ISET Journal of Earthquake Technology, Paper No. 557, Vol. 57, No. 3, September 2020, pp. 151-161

APPRAISAL ON RECENT SEISMICITY IN DELHI AND SURROUNDINGS

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ABSTRACT

Recently, more than 25 earthquake tremors were felt in Delhi during the last two months, which have caused panic amongst the people. This article makes an attempt to review the seismicity of Delhi and surrounding areas in the context of past studies. In view of the seismic history of Delhi, the occurrence of minor earthquakes in the vicinity of Delhi is not a very unusual phenomenon. There are several reports indicating small magnitude earthquakes occurring in and around Delhi in the past as well. The seismotectonic of Delhi region indicates the presence of several intraplate lineaments and faults in the region. But it is unlikely to have epicentre of a large magnitude earthquake event in the vicinity of Delhi. However a large magnitude event in the Himalayan plate boundary, though far away, can shake Delhi due to site effects. Three-fourth of Delhi is covered by alluvial soil because of Yamuna River, and it can amplify seismic waves. Natural hazards like earthquakes cannot be prevented. The main reason for India being more prone to these serious effects of earthquakes is because of this high density of population and poor construction quality of our habitat buildings. There is no need to panic. It is important to consider the seismic safety factors in new construction and retrofit existing structures to resist earthquake shaking in future. The awareness of earthquake-resistant design and earthquake preparedness is too important for the country.

KEYWORDS: Earthquakes, Delhi, Himalaya, Seismicity, Risk

INTRODUCTION

The recent seismic activity and tremors in Delhi have caused panic among the residents of Delhi and the people of the country. The area around Delhi has been experiencing a series of earthquakes of mild intensity for a long time. That is not a new phenomenon. Now a large section of people is noticing it, and that is also causing a fear. Most of these shocks are shallow and of low intensity. The earthquake zoning map of India divides India into four seismic zones (zones II to V), as shown in Figure 1; a previous version consisted of five or six zones. According to the present zoning map, zone V experiences the highest level of seismicity; zone II is associated with the lowest level of seismicity. Delhi is listed under zone IV, indicating a severe intensity of hazard. As per seismic microzonation report (Ministry of Earth Sciences, Govt. of India), Delhi and surroundings are divided into four seismogenic zones namely Himalayan Zone (part of Himalaya falling within 350 km from the centre of Delhi), Delhi-Haridwar Ridge Zone, Moradabad Fault Zone and Great Boundary Fault zone along the Delhi-Aravalli fold belt in Rajasthan. Figure 2 a & b present the geological map of Delhi and main seismic sources in and around Delhi extending from the Himalayas. The Himalayan seismogenic Zone is the most seismically active zones in the vicinity of Delhi. The Delhi-Haridwar Ridge zone is considered to represent shallow NE-SW trending extension of the Delhi Foldbelt towards the Himalayas. The Moradabad fault zone trends along NE-SW direction. Kolathayar and Sitharam [1] divided the entire country into 104 seismic source zones based on fault alignment, earthquake epicentres and spatial variation of seismicity parameters. Delhi and surroundings are placed in zone 56. The Frequency magnitude distribution of the Zone (Figure 3) shows low to moderate seismic activity with *'a'* value of 3.45. However, the adjacent zones in the Himalayas have high seismic activity and earthquakes in these zones can cause shaking in Delhi.

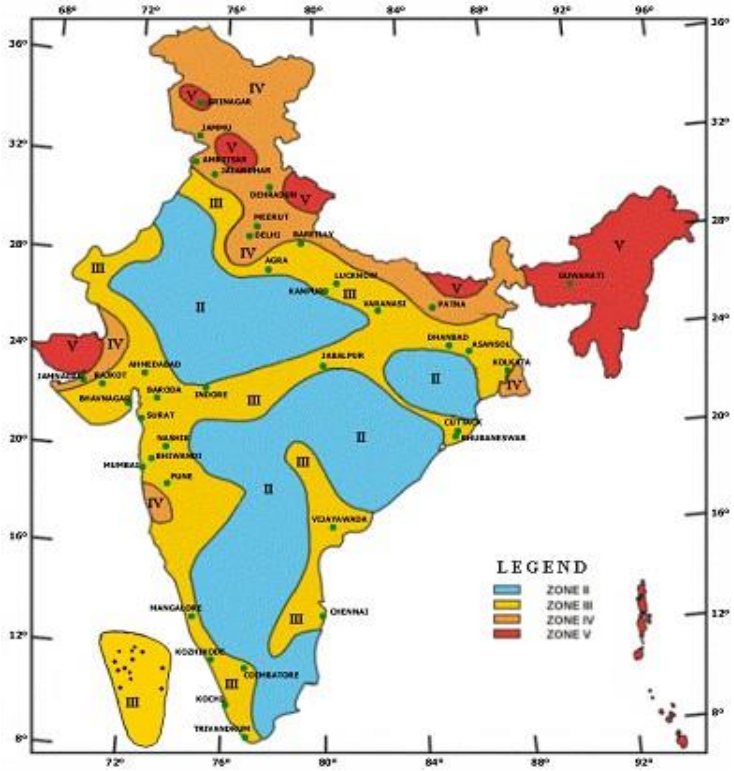


Fig. 1 Seismic zonation map of India (IS 1893, 2016 [2])

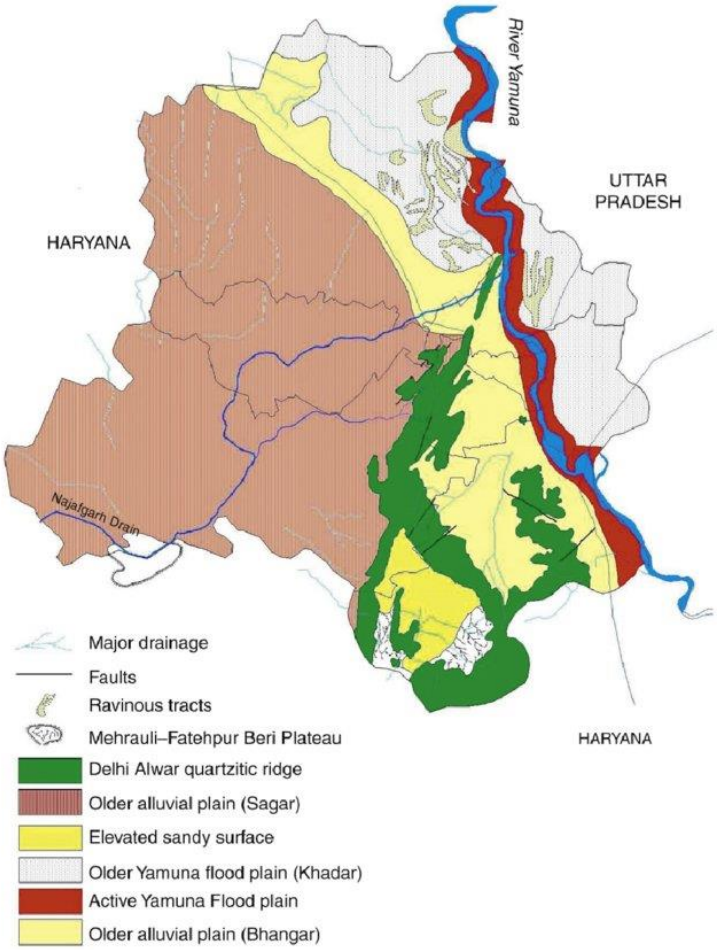


Fig. 2a Geological Map of Delhi (After Chatterjee et al. [3]; Sarkar et al. [4])

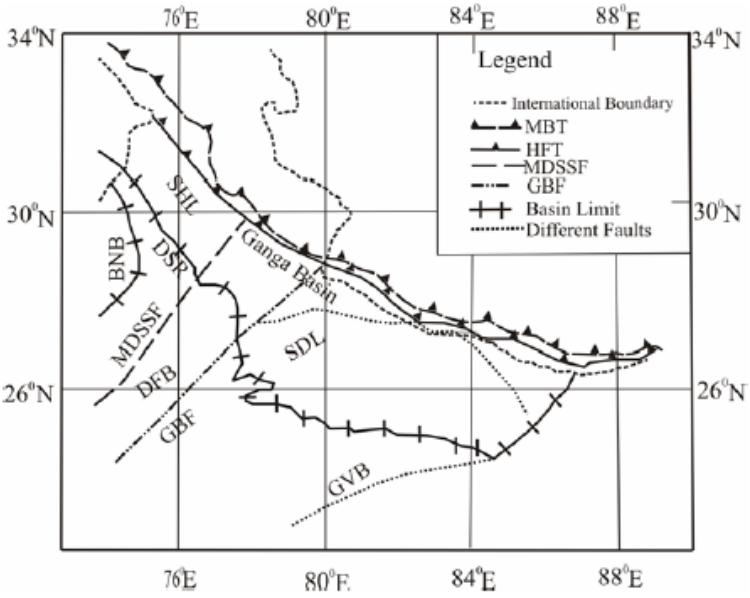


Fig. 2b Tectonic framework of Himalayan Belt (after Srinivasan and Khar [5]; Prakash and Shrivastava [6]). MDSSF = Mahendragarh Dehradun Subsurface Fault, GBF = Great Boundary Fault, DSR = Delhi Sargodha Ridge, SHL = Sahaspur Low, SDL = Sarda Low, DFB = Aravali Delhi Fold Belt

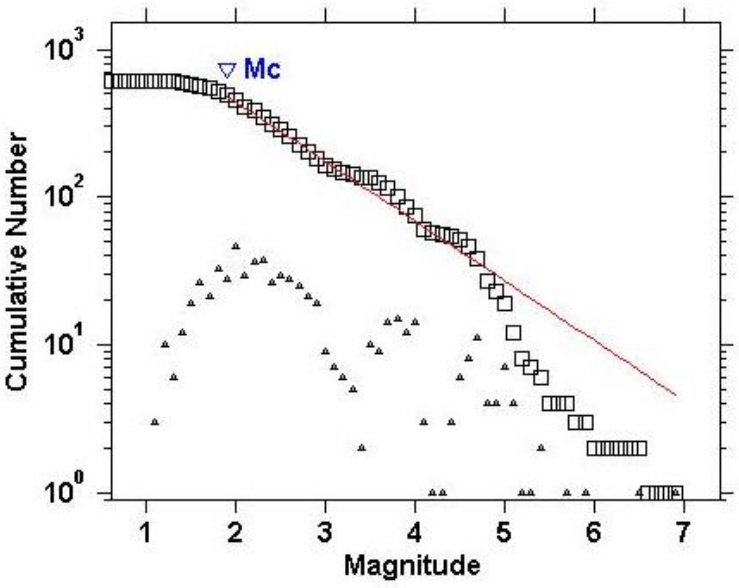


Fig. 3 Frequency Magnitude Distribution plot for Source Zone containing Delhi for the period 1720-2010 (Kolathayar and Sitharam, [1])

RECENT TREMORS IN DELHI AND THEIR IMPLICATIONS

Table 1 lists the earthquake events reported by USGS within a radius of 500 km from New Delhi (28.7° N, 77.2° E) during April-June 2020. Figure 4 presents the distribution of earthquake events within a radius of 500 km from New Delhi during April-June 2020, as per National Center for Seismology, Ministry of Earth Sciences, Government of India. The record by National Center for Seismology includes smaller magnitude events too. However, it can be seen that several smaller magnitude events are missing from the USGS catalogue. Table 2 lists the earthquakes within a radius of 100 km from New Delhi during April-June 2020 reported by National Center for Seismology. There are 56 events recorded within a radius of 500 km from New Delhi during April-June 2020, out of which 28 are within a radius of 100 km. Among these 28 events, only one event is of magnitude above 4.0. It happened near Rohtak, Haryana

(Lat: 28.8 N & Long: 76.7 E) on 29th May 2020 and the magnitude was 4.5. It is to be noted that an earthquake of Magnitude 5.0 occurred three years ago at the same location (on 02-06-2017, 04:25:56 IST, Lat: 28.8 N & Long: 76.7 E, Depth: 22 Km, Region: Rohtak, Haryana, Ref: IMD, Govt. of India).

Table 1: List of earthquakes within a radius of 500 km from New Delhi during April-June 2020 (Source: USGS)

Date	Latitude	Longitude	depth	mag (mb)	Location
2020-05-29	29.22	77.09	57.08	4.2	7 km E of Samalkha, India
2020-05-28	32.54	79.49	10	4.4	54 km W of Shiquanhe, China
2020-05-10	28.73	77.35	10	3.7	7 km ESE of Loni, India
2020-04-12	28.83	77.36	10	3.8	8 km ESE of Khekra, India

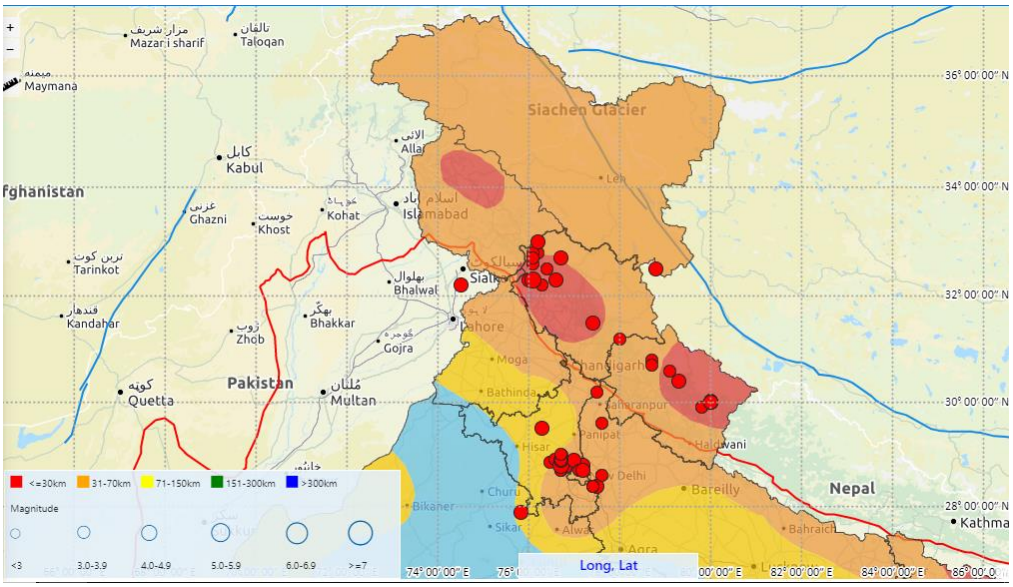


Fig. 4 Distribution of earthquakes within a radius of 500 km from New Delhi during April-June 2020

Delhi and adjoining cities in the Delhi NCR felt earthquake tremors on 3rd July 2020. The tremors lasted for nearly 3-4 seconds. The epicentre of the earthquake has been located in the Alwar district of Rajasthan, and the event magnitude is 4.7. The previous earthquake in the Alwar region occurred on 29th November 2006, with M 4.4. There are so many weak zones and faults in the Delhi-NCR: Delhi-Haridwar ridge, Mahendragarh-Dehradun subsurface fault, Moradabad fault, Sohna fault, Great boundary fault, Delhi-Sargodha ridge, Yamuna river lineament, Ganga river lineament etc. All the recent quakes recorded in the Delhi-NCR region were of low to medium intensity on the Richter scale.

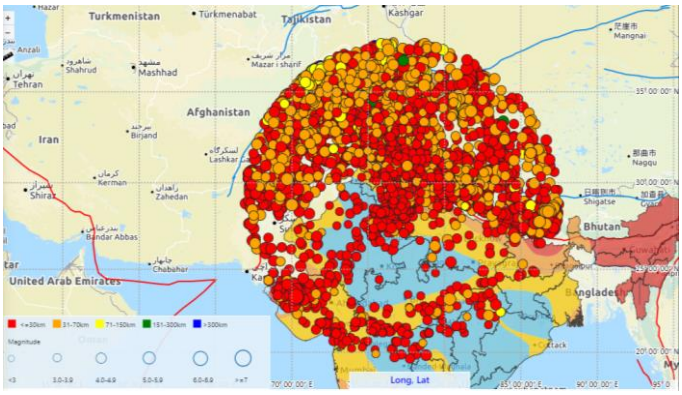
Table 2: List of earthquakes within a radius of 100 km from New Delhi during April-June 2020 (Source: National Center for Seismology, Ministry of Earth Sciences Govt. of India)

S No.	Origin Time	Lat	Long	Depth	Mag	Location
1	2020-04-05 06:32:53 IST	29	76.7	8	2.5	14 km NE of Rohtak, Haryana, India
2	2020-04-09 21:57:59 IST	28.6	77.6	15	2.4	21 km ENE of Noida, Uttar Pradesh, India
3	2020-04-12 17:45:03 IST	28.7	77.2	8	3.5	9 km N of New Delhi, India
4	2020-04-13 13:26:32 IST	28.7	77.2	5	2.7	9 km N of New Delhi, India
5	2020-04-16 08:26:22 IST	28.7	77.1	10	2	13 km NW of New Delhi, India

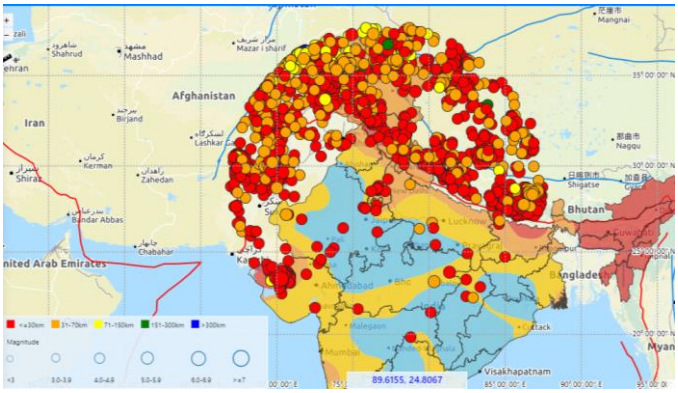
6	2020-04-18 17:36:39 IST	28.9	76.7	10	2.9	9 km E of Rohtak, Haryana, India
7	2020-04-21 04:34:43 IST	28.9	76.7	10	3.2	9 km E of Rohtak, Haryana, India
8	2020-05-03 00:29:53 IST	28.9	77	5	3	37 km NNW of New Delhi, India
9	2020-05-06 02:41:40 IST	28.4	77.4	10	2.3	8 km E of Faridabad, Haryana, India
10	2020-05-10 13:45:29 IST	28.8	77.2	5	3.4	20 km N of New Delhi, India
11	2020-05-15 11:28:51 IST	28.7	77.2	22	2.2	9 km N of New Delhi, India
12	2020-05-28 16:24:30 IST	28.4	77.4	10	2.5	8 km E of Faridabad, Haryana, India
13	2020-05-29 21:08:40 IST	28.8	76.7	15	4.5	14 km SE of Rohtak, Haryana, India
14	2020-05-29 22:00:07 IST	28.8	76.7	10	2.9	14 km SE of Rohtak, Haryana, India
15	2020-06-01 04:50:27 IST	28.7	76.7	5	1.8	23 km SSE of Rohtak, Haryana, India
16	2020-06-01 18:42:05 IST	28.8	76.7	10	3	14 km SE of Rohtak, Haryana, India
17	2020-06-03 22:42:29 IST	28.4	77.5	4	3	17 km E of Faridabad, Haryana, India
18	2020-06-07 11:55:31 IST	28.7	76.7	5	1.8	23 km SSE of Rohtak, Haryana, India
19	2020-06-08 13:00:34 IST	28.85	76.76	19	2.1	15 km ESE of Rohtak, Haryana, India
20	2020-06-18 04:18:30 IST	28.81	76.73	5	2.1	15 km SE of Rohtak, Haryana, India
21	2020-06-19 05:37:39 IST	28.84	76.75	5	2.3	15 km ESE of Rohtak, Haryana, India
22	2020-06-20 01:52:15 IST	28.76	76.81	10	1.8	24 km SE of Rohtak, Haryana, India
23	2020-06-24 12:58:13 IST	28.83	76.75	5	2.8	15 km ESE of Rohtak, Haryana, India
24	2020-06-25 01:30:11 IST	28.98	76.72	7	2.2	14 km NE of Rohtak, Haryana, India
25	2020-06-26 15:32:36 IST	28.83	76.77	10	2.8	17 km ESE of Rohtak, Haryana, India
26	2020-06-27 21:11:23 IST	28.92	76.58	5	2.4	3 km NW of Rohtak, Haryana, India
27	2020-06-30 03:14:09 IST	28.83	76.73	5	1.8	14 km ESE of Rohtak, Haryana, India
28	2020-06-30 05:46:06 IST	28.86	76.47	8.6	2.4	13 km WSW of Rohtak, Haryana, India

EARTHQUAKE ACTIVITY IN PAST DECADES

Figure 5 presents the distribution of earthquake events within a radius of 1000 km from New Delhi for 20 years (1999 to 2019) duration. Figure 5a presents all magnitude events, whereas Figures 5b to 5d show events of magnitude greater than 4.0, 5.0 and 6.0, respectively. This analogy clearly indicates that the chance of a high magnitude event is lesser near Delhi. The real threat is from the large magnitude event that can occur in the Himalayas, which is only a few hundred kilometres from Delhi. The soil conditions in Delhi may amplify the waves and cause damage to the structures.



(a)



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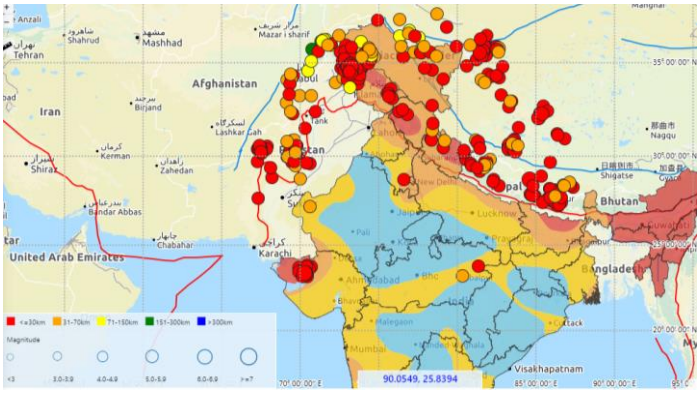

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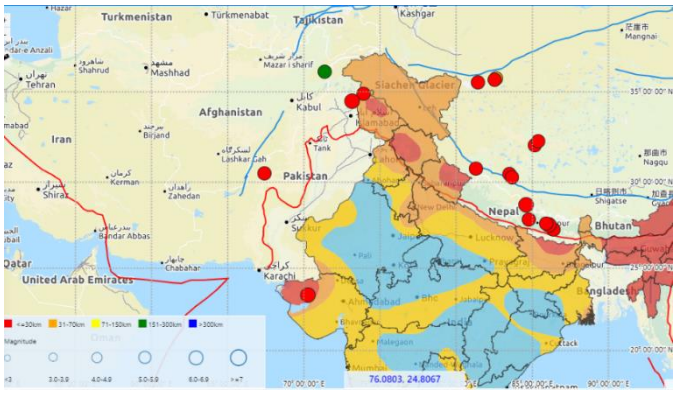

(d)

Fig. 5 Earthquake events within a radius of 1000 km from New Delhi during 1999 to 2019 a) All magnitudes, b) $M_L \geq 4$, c) $M_L \geq 5$, and d) $M_L \geq 6$ 9 (Source: https://seismo.gov.in/) [7]

HIMALAYAN SEISMICITY

The high seismicity of the Indian region can be attributed to the rapid, high-velocity drifting of the Indian plate toward the Himalayas in the northeastern direction along with its low plate thickness (Kumar et al. [8]). The Indian plate is moving northwards at about 45 mm per year and is colliding with the Eurasian plate (Bilham [9]). Deformation within Asia reduces India's convergence with Tibet to approximately 18 mm per year. This has resulted in the development of potential slip driving large thrust earthquakes beneath the Himalayas. When continents converge, a great deal of shortening and thickening takes place, as in the Himalayas and Tibet. This massive collision formed the Himalayas, and a great number of earthquakes were generated due to this process. The plate boundary extends from the Himalayan region to the Arakan Yoma and is a major cause of earthquakes in this region. The plate boundary areas along the Himalayas and northeast India are characterized by a very high level of seismicity (Gupta [10]). In addition, earthquakes occur within the Indian shield region. Analysis of seismic activity in India can be broadly characterized by three general seismotectonic considerations such as tectonically active shallow crustal regions, subduction zones, and stable continental regions (Figure 6: Nath and Thingbaijam [11]; Kolathayar et al. [12]). Delhi is geographically located in a stable continental region. However, past seismic hazard studies for Delhi used the Ground Motion Prediction Equation for the active tectonic region to predict the hazard at Delhi. It is to be noted that Delhi lies near the boundary of active tectonic region. A large magnitude event in the Himalayas can cause damage in Delhi. The attenuation characteristic of the active tectonic region is different from that of the stable continental region. There is a need to understand the attenuation through the interface of these two tectonic provinces for a reliable estimate of seismic hazard in Delhi.

The seismicity of the Himalayan arc tectonic belt is connected with the underthrusting of the Indian plate beneath the Eurasian plate (Molnar and Tapponnier [13]; Krishnan [14]). The tectonically active interplate regions include the Himalayas and southern Tibetan plateau, the northwest frontier province of the Indian plate (Nath and Thingbaijam [11]; Kayal [15]). The Indian plate once was one of the fastest moving plates in the world. Before its collision with the Eurasian plate, it attained a very high velocity of around 20 cm per year (Kumar et al. [8]).

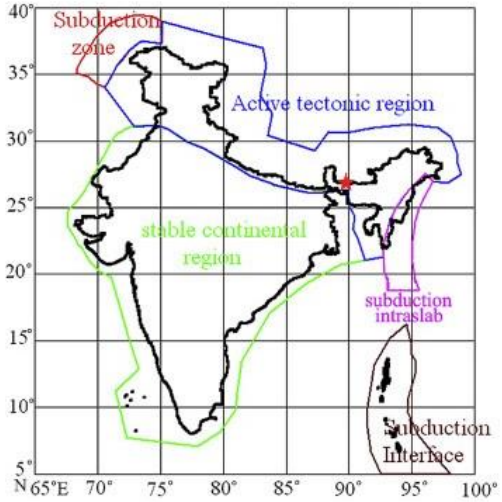

Fig. 6 Site location and its tectonic region, modified after Kolathayar et al. [12]

SEISMIC GAP IN THE HIMALAYAS

A seismic gap is a segment of an active plate boundary that, relative to the rest of the boundary, has not recently ruptured (Cassidy [16]). It is considered to be more likely to produce an earthquake in the future. A section of a plate boundary that has not ruptured recently has the highest chance of rupturing in the future compared to other segments that have experienced large earthquakes. This is based on the understanding that tectonic plates move relative to one another at an approximately constant speed and the assumption that the slip of plate boundary faults occurs primarily during major earthquakes. In view of this, the central gap in the Himalayas is awaiting a large earthquake in the near future (Figure 7). A seismic

gap is a segment of a fault that has created earthquakes in the past but is at present quiet. These are regions along an active fault where stress is accumulating as no earthquakes have occurred in recent history. These regions are considered to be high-risk areas for earthquakes in the near future (Bilham [9], [17].

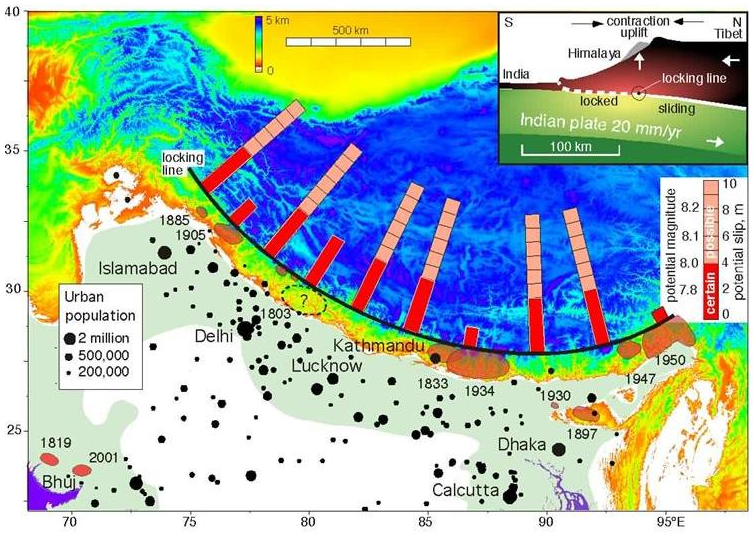

Fig. 7 Forecast of future earthquakes in seismic gaps of Himalayas (Bilham et al. [18])

SEISMIC HAZARD ASSESSMENT STUDIES FOR DELHI

There were several seismic hazard studies for Delhi and surroundings done in the past by different researchers. Table 3 presents a glimpse of several studies conducted in the past. Kumar et al. [30] reported that a soil column subjected to input motions with low PHA values would have a high amplification factor. Hence the effect of soil amplification can cause severe shaking even when the bedrock level PGA is low.

Table 3: Past seismic hazard studies done for Delhi and surroundings

Authors	Study	Remarks
Sharma et al. [19]	PSHA for 20% of exceedance in 50 years	Divided Delhi into 6 seismogenic sources and used GMPE by Abrahamson and Liteheiser [20]
Iyengar and Ghosh [21]	PSHA	Considered local site effects
Mohanty et al. [22]	Seismic microzonation	Used AHP to encompass PGA, soil type, geology, ground water and rock depth
Singh et al. [23]	Ground motion estimation	considered future great earthquakes in the central seismic gap
Kolathayar et al. [24]	DSHA	Used three GMPEs in a logic tree framework
Kolathayar [25]	DSHA	Used log-likelihood approach to select best GMPE and studied population exposure to seismic hazard
Sitharam and Kolathayar [26]	PSHA	Used areal source model to estimate PGA
Sitharam et al. [27]	PSHA	Etimated surface level PGA considering site effects with slope as a proxy for site amplification
Anbazhagan et al. [28]	Developed GMPE applicable for the Delhi region	Used combined dataset of recorded and simulated ground motions
Ramkrishnan et al. [29]	Developed GMPE applicable for the Delhi region	Used actual recorded strong motion data

SUMMARY

The plate boundary between the Eurasian plate and the Indo-Australian plate is only a few hundred kilometres away from Delhi. Main Boundary Thrust (MBT) is the plate boundary where large earthquakes can occur. An earthquake in the seismic gap of the Himalayas can cause damage to Delhi due to site effects. So any shake which occurs in the Himalayas or the Hindukush could be felt on Delhi. In 2015 Nepal earthquake which was felt across the Indo-Gangetic plain including Delhi is one such example. The possibility of a large earthquake close to Delhi is minimal. But there is a possibility of large earthquake in plate boundary which can affect Delhi due to site amplification. It is more of large earthquakes which can happen in plate boundary with the soil effect that can have a larger impact on Delhi. The smaller tremors in and around Delhi may not cause a bigger effect. So there is a clear distinction between the two things. The sediments in the Indo-Gangetic belt can amplify the earthquake motion, and the role of geotechnical engineering is very important to understand it. No one can say when an earthquake can happen. It is not able to predict an earthquake.

Seismic activity is much higher in Northern India due to its close proximity to the MBT and Main Central Thrust (MCT). Himalayas — the mountain belt of complex geo-tectonic set-up stretching about 2,400 km long in an East-West direction with variable width of 230 to 320 km is formed due to the convergent movement of two plates of the earth's lithosphere. The Indo-Gangetic belt and the deposited sediments make hazards much more significant in this area. These alluvium sediments amplify the earthquake motion, and thus its impact is much more in northern India. Many microzonation projects have been done in Northern Indian cities, which have mapped the seismic activity and the soil shear strength profiles with depth. The seismic microzonation of Delhi at the scale of 1:10,000 is completed and available to the public. It is time to put them to use. Microzonation maps which are available at a very refined scale can actually help us. We need to take up immediately the restoration of hospitals, schools and important buildings. The solutions lie in understanding these buildings subjected to earthquakes. We need to understand that most of our structures are not concrete structures. Majority of them are built masonry stone, with different typologies and different shapes. India is not the only country prone to more disasters, but many countries face more disasters than we do. But India's population and density of urban area are the major reason, and it is much more severe now as most of them are staying at home. Disaster risk in India is compounded by increasing vulnerabilities such as population, high demography, and change in construction habits. Buildings if they are not engineered and weak, they are affected by these earthquakes and can cause a large number of deaths. Hence the quality of construction plays a major role in deciding disaster.

It is important to put emphasis on considering people and precautionary measures. The awareness of earthquake-resistant design and earthquake preparedness is too important for the country. Structural engineers can identify the buildings which need retrofitting, and necessary action should be initiated by house owners and the Government. There is no need to panic, and there are plenty of guidelines available. Education and creating awareness is very important.

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