Dynamics of Ocean Structures

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Lecture - 9
Multi-Legged Articulated Towers

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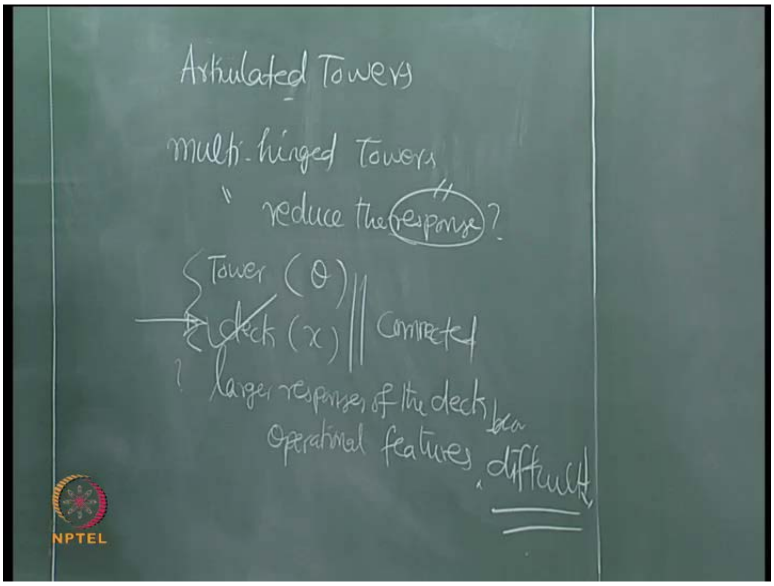

In the last lecture we discussed about the dynamic and a response analysis of articulated towers. We also discussed about the advantages of multi-hinged towers. In the primary focus of introducing multi hinges and multi legs were to reduce the response. The moment I say response, what is the response we are interested in. There are two kinds of responses here; one is the tower response which is measured in theta, the other is the deck response which is measured in x.

Of course, they are connected depending upon the length of the tower, if I know theta which is angel at the hinge at the bottom, so, I know the x value, both are connected. So, one is interested in reducing essentially the deck response, there may be reasons why it is done. The reason is, for larger the deck is responses, for larger responses of the deck the operational features becomes difficult becomes difficult. So, I want to make it easy, I have to reduce the response essentially the deck. So, the method attempted by designers in terms of its form, we have to introduce multi hinges we have to introduce multi legs. So, that is what we have introduced in the last lecture.

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In this lecture we will talk about the lecture 9 on module 2, where we talk about the response control of multi legged articulated tower using an artificial technique we will see how it is done? So just to understand, how we are attempting to control the response in the multi-legged articulated tower. We will first try to understand, what are the different methods available to achieve response control of any structural system? In general very few slides very quickly we will browse through because response control algorithm itself is an area of research. We will very quickly browse what are the different method which are commonly practice in structural engendering to attempt for response may be land based, may be offshore.

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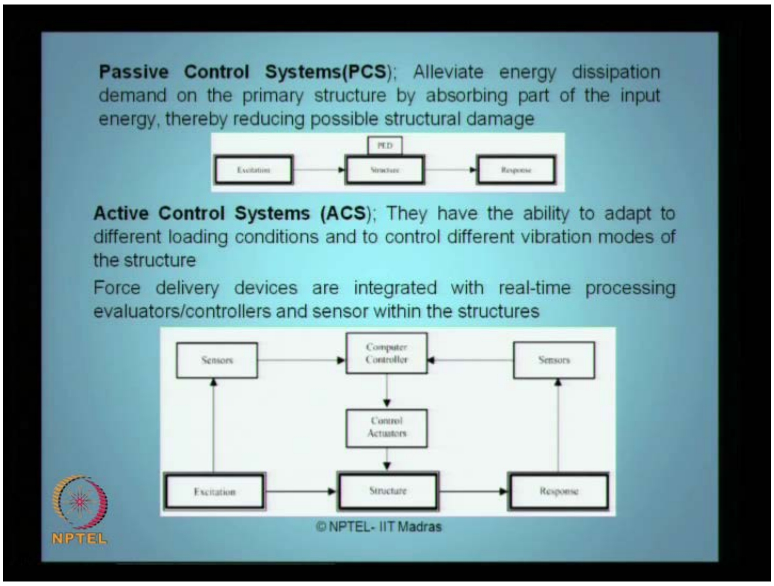

So, foremost idea what people borrowed in the early 70s is what they call as passive control systems. Passive control system float diagram looks like this when the excitation when the excitation acts on the structure, the structure has a secondary mass system which control the response that how the response is controlled. On the other hand, the energy dissipation demand and the primary structure are achieved by observing the part of the energy and they have been reducing the response. This is what they call as passive control systems. So, I do not need any extra power, I do not need any artificial intelligence to tune my system. Simply, what I do is? I attempt the secondary mass to my system, the secondary mass can have damping, can have stiffness, can have mass as proportional to the primary mass system.

So, I put a secondary mass system to the primary structure, I tune the secondary mass in such a manner that the response of the primary structure is controlled. This is what we call it passive controller algorithms. Followed by which people said this is not efficient they wanted to have it more dynamic in nature. One may say what is the dynamicity is involved in this?

Now, remember very importantly when impose on excitation time history to my structure which is a time variant phenomena I want my secondary mass system to be triggered or activated in the direction opposite to the top the response actuated by the exciting force. For example, the exciting force moves my structure to the right; I must have secondary mass system or a mechanism which control the motion by moving the structure to the left. So, there should be a compensative algorithm which is triggered off in the system which should be also time variant and which should be also intelligent enough to first force what is the excitation afford to the system and what force should we offer back to the structure, so the structure does not move.

So, people said can I do this kind of active controller algorithms so, that is what people attempt in early 80s saying that active control systems where started coming into play. These structure or these systems have an ability to adapt to different loading conditions as I said, depending upon its magnitude, depending upon its time instant it can activate any kind of counter loading on the structure which can control the response of the primary system with respect to the plat e exciting force.

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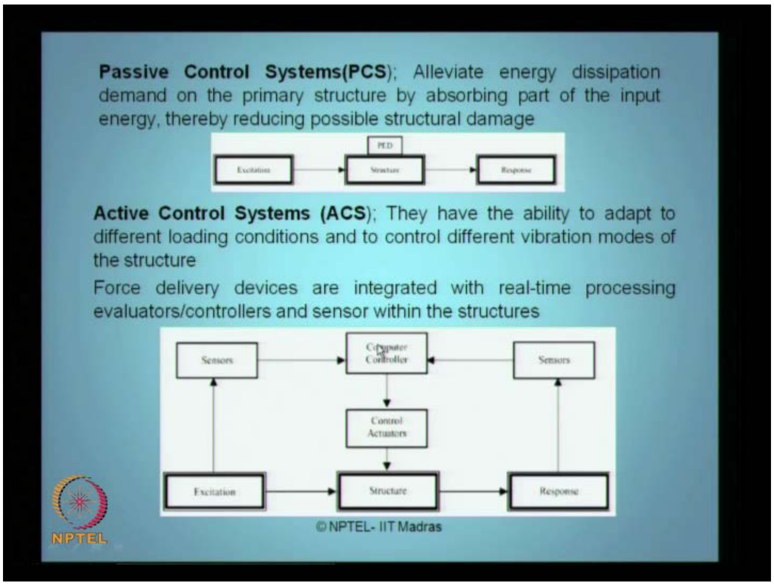

So, obviously this is more into dynamic in nature because this controls the vibration modes of the structure. So, how this is achieved? This has a very simple algorithm here. So, I have an exciting force, I have a structural system which gives me response this is as same as the primary system available here. Now, what I do here is, I put a control actuator attach to the structure, the control activator receive the signal using a computer algorithm which receives internal from the sensor of the exciting force. So, the sensor of the exacting force forwards the signal in advance to the control actuator using the algorithm and therefore, this applies the response back to my structure.

On the other hand, when the response applied to the structure is satisfactory I also get sensor receives from the response of the structure which feedbacks to the computer algorithm and stops this control activator. So, the actuator mechanism triggering on and off it is actually control by this algorithm, which receives when it is to be on and when it is to be off. So, what we call in general is artificial intelligence of the structure system. So, people also call this is ANN which is artificial neural networking.

So, the structural system has got to be tune for different kinds of exciting forces with the previous history what you have. Then, for that magnitude and time instance reach in the structure, the control mechanism or the control actuators has got to trigger on or trigger off so that, it produces a response which is compensative to the response that is otherwise cost by the exciting force.

Now, here you can obviously see, it takes lot of mechanical electronic interface because this needs a mechanical system because it requires lot of actuators. One can wonder that, why I need the largest this actuators? Then see, the reason being very simple all my structure where I am looking at for my responses are massive. So, I have a lot of inertia force developed at the structure when it is subjected to vibration modes. So, I must have a compensative force mechanism in terms of that mode of inertia force. Therefore, actuators need lot of power to produce that force in the compensative algorithm.

And also it needs an electric interface because it should have a sensor which governs the control actuator to trigger on the system as when it require and as when it is to be stopped. So, it needs lot of external power, it needs lot of computer algorithm interface and electronic interface with the mechanical system in the given design. Therefore, these systems are very expensive.

And also above all most importantly, the control actuators and the control algorithm should be tuned to the existing possible exciting forces which can come on the structure. For example, if the structure encounters all new time mystery for which this ne2rk does not been tuned this may not be as effective as you expect. So, the initially investment on this kind control algorithm or control mechanism is very high.

But, it proves to be very effective because you see obviously here I get the feet forward and feet forward look this is what I call a feet forward loop because this sensor posses on my exciting force in advance to my algorithm. This is what I call a feed backward loop because this sensor posses on the response of the structure and tells me system you please reduce a forces which are compromising the exciting forces so on. So, did intelligence interface it is a very interesting method and it has been attempted in land way structure essentially may countries but, predominantly in Japan.

These kind of structures or system mechanism controls where been found defective when you got all buildings were wind responses becomes predominantly high. If you ask me in the history of control mechanism and offshore structure so, far this kind of control mechanism I have never attempted in offshore except on ship halls were people use the buoyancy tanks as an indirect force of mechanism by using the sloshing value of the of the liquid inside the damping tanks or inside the buoyancy tanks to control the response.

So, because every hall has a buoyancy tank or every ship has a buoyancy tank there is liquid store in the buoyancy tank the sloshing effect of this liquid has been indirectly use as one of the mechanism. So, under the given knowledge what you have acquire now, in this one slide you can always tell that, control the response of a hall of a ship or a ship motion visas is using let us say the buoyancy tanks or the sloshing effect of the liquid is a passive mechanism because it has neither a feed forward nor a feed backward loop. So, it is basically mechanical system which is triggered on its own, because of the vibration mode being set in the hall and it activates the control or it comprises the response in the direction not necessarily opposite but, usually opposite because it has been tuned in such a fashion. So, passive control mechanisms have been attempted on floating structure that is the hint what we get from this like, whereas, active control mechanism are expensive and therefore, they are not very successful even on land base structure.

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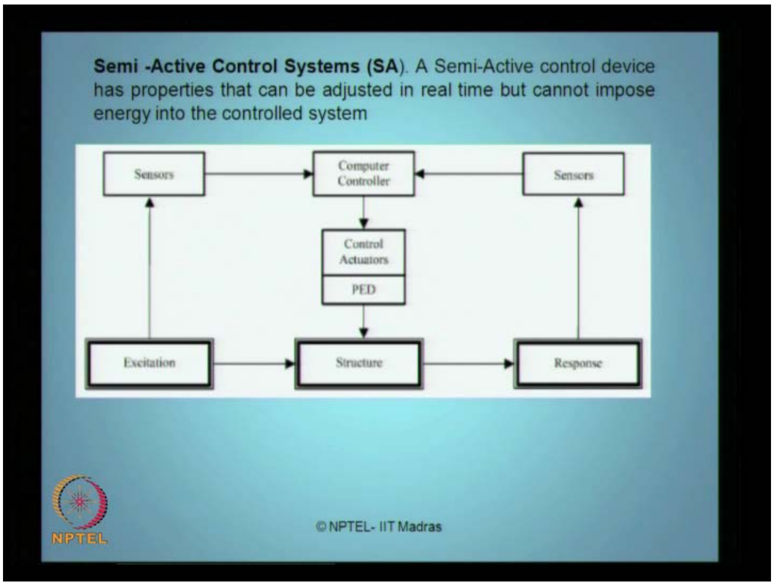

I have one more what is called semi active? So, it is a combination hybrid combination of passive and active. So, what I do is, I do not do the control mechanism completely on the real time, I partially do it on the off time and partially in the real time. Therefore, this has been seen as an advantage over the actual control mechanism, because the energy required for operating a semi active control system is far less in comparison to that of the actual or active control mechanism.

So, people have used this as a via media between a passive control mechanism and active control mechanism. That is why it is named as semi active control mechanism. So, the idea of applying this to offshore structure has been a fascinating idea and first the need or the necessity to the methodology. Both are important for us in dynamic perspective. So, in this lecture we will address that one example and see how a control mechanism has been attempted and how this has been verified, analytically and experimentally in a research for problem which has been attempted by us recently. We will talk about that in this lecture.

So, first we must agree that why I need to control the response. We have already seen as far as complaint structure or flexible structure are concerned, we see the response on the deck is fairly high on soft degrees of freedom, not necessarily in heel or steep degrees of freedom. On soft degrees of freedom, the response generally goes high. You may wonder the response how it is going high when the force not going high because force is not going high due to a simple reason the relative component in the drag forces risk. System is very compliant.

That is what we all saw in the last lecture conclusion saying that as the tower becomes highly flexible the forces on the system are reduced. So, on the other hand if are attempted a design your flexible system for deep and ultra-deep waters it is expected that your deck response is going to be on the larger dimension. So, if you want to do a comfortable operation on the deck for drilling production inspection whatever may be the reason why we are using the platform for I need to have a control environment whereas, my deck response may not become 0, but or should controlled within the threshold acceptable value. Is that clear? So, this is attempt which has been tried by people in researchers. It is not a new idea since, 90s people had attempted this idea. We will see quickly a literature review also on this.

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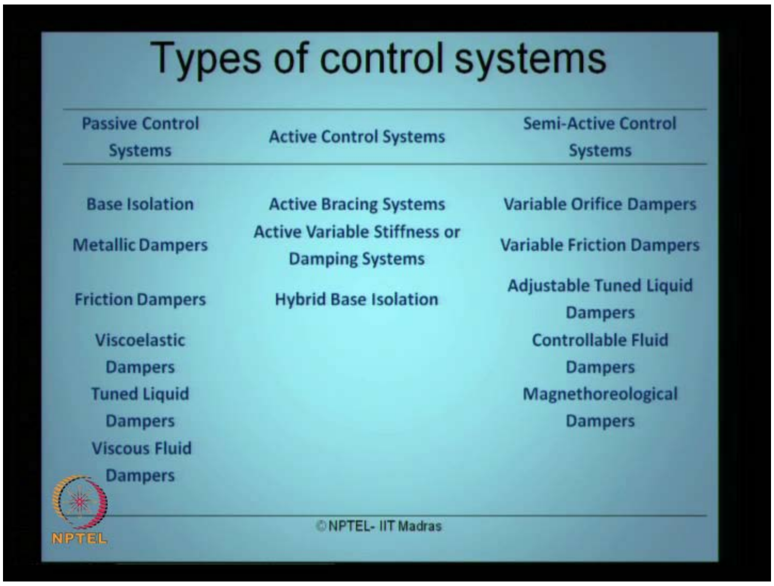

So, we will move further. It is a very interesting summary table which is tells us what are the different types of control mechanism attempted in general, in structure engineering. Not necessary to offshore engineering. Fully a passive control, base isolation, metallic dampers, friction dampers, viscoelastic dampers, tuned liquid dampers, viscous dampers are all different techniques adopted. If you look at the active control mechanism people say active bracing system, active variable stiffness or damping system hybrid base isolation techniques have been used. If you look at semi active, people have used variable orifice dampers, variable friction dampers, adjustable TLD what we call tuned liquid dampers, controllable fluid dampers and MR dampers that is, Magnetorheological dampers. This is special kind of fluid which has got magnetic property as well as friction as well as viscous damping both inherently provided in the fluid. So, these are different mechanism being attempted in structure engineering for response control of structures.

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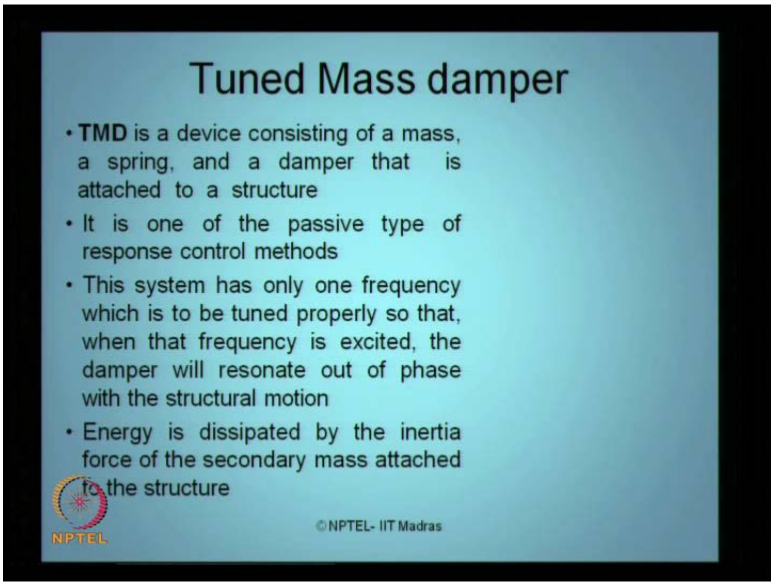

In this present example, we will pick up one of the passive system what we call is tuned mass damper. I will come to that what I am exactly tuning in my problem. TMD briefly abbreviated for tuned mass dampers, is the devise which consist of essentially a mass spring and the damper or without the damper. It has a mass and a spring because I need stiffness in the mass, I may or may not have damping it that, with or without the damper which will attach the structure as a secondary system, that is what the passive system is. Therefore, it is a passive type of response algorithm.

Now, more interestingly in dynamics perspective the system actually uses only one fundamental frequency for which you must tune the system. So, interestingly one may wonder, what is the frequency I must tune to the system for? There are 2 frequencies which I would not like to tune: one is the excitation frequency, one is the natural frequency of the primary system.

There are 2 frequencies you can tune: one is the excitation frequency of your force may be wave or wind whatever may be or we can say to be precise the predominant excitation frequency because excitation frequency may vary for a wide band. They may say the predominant excitation frequency is 1 band where I can tune. The other is of course, the fundamental frequency of the primary system. So, what should I tune for? It is a very interesting question. It is a dynamic problem because I want to tune it that is why we call this is tuned mass dampers. If you tune it, it is sure that the energy will be decapitated by the secondary mass system attached to the primary system that is sure.

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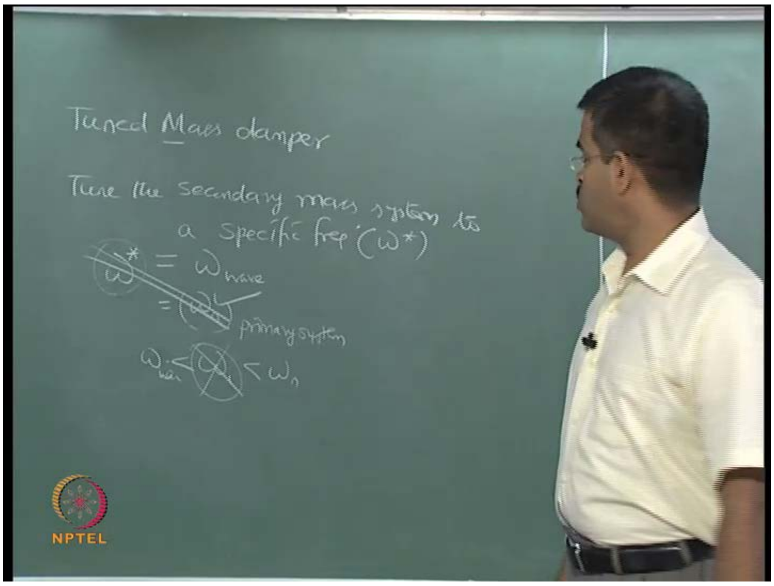

So, there are 2 questions asked here. In case of TMD, I want to tune the secondary mass system to specific frequency. Will this frequency which I am putting omega star will be exactly equal to omega of the wave, the dominant frequency or should it be equal to omega natural of the primary system. Let us quickly understand the consequence of this. If I tune the frequency of my secondary mass system which is omega star to that of the wave you will obviously, see the secondary mass system will have its maximum response when it exciting the specific dominant frequency of the exciting force, which may damage the secondary mass system.

If I tune this to the fundamental frequency of the primary system then, the response of the primary with respect to secondary may also go high it may in turn damage the primary system also. Is there any other I can tune this frequency other than this 2. For example, if I say I tune anywhere in between omega 1 which is less than omega wave and less than omega n for example, it can be other way also. I picked up any frequency, I can tune this because tuning means adjusting k and m of the secondary mass system I can tune this in such a way that this omega is neither equal to the dominant frequency of the wave or the exciting force nor equal to the natural frequency of the primary system, I will not get any advantage of this at all it will be a added mass to the system that is all, is not going to control.

Interestingly, you will see that this is what which is generally adopted. You may wonder that the primary mass system when tuned to the frequency of the secondary mass system there are response in the secondary primary mu, you will see in a video they show you now, when you tune this, this will ramp out of phase of this. So, the secondary mass system will bring the response in the opposite direction to that of the primary system. So, the secondary mass system should be tune in such a fashion that this should run or this vibrate out of phase of the primary. Why I am tuning to them maximum because this is where I will get the maximum response possible. So, we will show you video very clearly that how this goes out of phase with that of this and what is the advantage I get by tuning this. So, this is my primary and secondary mass system is a simple 2 freedom system model.

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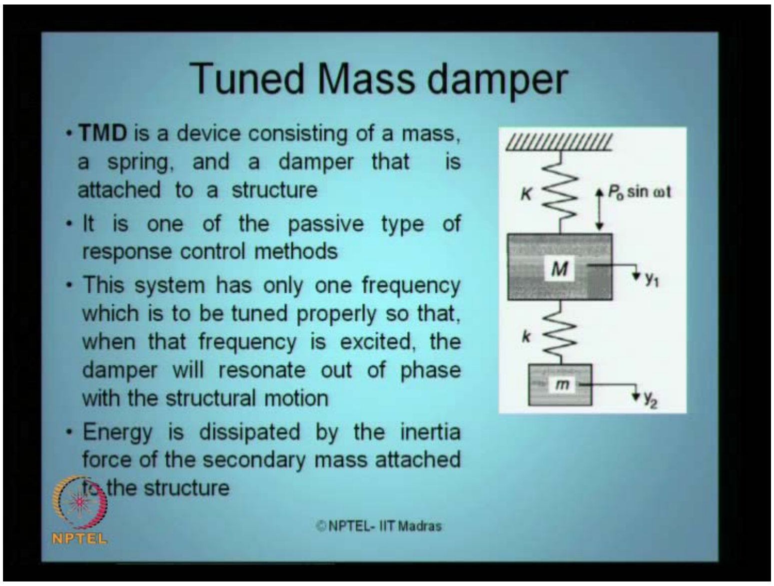

The primary system is M and K, the secondary system is small m and small k. Capital K is the primary system, y 1 and y 2 are my degrees of freedom and so on and here it the secondary mass does not have a damper. The primary mass does not also have a damper but, primary mass will have hinged damping because of the viscous properties present in the fluid medium so it will be there.

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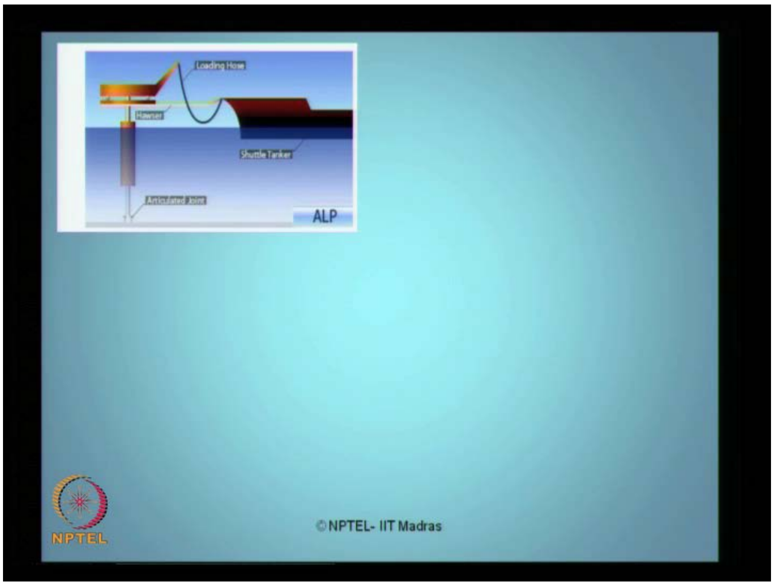

Let us quickly see what people have attempted in the literature of the offshore structure for this and then, we will move forward how we are going to do it. It is a single figure which we already shown, it is a single legged articulated tower which is a ALP.

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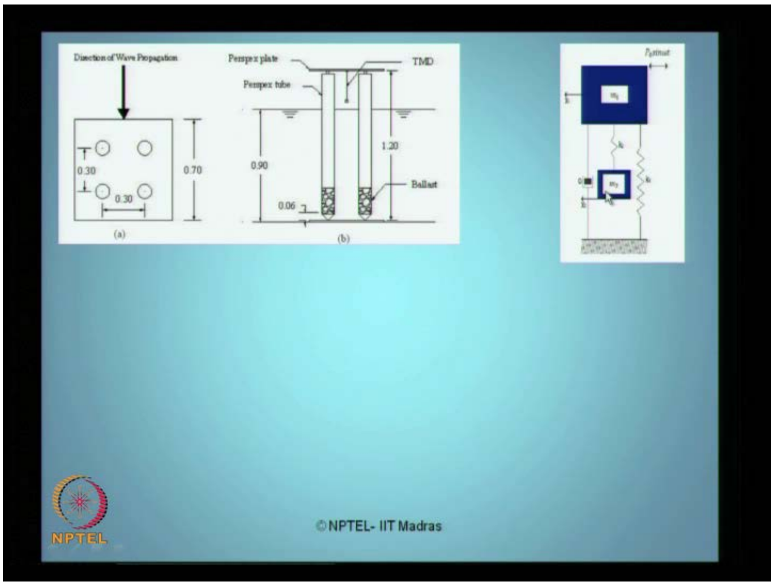

So, this is my plan and elevation of a multi legged, single hinge articulated tower. So, the hinge what I am mentioning is this. As I said in the last lecture, instead of making the deck and the tower is a rigid body I also put a hinge here, because this can isolate the deck response with that of the tower. So, this is my plan this is my elevation. So, the scheme at the view of this is primary mass and secondary mass. Primary mass of course, has stiffness and damping whereas, the secondary mass has only the stiffness and a mass and there is no damping m 1 and m 2 are my mass of the primary and secondary system.

Of course, k 1 and k 2 I am sorry for the size this thing. This is k 1, it is a primary mass primary spring and this is k 2 this is m 1 this is m 2 this is x 1 this is x 2 this is c u can call this c 1 also does not make a difference. For example, the mass of all the towers, the mass of the deck are all focus to c g which is m 1 and the stiffness of all the legs together is k 1 and proportional m 1 and k 1 is my c 1. And of course, I am going to attach the secondary mass to this which I tuned mass damper. There is a mass here there is of course, spring here that is k 2 and m 2.

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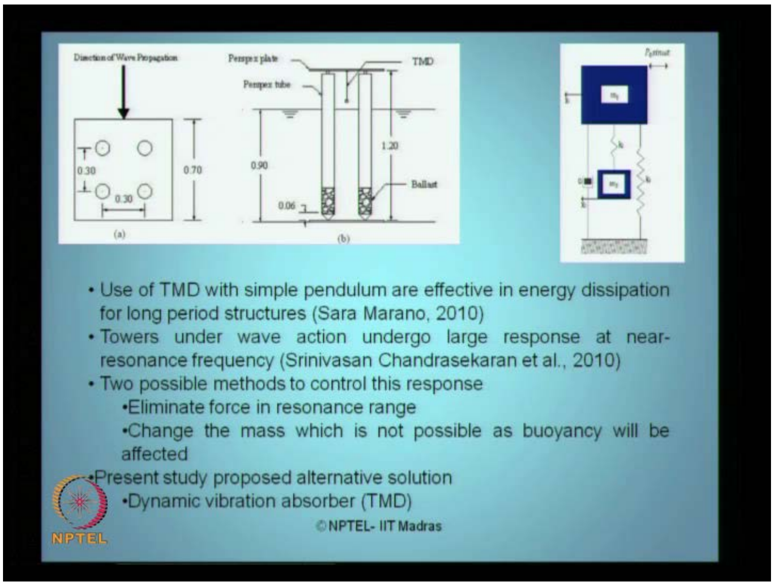

So, this idea was floated in 2010 use of TMD can be used using a single pendulum for effecting energy dissipation for long period structures. Sara Marano has cleared using a unlimited study. Towers under wave action undergo larger response at near frequency resonance. 2 possible methods have been attempted by the researchers: one is to eliminate the force and the resonance range, do not have the forces in the resonance at all. Change the mass which is not possible as buoyancy will be affected.

So, you cannot actually play with the mass of the primary system at all, you can only tune the secondary mass system for a specific frequency range.

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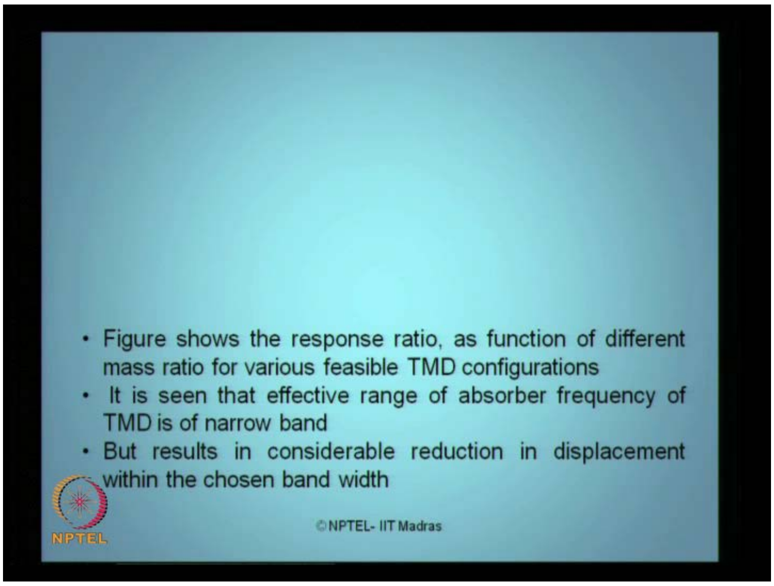

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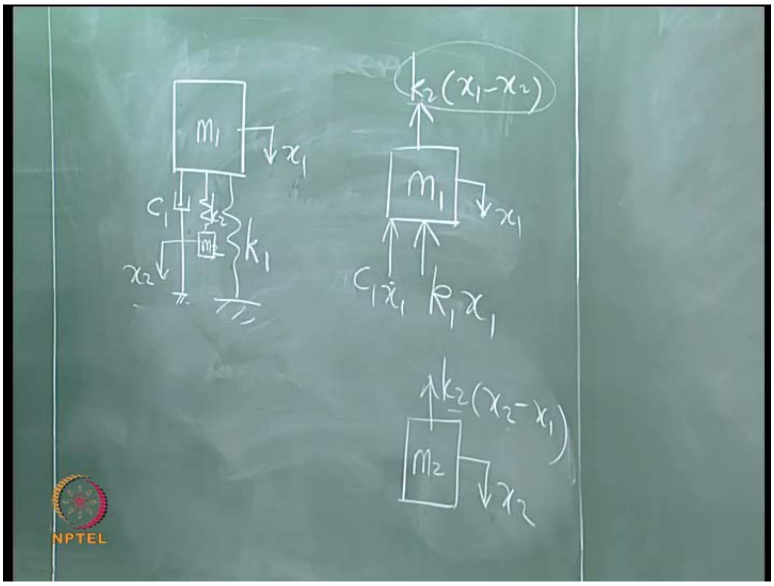

So, this method of approach is what we call as dynamic vibration observer. So, now I have a secondary mass system attached to the primary mass. Let us see how I will tune my response x 1 with respect to the top x 2. So, let us draw the figure or diagram of this. I think you remember how I am writing this we already said this in the previous module also. If I am talking about m 1 where x 1 being applied, I will write the stiffness of the secondary system since, they are connected x 1, x 2 are connected with k 2. I write x 1 minus x 2. When I do the same concept here, though k 2 connects m 1, m 2 when I write here write this k 2 of x 2 minus x 1 because I am writing it x 2 that is how it has been. Quickly, write the equation for this and try to simplify this in an easy way.

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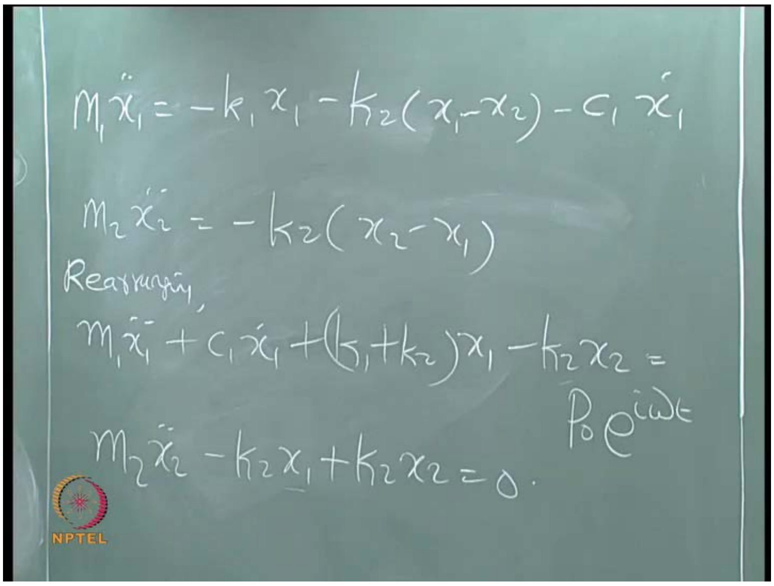

So, m 1 x 1 double dot minus k 1 x 1 minus k 2 of x 1 minus x 2 minus c 1 of x 1 dot. And of course, m 2 x 2 double dot minus k 2 x 2 minus x 1. I rearrange this because there are x 1 terms many x 1 terms here x 1 dot here and so on, I rearrange them, I get m 1 x 1 double dot plus c 1 of x dot plus k 1 plus k 2 of x 1 minus k 2 of x 2 is not actually 0. I am going to apply a force here this force is simply p naught e i omega so, having the sine and cosine components the amplitude of the forces is p naught. So, which will be equal to p naught e i omega of course, m 2 x 2 double minus k 2 of x 2 that is k 2 of x 2 is 0. You will obviously see the matrix will become symmetric, because x 1 with k 2 and x 2 with k 2 minus symmetric and so on.

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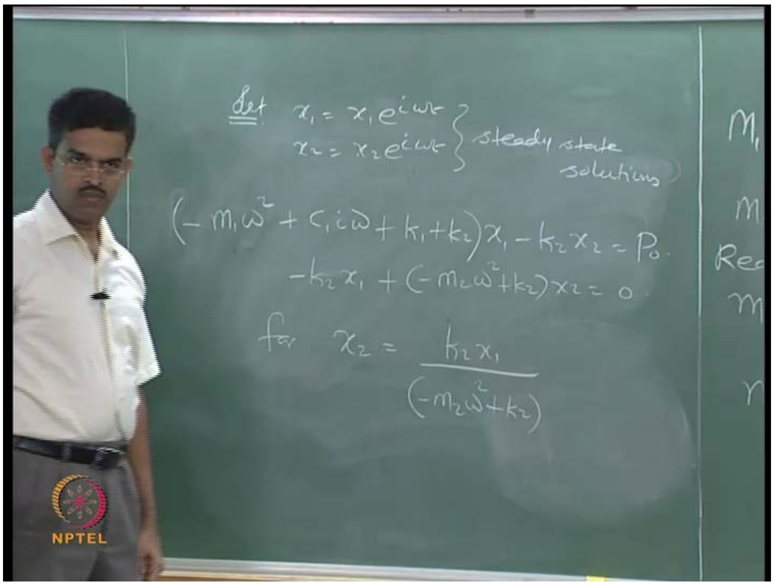

So, let us say, Let x 1 b, x 1 e i omega t and x 2 b x 2 e i omega t to maintain the same algorithm as that of the forcing function, substitute back in this equation. These are equation 1 and 2 for my values. So, these are let us say, steady state solutions. We are assuming this. So, you have a first derivative here, you have a second differential here and so on and substitute back and simply and rearrange them and see what happens. Do it faster. So, I get this minus m 1 omega square plus c 1 i omega plus k 1 plus k 2 of x 1 minus k 2 of x 2 is p naught. Is that ok? And minus k 2 of x 1 plus minus m 2 omega square plus k 2 of x 2 remain 0. Is that all right? e omega term left hand right hand will get canceled. And the minus term is attached to m and m 2 because of the x double dot term here. Otherwise, it is very simple. I think we should be able to get this. So, from the second equation down below I find x 2 as k 2 x 1 by minus m 2 omega square plus k 2.

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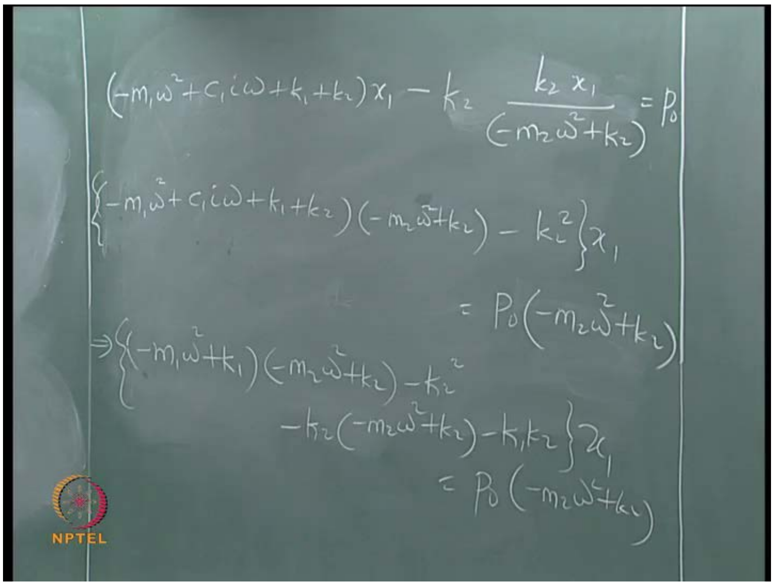

So, substitute this x 2 in the first equation and get x 1. So, let us quickly do this let us do this way minus m 1 omega square plus c 1 i omega plus k 1 plus k 2 of x 1 minus 2 of k 2. Now, I rearranging this term slightly in a different manner. So, this implies minus m 1 omega square plus k 1 minus m 2 omega square plus this is omega square plus k 2 minus k 2 square minus k t of m 2 omega square plus k 2 minus k 1 k 2 of x 1 should be of course, equal to p naught minus m 2 omega square plus k 2. I simplify this further and bring out as a ratio.

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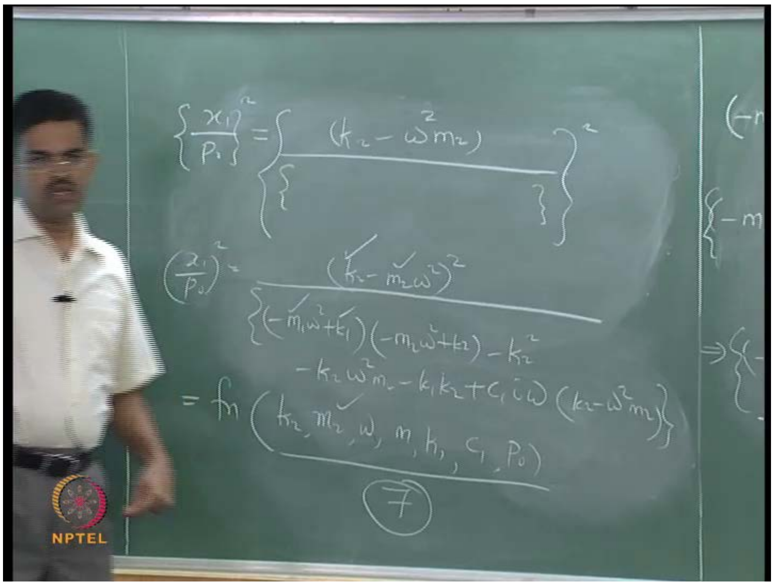

So, what I do here is x 1 by p naught I will bring out x 1 by p naught, will be simply k 2 minus omega square m 2 by of course, there is a term here, c i term c 1 i omega of minus m 2 omega square plus k. Now, I square this. I write the final equation. So, x 1 by p naught the whole square is coming to be k 2 minus m 2 omega square the whole square minus m 1 omega square plus k 1 minus m 2 omega square plus k 2 minus k square minus k 2 omega square m 2 minus k 1 k 2 plus c 1 i omega k 2 minus omega square m 2. This is nothing but my static response ratio.

Now, I will see here this equation of function of many variables. Let us see what are the variables, this equation of function of let us say k 2, m 2 of course, omega, m 1, k 1, c 1 and of course, p naught as well. So, there are 7 variables here. So, if you want to tune my secondary mass system, if you want to tune my secondary mass system. I must handle a parametric of about 7 to get my ratio of static versus; I mean x 1 by p naught for different values of this.

Is it not?

So, this by enlarge a large problem it cannot be solved easily so, I want to simplifyfurther this by expressing these independent values as ratios.

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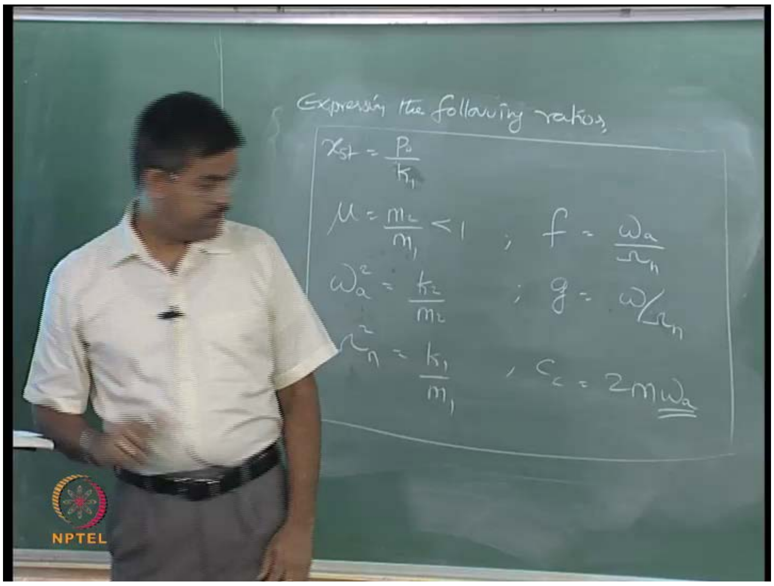

So, I now simplify this problem further expressing them as ratios. So, expressing the following ratios by equation can be reduced.

I simply say x static is p naught by k 1, mu is m 2 by m that is, the ratio of secondary to the primary mass, which will be of course, less than 1. Secondary mass will be lesser than the primary mass. Omega a observe, observer is the secondary mass system is nothing but, k 2 sigma I am just using this symbol because I am short of notation to represent the ratio nothing but, k 1 by m 1 that the primary mass system natural frequency. And the frequency ratio f, is frequency of the observer to that of the natural frequency of the system.

And I put another ratio g which is frequency by sigma n where this is the way frequency for which I am going to tune. And of course, critical damping will be based on the observer frequency. That is why it is called tuning. So, now I express this ratio in the earlier equation and try to plug or develop a relationship in this form we already saw the equation had a square value on either sides.

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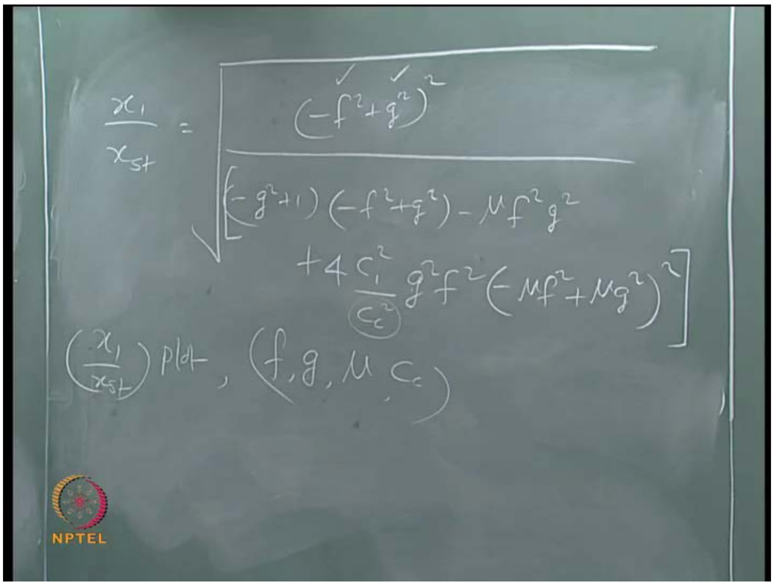

So, I want to find the static response, which is simply x 1 by x static. There was a square term in the previous equation we derived. Now, I will say it is a root of. So, these are my ratios which I would not implement in this equation now, which will be minus f square plus g square whole square, minus g square plus 1 minus f square plus g square, minus mu square g square plus 4 c 1 square by c critical square, this is my denominator. You can check it up back.

So, now what are the variables? So, if you want to plot x 1 x static if you wish to plot what are variables I must handle? I have variables of f, g, mu; and of course the critical damping. So, I have reduced the problem of 7 variables by putting these ratios to 4 problems now. So, for different frequency ratios for different wave excitation to the natural frequency for different mass ratios for critical damping, this is based on the observation frequency. I will like to plot the variation of x 1 by x static for these ratios that is what you see now.

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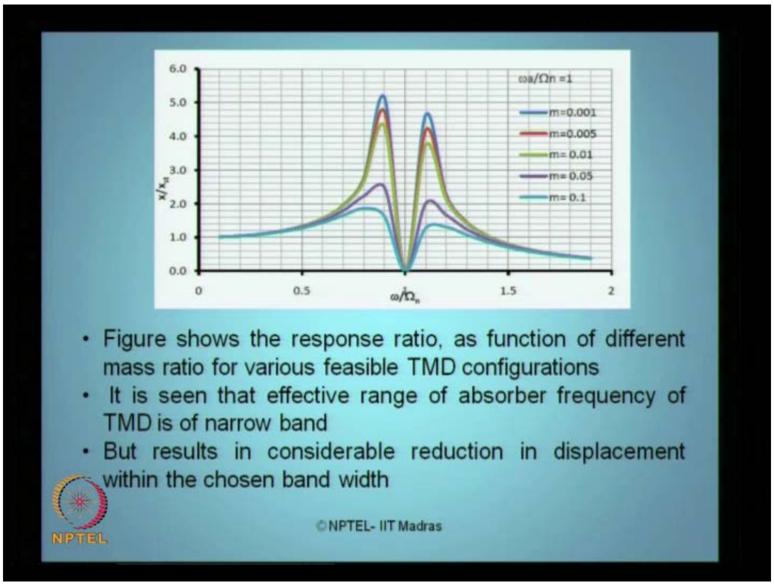

Here, the m which you see here in the right hand side for different colors is actually nothing but mu it is a mass ratio. For different mass ratio of 0.001, 005, 01, 05 and 0.1, you see that the variation of the ratio of the frequency that is nothing but g is plotted against x by x static or x 1 by x static 1 is, I think you are able to see, I do not know x 1 by x static. So, I am trying to plot x 1 by x static, because I always find x 1 a static is a standard value p 0 by k 1, so x 1 by x static for different ratios plotting it here. More interestingly what you see from this figure is that, when my frequency is at resonance omega by sigma it means, when a primary mass system is expected to resonate with the expedition frequency of the wave, my response practically becomes 0. It means at resonance I have controlled it to 0. Is it not?

Analytically at resonance response actually becomes 0 but, the other replication is instead of having a single peak response, single peak response which is infinity, I have 2 responses now which are on a different bandwidths. It means the peak responses of the system now will not occur at the natural frequency of the primary system number 1. So, the primary system will not be damaged. The second observation is, the peak frequency has been shifted to a narrow band and the values for all possible ratios are becoming finite. It means response has been controlled.

Now, what is the demerit of this? The basic demerit of a passive active system applied in this problem is that, the application of this control efficiency from this value of 5 to this value of 1.5 approximately. The efficiency of the controlling the response you think a secondary mass system is applicable only for a narrow band. So, only for a narrow band we are able to achieve this. So that can be seen as one of the demerit of this application.

But, the most important significant merit is that, even at resonance that is g value becoming 1 g is nothing but, remember g is not exchange due to gravity its some notation I am using here which is ratio of the forcing frequency to natural frequency of the primary system, sigma is primary system. Generally the secondary mass not attached to the system, system has to resonate and what will be the upper boundary of the system sorry (( )). No, it is not going to infinite it is going to be 1 by 2 zeta, it is the damped system no. So, it is not infinity but, the values very high. But, I am practically bringing it to 0 at that value. It means my system will never get damaged primary system.

Is it not?

So, before understanding the further advantages of this particular absorption methodology, we will quickly see the video and see how when it occur to a secondary mass system to the primary how my secondary mass getting out of phase of response with the primary how this is actually happening.

Experimentally this was verified and we have found that this can control the response.

Now, I may wonder why I cannot find out these ratios experimentally. I cannot find this experimentally because the moment I tune my system to the natural frequency of my secondary or primary or the wave my experimental model become damaged so, I cannot study this. So, this can be only study analytically.

One may wonder that even analytically also do not work out the ratios and simplify this I cannot solve this equation of motion at omega equal to sigma. So, analytically the problem is tricky, experimentally show you how this has been achieved. So, you have got to see it and believe it. So, we will have another I think is 08:50 if you want to see the video now, it will take about at least 10 minutes, I do not want to block the other class possibly, you can show it the next class I do not want to run we will show it to u next class. Then of course, will show you some results of this study and I will wind up as far as 80s are concern I will move on to real case. This is ninth lecture we are running, I have got 13 lectures in the second module. I set to all we will make it to 13 of 14.

Student: (( ))

X 1, x 1, I will talk about the response of the primary system. (( )) when you chosen the second one to the primary what will happen to the secondary. Yeah, very interesting question what is trying to ask is what will happen to x of x 2, x 2 actually depends on k 2 and m 2 only. So, as long as the frequency of the secondary system is not tune to that of the wave frequency and the primary one there will be no damage to the secondary it will be keep on vibrating.

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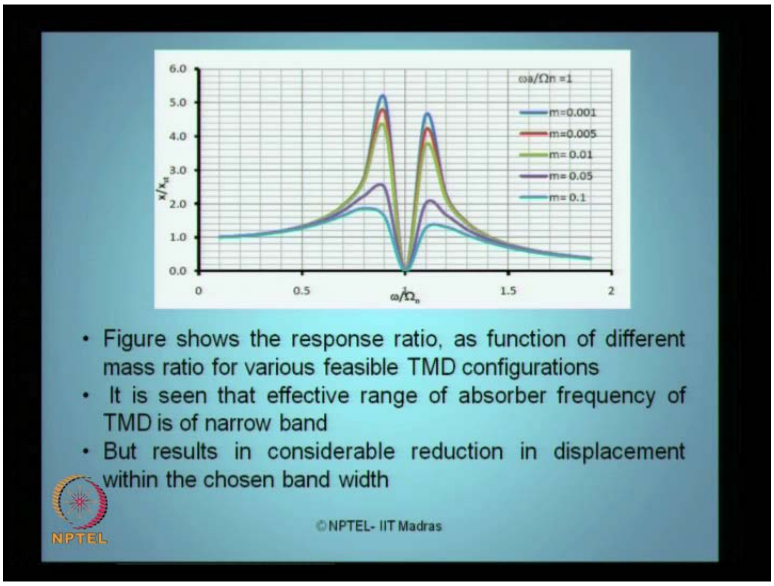

And of course, you will see the ratio here it is only about 0.1 percent. So, the mass of the secondary system is relatively very less compare to other primary. So, if you want to really control the secondary response also then, you must study the system with c 2 that is damping for the secondary system, there is undammed system of the secondary. So, if you want to control that then, c 2 u imply or reinvestigate the same model for this.

So, interestingly I think I have conveyed what I want to convey in this slide. At resonating frequency the response for a damp system should be 1 by 2 zeta whereas, it is practically become a 0. It may show 0 in the analytical study because that is how it has been programmed. Practically, it is not exactly 0 it will be very, very minimum in significant response.

So, the peak has been shifted to the adjacent bands that are great advantage. You have you are not damaging the primary system at all. Had this not been done primary system would have been damaged for omega equal to sigma that is, sigma again this value. At 1 at g equals 1, it is expected that you may get damage and this will purely depending on c 1 of the problem or zeta of the problem which we already know from the first module. So, we will extent this in the next I will show u some videos in the next class and you really see to believe it how it has been done. Any question here?