Introduction to Engineering Seismology
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Lecture – 48
Seismic Microzonation of Bangalore

Welcome. So we will continue our lecture on engineering seismology. So we have been discussing about the microzonation hazard index estimation. So we have seen that in any area depends upon the exposure what are the different possible hazard is expected. So we can list out all those hazard systematically which is called as a earthquake hazard parameters so depends on the city it keep varying.

As we told that the coastal such as tsunami will be part, the hilly terrain landslide will be the part and then the middle of any regions like Delhi or Bangalore kind of things both are not possible, but other hazard maybe possible. So irrespective of the place the earthquake hazard at the bedrock level is the common attributes common seismological attributes which will be necessarily countered in the seismic microzonation as a first and foremost step which is that seismic hazard due to the nearby seismic sources up to bedrock level.

Then depends upon the soil thickness and stiffness okay the waves are going to get modified. So you can add here geomorphological attributes which reflect a topographical soil thickness, soil type these are all the geomorphological attributes and then again estimate how much amplification going to take place that is again seismological attributes where you consider earthquake as an input to estimate a amplification.

Then the liquefaction depends upon the cohesionless soil, cohesive soil, cohesionless soil undergo a liquefaction and caused extensive damage. So we have to count that as one of the seismological attribute in the regions where the cohesionless soils are predominantly present. So then obviously the cohesion liquefaction is done landslide, tsunami. So you can list all of them and rank and give the weights.

So you assign a weight based on the decision maker past history of the earthquake. So you can assign the more weightage and less weightage depends upon the importance of the each parameters. Once you assign a weight within the parameter we have seen that there is a division for example one region Bangalore region, the soil thickness may vary 0 to 40 meter. So I should give more weightage to the 40 meter soil and less weightage to the 0.

Because more and more soil there is a more and more amplification and liquefaction and wave modification so that has to be ranked so which has to be given a higher ranking then estimate a normalized rank. Once we estimate a normalized rank you already estimated the normalized weight based on each earthquake hazard parameters and then you multiply each grade the normalized rank and weight and then for each parameters.

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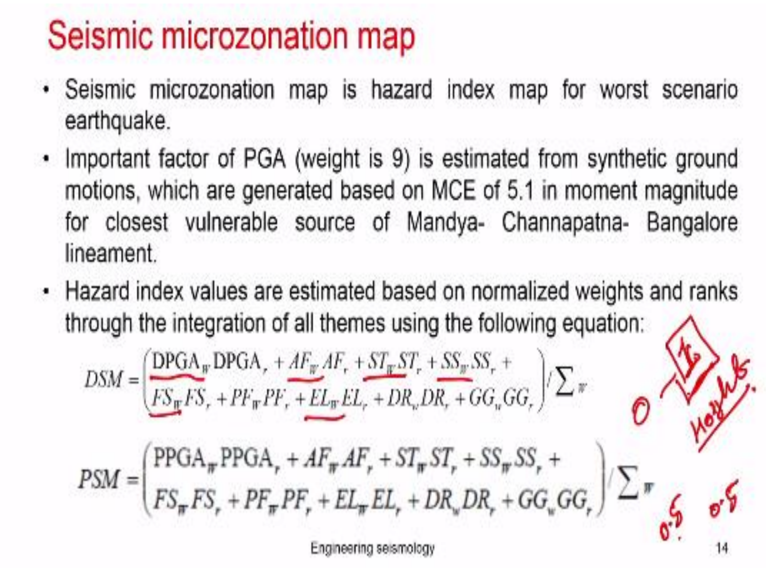

Finally make add all of them and estimate a final hazard index value. This hazard index values varies from basically 0 to unity it will vary from 0 to unity. So the 0 and highest value will be unity. So I1 will be the highest hazard. So here we should remember that this value one indicate a more severe, but again this will vary depends upon the weights what you assign for each parameter.

So that means it is not uniformly same for all the region. So one place you get the hazard index value of 0.5 the other place you also get 0.5 the 0.5 both are not indicating the level severity. One place this maybe low another place this maybe very high because of you assign weight yourself decision maker assigns a weight and then estimate a pair wise matrix of the normalized weight which is depends upon the user.

So you can estimate this by the deterministic approach and probabilistic approach. So let us see how this typical study was done for the Bangalore city. As I told you that which was done part of my PhD and where we consider all the possible scenarios and finally arrived a hazard index map of the Bangalore. We discussed how these hazard index map are the deterministic and probabilistic based approach results are varies.

So right now I am not going to discuss each hazard parameter estimation in detail only I will give you the glimpse because that itself is a separate topic of research. So it can be taught as a separate course so right now I am not doing that. So the first foremost step I told you that estimate a bedrock level hazard.

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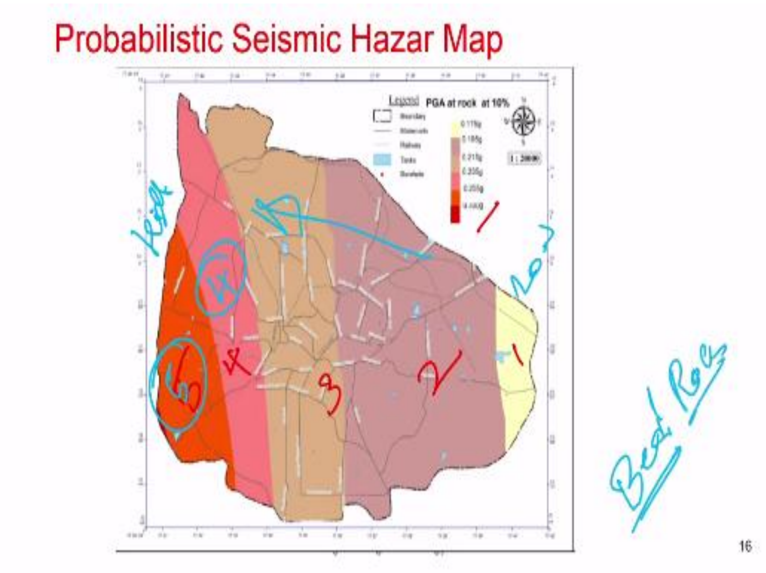

So this particular step we are going to discuss part of our course after finishing couple of lectures we will be going to do seismic hazard analysis of the any particular place with the case studies. So this is the seismic hazard analysis has been adopted and then we mapped a PGA distribution of each city. So each grid we mapped a PGA distribution. So the PGA distribution has been mapped and you can see the distribution of PGA which vary from lowest value is basically 0.1.

You can see this is a 0.1 is the lowest value, the highest value will be the 15. So this has been divided as a how many grid totally 5 the 1, 2 so then the so 1, 2 so the yellow one is actually this one here also this is the 1 actually this is the 2 so this is the yellow one is a 3 this is the 3 basically. So once we have done the 3 this is actually the 4 so the dark red one will be 5. You can see that the hazard was actually 5 category distributed here.

So the 4 categories are this area wherever you can see it. So this is and this part is 4. So this is how the hazards are distributed each grid is 1 value depends upon the earthquake magnitude, distance and then nearby active source so all those things taken into accounts finally produced by the Bangalore by systematic approach. So which; we will be discussing in the later stage of our class.

Once you are done that as I told you that the next affecting parameter is a soil. So what we discussed earlier was actually the deterministic based approach so same way you can estimate the hazard for the probabilistic based approach. So this method also we will discuss end of our course so where we will be talking about how to estimate a probabilistic based hazard at each grid.

So here also you can see a different zone 1, 2, 3 okay so the 4 and 5 so maybe I should use some other color. So the 1, 2, 3 also visible so there is a 4 and this is a 5 you can see so this is a 4, 5 so 5 group now you can see that change in the hazard pattern. You can see the deterministic hazard actually the hazard was highest on this part which varies like this. It is low here high here.

But when you talk about the probabilistic basically it varies like this. So this side is low and this side is high. So this is because of the procedural difference and then uncertainty associated with that which we will be discussing in the in detail in our class in the later stage. So this is about the hazard at bedrock level. So right now we are ready with our map at bedrock level we mapped.

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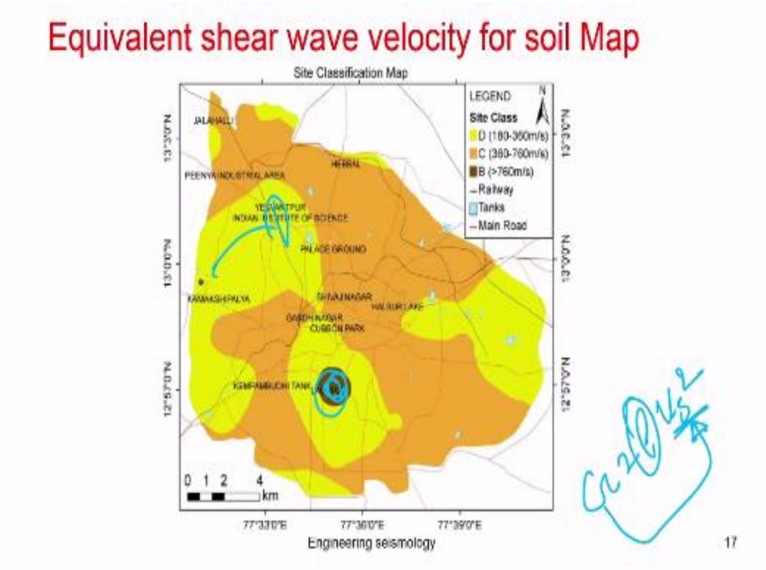

As I told you that the other important parameters which contribute the modification of the hazard is the soil parameter so the mapping of soil average has to be consider. So for this we have done a detailed geophysical, geotechnical investigation and collected a data and tried to arrive a Vs value shear wave velocity which is basically shear modulus because G = rho into Vs square so the rho values are variation small.

So the Vs square can be considered as your useful hazard indication at a particular location. So with that point the Vs has been measured the entire area of this one and mapped that so since this is not part of our scope I am only talking about the map how the map has come. So we mapped here Vs distribution based on the Vs30 average. So if you want to know about the Vs 30 average Vs measurement and all you can refer some of my publication.

And Google for more information so you can see the distribution there are 3 category you can see. So one is that site class D which is like more dangerous than the C which is relatively less dangerous than the D and then the B which is again relatively low. So this is basically a Lalbagh this area is Lalbagh where you can see a outcrop where you can see IISc and all as I told you that the shallow bedrocks the rocks are also outcrop.

You can see this comes under the category of the D and then the C these are all the major area comes under the category C. So like that you can divide this 3 category which is based on the equivalent soil shear wave velocity.

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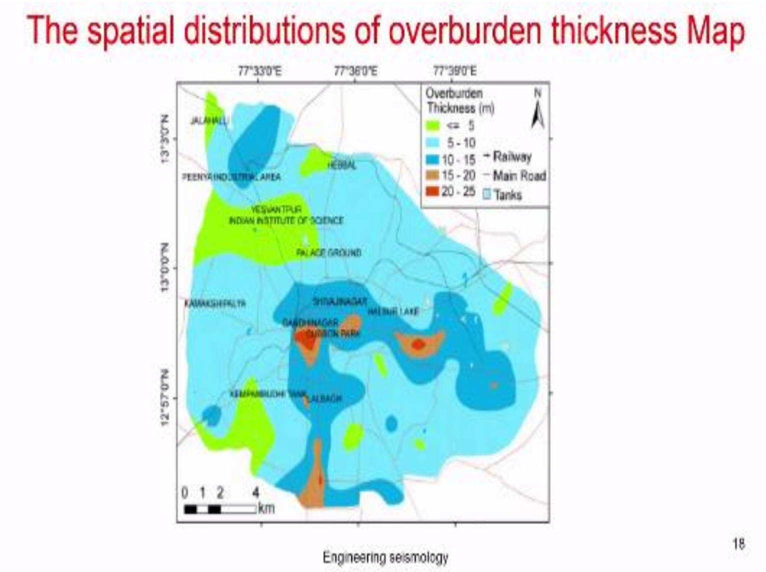

So then you can also estimate a thickness of the soil. So again you can see the thickness of the soil map from the borehole. You can again see the higher thickness and the lower thickness. So depends on that you can assign a weightage factor you can see the thickness distribution you can rank them. So this is the data based for this preparing both the map you need a geotechnical and geophysical investigation data.

Basically you need to get a geotechnical and geophysical investigation data. So this data as basically as close as you represent the accuracy of the mapping grid will be increased. So generally there is a 500 / 500 grid size for the more variation based size and then 2 kilometer / 2 kilometer grid size for the less variation size with respect to topography and soil variation that is how you can do and prepare this kind of map.

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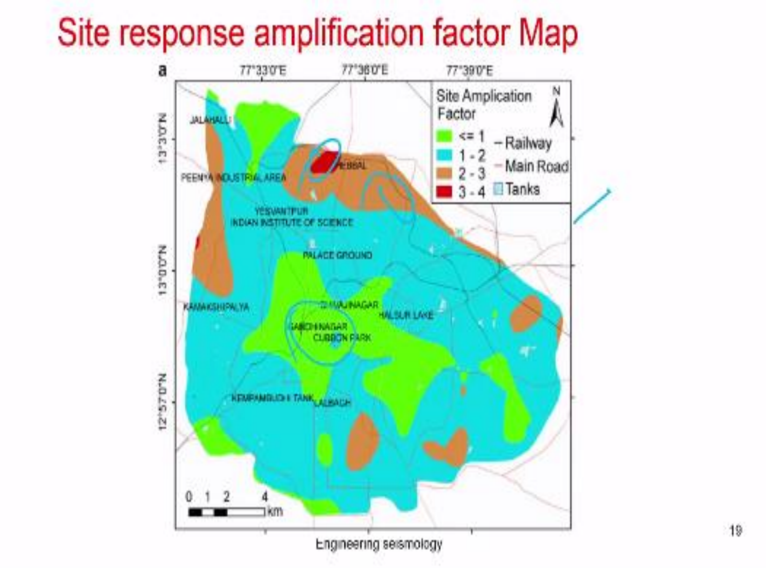

So once you are done that so next level is to estimate how much amplification going to take place by considering all the previous input. The hazard values and soil data clubbed together and modeled how much amplification going to take place and then map a amplification distribution map. So you can see that the rocky regions where your amplifications are negligible.

The more soil region you have the more amplification values. So this is what you can see in the map. So which is the function of earthquake as well as the soil not only soil alone, but some indication so how much PGA is taken, how many layered systems are there, what is the density and Vs variation all those things contribute this. So this map has to be estimated systematically.

So this kind of research I do, but I am not teaching part of this course in detail because of site response analysis itself can be taken a 5 to 10 hour class depend upon the in-depth knowledge what you want to go. Here we are not discussing that because our objectives only to introduce engineering seismology to you so not going into this one okay this is all done with lot of extensive field and numerical analysis of the data.

So once you are done that so you can also measure a prominent frequency or the resonance frequency at the area by experimental way which is experimental site response analysis or experimental site response studies.

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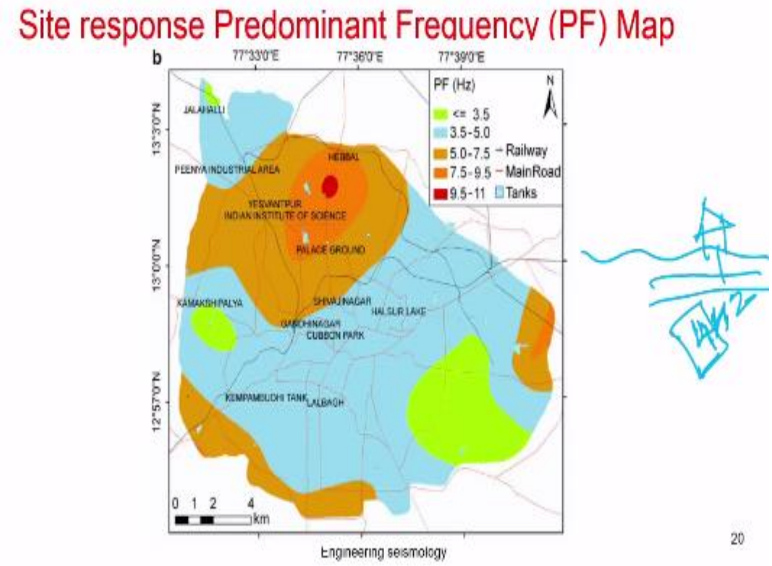

So where they will deploy a microtremor instrument which is like seismometer and monitor your vibration, noise and then take H / V ratio that gives the predominant frequency of the soil column. So for example in one location you deploy a equipment, you measure a predominant frequency and say 4 hertz. So which; indicates that the natural frequency of the soil column in this is actually 4 hertz.

When you want to build a building you should see that which never matches with the natural frequency of the soil column you should be away from the natural frequency so that is what will help you. So that kind of data will be obtained by carrying out a microtremor studies which is called as a Nakamura method, microtremor studies such extensive study I used to do because as I told you that we have a seismometer with us.

Where we deploy a seismometer and measure a microtremor signals then estimate a H / V ratio. So recently we are doing this kind of extensive study for Coimbatore, Bangalore and Bhubaneswar so where we have done almost close to 600 points in the Bangalore around 550 points in Coimbatore around 1,500 points in the Bhubaneswar because Bhubaneswar is a big city where it has been systematically this equipment has been deployed.

And noise has been measured and predominant frequency has been estimated. So even I do have published a paper how the predominant frequency of the region varies, how it is related to the thickness of the soil column. So which; we have done for the indo-gangetic basin which is the first time unique work in India where we related a thickness of the soil column from the borehole data from indo-gangetic basin with the predominant frequency.

If you want more information about this you can visit my publication pages and you can get more information. As I told you that each component of microzonation is a separate topic of research. So we do research on that we tried to establish and estimate parameters and say that how you can estimate more represented way that is what we published. So but here since this is the introduction class on engineering seismology I will only say how it has been done orally I am not discussing in detail.

So in case if I offer alternate course in the future where I will be talking about all this things in detail in that course. So we estimated the amplification and predominant frequency which is responsible for building damage due to the wave modification. So that is what we have taken. So once you are done that the next as I told you that the cohesionless soil where the liquefaction is possible.

So the liquefaction generally happens in the cohesionless soil not on the cohesive soil. So, the cohesionless soil generally found by the filings. So generally this Bangalore I do not know how many of you know the history of the Bangalore.

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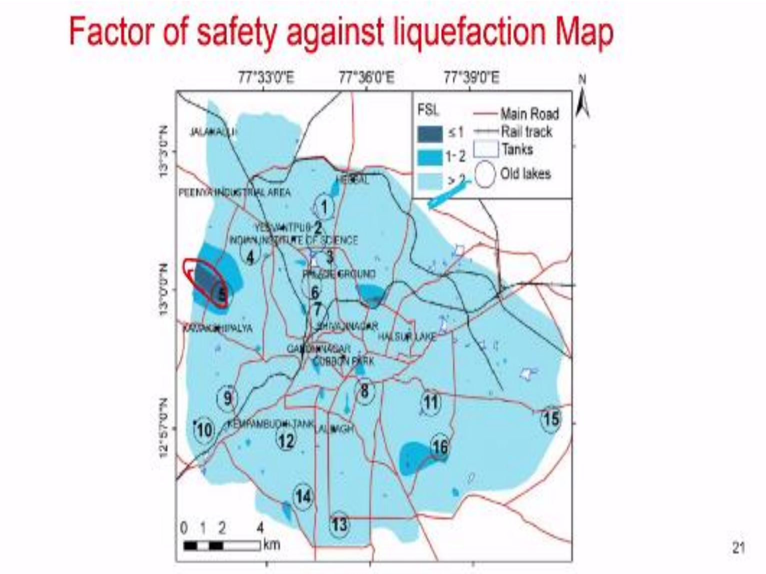

So the Bangalore was once had here 73 lakes if you go back to the history time about 100, 200 years back the Bangalore is actually having a plenty of lakes old lakes are there this lakes are actually stored for the water for drinking and agriculture purpose those days, but due to the agglomeration of the people, people who migrate from the different part of Bangalore city the Bangalore become a city.

So then the Bangalore lakes have been filed officially and unofficially by the people by even by the government and then they made a residential area. When they are filling generally you can expect that the filling will be done generally excavated material from somewhere or a demolished material. So this kind of filling actually adds here available material they use so these fillings, lose fillings may cause the more dangerous phenomena called liquefaction and settlement.

So this area what I told you that we collected a systematically geotechnical and geophysical data and try to estimate that and then considering the hazard value amplified from the previous step and estimated the liquefaction of the Bangalore city. So even though the

Bangalore is not highly liquefiable, but procedural wise we have given a step by step method if you go to my microzonation paper or the liquefaction analysis of Bangalore.

You can see how we can done the systematically liquefaction analysis considering the state of art, knowledge as of today. So whenever that map was done that time so we have done that and estimated a factor of as safety. You can see that many of the Bangalore has a factor of safety more than two which indicates that this is not liquefiable it is majority which is not liquefiable except few places where the factor of safety.

So this is actually some of the valley region where filled up soils are there. So remaining place does not much this one was there. So this is how you can estimate a factor of safety. As I told you that doing liquefaction analysis itself the master piece work or PhD work as I told you that we are only talking about the map integration I am not going in detail about the liquefaction analysis.

If you want to know more about liquefaction analysis refer my papers or any literature in Google or even you can approach me or my PA they will help you to clarify some of this doubts if you are doing some PhD or MSC related to this topic so that is what we can do. So we created a factor of safety against liquefaction map. So now you can see that we basically created a different level of maps starting from bedrock level hazard which we have discussed the deterministic probabilistic.

Then followed by we created a shear wave velocity map, thickness of the soil map and amplification map and predominant frequency map and liquefaction map. Since the Bangalore is located on the flood terrain region not too much hills are there so the landslide is not done and it is far away from the coast there is no tsunami has been done. So now we estimated all the required earthquake hazard parameter as per the microzonation procedures.

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Themes and its weights for GIS integration

Index	Themes	Weights
SOT	Soil Thickness using borehole	6
SC	Equivalent Shear wave velocity for Soil	5
FSL	Factor of safety against liquefaction	4
PGA	Rock level PGA using DSHA-DPGA	3
	Rock level PGA using PSHA-PPGA	3
SA	Soil Amplification factor	2
PF	Fundamental period / frequency	1

SOT: soil overburden thickness; SC: site classification; FSL: factor of safety against liquefaction potential; PGA: peak ground acceleration at the seismic bedrock; SR: site response in terms of maximum amplification factor; PF: predominant frequency.

Engineering seismology 22

So you can see all this parameters we estimated basically 6 parameters. One is that the soil thickness using the borehole, equivalent shear wave velocity which you have seen, factor of safety against liquefaction, rock level PGA and then so by deterministic approach rock level PGA by the probabilistic approach and the amplification factor then the fundamental frequency so this is how.

So now I shuffled this parameter and I assigned a weight soil thickness has a major role as the Bangalore has undulating terrain. So the soil thickness at one place will be more one place will be less because of that you will get a large impedance contrast related amplification. So I have given the highest weightage which reflect a soil thickness then the soil stiffness which is assigned as a 4.

Because the amplification is a function of thickness and stiffness as per wave propagation so this has been assigned. So then the factor of safety liquefaction assigned as a 4 then the PGA the rock level PGA and which maybe deterministic or probabilistic does not matter. So I assigned a equal weightage because when you are preparing a map this will be you will be using as this two as a independent parameter separately. Then the amplification factor and fundamental period so I have assigned a weight. So this weight this is description of whatever short form you have given in this place.

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Pair-wise comparison matrix of Themes and their normalized weights

Theme	SOT	SC	FSL	PGA	SA	PF	Weights
SOT	6/6	6/5	6/4	63	6/2	6/1	0.2857
SC	5/6	5/5	5/4	5/3	5/2	5/1	0.2381
FSL	4/6	4/5	4/4	4/3	4/2	4/1	0.1905
PGA	3/6	3/5	3/4	3/3	3/2	3/1	0.1429
SA	2/6	2/5	2/4	2/3	2/2	2/1	0.0952
PF	1/6	1/5	1/4	1/3	1/2	1/1	0.0476

Engineering seismology 23

So this weight basically used to arrive a pair wise matrix comparison of theme their normalized weight you can see the normalized weight what was told you there so you get a normalized weight some of them will be unity. So this is a pair wise comparison matrix where you can get a normalized weight using this pair wise comparison matrix concept. So now you can see that the weightage factor how it varies with this one. As I told you that each earthquake hazard parameters has its own classification and you have to assign a rank based on each classification.

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Normalized weights and ranks assigned to the respective themes and the features thereof for the thematic integration.

Themes	Values	Weight	Ranks	Normalized Ranks
SOT (m)	≤ 5.0	0.2857	1	0
	5 - ≤10		2	0.25
	10- ≤ 15		3	0.5
	15- < 20		4	0.75
	>20		5	1
EVS (m/s)	Site Class D	0.2381	3	1
	Site Class C		2	0.33
	Site Class B		1	0
FSL	< 1	0.1905	3	1
	1 - ≤ 2		2	0.5
	> 2		1	0
DPGA (g)	< 0.120	0.1429	1	0
	0.12 - ≤ 0.13		2	0.25
	0.13 - ≤0.14		3	0.5
	0.14- ≤0.15		4	0.75
	>0.15		5	1

Themes	Values	Weight	Ranks	Normalized Ranks
SA	1- ≤ 2	0.0952	1	0
	2- ≤ 3		2	0.66
	3- ≤ 4		3	0.33
	>4		4	1
PF (Hz)	≤ 3.5	0.0476	5	1
	3.5- ≤ 5.0		4	0.75
	5- ≤ 7.5		3	0.5
	7.5- ≤9.5		2	0.25
	9.5- ≤11		1	1
PPGA (g)	≤ 0.20	0.1429	1	0
	0.2- ≤ 0.22		2	0.66
	0.22- ≤ 0.24		3	0.33
	0.24- ≤ 0.26		4	1

Engineering seismology 24

So the soil thickness as we have seen that the thickness varies from 0 to 20 meter and above. So I group them as a 5 category so you can see the category 1, 2, 3, 4, 5. So I assign a highest rank for the more dangerous category. So the more thickness the more will be the problem.

So I put that as 5 and then accordingly I will reduce that the lowest category rank will be one. So this is the weights which we have discussed in the previous slide.

So now I calculated a normalized rank using this you can see. So that means whenever the lowest is that this weight will be multiplied by this like that. So similarly site class three category so the site class D as I told you that the more dangerous than the site class C and B so the highest rank has been assigned for this then the next rank, next rank then you get a normalized ranking.

Similarly factor of safety, the liquefaction less than 1 is more dangerous so you can assign a highest weight than the rank then the next rank and next rank and then this is the normalized ranking of the same. So you can get the normalized ranking of the same. So then the PGA distribution so the PGA distribution 5 group again the 5 category and then normalized ranking.

Similarly, the amplification factor so the 4 group and then the normalized ranking of this one. So similarly the predominant frequency so where the 5 group so the lowest frequency will be highest dangerous for the high storey building so that is why these having so you can see the normalized ranks. So, similarly this is the probabilistic based PGA this one. So, this two will be taken separately when you prepare a different map.

So at a time you can take any one of them deterministic or probabilistic. So you estimated the normalized weight of the each factor by the Eigen vector analysis pair wise comparison of matrix and then you estimated assigned a rank and estimated a normalized rank.

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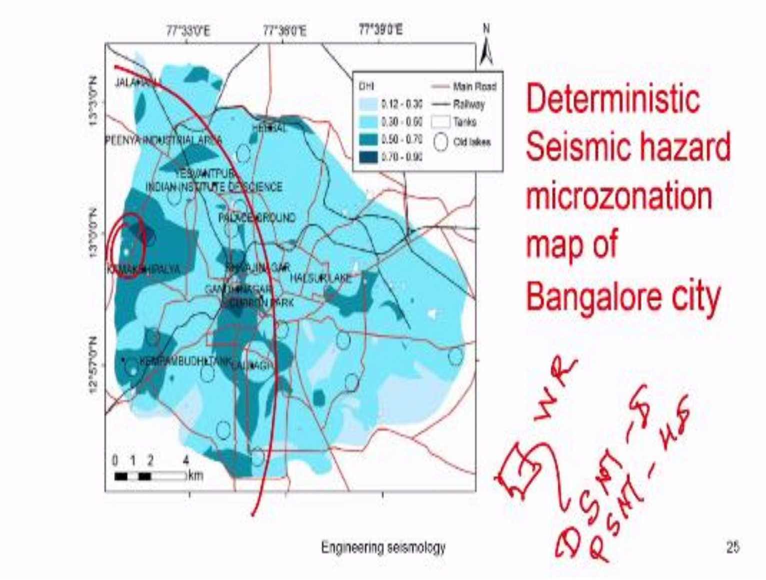

So with this we are ready with preparing the map. As we have seen that the hazard index at any particular place hazard index which may be deterministic microzonation map. Deterministic microzonation map so each grid point I will be estimating the deterministic hazard map and the probabilistic seismic microzonation map hazard index value. So this value is basically weights and the rank of the each earthquake hazard parameter that is what we have seen.

So if you want you can recall the formula what we have done. So this is the formula what I was describing. So this is the formula what we are describing so you can multiply both of them and each parameter and then sum up all of them and then indicate a value how it is done. So like this all the maps are especially this we can code this formula in the ArcGIS by giving graphical input and then ArcGIS take data from each grid point.

And estimate the formula values as per that and then it produce a map like this. We can define a division so the (()) (25:40) hazard index values has been categorized here you can see 0.3 to 0.7, 0.5 to 0.7, 0.3 to 0.5 we can see that the highest hazard has been expected on this places because we have given basically the thickness and the liquefaction all those things we can see the lowest.

So overall the only this part of the Bangalore where you can expect a more hazard index value then this part of Bangalore. So this is the findings from this map so this is the deterministic, seismic, hazard microzonation map of Bangalore which we have published. Okay these publications are available on the website as I told you that you can download and we can use it. So once we have done the deterministic hazard analysis in order to understand how the probabilistic hazard index values also varies the region.

We have done a repeated a same procedure only taken a PGA distribution at bedrock level based on the probabilistic hazard analysis and again produce a probabilistic hazard index value map of the region.

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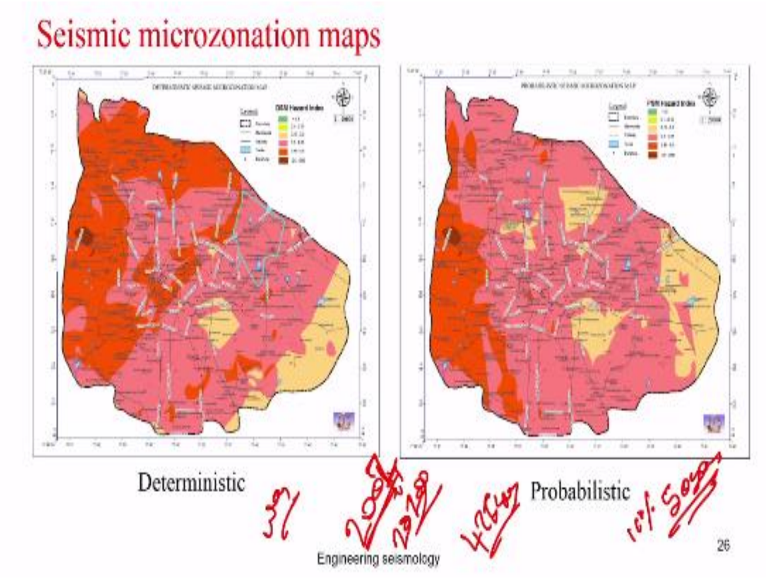

So this is basically the map which shows a probabilistic approach here, deterministic approach here with similar kind of coding pattern, color coding pattern. You can see here the pattern of hazard distributions are completely changed when you go for the deterministic and probabilistic. This is basically a 10% probability in the 50 years interval. So that is the map what we produce.

So this you can do whatever probability you want and then whatever return period you want this is why basically a 475 years return period hazard values. So you can see that the hazard index value also considerably different for both the method, but this is the worst case. So when you go for the worst case this is what you will get so when you go further the probabilistic approach this is what you will get.

So this kind of difference you can try to understand mostly the lower probability okay 2% probability of exceedance in the 50 years will be equal to the DSHA results of hazard. So similar kind of pattern you can also expect, but the composition how you are making a rank and weight also matters to decide what is the hazard index value at a particular grid. So this value this kind of map will be more representative and required for the city planning and a city development.

So the global scale map or country scale map does not account a regional soil variation which is responsible for amplification and liquefaction and modification of the seismic wave. So because of that the regional variation of the soil has to be modeled and accounted in the seismic zonation map accounting at that kind of zonation map is called as a seismic microzonation map.

So we have seen the case study of Bangalore how this was systematically analyzed and produced this kind of map. So this maps are basically they used but only we have restricted our study only to the BBMP area during the 2004. Now the city area actually extended so this study has to be updated according to the US and world level recommendation. So any microzonation map has to be updated frequently every 5 years or 4 years gap or soon after the major earthquake.

Since there is no major earthquake, but it was done on 2004 now we are in 2020 it is almost so 2007 we published officially it is okay. So even 2007 if we take it is almost 13 years of completing by preparing this map. So now it is a time for updating this kind of map so we have shown this basically to demonstrate how the hazard parameters are varies how you can precisely estimate using the state of art, knowledge developed in the world.

So that was our main motive so this guideline only now being adopted for microzonation of entire Indian cities MoES doing the microzonation of 30 cities they tried to adopt this procedure which has become a part of NDMA guidelines the MoES microzonation guidelines. Here I can note that whatever map we produced actually I am showing you as a only the image file even though we produced in ArcGIS, but it is not user friendly map as a microzonation map of GEM.

So GEM we all seen that where I can zoom and then get the data whatever grid point such kind of user interface interaction map is not done for this study. Even though we have developed a GIS somehow we could not develop those kind of website or references whatever is available nowadays maybe in the future some of the cities we can think of doing that kind of work which is more user friendly.

I hope the IMD so also IMD the MoES where they are doing the microzonation they will prepare a map which is a user interface interaction map what we have seen in the microzonation of GEM model global microzonation map. So this is how the microzonation map or zonation map has to be developed for a particular location. So now we discussed a microzonation, macrozonation how it has to be done with the example case study of world level, Indian level and Bangalore like city level.

So let us see how the Indian seismic code is presenting a resonation map of the country in the coming classes. So thank you very much for watching this video so we will see you in the next class. Thank you.