Introduction to Engineering Seismology
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Module No # 04
Lecture No # 16
Road Damage Intensity Scale; and Seismic Vulnerability assessment

So vanakkam, so we will start our class on earthquake measurements so last class we discussed that the earthquakes can be quantified okay so 2 ways one is the qualitative way which is called as a intensity the another one is the quantitative way which is magnitude. So the magnitude we told that it depends upon what type of wave you are considering so the magnitude type also changes. So we put discussion on the different intensity scale which is available.

And then we have seen that there are 4 intensity scale which has a 12 level of grading the earthquake and there is a 1 Japanese scale which is grading as a 7 level there is a 1RDS so which is 5 level. So we come to the discussion with the intensity scale so we have to see that okay so why this intensities are important? We are also discussed about the isoseismal map we also discussed that intensity basically described the damage due to the earthquake.

So, that means if you know the intensity from the past earthquake you can know that how much the level of damage occurred in that particular place okay.

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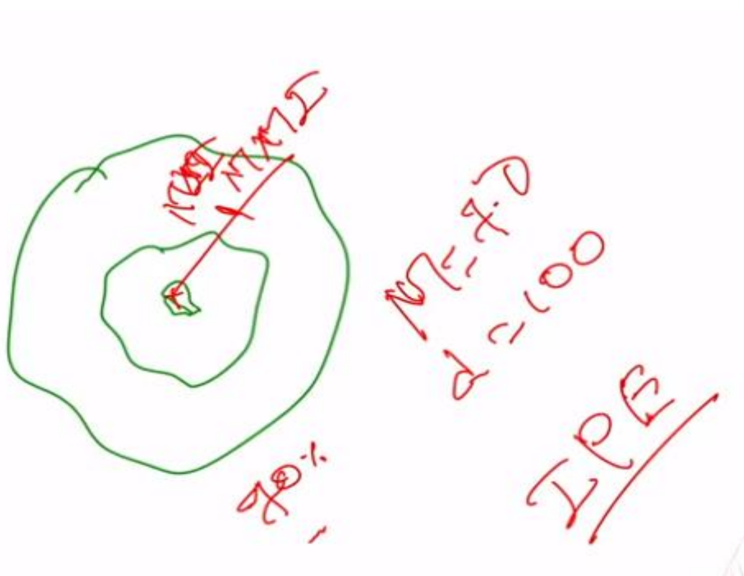

So we have discussed about the isoseimal map so basically the isoseismal map is basically like this. So this is the isoseismal map soon after the earthquake so, it will be released by the people okay so after observation and survey. So this isoseimal map basically give you the idea okay so whichever the places the buildings are damaged high level which are the places the buildings are damaged so lesser level. So that is what it will give you the idea.

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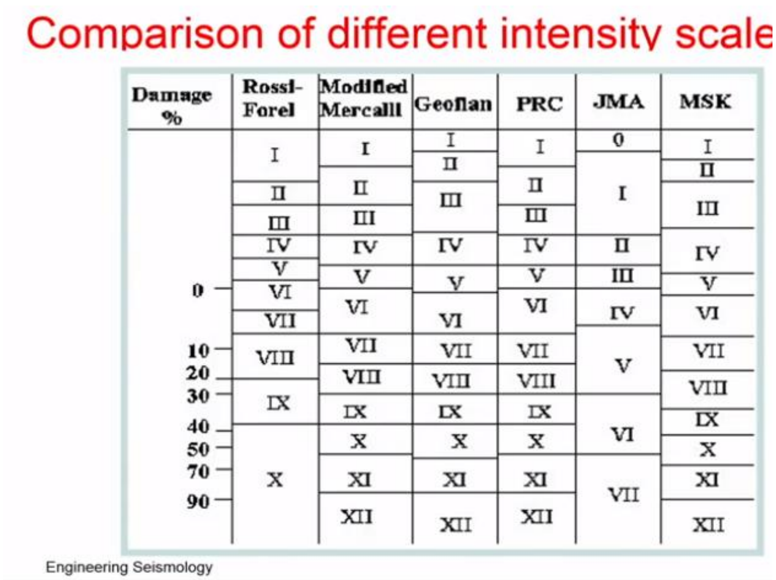

So if you look at this particular table you can see that the damage percentage related to your intensity scale. So which means if you know the intensity scale from the old earthquake you can assess a; damage. So where it helps basically this will help for the prediction of how much damage can expected at particular place. If the magnitude earthquake is assumed or the magnitude earthquake is predicted or the magnitude of earthquake is estimated from the knowing the seismic source and all which we will be discussing in detail this one.

So if I magnitude up the earthquake is for example magnitude of earthquake so we get the M as a 7 magnitude okay. So which occurred at the distance of from your place it is may be the d = 100 kilometer. So if you know these isoseismal maps basically so where that 100 kilometer comes you can know what is the intensity you are expecting at that particular place. So the MMI okay so modified mercalli intensity scale.

So this will help you to get so basically this intensity measurement okay are quantities are useful to assess what is the damage expected in the region. We should also remember that this intensity scales are based on the past earthquake building construction in that region. So if it is that similar practice is similar so it will predict very well if there is a difference in the practice there may be difference in the value predictor.

For example it is predicting a building damage of 70% okay so based on the old intensity map but the buildings are now improved. It you may vary depends upon the building construction okay so that 1 has to remember. So from here we can understand that the process of predicting this kind of damage level is called as a seismic vulnerability assessment okay. So by knowing the past earthquake intensity one can say that how much damage expected for the future earthquake also by comparing the magnitude and distance or by taking large amount of the data in the region.

And developing a intensity predictive relation which is called IPE intensity predictive relation. So intensity predictive equation or relation you can call so these equations are useful to predict what is the intensity we can expect if there is a X magnitude going to occur at Y places. So based on that you can say that okay my city is going to occur like this area 70% damage this area 50% this area 20% something like that you can map which will help basically to plan a disaster management and mitigation strategy.

So by knowing this okay if this is the status if the area which is going to damage more than 50% given a concentration and try to individual identify those places and try to improve the structures or demolish and retrofit with the new structures. So where there is a minor level you can tell them to repair it otherwise when earthquake comes you will be in trouble. So such kind of analysis these data's are useful for those kind of analysis.

So now when earthquakes are occurring it is not only with respect to the building damage but the mostly the MMI scale or most of the other scale only describe the damage with respect to buildings or rails or the chimney kind of things. So they did not talk about the one more very important parameters which; has been identified by some of the researchers okay. So basically as I told you that I am doing research on this area so I found that this research gap

What is that research gap? Soon after the earthquake okay this not only it affect a building it also affect a infrastructure particularly the infrastructure means roads I am talking. Why the roads are important? Soon after the earthquake the roads are basically used to move from one place to other place and evacuate a people and then getting a medical aid to the people. So 2005 Indo-Pakistan earthquake actually many people died due to the lack of evacuation and the medical facility soon after the earthquake not because of the earthquake.

Because this occurred in the very remote area of the Jammu and Kashmir and Pakistan border where there is not much access basically. So there is no most of the hill roads are closed due to the land slide and then people may not able to move. So this resulted people even with light injuries or they do not have much problem because of the earthquake but since there is no food and there is no water there was, no medical facility people obvious died after some time.

So this was one of the main concern then the researchers start thinking about that it is not only the building is very important to assess the damage. There is a need for assessing the road related damage also so that you can work out a evacuation and rescue strategy in the particular place. So in order to do that first of all you should also need to have the damage related to road studies on that.

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So when we look at those kind of studies there are very study has been given or even the intensity does not describe what was the road status in that particular earthquake or how many roads are failed why it is failed such kind of studies are not there. So which was realized by myself and my team so then we started thinking that if you want to assess a seismic vulnerability of the building okay you need to basically do the intensity scale and take a intensity predict equation and then asses the same.

The similar way If you want to concentrate on the seismic vulnerability of the road so that you can identify which are the roads are damageable and what percentage it can damage. So you can plan your evacuation and as so soon as the mitigation strategy for the soon after the earthquake particularly the disaster. So management and planning can be taken up okay soon after the earthquake if you have the good transportation connectivity of the roads okay.

So when we go back and see the intensity scale there was not much discussion was given in the road so which was actually understood and then studied so this is the typical example soon after the earthquake you can see the roads you can see this is the one of the road basically. So you can see this road so how it is badly damaged people only cross by walking you cannot go this road you can see that the partially collapsed but still there are 50% roads of available here you can see that in between the bridge and the road got cracked.

So here also the, another damage like this there are lot of damages so the researches like what this scale was basically developed by me. So what we did basically so we collected the information from the historic report where and all road got damage and photo of those damages and try to compile from the historic data. So like with respect to magnitude we collected and distance of that particular road from the epicenter has been collected and try to get a photo of that road and then the damage description this data's are compiled okay.

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- Earthquakes cause massive road damage which in turn causes adverse effects on the society.
- Existing Intensities quantified the damage caused to residential and commercial buildings; however, not many studies have been conducted to quantify road damage caused by earthquakes.
- The widely used MMI scale is found to be inadequate to clearly define the road damage.
- Anbazhagan et al., (2012) proposed a new scale to classify and quantify the road damage due to earthquakes based on the data collected from major earthquakes in the past.
- The proposed classification for road damage due to earthquake is called as road damage scale (RDS).
- Earthquake details such as magnitude, distance of road damage from the epicenter, focal depth, and photographs of damaged roads have been collected from various sources with reported modified Mercalli intensity (MMI)

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So why this is very important because if you want to do the transportation planning after the earthquake for the evacuation and mitigation and then the handling up the medical patient and treatment and all. So the road network is very important so that is why so we try to understand that how the previous earthquakes are caused damages. How such damages are scaled okay.

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Newly proposed Road Damage Scale with Description

RDS	Damage Description	MMI Scale
1	Damage is in the form of many minute cracks, one or two moderate cracks not exceeding 20 mm width, slight damage of shoulders and food path. Very little repair work is usually necessary to restore road for full traffic. This damage is seen when roads are of good quality and usually expected in road located away from epicenter for larger magnitudes.	XIII
2	Damage is in the form of settlement or moderate cracks, cracks or separation of pavement layers for width of less than 100 mm. Failure of sides and shoulder/footpath of the roads which reduces the road utility. Minor repair works have to be carried out to restore the road to its initial condition.	IX
3	A part of the road is damaged. Formation of big cracks and settlement of road is seen. Crack width may exceed more than 100 mm. Many bigger cracks in either one side or both sides of the road. Failure or crack can be attributed by liquefaction, landslide, fault rupture and failure of subgrade and sub base. Road can be used by limited traffic. Considerable road repair works should be carried out.	V, VI, VII, VII, IX, XI and XII
4	A portion of the road is rendered completely useless. Loose soil and debris is found all around. Road layers are washed away or slides. Damaged road can be used only for smooth walking or cycling. Vehicles cannot ply on the damaged stretch of the road and the stretch has to be completely rebuilt	VII,VIII, IX, X and XI
5	Maximum damage occurs to a road during an earthquake. Damage of total width of road, road may not be useful for smooth walking and cycling. The roads are completely rendered useless and are totally inaccessible. Roads are damaged structurally and debris from landslides renders the road totally inaccessible. Complete relaying and rebuilding is needed	VIII, X, XI and XII

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So we noticed that most of the previous earthquake damages are described in the form of MMI scale okay. So then based on the data what we collected okay so we collected large amount of the data and try to group the data and try to categorize that then we made a 5 category of the damages. So the level 1 okay which is called as a road damage scale so this is the new intensity scale purposefully developed to describe road damage due to earthquake and which will help for the seismic vulnerability assessment of the road network okay.

So that after the disaster you can know that which are the road networks are not damaged how you can evacuate the people how you can treat the people how you can move the necessary goods which road you can use what traffic condition so everything can be simulated on that. So we based on the data available so we described the entire RDS scale as a 5 category. Since the road things are coming basically the felt and then the any other description which is comes up to 4, 5, 6 in the MMI scale may not be record actually okay.

So that is also we discarded the preliminary part of the scale so we started with the level 1 RDS like intensity scale road damage scale level 1. So this is the damage from the many minute cracks and 1 or 2 red cracks not exceeding the 20MM width un-slide damage the shoulders and footpath very little repair work is usually necessary to restore the road for full traffic. That means if you do a small bit of work you can use the road immediately so those kinds of roads are categorized as RDS 1.

So similarly the RDS 2 so where there is a minor repairs are record and then but there was a damage was slightly larger than the RDS 2. So similarly RDS 3 where part of the road is settled and block but still you can access the road so this kind of things happens mainly due to the liquefaction and the fault rupture and then the land slide kind of. Then the fourth was like it is almost like rendered completely useless and loose soil debris found on the road, the road layers are rushed by the.

So the damaged road can be used to only to the smooth walking or something like that is the fourth. And fifth category it is not possible to use at all. Okay that is the fifth category so we categorize this definition we are given first time in the world to describe how the road damage and relative intensity scale which is called as a RDS. Okay this description. So let us see what is the comparison with the previous same road how it is described?

So we noticed that the previously whatever we talk as a one which is not even affected but it was given the intensity scale up. So 12 so basically it is given the intensity scale of 12.

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Sl No	Earthquake Description	Moment Magnitude (Mw)	Distance (km)	Depth (km)	Hypocenter Distance (km)	Reported MMI Scale	Proposed Road Damage Scale (RDS)
1	Loma Prieta earthquake October 17, 1989	6.9	16	16	22.63	VIII	4
2	Hokkaido Toho-Oki Earthquake of Japan, 1994	7.7	2*	33	33.06	VII	3
3	Great Hanshin Earthquake or Kobe earthquake January 17, 1995	6.9	20	16	25.61	X	5
4	Atico Peru June 23, 2001	8.4	25	33	41.40	XII	5
5	Atico, Peru Earthquake June 23, 2001	8.4	225**	33	227.41	XII	3
6	Atico earthquake in Peru June 23, 2001,	8.4	250**	33	252.17	XII	1
7	Gjilan/Gnjilane Region Earthquake 24 April, 2002	5.7	2*	8	8.25	VII	3
8	Au Sable Forks, New York Earthquake April 20, 2002	5.3	8	11	13.60	VI	3
9	Bam City, Iran Earthquake December 26, 2003	7	14	6	15.23	VIII	5
10	MIYAGI-OKI (JAPAN) Earthquake MAY 26, 2003	7	1*	71	71.01	IX	2
11	Tokachi-oki Earthquake, Semp 26,2003	8.1	250**	27	251.45	XII	1
12	Central (Chuetsu) region of Niigata Prefecture Earthquake 23 October, 2004	6.6	2*	16	16.12	IX	3
13	Central (Chuetsu) region of Niigata Prefecture Earthquake 23 October, 2004	6.6	1*	16	16.03	IX	2
14	Balakot in Pakistan, Muzaffarabad Earthquake October 8, 2005	7.6	30	10	31.62	X	5
15	Balakot in Pakistan, Muzaffarabad Earthquake October 8, 2005	7.6	30	10	31.62	X	5
16	Balakot in Pakistan, Muzaffarabad Earthquake October 8, 2005	7.6	20	10	22.36	X	4
17	Peru Earthquake August 15, 2007	8	30	39	49.20	XI	5
18	Peru Earthquake August 15, 2007	8	190	39	193.96	XI	5
19	Peru Earthquake August 15, 2007	8	220	39	223.43	XI	3
20	Peru Earthquake, August 15, 2007	8	200	39	203.77	XI	3
21	Sichuan (Wenchuan) Earthquake China May 12, 2008	7.9	5*	19	19.65	XI	4
22	MYANMAR (Burma) Earthquake March 24, 2011	6.8	29	10	30.68	X	5
23	Chile Earthquake Feb 27, 2010	8.8	105	35	110.68	VII	4
24	Chile earthquake Feb 27, 2011	8.8	215	35	217.83	VIII	3
25	Sichuan (Wenchuan) Earthquake China May 12, 2008	7.9	125	19	126.44	VIII	4

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So and then similarly for the other intensity scale whatever the damage description scale you can see so 9, 10, 6, 5 something like that so based on this new definition of the road damage and the data which we have collected up to like around 25 earthquake which had a photos and damage description particularly with respect to the road where the magnitude, distance, photos, damage description then.

So this is the data you can see basically this data so you can see the magnitude distance and depth of the earthquake which is (()) (14:34) then Hypocenter distance. And then reported MMI scale and that particular place so this is one you can see there are many. So based on the damaged distribution of the photo we reclassified this damages based on the RDS scale previously we discussed. So this is a new proposed RDS grouping of that okay this new intensity has been assigned. So after assigning this we did some statistical analysis.

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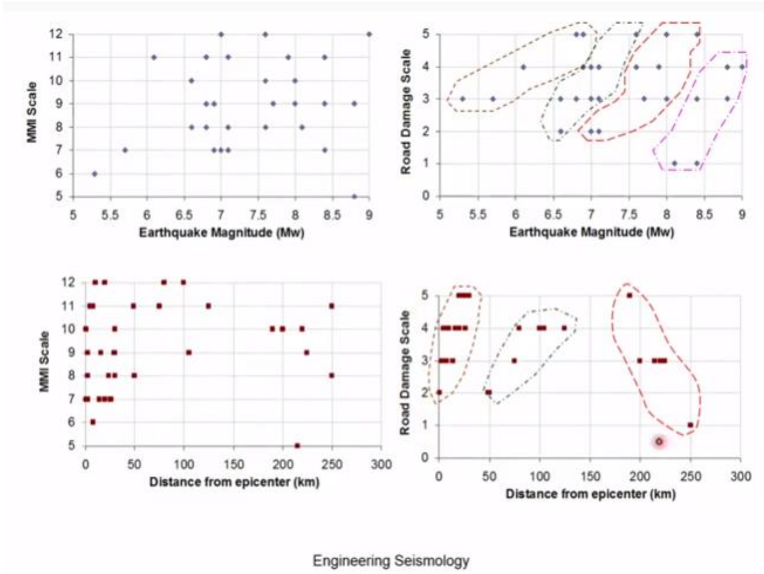

So we did some statistical analysis and see how the past reported MMI scale for the road goes with the magnitude and distance. How the new scale goes with the magnitude and distance. So this is the basically the graph of the MMI scale with respect to the moment earthquake magnitude. You can see it was scattered it was not much trend has been observed. So the distance you can see some trend but not so much uniqueness you can see with respect to the MMI scale

So which was previous used to describe the road damage even though this scale is not suitable for the road okay. Then the RDS scale so we find that there was a unique way of grouping the data you can see the earthquake magnitude for the same damage road but in the RDS scale redefinition of the RDS scale. So similarly again you can see with the distance.

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Correlations between Road Damage Scale and earthquake parameters

Eq. No	Equation Type	Parameter used to relate RDS	Number of data	Coefficients (90%Ci- 90% Confidence intervals)		Correlation coefficient (R^2)	RDS range	Magnitude range (Mw)	Distance range (km)
				a (90%Ci)	b(90%Ci)				
1	$RDS = aM^b$	M	7	0.12(±0.23)	1.91(±1.01)	0.81	3 - 5	5.3-6.9	-
2	$RDS = aM + b$	M	9	2.47(±0.87)	-13.87(±6.13)	0.81	2 - 5	6.6-7.6	-
3	$RDS = aM + b$	M	12	2.17(±0.87)	-13.27(±6.71)	0.67	2 - 5	7.1-8.4	-
4	$RDS = aM + b$	M	7	3.41(±1.69)	-26.58(±14.66)	0.77	1 - 4	8.1 - 9	-
5	$RDS = aED^b$	ED	21	2.32(±0.33)	0.22(±0.05)	0.80	2-5	-	1-30
6	$RDS = aED^b$	ED	7	0.14(±0.22)	0.72(±0.35)	0.87	2-4	-	49-125
7	$RDS = aED + b$	ED	7	-0.06(±0.02)	15.22(±4.27)	0.88	1-5	-	190-250
8	$RDS = aHD^b$	HD	20	1.54 (±0.65)	0.30(±0.13)	0.42	2-5	-	7-58
9	$RDS = aHD^b$	HD	18	1.67 (±0.27)	0.29(±0.05)	0.68	3-5	-	7-58
10	$RDS = aHD^b$	HD	8	0.07 (±0.13)	0.84(±0.39)	0.80	2-4	-	49-127
11	$RDS = aHD + b$	HD	7	-0.06(±0.02)	15.88(±4.46)	0.88	1-5	-	190-255
12	$RDS = a(M + ED)^b$	***M+ED***	***21***	***1.16(±0.34)***	***0.40(±0.09)***	***0.76***	***2-5***	***5.3-8.4***	***1-30***
13	$RDS = a(M + ED)^b$	***M+ED***	***7***	***0.05(±0.10)***	***0.91(±0.02)***	***0.88***	***2-4***	***6.8-9.0***	***49-125***
14	$RDS = a(M + ED) + b$	***M+ED***	***7***	***-0.06(±0.02)***	***15.58(±0.36)***	***0.88***	***1-5***	***8-8.8***	***190-250***
15	$RDS = a(M + HD)^b$	M+HD	20	1.06(±0.60)	0.39(±0.16)	0.43	2-5	5.3-8.4	7-58
16	$RDS = a(M + HD)^b$	M+HD	18	1.16(±0.44)	0.37(±0.11)	0.69	3-5	5.3-8.4	7-58
17	$RDS = a(M + HD)^b$	M+HD	8	0.05(±0.09)	0.92(±0.41)	0.82	2-4	6.8-9.0	49-127
18	$RDS = a(M + HD) + b$	M+HD	7	-0.06(±0.02)	16.31(±4.62)	0.88	1-5	8-8.8	193-253

Note:

RDS- Road Damage Scale, M- earthquake magnitude in Mw, ED- Epicenter Distance in km, HD – Hypocenter Distance in km, "a" and "b" are regression coefficients, 90%Ci - Coefficient in brackets are regression coefficient for 90% confidence intervals

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So now we combined both distance and magnitude. So this is like again the MMI scale with Hypocenter distance. So RDS scale with Hypocenter distance so the magnitude and distance combination okay RDS and magnitude with Hypocenter distance combination you can see there is unique trend can be obtained from this. So which says that okay so if, you know the magnitude and Hypocenter distance basically you can predict what is the road damage can be expected at particular location if there is a road.

So this is the unique trend we find and which was actually the first findings okay where so we did a lot of combination of the statistical analysis and try to see which form basically gives more, less error and more reliable prediction. You can see these are the several equation we developed and this is the equation 12, 13, 14 where the magnitude and epicenter distance combination okay where the data which gives a very good reliable prediction of the RDS okay.

You can see the R square value and then the range of damage you expected magnitude range and the distance range. So only thing these combinations are working for the different segment of the distance you should use a different formula or different formula coefficient which is given is not throughout the distance. For example 1 to 30 meter one setup so 49 to 125, 1, into 25. So, in between there is no data. But when you predict this obviously it will take care of this one.

So by using this you can basically predict a road damage expected in that region so if you know the road damage expected in the particular region basically you can use that for assigning the. So these are the roads which need to be improved before the earthquake so that the road can be used for evacuation or not or this earthquake this roads may get failed due to this kind of earthquake which will lead to the.

So problem in supplying the so the relief material as well as the evacuation process so that conclusion can be arrived. So even after identifying the damageable road and non-damageable road so you can identify what are the locations hospitals are there. So what are the places people are affected so by integrating with the satellite and live data one can do a traffic simulation and modeling and management. So that is where this road damage scales are help you.

So this is actually the unique study as I told you that apart from teaching this subject I also work on the problem which is in large extent the research solution can be given to that problem. This is such kind of one study so which is available in my website where this paper was published so on 2013. So it was accepted soon after we submit without much problem because this concept itself nobody was brought into the study so far okay.

So there are many people now they use this RDS scale and try to do identify the road network which is available for the evacuation and how they can manage a traffic management. So here you should remember that we only collected the existing data and used we assumed that all the roads are in the similar category okay that means the soil and road sections are similar. But which is not true on many cases so which need to be studied in the future.

So which will also fetch you get a this kind of best models okay so enhanced data and numerical analysis which will further improve the development in this area okay. So the RDS scale also one of the intensity scales which is specifically designed for the use in the roads okay. So specifically designed to use in the roads to describe; damage of the roads due to intensity. So all this intensity scales you can see that it is based on the damage occurred in the particular place.

So this RDS can be also used to notify the road damage and classify the road the earthquake caused road damages and grade them apart from giving the MMI you can also use RDS along with the previous MMI scale okay. So these are based on the descriptive this one there is no much earthquake measurement is gone whatever you are talking as a waves different type of wave which does not go into this one.

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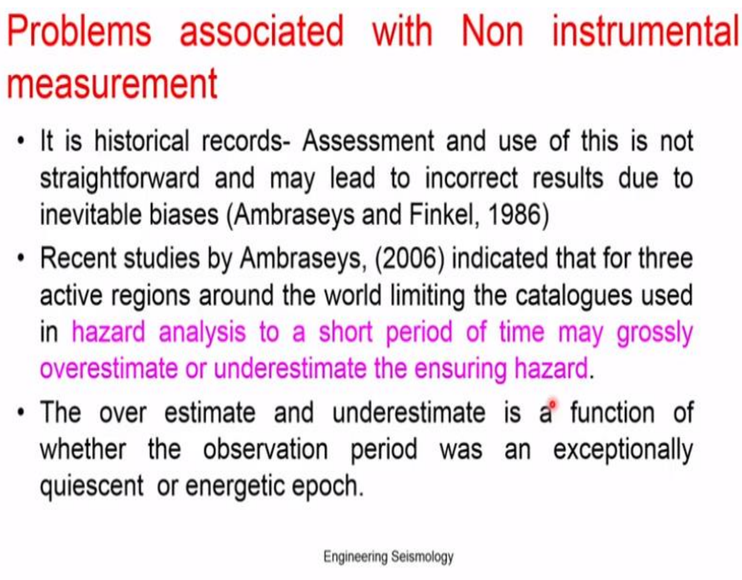

So because, of that this kind of non-instrumental measurement as some kind of limitation. So what are those limitations basically it is a based on the past historical records the assessment and use of this is not straight forward and may lead to incorrect result due to the inevitable bias. So for example when there was a developed the first intensity map during the 1950 the construction style and construction practice is completely different from as on today.

So using up that to predict your today's scenario one as to be careful unlike the RDS scale was very recent one but most of the intensity scales are very old okay. And also that time the construction and practice will be different. So the recent study Ambraseys indicated that for a 3 active region around the world the limiting up catalogues are used in the hazard analysis in the short period time and may grossly over estimate around the estimate the ensuring the hazard.

So the intensity value purely use and predict a hazard particularly it may over estimate and underestimate because of these are all non-instrumental recorded data there is no proper measurement. And the damage description also qualitative which depends upon the person to person and case to case it keep varying. So the overestimate and underestimate is the function of whether the observation period of exceptionally quiescent or energic epoch okay.

So these are all the some of the so things we have to remember when you talk about this kind of non-instrumental record. But still since the old since olden days there is not proper earthquake instrumentation so the damage based description scale data's intensity scales are very well needed for the better prediction of the hazard in the particular region for the future earthquake. That is why even though today the magnitude is there people still use intensity.

So now from this class you will understand that when you use intensity when you describe magnitude okay. So the magnitude is actually qualitative way of getting somebody reported you can use so the based on the damage somebody reporting you should use intensity you cannot inter-changingly use since the people who are reading the newspaper does not know that does not mean that we should interchanginly use and tell wrong things to the people.

So with this we will close the intensity class so we will move forward to the quantification of the earthquake by magnitude in the next class. So thank you very much for watching this video. So we will see in the next class thank you.