Tremors and built environment of Hyderabad, Telangana, India: safety of buildings using recorded ground motions

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Although the city of Hyderabad in Telangana, India lies in seismic zone II, low to medium intensity tremors that pose a serious concern towards safety of the built environment are not uncommon. One such series of tremors occurred during 13–20 October 2020, in the financial district of Hyderabad and created a panic situation due to perceivable shaking and jolts with loud sounds associated with hydro-seismicity. To understand the safety of the city's built environment, a study was conducted on low, medium and tall buildings using ground motions recorded at the International Institute of Information Technology (IIIT), Hyderabad, which is 2.3 km from the epicentre. The amplification of ground motion on the second floor of the Nilgiri Building in IIIT, Hyderabad was 1.2–2.3. The vibrations recorded on the ground floor of the Nilgiri Building were used to develop a site-specific response spectrum. This was further used to obtain the peak responses of the considered buildings through response spectrum analysis. The present study suggests that the low-rise buildings, mid-rise buildings and non-structural elements in high-rise buildings are under threat in the case of high-intensity earthquakes.

Keywords: Built environment, ground motion, hydro-seismicity, microtremors.

THE Information Technology (IT) corridor of Hyderabad, Telangana, India, experienced earthquake tremors of magnitude 0.8 during the second and third week of October 2020 (ref. 1). In the past, similar events have occurred in the Hyderabad region. In 1982, an earthquake of magnitude 3.5 occurred near Osman Sagar reservoir, followed by aftershocks for five weeks. The event was attributed to the north northeast (NNE) fault trending the area[2]. A total of more than 50 tremors were reported to have occurred according to the catalogue of earthquakes of $M \geqslant 3$ (ref. 3). In 1983, an earthquake of magnitude 4.5 occurred along the Musi lineament, causing minor cracks in a few buildings; some boulders were also displaced near the epicentral area[4]. The Jubilee Hills area has experienced a sequence of microtremors regularly from 1994 to 2016. The west northwest–east southeast (WNW–ESE) trending shear zone extending from Banjara Lake through Kasu Brahmananda Reddy National Park and going up to Durgam Cheruvu was related to this microtremor activity[5].

In 1984, three tremors were reported in Saroornagar, an area close to Vanasthalipuram. The maximum magnitude was 2.2. On 22 October 2010, localized micro-seismicity with subterranean sounds was reported in Vanastalipuram area located in the eastern part of Hyderabad city[4]. Table 1 shows the decade-wise list of microearthquakes. Table 2 lists the significant earthquakes that have occurred in the past in Hyderabad.

Tectonics and seismicity of the region

The Indian peninsular region is one of the oldest Archean shield regions of the world. It was deemed to be devoid of major seismic activity. However, in the past 50 years, there have been occurrences of few moderate to large earthquakes associated with major damage to property and loss of lives. The city of Hyderabad lies at 17.38°N lat. and 78.48°E long., in peninsular India, at an elevation of 576 m amsl. Geomorphically, the surrounding area of Hyderabad is characterized by undulating terrain with residual hills, inselbergs, pediplains and pediment zones, and valley fills. The general geology of the region consists of Archean granites and gneiss of the Precambrian era, which extend several kilometres from the surface to

Table 1. Decade-wise microearthquakes in Hyderabad, India

Decade	No. of microearthquakes
1970–80	5
1980–90	63
1990–2000	13
2000–10	47
2010–20	71

Source: refs 2, 4, 13.

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Table 2. List of earthquakes that occurred in Hyderabad, Telengana, India

Date	Location	Latitude	Longitude	Moment magnitude
1876	Secunderabad	17.5	78.5	5
14 January 1982	Gandipet	17.43	78.35	3.5
27 January 1982	Gandipet	17.4	78.3	3.3
30 June 1983	Medchal	17.6	78.5	4

Source: ref. 3.

Table 3. List of earthquakes that occurred near Hyderabad (within 300 km radius)

Date	Location	Latitude	Longitude	Moment magnitude	Date	Location	Latitude	Longitude	Moment magnitude
18 October 1800	Ongole	15.60	80.10	4.30	9 June 1990	Manuguru	17.90	80.60	4.00
31 December 1820	Nellore	14.50	80.00	4.30	9 June 1990	Manuguru	17.90	80.50	5.00
12 March 1843	Hyderabad	17.50	78.50	3.70	9 June 1990	Bhadrachalam	17.90	80.50	5.00
21 July 1859	Guntur	16.30	80.50	4.30	18 October 1992	Maharashtra	18.07	76.86	4.77
24 July 1861	Krishna	16.40	77.30	3.70	02 November 1992	Maharashtra	18.22	76.56	4.35
11 March 1867	Ongole	16.00	80.30	3.70	29 September 1993	Maharashtra	18.09	76.44	5.28
13 October 1956	Ongole	15.70	80.10	5.00	29 September 1993	Maharashtra	18.07	76.45	6.30
12 October 1959	Ongole	15.70	80.10	5.00	30 September 1993	Maharashtra	18.16	76.66	4.86
08 October 1960	Ongole	16.00	80.30	4.30	30 September 1993	Maharashtra	18.09	76.52	4.94
27 March 1967	Ongole	15.60	80.00	5.40	08 October 1993	MH-AP	17.93	76.40	5.03
14 April 1968	AP	18.00	80.80	6.10	29 October 1993	KT-AP	17.37	77.47	5.28
27 July 1968	Bhadrachalam	17.60	80.80	4.50	12 November 1993	Maharashtra	18.12	76.53	4.94
16 January 1969	Rayachoti	14.10	78.70	4.10	24 May 1995	Guntur	15.60	79.40	4.00
13 April 1969	Bhadrachalam	17.90	80.60	5.70	14 December 1995	Maharashtra	18.13	76.54	4.69
14 April 1969	Kothagudem	18.00	80.50	5.70	04 August 1996	Addanki	15.80	80.00	4.10
11 July 1970	Bhadrachalam	17.90	80.60	4.10	10 November 1996	Maharashtra	18.30	76.70	4.52
28 July 1971	Ongole	15.50	78.60	4.30	03 February 1999	Yellandu	18.10	80.40	4.00
02 October 1980	Rajamundry	16.90	82.00	4.00	19 June 2000	Maharashtra	18.01	76.49	4.77
27 January 1982	Gandipet	17.40	78.30	3.30	6 September 2007	Maharashtra	18.06	76.54	4.09
30 June 1983	Medchal	17.60	78.50	4.00	19 September 2011	MH-KT	17.92	76.56	4.43
3 December 1987	Ongole	15.30	79.80	4.00	25 January 2020	Jaggayyapeta	16.68	79.90	4.86
3 December 1987	Ongole	15.50	80.20	4.00	–	–	–	–	–

Source: ref. 5.

the deep crustal interiors[6]. The hard rocks are devoid of porosity, but the joints, fractures, faults and lineation can hold large volumes of groundwater, which is transported deeper. Like precipitation, surface run-off, etc. hydrological events at the earth's surface cause water to travel deeper through the joints, fractures and faults, triggering vibrations with thudding sounds. This phenomenon is called hydro-seismicity. From an analysis of the Indian Remote Sensing satellite 1D Linear Imaging Self-Scanning Sensor-III (IRSID LISS-III) satellite image acquired from the National Remote Sensing Agency (NRSA), Hyderabad, nearly 20 lineaments were mapped[7]. The main orientations of these lineaments are north–south (NS), north east–southwest (NE–SW) and east southeast–west northwest (ESE–WNW).

A series of minor and moderate earthquakes have occurred in Hyderabad (Table 2). Often, moderate earthquakes occur in Bhadhrachalam, Guntur and Ongole areas that fall within a 300 km radius of Hyderabad. There is a trend of occurrence of microearthquakes in the above regions at regular intervals. On the night of 25 January 2020, an earthquake of magnitude 4.5 occurred at 32 km southwest (SW) of Jaggayyapeta town which is 190 km from Hyderabad. Quakes were reported to be felt in Hyderabad. Table 3 presents the list of earthquakes within 300 km radius from Hyderabad. Figures 1 and 2 show the seismicity near Hyderabad region.

Behaviour of buildings during past earthquakes

During an earthquake, buildings are deemed to be safe when there is neither loss of life nor loss of contents of buildings, appendages to building and also no disruption to the services and utilities[8]. The overall size and configuration of reinforced concrete (RC) buildings play a crucial role in their performance during an earthquake. One of the common features in multi-storey buildings across India is the presence of open ground storey for vehicular parking. During an earthquake, buildings with such features either collapse or the structural elements on the ground floor are severely damaged. Figure 3 *a* and *b* shows the collapse and severely damaged columns of two separate buildings in Ahmedabad, Gujarat, during the 2001 Bhuj

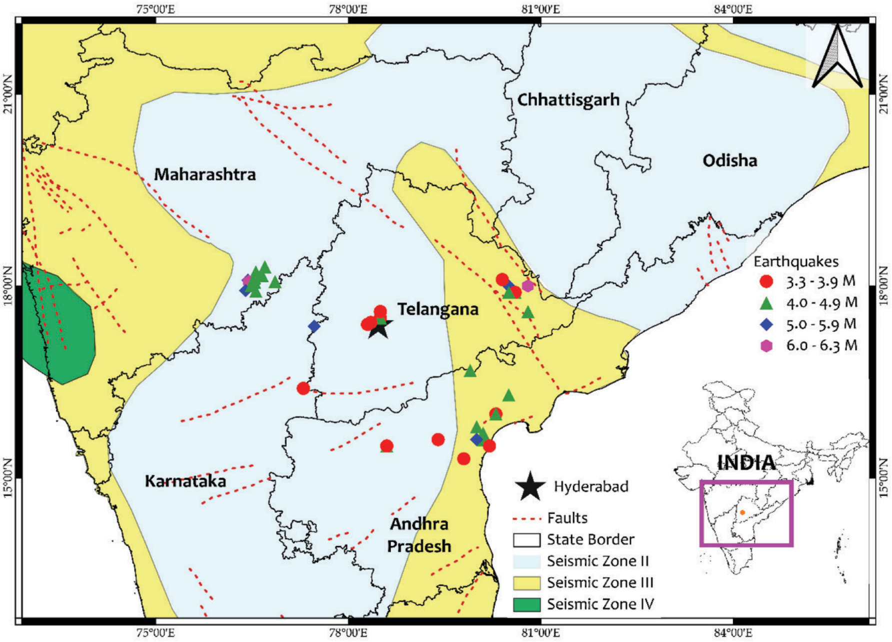

Figure 1. Seismicity near Hyderabad region (M = 3.3–6.3) from 1800 to 2020 (data source: ref. 5).

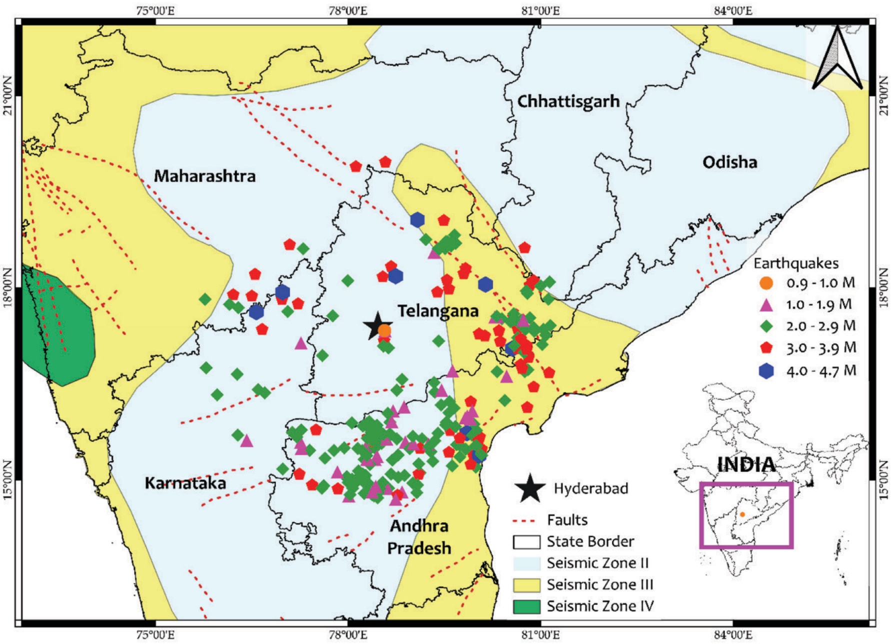

Figure 2. Seismicity near Hyderabad region (M_D = 0.9–4.7) from 1996 to 2010 (data source: ref. 14).

earthquake[9]. It has also been observed from the past earthquakes that buildings with intermediate soft and weak storeys are prone to failure. Similarly, buildings with floating columns and overhanging beams are a potential threat for failure during lateral shaking. Figure 4 *a* and *b* shows the failure of buildings due to overhangs and floating columns respectively, in Ahmedabad, during the 2001 Bhuj earthquake[9]. Majority of the multi-storey buildings in Hyderabad also possess the features mentioned above and are vulnerable to seismic hazard. Figures 3 *c* and 4 *c* depict the construction practice of open ground storey with unidirectional columns and buildings with large overhangs present in Hyderabad respectively.

In addition to the structural features, non-structural elements (NSEs) in high-rise buildings are more sensitive to ground motion compared to those in medium-rise and low-rise buildings. The recent 2013 Wellington earthquake, 2015 Gorkha earthquake, and 2016 Central Italy earthquake

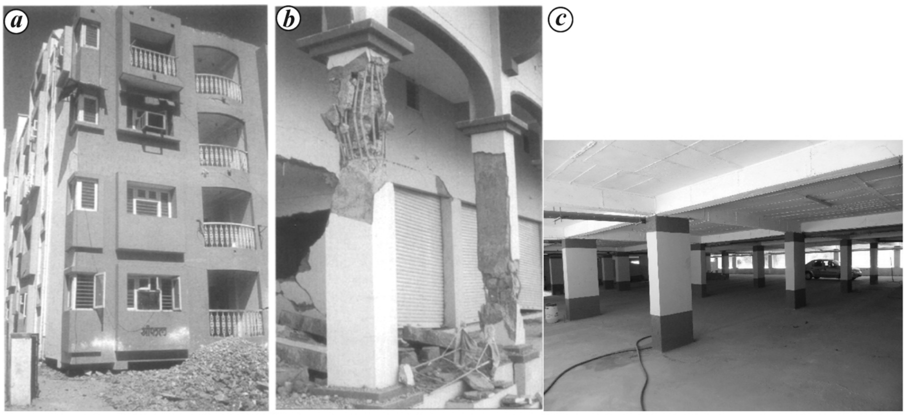

Figure 3. ***a***, Collapse of an apartment building in Ahmedabad city, Gujarat during the 2001 Bhuj earthquake (image courtesy: Murty *et al.*[9]). ***b***, Severely damaged open ground storey column which did not collapse (image courtesy: Murty *et al.*[9]). ***c***, Typical example of open ground storey for car parking with unidirectional column orientation in Hyderabad city.

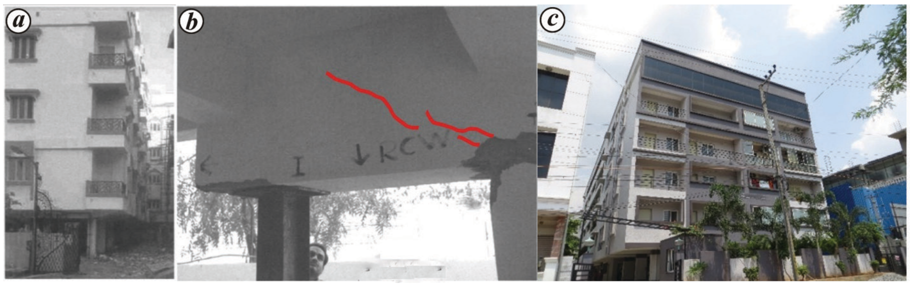

Figure 4. ***a***, Perimeter columns of building supported by tapered cantilever beams (image courtesy: Murty *et al.*[9]). ***b***, Shear cracks in beams supporting floating column (image courtesy: Murty *et al.*[9]). ***c***, A typical RC building with large overhang cantilever beams in Hyderabad city.

Figure 5. In-plane and out-of-plane damage in a high-rise building during the 2015 Gorkha earthquake, Nepal (image courtesy: Lizundia *et al.*[10]).

Figure 6. Photograph of Niligiri Building, International Institute of Information Technology (IIIT), Hyderbad.

are few cases that highlight the poor performance of NSEs. Figure 5 depicts the damage to masonry infill walls of Parkview horizon complex, Kathmandu, Nepal[10]. In addition, it has been observed that the locations close to the epicentre are subjected to ground motions which contain short-period pulses that are potentially dangerous to NSEs in high-rise buildings. The study of the performance of NSEs in India and the world is still in its nascent stage and beyond the scope of this work.

Ground motions due to tremors

The engineering characteristics of tremors observed in the last week of October in Hyderabad were studied using building vibration sensors installed at IIIT, Hyderabad (Figure 6). The epicentre has been reported at 17.4337°N, 78.3322°E located near ‘My Home Vihanga’ residential complex[1]. The instrument was located at IIIT Hyderabad at a distance of 2.3 km. The structural health of the Nilgiri Building was monitored using the building vibration sensors installed (Figure 7). Since the established epicenter of the tremors was near the building under study, the ground vibrations obtained on the building ground floor

Table 4. Engineering characteristics of ground motions observed during tremors at Hyderabad

Event ID	Date	Time	PGA (cm/sec^2) NS	PGA (cm/sec^2) EW	PGA (cm/sec^2) UD	Predominant period (sec) NS	Predominant period (sec) EW	Predominant period (sec) UD	Trifunac's duration (sec)
117	18 October 2020	12:44	4.0068	4.9731	2.9080	0.12–0.23	0.06–0.08	0.11–0.15	3.9
221	18 October 2020	14:31	0.7534	0.6083	0.2711	0.04–0.05	0.06–0.08	0.13–0.18	5.4
121	18 October 2020	14:31	0.6226	0.3572	0.1579	0.04–0.06	0.05–0.08	0.08–0.23	2.4
126	18 October 2020	17:04	0.2153	0.2736	0.1145	0.06–0.23	0.10–0.16	0.06–0.10	3.0
131	18 October 2020	18:36	0.2476	0.5573	0.1316	0.04–0.05	0.04–0.08	0.09–0.13	3.0
133	18 October 2020	19:11	0.2192	0.0746	0.0992	0.04–0.05	0.13–0.20	0.11–0.16	6.0
137	18 October 2020	21:07	2.4631	3.1111	0.9642	0.12–0.17	0.06–0.07	0.10–0.17	9.0
139	18 October 2020	21:17	0.6929	0.2714	0.1954	0.04–0.05	0.05–0.08	0.07–0.16	4.8
140	18 October 2020	21:18	0.685	0.3016	0.1743	0.04–0.05	0.06–0.07	0.11–0.15	6.0
148	19 October 2020	05:21	0.2055	0.1127	0.0763	0.04–0.06	0.04–0.05	0.06–0.09	2.1

NS, North–South; EW, East–West; UD, Up–Down.

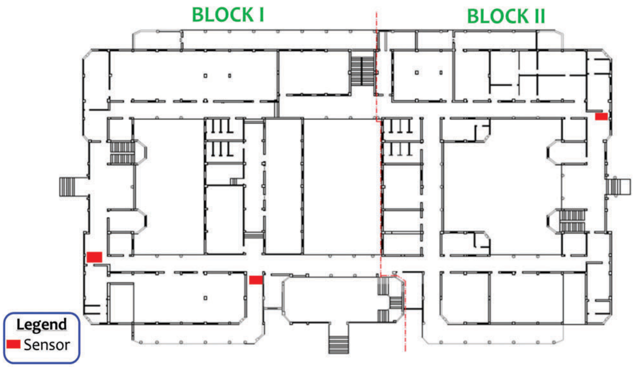

Figure 7. Plan view of Nilgiri Building with sensor location.

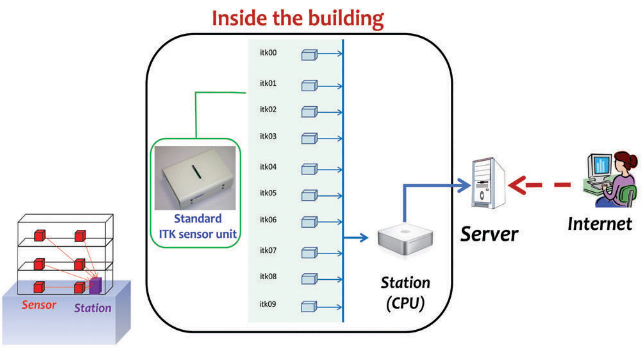

Figure 8. System configuration and the set of installed sensors.

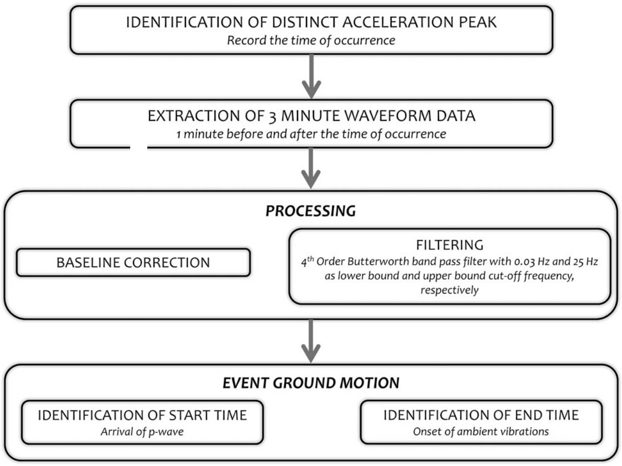

Figure 9. Flow chart of data processing.

were analysed to understand the engineering characteristics of ground motion during tremors.

The sensors were installed with a permanent network set-up and connected to a server. Figure 8 shows the system configuration and installation. The ambient vibration response of the building was recorded continuously. Data were acquired at a sampling rate of 100 and frequency of 0–50 Hz in the north–south (NS), east–west (EW) and up–down (UD) directions. The sensors include network-connected seismometers developed and standardized at the IT Kyoshin Consortium, Japan. The NS and EW components of sensors were oriented along shorter and longer dimensions of the building respectively.

The recordings from the ground floor were extracted from 16 to 22 October 2020, resulting in 74 events from the installed sensor. From the continuous ambient vibration, the peak was identified as a tremor. Around the peak, 1 min before and after, data were extracted for further processing. Performing baseline correction and filtering resulted in obtaining 45 accepted seismic tremors. The baseline correction was done using the standard MATLAB function, and a fourth order Butterworth band-pass filter was used for the filtering with suitable lower and upper cut-off values of 0.03 and 25 Hz respectively. From the corrected accelerogram, arrival of the *P*-wave was considered as the start of the record. The time step at which the vibration become normal, i.e. back to ambient vibration, was considered as the end time of the record. Figure 9 is a flow chart of the entire process adopted. Table 4 shows the engineering characteristics of the ten most critical tremors observed in one week. Figure 10 shows the 10 acceleration time histories with maximum peak ground acceleration (PGA).

From an engineering perspective, the most essential ground motion characteristics include PGA, predominant

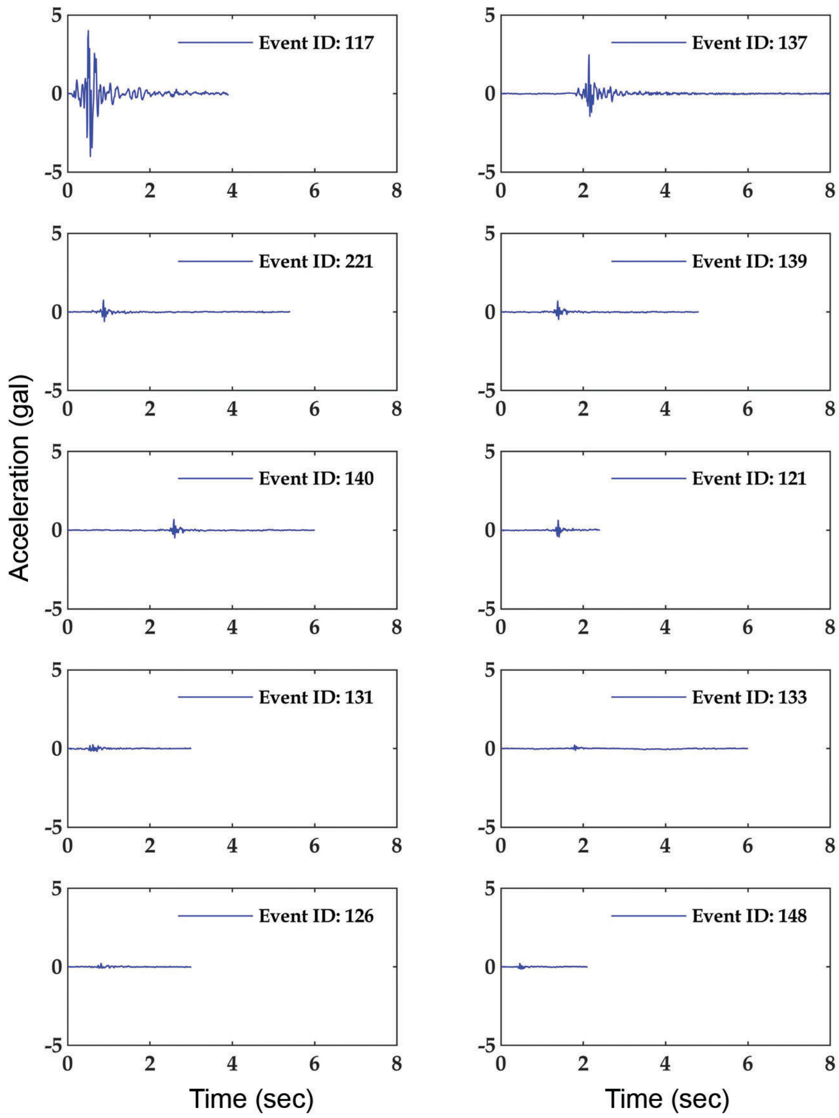

Figure 10. Ground motions recorded at the Block II, Nilgiri Building, IIIT-H.

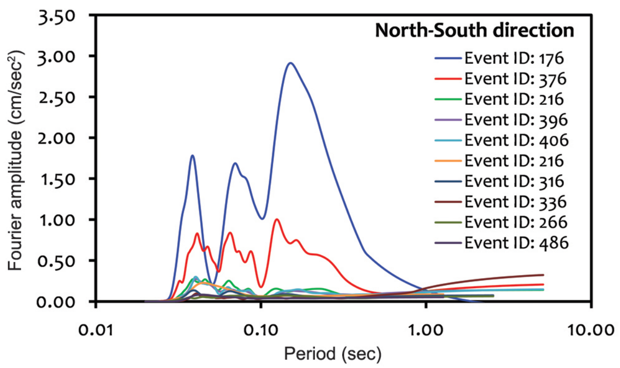

Figure 11. Fourier amplitude spectra of ground motions along north–south direction.

frequency range and effective duration. PGA is the absolute maximum value of acceleration in the time history of ground motion; predominant frequency range is defined by the half-power bandwidth measured as the range of frequencies that has $1/\sqrt{2}$ times the maximum Fourier amplitude of the ground motion. Effective duration is defined as the time difference between instants at which the amplitude is greater than 5% and becomes less than 95% of the cumulative acceleration[11].

Figures 11 and 12 show the Fourier amplitude spectra of all the ground motions recorded during tremors in the NS and EW directions respectively. The maximum value of Fourier amplitude from ground motions in the NS direction was 2.91 cm/sec^2 and in the EW direction it was 3.18 cm/sec^2. From the definition of half-power bandwidth, the value of $1/\sqrt{2}$ times maximum Fourier amplitude is 2.06 cm/sec^2 in the NS direction and 2.25 cm/sec^2 in the EW direction. Likewise, the predominant period range of the top events is located at 0.05–0.20 sec. This observation also indicates that the ground motions are critical for

Table 5. Acceleration and displacement response along with amplification of Niligiri Building (Block II), International Institute of Information Technology (IIIT-H) for the highest peak ground acceleration (PGA) tremor

	Acceleration (cm/sec^2)		Displacement (cm)	
Floor level	Along shorter direction (NS)	Along longer direction (EW)	Along shorter direction (NS)	Along longer direction (EW)
Second floor (ITK08)	7.109	5.980	0.0061	0.0026
Ground floor (ITK06)	3.460	4.690	0.0026	0.0013
Amplification ratio (ITK08/ITK06)	2.055	1.275	2.324	1.983

NS, North–south; EW, East–west.

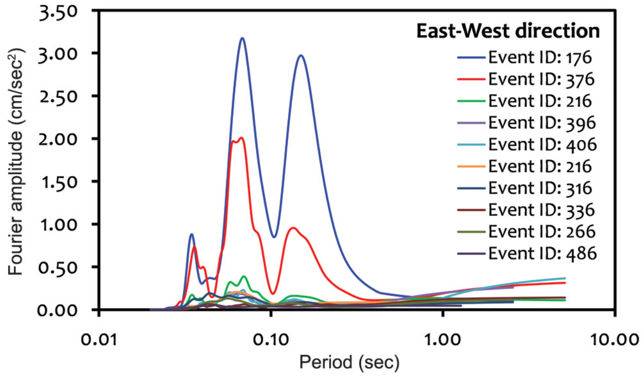

Figure 12. Fourier amplitude spectra of ground motions along east–west direction.

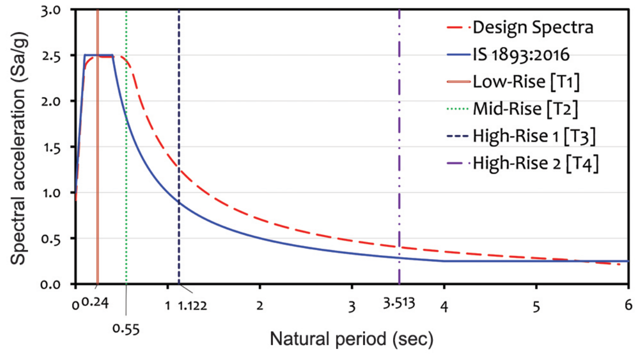

Figure 13. Comparison of 5% damped design spectrum specified in IS 1893: 2016 and that developed from the observed ground motions for the location under consideration.

those buildings with a natural period ranging between 0.1 and 0.3 sec. The match of the natural period of buildings with the predominant period of ground motion creates resonance-like conditions leading to large inelastic deformations. Although the recorded tremors have minimal PGA values, amplification of the same ground motion causes a concerning factor for the low- to mid-rise buildings. The effect of the recorded ground motions on the structure can be well understood from a site-specific response spectrum.

Site-specific response spectrum

Any building is designed for a lateral force equal to a certain percentage of seismic weight that depends on the seismic zone, the importance of structure, lateral load resisting system, and the spectral acceleration observed by the building present on a particular type of soil. According to IS 1893 (Part 1): 2016, Hyderabad lies in seismic zone II with an expected PGA of 0.1 *g*. The maximum spectral acceleration prescribed is 2.5 for the structures present in the city. However, these code-specified values are adopted from past earthquake data observed during macro-seismic studies. Therefore, it is crucial to verify the spectral amplification evident during the recent tremors observed.

A site-specific design spectrum indicates the effect of tremors on the existing building stock in the city. The design spectrum was developed using the standard procedure[12]. Figure 13 shows the design spectrum obtained from ground motion data observed during the recent tremors compared to the design spectrum specified by the standard code IS 1893 (Part 1): 2016. The generated spectra were used to determine the response of different categories of buildings in the preceding section.

Experimental study

As discussed earlier, the building response of Block II of the Niligiri Building was recorded successfully. Figures 14 and 15 show the acceleration and displacement response recorded for the highest PGA tremor respectively. The highest PGA experienced at the ground level was 3.460 and 4.690 cm/sec^2 along the shorter and longer building dimensions respectively. This value was amplified by 2.06 and 1.28 times along the shorter and longer side of the building respectively, resulting in a maximum acceleration value of 7.109 and 5.980 cm/sec^2 respectively on the second floor of the building (Table 5). Similarly, the displacement on the second floor was amplified by 2.32 and 1.98 times the displacement on the ground floor along the shorter and longer side respectively. It was observed that both acceleration and displacement were too low to cause any damage to the building. However, there was good certainty that amplification of acceleration and

Table 6. Structural details of the buildings analysed

	Niligiri Building	G + 1	G + 3	G + 16	B1 + G + 40
Number of storeys	3	2	4	17	42
Typical storey height (m)	3.6	3.0	3.0	3.2	3.3
Total height from base (m)	10.80	6.00	12.00	54.40	145
Plan dimension (m)	36.4 × 49.7	5.1 × 12.6	9.0 × 9.0	42.0 × 30.0	32.0 × 28.0
Usage	Educational institution	Residential	Residential	Office	Residential
Structural system	Moment resisting frame (MRF)	MRF	MRF	MRF + structural wall (SW)	SW
Maximum natural period (sec)	–	0.240	0.550	1.122	3.513
Soil type	–	Type I			
Importance factor (*I*)	–	1			
Response reduction factor (*R*)	–	3			

G, Ground floor; B, Basement.

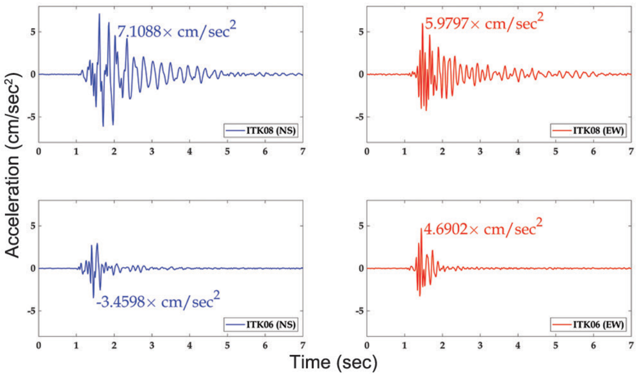

Figure 14. Acceleration time history of ground floor and second floor sensors of Niligiri Building, IIIT Hyderabad.

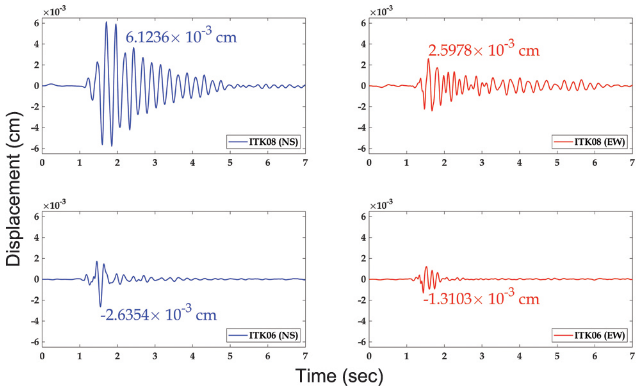

Figure 15. Displacement time history of ground floor and second floor sensors of Niligiri Building, IIIT Hyderabad.

displacement would be in the range of 1.2–2.3 times the shaking at the base level of the building. Further study of the same block was done with the help of an analytical model subjected to site-specific response spectra.

Analytical study

The Niligiri Building, whose response to tremors has been discussed above, was modelled first. This is necessary since details of this building are well known. The instrumented Block II of the Niligiri Building is the (G + 2) RC structure used for academic purpose. Further, to determine the effect of tremors on the existing building stock in Hyderabad, four more RC buildings representing the typical architectural and structural feature were modelled and analysed using the commercial Finite Element Modelling (FEM) software ETABS (version 18.1.1). To ensure diversification, buildings were selected such that they cover low-rise (up to two storeys), mid-rise (<18 m) and tall (>50 m) structures. Among the four RC representative buildings, two represent low- and mid-rise residential buildings respectively. Out of the remaining two, one represents a commercial building used as an office having a simple rectangular plan. The other represents a tall residential buildings to be constructed in the Cyberabad region. Table 6 provides the basic details of all the five buildings considered in this study. Figures 16 and 17 show the plan and elevation of these buildings.

Block II of the Nilgiri Building was modelled exactly as it exists, whereas the remaining four buildings considered in this study were assumed to be designed by IS 1893: 2016 seismic code. According to the specified regulation in the seismic code, Hyderabad is in seismic zone II. The buildings considered have been designed for importance factor (*I*) of 1 and response reduction factor (*R*) of 3. The soil profile of Hyderabad is rocky, type-I soil, which was opted for the design.

All the five buildings were assessed based on site-specific design spectra generated using the observed local tremors. Five assessment load cases were considered to determine the effect of tremors on the buildings. For case one, the response spectrum analysis was done by amplifying site-specific design spectra with an actual observed highest PGA of 4.97 cm/sec^2. The remaining four cases of response spectrum analysis were considered by amplifying the site-specific design spectra for PGA values of seismic zone II–V as specified in IS 1893:2016, i.e. 0.1, 0.16, 0.24 and 0.36 *g* respectively. For the above five cases, lateral load was applied to the structure, and linear inter-storey drift was checked against the limiting value specified according to IS 1893:2016.

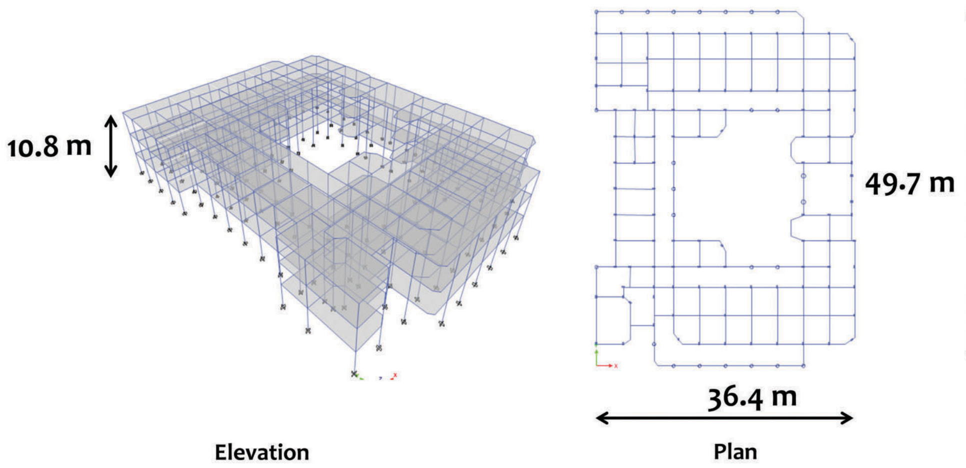

Figure 16. Elevation and plan of analytical model of Block II, Nilgiri Building, IIIT-Hyderabad.

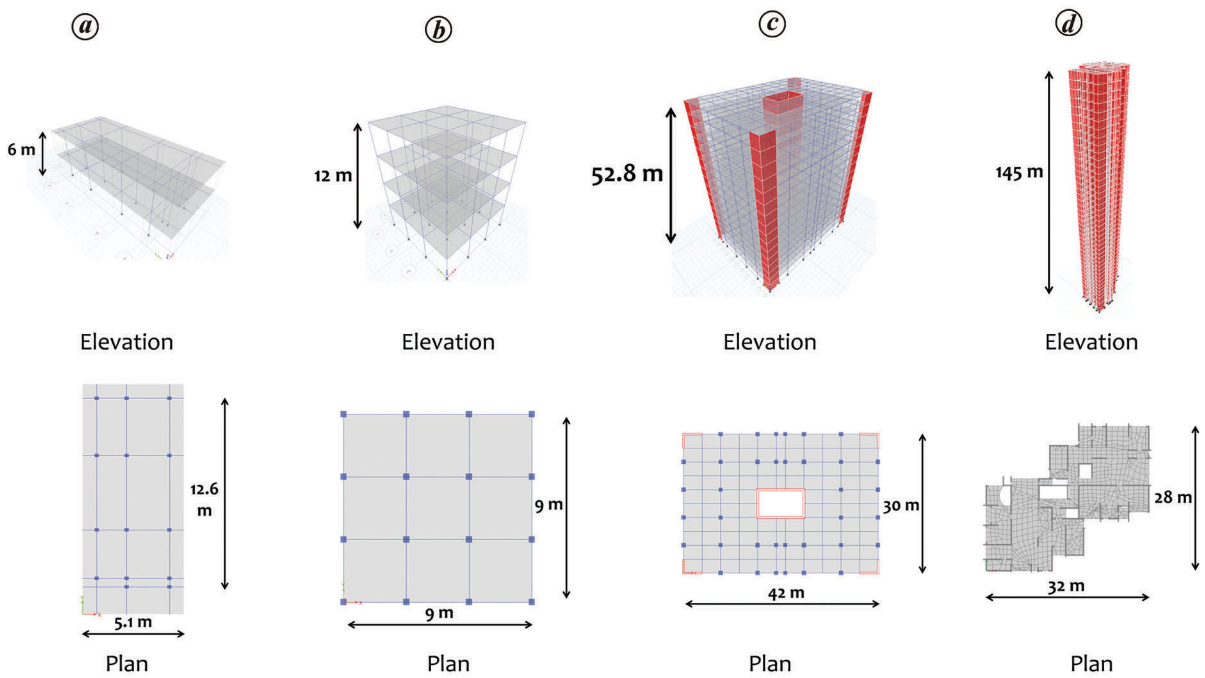

Figure 17. Plan and elevation of buildings under consideration: (***a***) G + 1; (***b***) G + 3, (***c***) G + 16, (***d***) B + G + 40 (G, ground; B, basement).

Observations and discussion

As specified above, response spectrum analysis based on site-specific design spectra was carried out for all the five buildings. The percentage of inter-storey drift values was consolidated for each building for all site-specific spectra analyses (Tables 7 and 8). The observed maximum PGA of recorded tremors was 4.97 cm/sec^2, which is about 0.005 *g*. When the site-specific design spectrum was amplified with this value, the inter-storey drift was found to be much less and within the code-specified inter-storey drift limit. This is true since the applied force is much less than the equivalent force for zone II for which the buildings were designed. However, as an assessment was carried out with the respective PGA values of zones II–V, the inter-storey drift values were found to increase for linear analysis.

While observing the inter-storey drift values of Niligiri Building, the drift along the shorter (*X*) side of the building was more compared to that on the longer side (*Y*) for all five cases. Further, inter-storey drift values were higher than the remaining four buildings, since the Niligiri Building is the oldest among all and is designed based on IS 1893:1984. However, it is interesting to note that the inter-storey drift limit did not cross the code-specified limiting value for all five cases. Assessment showed that

Table 7. Analytical study results of Block II, Nilgiri Building, IIIT-H

Analysis of Block II, Nilgiri Building, IIIT-H		Inter storey drift (%)	
		Along shorter direction	Along longer direction
Code-specified limiting value	Inter-storey drift limit (IS 1893 (Part-1): 2016)	0.4000	0.4000
Site-specific design spectra	Maximum PGA of the tremor is 0.005 *g* (4.97 cm/sec^2)	0.0086	0.0080
	Zone II: 0.10 *g*	0.0849	0.0787
	Zone III: 0.16 *g*	0.1358	0.1259
	Zone IV: 0.24 *g*	0.2038	0.1889
	Zone V: 0.36 *g*	0.3056	0.2834

Table 8. Inter-storey drift values (%) based on site-specific design spectra assessment

Analysis		G + 1	G + 3	G + 16	B1 + G + 40
		Inter-storey drift (%)			
Code-specified limiting value	Inter-storey drift limit (IS 1893 (Part-1):2016)	0.4000	0.4000	0.4000	0.4000
Along the *X* direction					
Site-specific design spectra	Maximum PGA of the tremor is ~0.005 *g* (4.97 cm/sec^2)	0.0024	0.0044	0.0019	0.0022
	Zone II: 0.10 *g*	0.0236	0.0436	0.0189	0.0221
	Zone III: 0.16 *g*	0.0377	0.0697	0.0302	0.0354
	Zone IV: 0.24 *g*	0.0565	0.1045	0.0453	0.0531
	Zone V: 0.36 *g*	0.0848	0.1568	0.0680	0.0797
Along the *Y* direction					
Site-specific design spectra	Maximum PGA of the tremor is ~0.005 *g* (4.97 cm/sec^2)	0.0032	0.0044	0.0023	0.0020
	Zone II: 0.10 *g*	0.0315	0.0436	0.0223	0.0202
	Zone III: 0.16 *g*	0.0504	0.0697	0.0357	0.0323
	Zone IV: 0.24 *g*	0.0756	0.1045	0.0535	0.0485
	Zone V: 0.36 *g*	0.1340	0.1568	0.0802	0.0727

the current tremors were insignificant and did not cause any damage to the buildings designed according to IS 1893 of the current or previous version. However, higher-magnitude earthquakes might damage non-engineered buildings. Among the four representative sample buildings considered in the present study, the mid-rise building of G + 3 was found to have maximum inter-storey drift compared to the other three buildings. The linear study on limited buildings in the present case shows that high-rise buildings are relatively safe against such local seismic activity. Considering the importance and occupancy rate in such buildings, much care is taken while designing and executing them. However, it must be ensured that such buildings do not come up on a lake-filled area or on soft soil. Soil investigation is a must for such sites to study amplification of seismic waves due to soil properties. On the other hand, many a times low- to mid-rise buildings are non-engineered in nature and are of higher stiffness. Such buildings are greatly affected by local seismic activity since they attract higher force due to inherent relative higher stiffness. Vulnerable features such as large overhangs and soft storeys should be avoided in such buildings. In future, it is suggested that all such buildings must be designed and executed by competent engineers. For the existing building stock in Hyderabad city, rapid visual screenings (RVS) should be taken up to identify the common seismic vulnerable features and the ward having a maximum number of such building stock. Findings from RVS will help the municipal administration to plan mitigation efforts and revise the city building bylaws to design better buildings.

Conclusion

A study was conducted on the ground motion and building response recorded at IIIT, Hyderabad, 2.3 km from the epicentre. Initially, the ground motion recordings were studied in detail and later, a site-specific design spectrum was developed. From the experimental study of the instrumented building at IIIT, Hyderabad, it was found that the existing tremor did not cause any damage to the building. However, amplification of acceleration and displacement in the second storey will be in the range 1.2–2.3 times the shaking at the base level for all such future micro-tremors originating from the study area. Further, four representative buildings were considered in the analytical study, viz. G + 1, G + 3, G + 16 and B +

G + 40 stories. The inter-storey drift values for all five buildings were found to be within the code-specified limiting value when checked using response spectra analysis with site-specific spectra, amplified to the highest observed PGA of 4.97 cm/sec^2 (approximately 0.005 *g*) and various seismic zone PGA values (0.10–0.36 *g*). It can be concluded that if the tremors are amplified, there is a high chance of risk/threat to low-rise buildings, mid-rise buildings and non-structural elements in high-rise buildings. To precisely understand the vulnerability of the existing building stock in Hyderabad city, RVS followed by a detailed assessment has to be carried out.

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Received 29 January 2021; re-revised accepted 11 February 2022

doi: 10.18520/cs/v122/i10/1174-1184