Geotechnical Earthquake Engineering

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Module - 7

Lecture - 30

Seismic Hazard Analysis (Contd…)

Let us start our today's lecture for this NPTEL video course on geotechnical earthquake engineering. We were going through module number 7 that is seismic hazard analysis, a quick recap what we have learnt in our previous lecture. We were going through one case study of seismic hazard analysis for the, for the Gujarat state in India which is the work done as part of Ph D thesis of Dr Jaykumar Shukla in 2013 at IIT Bombay under my supervision.

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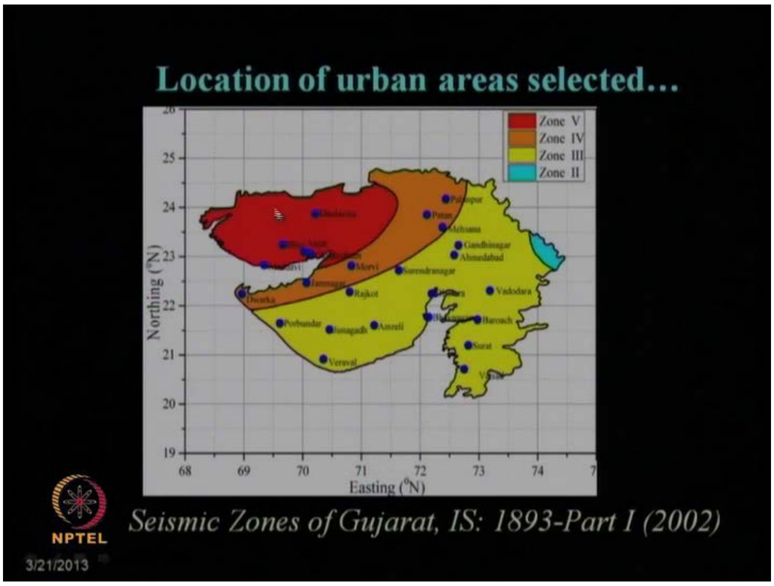

So, we have already seen that Gujarat is the only state in India which is having all the 4 seismic zones as per Indian seismic design code IS 1893 part 1 of 2002 version. So, we have sub divided it into 3 regions and selected 25 urban cities or urban areas in such way that they are coming from all these 3 major regions; one is Kach region which is essentially in zone 5 which is the most vulnerable seismically area, next higher seismically area is zone 4 which is lesser than zone 5. But still significantly high seismicity is possible in that area which is Saurashtra region, and then main land Gujarat region which is in zone 3. We have not taken any city in this small zone which is in zone 2 of course, it is least vulnerable or the lowest hazardous area as for the seismicity is concerned as per this IS code.

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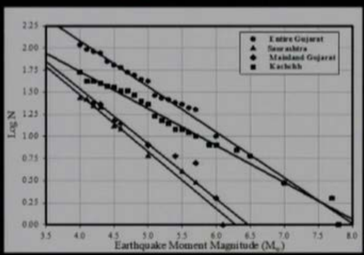

Region	Past seismicity used (Year)	a-value	b-value	G-R relation	R^2
Saurashtra	135	4.03	0.64	Log N=4.03 – 0.64 M_w	0.9783
Mainland	175	4.02	0.62	Log N=4.02 – 0.62 M_w	0.9370
Kachchh	189	3.41	0.41	Log N=3.41 – 0.41 M_w	0.9821
Gujarat	189	4.13	0.51	Log N=4.13 – 0.51 M_w	0.9899

Choudhury and Shukla (2011) in *Disaster Advances*, 4(2), 47-59.

Now, we had also seen in our previous lecture that for these 3 major regions of Kachchh Saurashtra and mainland and also for entire Gujarat how the number of occurrences of earthquake has been plotted with respect to earthquake moment magnitude. And in that case, we have taken only those earthquake magnitudes which are having magnitude more than or equals to 4. So, those points have been plotted and using the least square feet method or LSF method the Gutenberg Richter recurrence law has been obtained. So, these are the Gutenberg Richter recurrence equations with the best feet regression coefficient earth square values for all the 3 regions including the entire Gujarat region.

So, correspondingly the Gutenberg Richter coefficients a coefficient and b coefficients are obtained using this LSF method. The value obtained by this method the b value for Saurashtra region 0.64 which has been proposed by our result in this 2011 journal publication that has been again validated by Rastogi et all in 2013 for Saurashtra region they propose the b value of 0.67.

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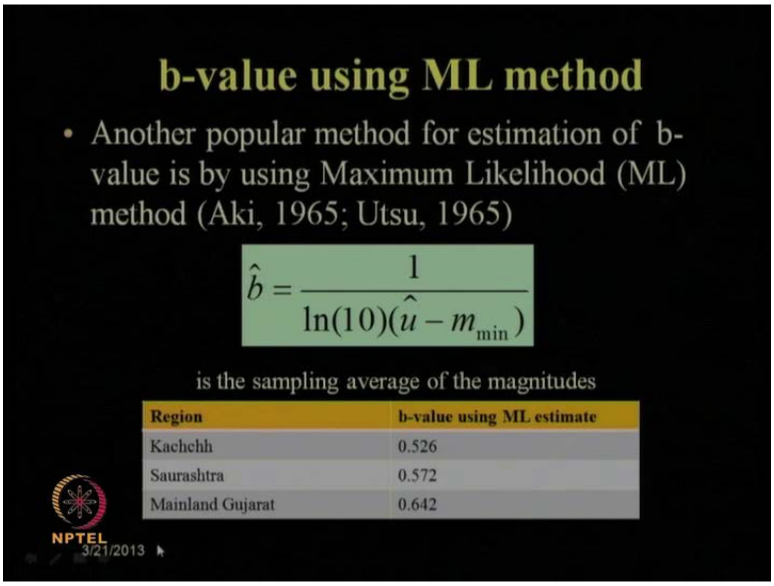

Then another method to obtain the b value is maximum likelihood method as proposed by Aki 1965 and Utsu in 1965. So, corresponding b values using this maximum likelihood method for Kachchh, Saurashtra and mainland Gujarat region are reported over here.

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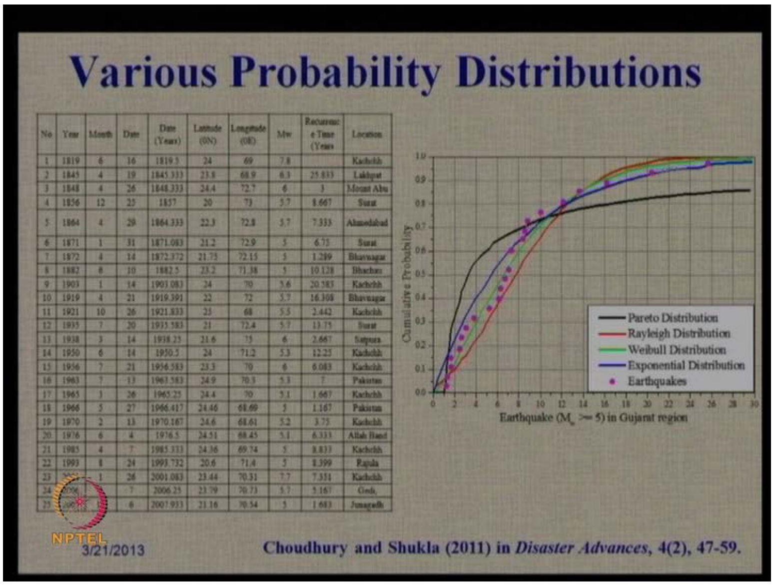

Then we have seen from our earthquake data available we have selected only those earthquake which are having magnitude greater than or equals to 5 to obtain the cumulative probability and using the 4 very well known probability distribution model or seismicity model. What are those distribution model, Pareto distribution, Rayleigh distribution, Weibull distribution and exponential distribution. And these dots are showing the actual earthquake which occurred on these dates and at this latitude longitude with this much of magnitude.

So, this column automatically we can calculate their recurrence time in years that is from the first one to second one, how many years? From second one to third one, how many years? Like that you can see till the end we have calculated our data set for this publication we have taken up to 2007. So; obviously, if today and 2013 somebody wants to do this analysis once again they need to add more earthquake data if any of magnitude 5 and above after 2007. Based on that what was our goal or objective to propose or predict, probabilistic way that when the next earthquake or to extrapolate when the next earthquake of magnitude 5 or more is going to occur in the Gujarat region.

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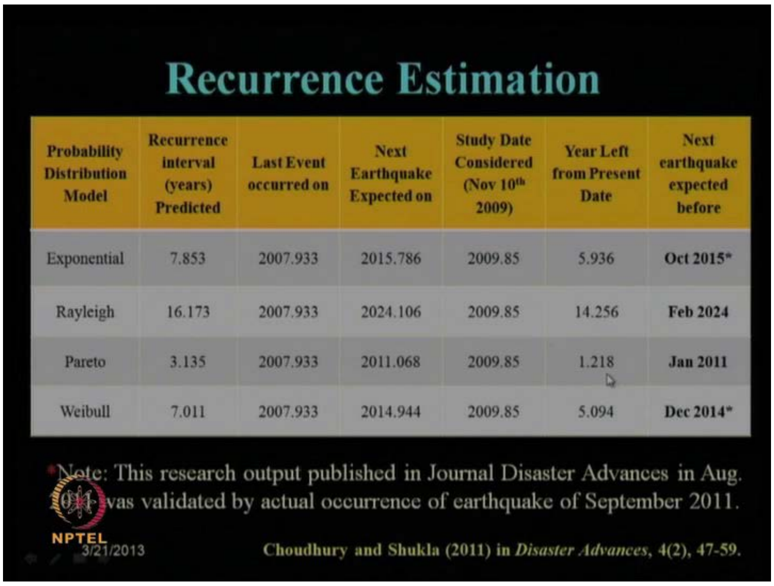

Probability Distribution Model	Recurrence interval (years) Predicted	Last Event occurred on	Next Earthquake Expected on	Study Date Considered (Nov 10th 2009)	Year Left from Present Date	Next earthquake expected before
Exponential	7.853	2007.933	2015.786	2009.85	5.936	Oct 2015*
Rayleigh	16.173	2007.933	2024.106	2009.85	14.256	Feb 2024
Pareto	3.135	2007.933	2011.068	2009.85	1.218	Jan 2011
Weibull	7.011	2007.933	2014.944	2009.85	5.094	Dec 2014*

So, to do that these are 4 basic probability distribution model which we have used these are the recurrence interval predicted using those equations last event occurred and next earthquake is expected over these years. So, you can see over here these data was published in August 2011 in this journal. And there was an earthquake of magnitude 5 and above in September 2011 which validates that Weibull and exponential model is actually predicting very well which is also seen from this plot that Weibull model and exponential model are very well predicting the actual earthquake data points are trend.

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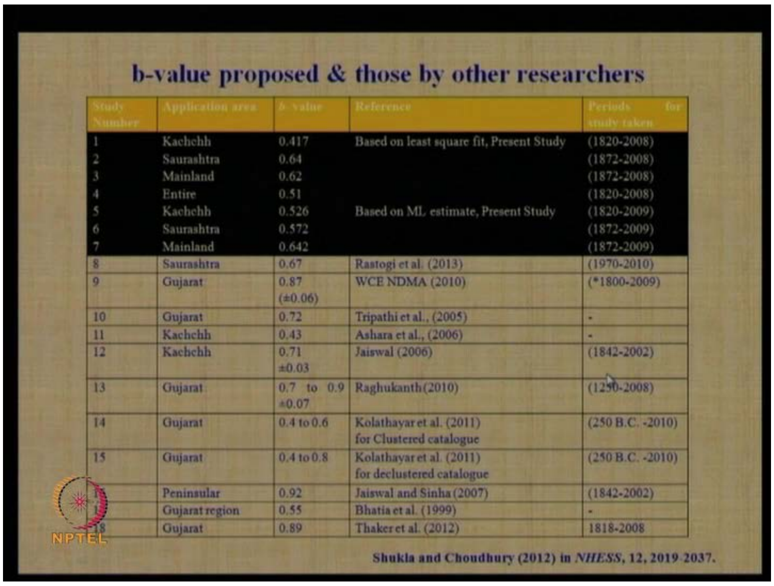

b-value proposed & those by other researchers

Study Number	Application area	b-value	Reference	Periods for study taken
1	Kachchh	0.417	Based on least square fit, Present Study	(1820-2008)
2	Saurashtra	0.64		(1872-2008)
3	Mainland	0.62		(1872-2008)
4	Entire	0.51		(1820-2008)
5	Kachchh	0.526	Based on ML estimate, Present Study	(1820-2009)
6	Saurashtra	0.572		(1872-2009)
7	Mainland	0.642		(1872-2009)
8	Saurashtra	0.67	Rastogi et al. (2013)	(1970-2010)
9	Gujarat	0.87 (±0.06)	WCE NDMA (2010)	(*1800-2009)
10	Gujarat	0.72	Tripathi et al., (2005)	-
11	Kachchh	0.43	Ashara et al., (2006)	-
12	Kachchh	0.71 ±0.03	Jaiswal (2006)	(1842-2002)
13	Gujarat	0.7 to 0.9 ±0.07	Raghukanth(2010)	(1250-2008)
14	Gujarat	0.4 to 0.6	Kolathayar et al. (2011) for Clustered catalogue	(250 B.C. -2010)
15	Gujarat	0.4 to 0.8	Kolathayar et al. (2011) for declustered catalogue	(250 B.C. -2010)
[illegible]	Peninsular	0.92	Jaiswal and Sinha (2007)	(1842-2002)
[illegible]	Gujarat region	0.55	Bhatia et al. (1999)	-
18	Gujarat	0.89	Thaker et al. (2012)	1818-2008

Shukla and Choudhury (2012) in *NHESS*, 12, 2019-2037.

Next in the previous lecture we had also seen what are the beta values or b values of Gutenberg Richter equation as proposed by present theory and by other researchers for the same Gujarat region. We have seen that our values are well comparable with some of the researchers finding, when the ranges of data set of earthquake considered is similar and more so with the recent day value of 0.67 of Rastogi et al of 2013 of Saurashtra region.

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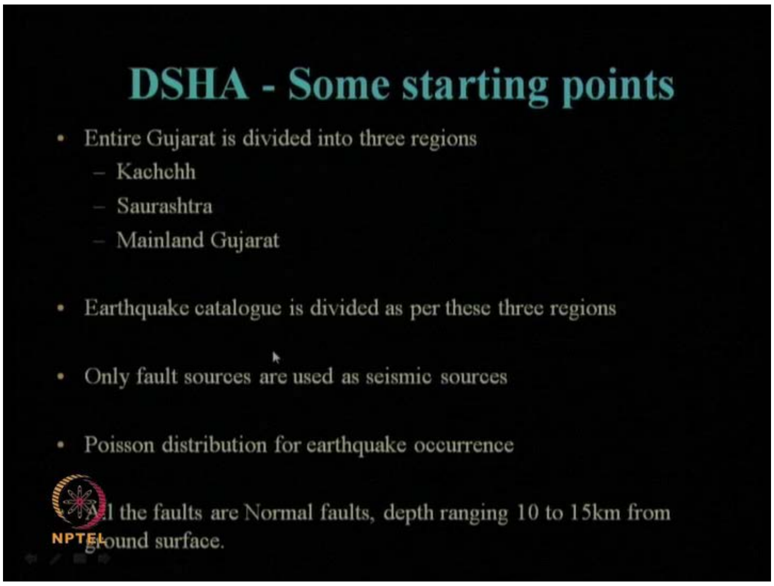

Now to start with the deterministic seismic hazard analysis we had mentioned that we have to make certain points to start with this analysis what are the salient features we considered, let us see like entire Gujarat we divided into 3 regions as we have already mentioned. So, earthquake catalogues also sub divided among these 3 regions based on the collected data set. And only the fault sources are considered for the seismic source and Poisson's distribution for the earthquake occurrence is taken care of one assumption is that all the faults are assumed as normal fault, there was no specific data about the collected fault information. And their death of ranging between 10 to 15 kilo meter from the ground surface which essentially means these are the shallow earthquake sources.

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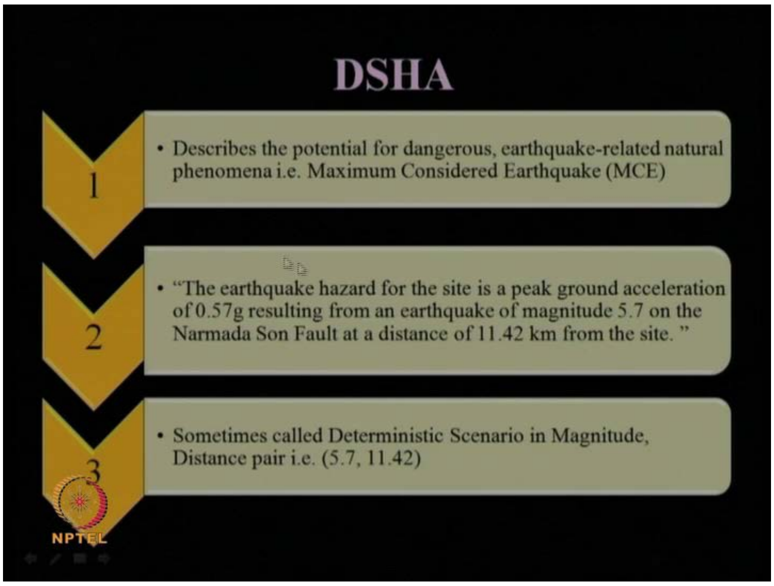

Then we have seen from DSHA how we mention about MCE maximum credible earthquake or maximum considered earthquake in the combination of magnitude and distance from one particular site with respect to the fault distance and the magnitude which is going to occur as per this deterministic seismic hazard analysis.

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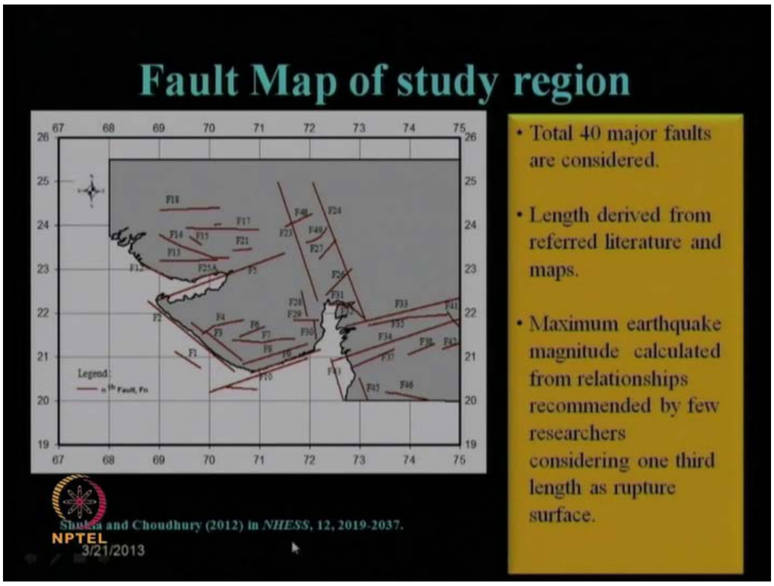

So, we need to know the complete fault map of the entire Gujarat region when we are planning to do the deterministic seismic hazard analysis for the region. This is picture shows the complete fault map there are more than 40 faults, but only the 40 major faults are considered in the analysis. And from the literature available whatever length was mentioned one third of that has been taken further for the calculation of the magnitude length of fault relationship. The details again can be obtained in this journal paper of natural hazards and earth system sciences.

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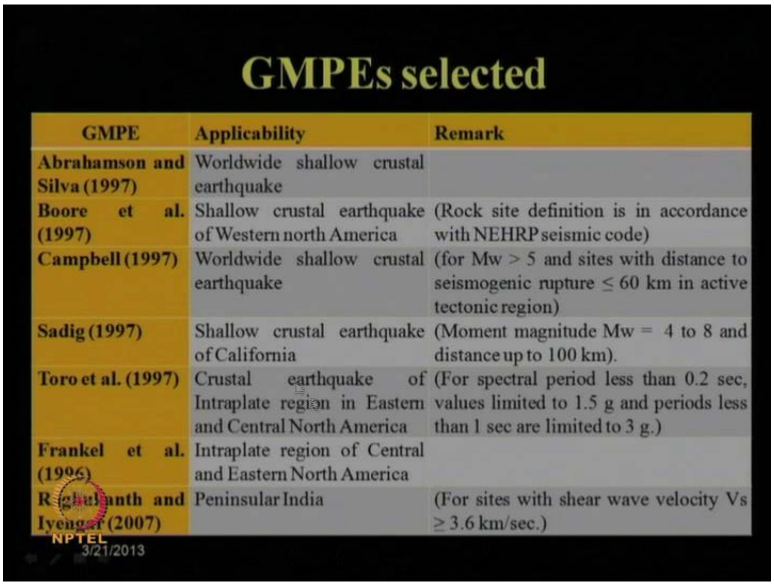

GMPE	Applicability	Remark
Abrahamson and Silva (1997)	Worldwide shallow crustal earthquake	
Boore et al. (1997)	Shallow crustal earthquake of Western north America	(Rock site definition is in accordance with NEHRP seismic code)
Campbell (1997)	Worldwide shallow crustal earthquake	(for Mw > 5 and sites with distance to seismogenic rupture ≤ 60 km in active tectonic region)
Sadig (1997)	Shallow crustal earthquake of California	(Moment magnitude Mw = 4 to 8 and distance up to 100 km).
Toro et al. (1997)	Crustal earthquake of Intraplate region in Eastern and Central North America	(For spectral period less than 0.2 sec, values limited to 1.5 g and periods less than 1 sec are limited to 3 g.)
Frankel et al. (1996)	Intraplate region of Central and Eastern North America	
Raghukanth and Iyengar (2007)	Peninsular India	(For sites with shear wave velocity Vs ≥ 3.6 km/sec.)

Then we have also seen in our previous lecture that what are the various GMPE’s is or ground motion prediction equations we considered seven ground motion prediction equations we considered in our analysis, 6 from abroad and one from India which is for peninsular India, because Gujarat region is within the peninsular India that is why it is logical to use the GMPE’s from peninsular India which is expressed both in terms of magnitude and distance that we should remember. And these are the salient remarks about each of the GMPE’s.

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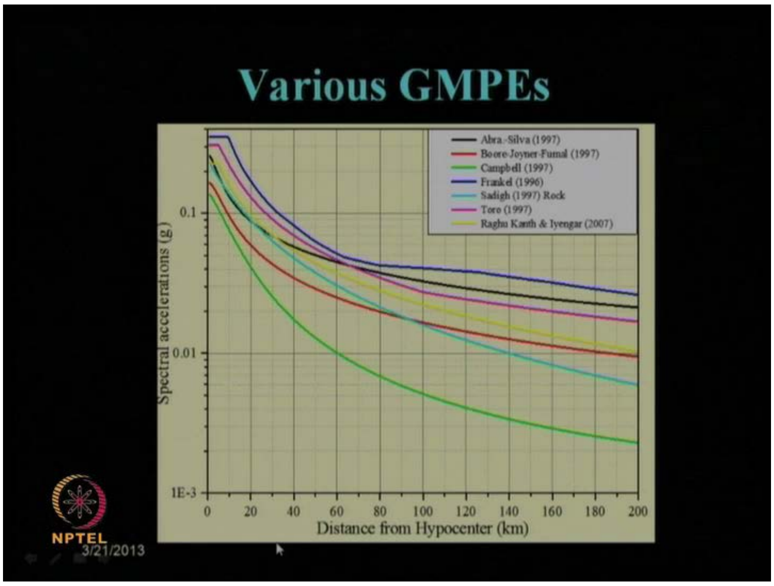

And this is the variation of spectral acceleration versus hypocenter for all the 7 GMPE’s which are considered in the present study as can be seen from the picture. So, up to this we have discussed in our previous lecture. Now, we will continue further in today’s lecture how we can obtain the deterministic seismic hazard analysis results. So, we know how to estimate this seismic hazard analysis result. Now, let us apply it for the selected 25 urban cities.

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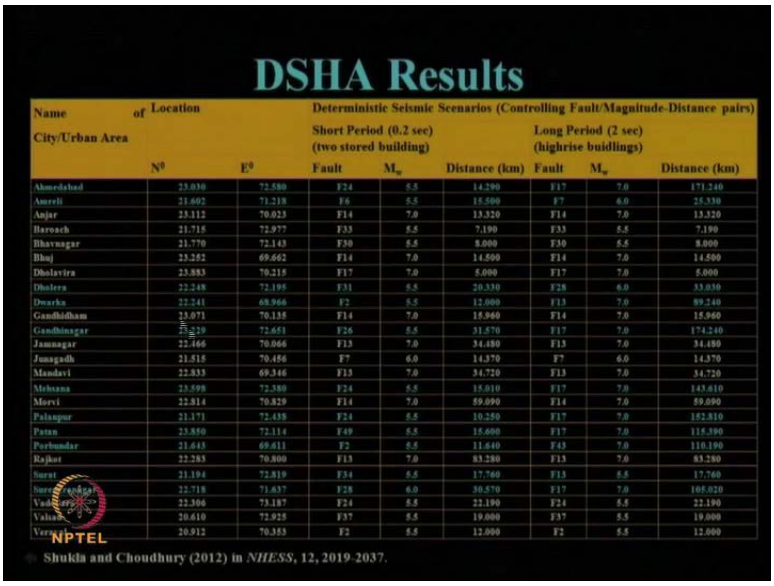

DSHA Results

Name of City/Urban Area	Location N⁰	Location E⁰	Short Period (0.2 sec) (two stored building) Fault	M_w	Distance (km)	Long Period (2 sec) (highrise buidlings) Fault	M_w	Distance (km)
Ahmedabad	23.030	72.580	F24	5.5	14.290	F17	7.0	171.240
Amreli	21.602	71.218	F6	5.5	15.500	F7	6.0	25.330
Anjar	23.112	70.023	F14	7.0	13.320	F14	7.0	13.320
Baroach	21.715	72.977	F33	5.5	7.190	F33	5.5	7.190
Bhavnagar	21.770	72.143	F30	5.5	8.000	F30	5.5	8.000
Bhuj	23.252	69.662	F14	7.0	14.500	F14	7.0	14.500
Dholavira	23.883	70.215	F17	7.0	5.000	F17	7.0	5.000
Dholera	22.248	72.195	F31	5.5	20.330	F28	6.0	33.030
Dwarka	22.241	68.966	F2	5.5	12.000	F13	7.0	89.240
Gandhidham	23.071	70.135	F14	7.0	15.960	F14	7.0	15.960
Gandhinagar	23.229	72.651	F26	5.5	31.570	F17	7.0	174.240
Jamnagar	22.466	70.066	F13	7.0	34.480	F13	7.0	34.480
Junagadh	21.515	70.456	F7	6.0	14.370	F7	6.0	14.370
Mandavi	22.833	69.346	F13	7.0	34.720	F13	7.0	34.720
Mehsana	23.598	72.380	F24	5.5	15.010	F17	7.0	143.610
Morvi	22.814	70.829	F14	7.0	59.090	F14	7.0	59.090
Palanpur	21.171	72.438	F24	5.5	10.250	F17	7.0	152.810
Patan	23.850	72.114	F49	5.5	15.600	F17	7.0	115.390
Porbundar	21.643	69.611	F2	5.5	11.640	F43	7.0	110.190
Rajkot	22.283	70.800	F13	7.0	83.280	F13	7.0	83.280
Surat	21.194	72.819	F34	5.5	17.760	F13	5.5	17.760
Surendranagar	22.718	71.637	F28	6.0	30.570	F17	7.0	105.020
Vadodara	22.306	73.187	F24	5.5	22.190	F24	5.5	22.190
Valsad	20.610	72.925	F37	5.5	19.000	F37	5.5	19.000
Veraval	20.912	70.353	F2	5.5	12.000	F2	5.5	12.000

Deterministic Seismic Scenarios (Controlling Fault/Magnitude-Distance pairs)

Shukla and Choudhury (2012) in *NHESS*, 12, 2019-2037.

Now let us look at this slide over here, these are the 25 cities or 25 urban areas for which we are doing the deterministic seismic hazard analysis. For that we have selected these latitude and longitude, northing and easting are given over here. So, at that point we have calculated that considering that point as a site, we have considered what are the deterministic seismic hazard results? For that is deterministic seismic hazard scenario for a controlling fault and magnitude distance pairs for two major cases. If you see this broad classification of the table; one is for the short period case, short period means we have taken a specific value of let us say 0.2 seconds as it is mentioned over here which is typically about a two stored building, why I have already mentioned it is a thumb rule not exact, exact we can easily find it out which I will discuss later in another module of this course that n by 10 is the formula which as a thumb rule we used to obtain the natural period of any structure.

So, if the two stored building then it comes about 0.2 seconds which is considered as a short period, whereas long period we considered in the present study as 2 seconds which is about how many stored building? Two empty stored building, as per our thumb rule typically remember. So, this comes under the high raised building category. Now, if you can look at this different cities which fault and which magnitude and distance is dominating or coming as an output result of a DSHA, because DSHA, how we express? We express in terms of magnitude and distance combination I have already mentioned.

In the previous lecture also and today in the recap that in that combination if you look here in this table of 25 cities which are in the blue color, sky blue color.

Those cities if you look carefully for short period and long period there is a difference of fault number, what does it mean? That means, let us say the first row that is for the Ahmedabad city. For Ahmedabad city when we are considering the effect of short period or we are analyzing for short period for that fault number 24 is coming to be more critical which gives us the value of M W as 5.5 and a distance from site this is the site to source is about 14.290 kilo meter.

Whereas if we do for the same Ahmedabad city for long period analysis with using the same deterministic seismic hazard concept, we will see that another fault, fault 17 becomes more critical. In that case the magnitude which is coming as output is 7 and the distance from side to source is 171.240 kilo meter. So, can you see? So, all these blue color cities are having different faults in different conditions of short period and long period which are considered as hazard fault or most hazarders faults as per this deterministic seismic hazard calculation. Whereas other cities which are in this light yellow or half white color like for example, let us say this 4th row Varudh city, for Varudh city whether it is short period or long period, the dominating fault or the influencing fault which influence the result or which dictates the results is f 33 fault number 33 in both the cases.

And value of this M W and distance are also same 5.5 and 7.19, can you see that? Which is again another validation one can easily say after obtaining this deterministic seismic hazard results, we are already have very well documented and well known 2001 Bhuj earthquake. In Bhuj earthquake the Bhuj city on the epicenter of earthquake was far away from Ahmedabad which is actually in main land Gujarat region if we go back to Gujarat map. So, Bhuj is somewhere here as you can we see over here where as Ahmedabad is here, so far away. Actually Ahmedabad is in zone 3, whereas Bhuj is in zone 5. But for Ahmedabad after this 2001 Bhuj earthquake several buildings collapsed, several high raised buildings collapsed, what was the reason? Now we got the mathematical proof also from this deterministic seismic hazard analysis from this table we as we have seen for long period or raised building this long distance from source to side dominates which is dominated by fault number 17 and magnitude is 7, but for small buildings it is not so.

That is the reason why Ahmedabad city though it is it was far away from Bhuj city during 2001 Bhuj earthquake, but as there were many high raised buildings which are coming as within the purview of deterministic seismic hazard of long period from this fault influence of f 17 at a distance of 171.24 kilo meter that dominated clear, whereas for other cities, where the same fault dominance for whether short period or long period, it will not matter that much. So, people may always think why Ahmedabad was so much devastated? One of the reason is this one which can be proved by this deterministic seismic hazard analysis. There were other reasons as well soil amplification also where another reason which anyway we will come lateral on.

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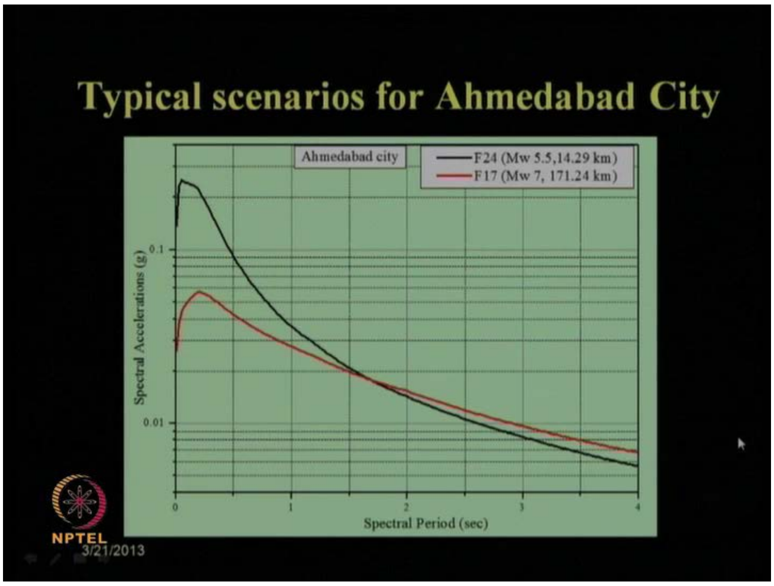

So, let us look at this picture once again, this result for Ahmedabad city only what are typical scenarios for Ahmedabad city? This red color curve; this red color result for spectral acceleration versus spectral period which has been obtained after this deterministic seismic hazard analysis you can see this red color curve dominates at higher period. That means, this red color gives the value of spectral acceleration higher at higher values of period, whereas this black color curve gives the higher value at smaller period. That automatically means this black color curve should be considered for shorter period or low raise building whereas this red color curve should be considered for design of high raise building.

So, accordingly we should select that is which fault and for high raise and which fault for low raise building will dominate and what will be that value of M W and what value what value of that source to site distance will dominate? So, this is the result of deterministic seismic hazard analysis as we express in terms of magnitude and distance pair. So, this is for long period; this is for short period clear.

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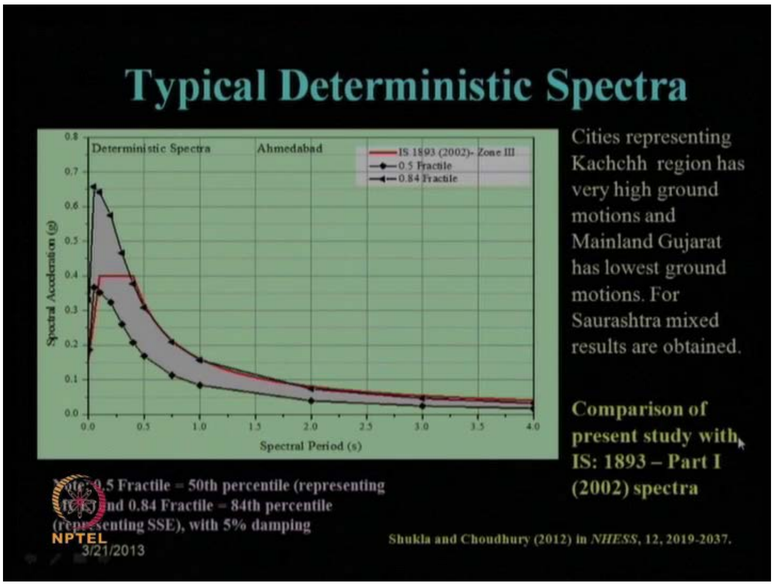

Now, let us compare our results with respect to the results or the suggested values given in our Indian seismic design code IS 1893. Let us look at the typical deterministic spectra which is given by IS 1893 2002 for zone 3. So, this is for spectral acceleration g versus spectral period. This red color line shows us the deterministic spectra as per the IS code. And the other two of course, showing two different data set, what are the those data set for deterministic spectra for Ahmedabad city? One is for 0.5 fractile, this black dots and another this black triangles are 0.84 fractile, let me mention you what are this fractile means. The 0.5 fractile means 50th percentile; 50th percentile is nothing but it represents MCE which is maximum credible earthquake. And maximum credible earthquake is nothing but which is proposed in our IS code also as per MCE values. And what will be the design basis earthquake? That will be typically half of that maximum credible earthquake.

And what is that 0.84 fractile? That 0.84 fractile is 84th percentile which represent SSE; SSE is nothing but safe shutdown earthquake I have already mention this in the beginning of this module, what does it mean? 84th percentile means there is a chance of remaining 16 percent, 16 percent probability of occurrence of earthquake more than or exceeding that value that is what it means. And remember this spectra, response spectra whatever deterministic spectra has been drawn that is drawn with 5 percent damping, considering 5 percent damping of an equivalent single degree of freedom mass spring dashpot system clear.

So, that the cities representing the Kachchh region has very high ground motions and mainland Gujarat has lowest ground motion which is quite of obvious. Whereas for Saurashtra region, mixed results are obtained. And in this figure we have shown the comparison of the present study whether it is MCE or SSE based on that with respect to IS code method. And we can easily see that our present result of MCE is matching very well with the IS code proposed deterministic spectra for Ahmedabad city, can you see that for Ahmedabad city it is matching closely. But still there is one problem as you can see at higher period there is a discrepancy between the 2 cases.

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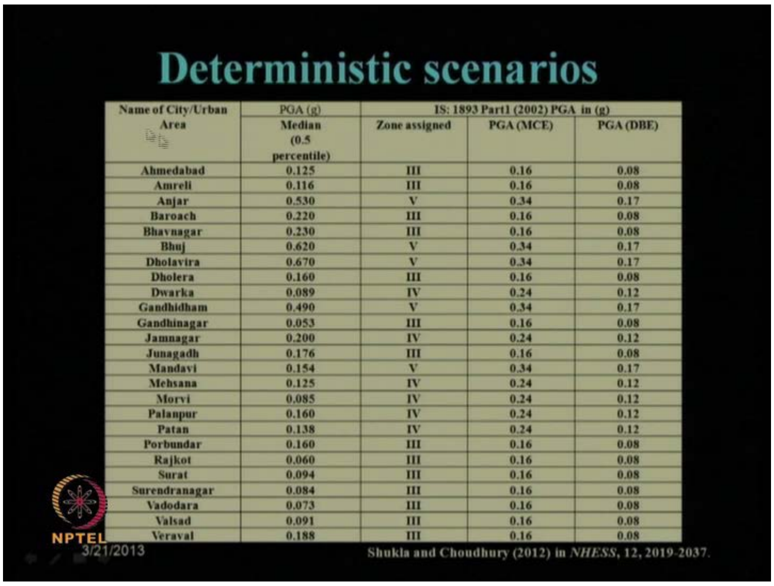

Name of City/Urban Area	PGA (g)	IS: 1893 Part1 (2002) PGA in (g)		
	Median (0.5 percentile)	Zone assigned	PGA (MCE)	PGA (DBE)
Ahmedabad	0.125	III	0.16	0.08
Amreli	0.116	III	0.16	0.08
Anjar	0.530	V	0.34	0.17
Baroach	0.220	III	0.16	0.08
Bhavnagar	0.230	III	0.16	0.08
Bhuj	0.620	V	0.34	0.17
Dholavira	0.670	V	0.34	0.17
Dholera	0.160	III	0.16	0.08
Dwarka	0.089	IV	0.24	0.12
Gandhidham	0.490	V	0.34	0.17
Gandhinagar	0.053	III	0.16	0.08
Jamnagar	0.200	IV	0.24	0.12
Junagadh	0.176	III	0.16	0.08
Mandavi	0.154	V	0.34	0.17
Mehsana	0.125	IV	0.24	0.12
Morvi	0.085	IV	0.24	0.12
Palanpur	0.160	IV	0.24	0.12
Patan	0.138	IV	0.24	0.12
Porbundar	0.160	III	0.16	0.08
Rajkot	0.060	III	0.16	0.08
Surat	0.094	III	0.16	0.08
Surendranagar	0.084	III	0.16	0.08
Vadodara	0.073	III	0.16	0.08
Valsad	0.091	III	0.16	0.08
Veraval	0.188	III	0.16	0.08

And this deterministic scenario when we compare for all the 25 urban cities or urban areas these are the median or 0.5 fractile or 50th percentile PGA value which we obtain from our present analysis in the unit of g, so for Ahmedabad it is 0.125 g. So, zone assigned as per IS 1893 for Ahmedabad is zone 3 and PGA value as per IS code considering MCE, maximum credible earthquake is 0.16 which is relatively closer to this finding, whereas if you consider the design basis earthquake, the PGA value comes out to be half of this MCE which is 0.08 g for Ahmedabad.

Like that for all other cities, you will find out the values, here typically Ahmedabad you can see our present study is on the lower side than IS code proposed value. But if I want to take your attention safe or seismic zone 5 which is most vulnerable zone as per seismic zonation map of IS code. Let us look at the Bhuj city, as per our present study the 50th percentile or 0.5 fractile of PGA or median PGA comes out to be 0.62 g which is in zone 5, as per IS code it gives only 0.34 which is much lower than what it should be taken and design basis earthquake is half of that, so 0.17. So, you can see here lot of discrepancy in zone 5, compare to present result and what is proposed by IS code and that discrepancy is towards the unsafe side I will mention that in that way. So, one need to take care of this issue very carefully, because IS code has mentioned these values on a gross way, they have not done or micro domination which it is based on the macro donation or the overall region study. Whereas we have seen for Gujarat doing an overall study is not justifiable, we have do region specific and location specific within a region also.

So, when we know that and after doing the analysis we found this kind of values very high value that automatically says that probably that may be a one of the several other reasons that why the Bhuj earthquake was so much of devastating though the IS code has proposed some values which is much lower than what has been obtained through this deterministic seismic hazard analysis. But another point I want to mention over here remember these are the deterministic seismic hazard value. So, if we want to use probabilistic seismic hazard value, probably it will come down it will come down, but this deterministic seismic hazard value should be used for suppose if somebody is interested to construct very important structure like nuclear power plant or very long important bridges or earthen dams etcetera in Bhuj region.

This is another reason one can correlate that after this 2001 Bhuj earthquake there were several damages in many of the earthen dams. These can be one of the reason that the, what is actual value of PGA for deterministic seismic hazard or probabilistic seismic hazard we will get or on the higher side than at what value was designed for using the earthquake code of previous version that is 1984 version. Now, let us move to the next step which is probabilistic seismic hazard analysis for this entire Gujarat. So, PSHA for Gujarat now we are going to do. Let us look at the slide.

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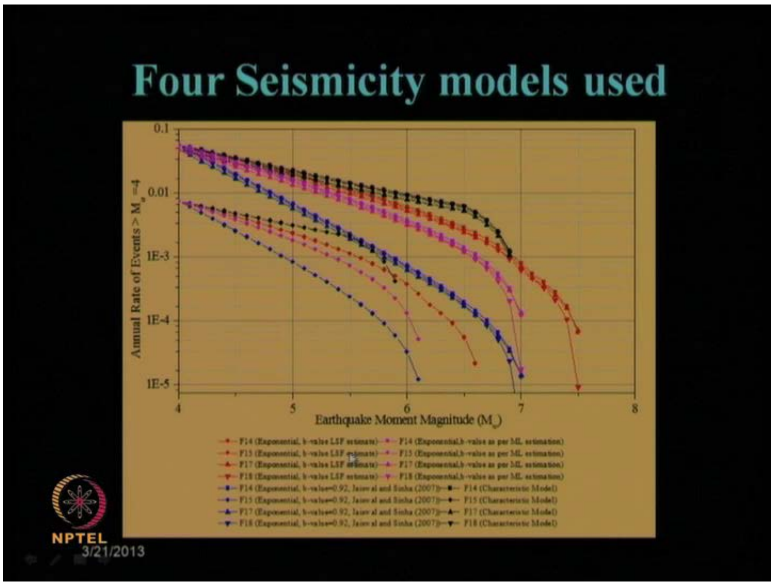

So, PSHA for Gujarat in this case also we are using 4 seismicity model to do the analysis, what are those 4 seismicity models? Let us look at here this red colors, these are showing exponential model because already we have mentioned that exponential model is one of the better model or good model. So, exponential model using the b value what we obtain from our proposed analysis using LSF, LSF means least square feet estimate. This pink colors these are showing exponential model b value as per M L estimation that is maximum likelihood estimation.

This blue colors are showing the exponential model has been used using the b value of 0.92 for peninsular India, as proposed by Jaiswal and Sinha in 2007, we want to just see what are the influence of other models that is why we have used this value of b. These first two are our proposed value or obtained value and this is as per Jaiswal and Sinha. And this black colored dots are the characteristics model for that side for that location. So, these are the 4 seismicity model parameters, and annual rate of exceedance of an event with magnitude more than or equals to 4 or taken care off.

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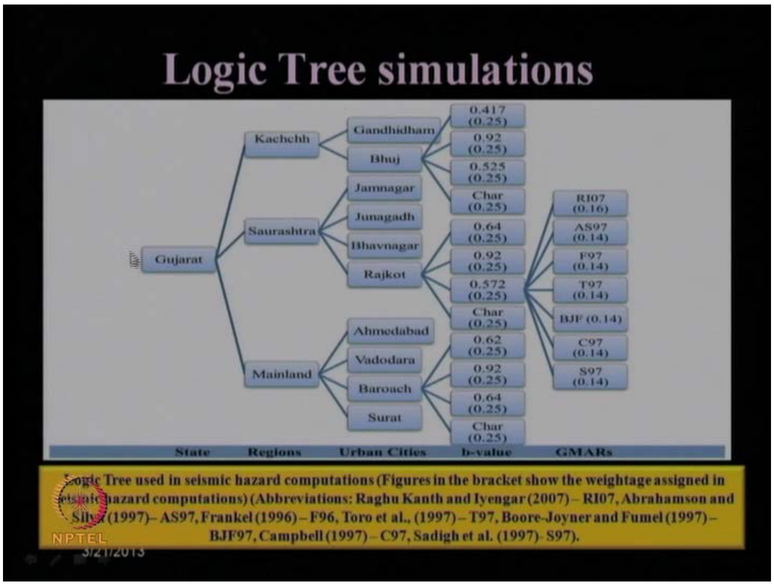

Next is to identify the logic tree which we are going to use for this probabilistic seismic hazard model Now, for the entire Gujarat we already have sub divided it into 3 major regions Kachchh, Saurashtra and mainland Gujarat. Now, within each of these regions we have several other number of cities, among them only few selected cities have been shown over here. But in actual calculation all are taken care of, because just to show one particular calculation it has been shown. Suppose within Kachchh region whatever cities were there, there were several cities we have mentioned over here Gandhidham and Bhuj, they were other cities also within Kachchh which we had considered in our present study. Similarly for Saurashtra these are the cities there are other cities as well for mainland Gujarat these are the cities there were other cities as well.

Now, if we consider one particular city say Bhuj city for that now we have taken 4 seismicity model, can you see that? So, b value of 4 seismicity models we have reported over here, like for Bhuj we obtain b value using the least square feet method by our present study 0.417 for Kachchh region that should applied to Bhuj then Jaswal and Sinha’s value is 0.92. Then as per the present study using maximum likelihood method, the value we obtain for Kachchh region is 0.525 and another one is using the characteristic model.

Let us give equal weightage to all of them, as I said it is the designer’s choice or based on the experience or knowledge on the area or the earthquake analysis and study etcetera.

So, we have given equal weightage of 25 percent to all this 4 characteristics model or all this 4 seismicity models similarly, for other cities as well. Now, when we are considering one particular value within that again we have 7 sub branches, what are the 7 sub branches? These are nothing but GMPE's, what GMPE's we have used? 7 GMPE's I have mentioned, 6 from abroad and one from India. So, all these abbreviations are listed over here, you can see logic tree used in seismic hazard computations, figures in bracket show the weightage assigned in the seismic hazard computation. So, these bracketed values are the weightage which has been assigned to them.

Abbreviations like Raghukanth and Iyengar in 2007 GMPE's is shown as RI07. So, this one is RI07, Abrahamson and Silvan in 1997 is AS97. So, AS97 then franklin like that all other model you can see. Here again we have tried to give equal weightage to all the 7 models 7 attenuation models or GMPE's. So, equality comes about 0.14 or 14 percent each of them, but 2 percent remains if we take 7 models equally distributed. So, 7 into 14 we will get 98. So, another 2 percent extra which have assigned to that Indian attenuation relationship for peninsular India given by Raghukanth and Iyengar, because it is a Indian model. So, that is why little higher weightage we have assigned to this model.

Now, if we have more Indian model, we can think about reducing the weightage of this American or the GMPE's which are exclusively for America you can exclude those things and you can take worldwide proposed GMPE's and the Indian GMPE's for this region particular region. You remember; you cannot take GMPE's of Himalayan region or northeast; you should take from this Gujarat region which is in peninsular India.

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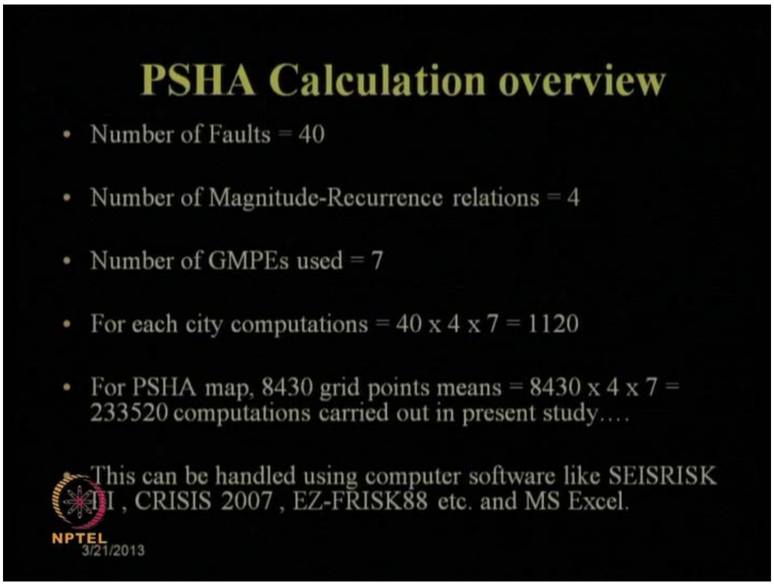

Next is PSHA calculation over view. So, what are the steps we are doing? Number of faults as I have already mentioned 40 major faults has been identified and those are considered only for further calculation. And number of magnitude recurrence relation which we are using are 4, 4 models we are using right. And number of GMPE's which are using is 7 GMPE's we are using. So, for each city how many competitions we should do? That is 40 into 4 into 7 that is 1120.

So, to create the PSHA map with the grid points of 8430 that will mean that you have to get the value of 8430 times of 4 and 7, why only this 4 and 7 we are multiplying? Because we already mentioned earlier that magnitude recurrence relation and the attenuation relation we are giving the independency to these two. So, these many competitions need to be carried out in the present study which of course, require the use of computer software. And there are several computer software are available which can perform this probabilistic seismic hazard analysis like Seisrisk 3 crisis 2007 e z-frisk 88 etcetera. And using the M S excel of course, after getting all these grid point values you have to then assign them and prepare a two dimensional chart. So that you can find out final probabilistic seismic hazard value that we have seen already how to arrive at that value.

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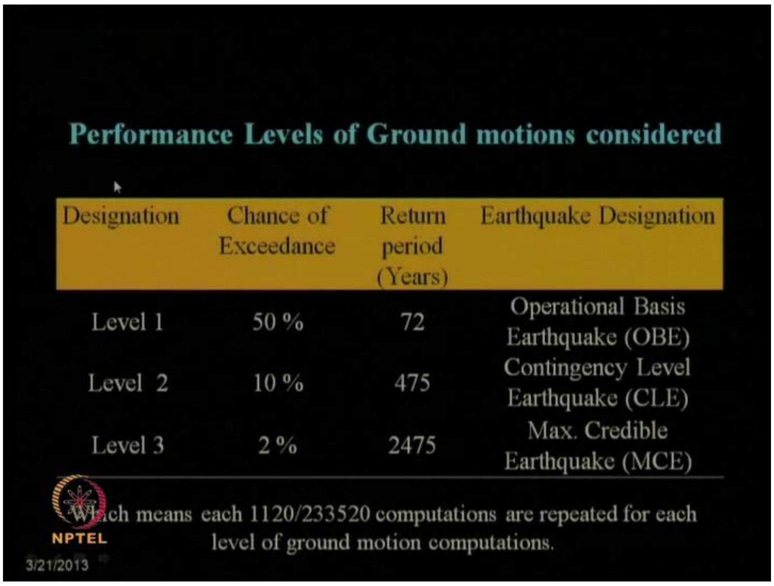

Performance Levels of Ground motions considered

Designation	Chance of Exceedance	Return period (Years)	Earthquake Designation
Level 1	50 %	72	Operational Basis Earthquake (OBE)
Level 2	10 %	475	Contingency Level Earthquake (CLE)
Level 3	2 %	2475	Max. Credible Earthquake (MCE)

Which means each 1120/233520 computations are repeated for each level of ground motion computations.

Now, let us look at this table which mentions about performance levels of ground motions considered. So, there are 3 designations commonly used worldwide and also in the seismic design code of various countries including Indian code which describes the performance level as level 1, level 2 and level 3. What does it mean? It means level 1 means level 1 means chance of exceedance or probability of exceedance is 50 percent in 50 years period at least once. So, how much return period will come if we calculate using that Poisson's distribution which we have already done, it comes out to be 72 years. Like for other two already we have done the calculation, level 2 is called probability of exceedance with 10 percent of probability of exceedance in 50 years span at least once comes out to be return period of 400 and 75 years.

Similarly, level 3 is 2 percent of probability of exceedance within 50 years at least once that gives us return period of 2475. So, these are the 3 levels by which one can go for a design. And these are characterized as their earthquake designation is known as for level 1 it is called operational basis earthquake or OBE. Level 2 is called contingency level earthquake CLE and level 3 is called maximum credible earthquake or MCE. So, depending on what level of performance we want for our structure to be designed, accordingly we can find out corresponding to PSHA curve or seismic hazard curve. It automatically means whatever this 1120 number of repetitions we have to do, out of these 233520 computations for this present study we have to repeat it so many times for each level, for level 1 also we have to do so many times for level 2 also, level 3 also clear.

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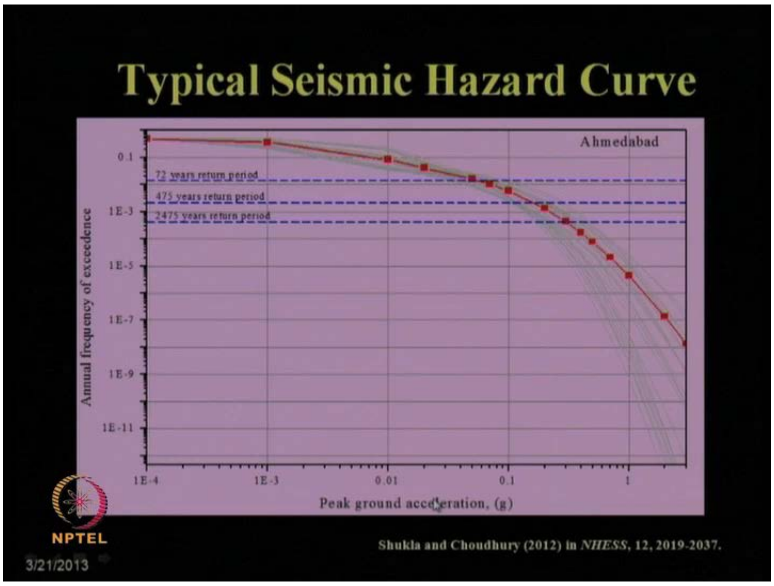

So, these curve shows the typical seismic hazard curve for Ahmedabad city, you can see over here annual frequency of exceedance in y axis and in x axis peak, peak ground acceleration. There are 3 levels you can see 72 years return period 475 years return period and 2475 years of return period. This is nothing but here that lambda max, can you see? And this is your a max and what are these faint lines shows, those are nothing but considering all year 7 GMPE’s and 4 model parameters. And this is the average of them or after taking I should not say average it is weighted average after taking the logic tree method, this is the final curve which you are getting for Ahmedabad city. So, like that for each city you can generate this kind of hazard curve of lambda versus lambda a max versus a max clear.

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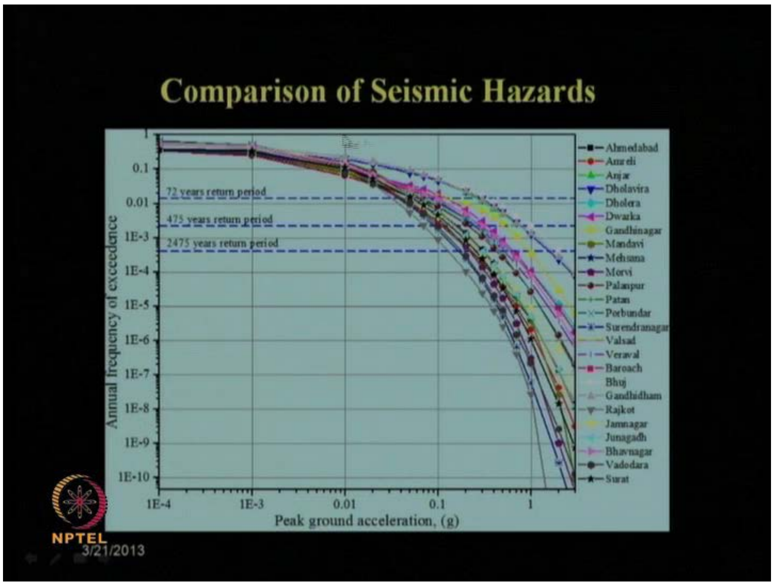

Now, this shows this picture; this slide shows comparison of various seismic hazards among this 25 cities. So, all the 25 cities we have combined in this picture and you can get a rough estimation of what is lambda a max versus max plot of various seismic hazard. And correspondingly you can go for a selected value of a max, what is the use of this graph or this result? As already I have mentioned let us take this example, suppose if you are going for a design with this OBE or OLE that is 72 years of return period then your a max value you should consider this much clear.

But if you want to go for your design of that 2 percent exceedance with 2475 year return period, you should go here you're a max value which you should use for design is this much can you see? So, here for Ahmedabad city corresponding to 2475, the value is coming typically about 0.3 g, am I right? Whereas if you go for 72 years of return period value is coming somewhere here which is 0.05 g, can you see? So, it depends for how many years of return period or for what probability of exceedance of an event you want design your structure at a particular city. Accordingly, your a max value or PGA value has to be selected from this hazard curve clear. Similarly, for other cities also you can obtain from this present result.

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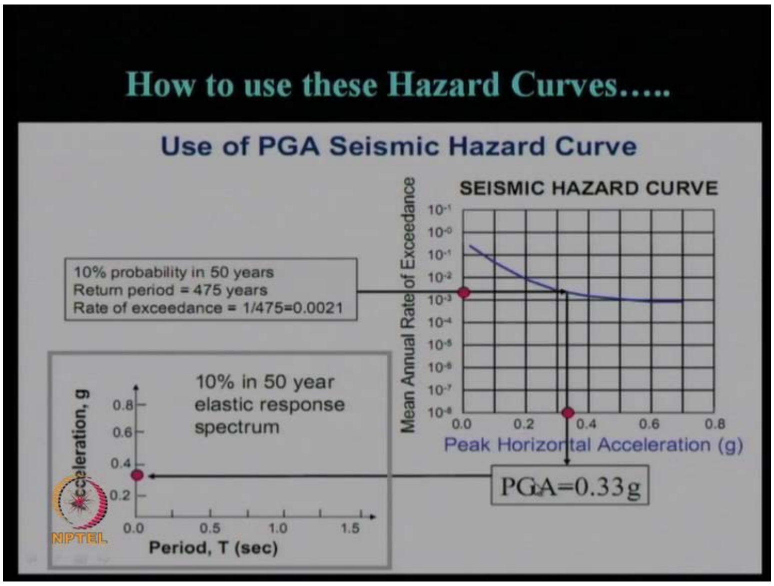

Now, how to use this hazard curves? As I have already explained, but further we need to compare this hazard curve with respect to the given Codal provisions because finally, one should follow the seismic design code if any countries having like our India is having seismic design code. So, how to generate a curve which can match or compare with respect to the result given in the code? So, let us see how it can be done. So, use of that PGA, peak ground acceleration what we have obtained just now for the seismic hazard curve. So, already we got some pattern something like this of mean annual exeedance lambda a max versus a max plot from which depending on your return period you can get a particular value of a PGA.

Now, what you are going to do? You take a plot of acceleration which will be your spectral acceleration versus time period; you can plot that value of PGA corresponding to time period equals to 0, am I right? Because this starting point will be always same. So, if you plot suppose from your seismic hazard curve you got the value of PGA is 0.33 g, like for Ahmedabad city we saw from our present result we got for 2475 year return period as was coming 0.3 g. So, similarly here one example is shown a typical example not related to our analysis, it shows that for 475 years return period PGA comes out to be 0.33 g. So, this is the 0.33 in this scale normal scale; this is also in normal scale.

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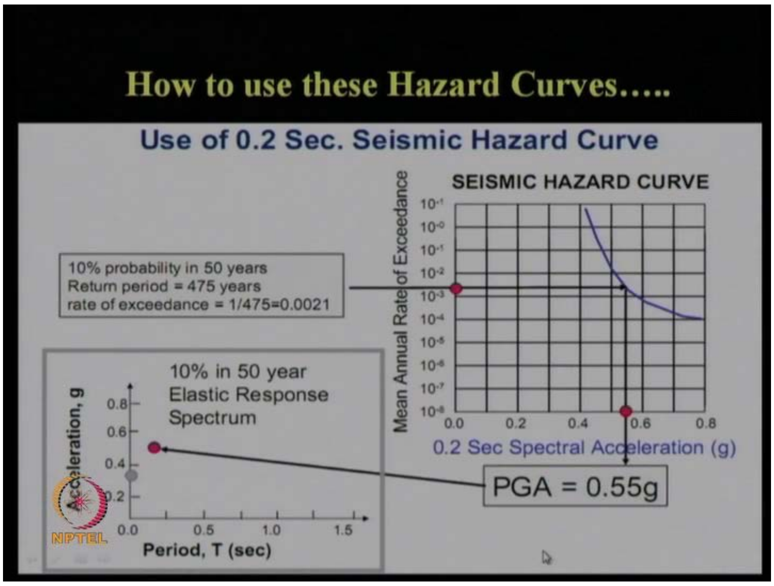

So, you plot that point, next what you need to do you need to draw another seismic hazard curve which will give you the mean annual rate of exceedance of spectral acceleration corresponds to 0.2 second. It should not be with respect to a max it should be lambda of a corresponds to 0.2 second of spectral acceleration clear. So, for the same return period you have to select what value you are getting for the spectral acceleration which corresponds to that 0.2 second. Let us say we got it as 0.55 g earlier we got this 0.33 g this value next corresponding to 0.2 second we got this 0.55 g. Like that for 0.5 g for 1 g for 0.5 second for one second, for 1.5 second, for two seconds etcetera you will get all these points when you will get all these points that will give you your spectral acceleration results obtained from your present analysis and that curve you can compare with respect to the IS code recommendation clear. That is how this seismic hazard curve is make use of for practical design purpose.

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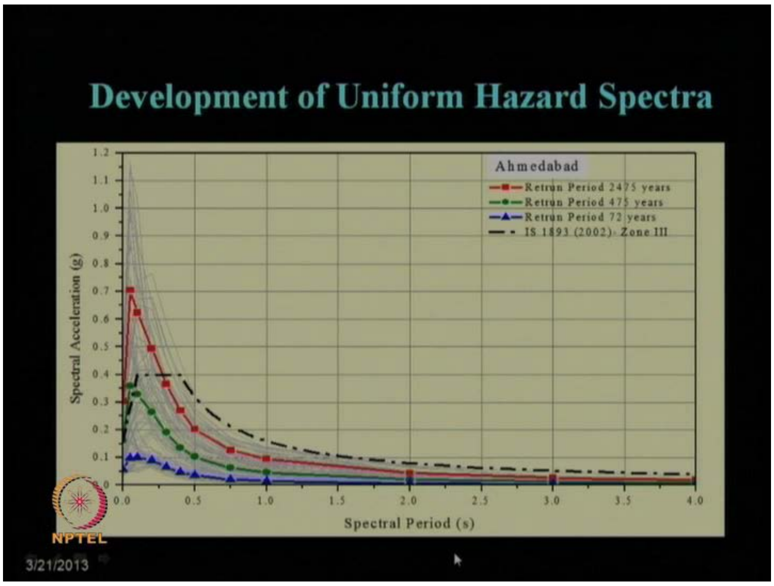

So, this is the comparison you can see development of that uniform hazards spectra. So, that spectral acceleration curve is nothing but we mentioned it already it is UHS or uniform hazard spectra which finally, we compare with our codal provisions or codal values as given in our IS code IS 1893 part 1 2002 version for zone 3. So, you can see that black color line that is for as per our Indian standard code prediction. And the 3 colored blue green and red shows here for Ahmedabad city what are the UHS obtained considering different return period. Say return period 72, this blue line return period 475 years; this green line and return period of 2475 is this red line, that means, if you are going to design any structure in Ahmedabad city using your IS code recommended value of this spectral acceleration, you will be actually designing it for return period of 475 years, can you see the similarity between their values? But if you are planning to design an earthen dam or an important bridge or a nuclear facility in Ahmedabad region you should go for return period of 2475.

In that case you should not design it for 475 years in that case again if you follow the codal provision blindly you will do a serious mistake, because that value of spectral acceleration is much lower than the highest value of the spectral acceleration given for this 2475 years.

So, am I clear now? How this IS code has value proposed value has to be used very minutely and with complete knowledge of this hazard analysis. Because manier times people tend to use the IS code recommended values blindly without knowing the inherent calculations of obtaining this hazard curve, because as I said code cannot give you individual curve like 1000s of cities of India like this. That we have to do the analysis if it is an important structure or important construction is going to come we have to do a region specific, location specific, hazard analysis in this fashion. And then recommend what value of spectral acceleration should be considered for design, it may match the IS code it may not match the IS code value clear. So, hence forth I will expect those will be going through this video lecture will not blindly adopt the IS code recommended values.

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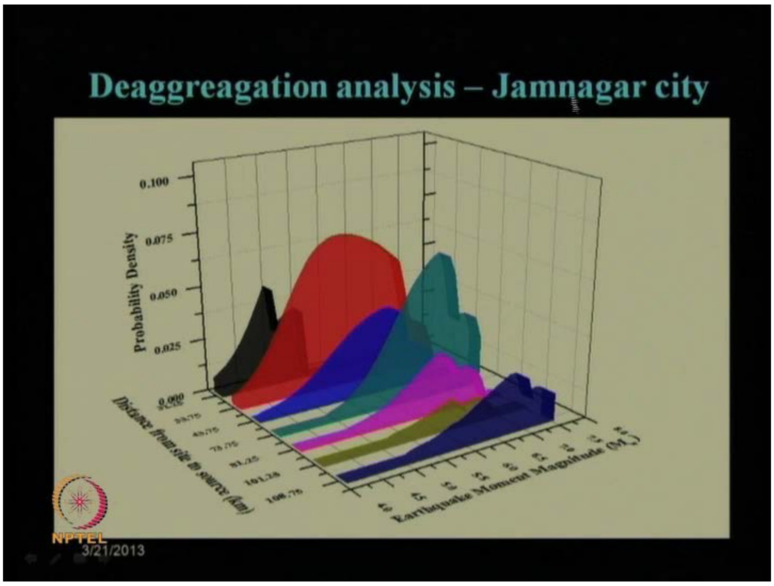

Next let us see the deaggreagation analysis for one particular city, let us say Jamnagar city, why I want to show this result deaggreagation or deaggreagation that gives us the idea which source and which distance dominates for a particular city or particular region. As you can see from this values or this peak you can see over here as per as probability density functions are concerned for higher magnitude this distance from source to site dominance. Whereas for moderate earthquake magnitude of about 5 to 6 this red color curve which is at a nearby location within say about 33 kilometer from source to site dominates. Like for a Jamnagar city we got a particular value of seismic hazard of course, from the design, but we should also know that it is valid for which range of magnitude and which range of magnitude is more influential and which distance of side to source is more influential so that you can take precautionary measures.

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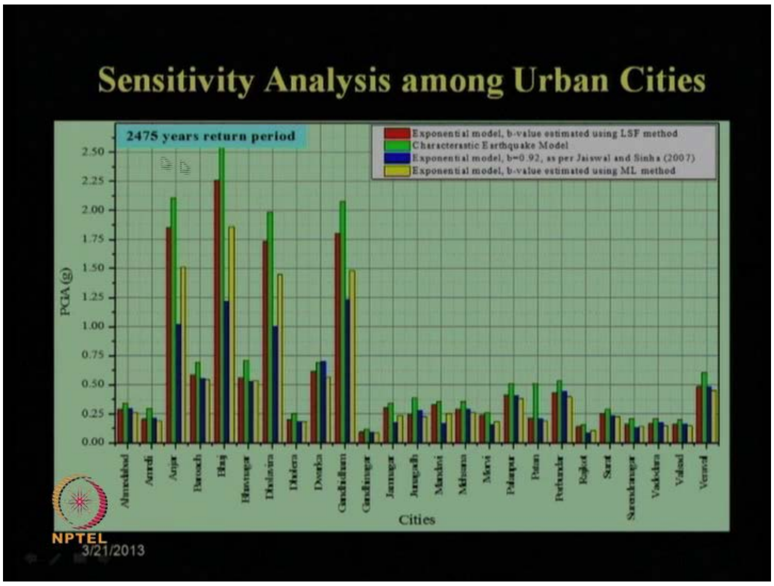

This is the sensitivity analysis among the various urban cities you can see Ahmedabad Amar, Varubhuj for a chosen value of return period of 2475 of PGA. So, these different histogram shows 4 seismicity models which we have used in our present study.

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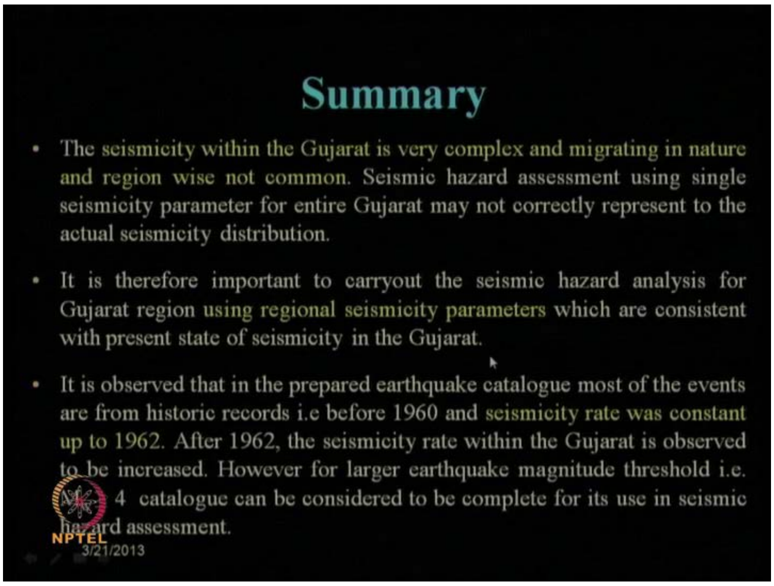

So, in summary what we can mention that the seismicity within the Gujarat is very complex and it migrates from region to region it is not a constant over the years. And seismic hazard assessment using a single seismicity parameter for entire Gujarat state, Gujarat state may not correctly represent the actual seismicity distribution, we have seen the reason. So, it is therefore, important to carry out the seismic hazard analysis for Gujarat region using the regional seismicity parameters which are consistent with the present state of seismicity in the Gujarat. So, it is observed that the prepared earthquake catalog for most of the events of the historic events they changes 1962 onwards that is seismicity rate has increased for Gujarat region beyond 1962 to till date.

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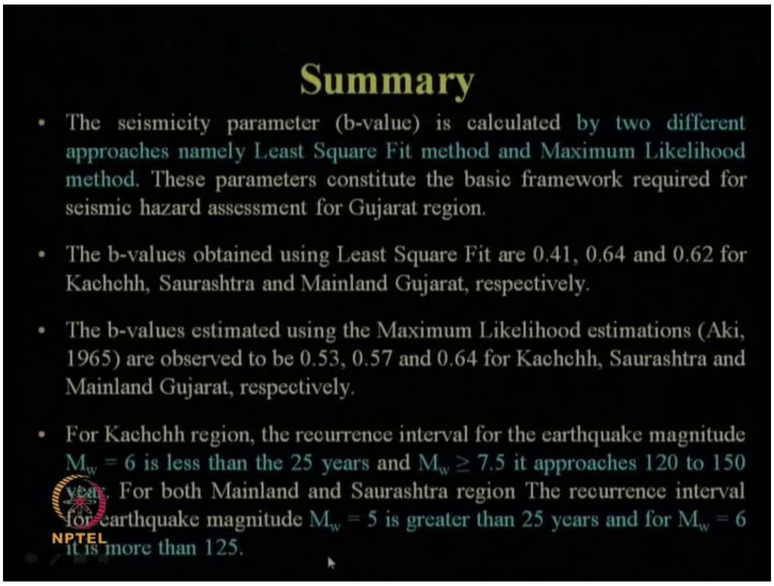

Then we have seen among the 2 methods we have used for obtaining b value; one is least square feet and maximum likelihood method, least square feet is a more realistic value. And these are the various b values recommended by the 2 methods and for Kachchh region, the recurrence interval of earthquake magnitude of 6 is less than of 25 years and when it is more than 7.5 it approaches 120 and 150 years.

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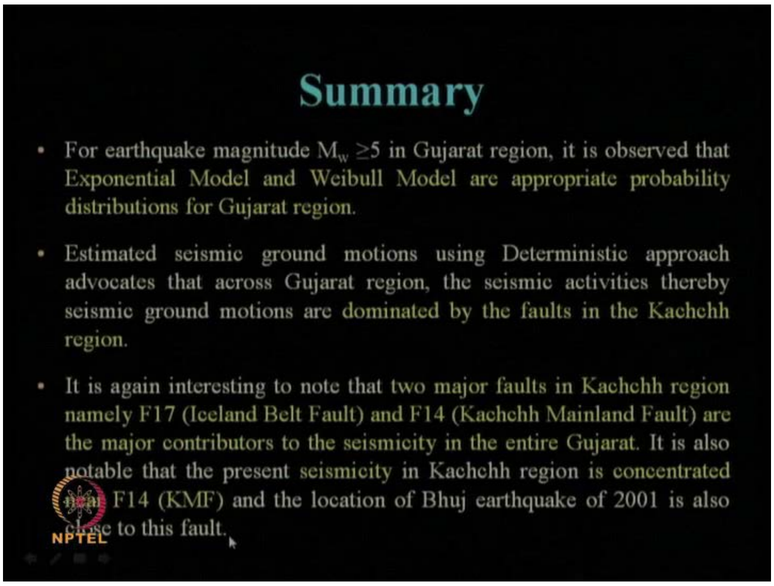

Whereas for earthquake magnitude M W greater than 5 in Gujarat region we mentioned and proved also that exponential model and Weibull model they are providing better results than other models. And we have carried out deterministic seismic hazard analysis as well as probabilistic seismic hazard analysis for deterministic hazard we have seen it is not necessary that only one fault will dominate, it depends on at which time period your doing the analysis.

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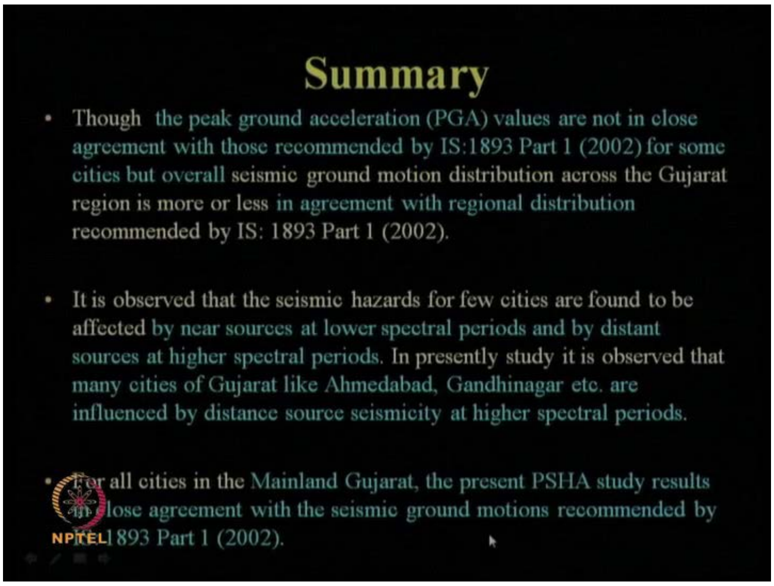

And according to IS code we have seen it is in a close agreement as for as MCE concerned, but if you want to do for another return period of level we need to do a rigorous analysis for a particular location.

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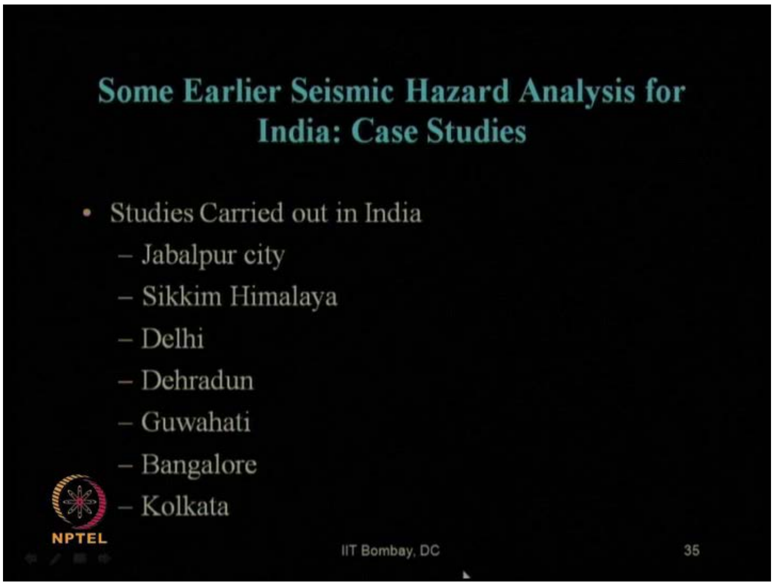

Now, some other researchers earlier also did several seismic hazard analysis for entire India for different cities of India various case studies are available in various sources in the literature studies are mainly carried out in India for Jabalpur city for Sikkim Himalaya for Delhi for Dehradun for Gowahati for Bangalore for Kolkata. There are many other regions for which even within these regions what I am going to say now other than those researchers also there are many researchers we have contributed a lot.

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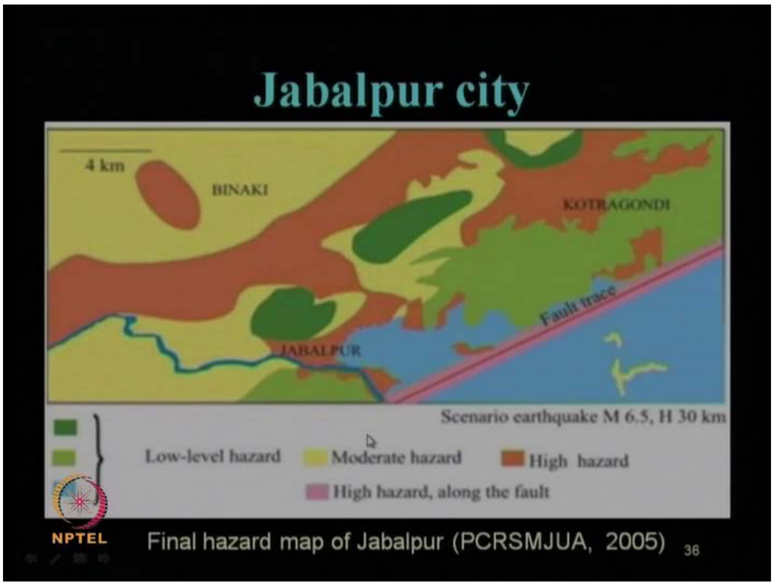

So, just a quick review that for Jabalpur city this is the reference; this is the final hazard map seismic hazard map proposed for the Jabalpur city.

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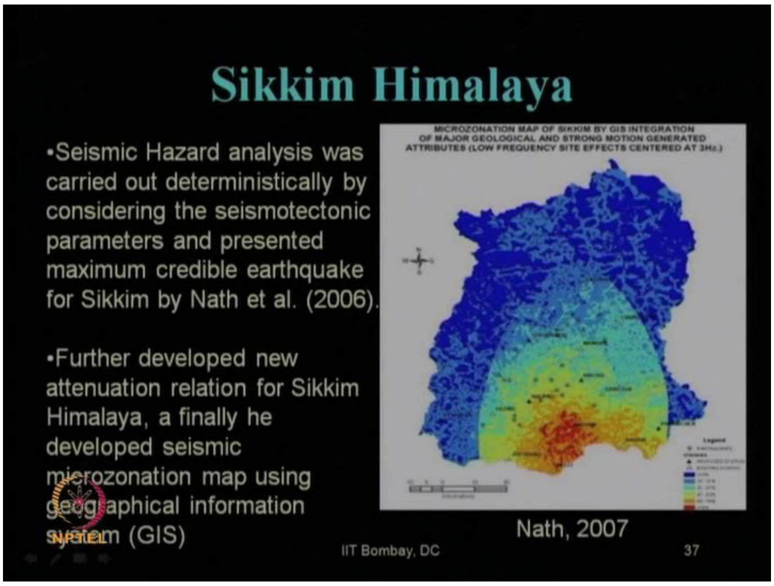

For Sikkim Himalaya as given by Nath et all given by east Nath given by 2007, this is the seismic hazard map.

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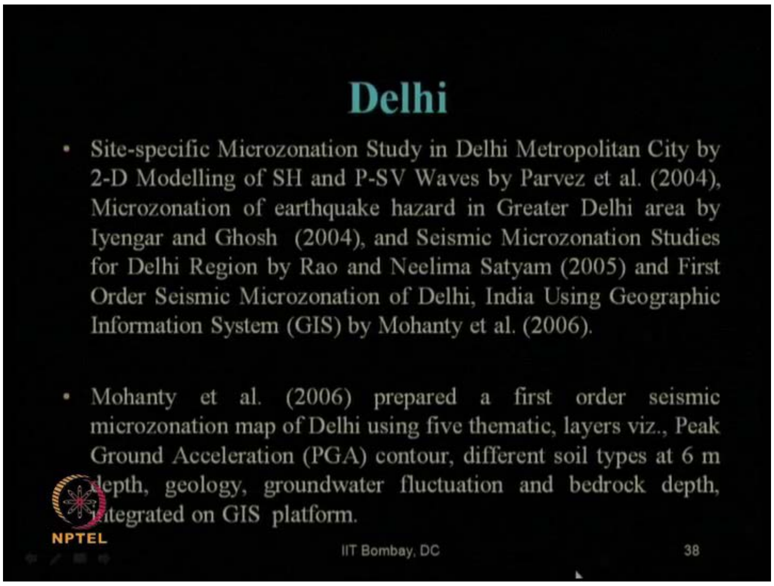

For Delhi city there are several researchers as mentioned over here Parvez et all at 2004, Iyengar Ghosh 2004, Rao and Neelima Satyam 2005, Mohanty et all 2006.

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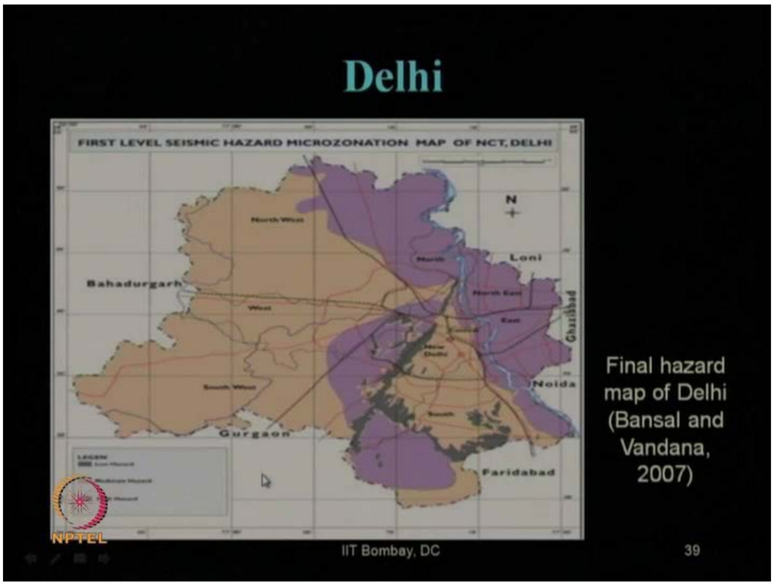

And so many other researchers they have given for Delhi region like Bansal and Vandana 2007, the seismic hazard map for Delhi city also in this fashion.

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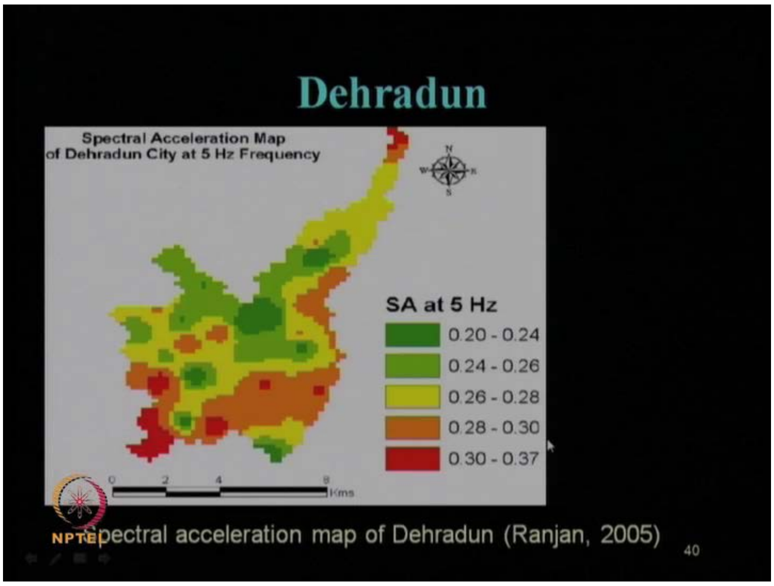

For Dehradun city Ranjan 2005 gave the spectral acceleration hazard map at 5 Hertz frequency in different bracketed zone of this seismic spectral acceleration values.

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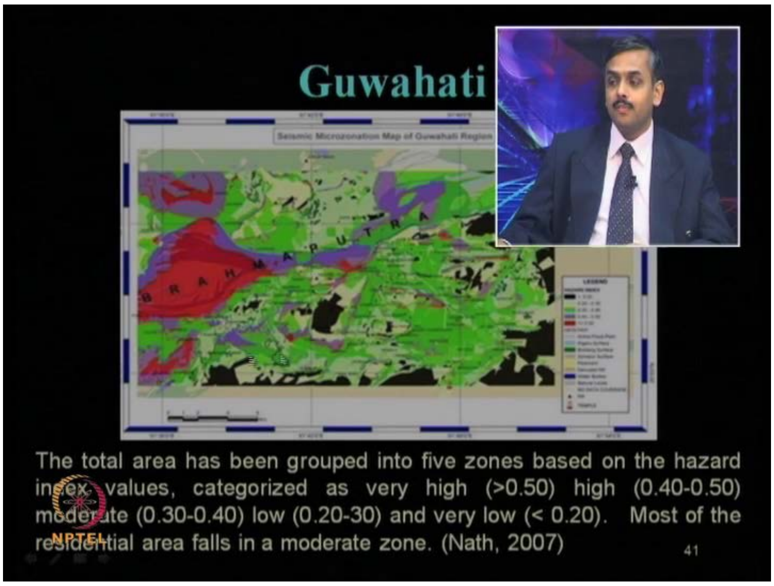

For Guwahati city also Nath in 2007, they sub divided entire Guwahati into 5 major zones characterized as greater than 0.5 within high as 0.4 to 0.5 these are the hazard index they have identified and sub divided the entire Guwahati region as per the seismic microzonation.

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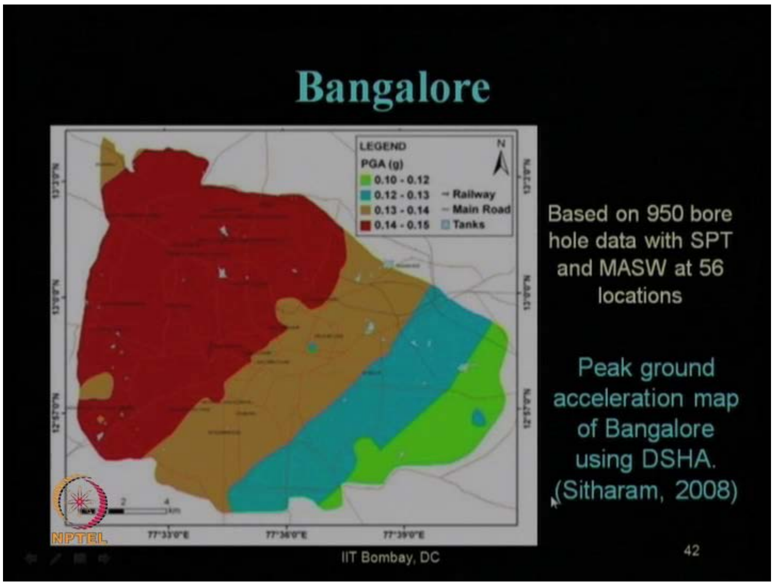

For Bangalore city also Sitharam in 2008 did the deterministic seismic hazard analysis based on bore hole data SPT data and MS, MASW data and the DSHA results have been mapped like this.

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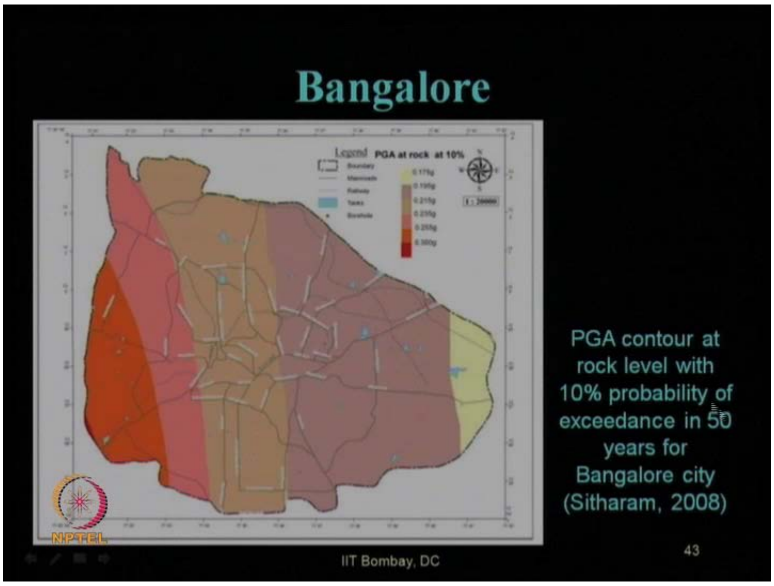

And PGA contours at the rock level with 10 percent probability of exceedance in 50 years was proposed by Sitharam in 2008.

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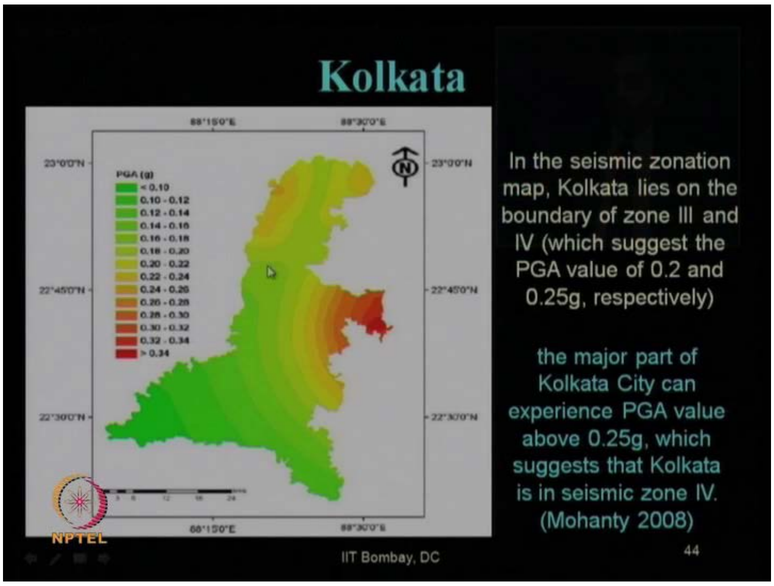

For Kolkata also it was proposed by Mohanty in 2008, this is the map for various ranges of PGA. We were the seismic zonation map of IS code Indian seismic code IS 1893 shows that Kolkata lies in zone 3 and 4 boundary which suggest a PGA value of between 0.2 to 0.25 g. Here it shows that it should be majorly in zone 4 which is above 0.25 g some of the portions you can see over here. So, these studies this case specific or region specific studies are very important when we are doing any important construction rather than using only the IS code recommendations. So, with this we can say that we have come to the end of our module 7 which is seismic hazard analysis and we will continue further in our next class with the next module.