Indian Earthquakes : An Overview

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ABSTRACT

India has a very high frequency of great earthquakes (magnitude greater than 8.0); for instance, during 1897 to 1950, the country was hit by four great earthquakes. However, the frequency of moderate earthquakes (magnitude 6.0 to 7.0) in the country is rather low. Moderate earthquakes create awareness and lead to improvements in construction at a low human cost. We have not had a earthquake of magnitude greater than 7.0 in the last 40 years. Also, we have also not seen earthquake shaking intensity of more than VIII or IX in the last 40 years. And finally, except the Jabalpur earthquake (1997), the other recent moderate earthquakes have not hit any of the large cities. This has led to complacence in our earthquake preparedness. We now have orders of magnitude higher levels of man-made construction and a significantly larger population than what we had at the time of great earthquakes of 1897, 1934, or 1950; hence, we are that much more vulnerable to earthquake disasters.

1.0 INTRODUCTION

India has had a number of the world's greatest earthquakes in the last century. In fact, more than 50% area in the country is considered prone to damaging earthquakes. The north-eastern region of the country as well as the entire Himalayan belt is susceptible to great earthquakes of magnitude more than 8.0. The main cause of earthquakes in these regions is due to the movement of the Indian plate towards the Eurasian plate at the rate of about 50 mm per year. Besides the Himalayan region and the Indo-Gangetic plains, even the peninsular India is prone to damaging earthquakes as clearly illustrated by the Koyna (1967), Latur (1993), and the Jabalpur (1997) earthquakes. Indian earthquakes have shown some remarkable features which have implications on strategies for reducing earthquake disasters in the country. This paper attempts to provide an overall perspective of past Indian earthquakes and the interesting features of the same.

2.0 Background on Earthquake Magnitude and Intensity

When reviewing the past earthquakes it is important to have the correct perspective on *earthquake magnitude* and *earthquake intensity*: two terms often misunderstood. *Earthquake magnitude* is a measure of the size of the earthquake reflecting the elastic energy released by the earthquake. It is referred by a certain real number on the Richter scale (*e.g.,* magnitude 6.5 earthquake). On the other hand, *earthquake intensity* indicates the extent of shaking experienced at a given location due to a particular earthquake. It is referred by a Roman numeral (*e.g.,* VIII on MSK scale). To draw a parallel, consider a *100W* light bulb used for illumination purposes. It dissipates energy of 100 *Watts*. However, the brightness of light at different distances from it, referred in *candlelights*, is different. The former is magnitude and the latter is intensity. Whether or not there is adequate light at a given location to enable one to read a book, depends on what is the intensity of light at that location; intensity itself depends on the magnitude of bulb (*i.e.,* Watts) *and* the distance of the bulb from the location under consideration. Similarly, intensity of shaking at a location depends not only on the magnitude of the earthquake, but also on the distance of the site from the earthquake source and the geology / geography of the area. *Isoseismals* are the contours of equal earthquake intensity. The area that suffers strong shaking and significant damage during an earthquake is termed as *meizoseismal region*.

The concept of earthquake magnitude was first developed by Richter (e.g., Richter 1958), and hence, the term "Richter scale". The value of magnitude is obtained on the basis of recordings of earthquake ground motion on seismographs. In practice, there are several different definitions of magnitude; each could give a slightly different value of the magnitude. Hence, magnitude is not a very precise number. Earthquake magnitude is measured on a log scale, and a small difference in earthquake recording on the instruments leads to a much smaller error in the magnitude. Earthquake magnitude is related to the elastic energy released by the empirical equation:
; where, E is the elastic energy released in units of *ergs*, and M is the earthquake magnitude. With increase in magnitude by 1.0, the energy released by the earthquake goes up by a factor of about 31. Thus, a magnitude 8.0 earthquake releases about 31 times the energy released by a magnitude 7.0 earthquake, or about 1000 times the energy released by a magnitude 6.0 earthquake. There are no upper or lower bounds on earthquake magnitude. In fact, magnitude of a very small earthquake can be a negative number also. Usually, earthquakes of magnitude greater than 5.0 cause strong enough ground motion to be potentially damaging to structures. Earthquakes of magnitude greater than 8.0 are often termed as *great earthquakes*.

Intensity indicates the violence of shaking or the extent (or potential) of damage at a given location due to a particular earthquake. Thus, intensity caused by a given earthquake will be different at different places. Prior to the development of ground motion recording instruments, earthquakes were studied by recording the description of shaking intensity. This lead to the development of intensity scales which describe the effects of earthquake motion in qualitative terms. An intensity scale usually provides ten or twelve grades of intensity starting with most feeble vibrations and going upto most violent (*i.e.,* total destruction). The most commonly used intensity scales are: *Modified Mercalli (MM) Intensity Scale* and the *Medvedev-Sponhener-Karnik (MSK) Intensity Scale*. Both these scales are quite similar except that the MSK scale is more specific in its description of the earthquake effects; Annexure I of the paper describes the MSK scale.

Efforts have been made to relate earthquake intensity with values of peak ground acceleration at the site. However, this can at best be only approximate, because intensity depends on many features of the ground motion including ground acceleration, ground velocity, duration of shaking, and frequency content of motion. Table 1 shows that as the intensity goes up by one point on the MM or MSK scale, the peak ground acceleration increases by a factor of about 2.0. The five seismic zones I, II, III, IV and V in the Indian seismic code (IS:1893-1984) correspond to areas that have potential for shaking intensity on the MMI scale of V or less, VI, VII, VIII, and IX or more, respectively.

3.0 SOME GREAT INDIAN EARTHQUAKES

Indian subcontinent has suffered some of the greatest earthquakes in the world with magnitude exceeding 8.0. For instance, in a short span of about 50 years, four such earthquakes occurred: Assam earthquake of 1897 (magnitude 8.7) (Oldham, 1899), Kangra earthquake of 1905 (magnitude 8.6) (Middlemiss, 1910), Bihar-Nepal earthquake of 1934 (magnitude 8.4) (GSI, 1939), and the Assam-Tibet earthquake of 1950 (magnitude 8.7) (CBG, 1953). Significance of such earthquakes can be gauged from the fact that in his famous book on *Engineering Seismology* (Richter, 1958) Professor C.F. Richter (known for the *Richter scale*) devotes an entire chapter entitled "Some Great Indian Earthquakes" to introduce the nature of earthquakes: the book has no similar chapter for great earthquakes in other regions of the world. Fortunately, since 1950 only moderate size earthquakes have occurred in India which is no reason to assume that the truly great earthquakes are a thing of the past. Of these four earthquakes, two more interesting ones (Assam of 1897 and Bihar-Nepal of 1934) are discussed here in some detail. Also discussed is another very interesting earthquake that took place about 180 years ago: the Cutch earthquake of 1819. To appreciate these earthquakes, one needs to keep in view that in the Latur earthquake of 1993 (the most tragic earthquake of last 50 years in India which caused about 8000 deaths), severe damage was limited to within an area of radius 10 km and that the maximum MSK intensity was only about VIII to IX in an even much smaller area.

3.1 CUTCH EARTHQUAKE OF 1819

This 8.3 magnitude earthquake took place on the west coast of India on June 16, 1819. It caused ground motion which was perceptible as far as Calcutta. The earthquake caused a fault scarp of about 16 mile long and about 10 foot high which was later named as "Allah Bund". In fact, this earthquake provided the earliest "clear and circumstantially described occurrence of faulting" during earthquakes (Richter, 1958). Cutch being far away from the plate-boundaries, this earthquake is one of the largest intra-plate earthquake to have occurred in the world.

3.2 ASSAM EARTHQUAKE OF 1897

The Assam earthquake of June 12, 1897 (magnitude 8.7) caused severe damage in an area of about 500 km radius (as against the area of about 10 km radius that sustained severe damage in the Latur earthquake!). The earthquake caused extensive surface distortions in the area. There were clear instances of upthrow of objects caused by the shaking (Fig. 1); this implied that the maximum vertical acceleration during the earthquake exceeded 1.0g. The earthquake caused extensive liquefaction in the alluviated plains of Brahmaputra. Very extensive damage to rail tracks and bridges took place (Figs. 2 and 3). The shaking in the meizoseismal area was so severe that it provided a model for specifying the modified Mercalli intensity of XII.

The buildings in the area around Shillong consisted of three types: stone buildings; ekra-built buildings which consisted of wooden framework with walls of san grass covered in plaster; and the timber plank buildings built on "log hut" principle, having a wooden framework covered with planks, and resting unattached on the ground. All the stone buildings were leveled to the ground (Fig. 4). About half of the ekra-type buildings were leveled to the ground particularly due to the stone chimneys (stone or brick chimneys projecting out of the buildings are easy casualties in earthquakes). The plank buildings were in general undamaged. Damage caused by this earthquake led to the development and adoption of *Assam-type houses* (Fig. 5) with the active involvement of the then government and with the help of Chinese carpenters and craftsman. Subsequently, these houses became prevalent in the north-eastern states and have shown excellent performance in the subsequent earthquakes. Unfortunately, it has taken only 100 years to unlearn what was learnt at a great human and economic costs from the 1897 earthquake: the Assam-type housing is now being discouraged even by the government agencies (to save nominal amount of timber that would go into it!). Instead of replacing the timber by alternate materials while keeping intact the earthquake-resistant features of these houses, construction activity in the area is now based on poorly-built reinforced concrete or brick masonry constructions; a sure recipe for future earthquake disasters.

3.3 BIHAR - NEPAL EARTHQUAKE OF 1934

This 8.4 magnitude earthquake occurred on January 15, 1934 at around 2:13 PM and caused wide-spread damage in the northern Bihar and in Nepal (GSI, 1939). The number of deaths was relatively low: about 7,253 in India and 3,400 in Nepal since most people are outdoors in the winter afternoon.

Serious damage was caused in an area of about 300 km mean radius. The earthquake caused a maximum intensity of X in 125 km long and 30 km wide area. Besides, two distant areas both located about 160 km from the main damage area suffered intensity of X; these were Kathmandu valley in the north and Munger in the south; this happened due to peculiar geology of that region (e.g., Richter, 1958). Most buildings tilted and slumped bodily into the ground in an area of about 300 km long and of irregular width (sometimes exceeding 65 km); this area was termed as the "slump belt". The area of slump belt underwent extensive liquefaction. At places, six feet high embankments became level with the surrounding area. On the other hand, the depth of lakes, ponds, borrow areas, and other depressions became lower. The area of slump belt was associated with fissuring and emission of sand and water caused by liquefaction and formation of sand boils. One of the fissure was 15' deep, 30' wide, 900' long.

4.0 SOME RECENT INDIAN EARTHQUAKES

All the damaging earthquakes in the recent years are rather moderate in size as compared to the great earthquakes discussed above. Nevertheless, these too have had some interesting characteristics which are briefly discussed here; some of these are discussed in greater details in the accompanying papers.

4.1 KOYNA EARTHQUAKE OF 1967

This was a magnitude 6.5 earthquake that took place close to the 103 metre concrete gravity dam at Koyna (Berg et al., 1969). Prior to this earthquake, the area used to be considered aseismic. However, after the construction of dam and filling up of reservoir in 1962, the seismic activity increased significantly. The main shock of December 10, 1967 caused widespread damage, killing about 200 persons and injuring more than 1500 persons. The maximum shaking intensity was assigned as VIII on the MM scale. This earthquake provides one of the important instances of the reservoir-induced seismicity. A strong motion accelerograph located in the gallery at mid-height of the dam recorded peak vertical acceleration of 0.36g and peak horizontal acceleration of 0.45g and 0.39g. The dam, designed for a seismic coefficient of 5% g by the pseudo-static analysis, performed quite well with only nominal damage to the dam. This earthquake lead to the revision of Indian seismic zone map wherein the area around Koyna was brought in zone IV from zone I, and seismic zone for Bombay was upgraded from zone I to zone III.

4.2 BIHAR - NEPAL EARTHQUAKE OF 1988

This magnitude 6.6 earthquake shook northern Bihar and Nepal on August 21, 1988 at 04:39 hours (e.g., GSI, 1993; Jain, 1992; Jain et al., 1991, Subramanyam, et al. ???, Thakkar et al. ???). About 1004 persons died (282 in India and 722 in Nepal) and more than 16,000 injured; casualties were significantly reduced since in the summer time most people sleep outdoors. Significant damage was caused in three distinct regions: the area near the epicenter, and the areas around Munger (India) and Bhaktapur (near Kathmandu in Nepal); this damage pattern due to peculiar geology of the area is exactly similar to that of the 1934 Bihar-Nepal earthquake.

4.3 UTTARKASHI EARTHQUAKE OF 1991

An earthquake of magnitude 6.6 shook the districts of Uttarkashi, Tehri, and Chamoli in the state of Uttar Pradesh on October 20, 1991 at 2:52 hours (GSI, 1992; Jain et al., 1992). The death toll was estimated to be around 768 persons, with about 5,066 injured. The area has one of the lowest population density in the state, and hence the rather low number of deaths and injuries. The maximum intensity of IX on the MM scale was assigned to an area of about 20 square km. This earthquake provided excellent ground motion records (acceleration versus time history) in the area (e.g., Jain and Das, 1993): maximum peak ground acceleration of about 0.31g was recorded at Uttarkashi. Ground motion records showed that in the Himalayan region, the motion has significantly higher amount of high-frequency contents. During the earthquake, collapse of houses with R.C. roof slab supported on weak random-rubble stone masonry clearly demonstrated the disastrous results of often neglected walls and columns vis-à-vis slabs and beams. Several 4-storey buildings in Uttarkashi (not designed or detailed by engineers) with R.C. frame and stone infills sustained the earthquake rather well! This was due to the presence of significant number of infills from foundation to the top of the building which acted as shear walls. From such examples, one could easily and incorrectly get carried away to conclude that all R.C. buildings in general are good for earthquakes. To sober one down, top two storeys of the 3-storey State Bank of India R.C. frame building collapsed (Fig. 6); clearly illustrating the disaster that R.C. buildings can cause if not done right. An important bridge on the strategically important Uttarkashi-Harsil route collapsed; causing disruption of traffic for several days (e.g., Murty and Jain, 1997).

4.4 KILLARI (LATUR) EARTHQUAKE OF 1993

On September 30, 1993 a magnitude 6.4 earthquake shook the area near village Killari in Latur district killing about 8,000 persons (GSI, 1996; Jain et. al, 1994; Seeber et al., 1993, 1996). The maximum intensity of shaking was about VIII to IX. Until this earthquake the area was considered non-seismic and placed in the lowest seismic zone (zone I) by the Indian code (IS:1893-1984). Most of the damage was contained in a relatively small area of 20 km x 20 km. The affected area did not have any modern towns, modern buildings or major industries. In some of the villages more than 30% of the population was killed. This earthquake will be known for outstanding rescue, relief and rehabilitation carried out for any earthquake in recent Indian history; perhaps outstanding by even international standards.

4.5 JABALPUR EARTHQUAKE OF 1997

This earthquake is the first moderate earthquake (magnitude 6.0) to have occurred close to a major Indian city in recent times: Jabalpur has a population of about 1.2 million people (Jain et al., 1997; Rai et al., 1997). It provided some indication of what type of seismic performance to expect out of modern Indian constructions. The maximum intensity was upto VIII (in a very small area); most parts of Jabalpur town experienced shaking intensity of VI and VII. Numerous R.C. frame buildings of three-four storeys with brick infills performed well even though these may not have been designed for earthquake forces: this is because the brick infill walls acted as shear walls and took most of the seismic loads in such buildings. On the other hand, several similar buildings but with open-first storey (i.e., few or no brick infills in the ground storey) showed heavy distress to the ground storey columns (Figs. 7 and 8): such buildings could have collapsed due to failure of ground storey columns if the shaking had been stronger or lasted for a longer duration. Another interesting feature of the earthquake was heavy damage to a very large number of two and three storey brick-masonry residential buildings belonging to different government agencies: e.g., the ordnance factories, Department of Telecom, railways, etc. Such buildings did not have any earthquake resistant features. Damage to mumtys (staircase projection above the building roof) in such houses posed a major problem. Most medium and large towns in the country now have a huge inventory of R.C. frame buildings with open first storey (to accommodate vehicle parking), and two-three storey brick masonry housing units; such buildings could cause major disasters in future earthquakes affecting Indian cities.

5.0 CONCLUDING REMARKS

Fig. 9 shows a typical earthquake recurrence plot of earthquake magnitude versus number of occurrences in a year in the entire world. It can be seen from the graph that on an average about one earthquake of magnitude greater than 8.0 takes place every year as against about 96 events per year of magnitude range 6.0 to 8.0: a ratio of about 1 is to 100. If this trend were to be applicable to India, the Indian subcontinent should have had about 400 earthquakes of magnitude range 6.0 to 8.0 in the last 100 years since we had four events of magnitude greater than 8.0 in that period. Clearly, we have had far less number of moderate earthquakes. This illustrates an interesting aspect of Indian seismicity: India has relatively high frequency of great earthquakes and relatively low frequency of moderate earthquakes. Moderate earthquakes create awareness and lead to improvements in constructions at relatively low human costs, which could be very effective in the long run. Due to rather infrequent moderate earthquakes, the Indian earthquake problem does not receive the attention of the country that it deserves considering our overall seismic potential, and this is a tragedy. For a poor country, the focus of political priorities anyway remains on day-to-day problems of poverty, shelter, law and order, health, sanitation, and it is as such difficult to seek priorities to once-in-a-while problems of natural disasters. Nevertheless, just like one takes a life insurance policy for unexpected disasters, the country needs to invest a small fraction of priorities towards earthquake disaster mitigation; the consequences otherwise could be truly unimaginable should a major earthquake cause severe shaking in highly populated areas of the country.

6.0 REFERENCES

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Appendix I: Medvedev-Sponhener-Karnik (MSK) Intensity Scale (1964)

I. Types of Structures (Buildings)

Structure A: Buildings in field stone, rural structures, abode houses, clay houses.

Structure B: Ordinary brick buildings, buildings of the large block and prefabricated type, half timbered structures, buildings in natural hewn stone.

Structure C: Reinforced buildings, well-built wooden structures.

II. Definition of quantity

Single, few : about 5%

Many : about 50%

Most : about 75%

III. Classification of damage to buildings

Grade 1 : Sight damage : Fine cracks in plaster: fall of small pieces of plaster.

Grade 2 : Moderate damage : Small cracks in walls: fall of fairly large piece of plaster: pantiles slip off: cracks in chimneys: parts of chimneys fall down.

Grade 3 : Heavy damage : Large cracks in walls: fall of chimneys.

Grade 4 : Destruction : Gaps in walls: parts of buildings may collapse separate parts of the building lose their cohesion; inner walls collapse.

Grade 5 : Total damage : Total collapse of buildings.

IV. Arrangement of the scale

Introductory letters are used in paragraphs throughout the scale as follows:

a) Persons and surroundings.
b) Structures of all kinds.
c) Nature.

Intensity Scale

I. Not noticeable

a) The intensity of the vibrations is below the limit of sensibility the tremor is detected and records by seismographs only.

II. Scarcely noticeable (very slight)

a) Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.

III. Weak, partially observed only

a) The earthquake is felt indoors by a few people, outdoors only in favourable circumstances. The vibration is like that due to the passing of a light truck. Attentive observers notice a slight swinging of hanging objects.

IV. Largely observed

a) The earthquake is felt indoors by a few people outdoors by few people. Here and there people awake, but no one is frightened. The vibration is like that due to the passing of a heavily loaded truck. Windows, doors, and dishes rattle. Floors and walls creak. Furniture begins to shake. Hanging objects swing slightly. Liquids in open vessels are slightly disturbed. In standing motor cars the shock is noticeable.

V. Awakening

a) The earthquake is felt in doors by all, outdoors by many. Many sleeping people awake. A few run outdoors. Animals become uneasy. buildings tremble throughout. Hanging objects swing. Pictures knock against walls or swing out of place. Occasionally pendulum clocks stop. Unstable objects may be overturned or shifted. Doors and windows are thrust open and slam back again. Liquids spill in small amounts from well-filled open containers. The sensation of vibration is like that due to a heavy object falling inside the building.

b) Slight waves on studding water; sometimes change in flow of springs.

VI. <u>Frightening</u>

a) Felt by most indoors and outdoors. Many people in buildings are frightened and run outdoors. A few persons lose their balance. Domestic animals run out of their stalls. In many instances dishes and glassware may break, books fall down, pictures move, and unstable objects overturn. Heavy furniture may possibly move and small steeple bells may ring.

b) Damage of grade 1 is sustained in single buildings of type B and in many of type A. Damage in some buildings of type A is of grade 2.

c) Cracks up to widths of 1 cm possible in wet ground; in mountains occasional landslips; change in flow of springs and in level of well-water.

VII. <u>Damage to buildings</u>

a) Most people are frightened and run outdoors. Many find it difficult to stand. The vibration is noticed by persons driving motorcars. Large bells ring.

b) In many buildings of type C, damage of grade 1 is caused; in buildings of type B, damage is of grade 2. Most buildings of type A suffers damage of grade 3, some of grade 4. In single instances landslips of roadway on steep slopes; cracks in roads; seams of pipelines damages; cracks in stone walls.

c) Waves are formed on water, and is made turbid by mud stirred up. Water levels in wells change, and the flow of springs changes. Sometimes dry springs have their flow resorted and existing springs stop flowing. In isolated instances parts of sandy or gravelly banks slip off.

VIII. <u>Destruction of buildings</u>

(a) Fright and panic; also persons driving motor cars are disturbed. Here and there branches of trees break off. Even heavy furniture moves and partly overturns. Hanging lamps are damaged in part.

(b) Most buildings of Type C suffer damage of Grade 2, and few of Grade 3. Most buildings of Type B suffer damage of Grade 3. Most buildings of Type A suffer damage of Grade 4. Many buildings of Type C suffer damage of Grade 4. Occasional breaking of pipe seams. Memorial and monuments move and twist. Tombstones overturn. Stone walls collapse.

(c) Small landslips in hollows and on banked roads on steep slopes; cracks in ground upto widths of several centimeters. Water in lakes become turbid. New reservoirs come into existence. Dry wells refill and existing wells become dry. In many cases, change in flow and level of water is observed.

IX <u>General damage to buildings:</u>

(a) General panic; considerable damage to furniture. Animals run to and fro in confusion, and cry.

(b) Many buildings of Type C suffer damage of Grade 3, and a few of Grade 4. Many buildings of Type B show a damage of Grade 2 and a few of Grade 5. Many buildings of Type A suffer damage of Grade 5. Monuments and columns fall. Considerable damage to reservoirs; underground pipes partly broken. In individual cases, railway lines are bent and roadway damaged.

(c) On flat and overflow of water, sand and mud is often observed. Ground cracks to widths of up to 10 cm, on slopes and river banks more than 10 cm. Furthermore, a large number of slight cracks in ground; falls of rock, many land slides and earth flows; large waves in water. Dry wells renew their flow and existing wells dry up.

X General destruction of buildings:

(a) Many buildings of Type C suffer damage of Grade 4, and a few of Grade 5. Many buildings of Type B show damage of Grade 5. Most of Type A have destruction of grade 5. Critical damage to dikes and dams. Severe damage to bridges. Railway lines are bent slightly. Underground pipes are bent or broken. Road paving and asphalt show waves.

(b) In ground, cracks up to widths of several centimeters, sometimes up to 1 meter. Parallel to water courses occur broad fissures. Loose ground slides from steep slopes. From river banks and steep coasts, considerable landslides are possible. In coastal areas, displacement of sand and mud; change of water level in wells; water from canals, lakes, rivers, etc., thrown on land. New lakes occur.

XI Destruction:

(a) Severe damage even to well built buildings, bridges, water dams and railway lines. Highways become useless. Underground pipes destroyed.

(b) Ground considerably distorted by broad cracks and fissures, as well as movement in horizontal and vertical directions. Numerous landslips and falls of rocks. The intensity of the earthquake requires to be investigated specifically.

XII Landscape changes:

(a) Practically all structures above and below ground are greatly damaged or destroyed.

(b) The surface of the ground is radically changed. Considerable ground cracks with extensive vertical horizontal movements are observed. Falls of rock and slumping of river banks over wide areas, lakes are dammed; waterfalls appear, and rivers are deflected. The intensity of the earthquake requires to be investigated specially.

Table 1: Average peak ground acceleration (horizontal component, as a fraction of gravity) as a function of earthquake intensity (MM scale) from different empirical relations (Murphy and O'Brien, 1977):

Indian Seismic Zone	Intensity (MM Scale)	Acceleration as a fraction of *g* Empirical Relations					
		1	2	3	4	5	6
I	V	0.015	0.032	0.031	0.021	0.022	0.032
II	VI	0.032	0.064	0.061	0.046	0.053	0.056
III	VII	0.068	0.13	0.12	0.10	0.13	0.10
IV	VIII	0.146	0.26	0.24	0.23	0.30	0.18
V	IX	0.314	0.54	0.48	0.52	0.72	0.32

Empirical relations:
1. Gutenberg and Richter, 1956;
2. Newmann, 1954;
3. Trifunac and Brady, 1975;
4. Trifunac and Brady, 1977 (revised by Murphy and O'Brien, 1977);
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