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EDITORIAL

If a Magnitude ~8 Earthquake Occurs in India Today……

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The observed subsidence in Joshimath located in Uttarakhand, India, during January 2023, has attracted the attention of the entire India. More than 600 structures of this small township, of about 45,00 structures, hosting a small population of ~ 17,000 have been declared unsafe for residents. The Joshimath Township is declared to be in a landslide subsidence zone by the authorities. There are close to 400 villages in 12 districts in Uttarakhand, India that have been recognized as belonging to Uttarakhand disaster prone belt. The news media is abuzz with views and possible causes of the observed subsidence. And while writing this article, news has started pouring in of subsidence, like Joshimath from Doda district in Jammu and Kashmir, India. Several houses are being vacated. The reporting in News Media, the public concern and the action of the State and Central governing bodies, and the work of the scientists and engineers involved would hopefully find the cause of the subsidence and ways and means to overcome the alarming situation.

M ~ 8 Earthquakes in India

The purpose of this article is to draw attention to a much larger possible consequences of the occurrence of an earthquake of magnitude ~ 8 in India. One of the most read books on Seismology is "Elementary Seismology" authored by Charles F. Richter (1958). I happened to procure a copy of this book in 1967 while on a UNESCO Fellowship, studying at the International Institute of Seismology and Earthquake Engineering in Tokyo, Japan. Very often, I get back to it and found it always useful. The present article has its beginning from this book. Chapter 5 of the book has the title: "Some Great Indian Earthquakes". After briefly addressing geology of India, Richter (1958) discusses in detail the 1897 earthquake, under the heading "OLDHAM AND THE 1897 EARTHQUAKE". This earthquake of magnitude 8.7 was studied in detail by Oldham (1899). It was felt for over 900 miles, the meizoseismal area extended 300 miles, the acceleration due to the earthquake exceeded 1g as boulders were seen being vertically up lifted from the base. India's population then was ~ 220 million. The population in Assam in those days was very low, just ~ 3 millions. The earthquake is estimated to have claimed some 1550 lives. Of course, there was a very widespread damage. The second earthquake dealt in detail by Richter (1958) is "THE BIHAR-NEPAL EARTHQAUKE of 1934". For this part Richter has heavily quoted from Officers of the Geological Survey of India, and Roy (1939). The Bihar-Nepal earthquake of 15 January 1934 had a magnitude of ~ 8 and claimed an estimated 8,000 human lives in India and another 7,000 in Nepal. By 1934, Indian population had grown to ~ 340 million, while Bihar's population was ~ 40 million. One of the most distinct features of this earthquake was the ~ 300 km long slump belt where a widespread soil liquefaction was observed, and most buildings collapsed or were heavily damaged. The other 4 earthquakes mentioned in this chapter include the 16 June 1819 Cutch (Kachchh) earthquake of M ~ 8 claiming ~ 1500 human lives. This earthquake provided one of the earliest pieces of evidence of faulting during an earthquake. It created Allah Bandh: a 16-mile-long scarp with a height of ~ 10 feet (Oldham, 1928); the 4 April 1905 M ~8 Kangra earthquake that claimed ~ 19000 human lives (Middlemiss, 1910); the 30 May 1935 M 7.6 Quetta earthquake that claimed ~ 30,000 human lives; and the 15 August 1950 Assam earthquake of M 8.7 claiming 4800 human lives (Tandon, 1954). The seismic seiches created by this earthquake were observed as far as England and Norway (Kvale, 1955). The pertinent details of all these 6 earthquakes are provided in Table 1.

Himalayan part of the Alpine-Himalayan seismic belt has been seismically very active during the period 1897-1952 hosting 5 earthquakes of magnitude ~8 (1897 Shillong, 1905 Kangra, 1934 Bihar-Nepal, and 1950 Assam earthquake and its 1952 aftershock). However, no such earthquake has occurred since 1952. Table 2,

Table 1

S. No.	Date	Region	Magnitude (M)	Human lives lost	India's Population in the Earthquake year (in millions)
Indian Earthquakes included by Richter (1958), and M ≥ 7.5 in India and its vicinity					
1.	16.06.1819	Cutch	~8.0	~ 1,500	200
2.	12.06.1897	Shillong	~8.7	~ 1,550	220
3.	04.04.1905	Kangra	~8.0	~20,000	250
4.	15.01.1934	Bihar-Nepal	~8.0	~15,000	360 (Nepal 5)
5.	30.05.1935	Quetta	~8.0	~30,000	365
6.	15.08.1950	Assam	~8.7	~ 4,800	400
Destructive earthquakes of M ≥ 7.5 in India and in the vicinity in the 21st Century					
S. No.	Date	Region	Magnitude (M)	Human lives lost	India's Population in the Earthquake year (in millions)
1	26.01.2001	Bhuj	~7.7	~ 20,000	1000
2.	08.10.2005	Muzaffarabad	~7.6	~ 87,000	1150 (Pakistan 170)
3.	15.04.2015	Gorkha (Nepal)	~7.9	~ 10,000	1320 (Nepal 27)

The first 6 earthquakes are the ones that are included in the chapter entitled "Some Great Indian Earthquakes" by Richter (1958). The bottom 3 are the M ≥7.5 earthquakes that have occurred in India and its immediate vicinity in the 21st Century.

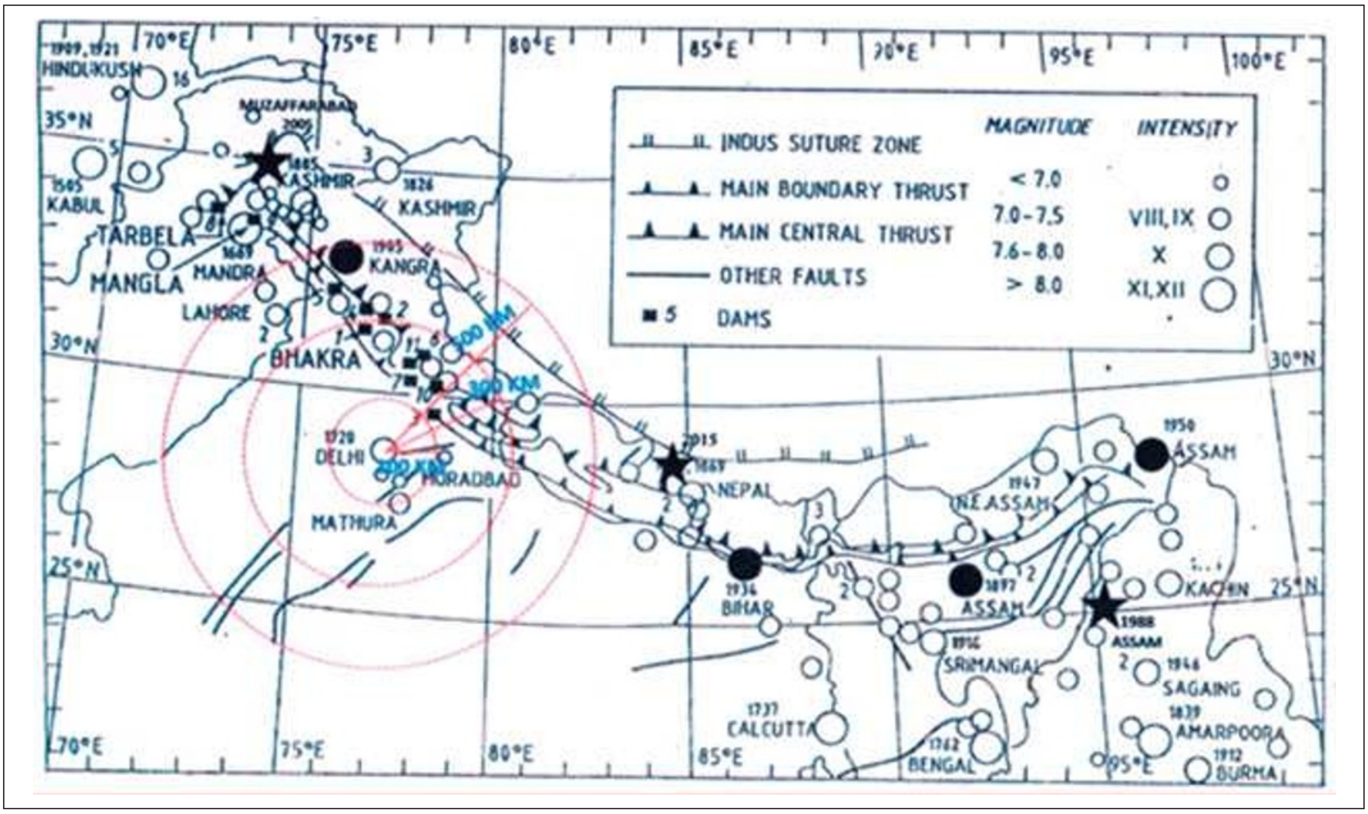

Fig.1. Earthquakes of M ≥ 7.0, epicentral intensity ≥ VIII, and/or recent damaging earthquakes that caused fatalities in the Himalaya and the vicinity (25°- 37° N, 69°- 83° E; 20°- 30° N, 83°- 100° E), updated from Chandra (1978). Four great earthquakes of M ≥ 8 are shown with filled circles. Stars: major earthquakes; in the east is the 8 August 1988 M 7.3 Assam; in the west is the 8 October 2005 M 7.6 Muzaffarabad and in the centre is 25 April 2015 M 7.8 Nepal earthquake. Red circles around Delhi indicate epicentral distances of 100, 300 and 500 km from Delhi. The 1720 Delhi earthquake was of M 6.5: historically the largest known earthquake in Delhi.

updated from Satyabala and Gupta (1996), underlines the paucity of M ≥ 7.5 earthquakes in the Himalayan region, causing a quiescence for M ≥ 7.5 earthquakes.

Figure 1 (updated from Chandra, 1978) shows the earthquakes of M ≥ 7.0, epicentral intensity ≥ VIII, and/or those claiming human lives in the vicinity of the Himalayan seismic belt (25°-37° N; 69°-83° E; 20°- 30° N, 83°- 100° E) from 1505 through 2022. The M ~ 8 earthquakes are shown by filled circles. The recent past earthquakes of M 7.3 in the north-east India, M 7.6 in Muzaffarabad and M 7.8 in Nepal are shown by stars.

M ~ 7.5 Earthquakes in India and her Vicinity in the 21st Century

Let us now examine the three M ~7.5 earthquakes that occurred in the 21st century in India and its vicinity. The first of these is the 26 January 2001 Bhuj earthquake of M 7.7 that occurred at 08:46 am local time and claimed an estimated number of ~ 20,000 human lives (Table 1). A comparison with the 16 June 1819 Cutch earthquake of M ~ 8 indicates that although the magnitude of the 2001 earthquake was less, but it claimed many more lives. However, India's population in 1819 was 200 million compared to 1000 millions of 2001. A lot of civil constructions were carried out since 1819, and literally there is no comparison between the urbanization that existed in 1819 to that in 2001. Several modern buildings not designed to sustain the anticipated earthquake generated accelerations were built (Gupta et al., 2001; Rastogi, 2001; Mandal, 2021). There was a very widespread liquefaction extending to 200 km from the epicenter, as reported. The estimated peak ground acceleration at the epicenter is estimated to be 0.7 g (Cramer and Kumar, 2003). As reported by Mandal (2021), the seismic activity in the vicinity has continued till now. The entire sequence included 1 Mw 7.7, 17 Mw 5.0 to 5.8, and over 250 Mw 4.0 to 4.9 earthquakes. Following the occurrence of this devastating earthquake the Gujarat State Government set up the "Institute of Seismological Research (ISR)" at Gandhinagar, Gujarat in 2003. Over the years the institute has done commendable work on earthquake hazard assessment and developing an earthquake resilient society in Gujarat. So, in a nutshell, it may be said that the 26 January 2001 M 7.7 earthquake demonstrated that the urbanization has taken place without taking adequate care to make structures resilient to the anticipated accelerations during the earthquakes. However, the silver lining is the creation of ISR and hopefully things would have improved.

Let us now take the case of 8 October 2005 M 7.6 Muzaffarabad earthquake. The epicenter was in the vicinity of India-Pakistan border near Muzaffarabad. The earthquake occurred at 8.50 am local time. There was a vide spread damage and the human lives lost were ~ 87,000, making it one of the deadliest earthquakes globally. It clearly exposed the poor level of construction in the region and a total ignorance of considering ways and means to build civil structure in the earthquake prone areas (Gupta, et al., 2009). The urgent need to pay adequate attention while building in earthquake prone areas was underlined. The observed damage and the loss of human lives was

Table 2. Earthquakes in the Himalayan region, updated from Satyabala and Gupta (1996)

Magnitude (M)	1897-1952	1953-2022
≤ 7.5	14	2
7 to 7.5	11	10
6.5 to 7	19	34

consistent with what was seen during the 1905 Kangra (M ~ 8) earthquake located ~350 km south-east and the 1935 Quetta earthquake (M 7.6) located ~ 950 km south-west of it. The increase in the human lives lost is consistent with the increase in the population. While in 1905 India's population was ~ 250 million, and in 1935 it was 360 million, whereas in 2005 India's population had risen to 1150 million and that of Pakistan to 17.5 million. It may be inferred that no serious attempts were made to consider the vulnerability of the region while making huge buildings and undertaking other developmental projects.

There is a different story as far as the M 7.9 Gorkha earthquake of 25 April 2015 is concerned. It claimed ~10,000 human lives (Mandal, 2021). The earthquake occurred at 11.56 am according to the Nepal time. The Bihar-Nepal earthquake of 15 January 1934 of M ~8 had claimed a total of ~15,000 human lives in India and Nepal. It had occurred around 2.15 pm Indian time. In 1934 population of India was ~ 360 millions and that of Nepal ~ 5 millions. Whereas in 2015 Nepal's population had increased to 27 million.

Why Gorkha Earthquake Claimed Fewer Hunan Lives?

Unlike the 26 January 2001 Bhuj and 8 October 2005 Muzaffarabad earthquakes, which claimed many more human lives than the earlier similar earthquakes in the concerned regions, and which is consistent with the growth of population, the 2015 Nepal earthquake claimed much fewer human lives. It appears that there are two major factors for this observed difference. The first one being the observation of the National Earthquake Safety Day being celebrated since 1999 on 16 January every year. This year the 25th National Earthquake Safety Day was celebrated on the 16 January 2023. The slogan this year was:

"Earthquake safe infrastructure, the basis of safe life".

The Ministry of Home Affairs, Government of Nepal acts as the National Coordinator and organizes a variety of events to increase awareness among the citizens of Nepal and emphasizes the importance of building earthquake resistant structure. Programs were conducted across the entire nation. An Earthquake Safety Digital Exhibition run through a virtual medium was organized all through Nepal (*nepaltraveller.com*).

Another important factor is the continuous lowering of the ground water table across Nepal (Gautam and Prajapati, 2014; Pandey et al., 2012). In a very recent report (The Kathmandu Post, 8 February 2023), it is mentioned that earlier ground water could be reached during the monsoon at depths of 20 to 25 feet, however now it is available at 150 feet. This has been caused by over-exploitation of the underground water for irrigation and construction as well as drinking purposes. The ground water levels are depleting 2-3 feet every year and in the past seven years a depletion of ~ 15 feet has been observed. It has implication on the availability of fluids at shallow depths, a requirement for soil liquefaction during the earthquakes. Unlike the 15 January 1934 Bihar-Nepal earthquake that witnessed immense soil liquefaction and there by the destruction of the structures, during 2015 Gorkha earthquake, not much of soil liquefaction was observed. So, in a nutshell, it may be stated that the good practice of Nepal observing "National Earthquake Safety Day" and a lower water table, which was not conducive to soil liquefaction reduced the number of human lives lost in the 2015 Gorkha earthquake as compared to the 1934 Bihar-Nepal earthquake, despite almost three-fold increase in the population in the earthquake affected area.

Training of School Students on Earthquake Safety

It is worth mentioning that an excellent beginning has been made in the north-east India region by the CSIR-North-East India Institute of Science and Technology (CSIR-NEIST), located at Jorhat, Assam. As is well known, the north-east India region is seismically one of the most active regions globally, having hosted the 1897 Shillong and the 1950 Assam earthquake and over a dozen M ≥ 7.5 earthquakes in the past 150 years. Realizing the importance of educating young students in what to do and what not to do before, during and after an earthquake. CSIR-NEIST has conducted mass awareness program about earthquakes and how to develop an earthquake resilient society involving over 30 schools/colleges in Jorhat, Golaghat, Nagaon, Sonitpur, Majuli, Sivasagar, Tinsukia districts of Assam during the period of May 2022 through October 2022 comprising ~ 11,000 students, ~500 teachers and 360 helping staffs of these school/colleges. During these extended visits to schools/colleges, in addition to familiarizing the pupil with the earthquake awareness and preparedness guidelines, fundamentals of seismology were also shared in simple language with quite a bit of the demonstrations. It was very encouraging to note the interest of the teachers and students in learning ways and means to be protected against the earthquakes. Additionally, pamphlets and a book entitled "Earth, Earthquakes: Essentials and Safety" was distributed among the participants. Overall, this has been a very successful initiative and needs to be perpetuated (Santanu Baruah, CSIR-NEIST, *pers. commn.*).

Earthquake Early Warning System

As summarized by Allen (2021), in the last 10 years there has been a noticeable advancement in the earthquake early warning methodologies and effective early earthquake warning systems have been successfully deployed in Mexico; California, USA; Japan; Taiwan and elsewhere. Using a variety of approaches, after the occurrence of a large earthquake, the anticipated acceleration is estimated, and public warnings are issued to minimize the possible damage when the destructive earthquake waves arrive at a given location. An earthquake is located using a local network of seismic stations, and its magnitude is estimated within seconds using earthquake generated P-waves. The destruction is basically caused by shear waves that travel slower than the body waves. So, depending upon the distance of a location from the hypocenter of the earthquake, the destructive waves would arrive later. The time interval is useful to take up preventive measures, such as switching off the electric and gas supply, stopping of lifts and vehicular traffic etc.

It is heartening to note that an Earthquake Early Warning System has been successfully implemented in the Uttarakhand State of India (Kumar et al., 2023). The system which consists of 169 seismic sensors in an oval-shape of network, 280 km east-west and 120 km north-south stretch, successfully alerted Uttarakhand citizens of the three moderate earthquakes on 9 November (M 5.8), 12 November (M5.4) 2022 and 24 January (M 5.8) 2023. Although these M ≤ 6 earthquakes were not likely to cause any damage in Uttarakhand. The appropriate functioning of the EEWS in Uttarakhand is a very welcome development and similar systems need to be installed in several locations in the vicinity of the Himalayan earthquake belt.

Earthquake Scenarios for M ~ 8 Earthquakes

For developing earthquake resilient societies, use of earthquake scenarios is a very successful tool. As is well known, accurate forecast of earthquakes is not yet available. Even if there is a forecast that on the coming Monday at 12 noon time, a M ~ 8 earthquake will occur in the vicinity of Delhi, can everyone leave Delhi? That is of course not possible. Therefore, it is important to learn to live with earthquakes. Developing an earthquake scenario, as to what would happen if one of the earlier earthquakes repeats today, is very helpful. The National Disaster Management Authority (NDMA), Government of India, in collaboration with State Governments and Research Organizations built scenarios for the repeat of the 1905 Kangra of M ~8 and 1897 Shillong M 8.7 earthquakes (Gupta et al., 2020). Using appropriate ground motion prediction equations, earthquake intensities were generated for a hypothetical M 8 earthquake located at Mandi, very close to the epicenter of the 1905 Kangra earthquake. The isoseismal map thus generated was compared with the 1905 Kangra earthquake isoseismals, and a consistency was observed. Next, using the 2011 census data for demography and building typology, it was estimated that if the earthquake occurs in the middle of the night, ~ 9,50,000 human lives could be lost in the states of Punjab, Haryana, Himachal Pradesh, and the Union Territory of Chandigarh. The number appeared to be a bit too high. However, if one takes the case of the 8 October 2005 Muzaffarabad earthquake, which was of M 7.6, the energy released by an M 8 earthquake is almost 10 times more than the energy released by an M 7.6 earthquake, and the fact that it occurred at 8.50 am local time when everyone was awake and most of them away from homes, the figure of 9,50,000 may not be out of place. NDMA took up detailed preparatory exercises in cooperation with the other central and state agencies for Rapid Visual Screening of the lifeline buildings, sensitization of school children about earthquakes as what to do and what not to do before, during and after the earthquake, Incident Response System (IRS), and general awareness program involving celebrities and all available media platforms. In these preparations the State Disaster Management Agencies (SDMA's), National Disaster Response Force (NDRF) and the State Disaster Response Forces (SDRF's) of the four states (Punjab, Haryana, Himachal Pradesh, and Union Territory of Chandigarh) played an important role. To test the preparedness of all these four states, a mega mock drill for a hypothetical M ~8 earthquake was held on the 13 February 2013. Performance of all the sectors was monitored by independent agencies. Public participated whole-heartedly. Several short comings were pointed out which were taken into consideration for further implementation.

Encouraged with the success of the Mega-Mock Drill for the hypothetical Mandi earthquake, a similar exercise was conducted for the 8 north-east Indian States for the repeat of the 1897 Shillong earthquake with the mega-mock drills being conducted on 10 and 13 March 2014, with equally positive outcome (Gupta et al., 2020).

CONCLUDING REMARKS

It is a fact that an M ~ 8 earthquake has not occurred in the Himalayan region since the 1952 M 8 aftershock of the great M 8.7 Assam earthquake of 1950. Incidentally, the 15August 1950 Assam earthquake happens to be largest, so far recorded, earthquake in a continental region. When and where such an earthquake will occur, is difficult to estimate as of now. The Turkey earthquake of M 7.8 that occurred on the 6 February 2023 and has claimed over 21,000 human lives (as of 10 February 2023) in Turkey and Syria is the latest example as to what an earthquake can do if proper precautions are not taken. It would be very undesirable to have a similar experience when an M ~8 earthquake occurs somewhere in the Himalaya. The following suggestions would be very helpful.

1. Observing an earthquake safety day in the vicinity of the Himalayan earthquake belt, like what is being done in Nepal on the 16 January of every year.
2. Training of the school students about earthquake safety.
3. Creating earthquake scenarios of the repeat of past M ~ 8 earthquakes and taking up preparatory phase of developing an earthquake resilient society followed by mega-mock drills in other parts of the Himalayan earthquake belt, like the exercise conducted by NDMA for the 1897 and 1905 earthquakes.
4. Strict implementation of the safety from earthquakes methodology in all constructions.
5. Deployment of the Earthquake Early Warning Systems along the Himalayan earthquake belt.

Hopefully, a timely implementation of these suggestions would bear fruits and fewer human lives would be lost and there would be less destruction to civil structures in the future.

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