Dynamics of Ocean Structures
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Lecture - 31
Retrofitting and Rehabilitation: Applications through Dynamics

So, this is 31st lecture in module two, where we are talking about the application of dynamics on ocean structures. In this class, we will talk about one interesting technique, which can be used for retrofitting and rehabilitation problems; of course approach is through a structural dynamics. Generally retrofitting and rehabilitation is done in three manners: one by the material retrofitting, other is by the stress release mechanism, third can be a use of a method by which force can be reduced.

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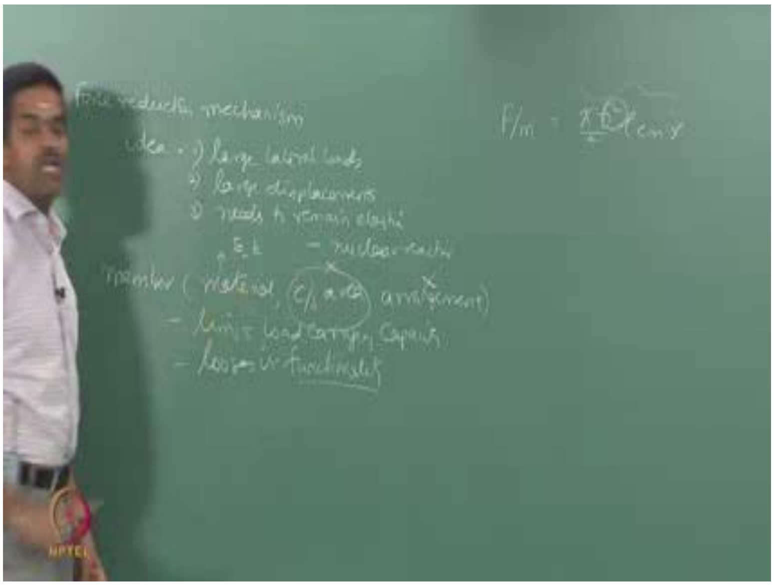

Now, this is a very – not a new idea; force reduction mechanism is of course an idea, which people have followed essentially when structures subjected to large lateral forces – one case. Two – the lateral loads will be lower, but the structure has large amount of displacements. Three – when the structure needs to remain elastic. You may ask me a question why there is such a need to remain elastic, because when a structure enters into an elasto plastic or a plastic mode in the transition, the structure develops a permanent deformation or the material develops a permanent deformation; permanent deformation always cause cracks. I can give an example.

The structure needs to remain elastic especially in the case of let us say nuclear reactor vessel, because in nuclear reactor, we do not allow any crack propagation or development of cracks, because that will cause endanger to the content inside the reactor. So, when you talk about a method of analysis or a design, a method of controlling large displacements or a method of envisaging large lateral loads, people generally talked about force reduction mechanisms; that are a general idea. So, in this lecture, we will talk about how hydrodynamics can be used as a tool to understand how lateral loads can be reduced on a given offshore structure. So, we will talk about retrofitting and rehabilitation applications through dynamics in this specific lecture.

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In this lecture we will talk about retrofitting of an offshore member using a perforated cylindrical structure outside cover. Of course this work is primarily carried out by one of my team researcher, who is doctor Madhavi. So, we acknowledge her work what she has done for finding out the results in this particular slide. I am using the results borrowed from the research conducted by her and under my supervision in IIT Madras. So, we will give credits to this researcher, who has done extensive work on this.

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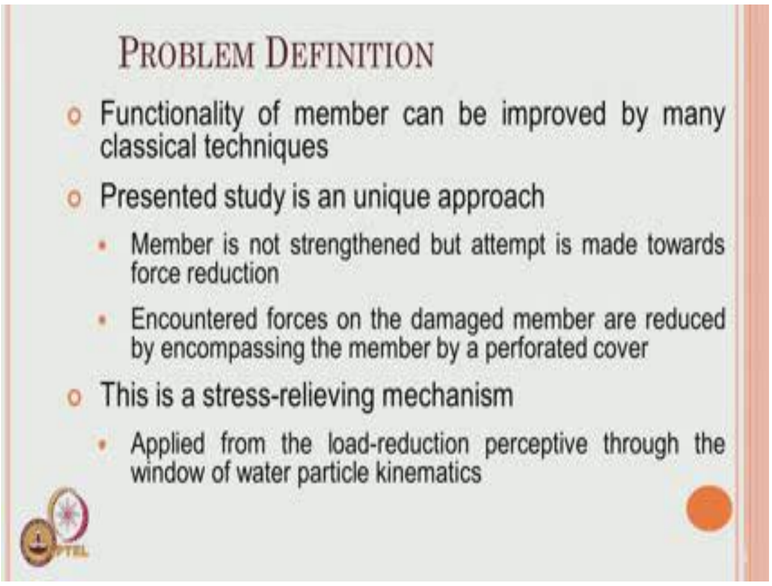

Let us quickly see how we define the problem. Now, one can easily understand that, the functionality of a member is always challenged when the forces exceed on a member. Now, what problem actually occurs when the force exceeds a given capacity of the member? For a given member, each member depending upon the material used depending upon the cross-sectional area depending upon the arrangement; you may ask me how arrangement will matter in load carrying capacity; I will talk about degree of indeterminacy. The more the degree of indeterminacy introduced in the system, the member will have more and more load carrying capacity. Depending upon the arrangement of the member – cross-section area of the member or material, member actually limits its load carrying capacity.

Now, if the load carrying capacity of the member is exceeded, the member loses its functionality; what we call as a failure. So, the member does not fail that is not able to disperse the load acting the member, actually it fails to perform the intended function. So, it is a functional failure actually. So, the functionality of the member can be generally improved by many classical techniques available in the literature. Of course the present study in this particular lecture will be a unique approach, because in this lecture or in this attempt, member is actually not strengthened. So, the member is not strengthened by improving the material characteristic.

For example, E can be improved; for example, stiffness can be revisited; it is not done in this specific case; the cross section area of this member is not altered; the member remains as it is, there is no change in the member, because once they alter the cross-sectional area, you will always know that it will attract large forces.

For example in case of Morrison equation per unit length of the member, you will see that, it is pi D square by 4 rho c m x double dot. So, D plays a very important role. If we increase the diameter of the cross-sectional area of the member; obviously, it will attract more forces. One component I am discussing; only the inertia component; there is a drag component also, which we know. So, it will also depend upon the diameter. So, therefore, it will vary.

And, I am not touching upon the cross-sectional area at all. Of course, we will not change the arrangement, because arrangement is actually a functional design of a given platform. I cannot change the arrangement, because I do not want to touch upon the top side characteristic of the platform at all. Therefore, none of these ideas are touched in the present study. But, however, the functionality is attempted to be improved. That is a very unique approach. That is what we say it is a unique approach. The member is not strengthened in the case, but attempt is made towards force reduction. The encountered forces on the damaged member are reduced by encompassing a member by a perforated cover. So, let us look at the plan.

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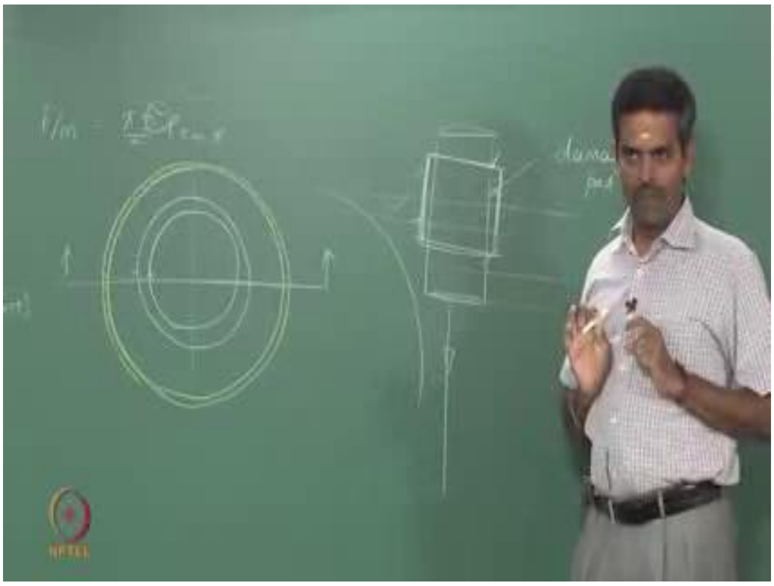

I have an offshore structural member; generally offshore structural members are cylindrical in shape. We know that the reason, because the characteristic dimension of the member is always constant in any direction for a given force. That is why they are cylindrical generally. Square also has a similar tendency, but the diagonal length of the square is much more than the side of the square. So, the character dimension will be more than the side of the square.

Therefore, square is also not considered as a equivalent structure as that of a cylindrical one. Therefore, it is not correct. Therefore, we use cylindrical. And, we also know. Generally, we use tubes; we do not use solid cylinders, because I am talking about the diameter of a very large size – 14 meter, 12 meter. One may ask me why I am bothered about the large size, because I am looking at buoyancy; buoyancy is the displaced volume. So, I have to have a larger diameter. I want more displacement volume; because the original design area including structures is buoyancy should exceed the weight; that is why we can make it afloat.

For example, TLP; you can easily transport from A to B; you afloat it, it floats automatically. So, no cost involved in transportation. You blast it, anchor it, and deblast it; structure becomes fit. So, that is the idea. Therefore, we have to make it float;

therefore, the large diameter. Obviously, I cannot have a solid section because the mass will become very heavy and I cannot have a massive system afloat, very difficult. Therefore, it is generally hollow in nature. And, I use t and I maintain D by t, which I already discussed in the last lecture what is the consequence of the D by t violation in terms of stability of the member; we know that.

Now, I have large member – diameter of the member. So, what I do in this case is I try to put an external cover to this member, which is also of course angular, which is also a tube. And, this will have a lot of perforations all along the periphery. If you look at the elevation, that is the elevation of this. Let us say I have a cylindrical member; the cylindrical member is actually anchored, because there is a pontoon here, let us say a TLP; it is anchored using a tether. Tether will have an axial tension. Now, this is my free surface or the mean sea level. We will know because of the splash effect of water, this area generally is highly corrosive in nature; the material degradation in this area becomes very faster, because it is about 60 to 70 mils per year; it is very very high. Therefore, the material degradation or deterioration is very fast.

When the material degrades, it loses its strength; we all know that. Therefore, I can call this segment of the member as damaged part – damaged part. Obviously, you will notice that, the member is not uniformly damaged, because it is not uniformly corroded; we all know that, there is a differential aeration. As we go deeper and deeper, the corrosion effect is practically 0. As you go free and free, again the effect is 0, because there is only aeration effect here. Only the wet and constant – wet and alternate dry will create more corrosion. Therefore, this area is highly susceptible to corrosion. So, there is always a possibility, the material degradation can be faster in the segment; we are not bothered about the dimension; we all know how to calculate this depending on the high tide and low tide value; we know this. Even if we do not know, let us not bother about the designer; but, we know that, this segment is important compared to this.

On the other hand, the idea is very clear here. The strength of the material at this segment is lower compared to this. So, if I have a cover which is bracketed by some arrangement and supported over here and here and the load of this cover transferred to this member at this point and this point, the member will be able to sustain that; because at this segment and this segment, the member is strong; the member is only weak here. So, I have to do a stress relief mechanism on this segment alone. So, it is foolish to cover the entire cylinder back again with the perforated member, because here and here, the member strength is perfectly okay; I do not have to cover the entire length of the member. So, only the damaged part will be circumscribed by a perforated cover. That is the idea here; the encountered force is therefore in this case; that is one reason.

The second reason is we all know from hydrodynamics so far, the force plot varies nonlinear and it is maximum near the free surface. And, as it goes down and down, practically becomes zero. Therefore, if I am talking about force reduction, I must always supply that mechanism only at the point, where the force is maximum. So, if we keep on doing it for the entire length, where there is no force; in fact, I am not doing the reduction at all, because there is no force at all. So, I must apply only in that segment, where the reduction is maximum. Therefore, second reason why I am putting the cover only at the zone is that, I want to aim at the force reduction with a unique approach in this case. That is what I already said. We are taking about force reduction as retrofitting, not strengthening of the material at all; we are not strengthening; we are not touching the internal member at all you see here. We are not touching the inner member at all. No material alteration, no cross-section area change; and, no arrangement changed. Only thing is an external member has covered over this. So, let us say cause and reduction is encountered force.

One can ask me what is this crazy idea, how this idea has come? Is it true? It has been verified in the literature. It is a very interesting stress relieving mechanism, which has got load-reduction perspective. Of course, this perspective is approached through water particle kinematics, because we all know in aerodynamics, if at all the force comes on the member, it actually comes from the velocity and acceleration of the water particle. If I can approach the force reduction by controlling the velocity and acceleration of the water particle by some means let us say, I can always reduce the force in the given member. So, the force reduction is achieved or attempted in this study through kinematics, which is hydraulic or hydrodynamic let us say; it is not structural dynamics.

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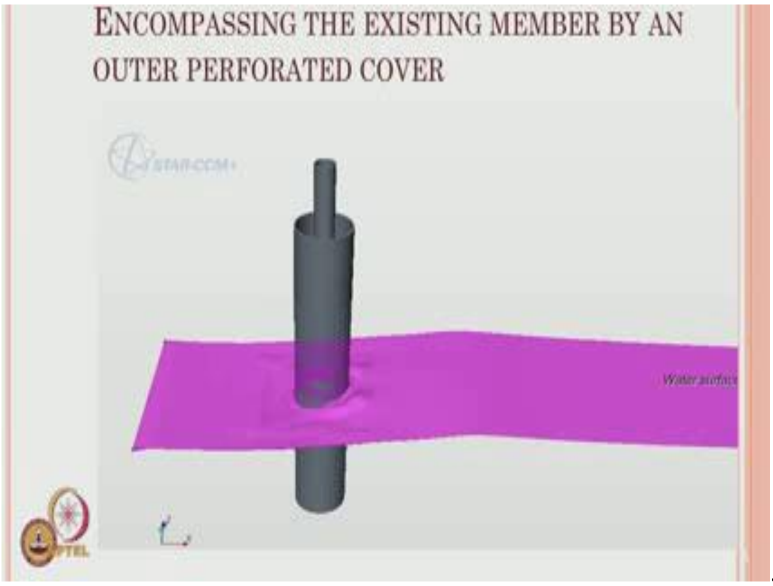

Now, one can ask – what is the existing damage in member's perception? Let us say I have a member, which is damaged. I am now covering it with the outer perforated member, which is both of the cases an equivalent model; numeric model is generated in star CCM as you see in the cylinder. I will show you a video subsequently later how does it react. So, water surface, water plane area is completely captured, modeled with a free surface boundary; where, the boundary effects do not influence the water particle kinematics in the given member.

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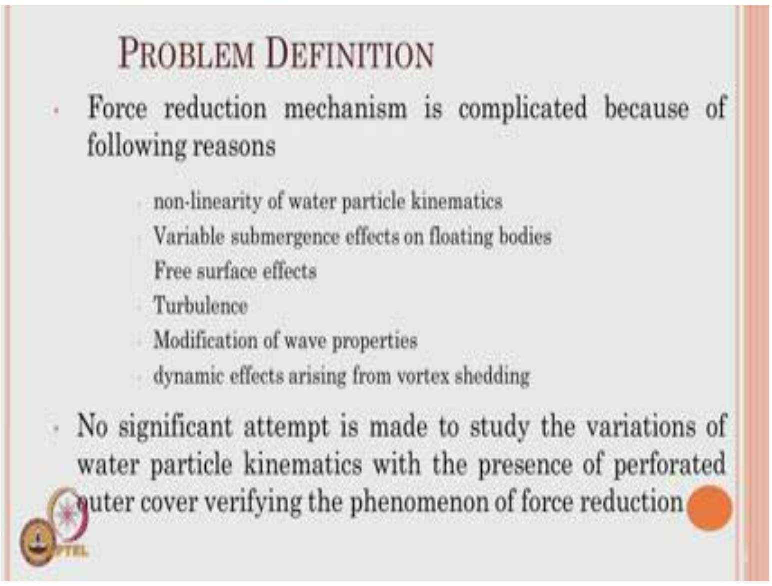

Let us quickly see; let us define the problem first – what actually we wanted to do. Force reduction mechanism is complicated because of many reasons. Let us see what are the reasons; why are they complicated? I am talking about the force reduction mechanism – how the force gets reduced. It will get reduced; one can ask me a question; obviously, when I put a cylinder, a cover over this, the force on this cover will be – in this member will be practically 0, because if this is completely impervious, this member will have no force at all. So, obviously, when we keep on putting an annular ring one over the other, the inner core will be perfectly protected. So, it is well understood psychologically and physically that, force reduction is always through and is guaranteed when we put a cover. But, the mechanism is complicated; it is not that simple, because there is extreme nonlinearity in the water particle kinematics. We all know Stokes fifth order, third order; it is very highly nonlinear. So, when it is nonlinear, you cannot really find out the force reduction mechanism so easily – one.

Two – my cylinder may be floating, may be fixed; if it is floating or fixed let us say; even if it is fixed because of the variable submergence effect, the alternative wetting and drying, high tide and low tide, I will have a variable submergence effect especially in floating systems. There is something called free surface effect. We saw already in the last lecture that, free surface effects are more dominant when the cylinder is kept either horizontal or vertical; there is a vertical shear happening. We have already seen that in certain cases, where the v a b will be very severe in the free surface effects, which we already saw. So, free surface effects will play a role. Of course, turbulence, because we are creating – we are putting a cover and it influences the inline flow direction. So, the annular space – if at all by any chance water gets in – water gets in by any chance, will create turbulence. That is one another problem. So, we will not allow the force reduction mechanism to become as simple as you see.

And, it has been also verified in literature that the wave properties get modified. They get modified because we already saw in the last lecture D by l characterization will modify the wave characteristics. Obviously, when you say this is my D by l for which originally it is designed; when this D is larger than this; obviously, the wave modification will happen, there is no doubt. As I suggest now, water shedding effects will also create dynamic effects in the system. And more interestingly and most importantly, there is no significant attempt made in the literature; I will show you in the next slide.

To study the variations of the force mechanism through the water particle kinematics in the present state, people have all agreed that when you put a perforated cover outside the circumscribing a given cylinder, force in the cylinder inner will get reduced; people have shown that. I will show you in the next slide what all literatures supporting this. But, none of them have verified this using water particle kinematics. They have verified this through some other mechanism in terms of design; in not in terms of hydrodynamic analysis. So, therefore, the study is of course, novel. And, when you anyway propose any novel idea for retrofitting, verification, validation becomes important. So, in this study, we have verified, we have validated also; I will show you what verification we have done and what validation we have done.

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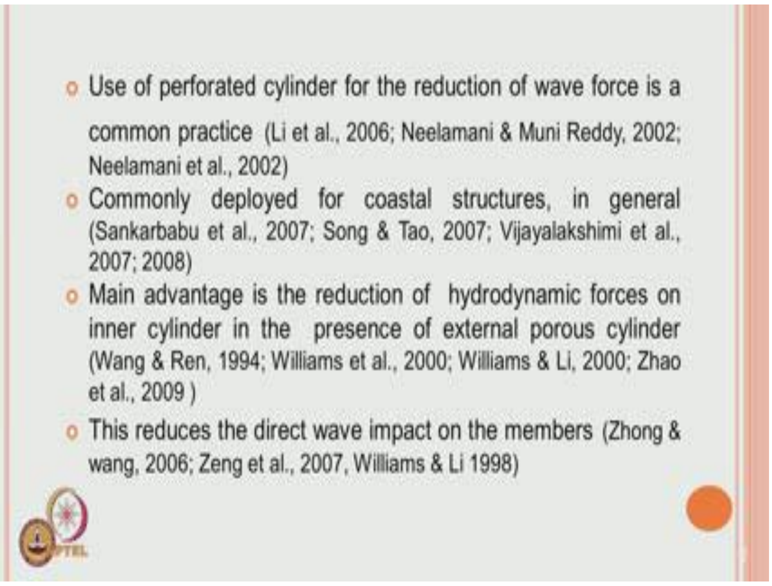

Now, foremost problem is let us quickly see what literature says about this, because we have to have an idea; we cannot propose anything new concept in research unless otherwise people have thrown a clue on that. Now, the clues are here. Use of outer perforated cylinder for reduction of wave forces is a common practice; people have said that – li et al., Neelamani; people have said that they have commented that, yes, it is a common practice can be done. Secondly, they are commonly deployed for coastal structures, in general. People have used them; again Shankar Babu, Song and Tao, Vijayalakshmi have proved experimentally and analytically, for coastal structures, this is true.

Now, what is the difference between applying this problem in a coastal structure and that of a TLP or a floating system? Water depth; the moment I say water depth, the moment I say D by l, the moment I say wave salinity and H by L values, all characterisation are different for a deep water to that of a shallow water, where the coastal structure is fixed – number 1. Number 2 – the mechanism can become higher, because in coastal systems or coastal structures, the force envisaged by the cylinder may be much lower in terms of magnitude compared to that of deep water waves. Therefore, you cannot actually attempt the same system as you apply here, because in this case, the force magnitude will be much larger. So, the design should be of a different order. Idea can be borrowed, but the design should be of a different order. So, let us catch that point very clearly here.

And, the main advantage is reduction of hydrodynamic forces in the cylinder in the present of external porous cylinder; people have already said. Wang and Ren said, Williams et al., proved it and Zhao also showed it in literature that, yes, when you put an outer perforated cover, there is a force reduction – hydrodynamic force reduction happening in the inner cylinder. Remember, all of them study the force reduction and verify – in a inner cylinder, there is a reduction. None of them study what happened to the force in the outer cylinder; they are not bothered about that.

Please do not ask a cross question – what will happen when the outer cylinder fails? Very simple; the outer cylinder fails like a bangle, you can replace it. One can ask me a question – why it cannot be done for an inner cylinder? Inner cylinder is not a cylinder; it is a part of the system actually. You cannot replace the member in a given system; it is very very difficult; you have to shut down the platform, if it is a working platform. So, it is not easy to replace a member in a commissioned system; whereas, replacing a cover in a commissioned system can be easily done. So, replacement is possible. So, if the external cylinder is damaged in due course of time because of corrosion effects, etcetera; then keep on replacing them without bothering much about the inner member, which is the original part of the structural system; that is the idea here.

So, main advantage is reduction of hydrodynamic force; people have already verified this. Therefore, these literatures review very critically viewed shows an advantage and confidence to the researcher saying yes, force reduction is possible by this idea. How to model this; how to verify it; how to validate it; becomes a problem. Let us see that. And, Zeng et al and Williams Li, 1998 also said, it reduces direct wave impact. So, that is very important, because generally if you divide the forces coming on the system, radiation, diffraction, direct effect inline forces; the inline force concepts are mapped into much larger than the remaining one; it reduces direct wave impact. People have already said that.

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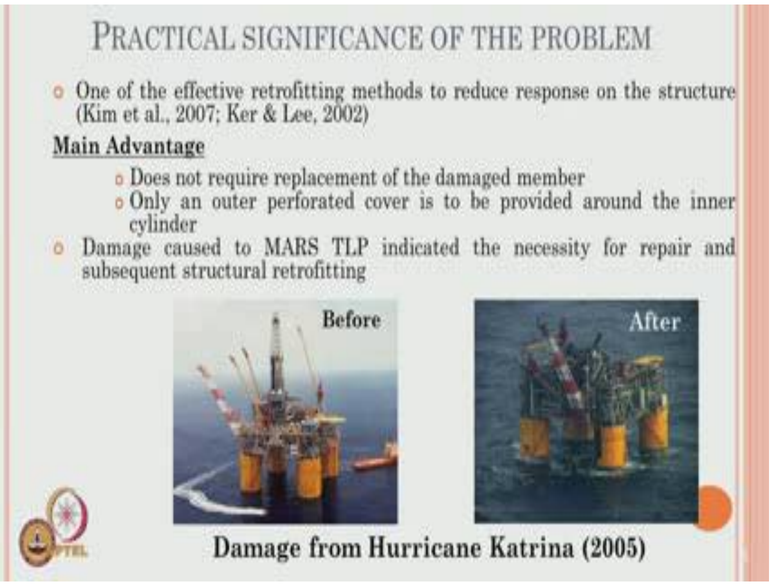

Now, the question is – what is the practical significance of this problem? Is it important? Where to apply? Look at this particular TLP, which is actually the mars TLP constructed; I will give you the status in the next slide – constructed and commissioned; production capacity will give you an idea. We can see two slides are shown now – two pictures: before Katrina hurricane, 2005; and, after – you see the top side is completely damaged. We must understand two things here. One we are not talking about the safety of the platform at all at this moment; we are talking about the destruction of the electromechanical equipments, which are dedicatedly designed for this system. Please understand – all these electromechanical equipments are dedicated unique for a given platform; you cannot reproduce them back again so easily. Now, this hurricane Katrina, 2005 has shutdown this platform – mars TLP for close to one year.

Now, one may ask me a question – what is the commercial importance of the shutting down of the platform for one year? If you know what is the production capacity of the platform; if you know the construction cost involved in the platform of repairing it; if you know what is the money and time spent on repair; then, you will really notice and appreciate – had this would have been avoided, it would be a better idea. Now, let us see the statistics now. So, retrofitting has been attempted. Kim et al and Ker Lee has said that, retrofitting method is impossible – possible for this kind of platform. The main advantage – if you attempt a retrofitting method for this platform is that, you must always show and ensure that, no replacement of the damaged member should be done; because if we are attempting to replace the member, today you will replace a leg A, tomorrow you have to replace leg B. It is very impossible. Therefore, it is practically constructing new another platform.

Now, see in this particular damage, legs are perfectly okay; only the top side is damaged. Now, if the legs are damaged, which will be more severe; then, the platform would not exist there. So, the damage member replacement is not an idea; should be avoided to only an outer perforated cover can be provided around the inner cylinder, which can reduce the forces on the member. Now, the damage causes to mars TLP initiated the study and retrofitting was attempted on this.

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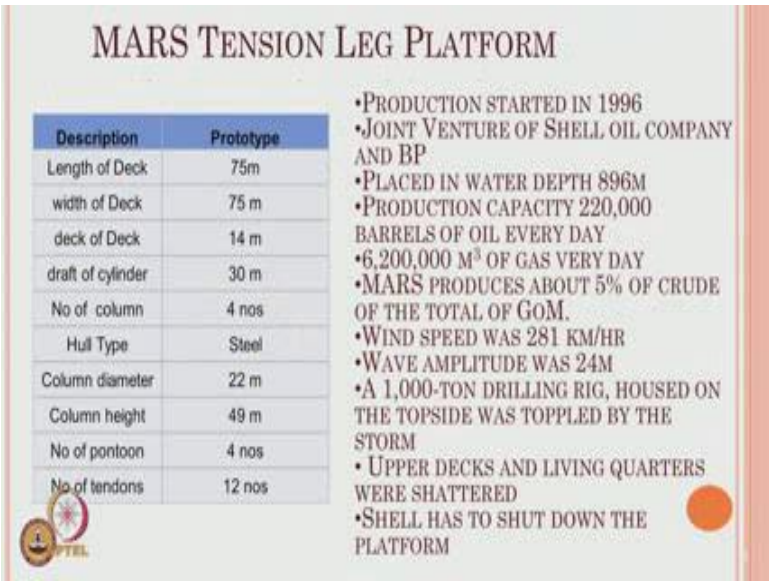

Now, let us look at the status of mars TLP; look at the right side of the slide. The production of this platform started in 1996. Katrina came in 2005 closely about 10 years – within 10 years. It was actually a joint venture of shell oil company – BP. It is located in the water depth of 896 meters – one of the deepest platforms in Gulf of Mexico. Very interestingly, the production capacity is 220,000 barrels of oil everyday and about 6,200,000 cubic meter of gas everyday. If you look at the statistics, mars TLP alone produces close to the 5 percent of the crude oil of the total Gulf of Mexico. It is a very important platform. Shell was earning lot of money and commercially (Refer Time: 22:20) platform was one of the flat platforms for their revenue. Wind speed at Katrina was about 281 kilometer an hour. It is unimaginable; you will understand; no courses will advice you to design a system for this wind speed.

Nobody would have designed it for this wind speed at all, because 281 kilometer per hour is terribly a very high unimaginable wind speed. That is because of the hurricane came. And, the wave amplitude is 24 meters; you see significant wave height what we design generally in offshore platforms, is not exceeding 15 meters – 1 5 for a design retaining period of 50 years; whereas, here the amplitude is 24 meters, which is unexpected. So, the natural forces or environmental forces coming on the system are highly unpredictable by a designer. In such situation, obviously, damage is sure. The damage was so severe that, about 1000 ton drilling rig was completely uplifted by the hurricane; it was thrown away totally by the storm.

And, upper desk in living quarters completely got shattered, which you saw in the photograph. And, shell ultimately had to shut down this platform for close to one year – 300,000 man hours were involved in repairing this. 1 man hour in offshore is equivalent to approximately 8 to 10 man hours on onshore; whereas, the cost there is very very high. Shell has to pay through the nose to repair this. There is no question of waving off the platform, because it was one of the deepest platforms; it is giving a very promising output of oil and gas production. Therefore, they cannot leave it off and they cannot get along with this, because the whole top side is damaged completely. They have to repair it. Replacement is impossible, because again they got to shut down for replacement. So, the prototype is about this – 75 meter is approximate length of the deck and water depth is about 896 meters, 4 columns, hull type steel, column diameter – 22 meter – very large diameter; column height about 50 meter; pontoon number – 4, and tendons are 12, that is, 3 each.

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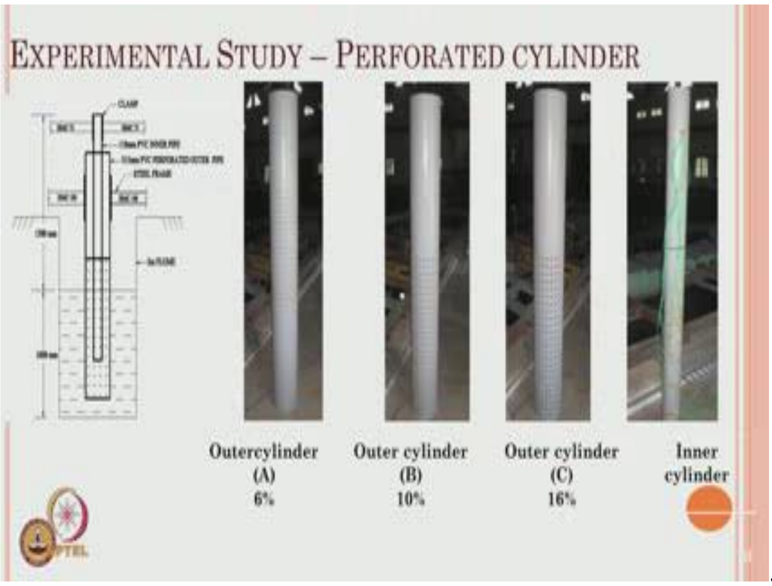

So, now, borrowing this idea, an initial experimental study was conducted on a laboratory scale, where putting an outer cylinder for different perforation ratio of 6, 10, 16 and etcetera. Different percentages were attempted. One can ask me a question – what is this window starting from 6 to 16. In the previous literature, people said, beyond specific percentage, the larger the perforation, the lesser the reduction, because it will become open; it will become completely transparent; the force will attack the inner member directly. Therefore, one has got to always see the window and try to attempt the percentage ratio lesser than and more than the window.

Let us see what is the influence of that particular character on the dimension. So, here single cylinder was taken; the arrangement of experiment is shown on the left-hand side tested string gauge are put all along force were measured on the inner cylinder, because the one which you see in the last right-hand side of the inner cylinder, which is having no perforation. So, the force mechanism measurements are put on the inner cylinder and it is put as an outer cover; and, inner cylinder forces were directly measured in the experiment.

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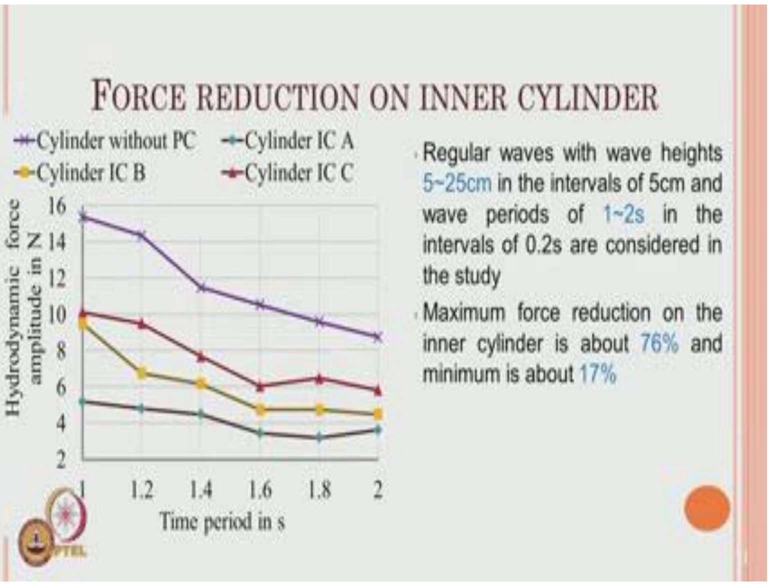

When we see that, the results very clearly shown here for different cases; there is an inner cylinder without perforated cover; PC stands for perforated cover with three configurations: inner cylinder A, inner cylinder B, inner cylinder C. They are of different perforation ratios of 6, 16 and 10 etcetera. You will see that, obviously, the one which you show here is without any cover; the one of these three are all with cover; you will see there is a significant reduction in the force amplitude measured experimentally for all the width of time bands of two seconds through one through. When you put a cover, there is a reduction. So, now, this experiment gave indication – verification that, yes, whatever people stated in the earlier literature is true. And, we also measure the reduction is close to about 76 percent maximum and about 17 percent minimum. So, you will get some reduction in the force.

Please understand the inner configuration of the material is not disturbed; cross-sectional area is not changed. And, arrangement of the member is not attempted to change at all. Only a cover has been put and force is reduced. So, therefore, it is a new attempt, where the force reduction is tested in terms of retrofitting of the member. So, this gave an idea that, there is a through one through reduction for the entire scale of 1 to 2 seconds. Why 1 to 2 seconds? Because this is a window at which this particular wave period in reality will act on a given mars TLP.

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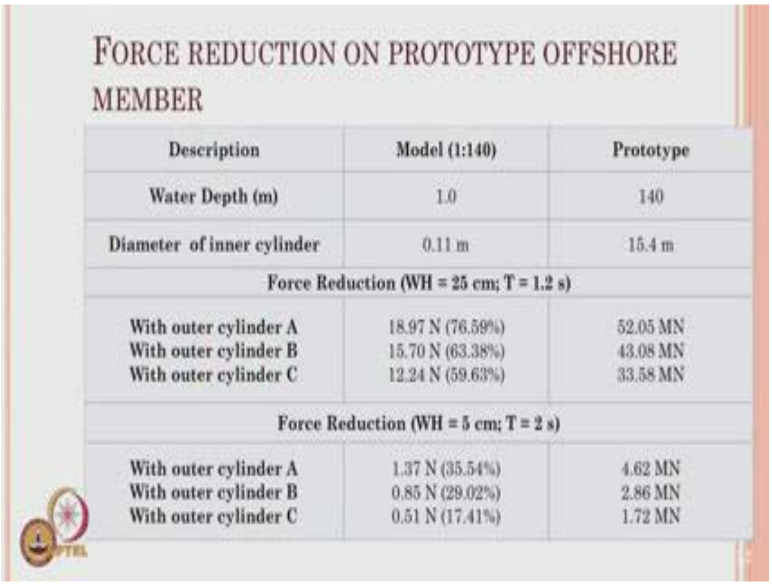
FORCE REDUCTION ON PROTOTYPE OFFSHORE MEMBER

Description	Model (1:140)	Prototype
Water Depth (m)	1.0	140
Diameter of inner cylinder	0.11 m	15.4 m
Force Reduction (WH = 25 cm; T = 1.2 s)		
With outer cylinder A With outer cylinder B With outer cylinder C	18.97 N (76.59%) 15.70 N (63.38%) 12.24 N (59.63%)	52.05 MN 43.08 MN 33.58 MN
Force Reduction (WH = 5 cm; T = 2 s)		
With outer cylinder A With outer cylinder B With outer cylinder C	1.37 N (35.54%) 0.85 N (29.02%) 0.51 N (17.41%)	4.62 MN 2.86 MN 1.72 MN

So, we looked at the force reduction in terms of percentage for different wave height and wave period varying from 25 centimeter to 1.2 seconds on lab scales. You will see that, the reduction anywhere varies from 17 percent as low as that and as high as about 76 percent, which we stated in the previous slide also. So, you will get about a good interesting promising reduction of force measured on the inner member directly using a force transducer.

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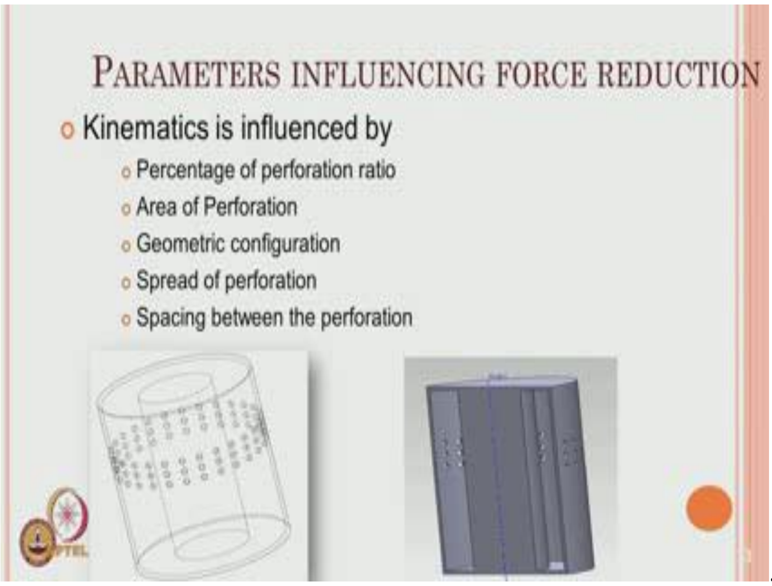

Now, after we understand there is a force reduction, one should also know what are the parameters will influence this force reduction; because the parameters to be identified, then only one can work about these parameters. We have to identify also which of those parameters are more important, so that they can be addressed. Now, kinematics is then influenced by different parameters: percentage of perforation ratio, area of perforation, geometric configurations, spread of perforation. Geometric configuration means we talk about the annular spacing; annular spacing with respect to the diameter. Then, spacing between the perforations, location of perforation etcetera, different models have been done.

Now, then the question is – when you want to attempt so many parameters influenced in the force reduction; obviously, you cannot conduct experiments, because equipments will have a scale limitation. The experiment what I showed you is about 1 is to 140 scale. You see here this is another very very crude micro scale of looking at the reduction. I want to actually look at the reduction 1 is to 1 scale really speaking; which I cannot do an experiment of 1 is to 1, but I must go as close as possible; obviously, I cannot go close possible in experiments. So, obviously, I will have to land up in the numerical study. So, the shift of the study moved from experimental verification to numerical analysis. So, star CCM was the tool used for numerical analysis.

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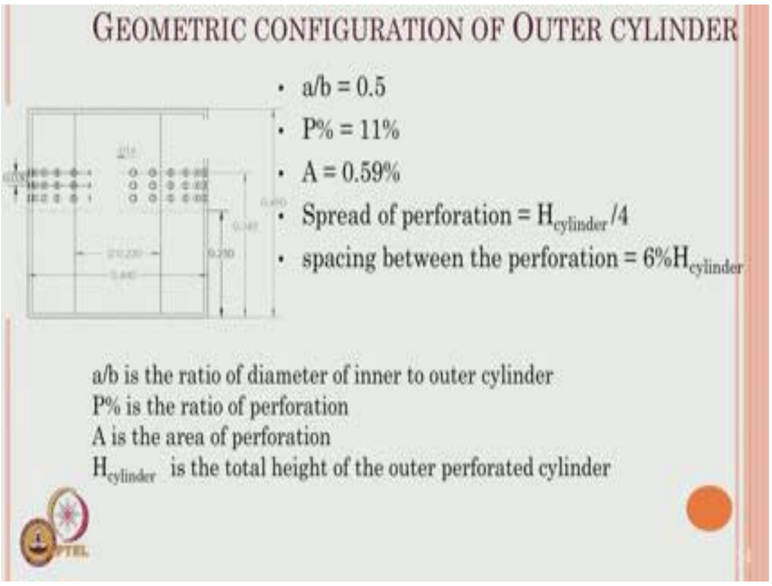

There are many good reasons why star CCM was chosen; we will anyway exclude those discussions at this moment in this lecture. However, you can look at the papers published in this topic; you will get more idea. So, the geometric configuration, the physical dimensions of the member are given here; which has been shown. So, as I said, a by b, that is, annular ratio versus the diameter is taken as 0.5, which has been one of the chosen parameter as identified by the existing researchers. P has been taken from anyway from 6 to 21 percent; 11 percent was attempted; and, area of perforation was taken to be – A is area of perforation is taken to be 0.59 percent; spread of perforation is about one-fourth of the cylinder and spacing is about 6 percent of the cylinder; where, H of the cylinder is only height of the outer perforated cylinder.

Please understand – if you have got this as H and this as H, I am here talking about only this H. So, in all these characterization, the original dimension of the inner member is never touched as a data; it means the study has no influence on the variation of the inner member: thickness, inner member diameter – nothing except only one connection – a by b; a by b ratio is the only connection. Once you maintain this, for any inner member, you put this design; you must get the force reduction. That is the idea. It means – this is the more general feature; does not only work at mars TLP any member of any diameter x can be attempted to do this, because all are now parametric definition, they are not absolute values.

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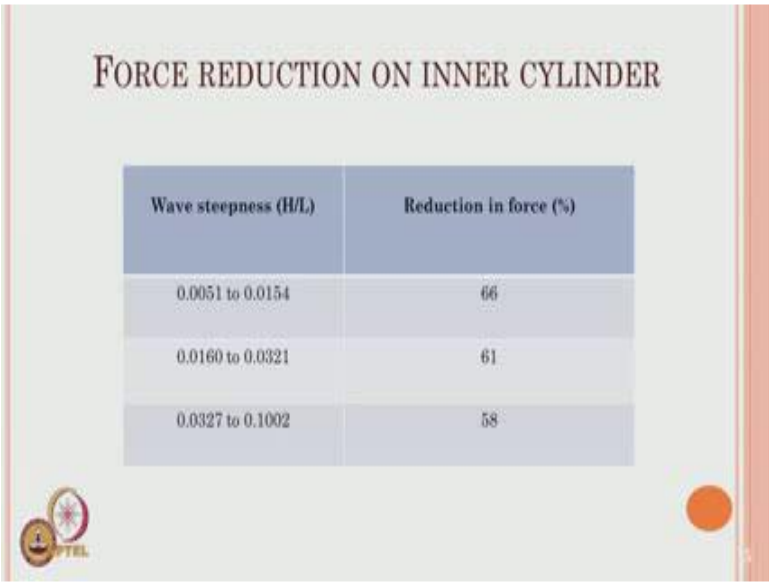

Now, the question comes when we talk about particular study in terms of deep water applications, because coastal – people have already done; shallow waters – people have already shown. But, in deep water application, we have to see whether this will work out for every wave steepness, because wave steepness is one of the important characteristic, which will influence or let us know what would be the characterization of the deep water forces in deep water on the structure. Say HBL has been configured varying from the lowest value of 0051 to the highest value of 0.1. A range has been done; that has been divided and classified as let us say a low, medium and high wave steepness.

And for all the categories varying from 0051 to 0.1002 for different incremental intervals, the numerical studies have been carried out. For all these data of varying a by b, varying P, varying A, varying spread of perforation, varying location of perforation; all has been done with the good amount of combination. And, for this particular case, we have seen that, the force reduction still verify the variations about not less than 58 percent. So, this very clearly shows a promising understanding a numerical analysis also that, the wave reduction – force reduction on the inner cylinder is close to about 60 percent, which is also verified experimentally for a single cylinder though at the scale of 1 is to 140; but, here the scale is 1 is to 10. That is very very close.

One can ask me a question – why 1 is to 1 cannot be done? If you do 1 is to 1, the Reynold's number will be a problem in the analysis – 1. 2 – you get meshed dimension in CFD out of bound; computer cannot do the analysis. So, close to 1 is to 10 it was attempted; 1 is to 1 cannot be done for this specific case. So, it has been also verified and seen about close to 60 percent reduction is still verified and guaranteed in the given design.

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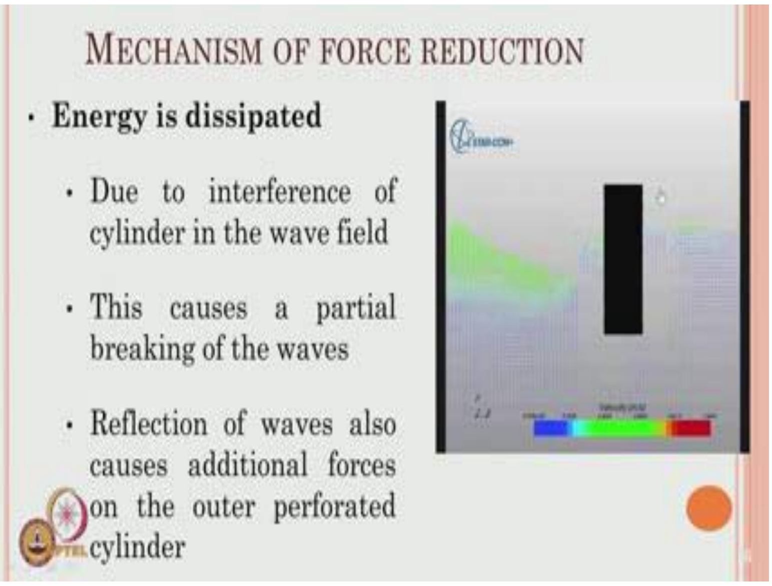

Now, the question comes on the engineering perspective, what would be the reason for this reduction. Though we have verified it experimentally; we have seen through the force transmission; experimentally verification is done. Numerically, we have also shown – yes, reduction is happening. But, physically as an engineer you want to percept and understand, because the design engineer will not believe by any curves, etcetera. So, this was shown.

If you see the video quickly here as the water particle red one enters, the outer one what you see here; I think you will be able to see that; there is a – there is a divider line available here; you can see that; that is a perforated member; that is a perforated member. As the red particle enters and hits the perforated outer boundary, the velocity should stop instantaneously. Then, it enters through the perforation and dies down, because it goes and hits the inner cylinder and returns back. The returning velocity dissipates entering velocity and stops the entering particle from the annular spacing. So, that is how physically the force is stopped coming to the inner member.

Now one can ask a question interestingly, what will be the pressure distribution in the vicinity of the perforation; can it break the outer cylinder completely? We have also studied the particle (Refer Time: 33:34) image velocimetry around the perforation, through the perforation; I will show you in the next slides. So, it is not creating a pressure distribution of that order, which will break the outer cylinder. So, the mechanical verification is very clear; energy is dissipated. Therefore, force is reduced. How it is dissipated? Due to the interference of the cylinder in the wave field, this causes actually partial breaking of waves within the spacing, there is a breaking of wave happening. The water particle gets broken and the return velocity of the particle stops further entry of (Refer Time: 34:08) particle. So, the reflection of waves also of course causes additional forces on the outer cylinder; but, as I said, the design of the outer cylinder is again an important major concern in the whole analysis.

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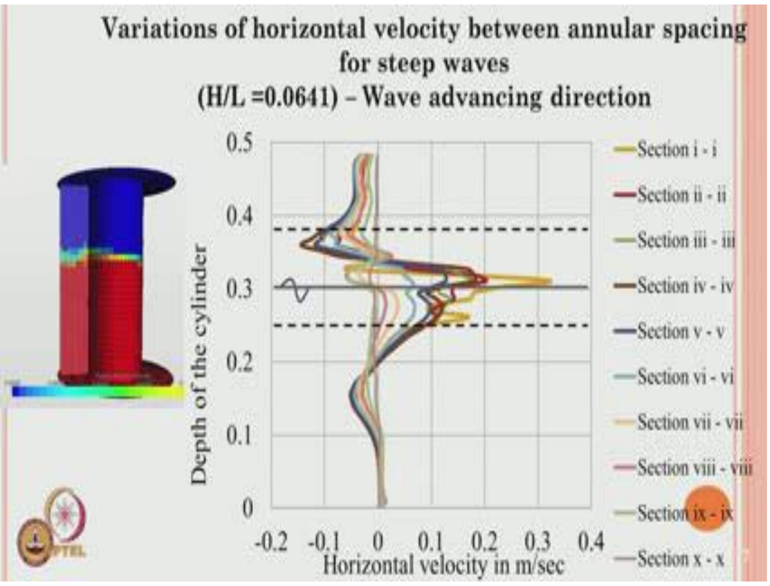

So, if you look at the water particle variation; because as I said, I want to know the force reduction through kinematics, not by any physical understanding. Kinematics means I want to look at the horizontal water particle relaxation velocity. Once I know the velocity, you can always find the acceleration. So, because it is continuous in time domain, I can always find the acceleration; we know the velocity. So, we were interested in looking at the velocity variation along the depth of the cylinder – along the depth of the cylinder for different parameters. Now, to do that, it is very interesting that, I do not also want to know only the force reduction at the section 1 1; but, I want to know what is happening within the annular spacing, because I want to actually categorically view and show – is it really decreasing or increasing and decreasing; what is happening in the annular spacing I want to know.

Now, the question comes very foolishly that, can I narrow down this annular spacing. For example, can I put this cylinder touching this? Because that should also be answered, to answer this, I must know that, characterization of the water body velocity variation within this spacing. So, we again did close sections 1-1 is the section what you see here near the inner cylinder. And, 10 times is near the outer cylinder. In practical dimension 1 is to 1, this is only about hundred millimeters. So, I can take about 10 millimeter – 1 centimeter equal intervals of section and plot it. You will obviously see the section 10-10 is the brown one; I think you will be able to see this in the graph clearly; I do not know the color is not very deliberate.

I will show you that. This is the section 10-10; this is what we see here. So, practically when it goes to the inner cylinder, the velocity is practically zero – horizontal velocity – we are talking about horizontal velocity only – 0; whereas, the variation is highly nonlinear, which was already told in the previous slide. There is very high nonlinearity in the water particle kinematics – very highly nonlinear. Therefore, very importantly you cannot characterize this force variation by any equation. You cannot neither form; you can neither form an empirical relationship to characterize this force reduction nor you can experimentally measure this in the scale. So, we can only characterize this force reduction by velocity. The moment I know the velocity variation, I can always write an equation using Morrison’s equation to use this velocity at any point and calculate the force whatever I want as a designer, which was not present in the literature as on today.

Because all experiments, all validations done; where, only on a physical scale; where, people say force reduction of so percentage is done; but, how it has happened, not explained. How this can be perceptually used on other design? No clue; they were all case specific. Now, this is more generic, because I give – we give a water particle kinematic variation for a generalized data. So, if I know the velocity variation, I can always find the force; which I also did. I will show you that later. So, again what would happen if the inflow field is dissipated, radiated and diffracted and rotated?

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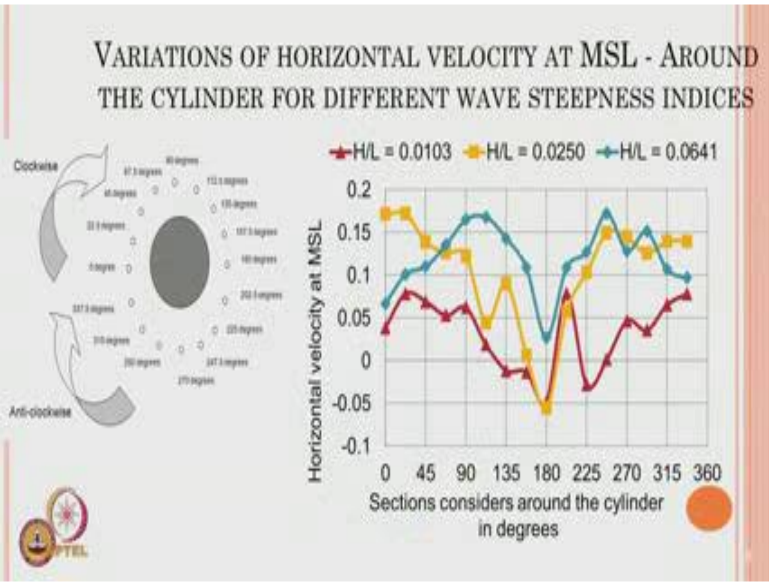

And so, a study circumferentially on cylinder is also done for different angles varying from 0 to 90, both wise; so, 180 and till 270. So, it passes, leaves – what happens. You will see that the variation is maximum at 90, again dies down and again maximum at minus 90. So, these are the two segments, where the reduction is maximum. These are the two segments, where the reduction is becoming maximum. As it passes, the reduction is not there; that is the idea, which has been verified by the circumferential study. This has been again done for different wave steepness indices varying from low, medium and high, that is, from 0.103 etcetera.

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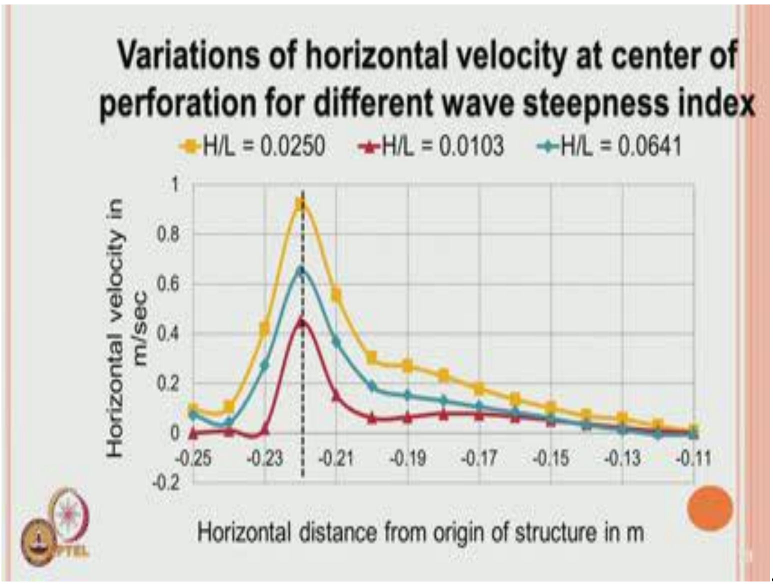

So, we can also characterize the horizontal water particle velocity at the center of perforation – at the center of perforation itself – at the center of perforation any hole you take, center of perforation; try to see what would be the variation. So, the variation is shown from 0.11 to 0.22. This value is at 0.22. This is actually a 0.22 value; this is 0.11. So, 0.11 actually is here and 0.22 from the center is here; one can ask me why it is minus, because this is the progressive direction of the wave; this is measured this way. And, we all very clearly know as we move this way, the effect of this velocity and reduction will be 0 here.

That is what we have also seen in the previous slide. So, we are interested in mapping the variation from 0.11 to 0.22; not here, here. So, this variation is also mapped; you will see that, at the outer cylinder, the velocity is maximum as it goes to closer to the inner cylinder, practically it becomes 0. One can ask me a question how the velocity is becoming negative. How the velocity is becoming negative here? Because there is negative also here; this is not negative actually; this is the wave trough and crest of the wave.

We really do not know whether the wave hitting the outer cylinder is a crest of the wave or the trough of the wave. Therefore, you may get anything as you capture, as you pass the velocity. And, this has not been taken at any random time scale, not either at the start of the wave nor at the end of the wave; any random during that cycle generation, any random scale you take and see. So, you see the variation is highly nonlinear. All H by L indices show the maximum forces only on the outer cover; all of them show 0 at the inner cover or inner cylinder. Velocity I am talking about, not the force here. Still we have not gone to the force.

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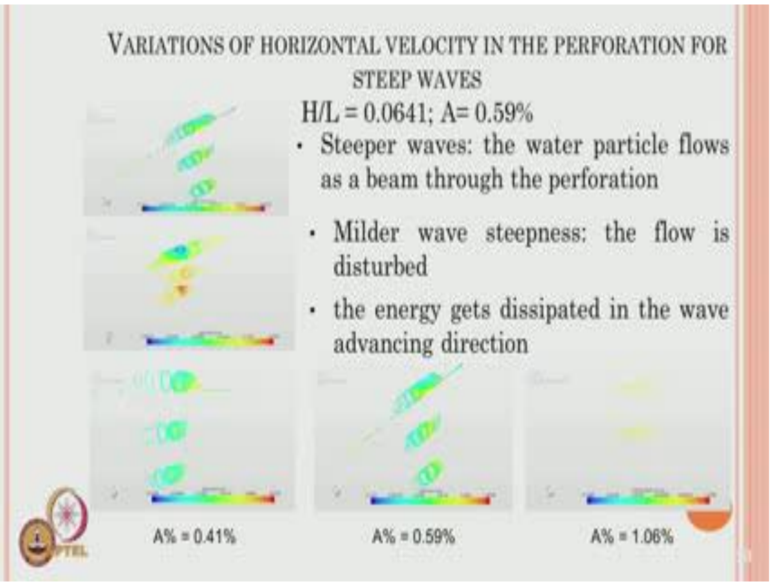

Again this has been done for different perforation for steep waves also. Steeper waves, mild steeper waves and etcetera. Of course, this variation was not very promising when we go for steeper waves. We also tested different area perforation varying from 0.41 to 1.06, because that is the literature window, which people have attempted already. Therefore, it has been tested.

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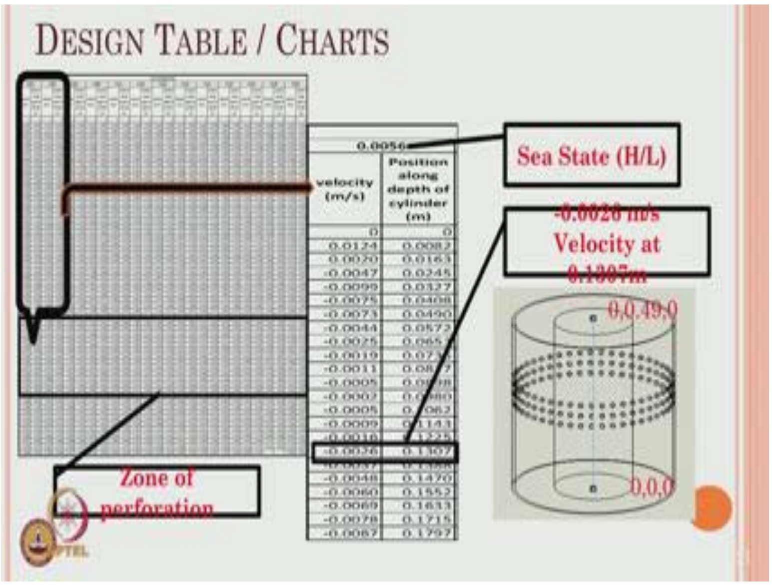

Interestingly, the whole exercises have been converted to a simple analytical design tool in terms of design charts. Now, because if I – as a designer, I want to know what should be the configuration of the outer diameter viz a viz the inner one. For the maximum force reduction of the inner one, I do not have to really do a mathematical model of this, do star CCM and do all the simulations back again and find the force. I must have a design chart telling me for a specific value of so and so, how much should I; because for example, I fix up my perforation ratio as 10 percent; fix up my area of perforation as 2 percent or 1 percent. For the design chosen value, what is the force available here I must know that. So, we come back to the design charts.

So, these design charts are plotted for all possible cases; one window is enlarged and shown you. If you know the sea state for your particular problem, let us say 0.0056, you-can always find out the velocity – horizontal water particle velocity at any point of your choice. For example, in a given cylinder, you want to know what is the velocity at this point when you put a cover of your choice; you will know this from here directly without doing any numerical analysis. So, directly it is available. Once you know the velocity, you substitute Morrison equation and get the acceleration, get the forces and design the system. So, it is very easy. So, this has been considered as a design chart. This is a direct visible output for the researcher as a design engineer.

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FORCE EVALUATION ON THE DAMAGED MEMBER WITH PERFORATED OUTER COVER – NUMERICAL STUDIES

Wave period (s)	Wave Height (H)				
	5 cm	10cm	15 cm	20 cm	25 cm
1	3.89 N	7.25N	11.68N	-	-
1.2	3.62N	5.96N	8.46N	10.05N	11.58N
1.4	2.75 N	4.74N	7.44N	9.57N	9.98N
1.6	2.15 N	3.79N	5.37N	6.96N	7.54N
1.8	2.04N	4.04N	5.31N	7.09N	8.64N
2	2.30N	3.66N	5.36N	6.16N	7.14N

So, force evaluation is done using a numerical study. It has been shown also that, for different waves; because now one can ask me a question what is the fun in doing a numerical study on a sole low wave at 5 centimeter and 25 centimeter because the prototype is in meters.

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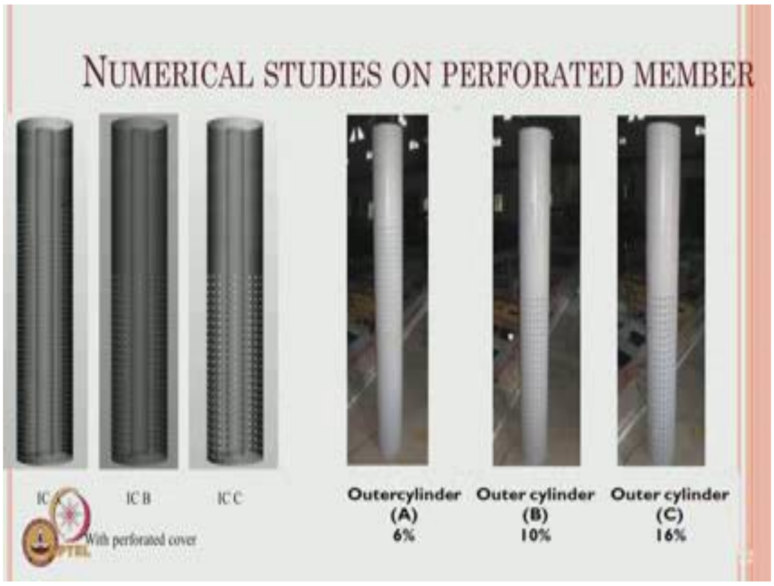

We have validated this parallelly with that of the experiment, because experiment is done only in a scale of 1 is to 140. So, the same numerical study is repeated 1 is to 140 just to check whether results are obtained from numerical analysis are same as that of the experiments. So, it has been done on the same case with 6, 10 and 60, which I showed you beginning.

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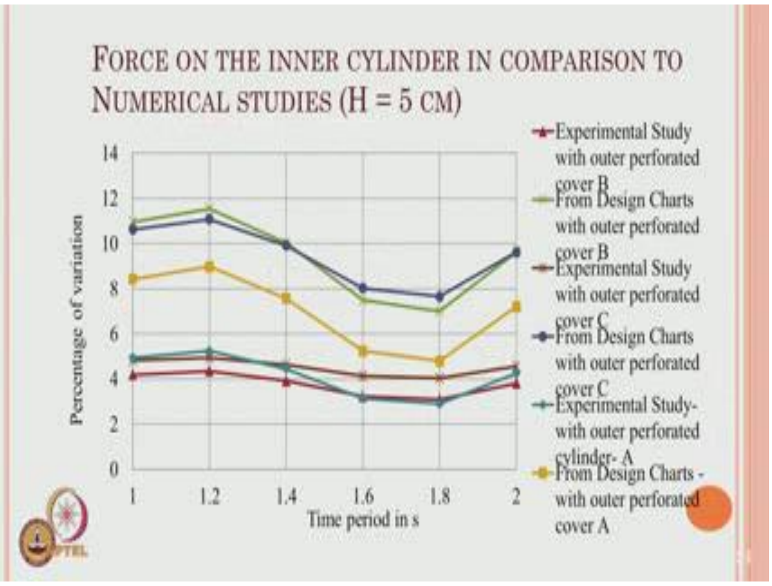

Forces have been plotted; they have been agreed upon clearly that, if you looked at let us say – let us take this value the one here, the one here; the experimental study with the outer perforated cover B plotted from design charts; they are closely matched; they are closely matched. Now, the question is when you talk about the values plotted from the design charts and experimental, on certain cases, they have differences; on certain cases, they have lower differences. So, they do not agree for the entire range of the time period. So, then we have to classify under what wave steepness regime, they closely agree and you can use the design chart; on what regime, you cannot use the design chart. Because it cannot be used for blindly from any value from 0.0051 to 1.06; you cannot use that. So, we have to classify that. So, the variation is not uniform; somewhere the difference is minimum, somewhere the difference is maximum.

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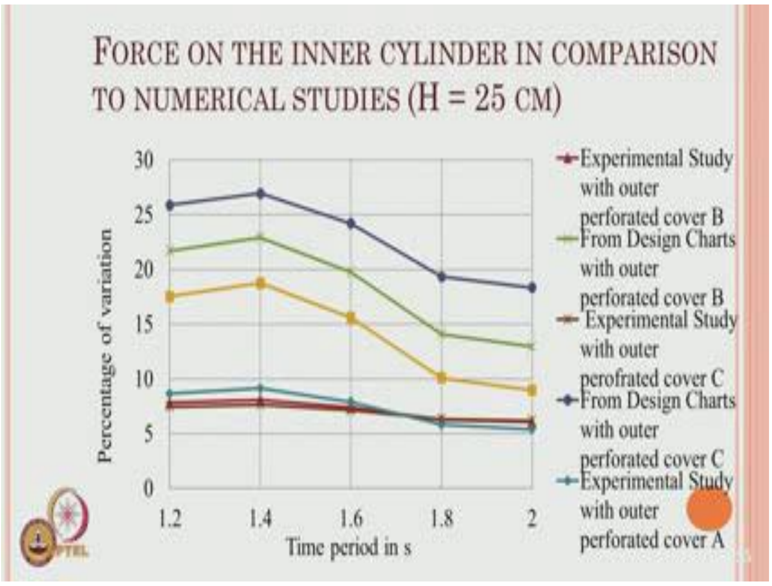

Which is shown for different wave height also; it has been validated.

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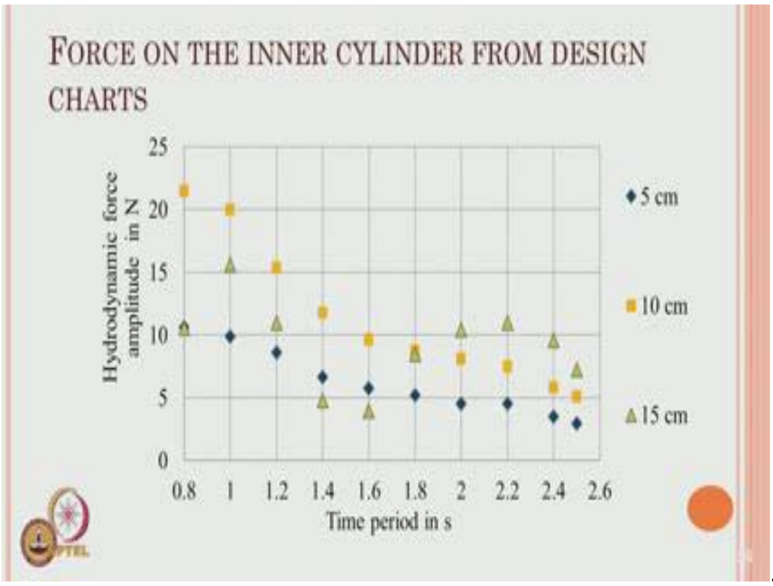

We have also plotted the force now directly from the inner cylinder from design charts for different waves in terms of amplitude in scale model.

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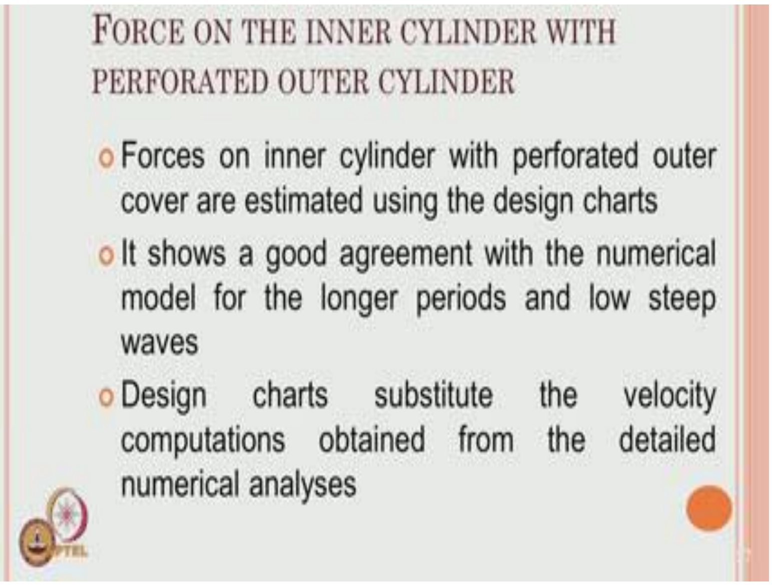

Then, force on inner cylinder with perforated outer cover estimated using design charts. It shows a good agreement of the numerical example for a longer period waves and slow steep waves, not for all. Therefore, it is found that, the design charts are substitute; the velocity computations obtained from the detailed numerical analyses only for the specific range of values.

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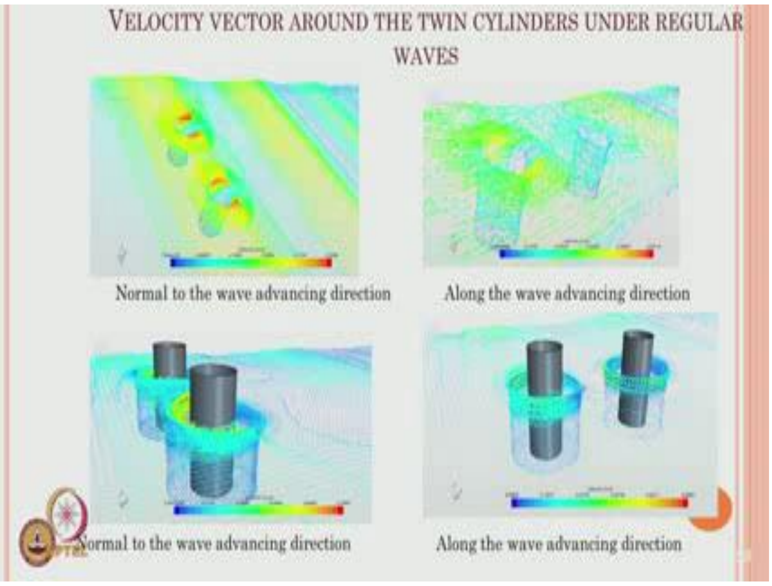

Subsequently, for a wave advancing direction, thin cylinders were also used, because we want to know what is the effect of the inner – the spacing between the members in the wave (Refer Time: 44:21) direction. So, twin cylinders have been used. So, it is then simulated; and, wave along direction and normal direction both have been simulated; studies have been done.

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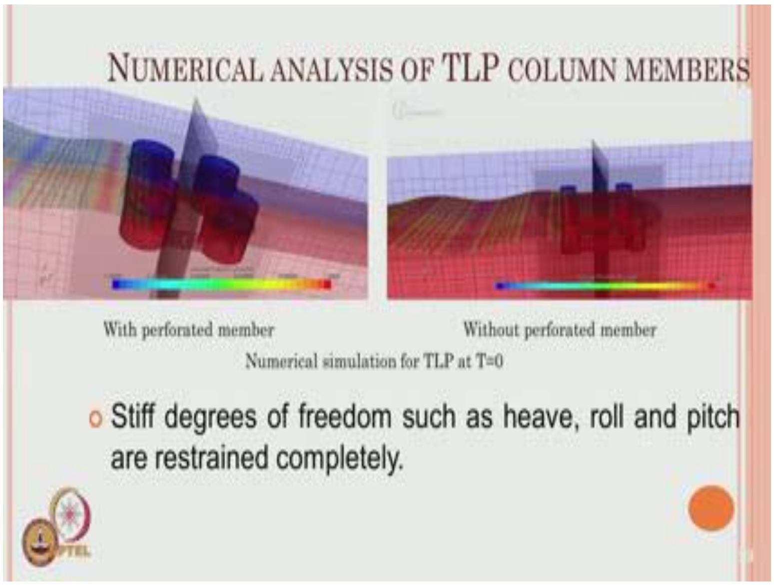

Then, they have been done on TLP column members with and without perforation at instant time T is equal 0. Simulation has been done. Results have been obtained. When you do an analysis of TLP, for example, a star CCM, which is not actually an aerodynamic analysis or structural analysis for TLP. The stiff degrees of freedom like heave, roll and pitch are restrained in the analysis. One may say this may cause some imperfection in the analysis; but however, this is the only way how you can map this directly in star CCM. Then, if you want to know really why star CCM was used for TLP; because all other results were developed in star CCM. Therefore, we want to compare it in star CCM itself; that is the idea why it has been done.

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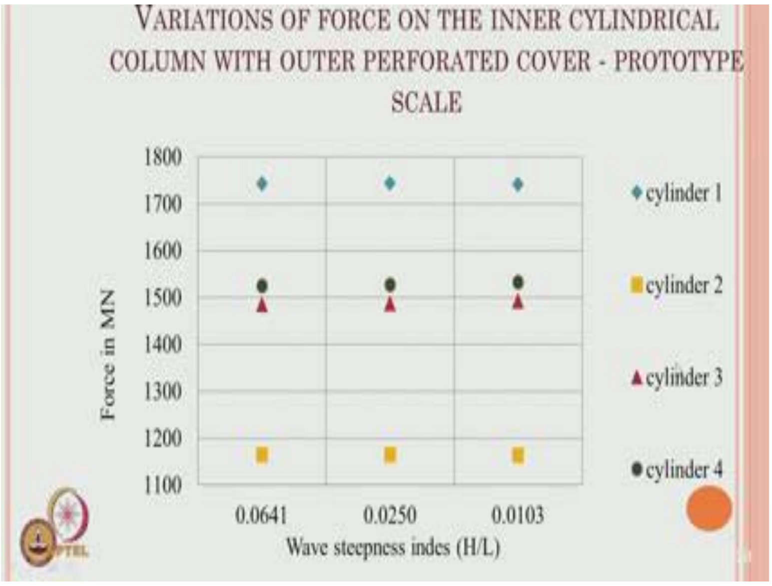

And, for all the four cylinders – all the four cylinders, because TLP has the four cylinders; the forces are now measured in – converted in mega Newton, which have been plotted directly from the design charts. And, you will see that, for all range of wave steepness indices, the force reduction is phenomenally high.

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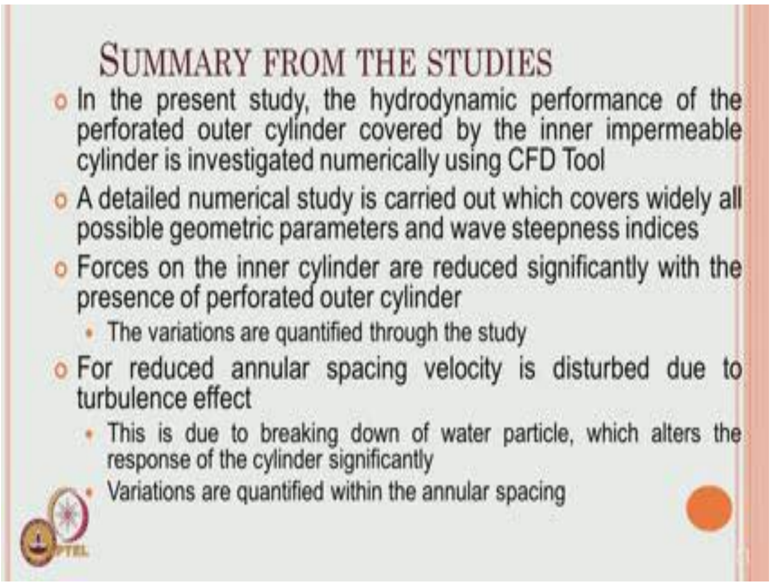

So, look at the summary. In the present study, the hydrodynamic performance of perforated outer cylinder covered by inner permeable cylinder is investigated using a CFD tool. A detailed numerical study is carried out widely for all possible geometric parameters and wave steepness indices. Forces on the cylinder are reduced significantly; maximum reduction is about 76 percent. The variations along the water particle – along the depth are quantified through the study; we have already seen them. For reduced annular spacing, velocity is distributed through the turbulence effect. So, if you do the reduction in the annular spacing, then it creates turbulence. You will not be able to map the water particle kinematics through this. This is actually due to the breaking down a wave, which alters the response of the cylinder significantly. Variations are also quantified within the annular spacing; we already said that.

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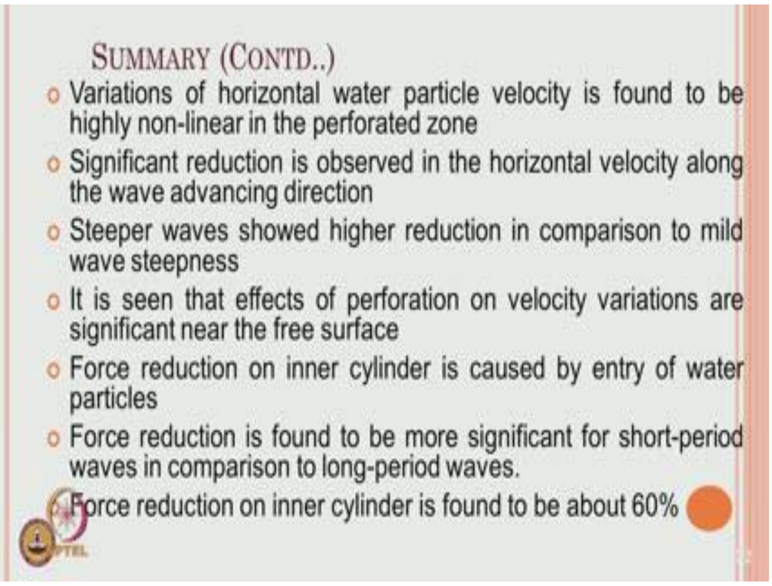

Variations are found to be highly non-linear. There is significant reduction in the horizontal velocity along the wave advancing direction. Steeper waves showed higher reduction. It is seen that the effects of perforation on velocity variation are significant near the free surface, where the force is maximum there. Force reduction is caused by the entry of water particles and reverse of them by reflection. Force reduction is found to be more significant for short period in comparison to long period waves. The force reduction on inner cylinder is found to be maximum – 60 percent, which is verified experimentally.

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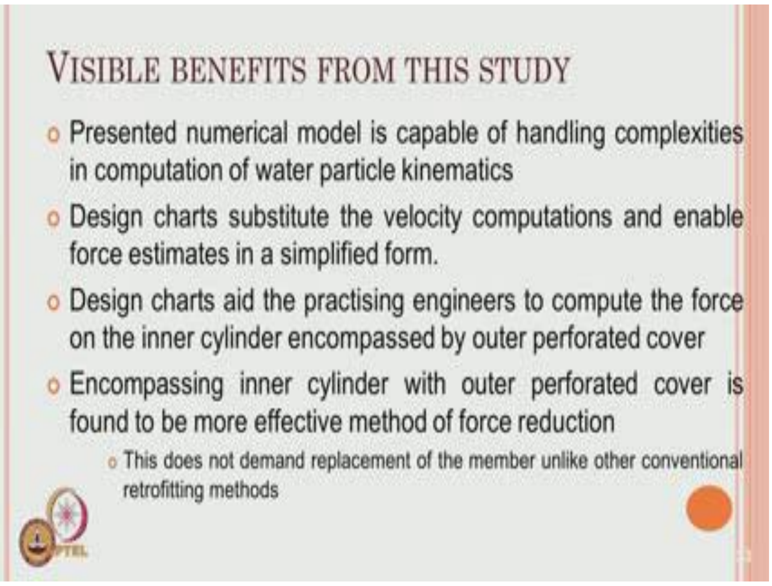

There are some visible benefits from this study. Presented model is capable of handling complexities in computation of water body kinematics. Design charts substitute the velocity, which can be used in a simplified form for design engineers. Design charts aid the practising engineers to compute the forces directly on inner cylinder encompassed by outer cover, which is perforated. Encompassing inner cylinder with outer cover is found to be more effective method of force reduction, because this method does not demand replacement of the member at all; simply put a cover and reduce the forces.

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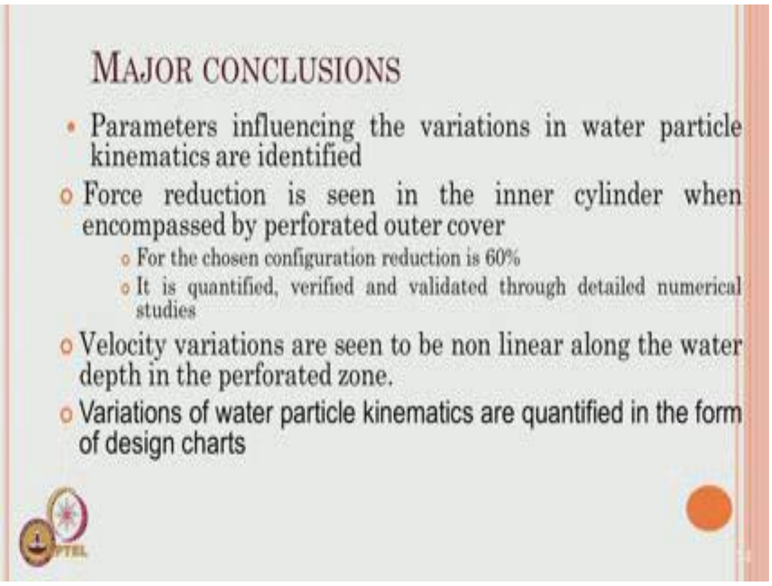

Major conclusions – parameters influencing variations is identified. Force reduction is seen in the inner cylinder. Velocity variations are seen to be nonlinear. Variations are quantified in the form of design charts. And, the study has resulted in lot of publication, which is available in the NPTEL website. So, we thank the researcher for putting out a very good effort. And ultimately, it has come out with the design aids; we have got a CD; we have got a GUI developed on this. So, you have to enter these parameters of the outer cover section, which is now a proprietary item of one of the government of India organization; we have handed over to them.

They are going to use it for the design purposes in their – in their ministry or in their department, which is not an open domain now at this moment. But, however, if that CD is becoming public domain property, then you can simply enter these values directly. You will know the force coming on the inner cylinder directly; you can design the inner cylinder accordingly. So, the whole exercises of water particle kinematics have been simplified to a form where design engineers can be directly using it. This is seen as one of the very interesting societal benefited hydrodynamic analysis of structures, which is talking about retrofitting; which is one of the important application in offshore structural engineering given at this point of time, because mars TLP was admitted to have this problem and the shut down effect was for about 1 year. You can imagine what is the cost of revenue or the revenue lost by Shell and BP during that one year. So, it is one of the interesting ideas, where our – our knowledge on dynamics can be directly applied to understand how this has been done, any questions?

So, the detailed results of these are available in the text book given by me. Of course, they are also available in the form of research papers available in NPTEL website. You can see them as references; read them. If you have anything to comment on this, please write to us in NPTEL; we will be glad to answer them. So, we once again place on record that, researchers done a very wonderful work on this. This is a very interesting work, which is done at IIT Madras. Therefore, we are proud that, we produced – let us say break, I mean path breaking research in terms of hydrodynamics. To some extent, it is having societal benefit directly in offshore engineering.

Thank you.