Geotechnical Earthquake Engineering

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Module - 9
Lecture - 43
Seismic Analysis and Design of Various Geotechnical Structures (Contd…)

Welcome to today's lecture for NPTEL video course on Geotechnical Earthquake Engineering. So, for this video course, currently we are going through the module number nine, which is the last module of this video course, which is on seismic analysis and design of various geotechnical structures. Before I go to the recap, what we have studied in the previous lecture.

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Just I want to share a latest news on major earthquake which has occurred in Iran, on 16th of April 2013, just few days back of before we are recording this video. You can see the event time, the details are given over here, location latitude and longitude is given over here, the magnitude was 7.8 earthquake. So, it was very devastating earthquake in Iran, which was felt far away even in New Delhi of India also. So, it occurred on

Tuesday April 16, 2013. All these details are collected from this USGS website; that is http earthquake dot usgs dot gov, which gives us authentic information as we have already mentioned and discussed during this course.

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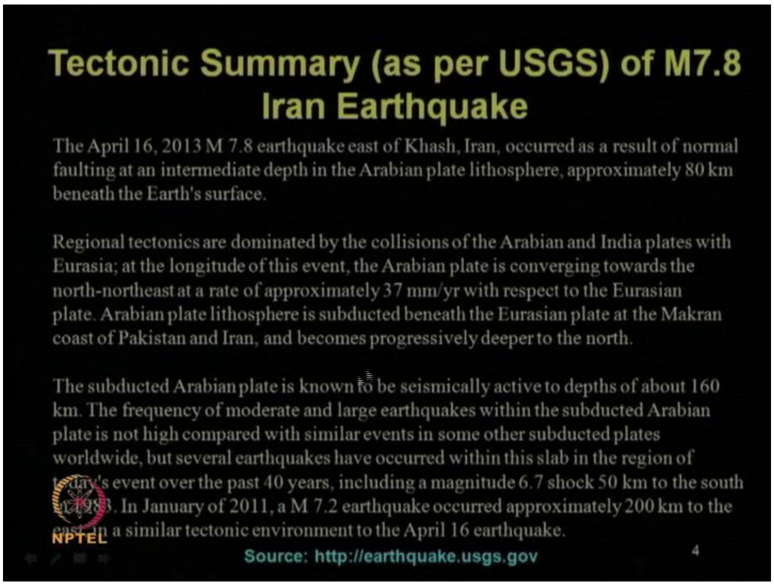

These are some of the tectonic summary which is provided by USGS about this magnitude 7.8 Iran earthquake, which occurred on April 16th of 2013. You can see over here, it is because of the collision between Arabian plate and Indian plate with Eurasian plate. So, these three major plates are moving, and because of that movement, these collisions occurred which cause this earthquake of 7.8 magnitude to occur on this day. And though this sub ducted Arabian plate is seismically active, but not as much active as other sub ducted plates worldwide, but still you can see over the last 40 years, there are few large magnitude earthquakes like 6.7 magnitude earthquake in 1983. Then in 2011 January, 7.2 earthquake, and the present one that is April 16 2013, 7.8 earth quake occurred, because of this sub ducted Arabian plate movement.

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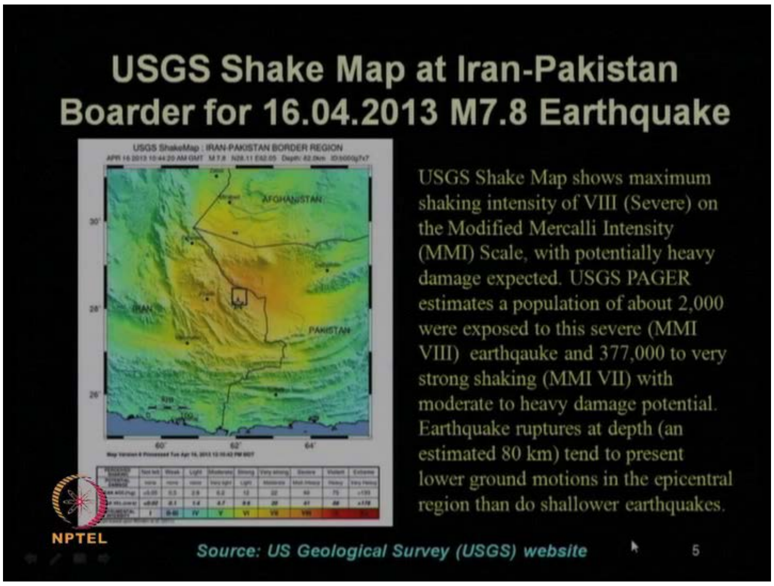

This shows the USGS shake map at Iran Pakistan border, for this 16th April 2013 magnitude 7.8 earthquake, which is provided by us geological survey USGS website. You can see from this shake map; that the intensity the modified Marcalli intensity scale or MMI scale, is about this 8, this is the magnitude. So, there was about the population of 2000 people were exposed to this severe intensity of earthquake 8 intensity, and about 3,77000 people were subjected to MMI scale of about 7, as has been detailed in the USGS website. So, this way, as we have already discussed, whenever there is large earthquake worldwide, we also experience the information through the collection of the data, during and after the earthquake. So, these earthquake data; obviously, will benefit the earthquake researcher, in the form of to better estimation or probabilistic hazard estimation, and ground response, and various other geotechnical earthquake engineering related aspects, for collected from this earthquake data.

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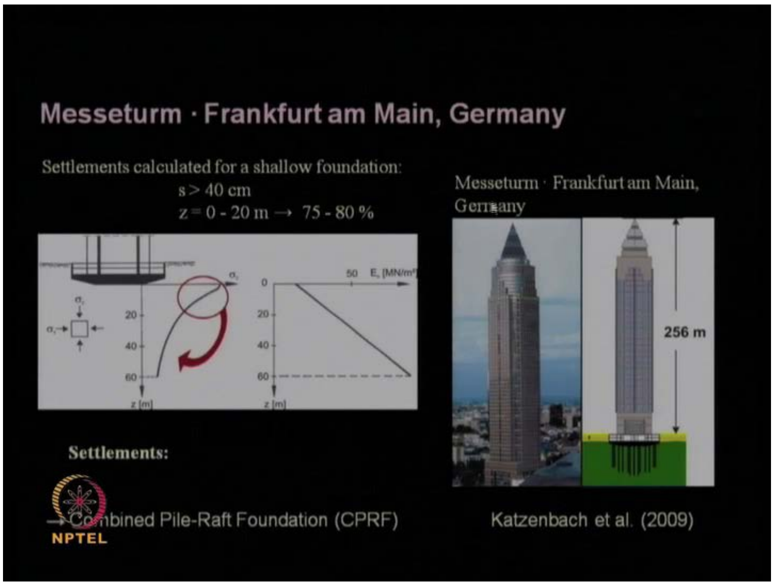

Now, let us do a quick recap, what we have learnt in our previous lecture. This is combined pile raft foundation CPRF, under earthquake conditions we were discussing for that we have already learnt what is combined pile raft foundation. There are several examples are existing in practice. Like Messeturm tower in Frankfurt am Main in Germany, why we go for combined pile raft foundation instead of only raft or only pile, that also has been discussed earlier. And the extensive research work carried out by Prof. Katzenbach of Technical University Darmstadt in Germany, has been mentioned over there.

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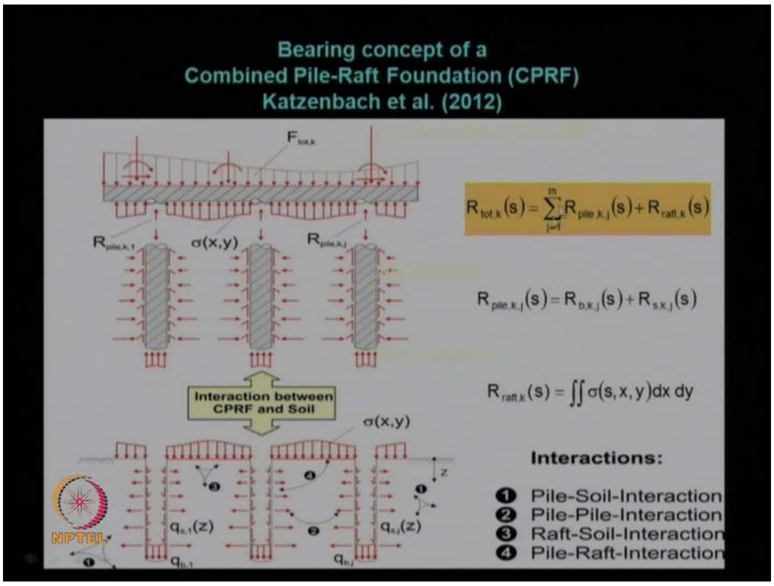

The basic concept of pile raft combined this foundation, combined pile raft or CPRF foundation, is through the pile soil raft interaction process. So, this is the complex interaction where, these major four types of soil structure interactions are involved, and the total load carried by the entire foundation, shared by pile as well as the raft.

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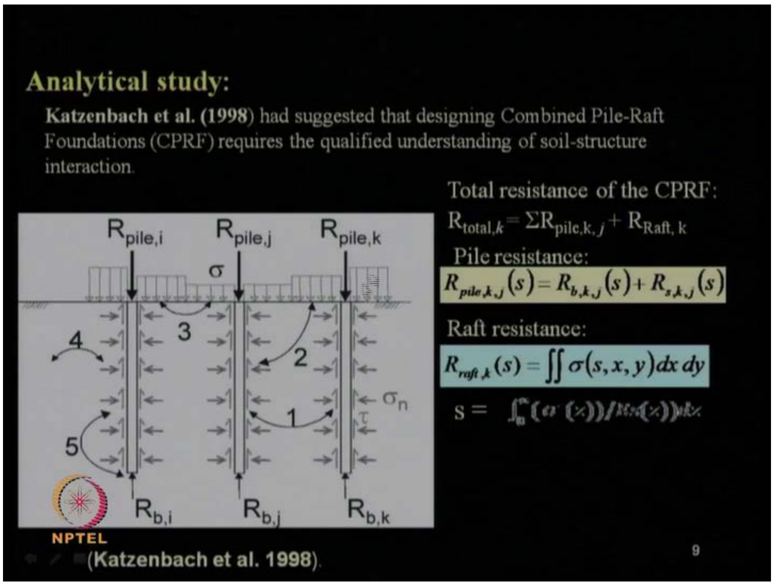

So, this is the analytical study which gives the details about sharing of load, between pile and raft.

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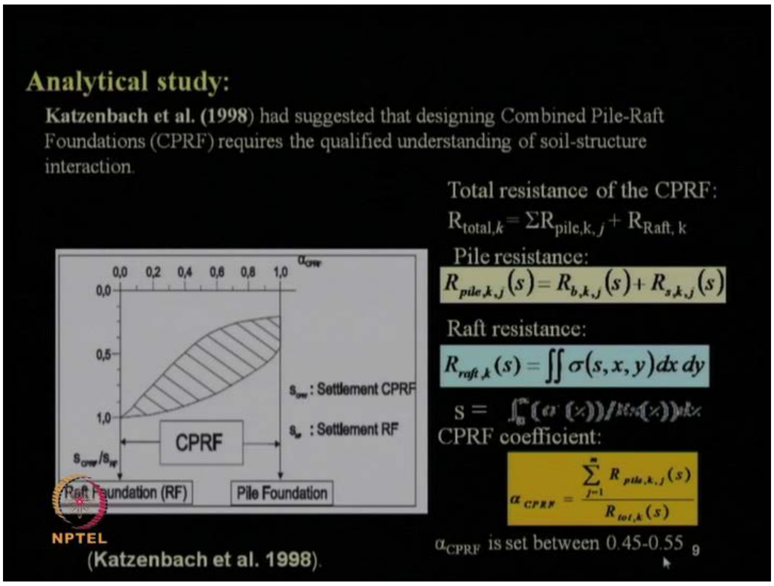

And from that, we also mentioned that CPRF coefficient is the designed parameter, which needs to be at 50 percent or 0.5; that shows the best design, because then pile and raft shares the equal amount of load coming from the super structure. So, alpha CPRF or CPRF coefficient is generally set between 0.45 to 0.55 for design purpose.

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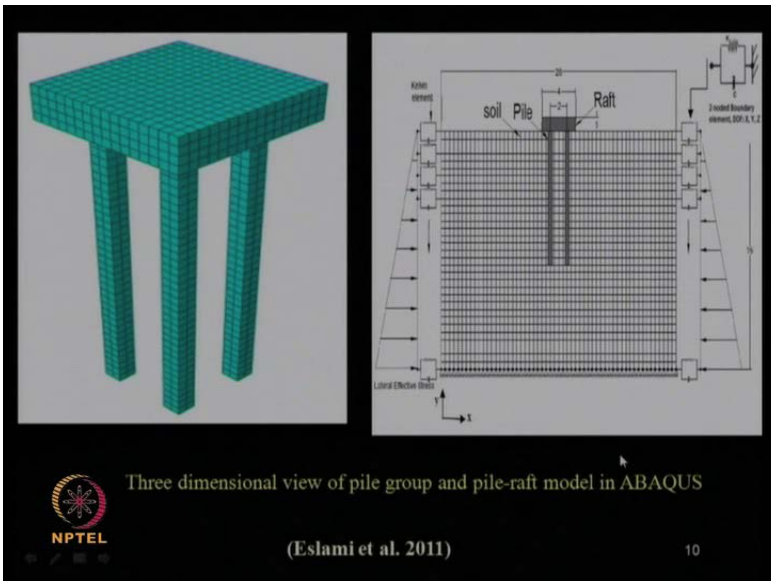

Then we discussed about the research work carried out by Eslami et al in 2011, using ABAQUS. The analysis was carried out for combined pile raft foundation, under dynamic loading condition.

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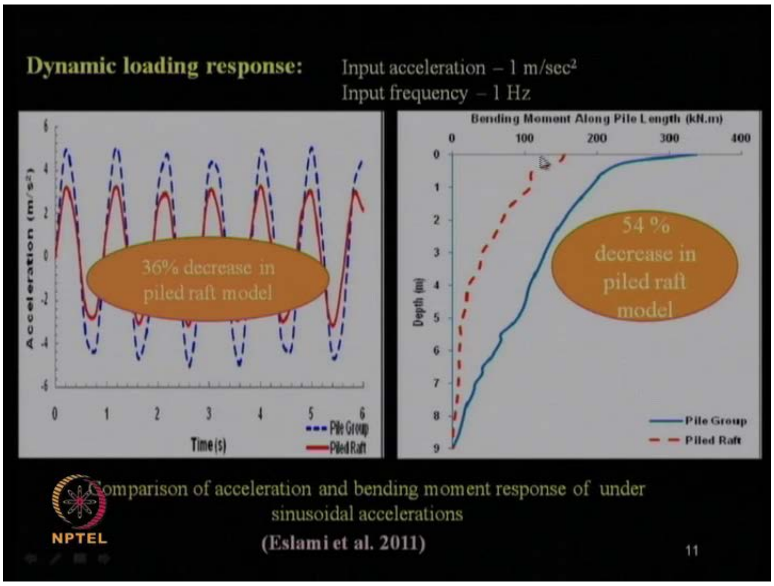

So, the dynamic loading response, as can be seen from the picture, input acceleration of one meter per second square, with input frequency of one hertz was applied. And it was observed that combined to the pile group acceleration response, in the combined pile raft, there is a 36 percent decrease in the acceleration value, so which is beneficial of course. As well as you can see from this results of Eslami et al 2011. It shows 54 percent decrease in the pile raft model in the amount of bending moment along the pile length.

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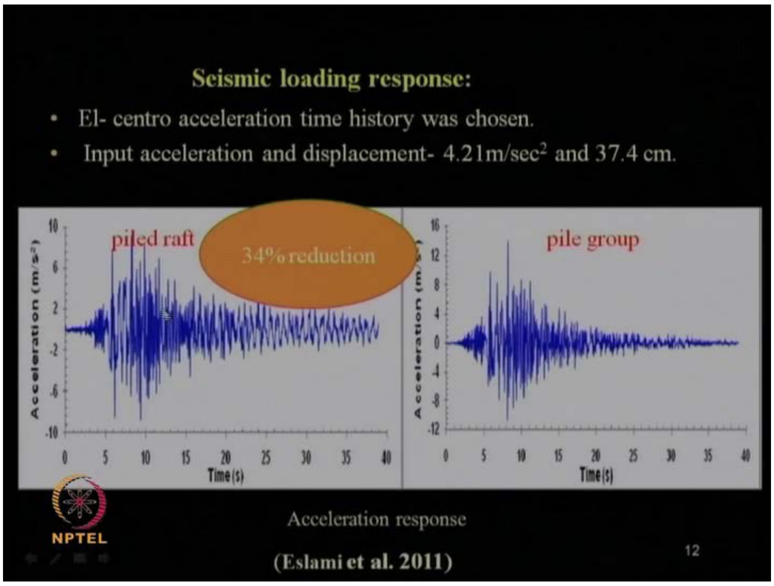

Also they carried out the research for the seismic loading conditions, using the El-centro acceleration time history, and it was found that there was 34 percent reduction in the acceleration value compared to pile group, in case of combined pile raft foundation.

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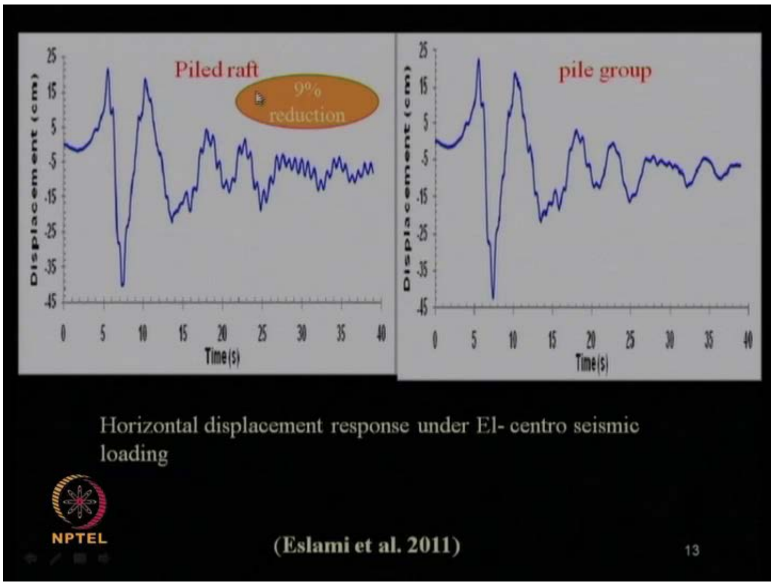

And for horizontal displacement response under this El-centro earthquake, they observed that there is a nine percent reduction in the displacement for the pile raft, compared to the pile group values. So, that automatically showed and we have discussed in our previous lecture, the importunacy of combined pile raft foundation even during the earthquake condition. Then we also discussed about a case study, of how a combined pile raft foundation behave during an earthquake.

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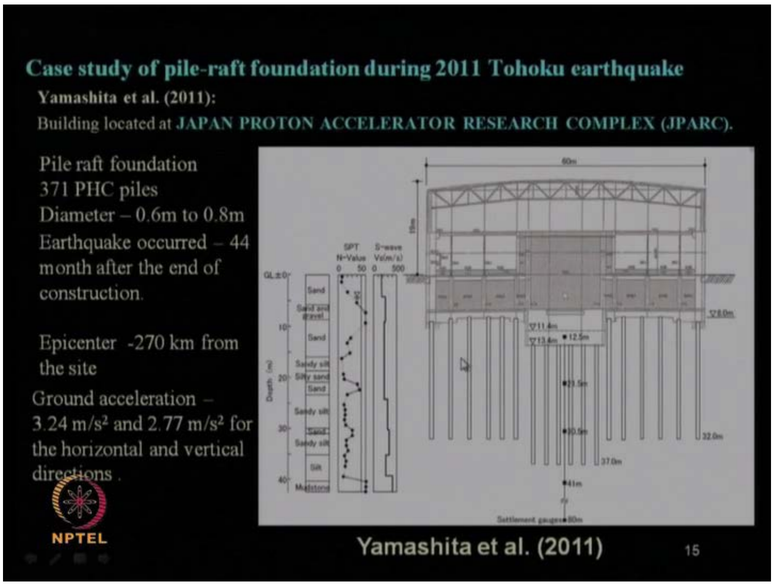

So, for that case study; the Tohoku earthquake of 2011 march in Japan, that earthquake response was considered on a constructed pile raft foundation, with these details given over here, and it has been reported by Yamashita et al in 2011. We have already learnt from this, that this place was 270 kilometer away from the epicenter, where this foundation was constructed, combined pile raft foundation, with the soil characteristics SPT value and shear wave velocity value reported over here.

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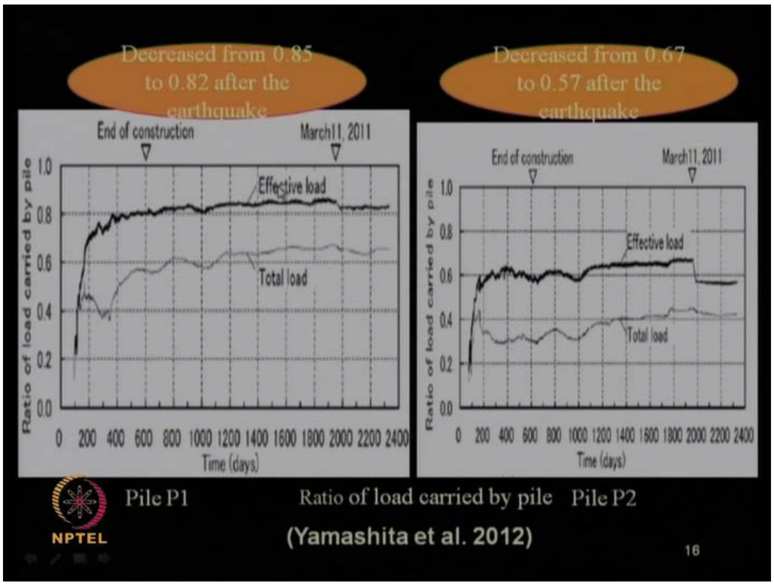

Then it was observed, that there were instrumented piles; pile P 1, P 2, and P 3. Instrumented pile P 1, observed the ratio of load carried by the pile. This is the effective load and this is the total load. So, after March 11 2011; that is the date when the big Tohoku earthquake occurred, after that there is very marginal decrease, so there was not much of a decrease over here. Whereas, for pile 2 there was little more significant decrease, but not that much, which can show that combined pile raft foundation is not performing good. In the other word it is performing better combined compared to the only pile foundation. So, you can see here the values of decrease of this load ratio, taken by the pile after the earthquake. Then in our previous lecture we also talked about, this Seismic Design of Ground Anchors, and I have mentioned this is a part of PhD thesis work done by Dr. Sunil Rangari at IIT Bombay, under my supervision, along with my colleague Prof. Dewakar.

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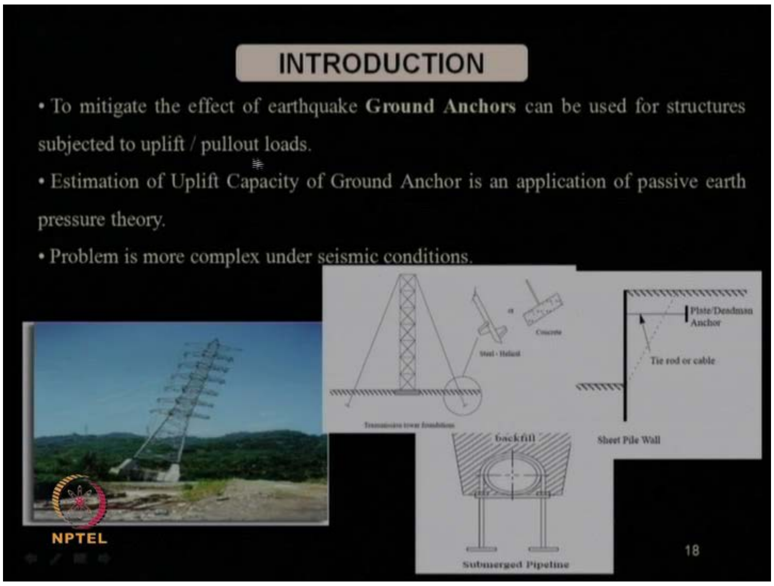

So, we have already learnt, what are the use of ground anchors we know about it, and whenever there is an earthquake or it is designed in seismically active region; obviously, we need to take special care for the design of this ground anchors, which will be subjected to uplift or pullout load.

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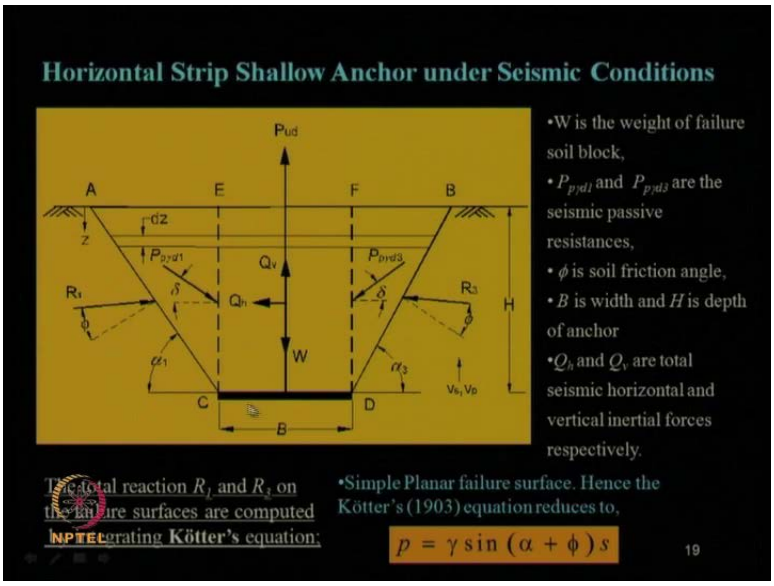

Then basic simple model which was given by Dr Rangari in his thesis; that under earthquake condition for a horizontal strip anchor subjected to vertical load. These are the inertia forces. These were computed both using pseudo-static as well as pseudo-dynamic approach. And Kotter's equation of 1903 was used for finding out the, soil reaction on these assumed planer failure rupture surfaces.

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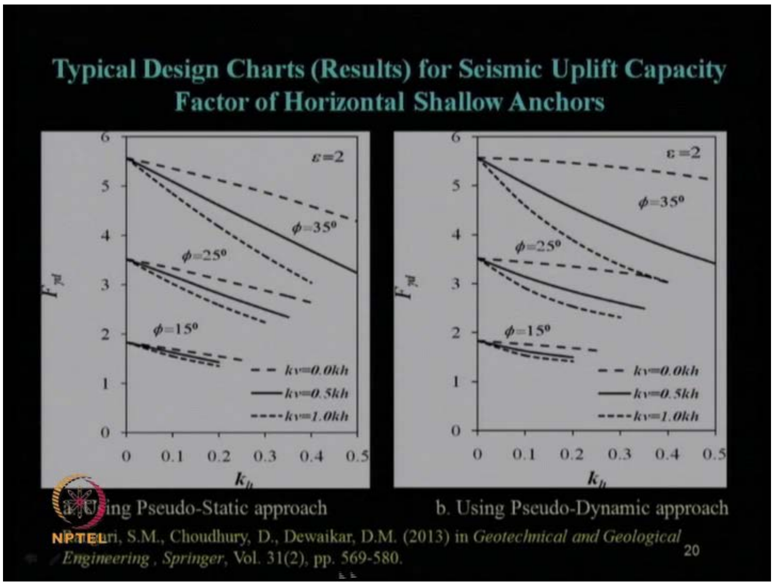

Finally, the typical design values of this uplift capacity factor under seismic condition, if gamma d has been proposed with variation of k h and k v; that is seismic acceleration in horizontal and vertical direction, for various values of soil friction angle phi, and for selected particular values of embedment ratio of anchor plate. And using both pseudo-static approach as well as pseudo-dynamic approach, the design charts are results have been given. The details can been obtained in this journal paper of 2013 in the journal Geotechnical and Geological Engineering, Springer publication. This is the volume and page numbers.

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Comparison of Results

Comparison of ultimate seismic uplift capacity factor ($F_{\gamma E} = P_{ud}/\gamma B^2$) for various values of k_h and $k_v = 0.5\ k_h$ for $\phi = 30°$, $\varepsilon = 4$ with H/λ=0.3 and H/η=0.16.

k_h	Ghosh (2009) Pseudo-dynamic	Kumar (2001) Pseudo-static	Choudhury and Subba Rao (2004) Pseudo-static	Present study Pseudo-static	Present study Pseudo-dynamic
0.0	13.27	13.27	12.89	13.01	13.01
0.1	12.59	12.48	12.44	12.12	12.08
0.2	11.90	11.71	11.96	11.25	11.29
0.3	11.14	10.90	11.53	10.39	10.61
0.4	10.21	9.81	11.01	9.56	10.05

ri, S.M., Choudhury, D., Dewaikar, D.M. (2013) in *Geotechnical and Geological Engineering*, *Springer*, Vol. 31(2), pp. 569-580.

Then the results have been compared the, results of Rangari et al, along with the other researchers results, and it can be obtained that, the present study give in most of the cases the critical designed values of this seismic uplift capacity factor, ultimate seismic uplift capacity factor, which is necessary for the design of this ground anchors in seismically active region.

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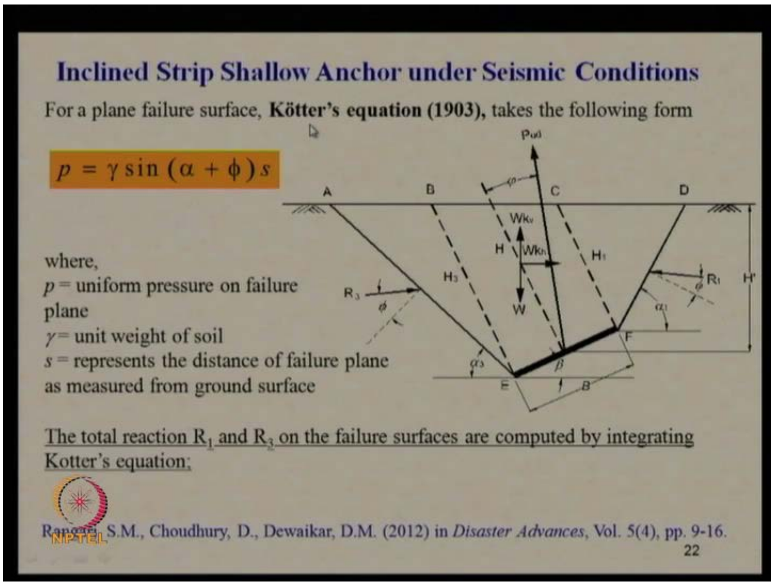

Also for the inclined strip anchors, under seismic condition, the analysis was carried out by Dr Rangari, and the details of these analysis is available in the journal paper, in journal disaster advances. This is the volume number and page number. This is the basic model which was considered using Kotter's equation for planer failure surface.

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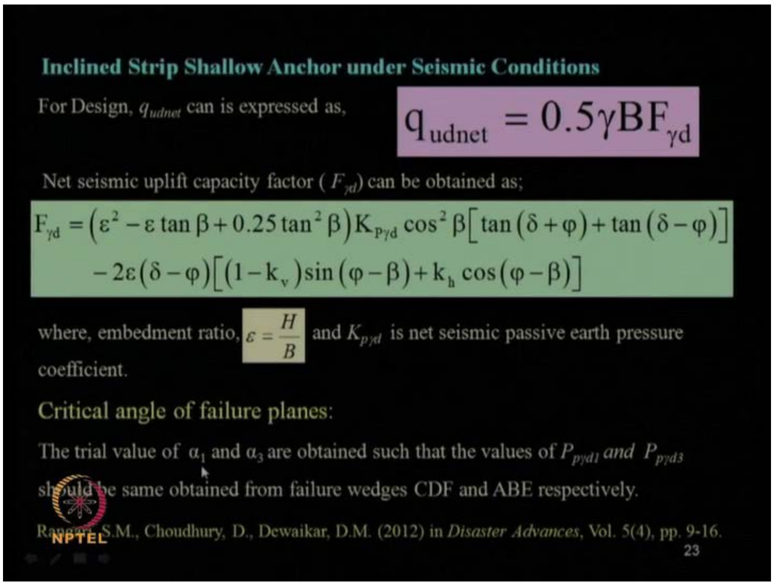

And we had already learnt that closed form solution for net, seismic uplift capacity factory f gamma d was proposed like this, and from which we can obtain the q udnet which is nothing but net ultimate uplift capacity for the anchor, for a particular value of embedment ratio, as well as the seismic passive earth pressure coefficient.

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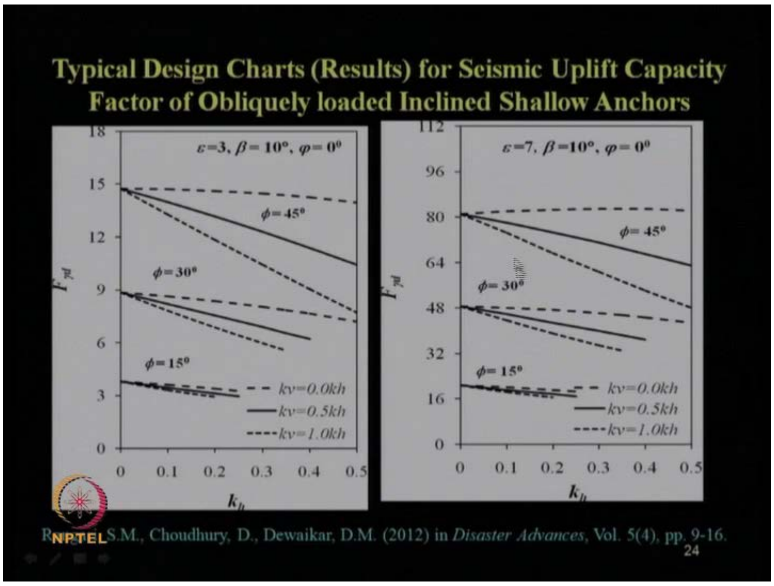

Then critical failure angles also were obtained, by optimizing the different failures angle alpha one and alpha three for different cases of earthquake accelerations. Finally, the designed charts are also proposed for this obliquely loaded, as well as inclined strip anchors like this.

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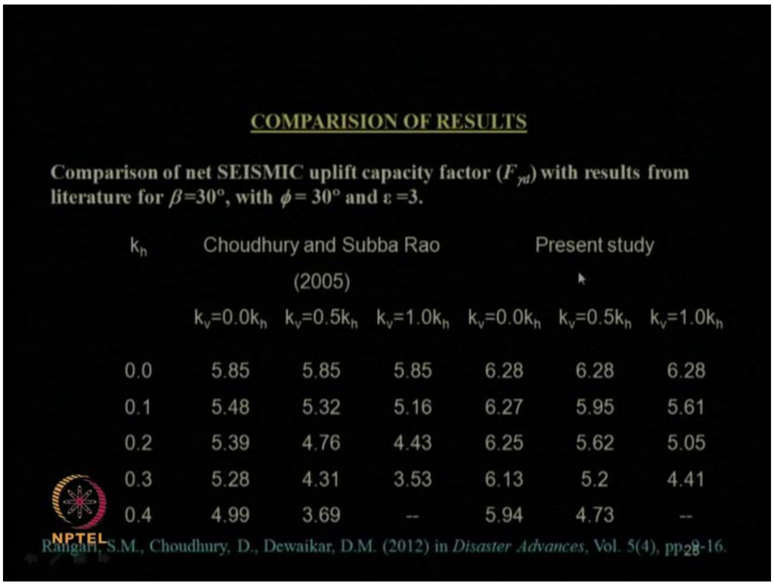

And results have been compared with only available one inclined anchor results, theoretically in the, available in the literature like this. And it shows the present result gives the very good estimation with the available result.

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So, we will start now today's lecture with the topic, another subtopic or new subtopic. Seismic behavior of municipal solid waste landfill, municipal solid waste, we will abbreviate it has MSW landfill. This work is carried out by Dr Purnanand Savoikar. He completed his PhD in 2009. It is his PhD thesis work, which was carried out at IIT Bombay, Mumbai India, under my supervision, along with my colleague Prof. Mandal, who was co supervisor for this PhD thesis work.

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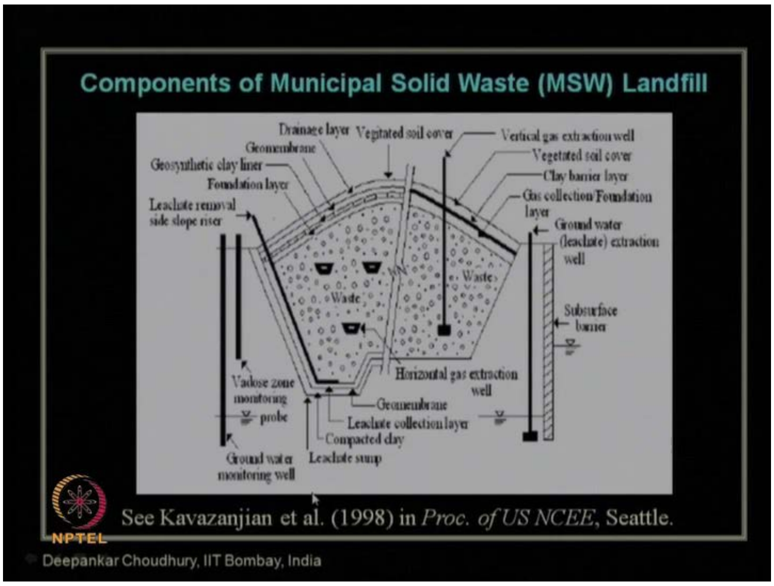

As we all know from the basics of municipal solid waste landfill, what are the various components of municipal solid waste landfill. This is the typical picture which shows various parts of municipal solid waste landfill, which are used for engineered landfill design, and this is taken from the Kavazanjian et al 1998, who did extensive research work on this Seismic Municipal Solid Waste Landfill Design and its Behavior. The first step, to understand the properties of this municipal solid waste landfill, under earthquake condition or under dynamic condition, is very necessary for further design of this municipal solid waste landfill. Why it is necessary, because unlike soil municipal solid waste material are completely different type of material. Also in most of the cases they will be in the loosed state, not in compacted or consolidated state.

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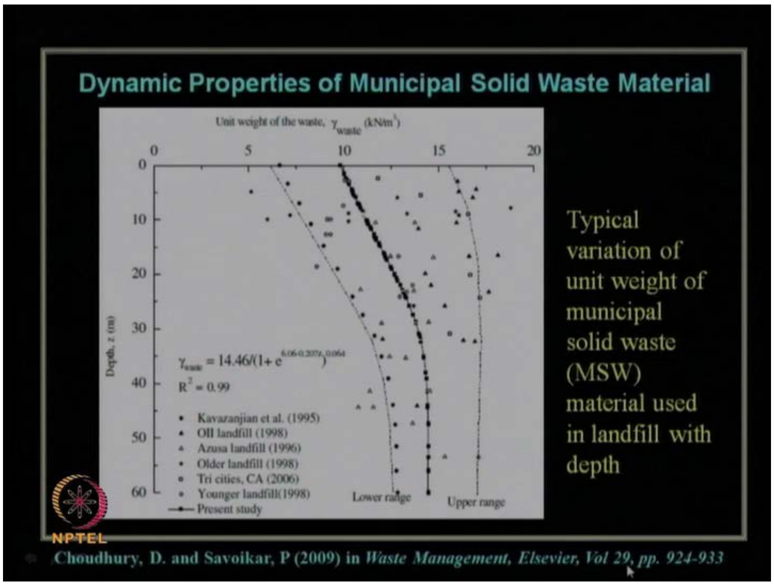

So, it is necessary for us first to understand the dynamic properties of municipal solid waste material. So, in the work of Dr Savoikar's PhD thesis, he used extensive literature which are available in various journals and conference papers, and collected all those literature, whether it is theoretical or analytical or experimental or field study results, those values he has taken. And finally, from the collected world wide data of municipal solid waste material properties, he estimated the unit weight of waste material, which is varying with respect to depth. As you can see there is a wide range of variation of gamma of waste, unit weight of waste material, which is expressed in kilo newton per meter cube with depth in meter.

There is a wide range of variation, as collected all over the world, but using all of them, and taking from this local coordinate system to a global coordinate system, mentioning the parameters in such a way that, all the data points comes in a narrow band, which is of course, not visible in this direct access system, but if somebody wants to plot in this form as you can see over here, the equation. It gives a very good estimate with a regression coefficient r square value of 0.99, and this equation can be used when somebody wants to do a preliminary design of municipal solid waste material, when they do not have the value of gamma of waste available, varying with respect to depth for this seismic design of municipal solid waste landfill. So, in absence of actual field data, one can easily use this proposed equation, which was proposed by Choudhury and Savoikar. This is available in this journal paper of 2009, in the journal paper Waste Management. Waste Management is a Elsevier journal, this is the volume number and page number.

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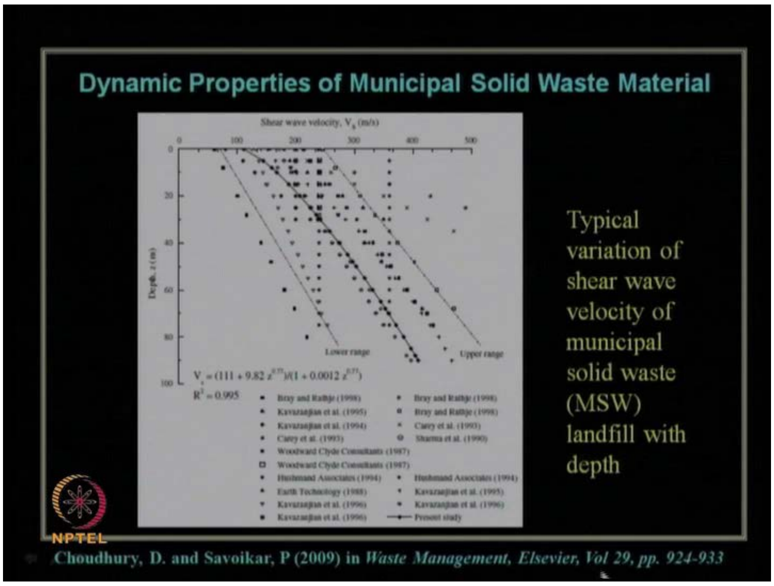

Further the shear wave velocity, another important parameter. Now another very important dynamic property of municipal solid waste material that is shear wave velocity, V s value in the unit meter per second, how it varies with respect to depth of municipal solid waste landfill. All these data points are collected from the available literature worldwide, as you can see over here, various researchers work extensive research work done by Prof. John Bray and Prof. Rabje. All these research papers have 1998 Kavazanjian et al 1994 1995.

Then Earth Technology Wood Word Consultant, Kary et al and so many other researchers work including the Zako's work. So, from the collected data once again the analysis was carried out to propose a semi empirical correlations of this world wide data, which will give a good value of regression coefficient, by taking these two parameters into different scale level, and the proposed equation is given over here. So, in absence of the exact shear wave velocity data, for the design in the preliminary state, people can use our proposed design over here, at any particular depth, what will be the typical value of shear wave velocity for a municipal solid waste material, as it is reported in this journal paper also.

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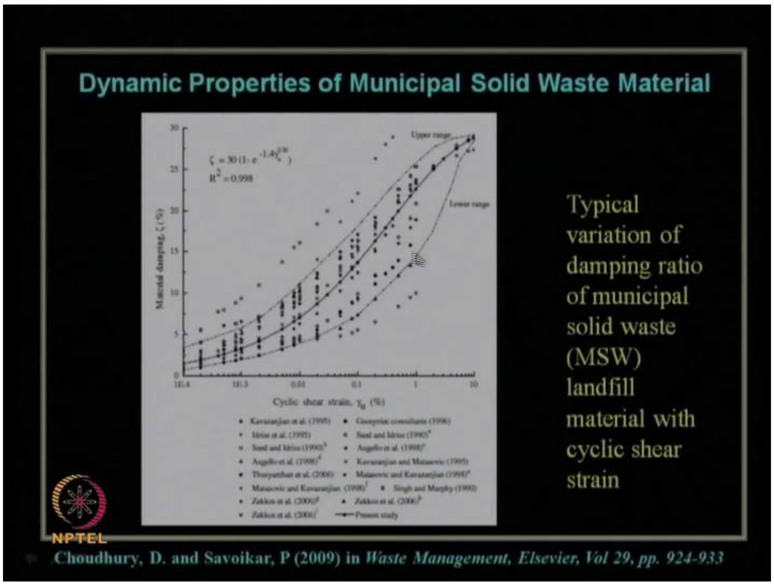

Next important dynamic property of municipal solid waste material is nothing but material damping. So, material damping this access is in percent, and this x axis is cyclic shear strain in percent. You can see over here, all these are again collected data points worldwide, through which the semi-empirical relationship has been proposed over here. So, depending on the earthquake shear strain value, one can estimate what will be the material damping. This damping curve is very necessary as we know for doing any ground response analysis or site response analysis. So, if we want to carry out the ground response and site response analysis for municipal solid waste landfill, in that case this material damping curve needs to be used, not the conventional soil damping curve.

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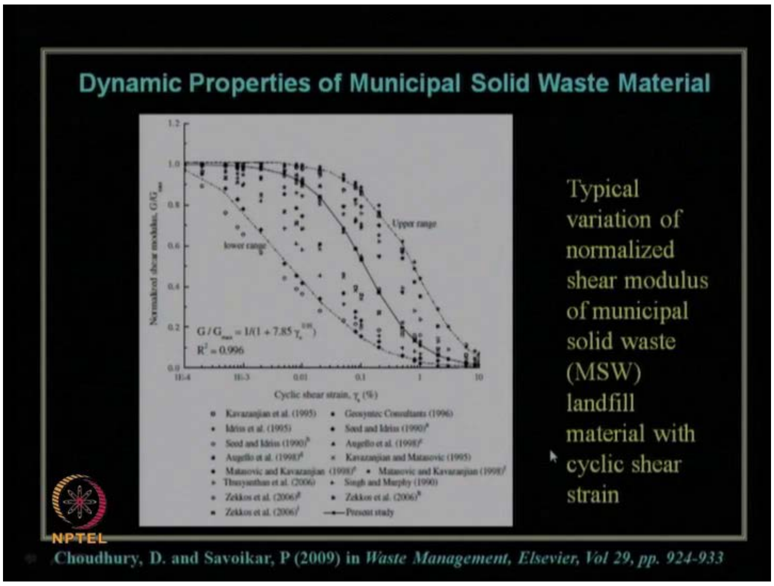

Further, the normalized shear modules; that is, G by G max ratio. This curve, how it varies with respect to cyclic shear strain; that is nothing but modulus reduction curve, how it varies. Those data also have been collected from the world wide researchers, data points which are proposed in various research papers, in journals and conferences technical reports and PhD thesis, like Zakos PhD thesis at U C Berkeley. Then Kavazanjian, Metazovic Seed and Idriss Kavazanjian et al, Edriss et al and so many other researchers, Singh and Morphy. from this collected results again a semi-empirical correlations were proposed, which gives r square value of 0.996 a very high value, by having this equation, one can easily do a preliminary design or can carry out site response analysis for this municipal solid waste landfill material, using this value of cyclic shear strain what will be the corresponding value of G by G max, which is helpful for any seismic design of municipal solid waste landfill.

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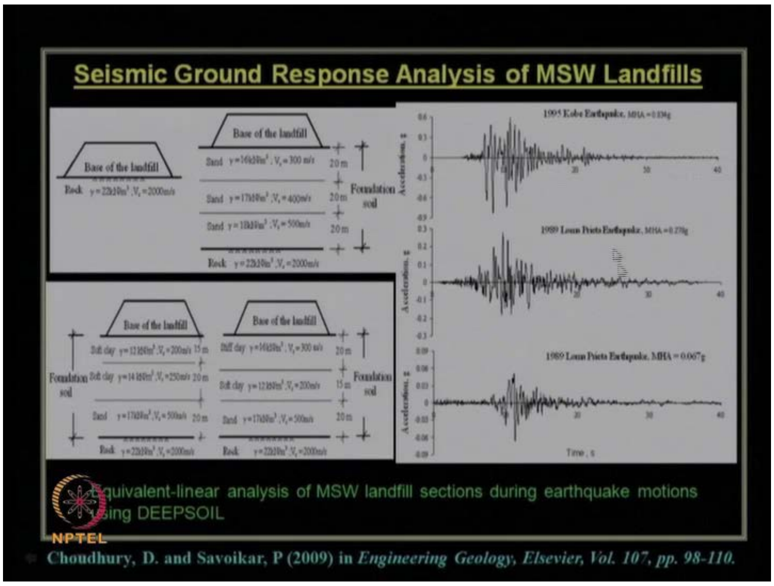

Now, once this dynamic characterization of this municipal solid waste landfill is over, then we can start to carry out, either equivalent linear or non-linear analysis for this municipal solid waste landfill. As we have done for the soil, various soil site, it is site specific as we have mentioned here also, it will be the material specific. So, in this case the municipal solid waste material dynamic property, needs to be incorporated for doing the site response analysis. So, this slide shows how the seismic ground response analysis for this municipal solid waste landfill were conducted, typical landfill like this, was considered, and this is the base of the landfill height of the landfill. And the foundation material different types of foundation material were considered. This is on the rock type foundation; this is on foundation soil, various layers of soil with different values of gamma and V s, followed by a rock. Then another MSW landfill which is founded on another type of soil; that is too soft clay followed by sand and then rock.

And another landfill which is constructed on foundation soil, like steep clay followed by soft clay, sand and rock. So, various layers and various combinations of foundation soil was considered for this seismic ground response analysis, which has been carried out, using this software deep soil, and also later on it has been carried out using the software FLAC 3 D. And for the analysis there are various types of earthquake motion; like Kobe earthquake motion, Loma Prieta, Loma Prieta at another recording station. So, these input acceleration time history were used, to carry out this seismic ground response analysis for municipal solid waste landfill; that is the soil properties as well as landfill properties needs to be considered. The details about this work is available in this journal paper Choudhury and Savoikar 2009, in the journal Engineering Geology, which is an Elsevier journal. This is the volume number and these are the page numbers.

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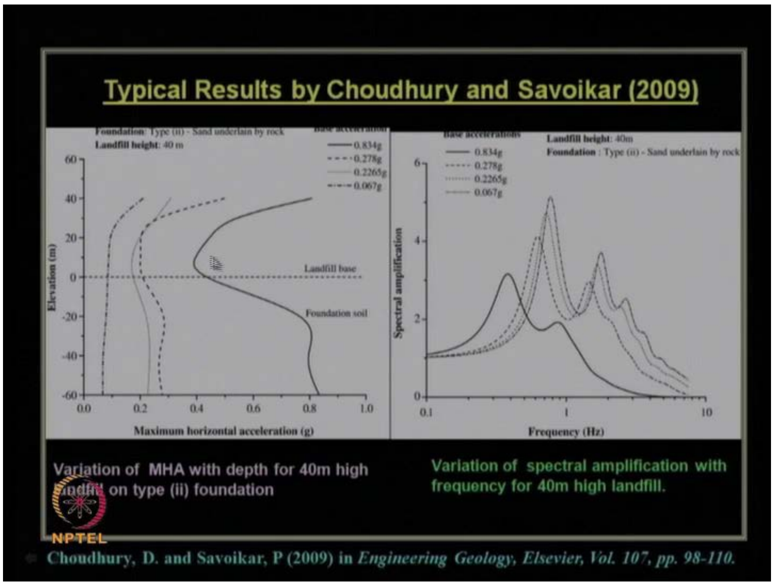

You can see here, that this slide shows the typical results, as obtained by Choudhury and Savoikar in this paper as I have mentioned just now. This shows how the maximum horizontal acceleration, or MHA in the unit of G, it varies with respect to the elevation. Elevation you can see over here, the zero line shows the landfill base, and below that is the foundation soil. So, for different foundation material, it has been considered different results, and on top of it, it shows the behavior within the landfill. So, from this figure; one can easily see this is the for the foundation type two, only for a specific foundation type, and landfill height was considered 40 meter; 40 meter is the height of the landfill. And base acceleration, these are four different types of seismic acceleration, was considered as input motion. You can see over here there is huge amount of amplification; that is increase in this value of this maximum horizontal acceleration, when you're considering at the base of landfill, and at the top of landfill, in all these four cases of input acceleration.

It automatically shows that the landfill material, which are in the loosed state, they amplify much more the input motion, which has been validated and proved, through this observation and results. Similarly, the spectral amplification, is shown over here for various input accelerations, for this landfill of height 40 meter, which is founded on type two foundation. Type two is nothing but as shown over here, this is type two foundations. And variation along with frequency, it has been shown over here. So, these are very useful, when somebody is going to design any landfill, of say 40 meter height at this height, using this type of foundation soil. And as we have already mentioned, to characterize the municipal solid waste material, in terms of its dynamic property like base value G by G max value, and damping ratio value, including the unit weight. They can use our proposed equations, and finally can obtain what will be the amplification etcetera, which further will help to design, this seismic, these municipal solid waste landfill in the seismically active region, so that there is no failure.

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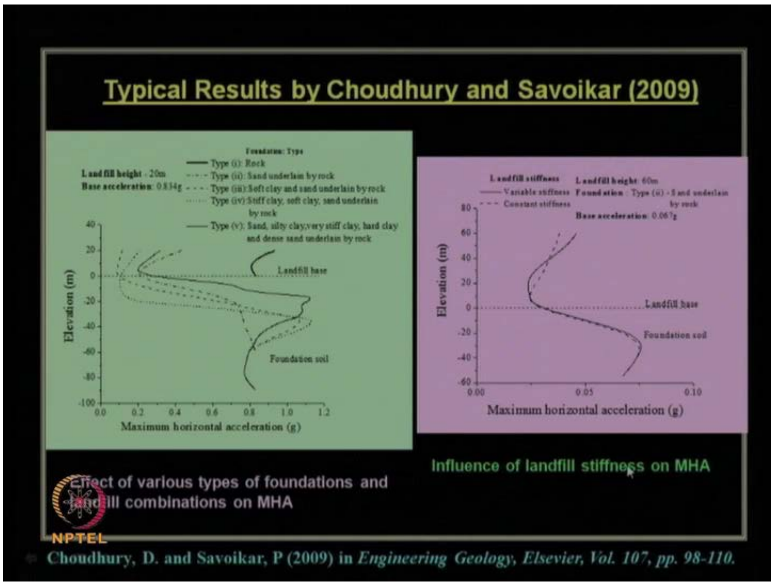

Because we know, whenever there is a failure of this municipal solid waste landfill, it will not only create a disaster in terms of damage of the landfill itself, but it will also initiate the process of lecher leaking and various other environmental hazards, which are additional damages to the society and locality. Another results have been shown over here, you can see. In this case landfill height is 20 meter, for a single base acceleration of 0.834 g was show over here. How the maximum horizontal acceleration is changing for different types of foundations. For different five types of foundation, depending on foundation soil also, the behavior of this seismic amplification of this maximum horizontal acceleration, within the landfill will depend on, as can also seen from these results.

As well as you can see form this, if somebody considers the variable stiffness, this solid line shows the behavior of maximum horizontal acceleration within landfill, and in the foundation soil instead of considering constant stiffness, why it comes into picture. If we go back few minutes back what we have discussed, when we have characterized the dynamic properties of the municipal solid waste landfill material with depth. So, in the variation with depth, there is a change in the value of G by G max and V s values etcetera; that will automatically change depth wise the stiffness.

If somebody wants to consider that variable stiffness which varies with respect to depth; that will give more correct result rather than assuming a constant stiffness throughout the layer. So, that is what it has been carried out and shown, but in terms of constant stiffness, within landfill region; that is from base of landfill to top of landfill, here the amplification of image A value was this much, whereas, in this case amplification was this much. So obviously, amplification is much more, if somebody considers the variable stiffness, and moreover it gives a more realistic results as shown over here.

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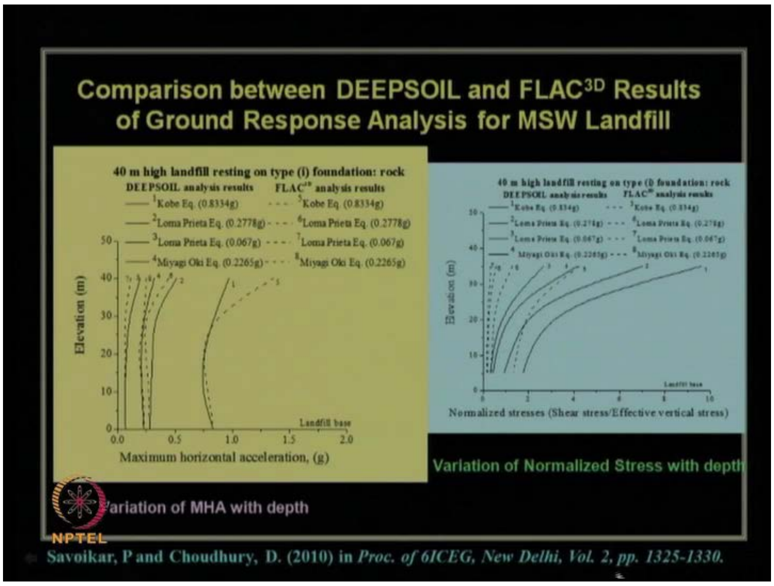

Now, this slide shows the comparison between the results obtained by using two different software's, as I have mentioned one is deep soil and other is FLAC 3D. One can see here easily, these solid line shows the results obtained from deep soil analysis, and the dotted lines shows the results obtained from, the FLAC 3D analysis. As can be seen, in most of the cases from this present study, what we had considered with the given input values and this given input seismic accelerations. In most of the cases the deep soil gives the higher results for these type of landfill, except this landfill, where for Kobe earthquake motion, one can find out that FLAC 3D results are showing much higher than the deep soil results. It depends on various characteristics of soil, various characteristics of seismic input motion and so on. Also the normalized shear stress how it varies with respect to depth, as obtained in deep soil and FLAC 3D are shown over here. The details about this work can be obtained, in the publication Savoikar and Choudhury 2010, in the proceedings of Sixth International Conference of Environmental Geo-Techniques, in New Delhi, volume number 2, and these are the page numbers.

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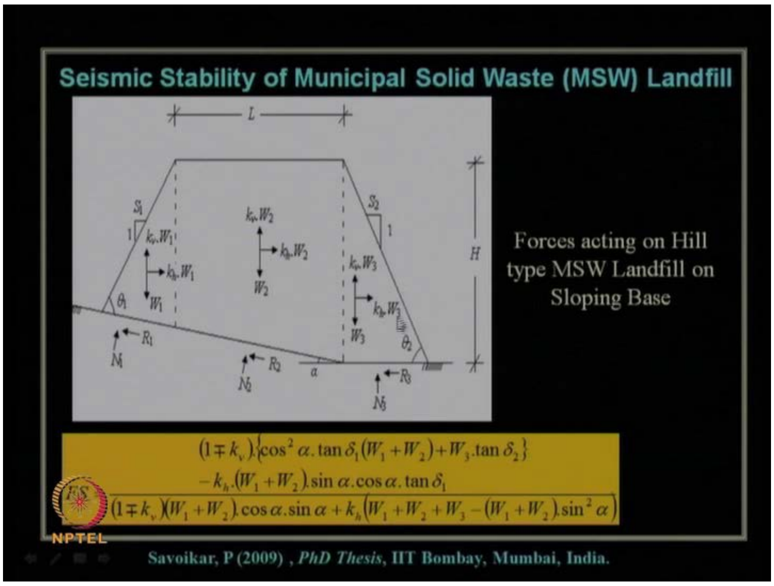

Now, once this dynamic characterization of municipal solid waste material is complete, and ground response analysis is complete. Next step is how to design a safe stable municipal solid waste landfill, in the seismically active region. So, for that; the seismic stability analysis of municipal solid waste landfill has been carried out, as can be seen from this basic picture. There are various types of landfill as we know. Here in this picture, only hill type municipal solid waste landfill has been shown, which is founded on a sloping base, so this is the sloping base. So, this is hill type MSW landfill, there are various others, like canon type, side hill type, various other types of landfill. And, in different regions, by considering the seismic inertia forces using the pseudo static, as well as, later on using pseudo dynamic approach. This work as I have mentioned was carried out Dr Purnan and Savoikar during his PhD at IIT Bombay under my supervision.

This is the equation of factor of safety, for this stability of this slope, were arrived at, after considering equilibrium of all the forces involved.

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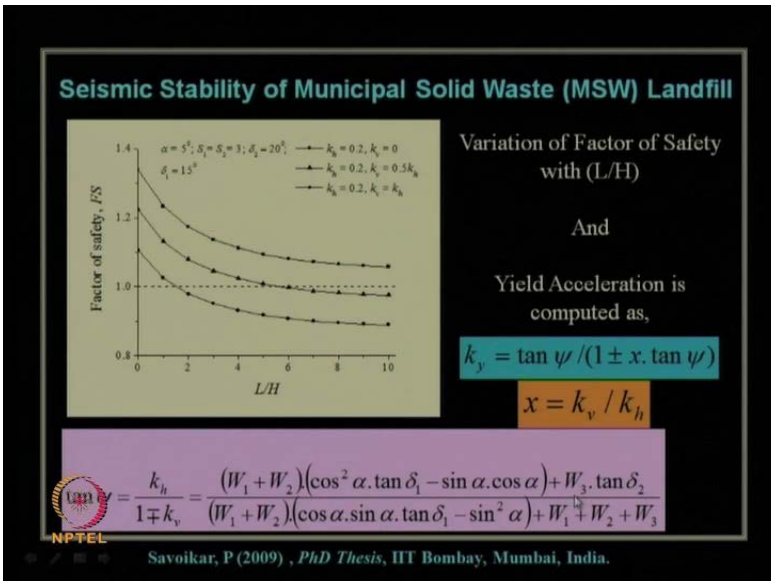

So, this is the typical results of factor of safety, one can see, which is varying with respect to L by H ratio, for different input values of k h and k v combinations with these given parameters. As it is seen, at some of the cases the factor of safety may go below one; that means, we need to find out the yield acceleration for those cases, and also want to estimate the displacement. So, the expression for yield acceleration, is given by this, where various parameters like x is given by this ratio of k v by k h, and this tan of psi is expressed as this, which can be estimated from this values given in this equation.

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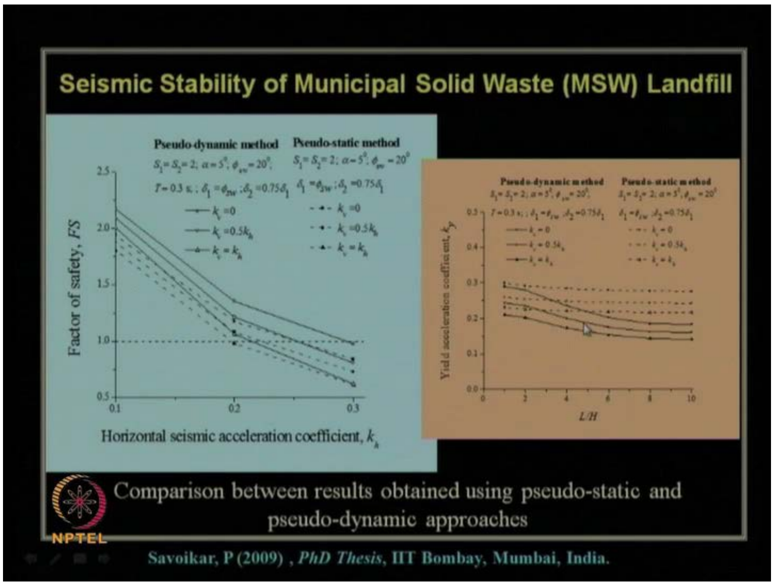

And these are the results which shows a comparison of pseudo-dynamic and pseudo-static method. The solid line shows the pseudo-dynamic results, and dotted lines shows the pseudo-static results of factor of safety, varies with respect to the seismic horizontal acceleration. And you can see here, pseudo-dynamic method is giving, in most of the cases for this chosen set of input data, little higher value than the pseudo-static results. And the yield acceleration coefficient value, the k y which is varying with respect to L by H. You can see over here the pseudo-dynamic gives the more critical value, than the pseudo-static results.

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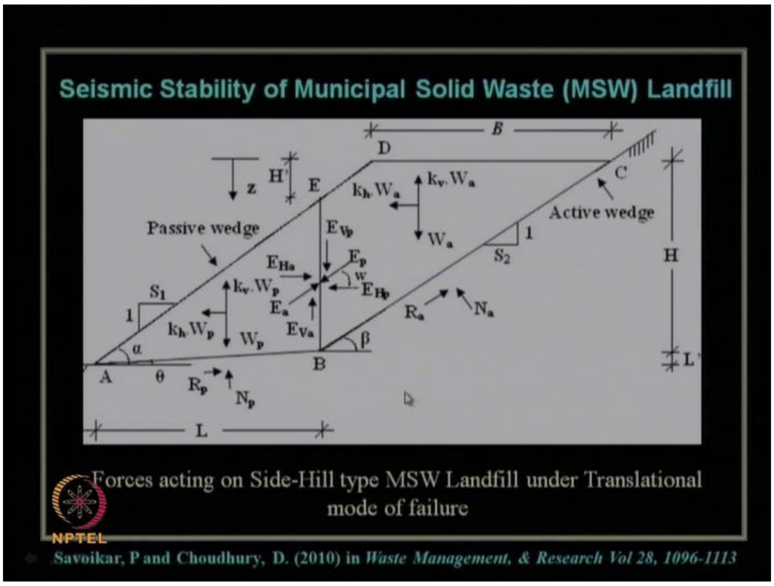

Further, the analysis was carried out for seismic stability of MSW landfill. This is for side hill type landfill, another type of landfill which is called side hill type. So, this is the slope of the hill, and this portion is the landfill. So, by considering two zones; that is active weight zone and passive weight zone, involving all the forces, which are present in this zone.

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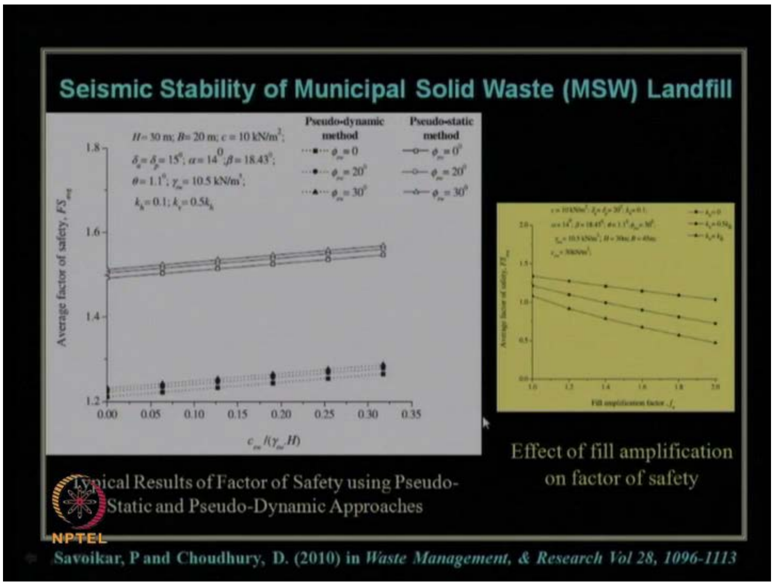

Then limit equilibrium of all this forces are considered, to carry out the stability analysis, and finally, the factor of safety, average factor of safety has been reported, considering also the quotient component of municipal solid waste material, as well as the quotient of the soil. So, these are the variations of pseudo-dynamic and pseudo-static results of factor of safety. Whereas, this picture shows the effect of field amplification factor, which is not possible to consider in pseudo-static method, but we can consider only in pseudo-dynamic method, as we have discussed earlier also.

And you can see, as the felid amplification increases, there is a significant decrease in the value of this factor of safety of this MSW landfill slopes. So, as we have already learnt from the ground response analysis, equivalent linear ground response analysis for MSW landfill, that there are always some amount of amplification, seismic amplification. So, one needs to consider this amount of amplification, when somebody is designing the MSW landfill for the stability of the slope, in terms of translational failure or rotational failure like this, and then factor of safety and yield acceleration needs to be estimated.

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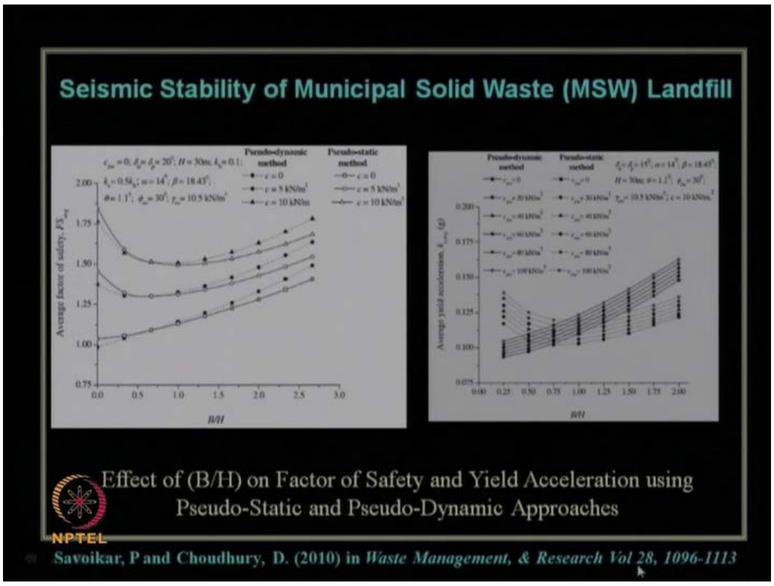

Some more results of factor of safety, for both pseudo-dynamic and pseudo-static results, with respect to B by H ratio are shown over here. There details about these results are available in the journal paper by Savoikar and Choudhury of 2010, available in the journal Waste Management and Research. This is the volume number and page number.

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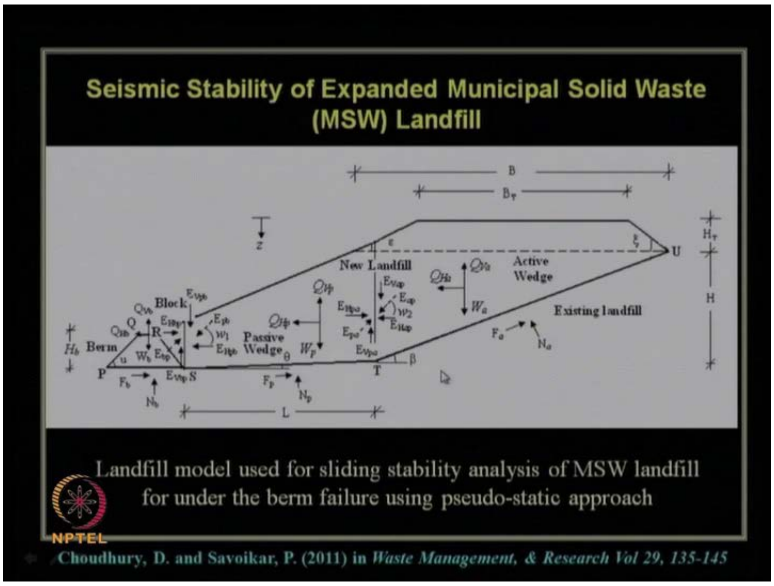

Now, another important aspect of this MSW landfill, because of scarcity of available space or land, in urban areas; like in Mumbai, somebody will find it very difficult, to find an open land, to construct a new structure or building, or a very big structural things in

Mumbai, to find out an open space. Because of this problem of space crunch in urban cities, not only in Mumbai, but in other urban cities worldwide, like in Tokyo, in New York, in Frankford and all these places. There is a need that whenever this engineered landfill; that is the landfill which are designed, using the engineering methodology, and after closing of this landfill if somebody wants to use that space, for further construction. And if seismic event is supposed to happen at that place, then what are the extra precautions needs to be considered, for the design of this landfill. And, if there is a need for extension of the landfill, because manier cases, because of the space crunch horizontally the landfill may not be able to get expanded, one need to go for vertical extension of landfill, or a combination of vertical and horizontal expansion of landfill, and further the use of that landfill, area for further civil construction.

So, in this slide, we are now going to discuss about the seismic stability aspects of the expanded MSW landfill; that is, this is the original Berm, and on that new landfill or expansion of landfill has been proposed over here, over the existing landfill like this. And a Berm has been provided over here to maintain the stability, this is the existing landfill, this is new landfill. It is not in scale, but it gives a schematic diagram, of how the expansion of landfill can be carried out, and the seismic stability aspect of this expanded landfill also needs to be ensured. The details about this research work are available in the journal paper by Choudhury and Savoikar 2011, in Waste Management and Research. This is the volume number 29 and page numbers. So, all the forces are given over here, there can be two possibility mode of failure for this new landfill over the existing one; one is known as bottom Berm failure, and another is upper Berm failure.

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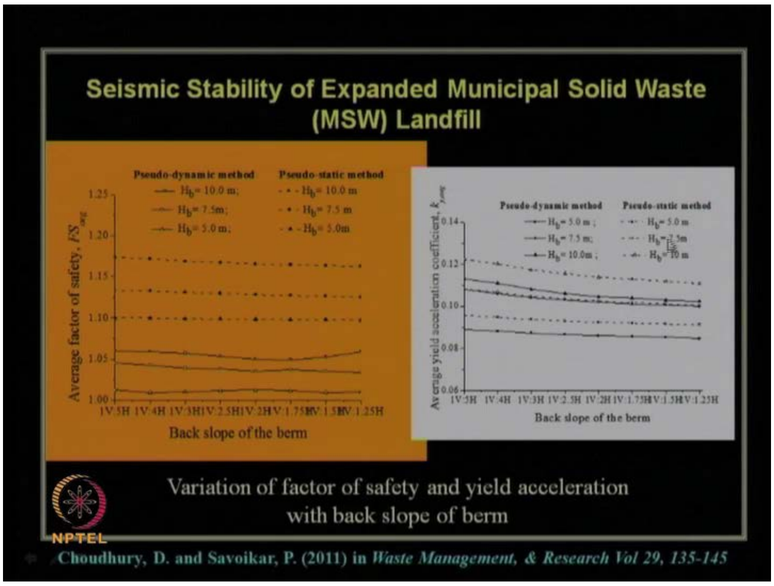

So, considering this Berm failure, one can easily find out, using the limit equilibrium approach for all forces, involved in the basic picture what I have shown just now. What is the factor of safety of that expanded landfill region, depending on various other input values like back slope of the Berm, and using either pseudo-dynamic approach or pseudo-static approach. In these results one can see the pseudo-dynamic approach gives the, least value or critical value compared to pseudo-static approach. Also for the average yield acceleration coefficient, the pseudo-dynamic approach gives the least value or the critical designed value, compared to the pseudo-static approach. So, with this we have completed our module number nine, for this video course, and that was the last module for this course. Now before I wind up the entire video course, I would like to acknowledge various people, who helped me, while making this presentation, and also to understand the subject, and also through my collaboration and research work carried out with my students, with my collaborators, with my teachers and various other funding agencies.

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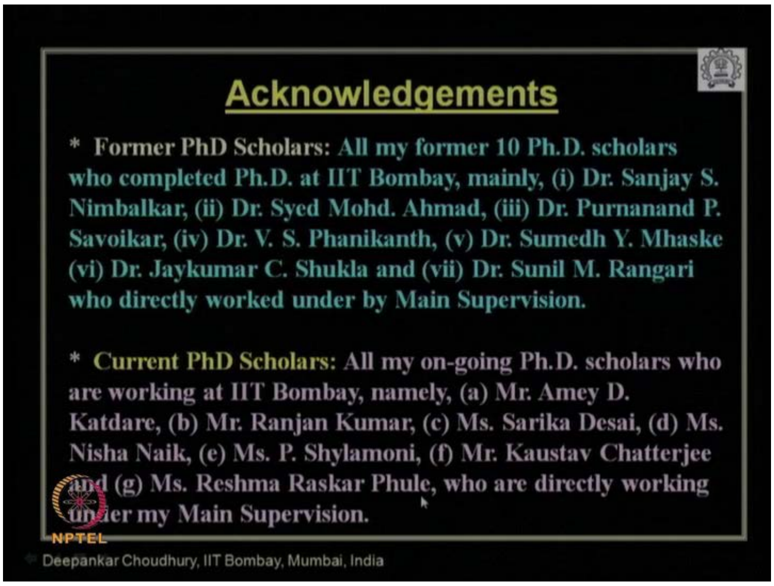

So, these are the acknowledgments goes like this; first of all, I must thank my former PhD scholars. Total ten PhD scholars, who have completed PhD at IIT Bombay, under my supervision, either as myself as main supervisor or co supervisor among those ten PhD. Scholars who have completed already at IIT Bombay their PhD thesis. Seven of them did work under my direct supervision, as myself as main supervisor. Their names are Dr. Sanjay S Nimbalkar, Dr. Syed Mohammad Ahmad, Dr. Purnanand P Savoikar, Dr. V S Phanikanth, Dr. Sumedh Y Mhaske, Dr. Jaykumar C Shukla, and Dr. Sunil M Rangari. Also I want to acknowledge, the research work carried out by my ongoing PhD scholars, or current PhD scholars, who are working under my supervision at IIT Bombay. Like Mr. Amey D Katdare, Mr. Ranjan Kumar, Ms. Sarika Desai, Ms. Nisha Nayak, Ms. P Shylamoni, Mr. Kaustav Chatterjee, and Ms.. Reshma Raskar Phulc.

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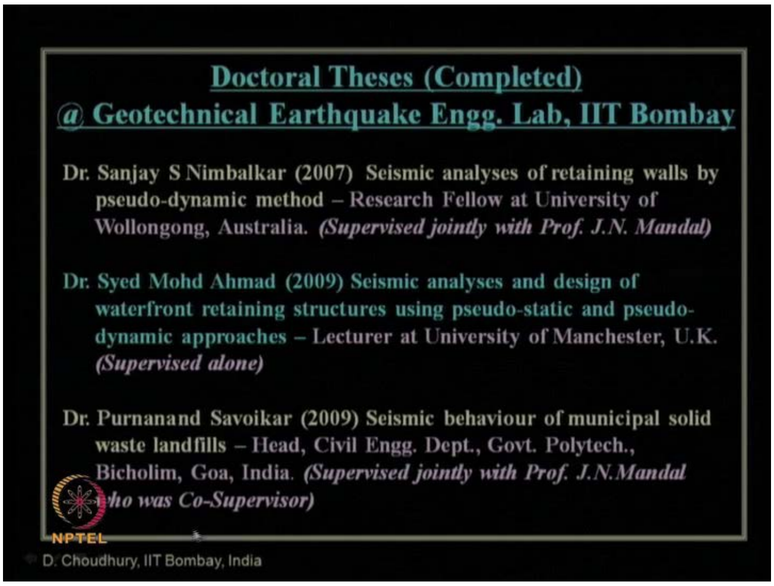

Now, while acknowledging my PhD students, who are the main pillars for the research work in this area of Geotechnical Earthquake Engineering. I want to share this information with all of you, that what are the doctoral thesis or PhD thesis, which are completed at our lab; that is at Geotechnical Earthquake Engineering Laboratory at IIT Bombay at my laboratory. As I have already mentioned their name, this slide shows their this title, and at present where they are working, all these details. Like Dr. Sanjay S Nimbalkar, he completed his PhD thesis in 2007. His topic of research was Seismic Analysis of Retaining Walls by pseudo-dynamic method, as I had already mentioned and discussed several times, he developed pseudo-dynamic method extensively. Currently he is a research fellow at university of Wollongong, in Australia, and this research work was supervised jointly with Prof. J N Mandal of IIT Bombay.

Next my second PhD student Dr. Syed Mohammad Ahmad, who completed his PhD in 2009. His PhD thesis topic was Seismic Analysis and Design of Waterfront Retaining Structures, using pseudo-static and pseudo-dynamic approaches, as I have mentioned he first worked on this combined effect of tsunami and earthquake, using this pseudo-dynamic approach as well as pseudo-static approach. Currently he is a Lecturer at University of Manchester in U K, and this thesis was supervised by myself alone. My third PhD student Dr. Purnanand Savoikar, who also completed his PhD in 2009, his PhD thesis topic was, Seismic Behavior of Municipal Solid Waste Landfills as I have discussed just now, about his work. Currently he is Head of civil engineering department at Government Polytechnic in Goa, and this PhD thesis was jointly supervised with Prof. J N Mandal, who was co supervisor for Dr. Savoikar.

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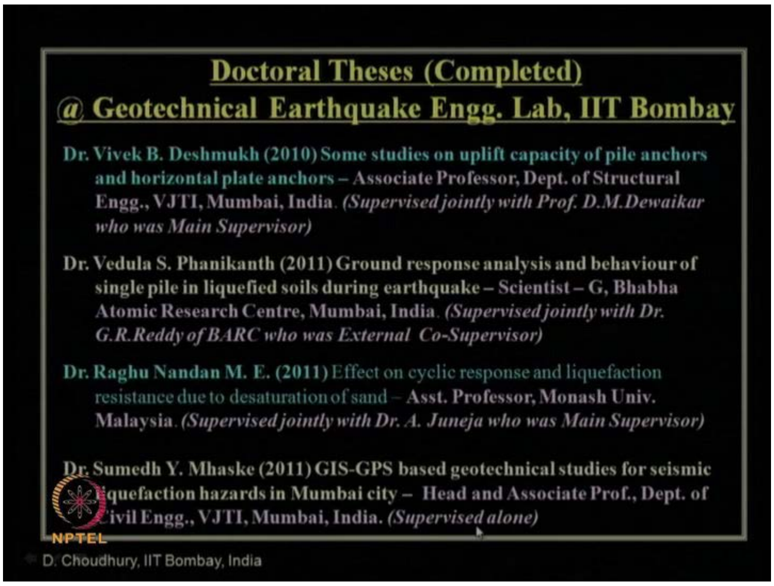

Next Dr. Vivek B Deshmukh, he completed his PhD thesis in 2010. His PhD thesis topic was some studies on Uplift Capacity of Pile Anchors and Horizontal Plate Anchors. Currently he is an Associate Prof., at Department Of Structural Engineering at VJTI in Mumbai. And this thesis was supervised jointly with Prof. D M Dewaikar of IIT Bombay, who was the main supervisor for this student. Next, my PhD student Dr. Vedula S Phanikanth, who completed his PhD in 2011, his PhD thesis work was on ground response analysis, and behavior of single pile, in liquefied soils during earthquake, as I had already discussed about his work. He developed the new method how to incorporate the local soil conditions, like Mumbai soil condition to carry out the ground response analysis, and for that we incorporate that effect in the pile analysis, in the liquefiable and non liquefiable soils during earthquake. Currently he is Scientist G at Bhabha Atomic Research Centre in Mumbai, and this thesis was supervised jointly with Dr. G R Reddy of BARC, who was the external co supervisor for Dr. Phanikanth.

Then Dr. Raghu Nandan M E, who completed PhD in 2011, his PhD thesis topic was Effect on Cyclic Response and Liquefaction Resistance, due to De-saturation of Sand. Currently he is an assistant Prof. at Monash University Malaysia campus, and this thesis was jointly supervised with my colleague Dr. A Juneja, who was the main supervisor for this student. Next my student Dr. Sumedh Y Mhaske, who completed his PhD in 2011 at IIT Bombay, his PhD thesis topic was, GIS GPS based geotechnical studies, for seismic liquefaction hazards in Mumbai city. I have described about his work, how to prepare the liquefaction hazard map, and what is the use of that hazard map, in the mitigation of the disaster, after the event of earthquake has occurred at a particular city, how to find out the rescue operations etcetera, and the dynamic soil properties and other things, how to map it in the GIS GPS based interface, which is useful for the designers in a particular city like Mumbai. So, currently he is head and associate Prof. in Department of Civil Engineering of VJTI in Mumbai, and this thesis was supervised by my myself alone.

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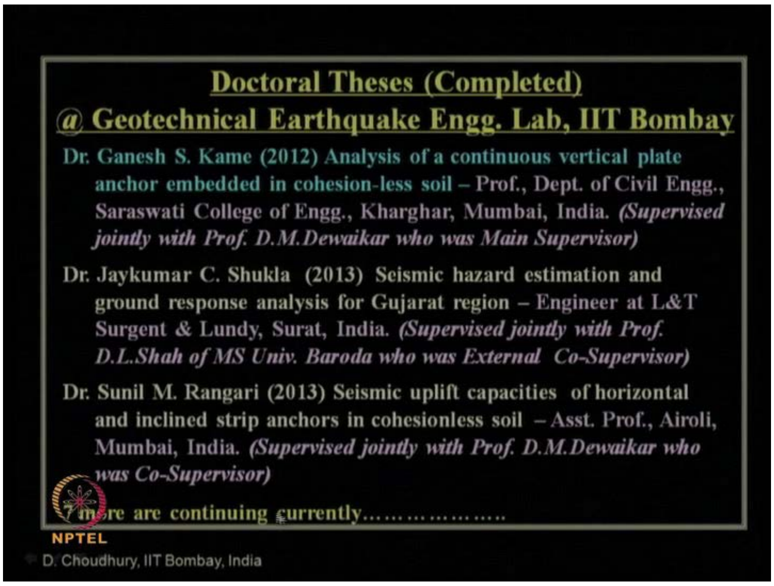

Next Dr. Ganesh S Kame, who completed his PhD in 2012, his PhD thesis topic was Analysis of a Continues Vertical Plate Anchor, Embedded in Cohesion Less Soil. Currently he is Prof. at department of civil engineering in this college, in Mumbai. This thesis was supervised jointly with my colleague Prof. D M Diwaikar, who was the main supervisor for this candidate. Next my PhD student Dr. Jaykumar Chandrakanth Shukla, who competed his PhD in 2013 very beginning, his PhD thesis topic was Seismic Hazard Estimation, and Ground Response Analysis for Gujarat region. I have already discussed in detail about his research work, how to carry out the seismic hazard analysis, using both deterministic seismic hazard as well as probabilistic seismic hazard, and ground response analysis, and for that to apply those in various cities and ports of Gujarat. So, currently he is an Engineer at L&T Surgent and Lundy in Surat. This thesis was supervised jointly with Prof. D L Shah of MS University, who was the external co supervisor.

Next my PhD student Dr. Sunil M Rangari, who also completed his PhD in 2013, his PhD thesis topic was seismic uplift capacities of horizontal and inclined strip anchors, in cohesion less soil. Currently he is assistant Prof. in a college in Mumbai. This thesis was also supervised jointly with my colleague Prof. D M Diwaikar, who was the co supervisor for this candidate. So, you can see there are many students in, who worked in this laboratory of geotechnical earthquake engineering at IIT Bombay, and from their work my course of this geotechnical earthquake engineering has been majorly developed, and the work research, work majorly in various modules what I have mentioned are given over here. So, currently seven more PhD students are working in various topics, related to this Geotechnical Earthquake Engineering, at IIT Bombay under my supervision, as I have already mentioned their name.

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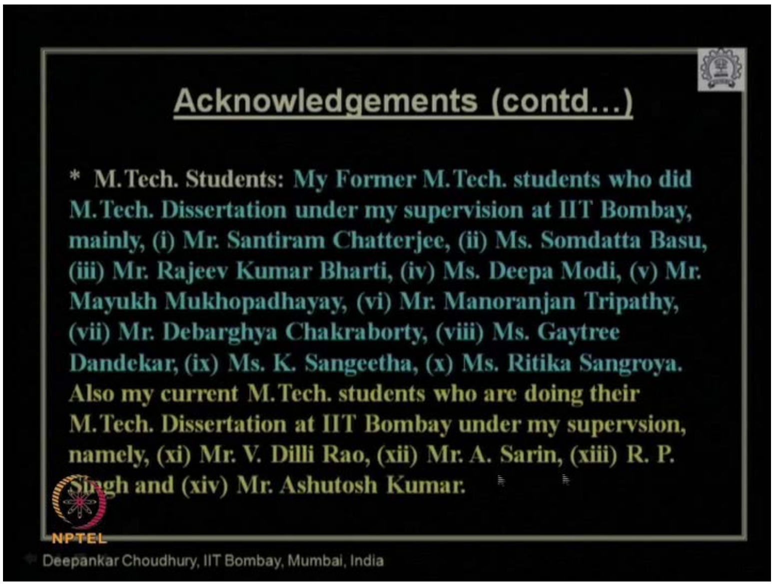

Next acknowledgment goes to all my master student, who worked under my supervision at IIT Bombay for their masters dissertation, and master's thesis. First I want to acknowledge the work carried out, by my former or previous master student, namely Mr. Shantiram Chatterjee, Ms. Somdatta Basu, Mr. Rajeev Kumar Bharti, Ms. Deepa Modi, Mr. Mayukh Mukhopadhayay, Mr. Manoranjan Tripathy, Mr. Debarghya Chakraborty, Ms. Gaytree Dandekar, Ms. K Sangeetha, Ms. Ritika Sangroya. They have done excellent masters dissertation work, and some of their work I have also have mentioned in this course, while discussing about various research aspects, design aspects and findings. Also my current M-Tech students, who are also currently doing their M-Tech dissertation, work at IIT Bombay under my supervision. Like Mr. V Dilli Rao, Mr. A Sarin, Mr. R P Singh, and Mr. Ashutosh Kumar.

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Next my thanks goes to my supervisor, my teachers in India; like my PhD supervisor Prof. K S Subba Rao, with whom I did my PhD at IISC Bangalore, in this area of Geotechnical Earthquake Engineering, and also my another teacher Prof. A Shridaran, who also worked extensively in the Area Of Soil Dynamics And Mission Foundations, I worked with him at IISC Bangalore as well. Then Prof. T G Sitaram, Prof. GLS Babu, Prof. J Kumar Prof. C S Manohar of IISC Bangalore, from whom I have learnt various aspects of soil dynamics or geotechnical earthquake engineering, or structural dynamics. Also I want to acknowledge the help of Prof. N N Som, Prof. R D Purkayastha, Prof. S C das, Prof. C Battacharya, Prof. S P Mukarjee, and other teaches of Jadavpur University, who thought me various aspects of foundation engineering, though those things are not directly related to geotechnical earthquake engineering, but concept of geotechnical engineering their application in foundation design etcetera, were developed, and given by these teachers of mine.

My various collaborators in India with whom I have worked, and with some of them I have also joined publications, which I have discussed during this course. And some of them are also currently working with me, and I am happy to acknowledge their help in this slide; like Prof. M R Madav of JNTU Hyderabad, who was former Prof. at IIT Kanpur. Then my colleague of Prof. J N Mandal, Prof. D M Diwaikar Prof. BVS Viswanadham, Prof. S Ghosh of IIT Bombai, Prof. Priyanka Ghosh of IIT Kanpur, Dr. G R Reddy, Dr. K Bhargava, Dr. A K Ghosh of BARC Mumbai, Dr. P C Basu of AERB Mumbai, Prof. D L shah of MS university Baroda, Prof. P Samui of VIT, Prof. G Battacharya of Besu, Prof. A M Krishna of IIT Guwahati, Prof. C gosh of NDMA.

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Now, my other collaborators form outside India, with whom I have worked at various times, and also currently with some of them I am working. Also with some of them, I got various publications, either in this area of geotechnical earthquake engineering or the related area. So, I want to acknowledge their help, like Prof. Jonathan D Bray of UC Berkeley USA, Prof. Buddhima Indraratna of University of Wollongong Australia, Prof. C F Leung of national university of Singapore, Prof. Rayasuke Kitamura of Kagoshima University Japan, Prof. Rolf Katzenbach of Technical University Darmstadt Germany, and Prof. S Battacharaya of University Of Surrey in U K.

I must acknowledge the funding agencies, the major or significant funding agencies; like AERB Mumbai BRNS DAE Mumbai, INAE Indian national academy of engineering

New Delhi, SERC DST department of science and technology New Delhi, INSA that is Indian national science academy new Delhi, IRCC of IIT Bombay Mumbai India. So, these are the national funding agencies, and also various international funding agencies; like Alexander Von Humboldt foundation of born Germany, Japan society for promotion of science Tokyo Japan, U K IRI of U K India jointly, Samsung C and T of Korea.

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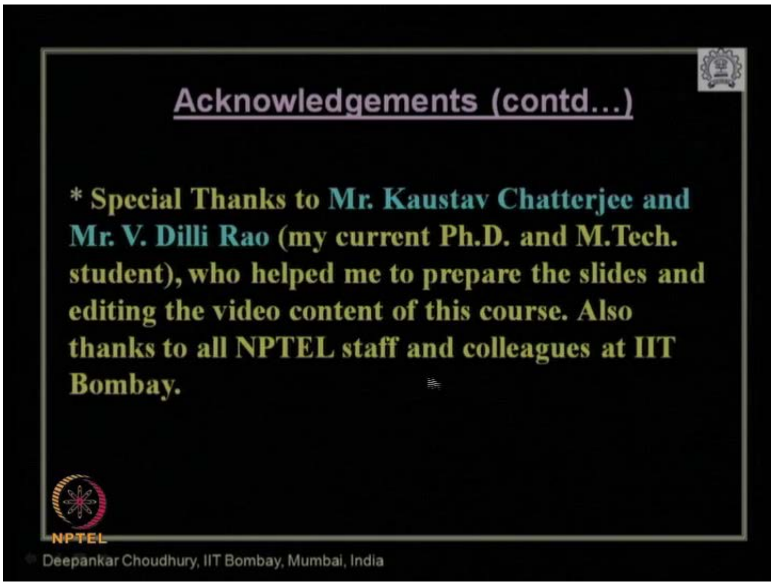

And a special thank goes to Mr. Kaustav Chatterjee and Mr. V Dilli Rao, who are my current PhD student and my M-Tech student, who helped me to prepare the various slides, and to edit the various video contents, which were prepared for this video course of NPTEL. Also, I want to thank all NPTEL staff and colleagues of IIT Bombay, who helped me at various times to develop this course, and to make it more meaningful for the society. So, with this, I want to end my, this video lecture of NPTEL on this course of geotechnical earthquake engineering. I want to thank all of you, who are listening to this video lecture and getting benefit from this lecture. You can see here my contact email address, so if you have any doubt further on this course or on this topic, you are free to contact me by these email ids. Thanks a lot for your patience hearing of this course.