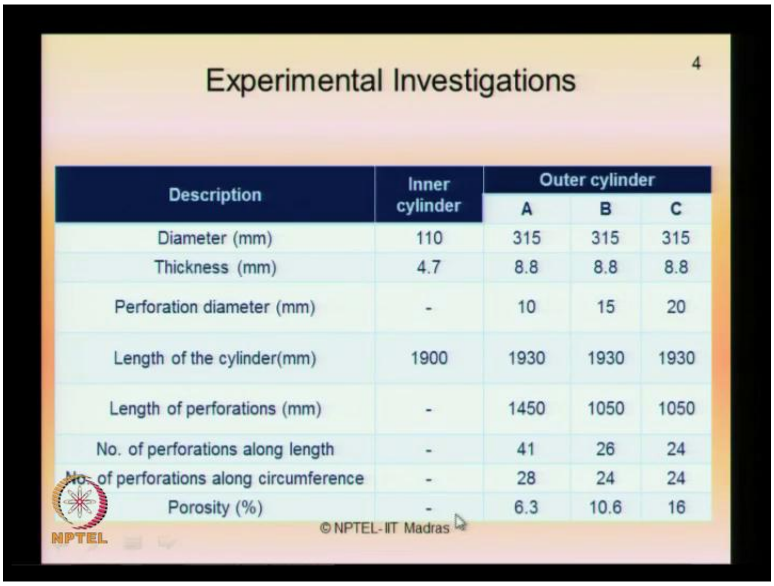

Experimental Investigations

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Description	Inner cylinder	Outer cylinder		
		A	B	C
Diameter (mm)	110	315	315	315
Thickness (mm)	4.7	8.8	8.8	8.8
Perforation diameter (mm)	-	10	15	20
Length of the cylinder(mm)	1900	1930	1930	1930
Length of perforations (mm)	-	1450	1050	1050
No. of perforations along length	-	41	26	24
No. of perforations along circumference	-	28	24	24
Porosity (%)	-	6.3	10.6	16

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The inner cylinder diameter is kept as 110, whereas outer cylinder is in different categories of 315 millimeter diameter but different porosities varying from 6.3 percent to 16 percent. The thickness perforated diameter length of the cylinder and length of perforations are all explained in this table. Now we have got 3 cylinders, outer cover A B C configurations covering the inner cylinder with different perforation or porosity ratios.So the test specimens look like this, you can see here there an outer cylinder A B and C and the inner cylinder is having no porosity or no porous.

So these 3 outer layers of A B and C have different regions of perforation which are coveringthe inner cylinder, and the forces are measured in the inner cylinder you can see the instrumentation done on an inner cylinder. So the whole assembly now the outer covers of A B and C on the inner cylinder separately are put in an assembly and they have been supported using clamp and the cylinder is suspended and the wave field is been activated, that is a set up what we have.

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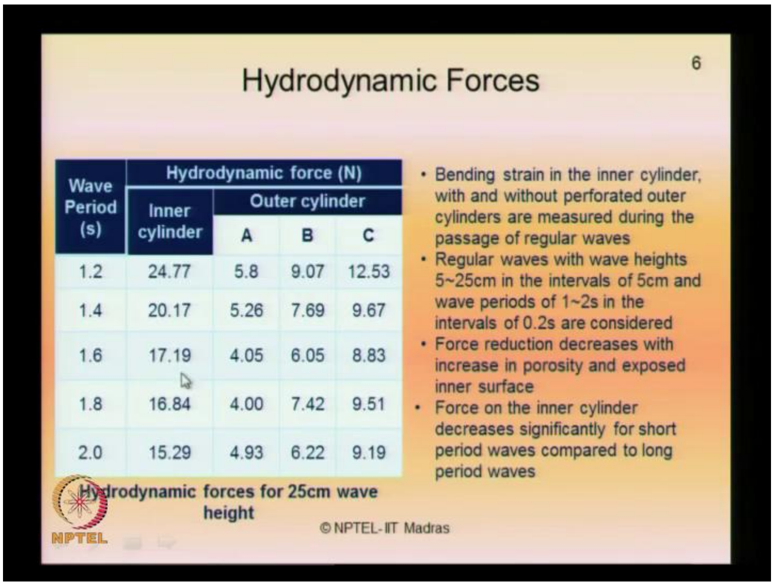

Once we do this the hydrodynamic forces on the inner cylinder as I told you are measured, the bending strains in the inner cylinder with and without covers are measured when the waves are passing the cylinders. Different regular waves or various wave heights varying from 5 centimeter to 25 centimeter and wave periods varying from 1 to 2 seconds at an interval of 0.2 has been considered in investigation.

It has been seen that there is a force reduction, the table shows hydrodynamic force measured in newton on the inner cylinder for different outer cylinders of A B C for different wave periods. Of course, this table shows the value for a specific wave height of 25 centimeters. We have seen that there is a force reduction and this force reduction decreases with increase in porosity. You can see here that when the porosity increases the force reduction decreases, further the forces on inner cylinder decreases significantly for a short period wave compared to long period. The reduction is significant for a short period wave compared to a long period wave, these 2 have been quantified experimentally to understand what is effect of wave hydrodynamics on a perforated outer cover and effect is measured on theinner cylinder which is covered by perforated layers of different ratio of perforations. So A B C stands for different porosity ratios, as we saw in the last table.

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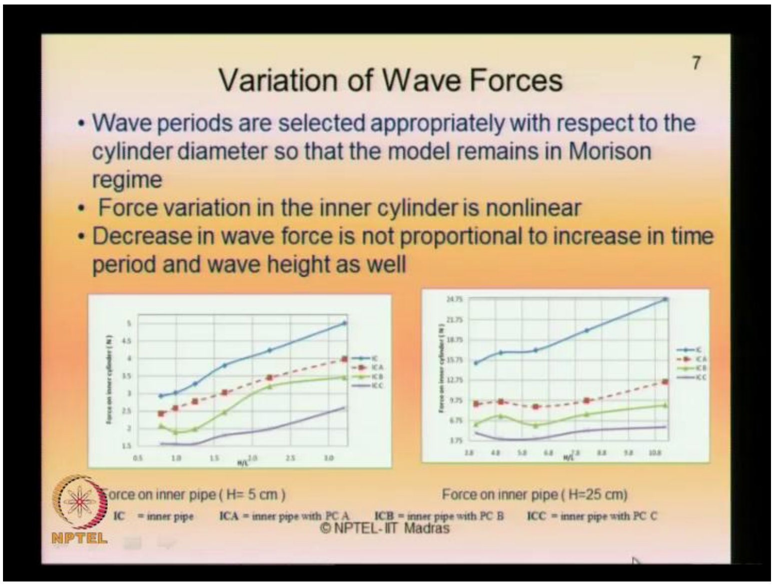

If you also look at the variation of wave forces on the inner cylinder because of the influence of perforations on the inner cylinder, the wave periods are selected appropriately so that the cylinder rise of course in the Morison regime. The force variation seems to be non-linear; the force on the inner cylinders seems to be non-linear so the blue lines what you see here is the inner cylinder without any perforations. If you look at ICA it is inner cylinder with perforation of outer cover A B and C you will see that the forces which are measured in inner cylinderreduces significantly for different perforated covers on the inner cylinder when they are having no cover.

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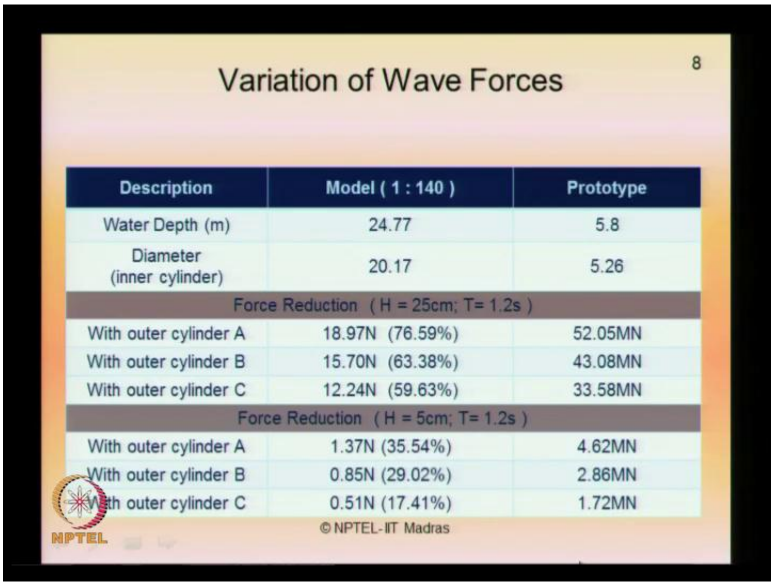

Description	Model (1 : 140)	Prototype
Water Depth (m)	24.77	5.8
Diameter (inner cylinder)	20.17	5.26
Force Reduction (H = 25cm; T= 1.2s)		
With outer cylinder A	18.97N (76.59%)	52.05MN
With outer cylinder B	15.70N (63.38%)	43.08MN
With outer cylinder C	12.24N (59.63%)	33.58MN
Force Reduction (H = 5cm; T= 1.2s)		
With outer cylinder A	1.37N (35.54%)	4.62MN
With outer cylinder B	0.85N (29.02%)	2.86MN
With outer cylinder C	0.51N (17.41%)	1.72MN

In both cases, one is for wave height of extreme 25 centimeter; other is for the other extreme of the lower value of 5 centimeter. In both cases you will see there is a force variation in inner cylinder with the different outer covers and this seems to be non-linear. You can also see that the decrease in the wave force is not proportional to the increase in time period and the wave height as well. So this has been tabulated again and the model has been studied at 1 is to 140is projected back in the upward scale the prototype to find out what is approximate reduction in terms mega newton, on the prototype forces members when compared to the experimental values are different wave height, wave period. We have kept the wave period same in this table just to see what is the influence of wave height on the force reduction.

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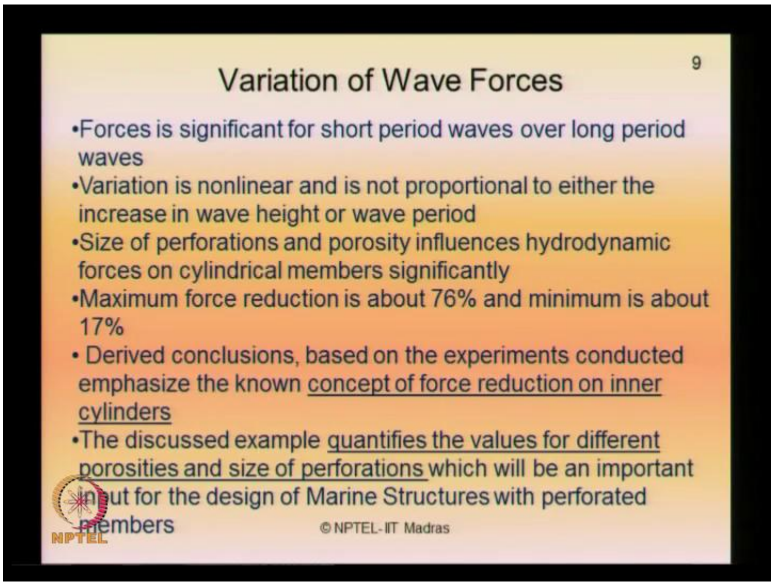

So from the table one can easily identify that the forces is significant in short period waves compared to long period waves. The reduction of the force variation is significant, and we have also seen that this variation is non-linear as it is not proportional either to the increase in wave height or to the change in wave period. It is also understood that different layers of A B C configurations have been put on the inner cylinder, the size of perforation; because A B C has different size of perforation also, you can see that in this table the perforation diameter for configuration A B C are not same.

And the porosity ratio of A B C are not same, though the length of perforation is also vary by the length of the cylinder is not vary. Therefore, we can now clearly say that the size of perforation and porosity influences hydrodynamic forces on the inner cylinder when it is incompest by in outer cover. So why this idea was studied, because we have understood from the literature theoretically and analytically that as we have seen from different references in the last lecture, that presence of porous outer covers will reduce the effects caused by vortex shedding frequencies on the members. We have also understood that there is going to be a force reduction on the inner members when outer cover is encompassed from different literature review in this presentation very briefly.

So adding thesetwo effects together, we have understood now that the size of perforation and porosity influences the hydrodynamic forces on the inner cylinder significantly. The maximum force reduction is as high as 76 percent and as low as 17 percent. Therefore, one can make a very brief conclusion from this experimental studies sited that the concept of force reduction on inner cylinder is emphasized. Further, the discussed example quantifies the value for different porosities and size of perforations which can be understood as an important input for the designer marine structures with perforated members. One can ask an fundamental question why the marine structural members should have perforated layers, we have seen in the last lectures the perforated covers are porous regions coveringsolid members reduces secondary responses caused by V I V. Primarily they also reduce forces on a members, now is it a good practice to recommend this kind of application for a new structure? The answer is no. For a newly designed structures reduction in forces may not be a good idea though reduction in responses induced by V I V can be a good suggestion. But this kind of analogy is acceptable and recommended if you really wanted to strengthen the existing marine structures what we call as retrofitting or rehabilitation of existing marine structures.

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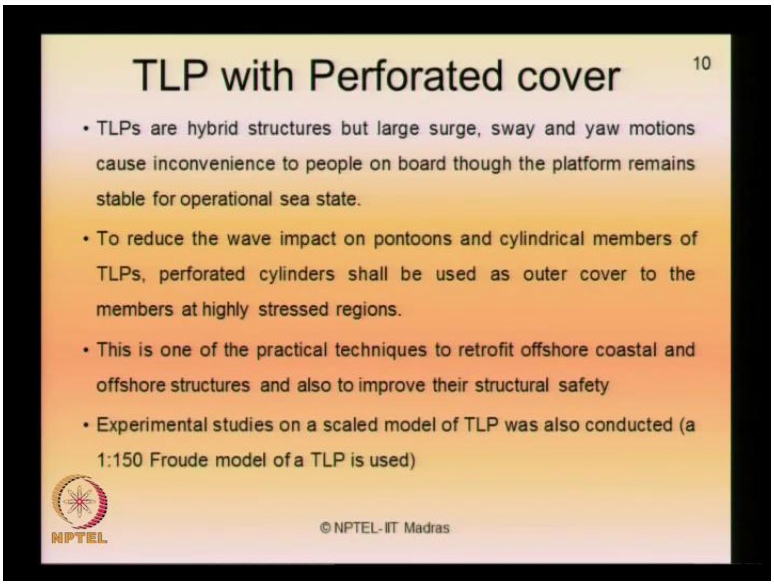

Now as an example of this application extended on a marine structure, a tension like platform of members with outer perforated cover has been attempted, experimentally and numerically.We all understand that T L Psare hybrid structures, they are very large surge, sway and yaw motions which causes inconvenience to the people on board which we do not want. Therefore, to reduce a wave impact on pontoons and cylindrical member one can think of attempting a perforated cover on an existing outer cylinder at highly stressed region.This can be seen as one of the practical techniques the retrofit offshore coastal and offshore structures and also to improve their structural safety. Experimental studies are conducted on a scaled model of tension like platform using in 1 is to 150 Froude scale model which will be now discussed.

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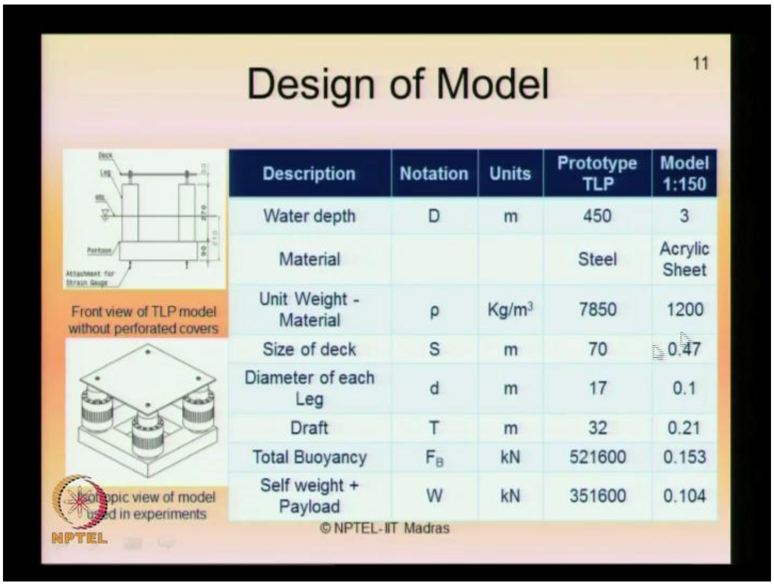

This is the model ofT L P which was an isometric view which is used in the experiment.This is the front view of the model, this is the description of the design parameters of the model where the water depth study of a T L P in a prototype is450, whereas on scale of 1 is to 150 a 3 meter water depth is used for experimental investigation. The original material in the prototype is of course, recommended as steel which is used for tension like platform but, of course, here the material used is acrylic. The mass ratio which is one of the important parameter to influence V I V induced responses is of course a limitation in the study, the mass ratio is now drastically different. This has been conducted only just to quantify the values to understand how this can remain effective, because you can see here the unit weight is about approximately about 5 to 6 times, ok.

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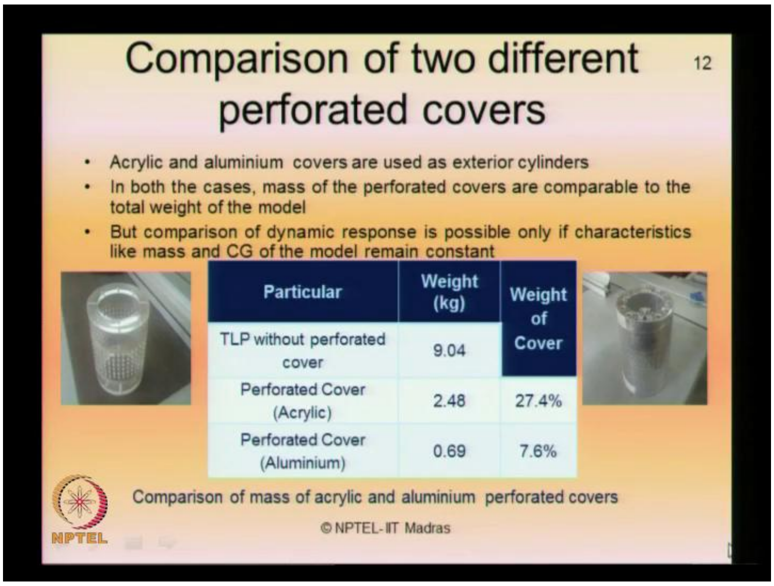

Particular	Weight (kg)	Weight of Cover
TLP without perforated cover	9.04	
Perforated Cover (Acrylic)	2.48	27.4%
Perforated Cover (Aluminium)	0.69	7.6%

Now the outer cover can be of 2 different materials which has been attempted in the study. One can be simply an aluminum cover; one can be acrylic cover though again as different densities. Now what would be the bases if you really wanted to conduct a study of this order? The bases could be the acrylic and aluminum covers can be used as exterior cylinders with porous members of porosities in the outer layer. In both the cases mass of the perforated cover should remain comparable to the total weight of the model but, if you use aluminum the added weight because of the cover is about 7 percent to the overall weight of the model; whereas if you use acrylic then the weight cover comes to around 30 percent. Therefore, it is not a good practice to have a heavydensity material as an outer cover in practice as well as in experiment; because one must match more or less the mass ratio between the materials at least between the inner and the outer cylinders, because it is essential that the comparison of the dynamic response is possible only if the characteristics like mass and CG of the model remains almost constant.

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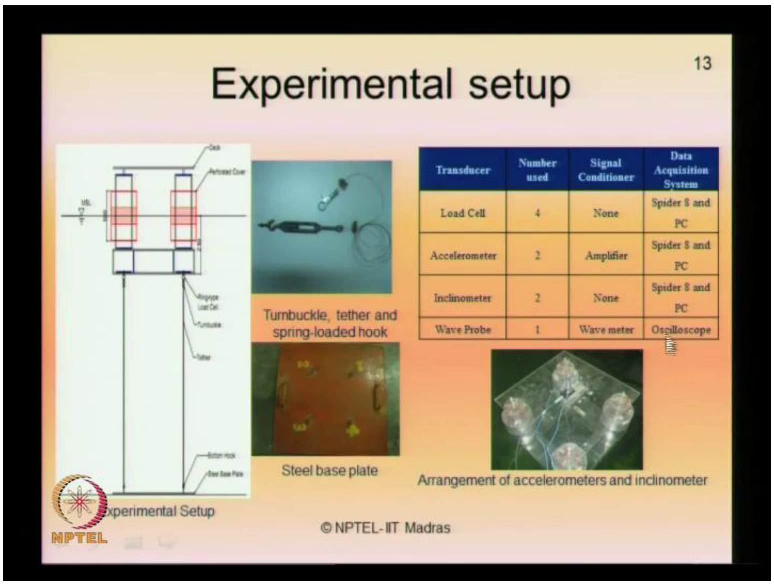

So the model has been installed in the deep water plat picked in the experimental setup using the turnbuckle, tether,spring hook loaded system. The tension is given at the top, so this is the base plate which is having the arrangement to hold down the tethers in position. There is the steel base plate which is shown here, this is of course the same model which you saw in the last light which is now shown with the arrangement of accelerometers to measure theacceleration and inclinometer to measure the rotations. This is the arrangement of different measuring devices like load cell, accelerometers, inclinometer and wave probes which are fixed or which is the forming the path of the data acquisition system which is used in the experimental study.

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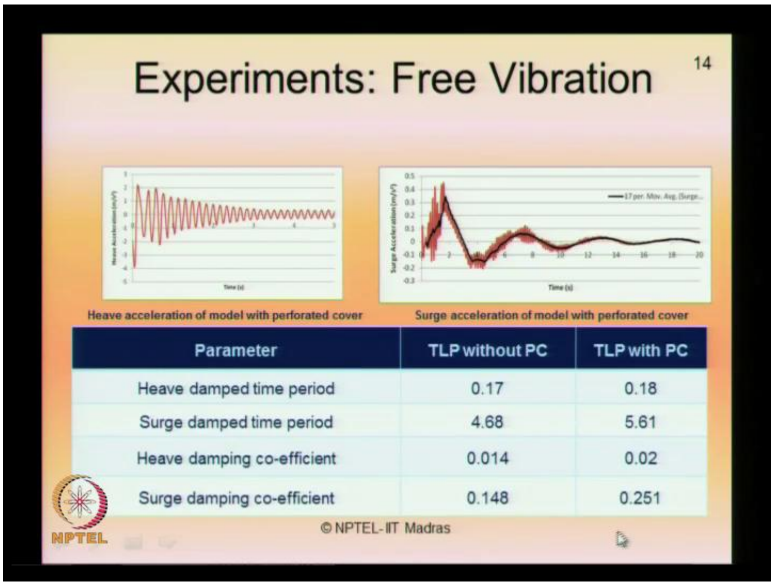

Now free vibration test have been conducted to understand the response characteristics in the heave and surge degree of freedom. So if you look at the heave acceleration of the model with the perforated cover and the surge acceleration of the model with the perforated cover; as you see in the 2 figures on the left and right, the heave damped time period without perforated cover is around 0.17whereas, with perforated cover is 0.18.That is on the heave, where as in the surge damped period you will see that there is a significant variation in theperiods with and without perforated outer covers.

So dampening is also affected significantly in the surge degree freedom like heave, sorry surge. In the heave degree the variation in not significant for the model, so we have also understood that damping also plays and very important role or one of the decent techniques by which the secondary vibrations caused by vortex shedding frequencies can be controlled; because we spoke about external damping functioning of the materials where the damping can be increased by sandwiching materials like rubber or wood between the steel members to increase the internal damping, because the internal damping characterizes can be increased can control the responses because induced by vortex shedding frequencies. So in this case you can see here by providing the outer coverto an inner cylinder we can achieve a good damping in a complained degree like surge.

Now the response are now doing discussed in a dimensionless format, which is thickness ratio h by l, the T L P was subjected to a time period ranging from 0.8 to 2.4 seconds because the model has a resonance close to 2.7; so the time periods all the waves were not taken to resonance response on the natural frequency of the system so that the model cannot be disturbed for a permanent damage. The wave rates tested by around 56 and 7 and 9 centimeters in the course of the experiment, you will see that for increase h p l values the blue lines shows the responses on a 7 centimeter wave in the model on the head sea condition 0 degree angle of inclination without perforated cover but, with perforated cover for a specific porosity value of 6.5 percent you will see the reduction shows a similar trend but, there is a reduction significantly for lower h p l values.

For higher h p l values the reduction is not significant in the surge degree, where as in heave degree since the damping effect is not predominant you will see that even in lower h p l values the effect is not significant. In case of pitch of course, the effect is significant and the trend remains same and the maximum reduction occurs at a specific value of h by l which is developed or which is seen as a coupling effect between the heave and pitch degree of freedom. Interestingly you will also see that the tether tension variation that is the tension, variation in tethersor cables are also significant for higher h p l values reduction is significant.

So perforated cover or perforation layers on an inner cylinder encompassing inner cylinder not only decreases the response of the members of the inner cylinder but, also decreases the tether tension variation. I am not talking about the tether tension reduction, the variation is controlled significantly therefore, this can also be seen as one of the ideas of indirectly controlling the vibration induced responses on cables; which is also one of the ideas on V I V reduction phenomena which we discussed in last lecture.

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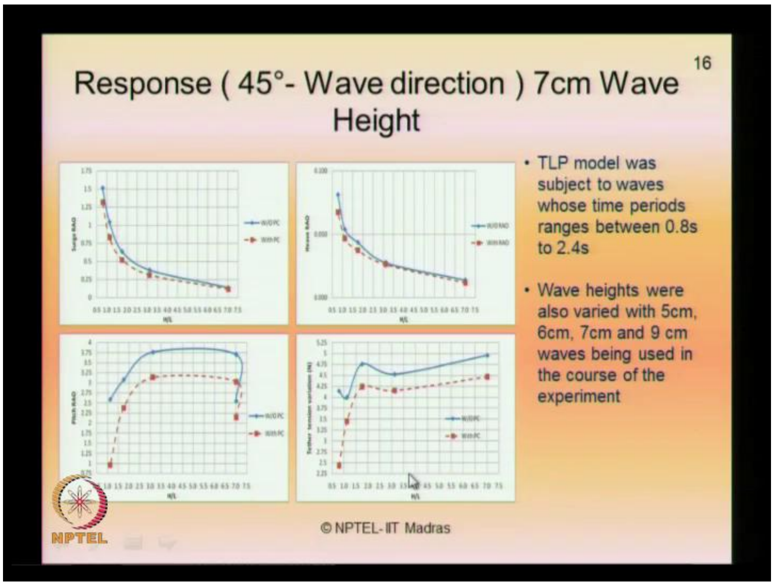

If you look at this trend for different angle of attack at 45 degree for example, for 7 centimeter wave height the same wave height is being kept for the same range of wave period in wave heightsyou will see that the trend is again similar, whereas in pitch and tether tension radiation you will see that the variation suddenly has a significant effect in at a specific h by l value close to around 2 or one point eight1.8. Then the trend follows as you see the increase in h by l causes significant reduction in the tether tension variation as well this can be seen as one of the ideas of retrofitting the members which can also reduce the tether tension variation in the cables or in the tethers.

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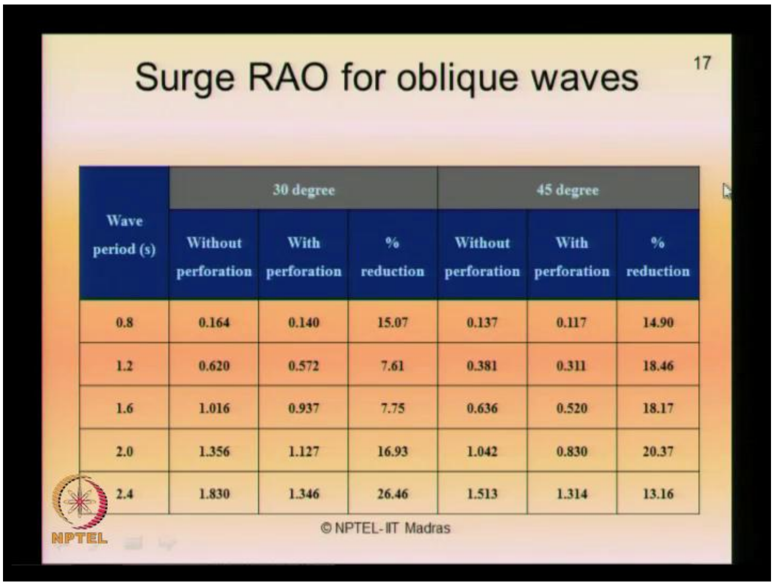

Wave period (s)	30 degree			45 degree		
	Without perforation	With perforation	% reduction	Without perforation	With perforation	% reduction
0.8	0.164	0.140	15.07	0.137	0.117	14.90
1.2	0.620	0.572	7.61	0.381	0.311	18.46
1.6	1.016	0.937	7.75	0.636	0.520	18.17
2.0	1.356	1.127	16.93	1.042	0.830	20.37
2.4	1.830	1.346	26.46	1.513	1.314	13.16

We look at the surge responses in oblique waves for 30 and 45 degrees, the percentage reduction which you see in the fourth and the seventh column as you see in this table is significant varying from 15 percent or let us saythe lower percentage around 7 and highest reduction is around 27 percent, which is significant for a model of 1 is to 150 scale which is been discussed in this presentation.

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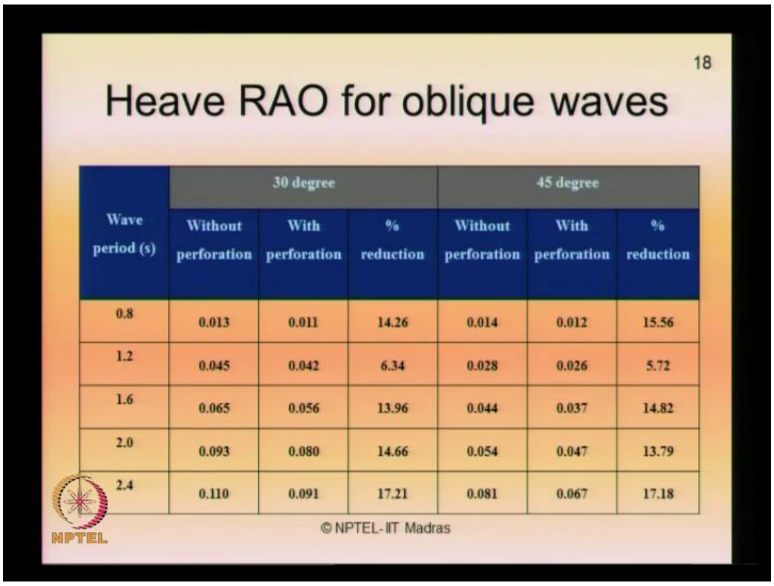

Wave period (s)	30 degree			45 degree		
	Without perforation	With perforation	% reduction	Without perforation	With perforation	% reduction
0.8	0.013	0.011	14.26	0.014	0.012	15.56
1.2	0.045	0.042	6.34	0.028	0.026	5.72
1.6	0.065	0.056	13.96	0.044	0.037	14.82
2.0	0.093	0.080	14.66	0.054	0.047	13.79
2.4	0.110	0.091	17.21	0.081	0.067	17.18

If you look at the heave responses in oblique ways for a 30 degree and 45 degree, the variation or the reduction in the variation percentage reduction varies from about

6percent to as high as 17 percent; for 30 degree as well as 45 degree. It means the angle of attack or the angle of approach of the waves on the member encompassed by perforated cover does not cause significant variation because whatever may be the angle of attack, the percentage reduction remains almost same varies from 6 percent to around 17 percent in this case as well.

So it is understood thatthere is a significant percentage reduction in surge and heave responses on the inner members when they are covered by perforated outer covers. There is a reduction in tether tension variation when you cover the members using perforated outer covers. We have understood that there is a reduction in the response which can be connected to increase in damping coefficient in surge response because the moment you put a outer perforated cover the damping coefficient in surge degree also varies significantly

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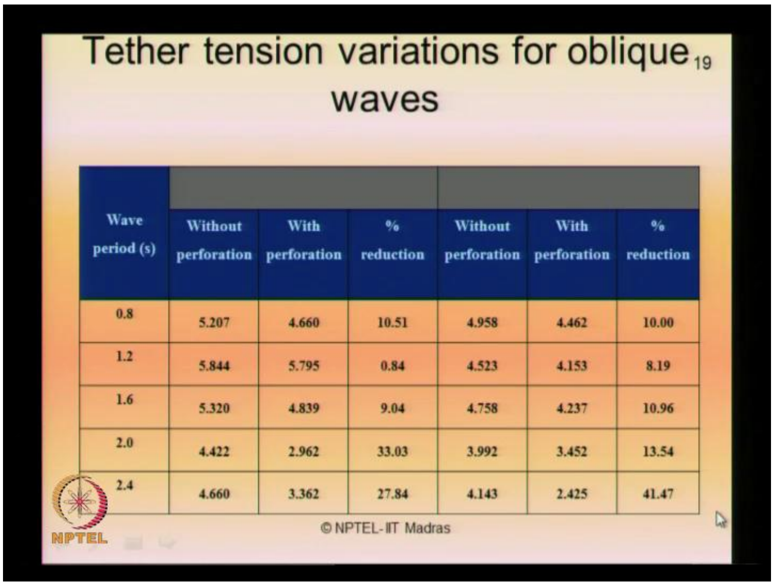

Tether tension variations for oblique waves 19

Wave period (s)	Without perforation	With perforation	% reduction	Without perforation	With perforation	% reduction
0.8	5.207	4.660	10.51	4.958	4.462	10.00
1.2	5.844	5.795	0.84	4.523	4.153	8.19
1.6	5.320	4.839	9.04	4.758	4.237	10.96
2.0	4.422	2.962	33.03	3.992	3.452	13.54
2.4	4.660	3.362	27.84	4.143	2.425	41.47

If you look at tether tension variation for oblique waves, the percentage reduction for 30 and 45 degrees is also varying from as normal as low variation that is 1 percent to as high as 33 percent; so there is a reduction significantly in teeter tension variation as well.

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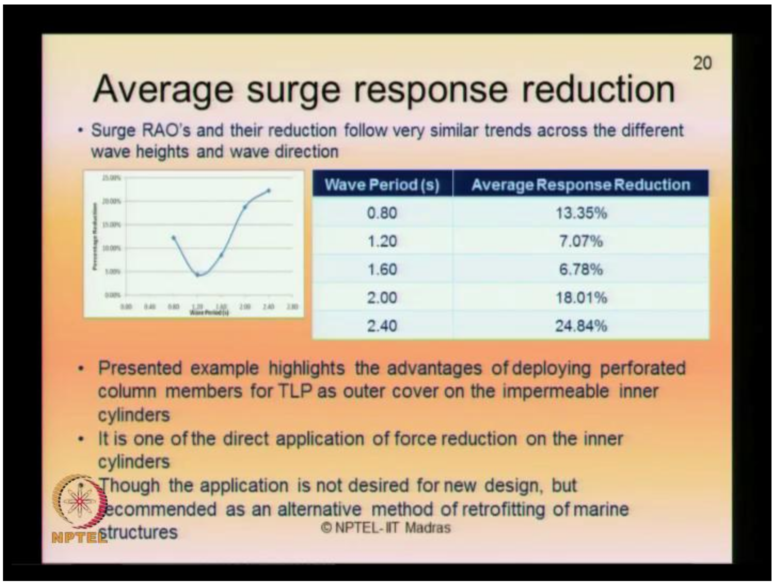

If you look at the average surge response reduction, you will see that for increase in wave periods from let say 0.6 to 2.4 seconds you will see notice that there is a significant reduction in percentage which happens at around 1.2 let us say in this case, and then afterwards the percentage reduction changes drastically. So you can also see from the table here the average reduction is varying from 13.35 and drops down to 7 percent, so there is a critical value of wave period in the experiment conducted at which the reduction is lowest. But once you skip this region then the reduction becomes as high as 25 percent. The presented example highlights the advantages of deploying perforated column members on example problem of T L P as an outer cover on an impermeable inner layer. It can be seen as one of the direct applications of force reduction on inner cylinders. Though the application is not desired for a new design but, recommended as an alternative method for retrofitting of marine structures.

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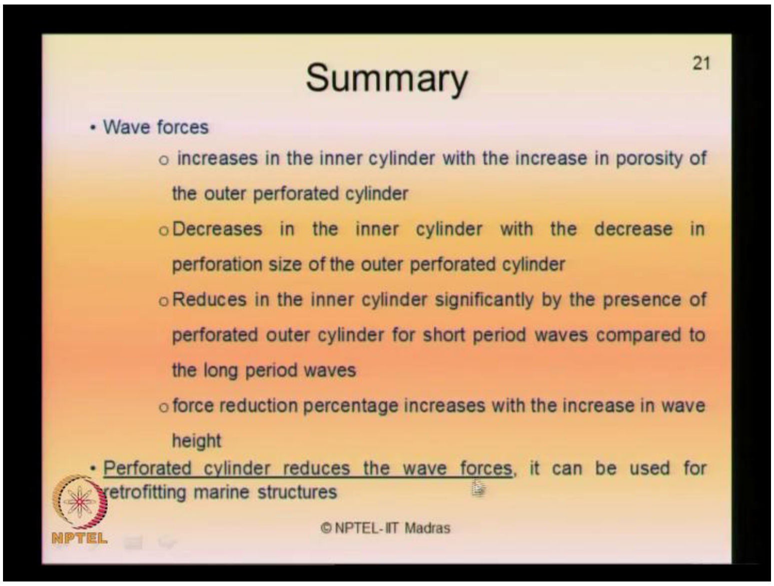

So we can see that the wave forces increases in inner cylinder with increase in porosity,decreases in inner cylinder with decrease in perforated size, reduces in inner cylinders significantly by the presence of perforated outer cylinder for a short period waves compared to long period waves. Force percentage reduction increases with increase in wave height, so perforated cylinder reduces wave forces which can be seen as one of the direct method of retrofitting marine structures.

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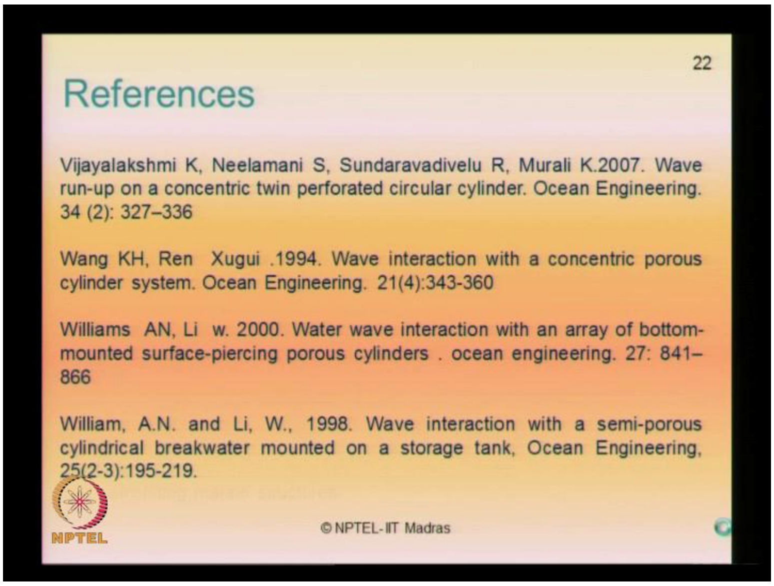

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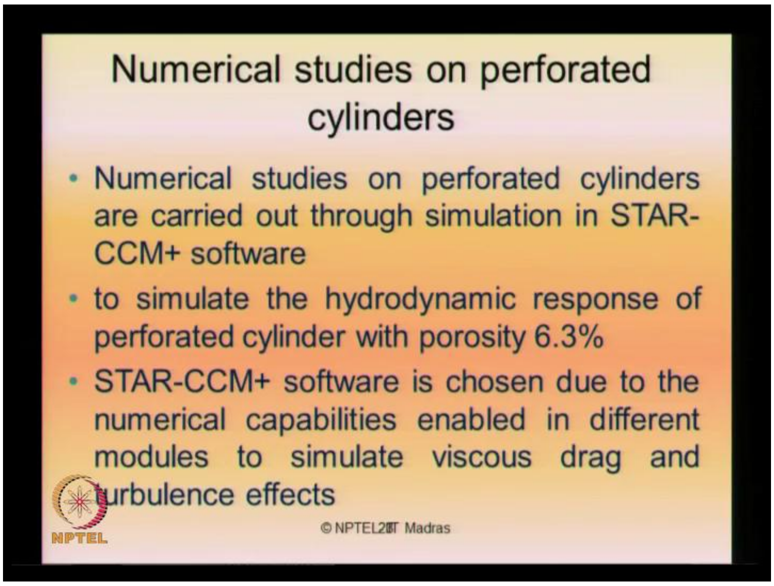

Subsequently this has been also verified using numerical studies. The numerical studieson perforated cylinders are carried out using a software simulation in star CCM. Now idea was to simulate that hydrodynamic response with the porosity of 6.3 percent, softer CCM is chosen because the numerical capabilities enabled in different modules to simulate viscous drag and turbulence effects are good in this software.

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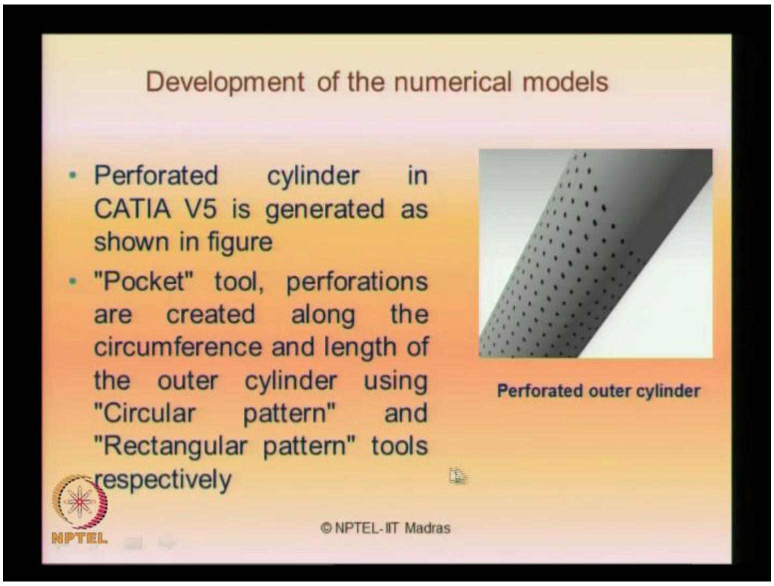

The numerical model of a perforated cylinder is developed in CATIA V5 as shown in the figure here. The pocket tool perforations are created along the circumference and the length of auto cylinders using circular pattern and rectangular pattern tools respectively.

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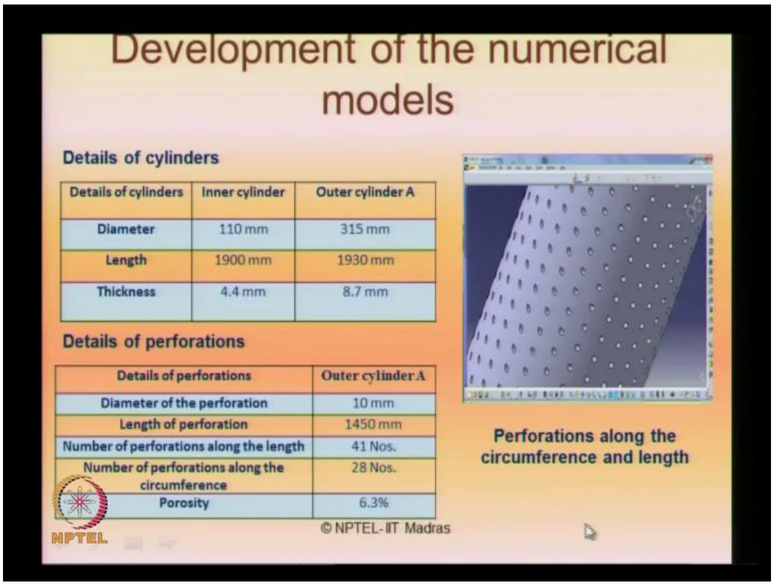

The details of cylinder created in the model numerically are shown here in outer cylinder for a different diameter you can see the length of the perforation is keptas same as the experiment of 1415 millimeter and the porosity is achieved as 6.3 percent numerically.

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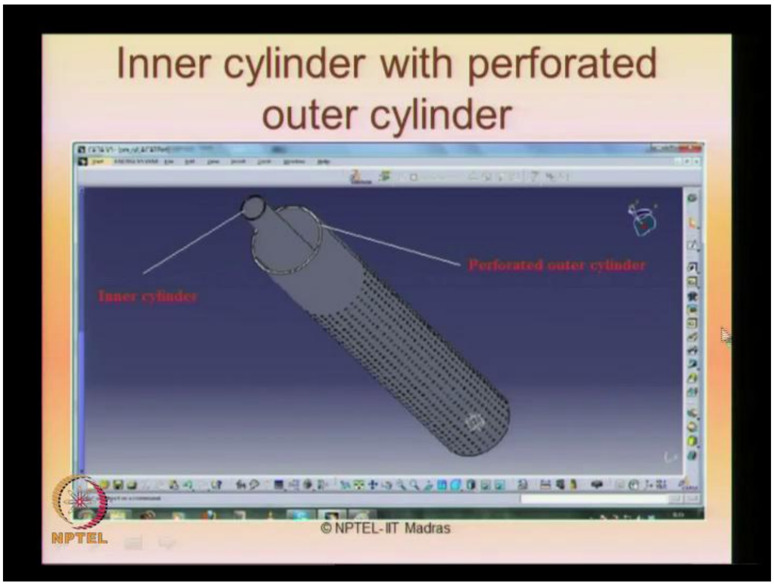

This picture shows you the inner cylinder with the outer perforated cover generated in star CCM for numerical analyses.

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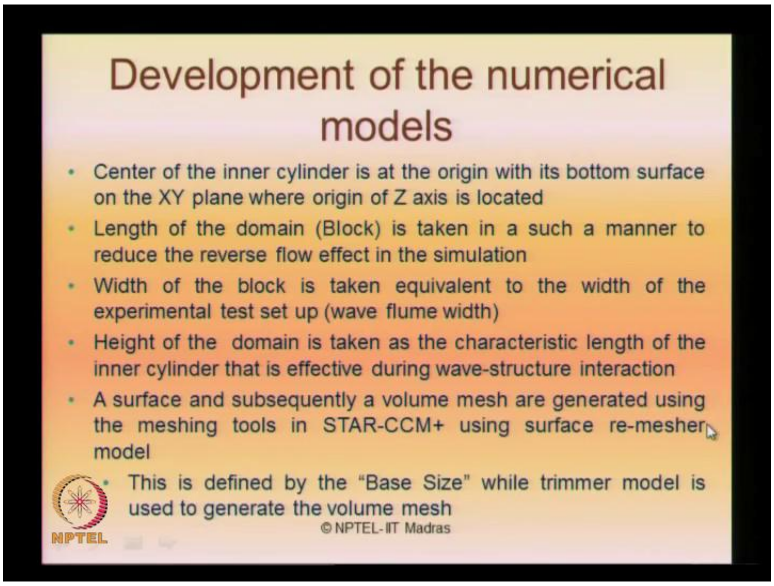

Let us quicklysee some of the details of the numerical models; the centre of the inner cylinder is kept as an origin because bottom surface in x y plane, the length of the domain block is taken in such a manner to reduce the reverse flow effect in the simulation, the width of the block is taken equivalent to the width of the flow, the height of the domain is taken equal to the characteristics length of the inner cylinder that is effective during the wave structure interaction because the domain is got to be define very clearly in the numerical model. A surface and subsequently a volume mesh has been generated using the machine tools in star CCM, this is defined by the base sizewhile the trimmer model is used generate the volume mesh in the model.

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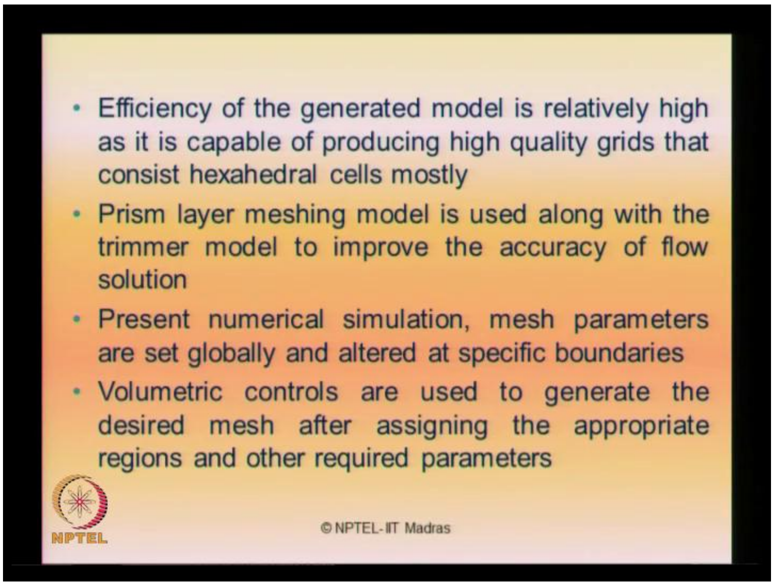

The efficiency of the generated model is relatively high because it is capable of producing high quality grids that consists hexahedral cells mostly. The prism layer meshing model is used along with the trimmer model toimprove the accuracy of the flow solution. The present numerical simulation, the mesh parameters are set globally and altered at specific boundaries as desired. The volumetric control as an ((example))generate the desired mesh after assigning the appropriate regions and other required parameters.

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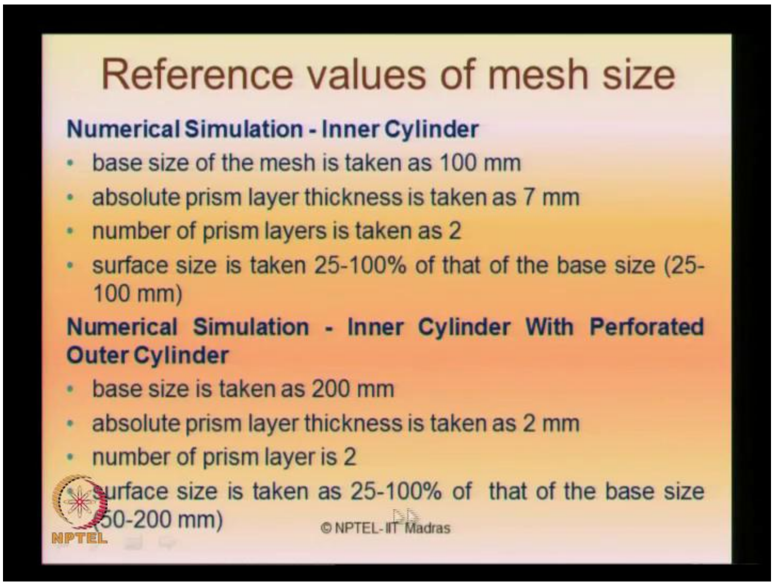

If you look at the reference values of the mess size used in inner cylinder and inner cylinder with perforated cover, you can see the base size of the mesh in this case 100 mm where as in this case 200 mm and absolute prism layer thickness is 7 mm in the inner cylinder where as in used PC it is taken as only 2 mm. The number of prism layers in both the cases is kept as 2 and the surface size is not varied much; whereas the base size is varied significantly from 25 to 100, that is what the limit is whereas in this case 50 to 200, that is what the limit is.

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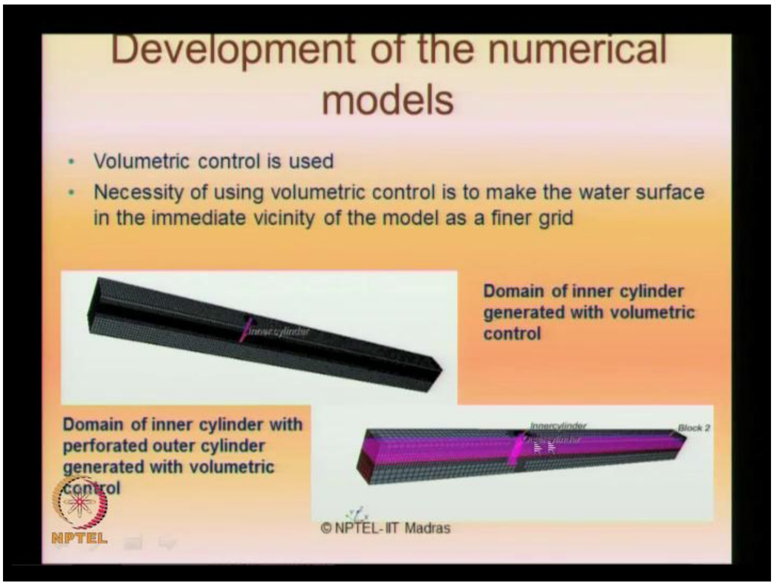

This is how the model looks like for a domain of inner cylinder and the domain of inner cylinder with perforated outer cover, this is a domain what we are showing.

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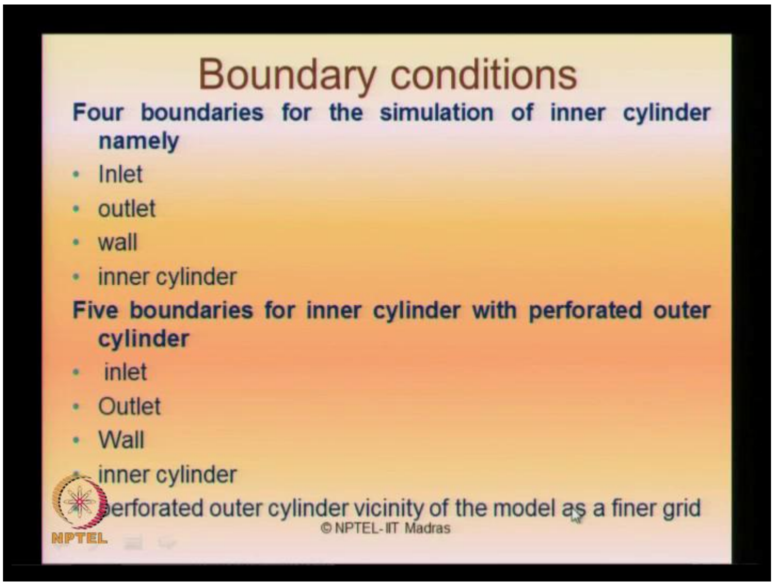

Different boundary conditions deployed for the analysis for the inner cylinder is basically inlet, outlet, wall and of course the cylinder, whereas by perforated outer cover we have got 5 boundaries inlet, outlet, wall, inner cylinder and perforated outer cylinder vicinity of the model as the finer grid.

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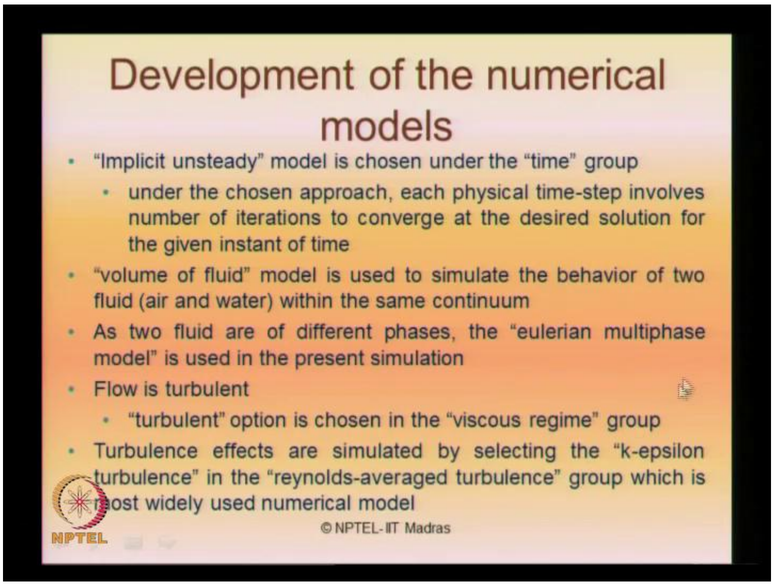

Implicit unsteady model is chosenunder the “time” group in star CCM. Under the chosen approach each physical time-step involves number of iterations to converge to the desired solution. The volume of fluid V of model is used to simulate the behavior of the 2 fluid that is iron and water. As 2 fluids are of different phases the eulerian multiphase model is used in the present simulation. The flow is retain as turbulent, turbulent option is chosen in the viscous regime group in the star CCM. Turbulence effects are simulated by selecting the k-epsilon turbulence the reynolds-averaged turbulence group which is most widely used in similar numerical models as see from the literature.

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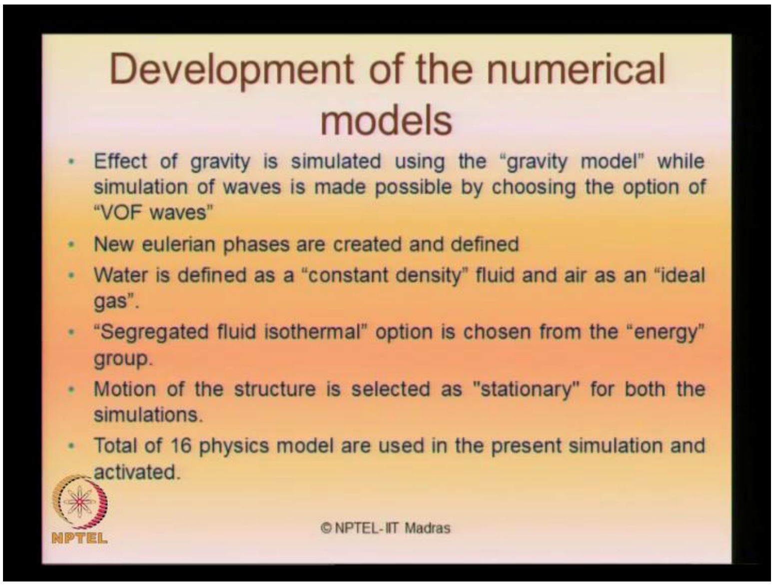

The effect of gravity is simulated using the gravity model while simulation of waves is made possible under the option of VOF waves. The new eulerian phases are created and defined, water is defined as constant density fluid and air as an ideal gas. The “segregated fluid isothermal” option is used for the energy group. Motion of the structure is selected as the stationary for both the simulations. Total of 16 physics models are used in the present simulation and then activated subsequently.

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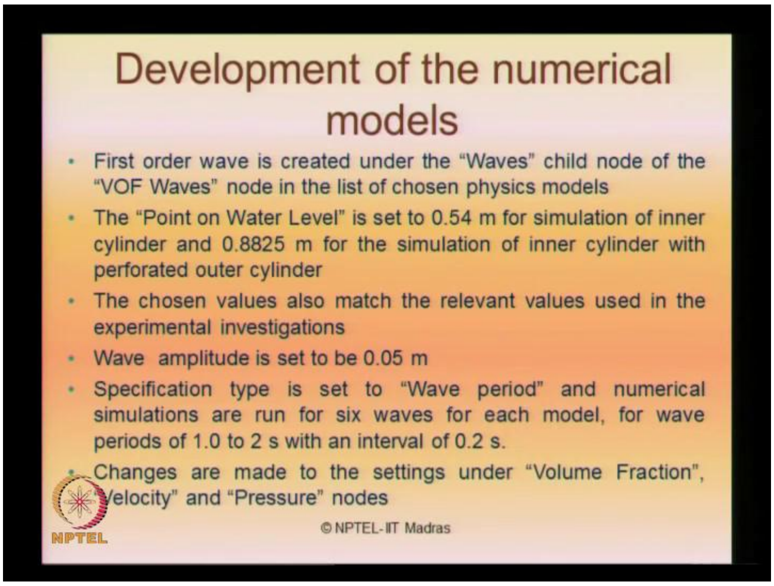

The first order wave is created under the "Waves" child node of VOF models. The point of water level is set as 0.54 meter by inner cylinder and 0.8825 meter for the simulation of the inner cylinder with perforated outer cover. The chosen values are matching; the relevant values usually experimental studies as I showed you in the table in the last slide.The wave amplitude for the experiment for the numerical study is set as 0.05 meters. The specification type used is wave period and numerical simulations are run for 6 waves of each model, wave periods varying from 1 to 2 seconds at an interval of 0.2 seconds. The changes are made for the setting under the "Volume Fraction", "Velocity" and "Pressure" nodes.

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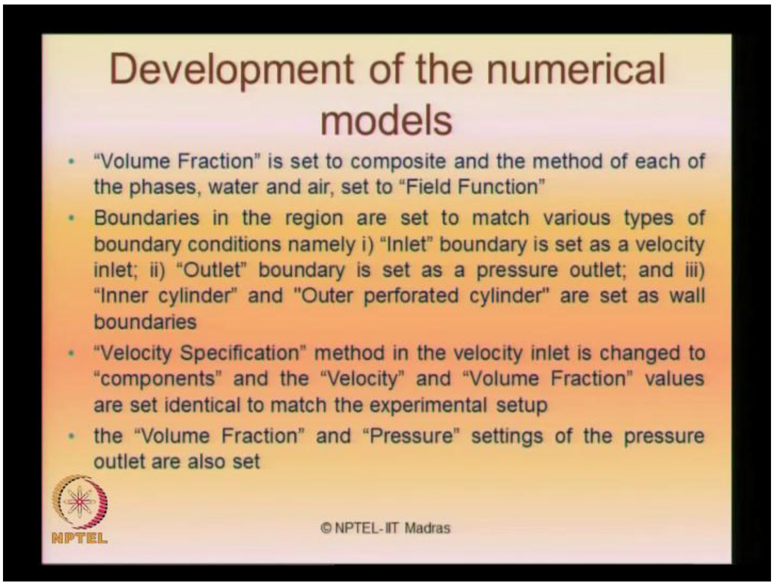

The "Volume Fraction" is set to composite and the method of each phases, water and air; they have set to "Field Function". The boundaries in the region are set to match various types of boundary conditions; inlet boundary is set at velocity inlet, outlet boundary is set as a pressure outlet, and inner cylinder and outer perforated cylinder are set as wall boundaries. The "Velocity Specification" method in the velocity inlet is changed to components and the velocity in volume fraction values are set identical to that of experiments. The "Volume Fraction" and "Pressure" settings of the pressure outlet are also set accordingly in the numerical study.

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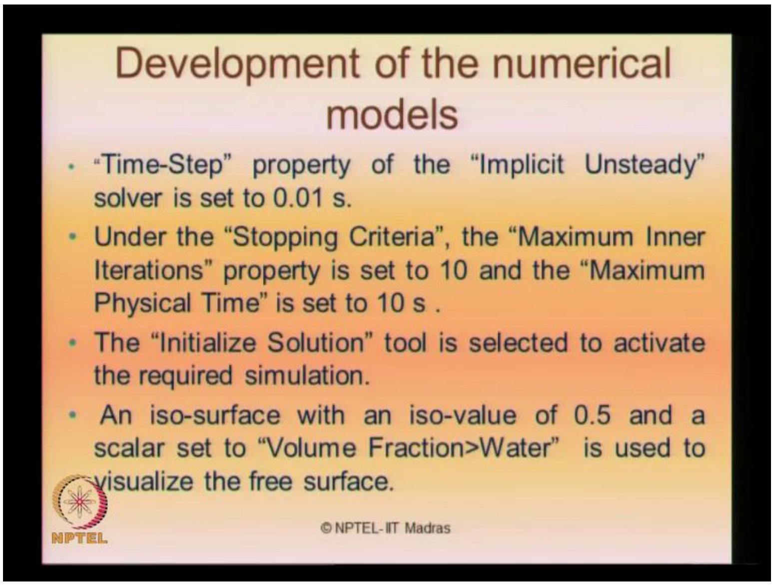

The "Time-Step" property of the "Implicit Unsteady" solver is set to 0.01 seconds. Under the "Stopping Criteria", the "Maximum Inner Iterations" is set to 10 and the "Maximum Physical Time" is set to 10 seconds. The "Initialize Solution" tool is selected to activate the required simulation. An iso-surface with an iso-value of 0.5 and the scalar set to "Volume Fraction greater than Water" is used to visualize the free surface.

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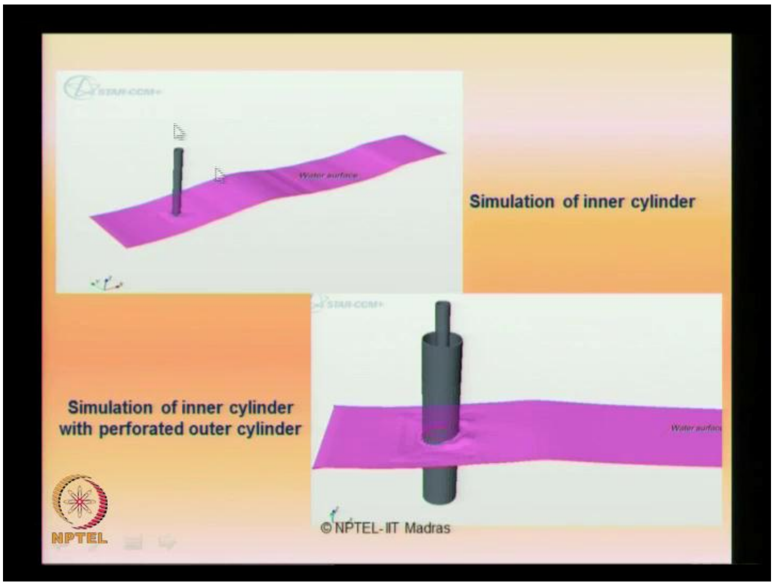

Now after doing all these settings you can see the screen saved from star CCM for simulation of inner cylinder in the boundaryand the simulation of the inner cylinder with the outer perforated cover in the boundary, both generated in the star CCM software.

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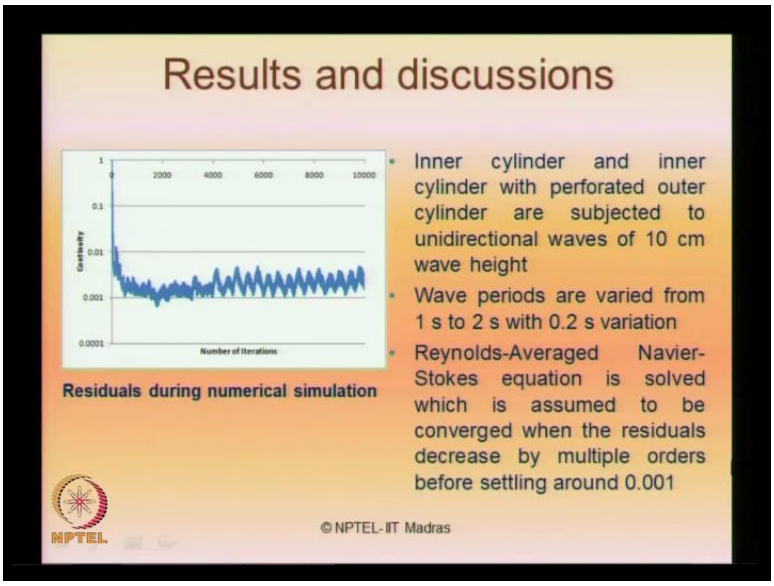

If you look at the residuals which are arrivedfrom the numerical simulation which is used as one of the check pressure to see whether the results are converged the inner cylinder and out inner cylinder with perforated cover are subjected to unidirectional wave. Wave period are varied. Reynolds-averaged Navier-stokes equation is usedand is solved used for converging with the residuals which decrease by multiple orders before setting around 0.001 as you see in this figure.

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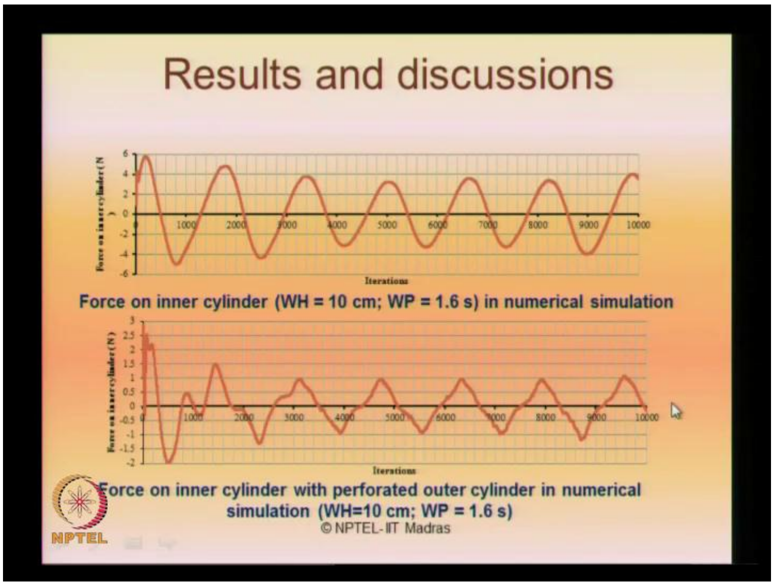

The results and discussions as you see here for force on inner cylinder in numerical simulation and force on inner cylinder with perforated outer cover in the numerical simulation, for the same wave period and wave height.

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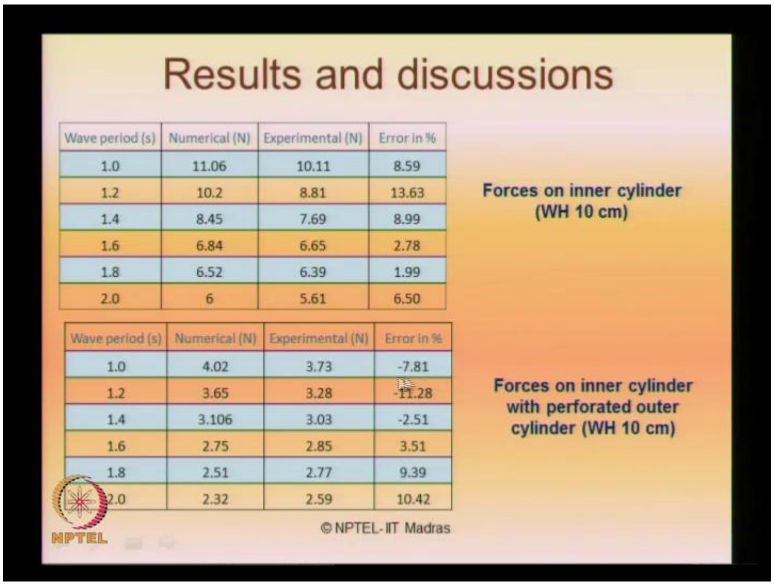

You compare the results and look at the error, the error varies, the force inner cylinder varies about 13 percent as high as that; whereas in case of forces on inner cylinder with perforated cover varies as high as 11 percent for different wave periods and you will see that how are they compared with the numerical value obtained from the star CCM with that of the experimental value measured in thetest set up in the laboratoryand the residual the error what shows here is the comparison between these two, so this is high as 13 percent in inner cylinder without outer cover on the forces, whereas with outer cover on the forces as high as about 11 percent.

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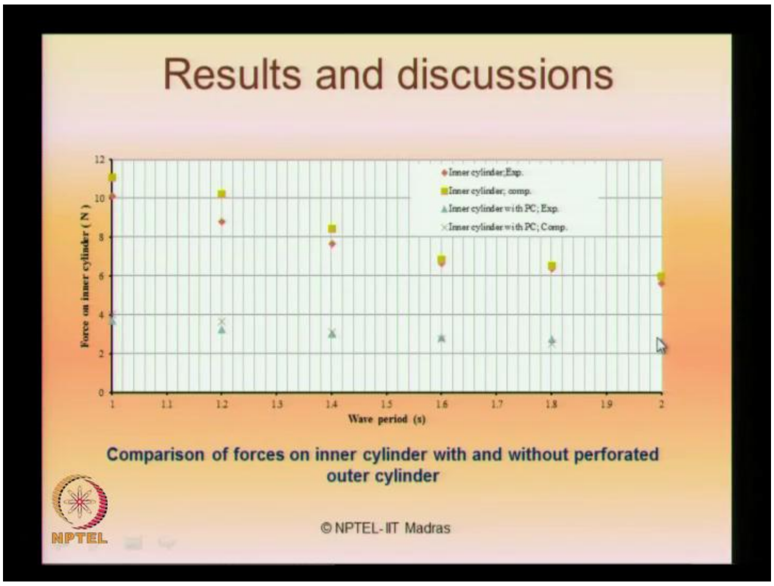

If you compare the results on forces on inner cylinder with and without cover, you will see that these are showing inner cylinder experimentally, these are showing inner cylinder analytically so they match very closely for higher wave periods. And if you look at the results with inner cylinder with perforated cover experimentally the triangles and the crosses, you will see that even for lower periods the force measured experimentally and the force computed in inner cylinder with perforated cover which is the idea of the whole experimentis matching very closely with the very less error of only about 7 to 10 percent.

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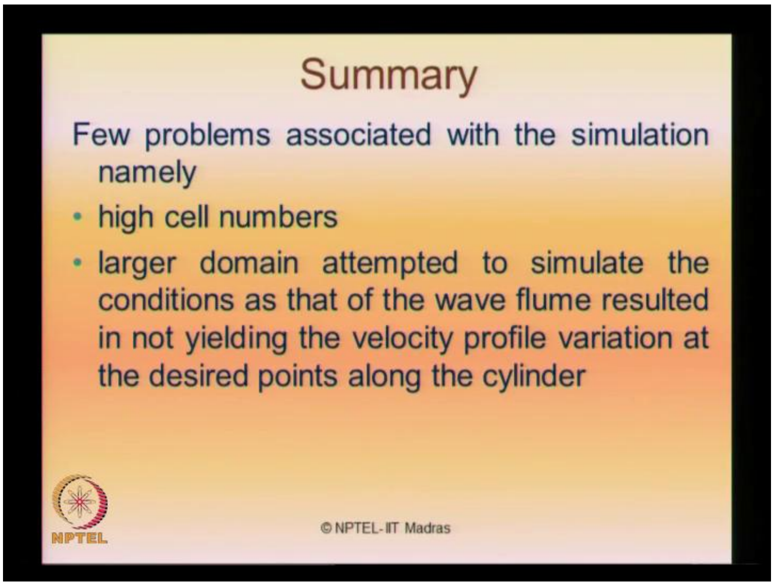

There are some few problems associated with the simulation which I want to tell to viewers before they attempt such a similar study in their research; high cell numbers are required to simulate these kind of studies which is one of the restriction or limitation,study large domain attempted to simulate the condition as that as the wave flow resulted in not yielding the velocity profile variation because the interesting thing could be whether can we examine the velocity profile variation also, what we saw in the literature now or the study now is only the force variation if you want to really look at the velocity potential variation also the larger domain attempted in the study is not suitablebecause it requires more desired points along the cylinderreally wants to trace the velocity profile variation. This can be seen as few limitations in the numerical study which we have experienced when we compared it with the experimental studies

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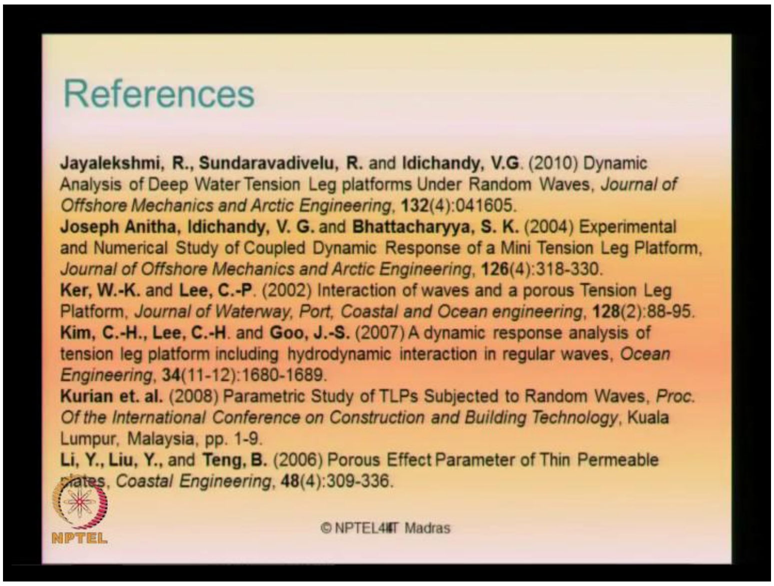

This particular presentation as references from different authors as you see here, so different studies are also being quoted by different researchers in various regimes of comparing experimental and numerical studies. You can also see the porous effect parameters on thin permeable plates as studied by Li at are in 2006.

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As we have also seen some of the studies conducted in our own laboratories by different researchers at different time periods. As we see here we have attempted to study the hydrodynamic responseon twin perforated cylindrical systems experientially and analytically. So the studies referred emphasis and the case studies mention show that there is significant reduction in the forces on inner cylinder encompassed by porous outer cylinders. Literature also verified as we discussed in the last presentation that they also reduce secondary vibrations caused by VIVs. So this can be seen as one of the interesting application area of force reduction or retrofitting members on marine structures. Thank you very much, this leaves and completes the discussion on the module 2 where we discussed very briefly about the flow induced vibrations, variation and flow characteristics because of interference of members in the study and uniform flow field.

We have also seen some of the thumb rules suggested by the designers, some of the imperial relationships recommended by the course by which can handle the lift force coefficients which are caused because of secondary vibrations induced by the vortex shedding frequencies on the near vicinity region of the members. We have also shown you 2 interesting case studies; experimental and numerical where force reduction as been quantified and showed numerically and compared experimentally on scaled models. So this discussion on model 2 definitely leaves an very important aspect of designer’s perspective of understanding how the flow induced vibration and how the flow passed cylinders helps one to understand what would be those parameters which would be considered while designing marine structures which is seen as one of the interesting and region advancements in marine structures.

Thank you very much.