



Back Home Again in Indiana

Session Name: International uses of HAZUS

New Intensity Scale for Road Damage due to Earthquake for Estimate Seismic Vulnerability of Roads

Sub Title - Intensity Scale for Road Damage

Anbazhagan, P

Department of Civil Engineering,

Indian Institute of Science,

Bangalore India 560012

E-mail: anbazhagan@civil.iisc.ernet.in and

anbazhagan2005@gmail.com,



Introduction

- Transportation network is a valuable asset to a city and plays a vital role in emergency operations, i.e., to evacuate dead and injured people during a deadly earthquake.
- Earthquake induced road damage assessment and post-earthquake damage control studies are equally important as building damage control studies, for an effective disaster management plan in urban centers.
- Numerous studies have discussed building damage assessment, vulnerability and risk analysis of structures due to earthquakes and have seldom made exclusive attempt to assess road damages due to earthquakes.



Road Damage due to Earthquakes



Continue...

- History shows that major loss of life has been caused due to delay in timely assistance to earthquake victims.
- Thus it becomes imperative to study the damage quantification of roads which will help in better disaster management.



Road vulnerability assessment for earthquakes

- Focus on seismic vulnerability of roads is very recent and limited.
- Pho Thanh Tung (2004) carried out road vulnerability studies in Lalitpur, Kathmandu city-Nepal using **MMI scale** and has classified the roads as low to high vulnerability index for earthquakes.
- The author has used well defined seismic vulnerability methods of Risk Assessment, Tools for Diagnosis of Urban Areas against Seismic Disasters (RADIUS) Program (RADIUS, 1996) and HAZUS developed by FEMA (NIBS, 1999).



Continue...

- Pho Thanh Tung (2004) has highlighted that the MMI scale is highly inadequate in categorizing road damage because the MMI scale of damage classification does not account for site effects and distance of the road from the epicenter, which are the major factors contributing to the damage of the particular road.
- The importance of risk assessment of transport networks and summary of different methods are given in Kiremidjiam (2007).



Modified Mercalli Intensity Scale (after Day, 2002)

INTENSITY LEVEL	REACTION OF OBSERVERS & TYPES OF DAMAGE
I	Reactions: Not felt except by a very few people under especially favorable circumstances Damage: No damage
II	Reactions: Felt only by a few persons at rest, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Damage: No damage delicately suspended objects may swing
III	Reactions: Felt quite noticeably indoors, especially on upper floors of buildings. The vibration is like the passing of a truck and the duration of the earthquake may be estimated. However many people do not recognize it as an earthquake. Damage: No damage, standing motorcars may rock slightly.
IV	Reactions: During the day, felt indoors by many, outdoors by few. At night, some people are awakened. The sensation is like a heavy truck striking the building. Damage: Dishes, window and doors are disturbed. Walls make a creaking sound. Standing motorcars rock noticeably.
V	Reactions: Felt by nearly everyone, many awakened Damage: Some dishes, windows etc., are broken. A few instances of cracked plaster and unstable objects overturned. Disturbances of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Reactions: Felt by everyone. Many people are frightened and run outdoors. Damage: There is slight structural damage. Some heavy furniture is moved and there are instances of fallen plaster or damaged chimneys.



VII	<p>Reactions: Everyone runs outdoors. Noticed by persons driving motor cars</p> <p>Damage: Negligible damage in buildings of good design and construction, slight to moderate damage in well built ordinary structures and considerable damage in poorly built or badly designed structures. Some chimneys are broken.</p>
VIII	<p>Reactions: Persons driving motor cars are disturbed</p> <p>Damage: Slight damage in specially designed structures. Considerable damage in ordinary substantial buildings, with partial collapse. Great damage in poorly built structures. Panel walls are thrown out of frame structures. There is fall of chimney, factory stacks, columns, monuments and walls. Heavy furniture is overturned. <i>Sand and mud are ejected in small amounts</i> and there are changes in well-water levels.</p>
IX	<p>Damage: Considerable damage in specially designed structures. Well-designed frame structure thrown out of plumb. There is great damage in substantial buildings with partial collapse. Buildings are shifted off their foundations. <i>Ground is conspicuously cracked</i> and underground pipes are broken</p>
X	<p>Damage: Some well built wooden structures are destroyed. Most masonry and frame structures are destroyed, including the foundations. <i>The ground is badly cracked. There are bent train rails</i>, considerable amount of landslides at river banks and steep slopes, shifted sand and mus, water is splashed over their banks</p>
XI	<p>Few if any masonry structures remain standing. Bridges are destroyed and <i>train rails are greatly bent. There are broad fissures in the ground</i> and underground pipelines are completely out of service there are earth slumps and landslips in soft ground.</p>
XII	<p>Reactions: waves are seen on the ground surface. The lines of sight and levels are distorted.</p> <p>Damage: Total damage with practically all works of construction greatly damaged or destroyed. Objects are thrown upward into the air</p>



Limitation of MMI Scale for Roads

- The damage due to earthquake in MMI is defined and explained mainly focusing on damage of building components, factory components, ground failures and also bending of train rails.
- Intensity scale of VIII and above includes different ground damages due to earthquakes such as cracks, liquefaction and slope failures
- But **none of the MMI scales fully talk about the cracks or damages of roads.**



Damage measure

- The major component in the risk and vulnerability assessment of a transportation network is the damage measure (DM), which is basically the level or measure of damage for a given hazard.
- Damage measure is used to estimate severity of damage and thereby arrive at a damage ratio.
- So measure of road damage is important for risk assessment of transport network.
- Inadequacy of MMI scale for road vulnerabilities assessments warrants to Road Damage Scale



New Road Damage Intensity Scale

- Road damage depends on the amplitude of vibrations caused by an earthquake, which mainly depends upon the distance of the damaged road from the epicenter and the magnitude of the earthquake.
- Furthermore, road damages are also caused by earthquake induced effects like liquefaction, landslide and tsunami which act as major contributors toward road failures.
- The road damage scale proposed by us includes all the above parameters and condition/usage of pavement after the damage.



Continue...

Road Damage Scale	Damage Description
1	Damage is in the form of many minute cracks and very little repair work is usually necessary. Damage is seen when roads are of good quality and epicenter is far away from the damage site.
2	Damage is in the form of settlement or moderate cracks or 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.



Continue...

3	A part of the road is damaged. Formation of big cracks and settlement of road is seen. Either one or both sides of the road is in its usable form and vehicles can ply on the road. Considerable road repair works should be carried out.
4	A portion of the road is rendered completely useless. Loose soil and debris is found all around. Vehicles cannot ply on the damaged stretch of the road and the stretch has to be completely rebuilt
5	Maximum damage occurs to a road during an earthquake. The roads are completely rendered useless and are totally inaccessible. Roads are damaged structurally and debris from landslides render the road totally inaccessible



Discussion about new scale

- Damage Scale 1

- The roads are in a satisfactory condition and can be used with minor repairs. It can be used for all post earthquake relief works. Usually, this kind of damage occurs when the roads are of good quality and far away from epicenter.

- Damage Scale 2

- Less damaged roads can be represented by this scale. The damages may be moderate cracks, failure of side and shoulder/footpath of the roads. This kind of damage may occur during moderate earthquakes. The roads are accessible and moderate repair works may be needed for them to function effectively



Continue...

- Damage Scale 3

- This scale is used to represent moderate damage of roads with big cracks due to earthquake. Roads are partially blocked due to building collapse, land slide, etc. Partially washed away due to storm surges, tsunami, etc. These damages may occur due to any magnitude from moderate to high depending upon the distance from the source.

- Damage Scale 4

- High damage to roads which render the roads partly inaccessible and partly accessible. Roads blocked due to building collapse, land slide etc. Washed away due to storm surges, tsunami etc. Moment magnitudes of 6.5 to 8 may cause these damages.

- Damage Scale 5

- Very high damage of roads close to epicenter of earthquake and having moment magnitude of 7.5 and above. The roads are completely rendered useless and are totally inaccessible. One of the major reasons for this is their proximity to epicenters and very high magnitudes of the earthquakes.



Road damages due to Earthquake

- The very first road damage that is reported was during the Loma Prieta earthquake (Mw 6.9) on October 17, 1989.
- All major transportation networks were closed after this earthquake (Kiremidjiam, et al., 2007).
- Kiremidjiam, et al (2007) has stated that many roads were closed during past earthquakes but no details regarding those road damage (photo or description) and the earthquake is provided.



Continue...

- Great Hanshin Earthquake or Kobe earthquake (Mw 6.9) that occurred on January 17, 1995.
- Road damaged at Awaji Island located 20 km from the epicenter. The reported MMI scale is X (Pho Thanh Tung, 2004)



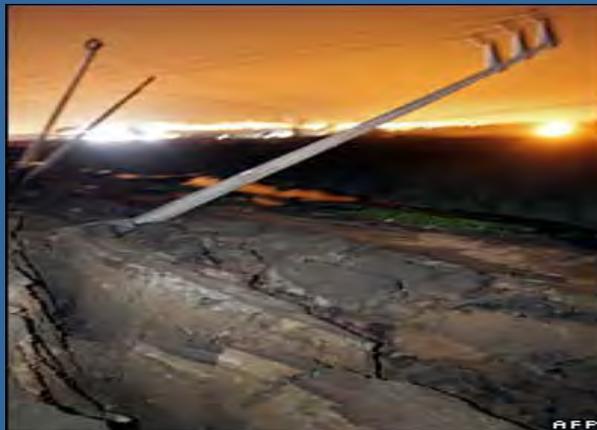
Continue...

- Atico Peru earthquake (Mw 8.4) June 23, 2001.
- The damage site was 25 km from the epicenter and reported MMI scale value is XII (ASCE-TCLEE, 2001)



Continue...

- Peru Earthquake (Mw 8.0) on August 15, 2007
- The damage to a road in Southern Peru and the damage site was about 30 km from the epicenter
- MMI scale of XI is reported (EERI special report, 2007)
- The road embankment failure on the Pan-American Highway -190 km from the epicenter
- The reported MMI scale is XI (MCEER, 2007)



Continue...

- Road damage description with photo has been collected for 21 cases
 - Hokkaido Toho-Oki Earthquake of Japan, 1994
 - Gjilan/Gnjilane Region Earthquake 24 April, 2002
 - Au Sable Forks, New York Earthquake April 20, 2002
 - Bam City, Iran Earthquake December 26, 2003
 - MIYAGI-OKI (JAPAN) Earthquake MAY 26, 2003
 - Tokachi-oki Earthquake, Semp 26,2003
 - Central (Chuetsu) region of Niigata Prefecture Earthquake 23 October, 2004
 - Muzaffarabad earthquake October 8, 2005
 - Wenchuan, China Earthquake on May 12, 2008



Sl No	Earthquake Description	Moment Magnitude (Mw)	Distance (km)	Reported MMI Scale	Road Damage Scale
1	Loma Prieta earthquake October 17, 1989	6.9	16	VIII	4
2	Hokkaido Toho-Oki Earthquake of Japan, 1994	6.2	2*	VII	3
3	Great Hanshin Earthquake or Kobe earthquake January 17, 1995	6.9	20	X	5
4	Atico Peru June 23, 2001	8.4	25	XII	5
5	Atico, Peru Earthquake June 23, 2001	8.4	225**	XII	3
6	Atico earthquake in Peru June 23, 2001,	8.4	250**	XII	1
7	Gjilan/Gnjilane Region Earthquake 24 April, 2002	5.7	2*	VII	3
8	Au Sable Forks, New York Earthquake April 20, 2002	5.3	8	VI	3
9	Bam City, Iran Earthquake December 26, 2003	7	14	VIII	3
10	MIYAGI-OKI (JAPAN) Earthquake MAY 26, 2003	7	1*	IX	2
11	Tokachi-oki Earthquake, Semp 26,2003	8.1	250**	XII	1
12	Central (Chuetsu) region of Niigata Prefecture Earthquake 23 October, 2004	7	2*	IX	3
13	Central (Chuetsu) region of Niigata Prefecture 23 October, 2004	7	1*	IX	2
14	Balakot in Pakistan October 8, 2005- North of Epicenter	7.6	30	X	5
15	Balakot in Pakistan October 8, 2005 – East of Epicenter	7.6	30	X	5
16	Muzaffarabad earthquake October 8, 2005	7.6	20	X	4
17	Peru Earthquake August 15, 2007	8	30	XI	5
18	Peru Earthquake August 15, 2007	8	190	XI	5
19	Peru Earthquake August 15, 2007,	8	220	XI	4
20	Peru Earthquake, August 15, 2007,	8	200	XI	3
21	Wenchuan, China Earthquake on May 12, 2008	8	5*	XI	4

** Average distance based on report and * Assumed distance based on report



Analysis and Discussion

- The collected road damages reported for earthquakes have magnitudes from 5.6 to 8.4 and epicenter distance of 1 km to 250 km.
- These data are classified based on the newly proposed damage scale.
- Road damages listed in Table (slide 22) sl no. 3, 4, 14, 15, 17 and 18 come under the damage scale of 5.
- Sl. no 1, 16, 19 and 21 come under damage scale of 4
- Sl. no 2, 5, 7, 8, 9, 12 & 20 come under damage scale of 3
- Sl. no 10 and 13 come under damage scale of 2 & Sl. no 6 and 11 come under damage scale 1

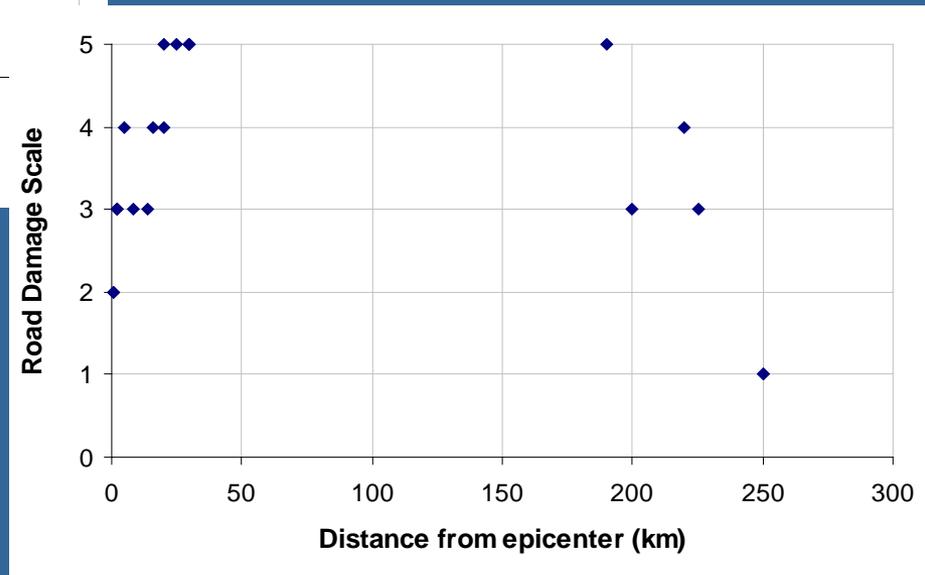
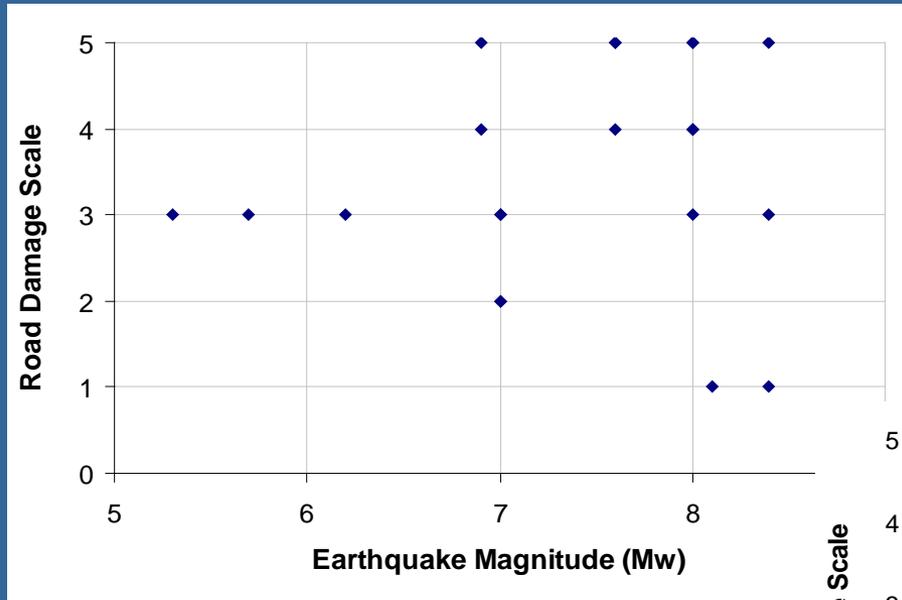


Continue...

- These damages are also scaled in MMI scale.
- *The comparison between newly proposed scale and reported MMI scale are given in Table.*
- *MMI scale of XII is used to refer minor damages to roads, moderate damages to roads and high road damage.*
- *This may happen because no proper definition of road damage has been given in MMI scale.*



Newly proposed road damage scale related with earthquake magnitudes and epicenter distance

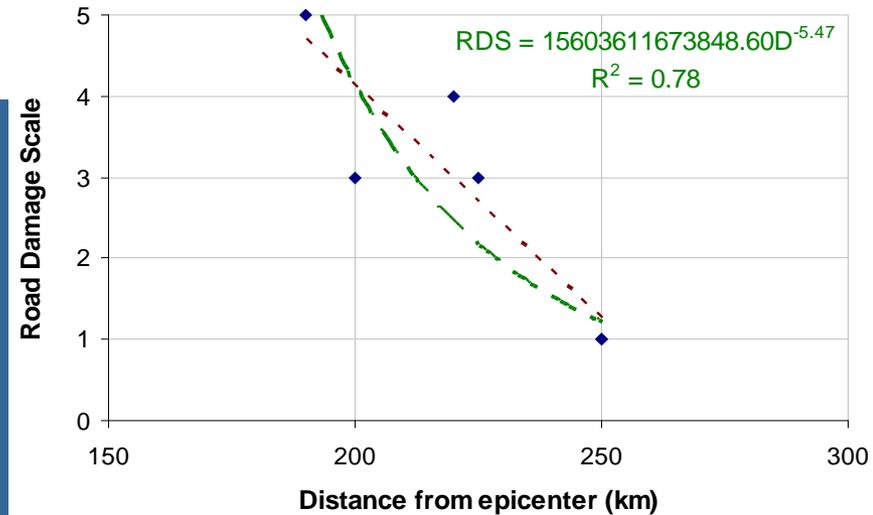
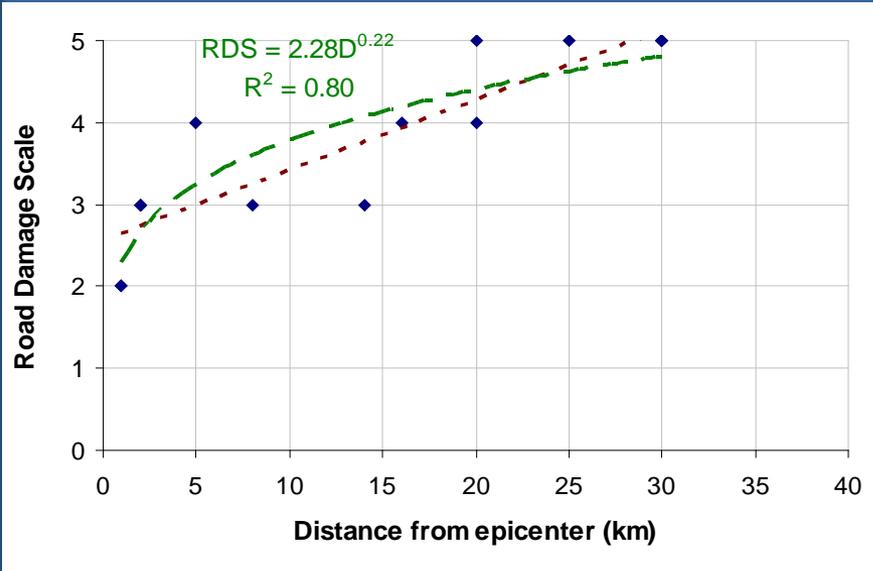


Continue...

- It is clear that these data do not follow any trend with Earthquake magnitude.
- However, it is interesting to note that earthquake magnitude of less than 6.5 may cause damage level less than damage scale of 3.
- It can be seen that even if these data do not follow any trend as a whole but they do give an idea that road damages can be classified based on short distances (less than 50 km) and long distances (150 to 300 km).
- Meanwhile, it is necessary to highlight that there is no reported road damage data in between 50 to 150 km.



Road damage scale (RDS) with short and long distances



Very good regression fit for linear and power trends with high regression coefficients were shown for RDS with short and long distance damages

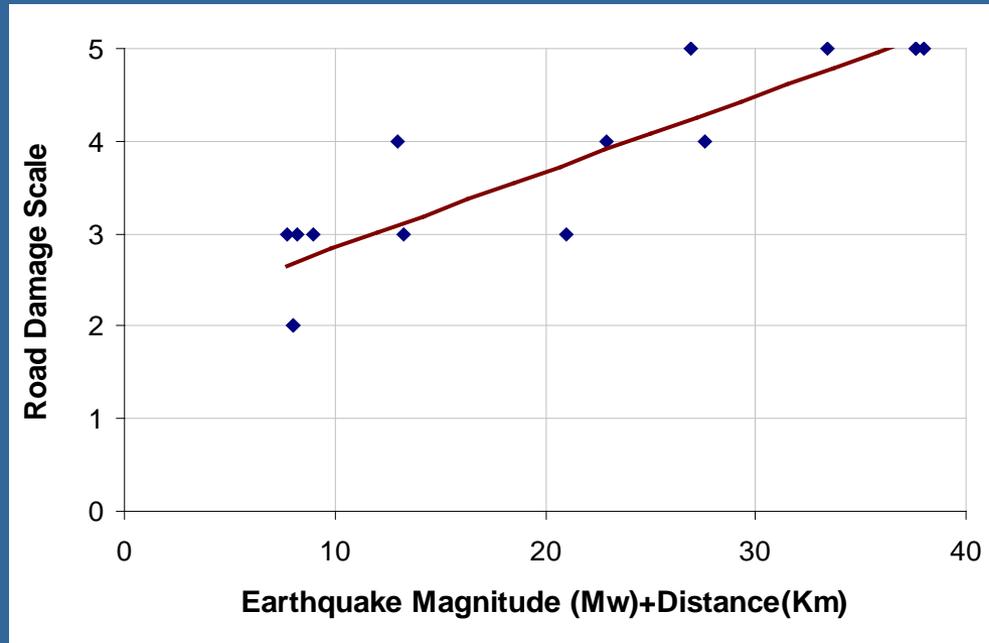


Continue...

- Very good regression fit for linear and power trends with high regression coefficients are shown for RDS with short and long distance damages
- Even though damaged distance versus RDS gives very good regression, it cannot be used to estimate the RDS for future road damage assessment due to earthquake, because assessing the **road damage scale without earthquake magnitude is meaningless.**



Short distance road damage



- 15 data sets are further used to generate multi regression correlation between RDS versus magnitude and epicenter distance



Continue...

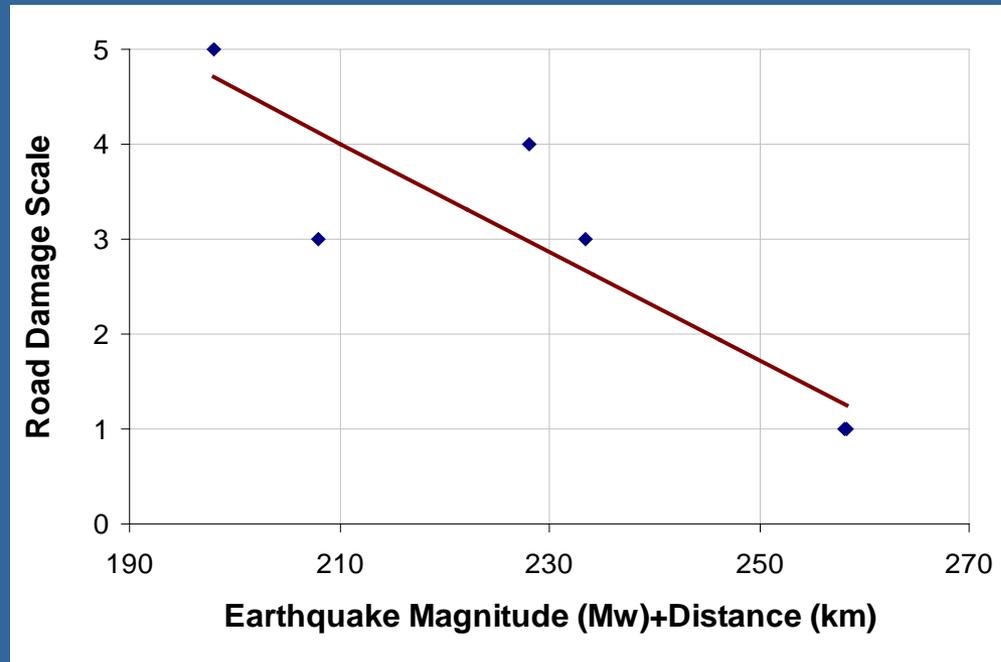
- Short distances can be classified 1 to 5 as per RDS, damages varies from cracks to extensive damage
- These damages are reported for earthquake magnitudes ranging from 5.3 to 8.4.
- Short distance earthquakes cause moderate to very high road damages, which require minor to extensive repairs.

$$RDS = 0.082(\pm 0.011)M + 0.082(\pm 0.011)D + 2.03(\pm 0.27)$$

Valid for a magnitude of 5.0 to 8.5 and epicenter distance upto 35 km



Long distance road damage



- Six past earthquake road damages are reported for long distances



Continue...

- Long distances road damages are reported for 150 km to 350 km from the epicenter
- These damages vary from minor cracks to extensive damage and are reported for earthquakes whose moment magnitudes are 8.0 and above

$$RDS = 16.03(\pm 3.37) - 0.057(\pm 0.015)M - 0.057(\pm 0.015)D$$

Valid for a magnitude of above 8 and epicenter distance of 190 to 250 km

Upper limit and lower limit for 95% confidence interval is given in bracket



Summary

- New Road damage scale has been proposed, which is compared with old MMI scale and correlated for reported road damages
- This scale and correlation can be used to assess the damage level of road to forecast seismic vulnerability and risk of urban transport network.
- These correlations are developed based on available data and newly proposed road damage scale, by assuming all the roads are having same structural features and quality.
- If the quality of road is considerably poor, the estimated damage may be upgraded to one or two higher damage scale level based on the road quality judgment.



Thank You

Contact Info:

Dr. P. Anbazhagan, M.E, Ph. D, ERF (Australia), FICDM

Department of Civil Engineering,

Indian Institute of Science

Bangalore, India 560 012.

Phone: 91-80-22932467

Cell 91-9448100410

Email: anbazhagan2005@gmail.com

HAZUS web page: <http://civil.iisc.ernet.in/~anbazhagan/>

