Offshore structures under special loads including Fire resistance
Prof. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module – 02
Advanced Structural Analyses
Lecture – 38
Marine Risers Under VIM

Friends, welcome to the 38th Lecture titled Marine Risers Under Vortex Induced Motion. In the last lecture we were discussing about the governing equations for estimating, the motion response on marine risers. We also discussed about varieties on marine risers which are used for offshore application, we will continue with the discussion on motion response analysis of marine riser. Then we will look into a specific special application of marine riser under vortex induced motion in this lecture.

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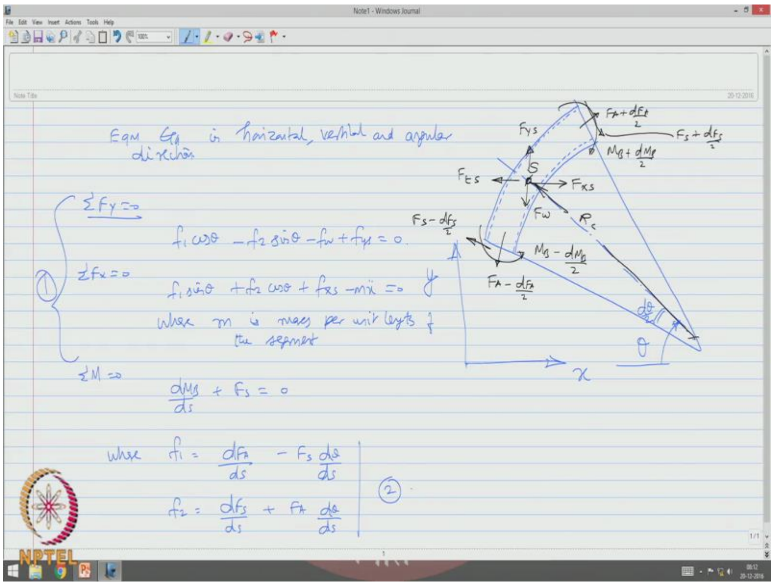

We continue with the discussion on marine riser motion analyses. Let us say we have an elemental strip which is at an angle theta and strip angle about d theta. So, the forces acting on this at any centre point s can be F xs, F ts, F w and F ys as we mentioned yesterday. There will be incremental force variation between the left and right boundaries of the strip. Let us say this is going to be F A minus dF A by 2, so that is going to be F A plus dF A by 2.

Similarly, look at the moment this going to be M B minus dM B by 2, whereas this going to be M B plus dM B by 2. Similarly, this going to be F s minus dF s by 2, whereas this value will be F s plus dF s by 2. Then at the centre value is radius of curvature of the strip, theta actually measures to the centre; this is theta. Therefore, the equation equilibrium in horizontal vertical and angular directions was discussed in the last lecture, we will continue with that now.

We know that sigma F y 0 will lead to f 1 cos theta minus f 2 sin theta minus f w plus f ys let us set this to 0. Sigma f x 0 will lead to f 1 sin theta plus f 2 cos theta plus F xs minus m x double dot set to 0, where m is the mass per unit length of the segment considered and sigma m 0 will yield to dM B by ds plus F s will be 0. Where, f 1 is dF A by ds minus F s d theta by ds and f 2 is dF s by ds plus dF A plus F A d theta by ds. Let us say this is equation 1, this equation 2.

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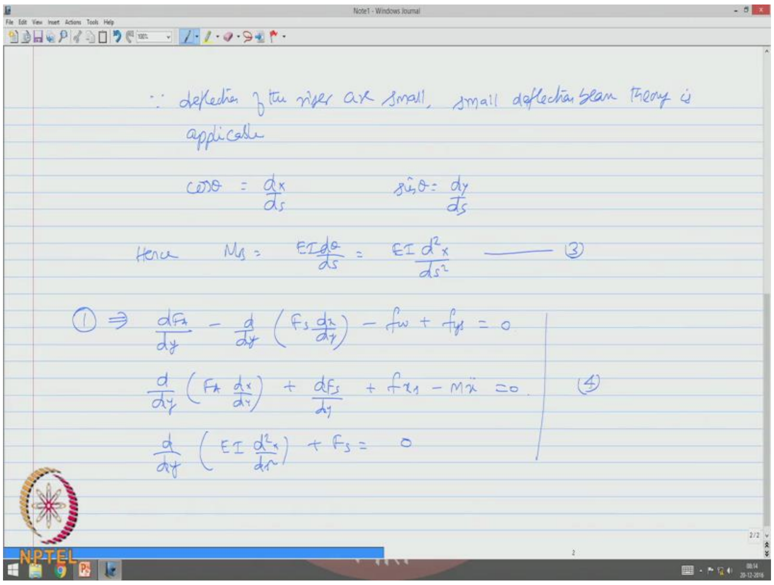

Since, deflections of the riser are small they can apply the small deflection beam theory. Also we know from the geometry cos theta is dx by ds and sin theta is dy by ds. Therefore, M B is actually E I d theta by ds can be expressed as E I d square x by ds square equation 3. So therefore, now the first equation set of equation we now turn to dF A by dy minus d by dy of F s dx by dy minus f w plus f ys is 0. Similarly, sigma f x 0 equation will turn out to be d by dy of F A dx by dy plus dF s by dy plus F xs minus m x double dot is 0.

The third equation which is sigma m 0 will turn out to be d by dy of E I d square x by ds square plus F s is set to 0, I call this equation number 4.

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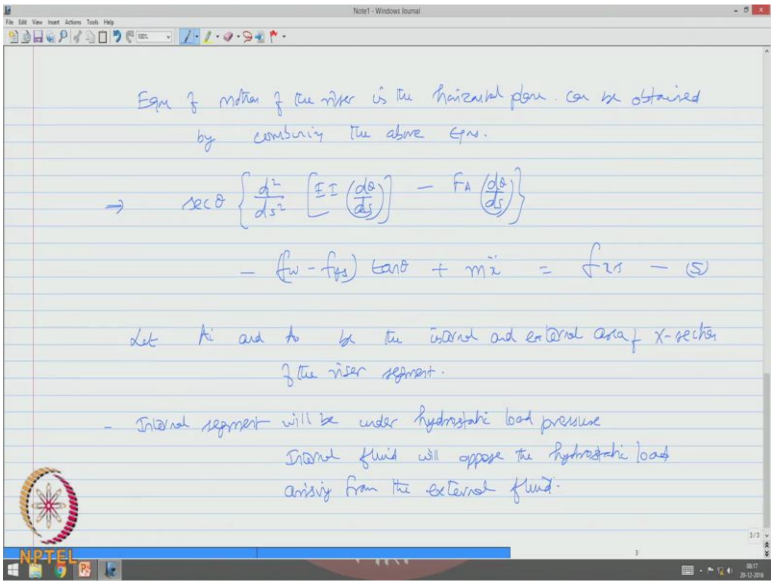

Now, I want to write equation of motion of the riser in the horizontal plane. As we said in the last lecture one can write this in any plane that we are interested in writing in the plane where the motion response of the platform is captured. So, we will do it in the horizontal plane.

This can be obtained by summing up the above equations or let us say by combining the above equations. When I combine them it simplifies to secant theta d square by ds square E I d theta by ds minus F A d theta by ds minus f w minus f ys tan theta plus m x double dot will lead to F xs; we call this equation number 5.

Let Ai and A0 be the internal and external area of cross sections of the riser. Interestingly, the internal segment will be under hydro static load pressure, because the internal fluid which is flowing through the riser will oppose the hydro static load arising from the external fluid.

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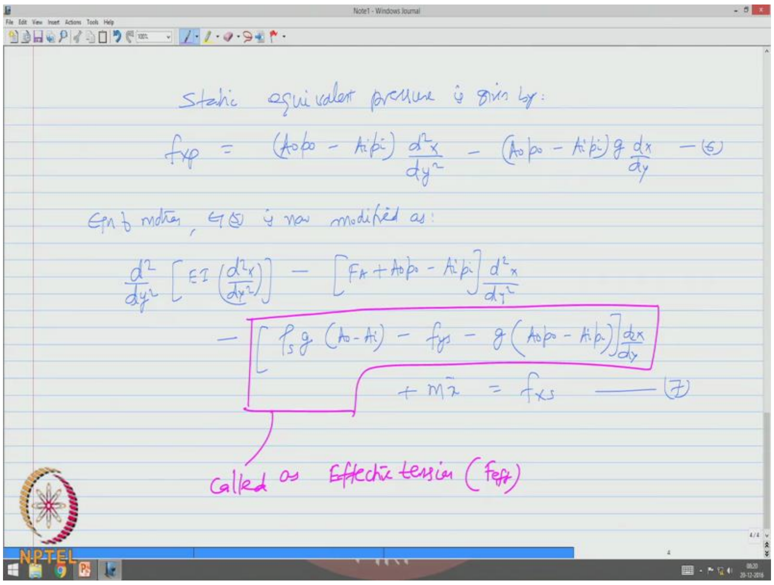

Therefore, they should look for a static equivalent pressure which is given by f xp A0 p0 minus Ai pi external minus internal of d square x by dy square minus A0 p0 minus Ai pi of dx by dy; equation number 6.

Therefore, the equation of motion which is shown in equation 5 is now modified which would be d square by dy square of E I dy square minus F A plus A0 p0 minus Ai pi of d square x by dy square minus rho s g A0 minus Ai minus f ys minus g times of A0 p0 minus Ai pi the whole by dx by dy; plus of course m x double dot will now deal with F xs equation number 7 which is the modified form of equation 5.

Now, in this equation this particular term is called as effective tension which is referred as effective in the literature.

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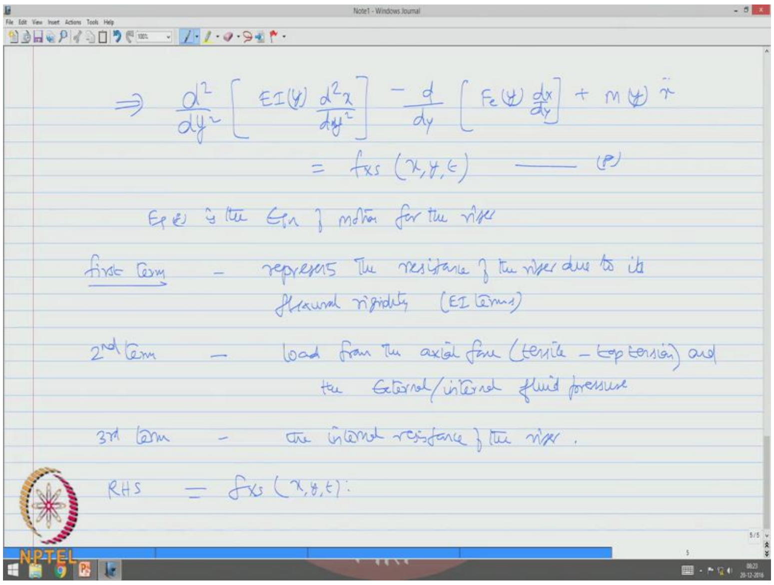

Hence, let us rewrite this equation as d square by dy square of E I a function of y x by dy square minus d by dy of Fe this is an effective tension of dx by dy plus m mass per unit length this is also function of y x double dot, can be now said as F xs of x y and t.

Now, the one what you see here equation 8 is the equation of motion for the riser under the given set of loads. In this equation the first term represents the resistance of the riser due to its flexural rigidity. You can very well see here the E I terms accounts for this. The second term, in the above equation refers to the load from the axial force essentially the tensile force what otherwise we call as top tension, and the external internal fluid pressure. The third term in the above equation is the internal resistance of the riser segment. The right hand side of this equation needs a special attention which is F xs of x y and t.

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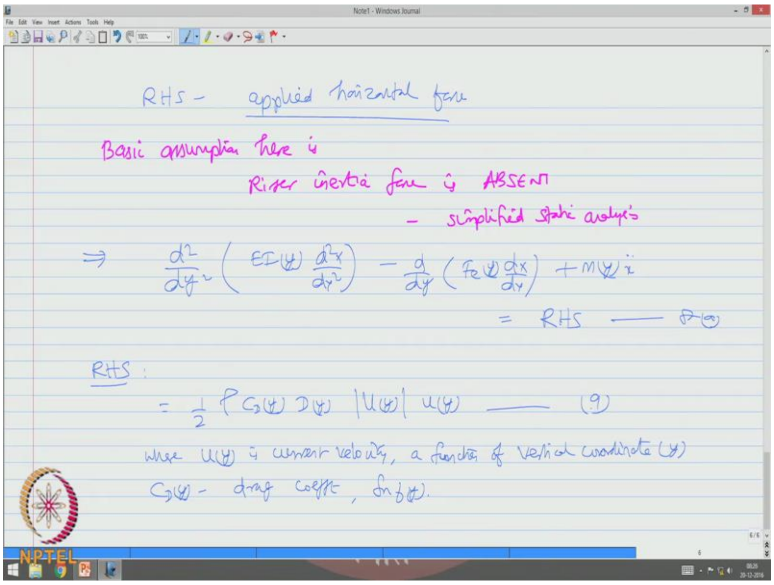

The right hand side of this equation represents the applied horizontal force on the riser. So very importantly the basic assumption here is, riser inertia force is absent because we are looking for a simplified static analysis. Therefore, equation now reduces to d square by dy square E I function of y d square x by dy square minus d by dy of F equivalent of y dx by dy plus x y of x double dot is some value on the right hand side; I call this as equation number 8 a, it is a modified form.

Now, the right hand side of this equation of motion is given by half rho which is the applied horizontal force C D which is again a function of y diameter again a function of y u y and u y where u y is the current velocity which is a function of the vertical coordinate y. Of course, C D of y is the drag coefficient which is again a function of y; equation number 9.

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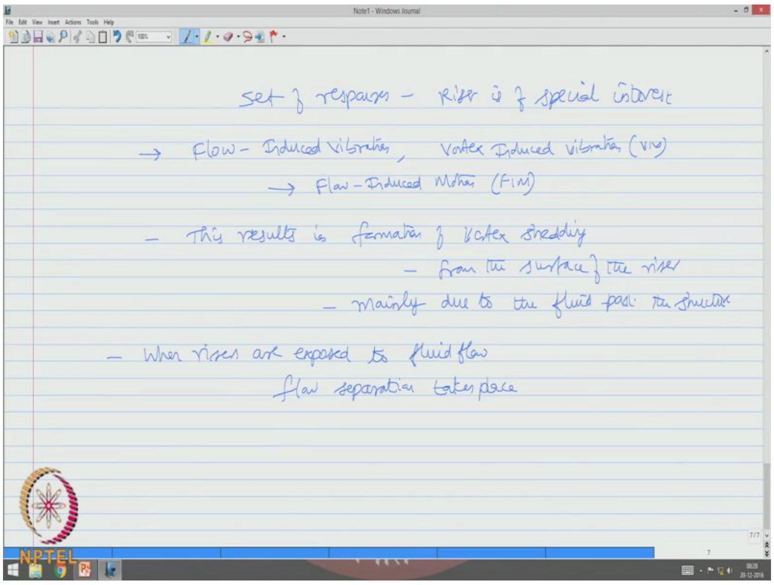

So friends, when the marine riser is subjected to the loads as shown in the segmental lengths it undergo various special set of responses. The set of responses what the marine riser undergoes is of a special interest. This essentially induces what we call as flow induced vibration are sometimes referred as vortex induced vibration. Essentially this is a characteristic of a flow induced motion what we call as FIM.

So, this results in formation of vortexes which arise or originate from the surface of the riser. This occurs mainly due to the fluid past the structure, when risers are exposed to when risers are exposed to fluid flow separation takes place.

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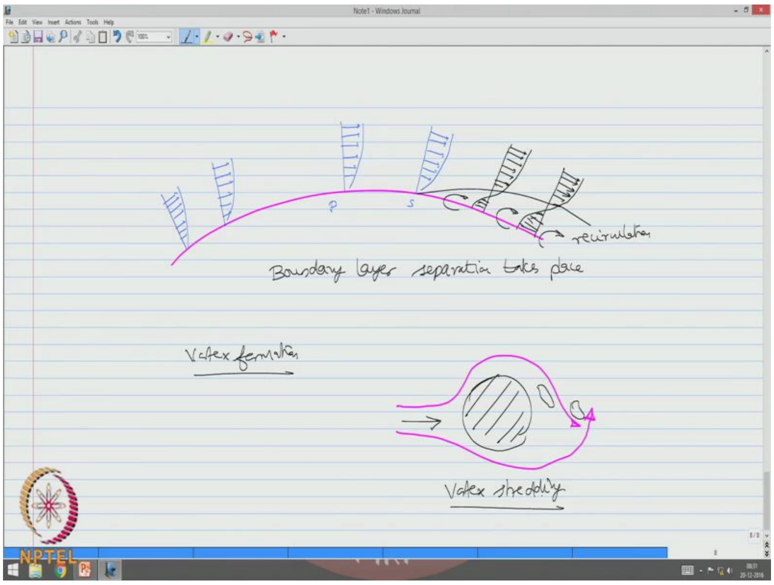

For example the surface, let us try to plot the variation of flow as various locations. Let us say at the point p and at the point s; from this point onwards you will notice that there is a separation takes place and because of the separation the flow characteristics will vary.

Similarly, at this point it initiates what we call recirculation. So, boundary layer separation takes place and the pressure distribution shows there is a clear separation. So, this may result in what is called vortex formation, schematically if the body which is kept in the flow field obstructs the flow the flow pattern causes rotation like this which forms vortex shedding.

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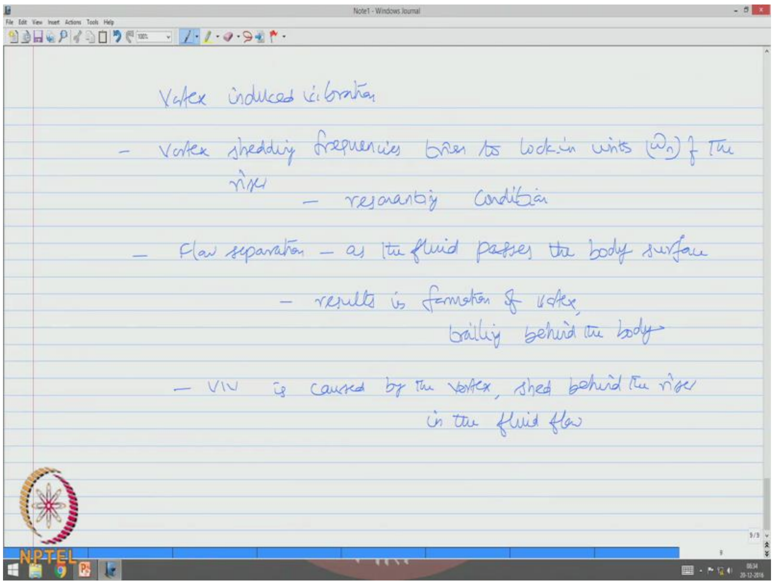

Now, the consequences of vortex shedding; what will happen when vortex induced vibration is generated? The vortex shedding frequencies tries to lock in with the natural frequency of the riser; this will lead to a resonating condition. So, the flow separation which has taken place as the fluid passes the body results in formation of vortex which is trailing behind the body. So, VIV is caused by the vortex which is shed behind the body in the fluid flow.

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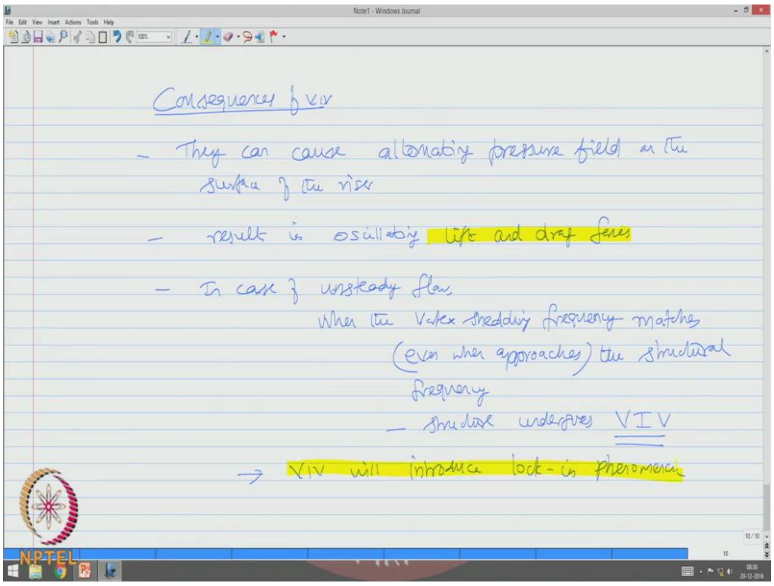

Now let us ask a question, what would be the consequences if VIV is formed. They can cause alternating pressure fields on the surface of the riser; this can result in oscillating, lift and drag forces that are a very important consequence. In case of unsteady flow when the vortex shedding frequency matches or I should say even when approaches the structural frequency, the structure undergoes what we call vortex induced vibration. So, the serious consequence of VIV varies it will introduce what we call something a lock in phenomena.

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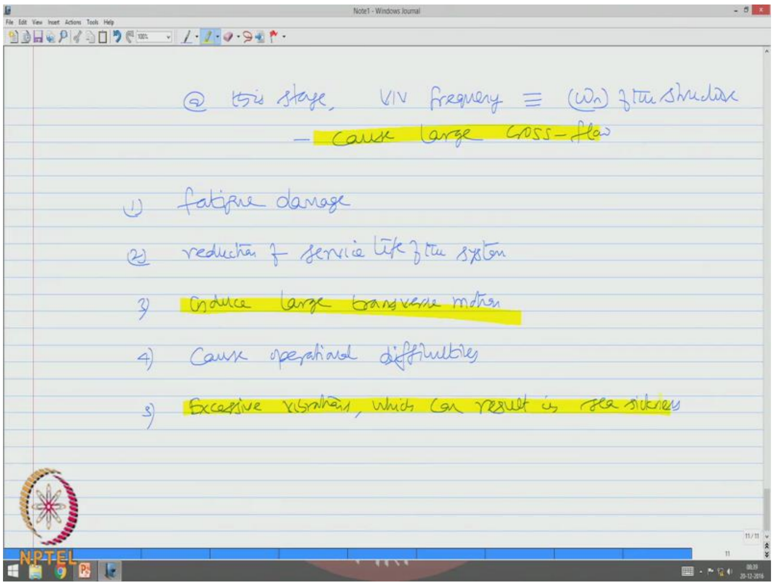

So, at the lock in phenomena at this stage the vortex induced vibration frequency will be more or less closer to the natural frequency of the structure which will cause large cross flow. So, that is another consequence we have. So, this can result in fatigue damage, it can result in reduction of life of the structure system. This can induce large transverse motion that is a very serious consequence, because in such vibration inductions failure can occur very easily even at the low amplitude of vibration in transverse motion.

Many mooring lines or cable straight bridges have been analyzed for this. One important failure is the Tacoma Bridge which has failed in one of such consequences. So, large transverse motion initiation is a major drawback when VIV is induced in the system. It can cause operational difficulties, the operability of the platform can be challenged, and it can cause excessive vibrations which can result in sea sickness; that can be one of the consequences on human on board.

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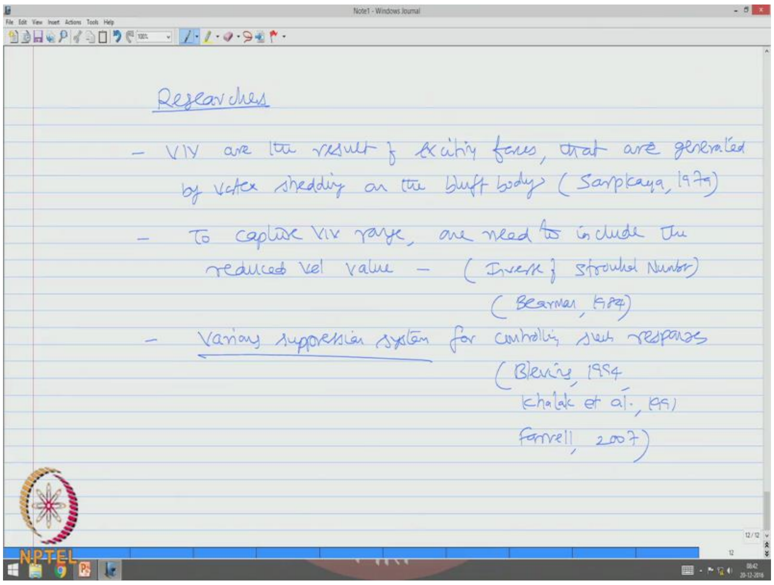

So, people have studied these consequences and these kinds of responses very widely in the literature. The researches state: VIV are actually are the results of additional exciting forces that are generated by vortex shedding on the bluff body. This motion response can be captured as people have indicated this is very clearly said by Sarpkaya in 1979. If you want to capture vortex induced vibration response range one need to include the reduced velocity value which corresponds to Inverse of Strouhal Number, as said very clearly by Bearman 1994.

People have also proposed various suppression systems for controlling such responses. for example; Blevins 1994, Khalak et al 1991 and Farrell at 2007 proposed many suppression systems which are helpful in controlling such responses caused by vortex induced vibration essentially on offshore cylindrical members.

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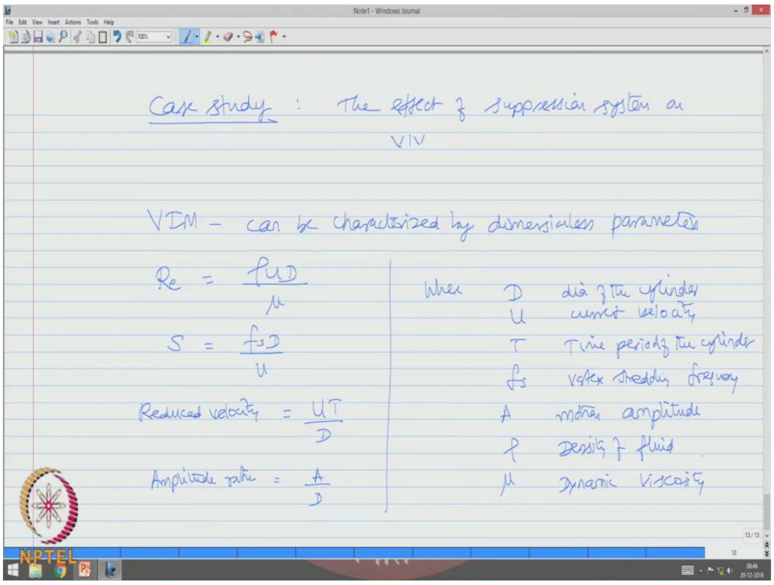

Keeping this in mind let us discuss quickly a case study example to illustrate the effect of suppression systems on vortex induced vibration on a given offshore cylinder. An external study was designed; to examine the left hand side shows the line diagram of the study a cylindrical member is suspended from a spring from a support. And there is a horizontal shaft which holds the cylinder by means of rollers the full setup in a three dimensional view is shown in the photograph here which the setup assembly. The model dimensions as indicated here are the diameter of the cylinder, the thickness of the cylinder, the length of the member which has got a draft of about 917 and then the rest is of a clear height.

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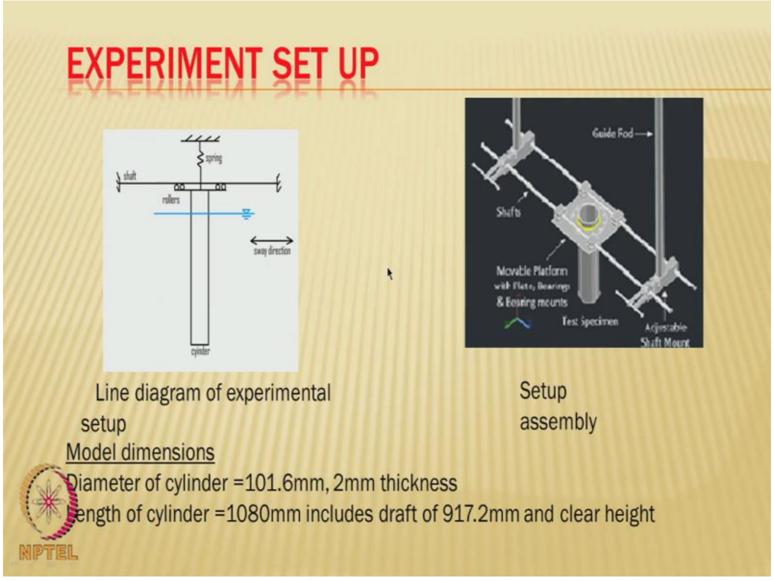

The vortex induced motions generally can be characterized by different dimensionless parameters. For example, Reynolds number rho u d by mu the Strouhals number D by u. The reduced velocity which is very necessary to estimate the response which is u T by D, and then the amplitude ratio which is a by d where d is the diameter of the cylinder, u is the current velocity under study; T is the time period of the structure. Let us say in my case the cylinder f s is the vertex shedding frequency, A is the motion amplitude, rho density of fluid, and mu the dynamic responses.

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Let us quickly see the experimental setup which is assembled to conduct the response study. You can see the cylinder suspended from the arrangement held down by a spring is now attached to the moving carriage. This carriage is going to move with the specific velocity in the fluid medium which is essentially water, this is immersion of the cylinder you can see the cylinder here. The safety clamps will hold down the cylinder to the assembly and the LVDT is being used to measure the response of the cylinder in the transverse direction. And now this is attached to the assembly and the carriage is going to move where we are going to measure the response of the cylinder under the vortex induced motion.

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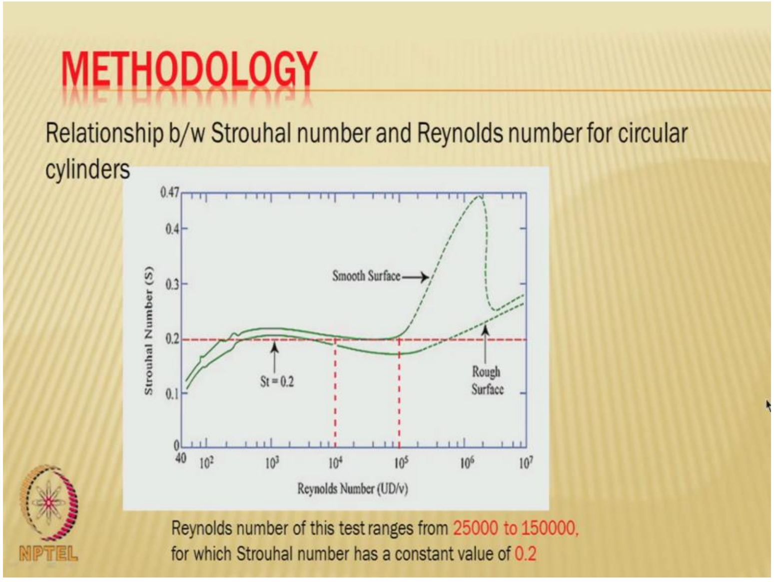

Interestingly, before we look at the test results and conclusions. Let us try to look at this figure where the relationship between the Strouhals number and Reynolds number for a circular cylinder is indicated. One can very clearly see here for the range of Reynolds number varying from 25000 to 150000, the Strouhals number remains almost constant at 0.2. So, this is the range where the study can be now carried out.

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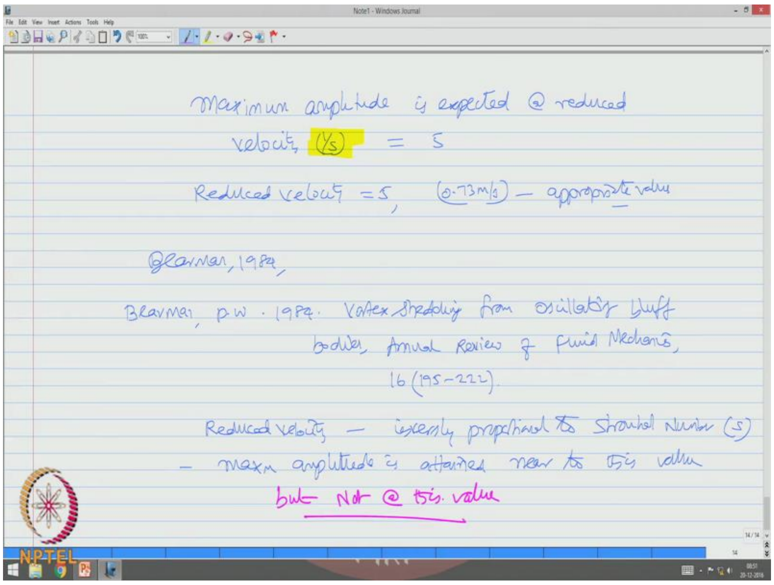

So, the maximum amplitude is expected at reduced velocity of 1 by s is actually equal to 5. The reduced velocity of 5 means that 0.73 meter per second is the appropriate value which we are looking.

So, as said by Bearman in 1984 which is Bearman, p. w. 1984 vortex shedding from oscillating bluff bodies annual review of fluid mechanics volume 16 195-222 says that; the reduced velocity at which the VIV can be captured is inversely proportional to the Strouhals number. So, that is why we said this 1 by s, and the maximum amplitude is attained closer to this value, but not at this value; that is very important.

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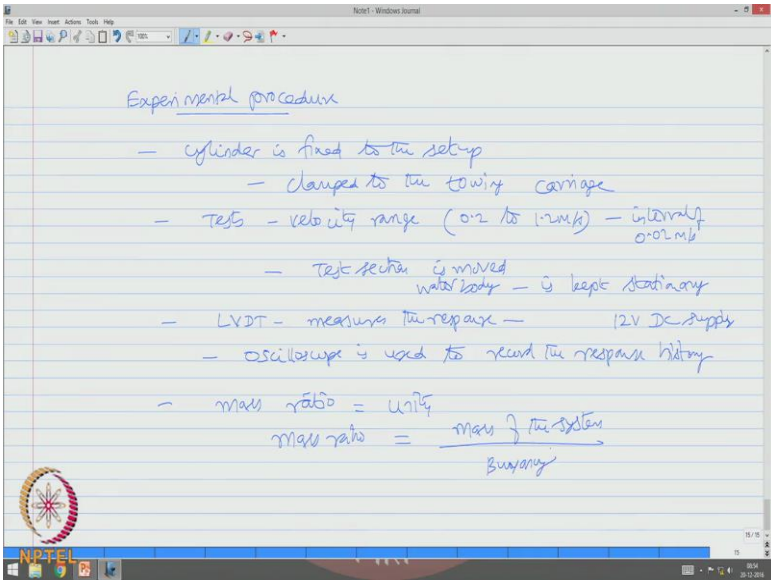

Let us quickly discuss very briefly the experimental procedure. The cylinder is fixed to the setup; the setup is clamped to the towing carriage. Tests are carried out in the velocity range 0.2 to 0.12 meter per second at an interval of 0.02 meter per second. It is very interesting to note that the test section is moved and water body of the fluid medium is kept stationery.

LVDT which measures the response receives supply from a 12 volt DC supply oscilloscopes are used to record the response. I should say the response history all tests are conducted by the specific moist ratio of unity. The mass ratio is actually the ratio of mass of the system to the buoyancy.

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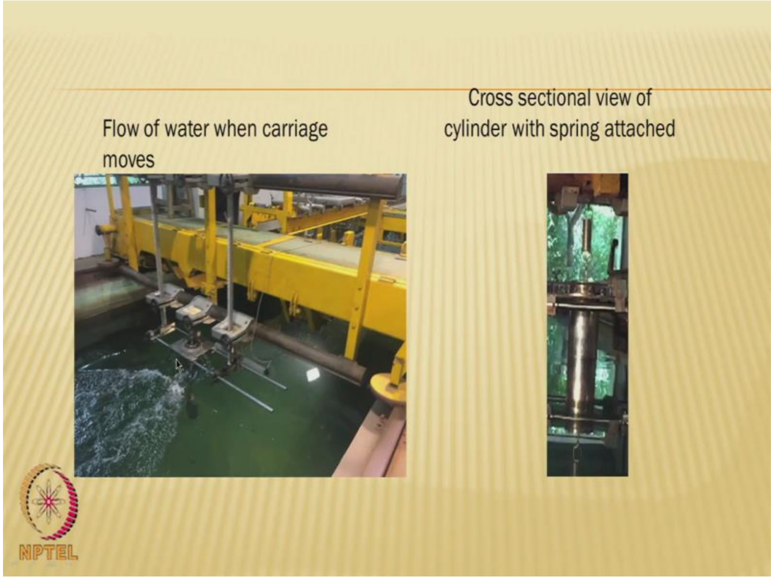

The photograph on the left hand side shows the flow of water when the carriage moves you can see a very interestingly the shedding frequency happens at the trailing side of the cylinder and the surface where the flow separation is expected to take place. The right hand side picture shows very clearly the cross section view of the cylinder with a spring attached to the cylinder.

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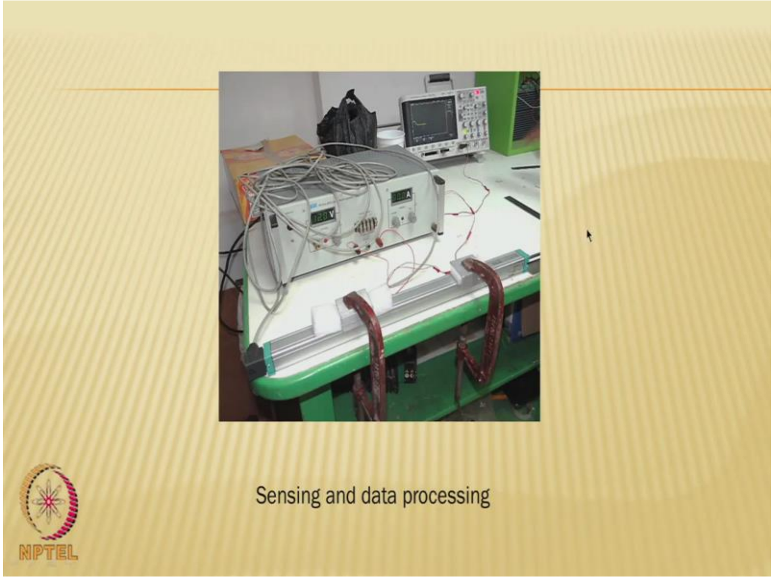

The equipment used the oscilloscope and the data recorder used for sensing and data processing is shown in the screen now.

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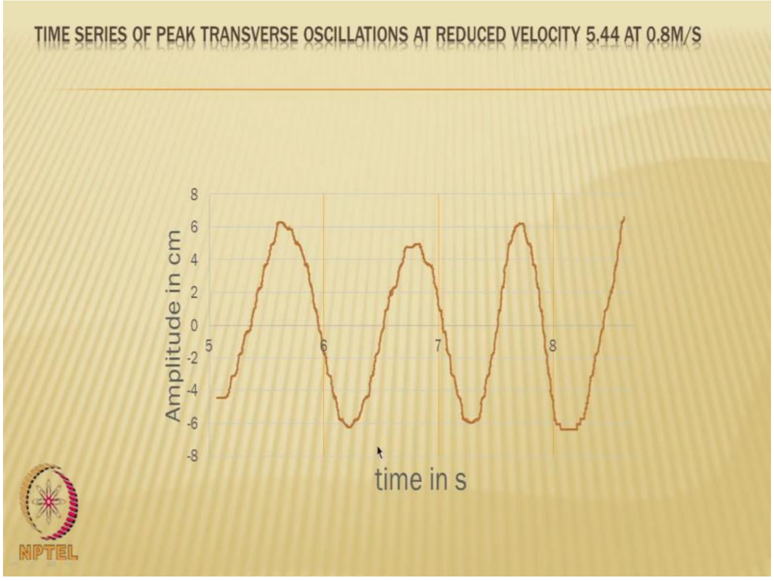

The screen now shows the time series or times history in seconds of the peak transverse oscillation which is now recorded at reduced velocity 5.44 at 0.8 meter per second.

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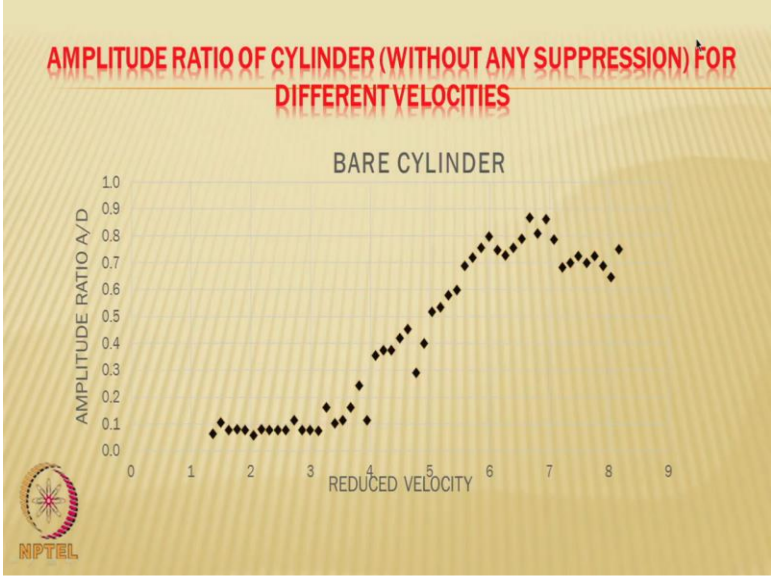

We have also plotted the amplitude ratio of the cylinder without any suppression for different velocities. The reduced velocity of different range is shown in the x axis and on the y axis shows the amplitude ratio for a bare cylinder which does not have any proposed suppression systems for controlling the vortex induced vibration.

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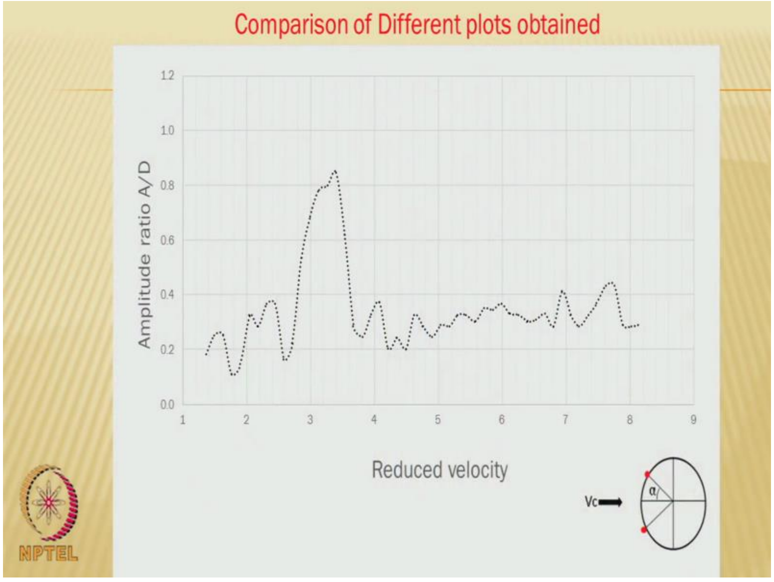

It very clearly shows by comparing the different plots, that following observations can be recorded on a bare cylinder.

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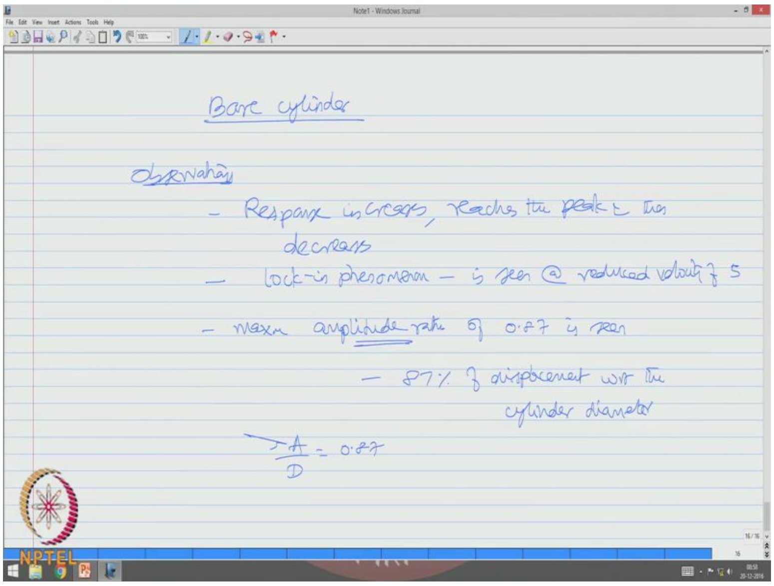

Response increases, reaches the peak and then decreases. Very interestingly a lock in phenomena is observed at reduced velocity of 5. The maximum amplitude ratio of 0.87 is seen which indicates about 87 percent of displacement with respect to the cylinder diameter, because A by D is about 0.87 where A is amplitude ratio.

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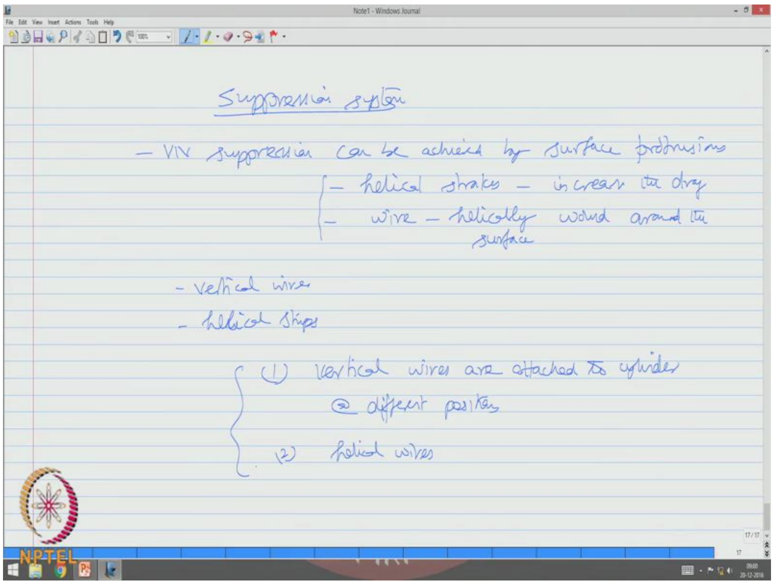

Then suppression systems are proposed; is interestingly seen that VIV suppression can be achieved by surface protrusions by putting helical strakes etcetera. Examples; helical strakes, but of course this will increase the drag. One can also use helical wires helically bound around the body. So, both studies are carried out like vertical wires and helical strips. So, essentially vertical wires are attached to the body at different positions, helical wires are also attached. So, two set of studies are conducted.

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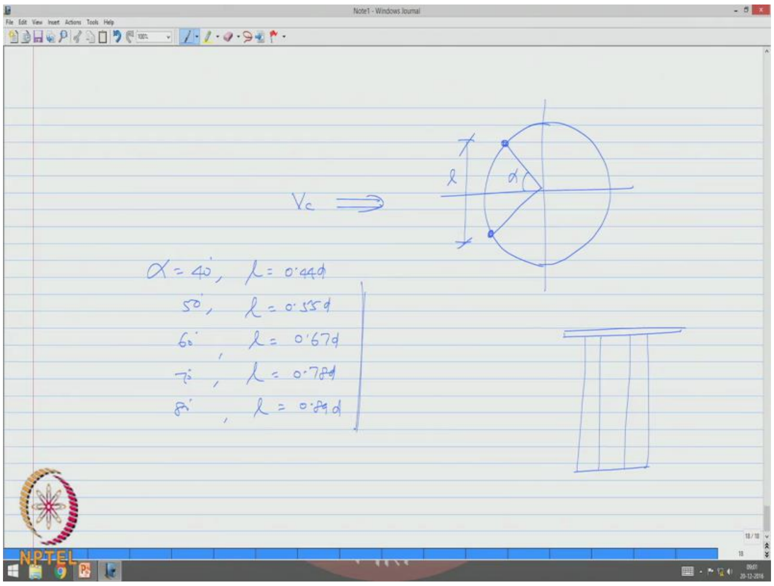

If you look at the cylinder diameter helical wires are attached at different angles. This is one of the variables used in the study alpha and this is indicated as l and this is my flow direction. If you look at the elevation the suspended cylinder has got wires for the entire length. So, for alpha being 40 l becomes 0.44 d, for alpha 50 l is 0.44 d, alpha 60 0.66 d, alpha 70 l becomes 0.78 d, and alpha 80 degrees l becomes 0.89 d for which the tests are being conducted.

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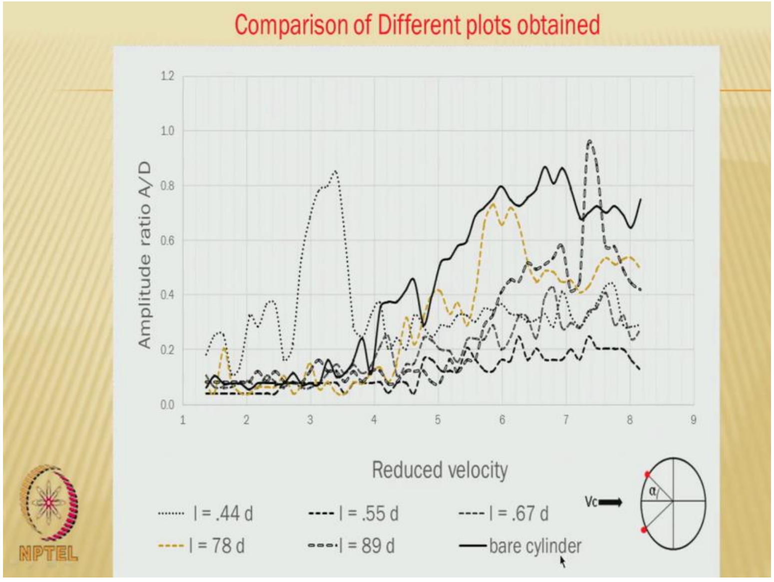

Now, the response plots have been obtained. We can now compare these response plots as shown in the figure for different values of alpha, so 0.66 d if you change it to 0.66 d then further at 0.78 d and 0.89 d. So, there are different plots now superimposed for different values of l. And the dark line what you see here the dark line this shows the response of the cylinder without any suppression system what we call as a bare cylinder.

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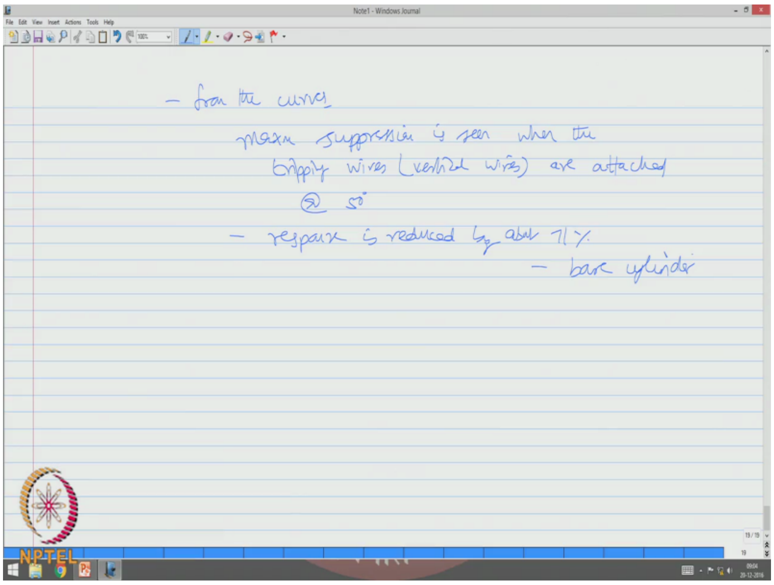

So interestingly, from the curves one can see that the maximum suppression is seen when the tripping wires nothing but the vertical wires are attached at 50 degrees. In this case the response is reduced by about 71 percent when compared with the bare cylinder.

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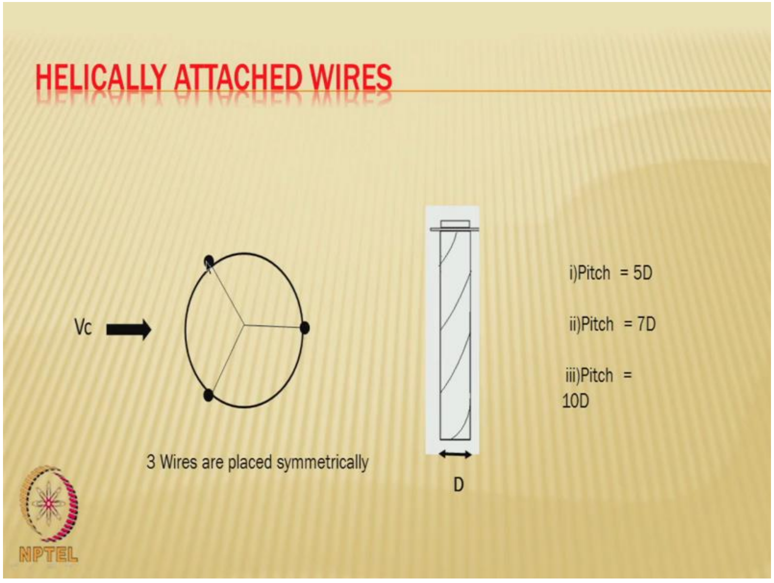

The next study was with the helical strakes at three different points on the surface equivalent to 60 degrees the wires are connected and they helically bound at different pitch 5 times the diameter, 7 times the diameter and 10 times the diameter and the wires are placed symmetrically with respect to the wave direction for the cylinder as shown in the figure here.

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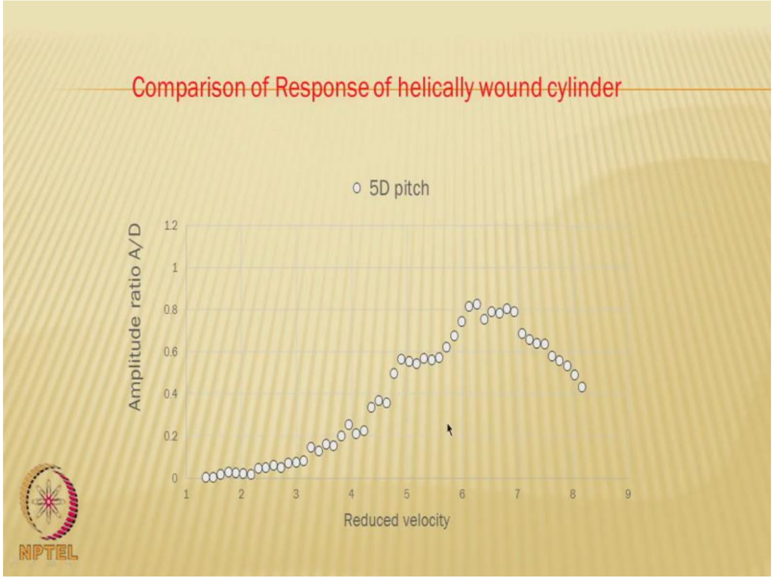

Let us compare the responses of the helically bound cylinder for different pitch ratio as 5D which is seen in this screen here.

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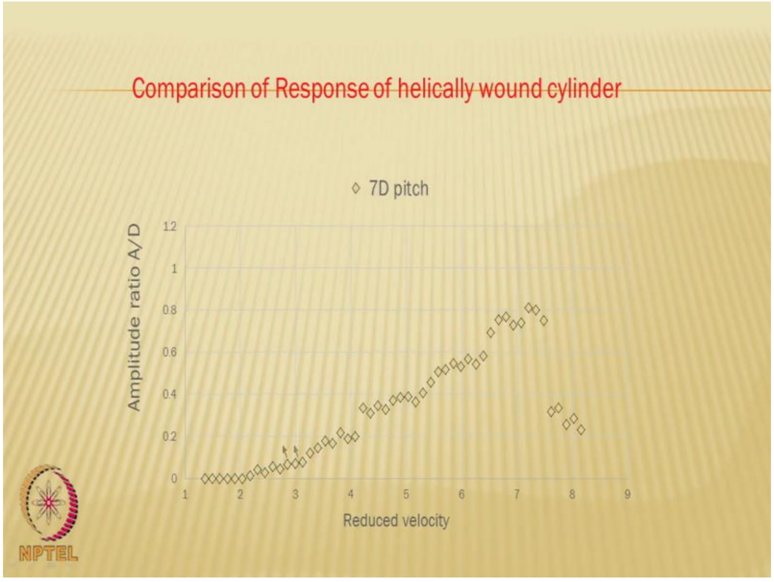

For 7D.

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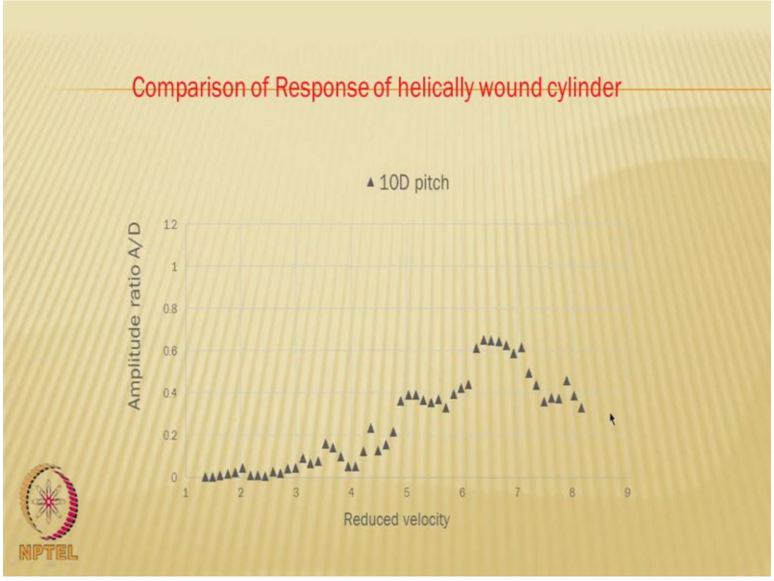

And for 10D; so the plots are now compared for different pitch of the helical strakes of the wires which are bound on the surface of the cylinder at different pitch values.

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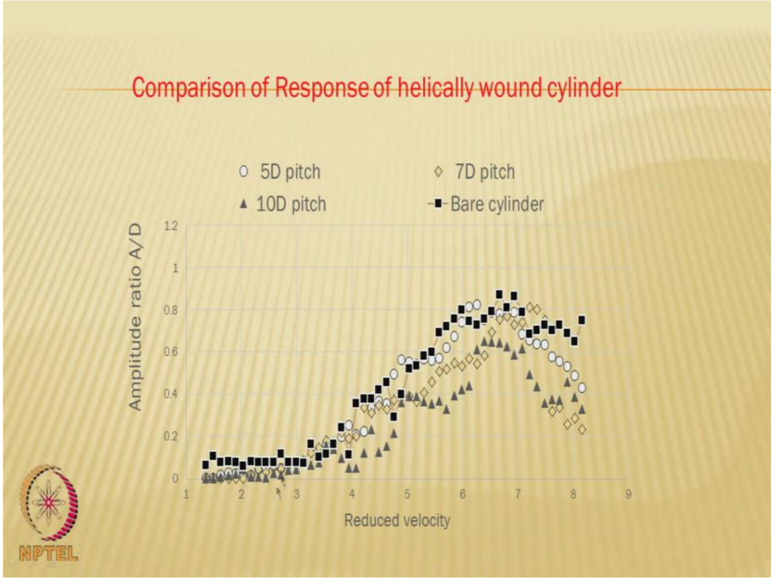

So, now they are super imposed and compared with the bare cylinder the plot what we see here with the black square filled in is for the bare cylinder, whereas other all the plots are shown for the helical wires bound around the cylinder. One can very clearly see this gives a very effective suppression of the response of the cylinder at various reduced velocity ranges for different amplitude ratio as seen in the curve.

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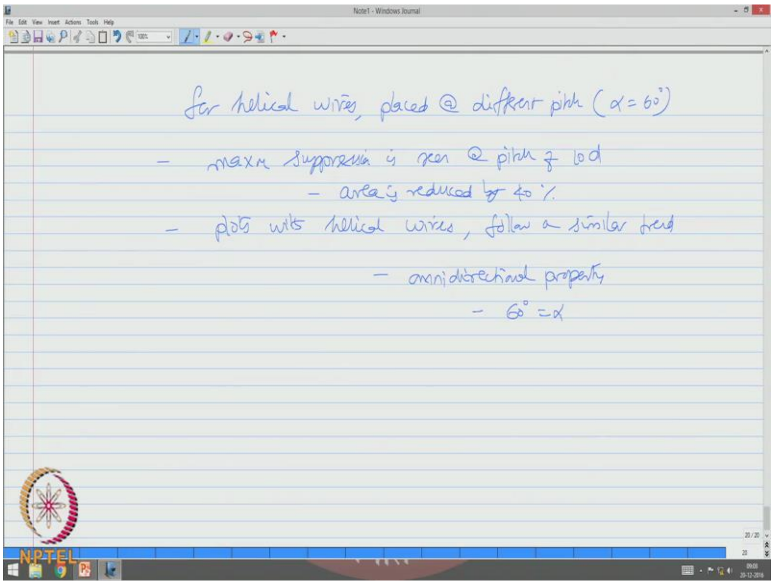

So by comparing these plots, one can now see for helical wires placed at different pitch, but at an angle of 60 degree which was found to be effective from the previous study which was 50 degrees. It is seen that the maximum suppression is recorded at a pitch of 10D where the area is reduced by above 40 percent. It is also seen that all the plots with helical wires follow a similar trend; this is essentially due to the omnidirectional property achieved by laying the wire at 60 degree inclination at different pitch analysis.

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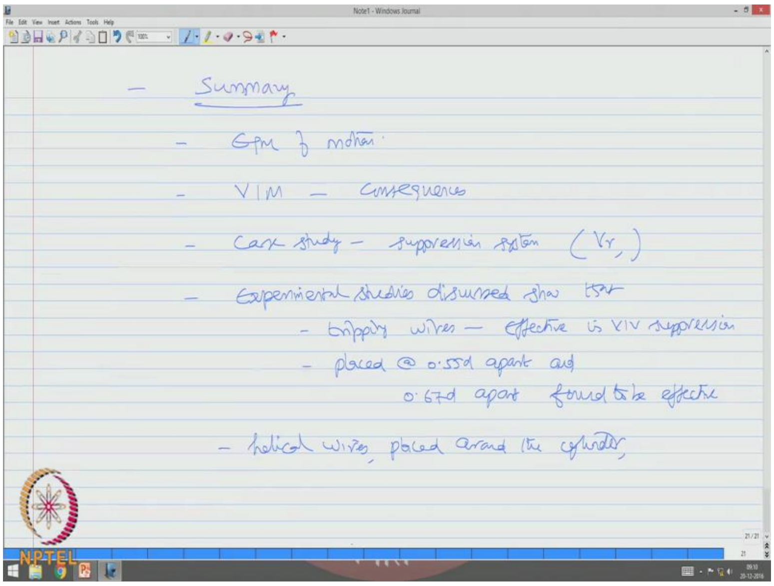

So friends, in this lecture we have seen how to derive the governing equation of motion for a riser under the environmental loads acting on the riser. We also tried to understand the equation of motion governing the response of the riser. We have also understood what would be the vortex induced motion and their consequences on the riser configurations. We picked up a case study to examine the suppression systems which are caused reduction in response at different reduced velocity at different range of Strouhals and Reynolds numbers.

We said that, the experimental studies discussed show that tripping wires are effective in VIV suppression. Vertical wires placed at 0.55 d apart and 0.67 d apart found to be effective. For the helical strakes or helical wires placed around the body it is seen that for a pitch of 10 times the diameter the response suppression or I should say the response reduction is seem to be maximum.

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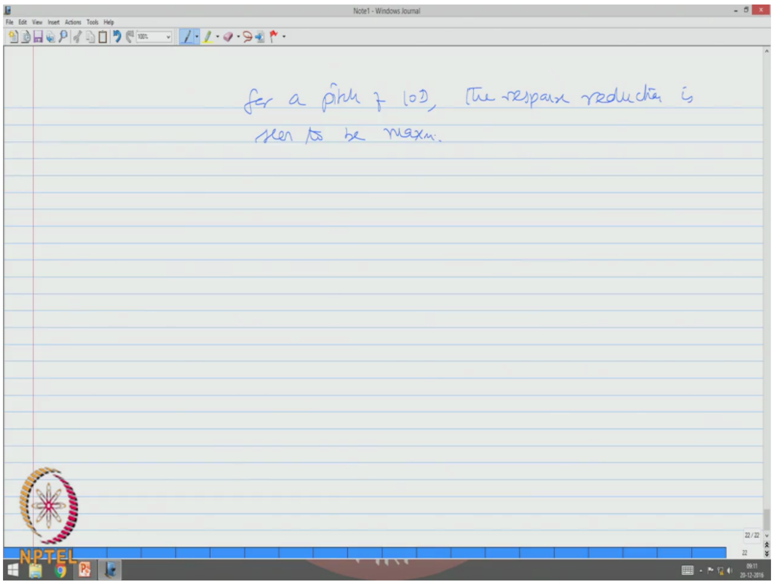

The study has got interesting references which can be seen from the list of references on NPTEL website of this course. So interestingly, in this lecture we learnt how to examine and understand the suppression systems under VIV responses which has got very serious consequences on marine risers.

Hope this experimental study shown to you will intuit you to examine such more detail analysis with more experimental, numerical and analytical investigations on marine risers, because these are special kind of responses induced on offshore systems under the fluid flow.

Thank you very much.