Introduction to Engineering Seismology
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Lecture - 59
SHA Contd - Seismic Data Collection

So, vanakkam. We will continue our lecture on engineering seismology. Last class, we have discussed about the preparation of seismotectonic map and seismic study area. I did revision. So in this class, we are going to talk about the seismic data, which is like earthquake data and how to homogenise the earthquake data.

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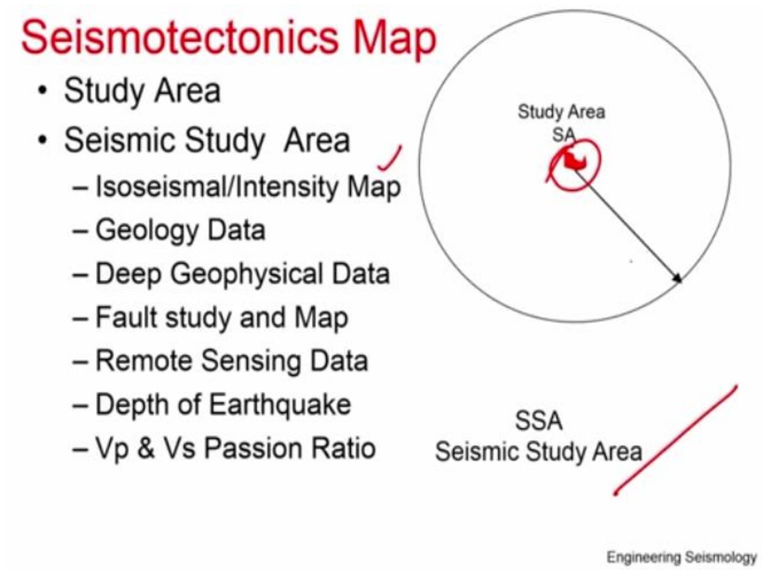

We have seen that the identification of the seismic study area is a very important process, where you need to take a reliable seismic study area, which represents the hazard at your study area. When you are taking a seismic study area, you should not worry that we are taking within India border, excluding India border and all. As per earthquake is concerned, there is no border business. The earthquake happening in Kashmir also affects Pakistan.

Earthquake happening in Pakistan also affects Indian place. Similarly, Kutch will affect Pakistan area; Pakistan area will affect Kutch. So Nepal earthquake will affect Indian side; Indian side earthquake will affect Nepal; Bangladesh also similarly. So we should not need to worry too much about any border when you talk about seismotectonic map. There is no border, only you have to worry about the geology and seismotectonic details of the particular place, not about the border.

So what are the information you collect in the seismic study area. So isoseimal map and intensity map decide the radius. Geology data, deep geophysical, fault study map, remote sensing, and depth of earth earthquake, Vp and Vs Passion ratio. So these are all the information you compile and then try to generate a map as a seismic source map.

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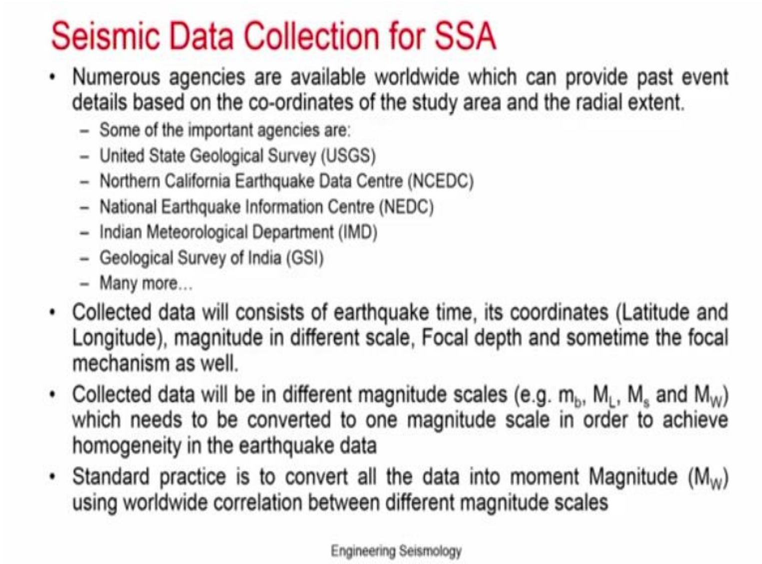

So once you generated that map, the next process is compiling a seismic data in the region. So this is also part of the seismotectonic map preparation only. So as we have seen that the past earthquake location indicates how potential the area is a particular seismic activity. So the occurrence of some earthquake in the region indicates that the seismically, the area is active. So, generally seismic data are available from the national seismic network and then global seismic network and some of the international agencies who compile different part of data and publish.

So these are all some of the agencies, where you can get a global data, which includes India data also. Once you identified your seismic study area, you have to collect an earthquake data within your seismic study area by browsing different sources and try to collect the data and compile. For example, USGS, Northern California Earthquake Center, National Earthquake Information Center, IMD, geological survey and any other site. It should not be limited.

All the sites you should visit and collect data as much as possible, whatever available. So this collection of data generally consists of the earthquake location latitude, longitude of the earthquake, magnitudes of the earthquake, which may be in any scale, Ml, Md, Mc, Ms, Mb and Mw and then the focal depth, sometimes the focal mechanism all those information we have to work. That is what we have seen in the last class, some of the researchers who have described these kinds of details by collecting several recorded earthquake in the region.

So those kinds of information are useful to us. Collected data will be different magnitude scale, such as this one. This is the most widely represented magnitude and converted to the uniform magnitude. That is called the; presently used magnitude is basically a moment magnitude, which does not saturate with any higher level. So that magnitude has to be converted. So now you may understand why we studied a different earthquake scale, in order to use in hazard analysis.

If you understand the different earthquake scale, how it has been developed then you believe that the moment magnitude is the most reliable magnitude. All the magnitude should be converted to moment magnitude. So the conversion from one magnitude to other magnitude is called as homogenization. The process of conversion from one magnitude to other magnitude making a similar magnitude is a homogenization process.

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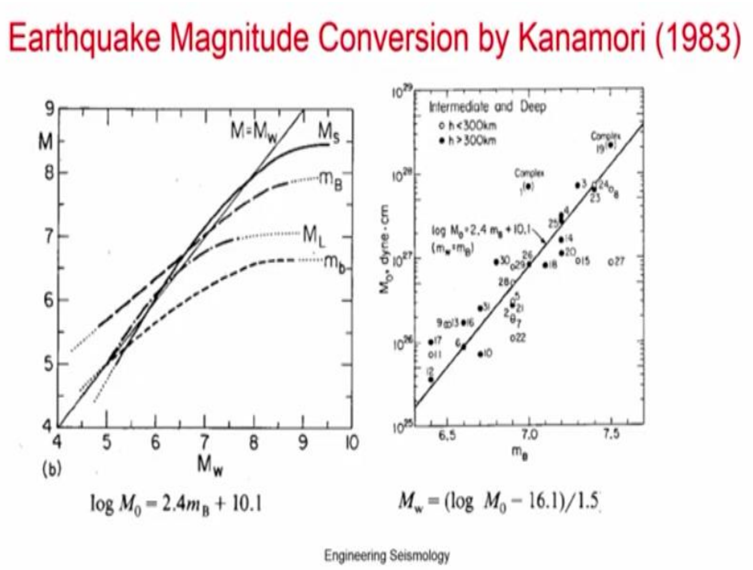

So these are some of the examples, where you can see that Mw equal to, this is actually Mw plot. So Mb you can see Ml, Mb, Ms, where you can see the saturation. Based on this magnitude, you can take what is the Mw magnitude. So this is some kind of relation given with the function of seismic moment and then Mb, which is released by Kanamori, using the world data in 1983. It is a very old relation, you can also see as another relation, where you can see the data, they use and try to compile this kind of relation. So they are also given for the depth of data also they will give.

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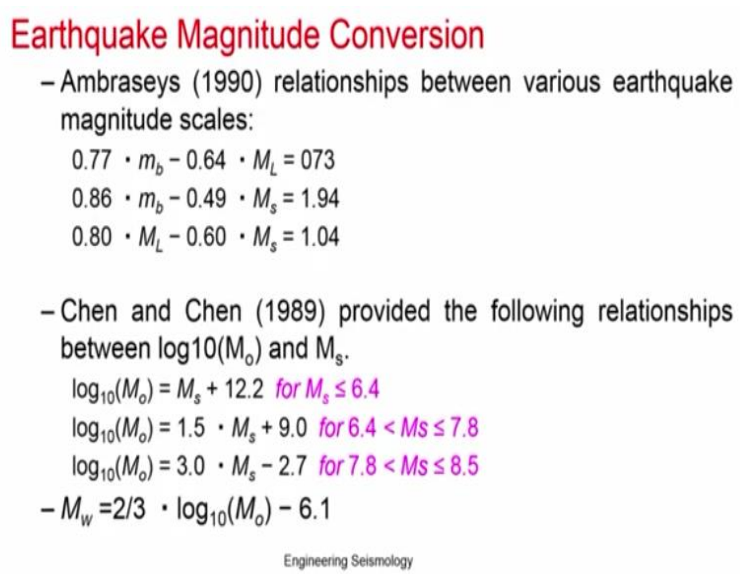

Such kind of relation also developed by several people, you can see this is a typical relation developed by Ambraseys in 1990, relation between the various Mb versus Ml. So then the Mb, Ms, Ml and Ms, so like that there are different equations are there and then these equations are also related to the M naught. If you know the M naught, from the M naught, you can Mw. This also you can see. You also need to note what is the condition that equations are developed.

Somebody developed equation for 6.4 to 7.8, you cannot use that equation for less than 6.4. So those are all the clear understanding of the equation and use, because somebody used, you should not assume that that equation is right and you should use, including myself. If I publish some paper using some equation, you should not assume that that equation is right. You have to verify yourself how that equation is applicable to your region.

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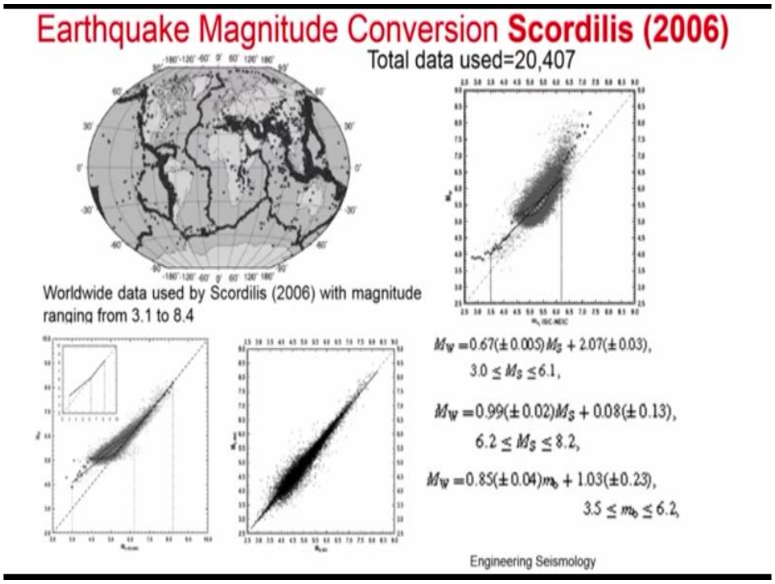

We will also see some of the most widely used equations. So this is actually the equation given by Scordilis. This was actually considering the global data, where he considered 20,407 earthquake. This is the distribution of the earthquake, you can see where he plotted, but you can also note here that India has a very small number of data, you can see here, where you can see, this is actually India. You have very small number of data here.

So he has given Ms versus Mw, then another Ms, Mw, so this he proposed this kind of equation and range is here. These are all some of the equations, you should need to know these equations, but again I am telling that I am not recommending any particular equation to be used. You have to select this equation according to your region, not based on the literature or known data.

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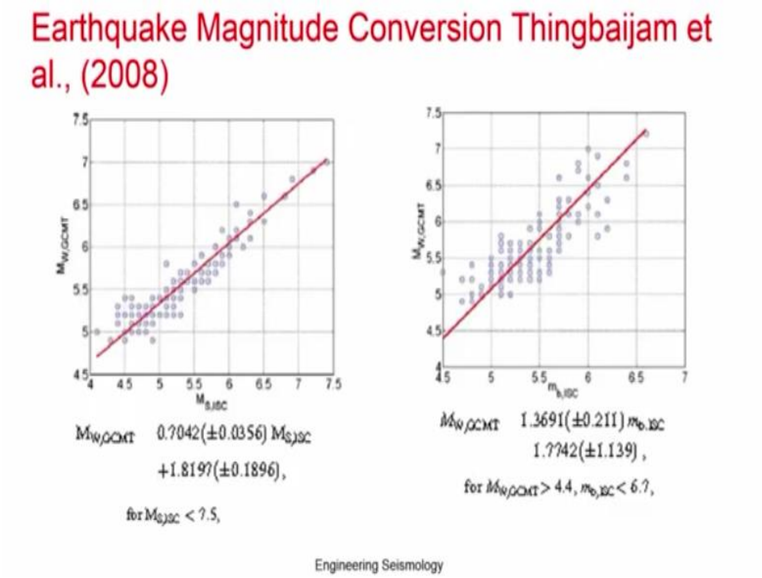

So the earthquake magnitude conversion, Thingbaijam also given some equation. This is basically for the Indian data, you can see here. So this is from the Indian earthquake, he has converted and this was published in 2004, where they have given Ms versus Mw, Mb versus Mw relation.

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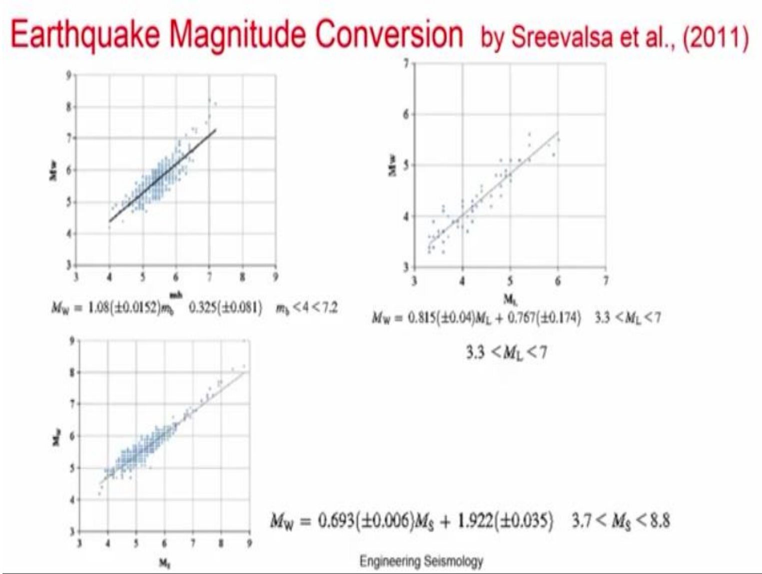

So then Sreevalsa et al 2011, he also published some equation using the Indian data. You can see here. So these equations you can see. So they are given like that.

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Earthquake Magnitude Conversion by Ashish et al., (2016)

Magnitude conversion relations estimated from the Harvard CMT catalogue for the Indian peninsula

Conversion	Relation	Data points
$mb \leftrightarrow M_L$	$M_L = 0.9930(\pm0.023)mb + 0.0550(\pm0.097)$	441
$mb \leftrightarrow M_W$	$M_W = 1.3488(\pm0.051)mb - 1.6520(\pm0.274)$	194
$M_L \leftrightarrow M_W$	$M_W = 0.6044(\pm0.337)M_L + 2.5938(\pm1.615)$	17
$M_0 \leftrightarrow M_W$	$M_W = 0.7570(\pm0.011)M_0 + 1.4299(\pm0.066)$	98
$M_S \leftrightarrow M_W$	$M_W = 0.5667(\pm0.006)M_S + 2.6046(\pm0.034)$	125

mb body wave magnitude, M_L local magnitude, M_S surface wave magnitude, M_W moment magnitude, M_0 other magnitude

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So after that Ashish et al 2016, he published some equation, you can see here. So these are all considering the overall Indian data. When you consider overall Indian data, you should also know that we have different seismotectonic behavior at different parts of India that you have to account and wisely take which equations are more suitable. They have given like different conversion from this to that and that to this, something like that, so that you can do conversion vice versa and get finally a moment magnitude.

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Earthquake Magnitude Conversion by Nath et al., (2017)

- International Seismological Centre(ISC,http://www.isc.ac.uk, last accessed September, 2014), US Geological Survey/National Earthquake Information Center (USGS/NEIC,http://neic.usgs.gov.us, last accessed September, 2014) and Global Centroid Moment Tensor(GCMT,http://www.globalcmt.org, last accessed September, 2014).
- India Meteorological Department (IMD,http://www.imd.gov.in, last accessed September, 2014) and Jaiswal and Sinha (2004).
- Various magnitude types used in the earthquake databases (modified after McGuire 2004) used inthe present study

Magnitude type	Saturation	References
Local/Richter, M_L	~6.8	Richter (1935)
Short-period body wave, m_b	~7.0	Kanamori (1983)
Surface wave, M_S	~8.0	Gutenberg (1945)
Duration, M_D	N/A[a]	Real and Teng (1973)
Vertical p-wave, m_{pv}	~7.0[b]	Hori (1969), Bune et al. (1973)
Moment, M_W	None	Hanks and Kanamori (1979)
Lg wave, M_N or M_{bLg}	~7.0[c]	Nuttli (1973)
Vertical surface wave, M_{Lv}	~8.0[d]	Hori (1969)

[a] Duration magnitudes are used for small earthquakes, [b] based on characteristics of short-period p-waves, [c] comparable to M_L, [d] vis-a`-vis characteristics of surface waves

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This is another equation published by Nath, where he compiled 2017, they compiled data from the different website source and then the IMD and then the previous studies and then they nomenclature all these magnitude scale, which is reported in the region and their saturation level and then the source of that saturation level. From here, they went to developing a magnitude conversion equation, which is like the equation, which is given here. You can see here.

This is the equation for typical conversion. They used 2 different set of data and number of data, they mentioned like the minimum magnitude, maximum magnitude converted into magnitude range, the equation number for the paper reference actually. You can see the equation range, which earthquake should be what conversion you should use, all these things you should know. So you can see that the highest range given was here actually 7.8.

That means, if you have some other earthquake, which is beyond this, so one has to be really concerned about those kind of data. You should know in detail before using any kind of relation, which is useful or not. They have also taken here basically the proxy magnitude concept, where they take this by considering the proxy of this point by applying a proxy magnitude concept for getting a better regression model.

Again what type of better regression model they use, that also plays a major role in your conversion equation.

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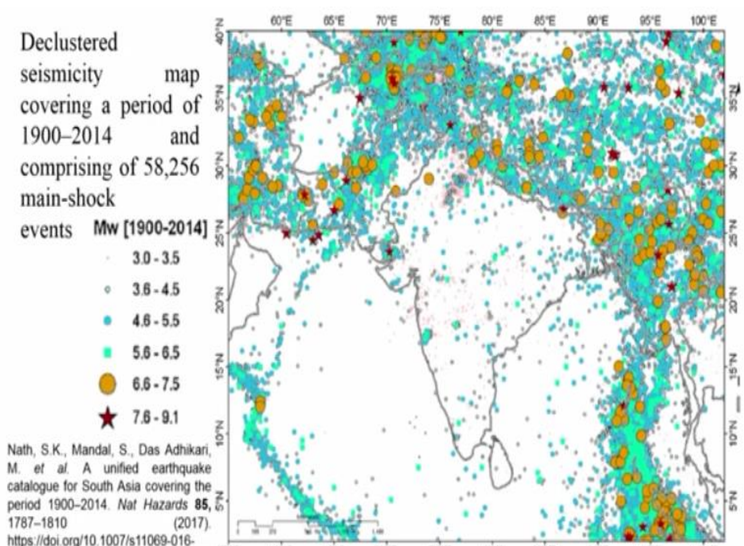

So this is earthquake after conversion and declustering. These people published a seismic map from 1900 to 2004. You can see here, the legends used in almost Southern India. So the entire part of Southern India, this is the peninsular India kind of things. So your highest magnitude reported is basically only 6.5. There is no beyond that magnitude. So red dot is 7.5 that you can see mostly on this part.

Here also you can see some of the area, this is not there, but that is a plate boundary. So those kind of places also you should put some kind of effort and try to see if there is any kind of seismic activity is happening and to fulfill the seismic gap kind of things. This paper details are given here. This is the figure taken from that paper actually.

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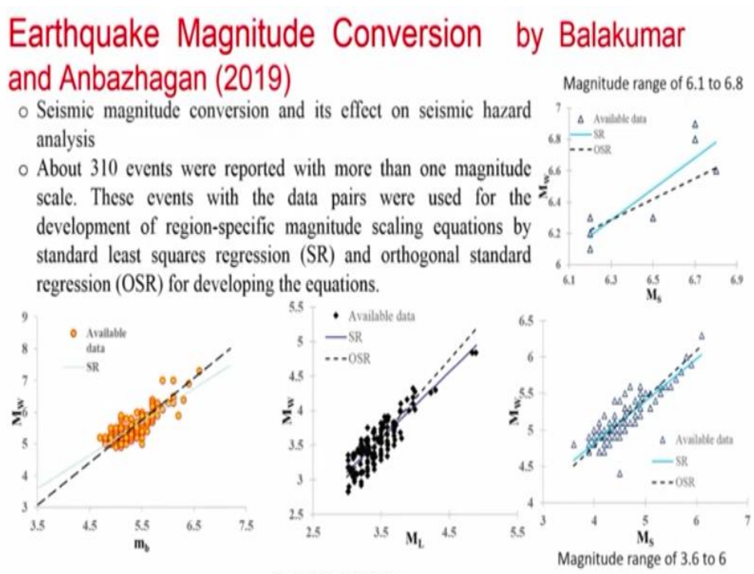

Then, actually if you see this equation, most of the equation concentrated on throughout India. So in order to understand how the seismic magnitude conversion will affect your seismic hazard analysis itself, we carried out a study, considering the northeast region as our study area, basically, we have taken northeast as seismic study area and tried to get a seismic study area map based on the intensity and collected different earthquake and tried to generate our own regression model.

And then tried to take a previous model and tried to assess how this model conversion will affect your number of data. Then how the AB parameters will be affected, AB parameters we will be discussing in the coming classes and then how it affects really your hazard values. So that is all we studied by taking this paper. If you want to know more about that, you can see. We used actually least square regression as well as orthogonal regression.

Even we studied the effect of regression model on the conversion equation and that effect in the hazard by looking at the study. This paper was published last year actually about one year back.

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$$M_1 = \alpha + \beta M_2$$

where M_1 and M_2 are different magnitude scales of interest, β represents the slope and α represents the intercept of the regression line. The coefficients obtained for different conversions obtained in the present study have been presented in Table

Equations	Regression Technique	Intercept(α)	Slope(β)	R^2 value	No of data points	Magnitude Range
m_b - M_W	SR	-0.0677 (±0.3413)	1.0483 (±0.0637)	0.71	127	4.7 to 6.6
	OSR	- 1.5725 (± 0.4329)	1.3296 (±0.0808)	0.64		
M_L - M_W	SR	0.209 (±0.1502)	0.967 (±0.044)	0.75	162	3 to 4.9
	OSR	-0.3573 (±0.1758)	1.1327 (±0.0512)	0.73		
M_S-M_W	SR	2.4939	0.5805	0.8	101	3 to 6.1
	OSR	2.3172	0.6189	0.79		
M_S-M_W	SR	0.0283	0.9934	0.74	8	6.1 to 6.8
	OSR	-0.1401	1.0238	0.68		

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So this is the general functional form we used for the model and this is the equation we have given. You can see Mb to Mw, Ml to Mw, Ms to Mw, you can see the number of data points R square value of that and then the magnitude range, which is applicable. So this paper, I am only presenting this equation, further we carried out studies and concluded what are the important observation, we should follow, when you do the conversion equation. You can refer those kinds of things from that paper.

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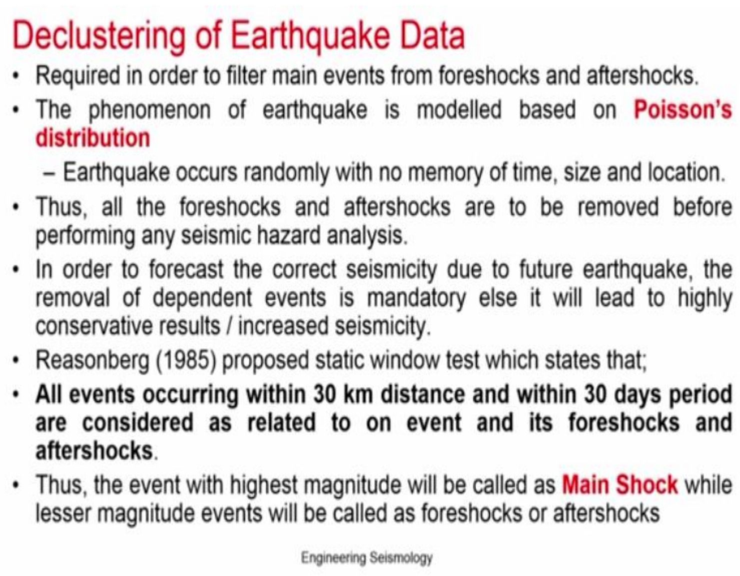

Once you convert and homogenize the data, now since you have collected data from different source, you will have the same earthquake reported on different source. So that means, there will be a main shock and repeated main shock and then the aftershock and foreshock. So generally the aftershock or foreshock does not contribute to the seismic activity of the region, why because it is a minor earthquake, generally minor earthquake, which will be smaller in size and energy released also smaller.

The main event only, we should be focusing on the concentration. So the phenomena of earthquake is modeled as Poisson distribution. The earthquake occurs randomly with no memory of time, size and location. So that means, there should not be any overlap of same earthquake in the region. That has to be taken care. So, all the foreshock and aftershock has to be removed from performing any seismic hazard analysis.

Before doing, seismic hazard analysis, we need to remove the foreshock and aftershock in order to forecast a correct seismicity due to the future earthquake, the removal of dependent event, foreshock and main shock and repeated main shock mandatory, else it will lead to highly conservative result and increased seismicity. So Reasonberg proposed a static window test, which states that all the event; occurring within 30 km distance within 30 days period are considered related to on event and foreshock and aftershock.

So you should remove the event within this span. Again I am telling that this was suggested by the Reasonberg, so recently we are doing research on that to understand how the declustering window should be defined for Indian data, maybe we will come up with the result. You can refer in the future. So the removal of dependent event from the main shock is actually a declustering process.

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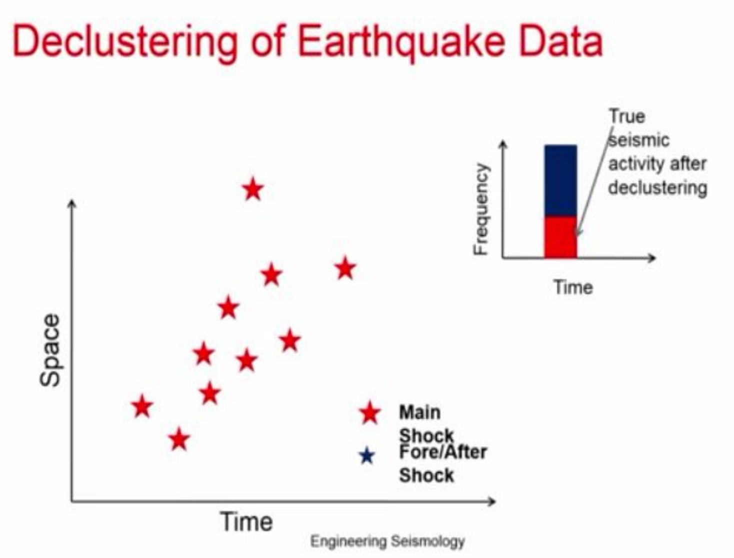

Why the declustering is done? For example, the phase and time if you look at earthquake, this is the overall earthquake what you collected and converted, but the main events are only the red one. The remaining are aftershock and foreshock or repeated events. This will contribute to this is actually the total data frequency, time relation. This is the data only for the main shock. It will show an increased seismicity. In order to avoid that, you should do the declustering process after conversion.

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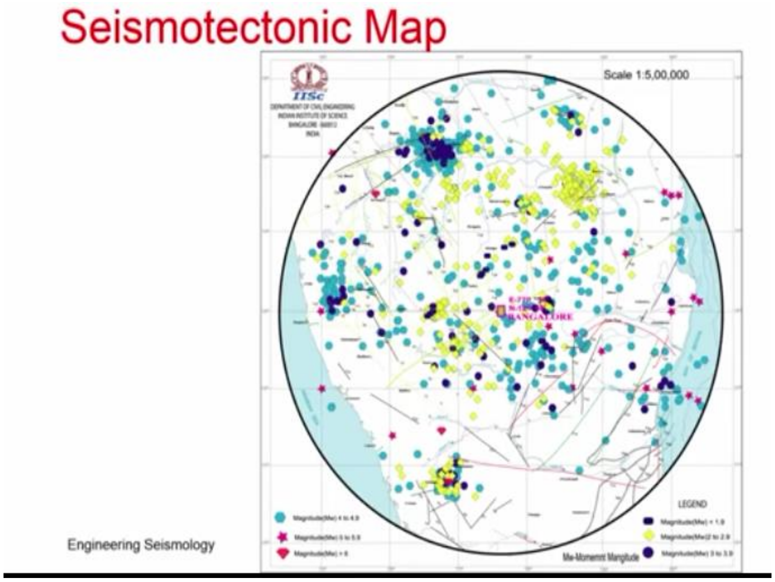

Once you decluster the data, then the remaining data you can plot on the source map earlier you prepared and now you have a seismotectonic map, which consists of the seismotectonic parameters and seismic data, so that map is called complete seismotectonic map ready for hazard analysis. So this is the seismotectonic map, this is the seisemic study area Bangalore. You can see the scale of the map and then the legend is given and then different scale and then the source details all the information has to be prepared.

This is the typical seismotectonic map prepared by me for Bangalore microzonation work. We have done systematically selected a study area, collected a seismotectonic parameter, geology parameter, geophysical parameter, collected a data, converted that, homogenized and declustered and finally superimposed all the data and prepared a seismotectonic map. Now, you will know that what are the sources associated with the earthquake.

What are those places, there is no source, but still there is earthquake, this has to be modeled well for further analysis. So that discussion we are going to continue in the next class.

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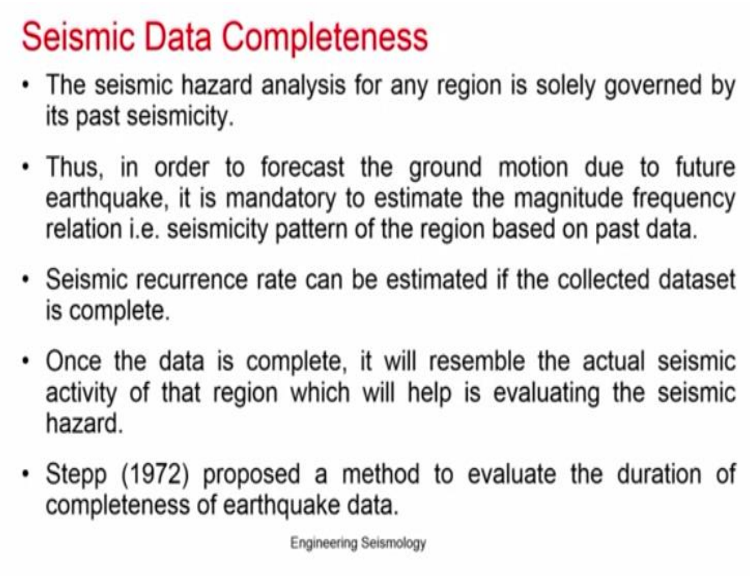

This analysis, whatever is going to do that, the first part, after declustering the first part is you have to understand your data is complete or incomplete. What is meant by complete? So complete means, your region. Complete means you should have all the range of recorded in that particular place that is called as a complete data. For example, last 10 years, after installing the seismometer, I will have minor earthquake to major earthquake everything.

So that detail is the complete period, but when I talk about 100 years, my instrumentation started very late. I may not have the minor earthquake, only the earthquake which is felt by the people, like isoseismal map, so that period is called as incomplete or you can say that the earthquake complete and incomplete, which depends upon the analyzing systematically and the complete data follows some pattern with time.

So that kind of analysis is called as earthquake data completeness analysis. With this analysis basically proposed by the Stepp 1972, he has given a method to describe and analyze the completeness of the earthquake data.

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- As per this method the whole data need to be divided into number of events occurred in suitable time interval.
- Each bin should be as small as possible but should be large enough to have sufficient number of data.
- Thus, when the sample set is more, the variance will be small.
- if x_1, x_2, x_3, ……., x_n are the number of events in unit time interval, then the unbiased mean for each time interval for this data set can be given as (Hamilton, 1964) as;

  $\lambda = \frac{1}{n}\sum_{i=1}^{n} x_i$
- And the corresponding standard deviation can be obtained as; $\sigma_\lambda^2 = \frac{\lambda}{n}$
- Where n is the number of unit time interval. Keeping the time interval as 1 year, the standard deviation will be proportional to sample length T as $\sigma_\lambda = \frac{\sqrt{\lambda}}{\sqrt{T}}$
- For stationary process, the variance will be unity and the standard deviation will be proportional to $\frac{1}{\sqrt{T}}$
- Hence, when the data is complete, the mean annual rate of exceedence of each magnitude value in constant time interval will be same and its standard deviation will be equal to $\frac{1}{\sqrt{T}}$

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So what he said actually, the whole data need to be divided as a number of occurred suitable time interval bins, like every 10 years, 5 years, you can make a bin. Then, you can count each bin, what is the number of event or particular magnitude range, like 4.5 to 5.5, how many earthquakes? 5.5 to 6.5, how many? Like that each bin, you can estimate. When the sample set more, the variance will be small.

That means, you should divide a time period and number of data should be smaller as possible. If the x1, x2, x3, xn is the number of event unit time interval, then the unbiased mean of each interval of dataset can be given as lambda = 1 by n into epsilon i = 1 into n into xi. So this is the rule it has been followed. So corresponding standard deviation, the sigma lambda square = lambda by n, when n is the number of unit interval keeping the time interval of one year, the standard deviation is proportional to the sample data.

This is the T you will get. So that means, for the stationary process, the variance of unity and standard deviation will be proportional to 1 by root 2. So if the data follows a pattern of 1 by root 2, that data is complete data. Data which does not follow a pattern of root 2, that data is incomplete data. So this will give you the complete period, the earthquake data complete period in this one.

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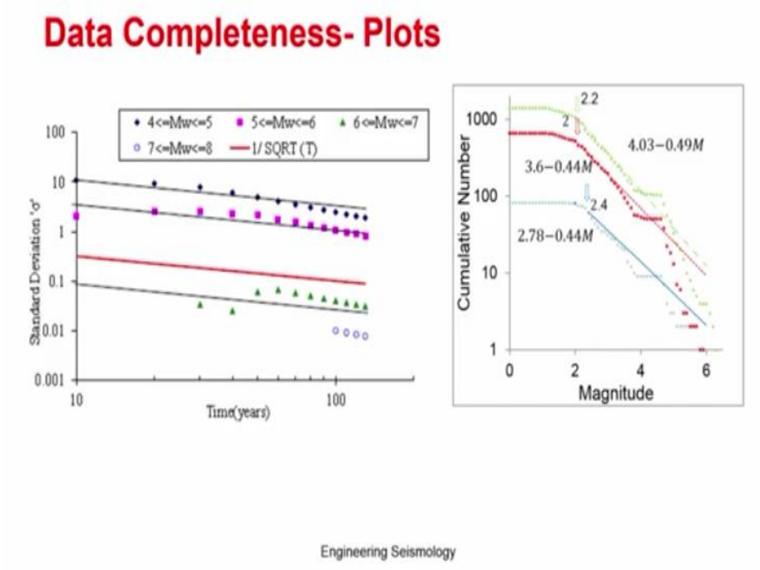

You can see that the typical data we have taken, then the time interval we made and then the standard deviation we prepared, and data has been divided as a different segment. You can see the symbol. So this red line is actually 1 by root T, that you have copied. You first plot a data and copy these lines parallel to that, then identify, which are the data following the line. So the data which follows a line is a completeness period.

So generally the instrumented data will be complete for the short period, larger magnitude data will be complete for the longer period, because that has been felt by the people, definitely it had been reported. This is actually the time of completeness or period of completeness. Another one is actually the magnitude of completeness. So the magnitude of completeness means what lowest magnitude the data is recorded in the region.

That is what you can do. You can do a cumulative number and magnitude versus a plot and wherever you see that, there is a slope starting. That point is actually considered as a magnitude of completeness. So you can get a period of completeness and magnitude of completeness, which will decide; what is the lowest magnitude, you have the accurate data and what period in your region. So that is what you will get from the completeness analysis.

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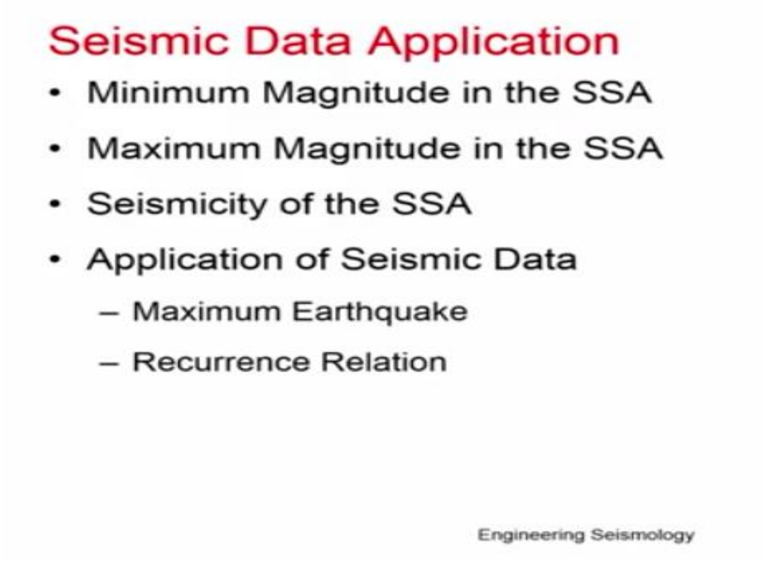

This completeness analysis is also a part of your seismic hazard analysis, where you get a period of complete and magnitude of complete. So the seismic data, what we have seen that, you have to collect a data, homogenize and decluster and then superimpose on the seismotectonic map and get a seismotectonic map. After getting that, you will get a minimum-maximum earthquake data in the region, seismicity mapping distribution of the earthquake data, which will help basically to get maximum earthquake in the region and recurrence model for the region.

This is both the application, which we will be discussing in the next class. Thank you very much for watching this video. We will meet in the next class and talk about how we can estimate maximum magnitude based on the seismotectonic map and seismicity details collected in the literature, whatever we compiled and also followed by the recurrence model in the coming classes. Thank you very much.