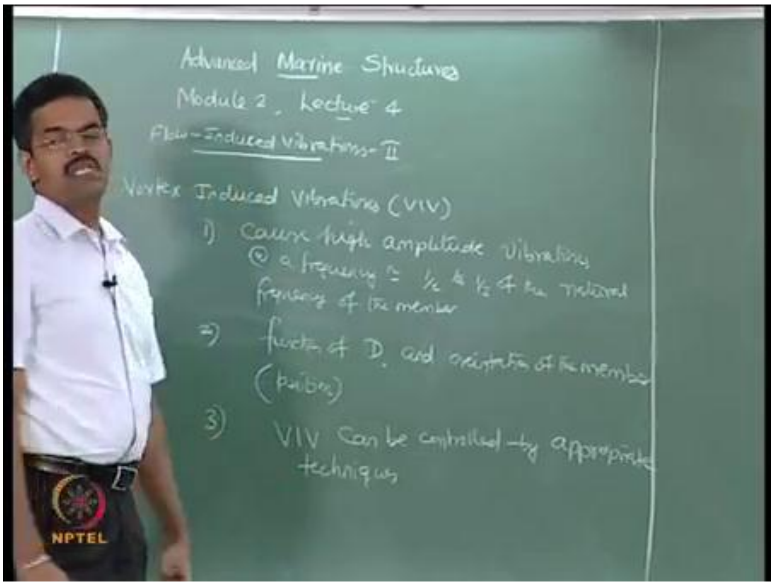
Advance Marine structures
Prof. Dr. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute Of Technology, Madras

Lecture - 4
Fluid Induced Vibration - II

In the last lecture, we discussed about the vortex induced vibrations, which are called briefly as VIV.

(Refer Slide Time: 00:15)



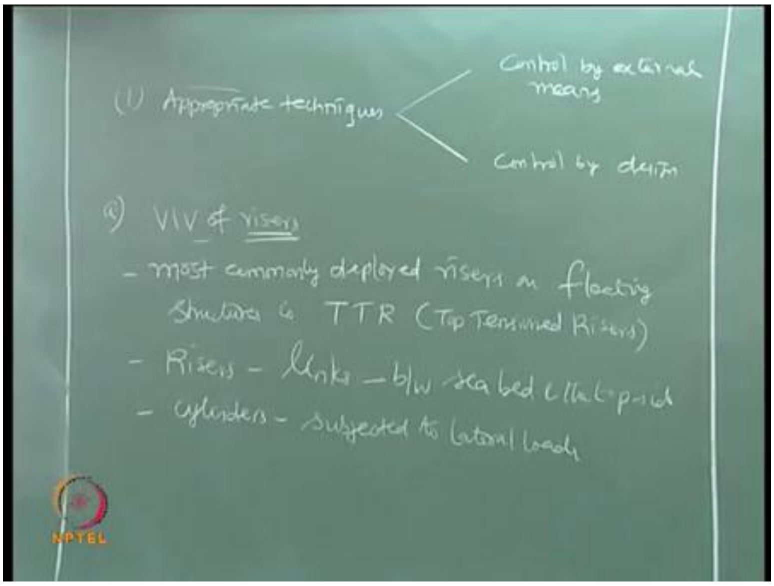
So, two important points we learnt from flow induced vibrations or vortex induced vibrations in the last lecture are the following; one they cause high amplitude vibrations at a frequency, which is approximately equal to half to one-third of the natural frequency of the member. So, necessarily resonance may not be set, when the vibration frequency is of flow induced vibrations match exactly with the natural frequency of the member. Here is an example when the flow separation takes place.

When the flow gets detached from the member, when the member is placed in the steady uniform field of flow, there is a possibility that secondary vibrations can be created, whose amplitudes can be significantly high. But they can cause this kind of phenomenon not exactly natural frequency of the member, which we address otherwise as resonance. In dynamics, it can happen even at 50 percent of the frequency. So, one has got to be very careful in designing the dynamic amplification effects on the members; when the members are placed in flow field, which are interfering the flow field as commonly is a case for marine structures.

The second thing what we learnt is, the flow induce vibrations or functions of diameter of the member and let us say the orientation of the member. The moment I say orientation, I can also say position of the member. Whether the member is placed closed to the mean sea level, whether the member is made to is placed in between the water depth, whether the member is placed in the direction of inline flow or the member is placed in the transverse direction of the inline flow. So, orientation and position will also affect. The third thing, what we understood is VIV can be controlled.

I, should say rather flow induced vibrations can be controlled. You cannot control the vortex induced vibration, but flow induced vibration responses can be controlled. There are techniques, by appropriate techniques. What we are going to see in this lecture is few of these techniques, which has been practically implemented in marine structural design.

(Refer Slide Time: 04:31)



The moment I understand, that there can be appropriate techniques by which the responses caused by the flow induced vibrations can be controlled, then I can divide this in two domains. One control by external means, we will see what It is. The other is control by design. Can also design the system to control this kind of vibration or you can use some external agency, some mean, some methods, and some techniques to control this vibrations. What we call as appropriate techniques, which has been attempted in the literature by the designers in the recent past.

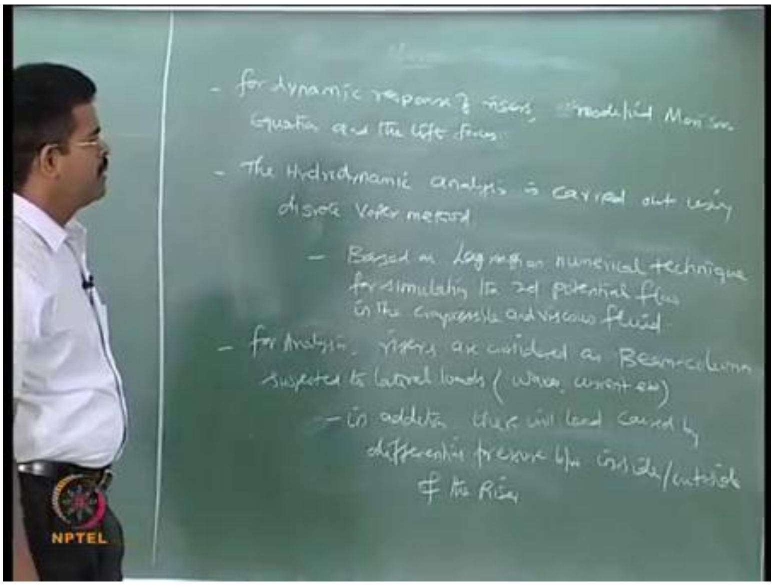
Analytically or in fact in real time applications they have been used. Let us start looking at these appropriate techniques in different domains of our interest. We will pick up the first domain, which we also briefly describe in the last lecture. But, still for continuity sake we will start from there. We will talk about, let us say VIV of rises. As I told you in the last lecture, in this lecture let us re insist that in the aspect of looking VIV. We are not focusing on the hydrodynamic effects or the causes for vortex induced vibration. What we are looking at is in the designer's perspective.

If the vortex induced vibration is happening is created, where are they created, why are they created, how are they created, how what are the significance if they are created and the designers perspective can I handle them. So, my whole angle of looking at VIV is not on hydrodynamic perspective. It is under designer perspective. So, if you really wanted to look at the reasons the equations or the simulations of numerical analytical studies of VIV on different members, for example, on riser. For example, on cylindrical member etc., I would request you that you should look into some alternate parallel courses, which discuss on generation of this kind of response on members in the hydrodynamic perspective.

This lecture will focus only on the designer's perspective of VIV effects on members. Is that clear? I made it clear in the last lecture. Let us re insist again, so that… Let us not look forward, to look at the details of hydrodynamic aspects of flow induced vibration. That is not the focus of the lecture at all now. The moment I say risers, it is most commonly deployed kind of risers in floating structures. Our aim is addressing floating structures, because they are the third generation structures these days for deep water oil exploration. So, most commonly deployed riser,; on the moment I say floating it includes complain type structures as well, does not mean always floating structures are drill ships and FPS source, can also be TLP's floating structures, is top tension risers.

We discussed very briefly about this in the last lecture. But still let us start from this point to understand better how we handle response control of secondary vibrations, which are induced by VIV. Essentially risers are links. If you look at risers as a member risers are nothing but links or connections between the sea bed and the top sea. For all practical purposes they can be considered as cylinders, subjected to lateral loads. The lateral loads can be essentially from wave and current of course. You cannot ignore the impact loads caused by the vessels. That part anyway we are not discussing here.

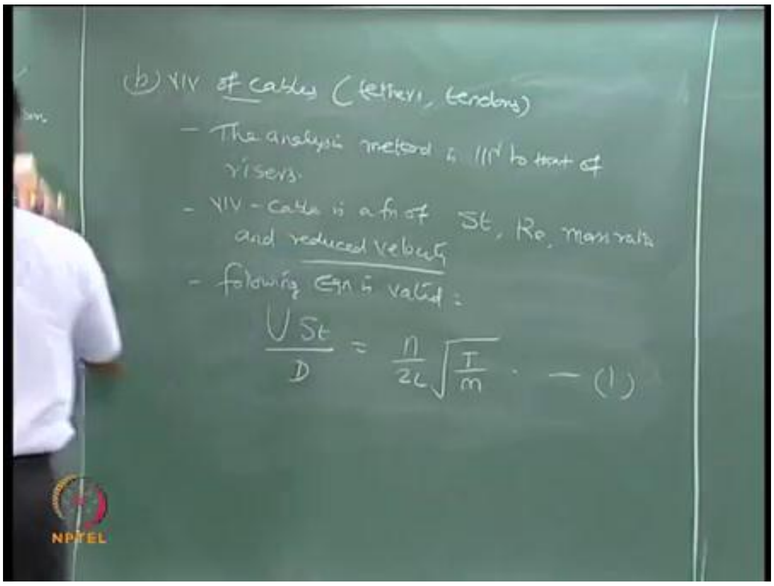
(Refer Slide Time: 10:19)



So, for dynamic response of risers, one can use the modified Morison equation and the lift forces. We have already given you the equations to compute lift forces for this kind of activities. The hydrodynamic analysis is carried out using discrete vortex method. This method is actually based on Lagrangian technique, for simulating the 2 d potential flow in the compressible and viscous flow. For analysis case, the risers are considered as beam columns subjected to lateral loads. Thus essentially, comes from wave current etc. In addition to this loading, there will be load caused by the pressure difference between internal and external of the riser. I should say differential pressure between inside and outside of the risers.

So, where you are now looking for, have to actually analyze the different members of marine structures for flow induced vibration. One common technique, which people have used for risers, is discrete vortex method. Of course, for conducting dynamic analysis of risers or dynamic response analysis of risers, people have simply used the Morison’s equation in the modified form and did the dynamic analysis. Of course, they will account for the lift forces also in the analysis. You can find numerous papers in the literature, which talks about dynamic response analysis of risers.

(Refer Slide Time: 15:18)



The next part is VIV of let us say cables. Cables are inherent component of any kind of floating system essentially when you talk about third generation platforms, where we are thinking of deploying marine structures are off shore platforms in deep and in ultra deep waters. Obviously, we cannot have the column members for the entire length of the water depth. They are going to be highly and exponentially, I mean very expensive. Therefore, people really go for positive buoyant floating system, where the portion restrained of the system is essentially hilled down by group of tethers what we call as tendons or cables, so I can say etc.

The moment we say cables or tendons or tethers, you will realize immediately that the cross sectional dimension or the projected area of the cable, for the lateral loading from the wave and current is much lesser compared to the top, any pontoons or any column members of a floating structure. They are very large in dimension, because they are positively buoyant. They should have a large draft or a large immersed volume. So, they have a very large diameter varying from 12 meters to as high as 16 17 meters, whereas the cable diameters may vary from 300 millimeters to 400 millimeters. They can be in clusters they can be in groups.

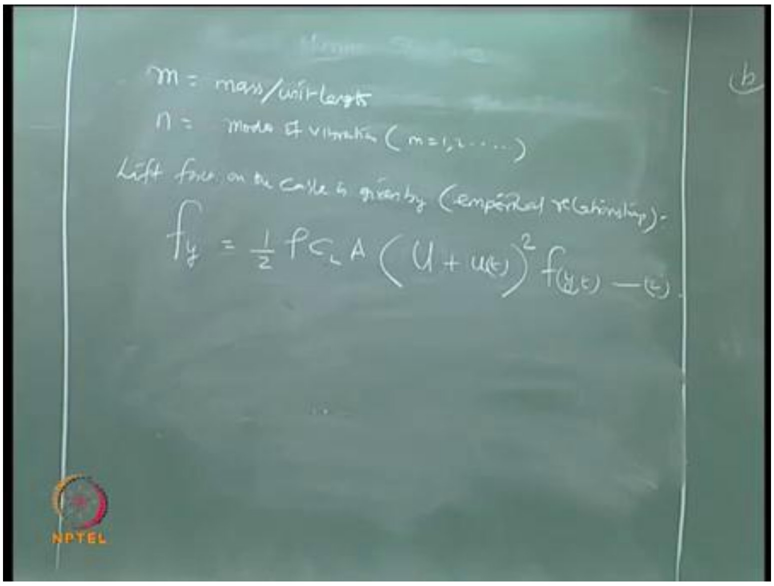
So, their projected diameter, which can interact with the fluid flow or which interfere on the fluid domain or the fluid flow field is marginal or very less in comparison to that of the members. Therefore, one can expect that the effect of flow induced vibration on these members will be different from that of the member with a very large diameter. We already understood in the previous case, that vortex induced vibrations or functions of diameters of the members. So, the projected diameter of these kind of members are relatively small or insignificant compared to the diameter of the column members or pontoon members in a given off shore platform. Is it or not?

Then, how do we handle VIV for cables. Cables are susceptible to higher order vibrations otherwise, because they are in axial tension and they have to maintain a specific profile; may be a centenary profile. They cannot be always thought more, because of the action of the waves in terms of its direction and oblige angles, you will always see the T zero variation in the legs will not be always uniform. There can be slackening happening in the cable. The cable can also be tightening. So, there is always a reversal of forces happening in the cable so cable will always not remain in a tot mode system. There can be always a slackening happening depending upon the wave action or the set down action of the platform depending upon the swell on the waves.

So, VIVs of cable are also handle similar set of risers. VIV happening on cables is a function of Strouhal number, Reynolds number, mass ratio we already said what mass ratio is we already described what mass ratio is in the last lecture and reduced velocity. First of all, we must understand why the velocity is getting reduced. Whenever a member interfere the fluid field flow field, you will see that because of the group effect on the member the velocity encountering the member gets retard or reduced. The reduction of velocity one may be happy that the forces may get reduced; it is not true. This is going to increase the force on the members. This is what we call as, what is the effect, which is accounted for in the codes for this blockage factor.

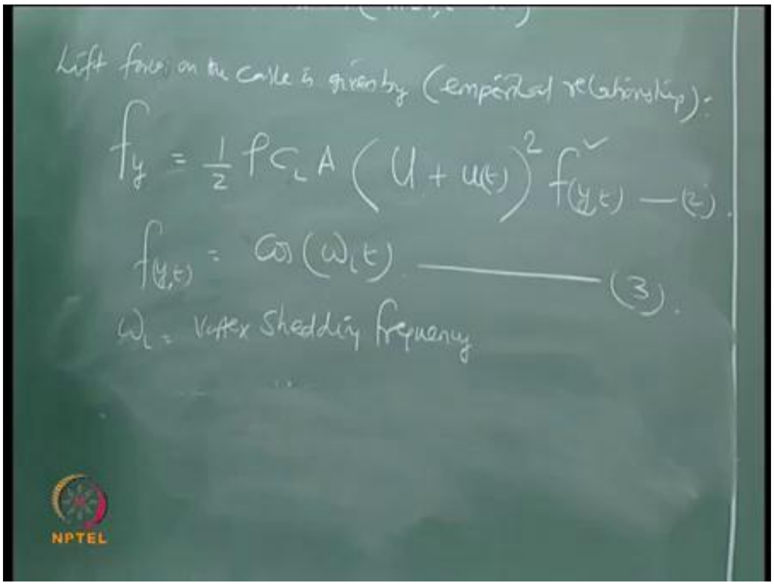
We already seen the equations given by API for computing the blockage factor, whether the members are in single with they are in clusters or groups. So, reduced velocity creates additional forces or increment in force in the members, because of blockage effect number one. Number two you see the maximum force not going to happen and the free surface will shift towards the d by 2 of the member or l by 2 of the member, half of the length of the member. So, VIV in cables is a function of, of course, Strouhal numbers which is a function of diameter and Reynolds number. So, the following equation varies which is valid. Of course, St stands for the Strouhal number, d stands for the diameter, U stands for the mean velocity component of the flow, and m is the mass per unit length, that is important to write.

(Refer Slide Time: 22:07)



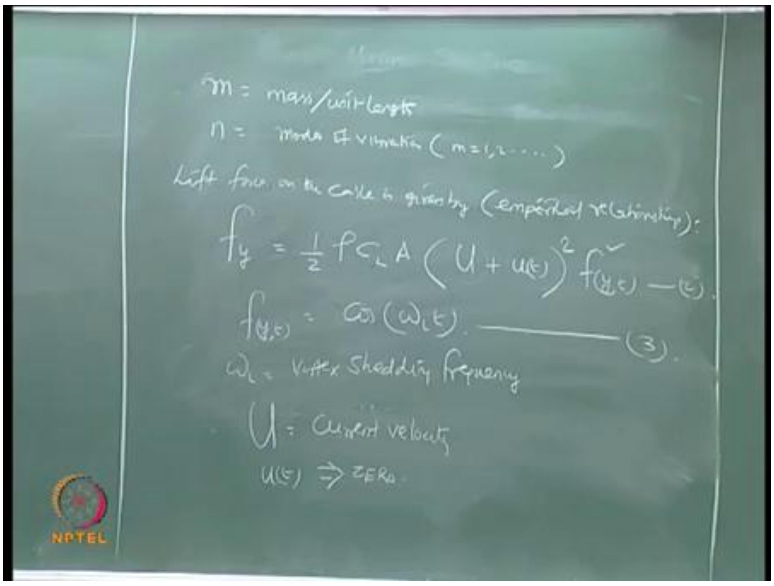
n here denotes the number of modes of simply we say modes of vibration. Now, the lift force I said set we must include the lift force also. The lift force on the cable is given by; again I am using an empirical relationship, which is f y half rho C L A U plus u of t whole square f of y t. We can see that the lift forces will be random phenomena, because the time dependent component and the mean component are added. CL is a lift force coefficient. Row of course, the mass density and f y t, f y t in this equation, is cause of omega L of t, whereas omega L is called vortex shedding frequency.

(Refer Slide Time: 24:01)



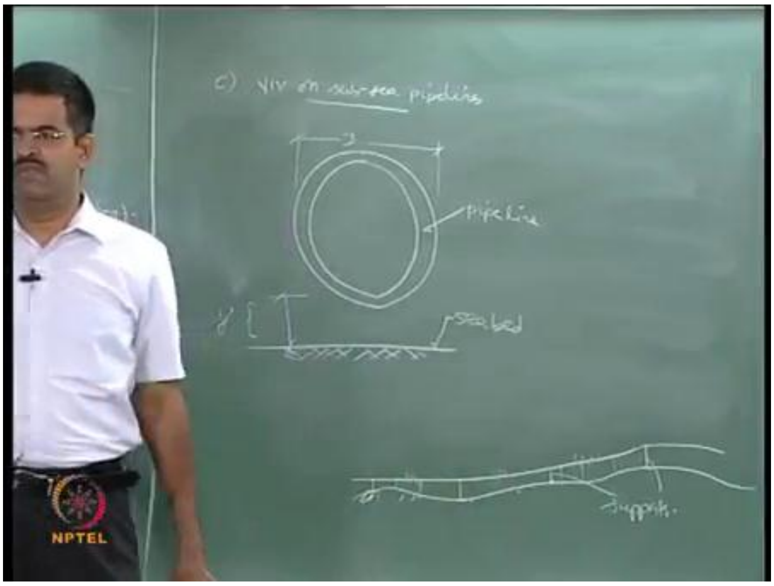
In this case, U is set to the current velocity and u of t is generally set to 0 in the analysis.

(Refer Slide Time: 24:49)



Let us talk about VIV on subsea pipelines. The primary factor, which influences the secondary vibration caused by the vortex shedding on the subsea pipelines, is the proximity of the pipeline, with respect to the sea bed. If this is my pipeline, let us say of some thickness whose diameter is d. This is my seabed. This is pipeline. Proximity of the pipeline with respect to the seabed is a governing parameter, which controls or which induces significantly the secondary vibration on the pipeline, which is caused by the shedding vortex shedding frequencies.

(Refer Slide Time: 25:16)

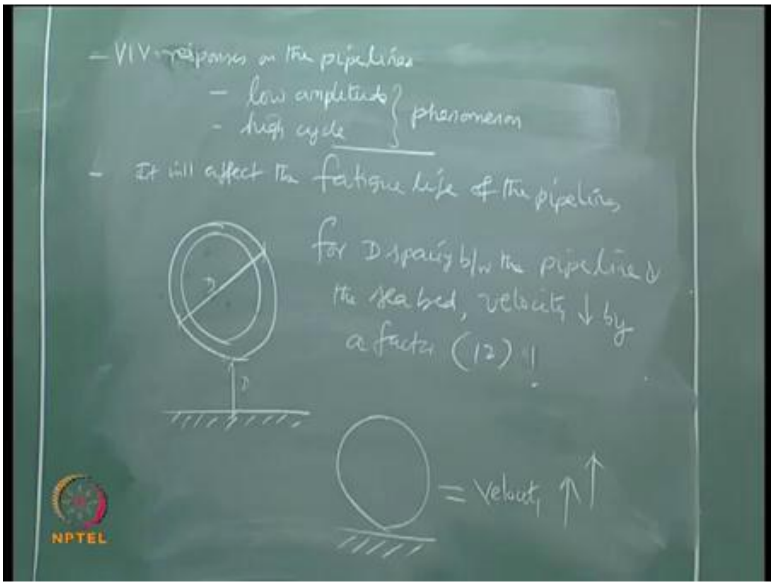


Now, one will wonder, that how this will vary. One can think, sir I want prefix this value, so that the effect of VIV on the sub-sea pipeline will be lower. You cannot prefix because of the following reasons. Let us say I have a sea bed profile. This is a sea bed profile, which is of course not uniform, is undulating. You lay the pipeline more or less parallel to this, thinking that you want to maintain the constant depth or constant gap between the pipeline and the seabed, which decreases or tend to decrease the VIV effect on the pipeline.

Obviously, you cannot actually have a supported support less link pipeline for a large length. Is it or not? The length of the pipeline is got to be supported at intermediate requirements. Let us say, these are my supports. Now, let us look this problem in a different manner the unsupported link between the supports of the pipeline will have a variation in this value of y prime anywhere. You cannot control this, because it will vibrate. This variation will occur too, because of the sea beds covering seabed deposition. Again this will vary.

Thirdly, when any one of the support failed which you could not identify instantaneously you will come to know only after a specific point of time. The unsupported length of the pipeline increases, which causes very high frequency by vibrations on the pipeline structurally. Forget about VIV. A support of a span and the support of b span where b is much larger then a, the vibrations induced on the pipeline of the member will be different from that of a.

(Refer Slide Time: 29:32)



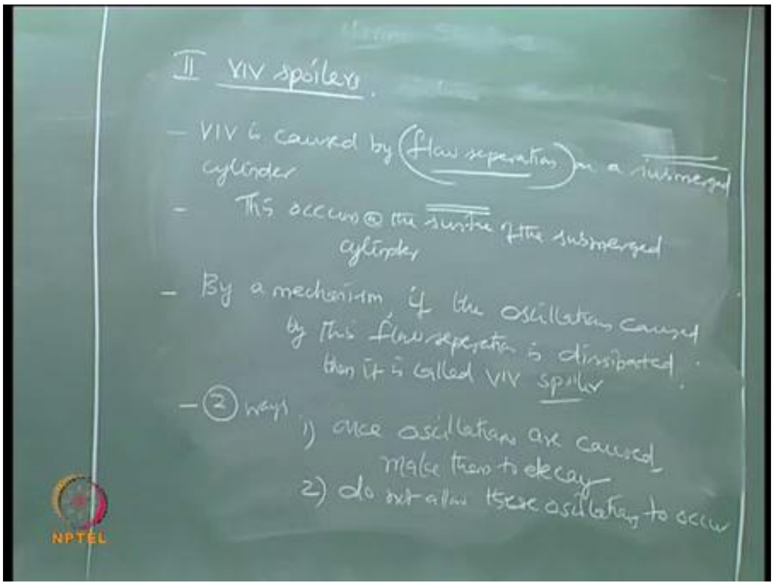
So, the VIV induced responses on the pipeline are generally low amplitude and high cycle phenomena. Interestingly, it will affect the fatigue life of the pipeline. Suppose, if you have the diameter of the pipeline as d and this spacing is also d; for d spacing between the pipeline and the seabed. It is seen that the velocity reduces by a factor of as high as 12. It has been seen experimentally, that the velocity gets reduced. Now, when the pipeline is very close to the proximity, simply it is resting; in this case the velocity increases significantly.

So, people have seen, that the ideal design parameter to control the secondary responses on the subsea pipelines, which is induced by vortex shedding frequencies is simply place the pipeline, alters gap of equivalent to the diameter of the pipeline from the sea bed. Now, we are talking about pipes, which are about HDPE high density polyethylene pipelines of a very large diameter. May be 10 meters 8 6 meters etc; specially fabricated pipelines. So, we have to have a gap about 6 meters, let us say. So, 6 meter gap, you cannot simply leave the pipeline as it is.

There are designs, which will hold the pipeline position, which are called as anchors. These anchors or these collars will be placed at uniform spacing along the length of the pipeline, which will make the pipeline to rest indirectly in the seabed by maintaining a gap of d. But, this gap of d cannot be ensure, because sea beds covering deposition etc or dredging etc will start affecting this gap.

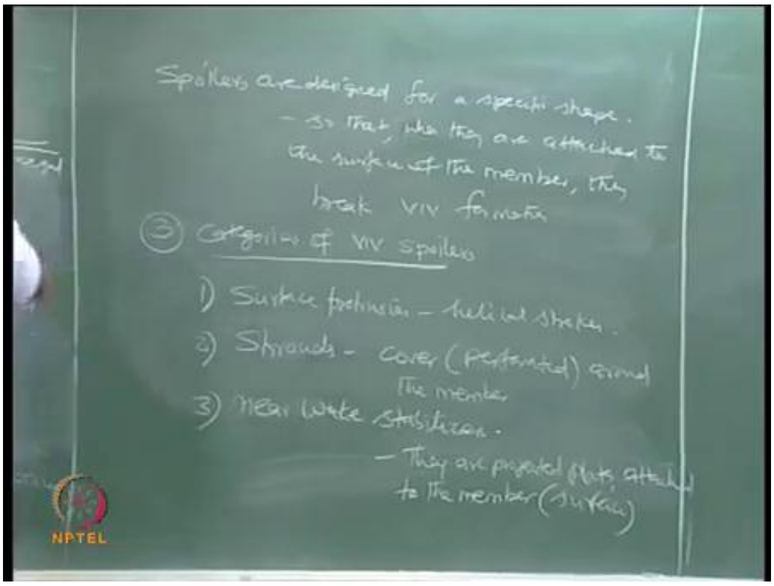
As the pipeline comes closer and closer to the seabed the velocity will keep on increasing. There is a one important aspect what we want to discuss about the response caused by VIV on subsea pipelines. Say essentially the hint or the clue or the suggestion or the guideline given to the designers of marine structures is that, see that the gap of d is at least maintained between the pipeline and the sea bed. The next application will be response control using what we call VIV spoiler.

(Refer Slide Time: 34:11)



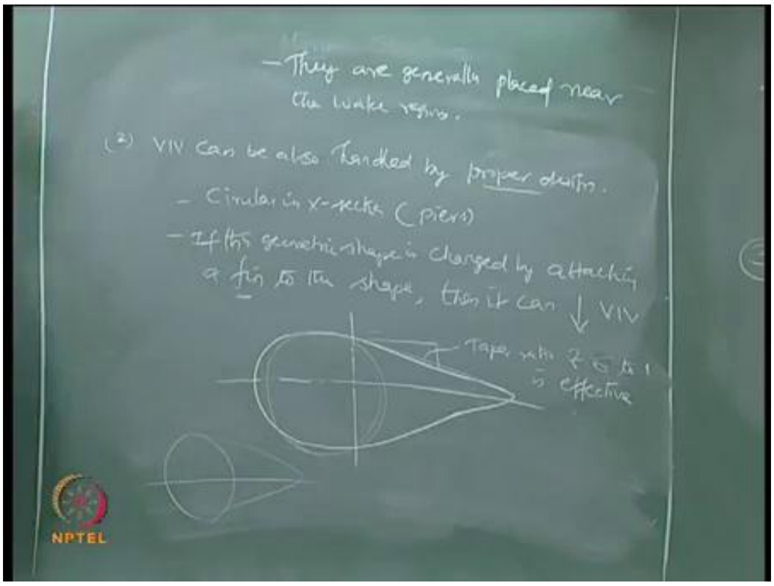
There are something called VIV spoilers. We all know that VIV is caused by flow separation on a submerged cylinder and this occurs at the surface of the submerged cylinder. Is it or not? It occurs at the surface, when the cylinder is submerged. Essentially this is due to the flow separation. The flow gets detached from the member. Now, by a mechanism, if the oscillations caused by this flow separation is dissipated, then it is called VIV spoiler. We can do this with two ways. First, once the oscillations are caused, make them to decay. That is one method. The second is, do not allow these oscillations to occur. Both are called spoilers. Either stop them from occurrence or let them form and have a mechanism to decay them or to control them or to dissipate. Both of them are spoiler.

(Refer Slide Time: 37:50)



Therefore, spoilers are designed for a specific shape, so that when they are attached to the surface of the member they break VIV format. There are three categories of VIV spoilers. One is by surface protrusion by helical strakes. The other one is shrouds, is nothing but a cover which is perforated around the member; provide a pores cover around the member this called shrouds. Near wake spoilers near wake stabilizers, they are projected plates attached to the member at its surface. They are generally located near wake region.

(Refer Slide Time: 41:10)



That is why they are called wake region stabilizers. Now, VIV can be also handled by a proper design. You can understand very well in marine structures that they are pear supported structures in shallow waters. For example, costal structures; they are pear supporter's structures in shallow waters. Generally, pears are circular in shape, if you make the geometric shape. If this geometric shape is changed by attaching a fin to the shape, then it can reduce VIV. Let us see how this shape will look like.

The tapper ratio; this ratio of 6 is to 1 is effect. 6 horizontal, 1 vertical that is the tapper ratio. This is found to be effective for reducing behaviors. So, instead of having a circular shape, attach a fin to it. Instead of having a circular shape, attach a fin and extend it. So, this can reduce the VIV effect on submerged structures like pear's. The third suggestion or the idea recommendation given by the practical designers; see in the literature for controlling VIV responses or have or ensure smooth surface of the members.

(Refer Slide Time: 45:01)

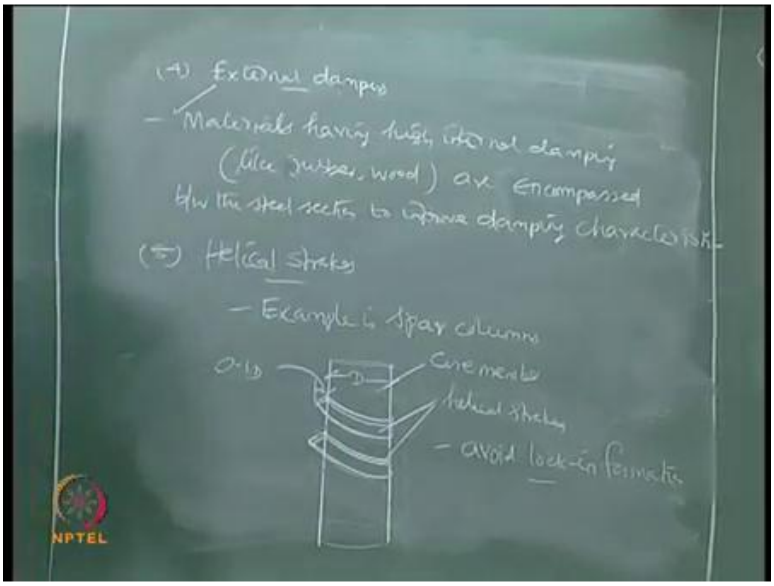
So, if you have a smooth surface of the members, it is very well evidently seen in the studies that VIV or the responses or the vibrations oscillation caused by VIV on smooth surfaces is significantly lower. In addition, we also know that surface roughness is otherwise unavoidable in marine structures because corrosion affects marine growth etc. We also know surface roughness alters C d C m coefficient. Is it not? C d C m coefficient. So, they have increased effect in the Morison coefficient C d C m drag inertia coefficient, forces will be higher.

So, it is seen that if you can ensures a smooth surface. What is suggestion as a designer, people are now looking for composite layering on the members. Can have an epoxy coated layer can have an STP layer strapping layer around the cylinders, so that the marine growth or the corrosion effects are minimized and the surface remains smooth. It reduces the force that is one advantage. It enhances the maintainability of the system second advantage. Third it reduces oscillations due to VIV. Now, this effect is a later theory of research in marine structures, where we call as people look for functionally graded materials.

It is not a new material. It is a composition of various materials where the outer cover… This is the inner core is actually my member, maybe steel. The outer covers or outer layers are all different depending upon the applicability what you are looking at, because on the outer surface the stress variations or the stress design may not be an important parameter. The stress we got may be taken by the inner core, the outer should function essentially for reduction of corrosion effects and reduction of marine growth or formation of smoothness on the surface. So, these characteristics or the functional requirements of these outer layers are different than that of a core layer.

When you form a material artificially and combine them as a composite for analysis, we call this kind of material as functionally graded material. It is a latest area of research, where people looking for different kinds of composite align together to form a member or a material for a member. It can be used in underwater constructions not necessarily for marine application or marine structures even for bridge pears, people are looking for this kind. This will enhance the serviceable life of the structure and reduces the forces on the members. It of course, in the context of the present discussion, it reduces effects of VIV on the members. We will have one more application very quickly, which will end this lecture.

(Refer Slide Time: 49:52)



People use external dampers for controlling responses or vibrations caused by VIV. So, materials having high internal damping like rubber wood or sandwiched let us say or encompassed between the steel sections to improve the damping characteristics. Damping is nothing but, energy absorption characteristic. Dissipation of energy is damping. To improve the damping characteristics is another way by which you can design the system to control the responses caused by secondary vibrations, resulting from vortex shedding frequencies. The next application quickly is that helical strakes. Best example is spark columns.

These are all streaks, so are nothing but plates projected circumferentially around the member. This is the original member, the core member around the member in the helical form. Now, if I say this is my d the diameter of the member, which is the original core member. Then, essentially these projections are limited to 10 percent of that 0.1 d. So, these kinds of helical projections, what we call as helical strakes are found to be very effective in reducing the responses caused by vortex shedding frequencies and members. Best example is spark columns.

You will find helical strakes columns and spar members, where it has been used. But they have other parallel demerits. What are the parallel demerits of this? Anyone demerits anyone disadvantage; marine growth, surface roughness projection will increase c d c m etcetera. There are other parallel effects of this. But, this is seen as one of the effective alternative, which can reduce responses on the member induce essentially vortex shedding frequencies. This are called helical strakes. It is been seen that this strakes avoid lock in formation.

So, in this lecture we have quickly seen, what are the different methods by which the VIV induce responses can be analyzed. The hydrodynamic aspect of modeling of this VIV formation is not discussed in the lecture. We are looking this in the designer's perspective; what would be the counter effect if VIV is set in my member. Why are they set in is what we discussed in last lecture. So, in this lecture we also summarize what are different techniques, external internal material design etc. How VIV induce responses can be controlled or minimize as a designer or as an idea, where I can use external members or additional members to safe guard my original core member from VIV induce responses?

So, this ends this lecture on VIV. The next lecture we will talk about one important application of reduction of VIV, using porous outer cover and members. We have already seen one of the design principles is we can use porous cover. So, we will discuss the experimental and numerical modeling of an example case, which we did on a porous outer layer. We see how the forces are essentially getting reduced hydrodynamic forces are getting reduced on the members. We are now not focusing exactly reduction of VIV on the members, but we will discuss how this can be effective in force reduction.

Thanks.