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Field investigation of the 30 September 1993 earthquake in Maharashtra

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An engineering field study of the 30 September Marathwada earthquake is reported. The study covered Osmanabad, Latur, Sholapur, Bijapur, Gulbarga and Bidar districts. The level of ground acceleration was estimated based on tilting of free standing objects. The study shows that the epicentral intensity has been VIII on the UNESCO scale. The horizontal ground acceleration near the epicentre has been estimated to be about 0.2 *g*.

THE 6.4 magnitude earthquake of 30 September 1993 with its epicentre in the Marathwada region of Maharashtra has been a reminder that peninsular India is also seismically active. This earthquake which was felt in the distant cities of Bangalore and Madras has resulted in complete destruction of several villages located in the epicentral tract.

From past data available for about 300 years it can only be said that earthquakes are more frequent in the Himalayan region than in other parts of India. Since the available historical data are scanty, other regions wherein seismic activity is less frequent, are not well delineated. This may be the reason for the popular opinion that peninsular India in general and Deccan plateau in particular, is aseismic. On the contrary, from well documented historical data it is known[1] that during the period 1340–1984, nearly 300 earthquakes have occurred in the peninsular region (8° N–25° N latitude). Of these, 70 events have been of magnitude 5 and above. Still considering the vastness of peninsular land mass, for any given subregion, the average recurrence interval of a strong earthquake is perhaps of the order of centuries. This is in contrast to the frequent occurrence of earthquakes in the northeastern parts of India, which in turn, has influenced construction practices in rural areas of Assam and neighbouring states. This observation explains to some extent the large number of house collapses and subsequent loss of life in the Marathwada region.

Objectives

The field study was undertaken (i) to understand the extent and severity of structural damage from an engineering point of view and (ii) to estimate ground acceleration values through a study of displaced rigid objects. This is perhaps the only reasonable means to find the severity of ground shaking, since there are no strong motion records available for the event.

The earthquake

After the Koyna earthquake of 11 December 1967, which was of magnitude 6.8, the present earthquake of magnitude 6.4 on 30 September 1993 has been the major seismic event in this part of the country. The epicentre of this event has been identified by the USGS as 18.22° N, 76.356° E. However NGRI[2], Hyderabad has fixed the epicentre as 18° N, 76.5° E. The focal depth is estimated to be between 5 and 15 km. During the earthquake, the ground reportedly shook for about 30 to 40 s, destroying about 25 villages such as Khilari, Kavatha, Sastur, Rajegaon, Ekkundi, Pethsanghavi among several others in the epicentral tract (Figure 1*a*). Prior to the main shock, there were many reports of earth tremors from these places. Events which preceded the main event by about a month had magnitudes ranging from 3.2 to 5.1. The severest of these, with $M = 5.1$, occurred on 28 August 1993. During the three month period 1-10-1993 to 30-12-1993, several aftershocks with more than ten events having magnitude greater than 4 have originated from the epicentral region.

Damage survey

The field study was done in three stages. The districts of Bijapur in Karnataka and Sholapur in Maharashtra were surveyed first. This was followed by a longer visit to Gulbarga, Bidar, Latur and Osmanabad districts. In the third stage, a few towns and villages not well covered in the two previous visits were surveyed. Since the affected region is too vast and diverse to traverse, the authors have restricted their attention to the towns and villages affected as reported by the administrative district officials.

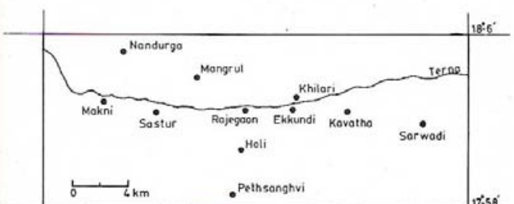

Figure 1*a*. Index sketch of river Terna, Khilari and nearby villages.

Epicentral tract

The topography of the region affected by the earthquake may be described as being mildly undulating. A view of the region as seen from an elevated site on the Gulbarga–Bidar highway is shown in Figure 2. The landscape is punctuated with many flat topped mounds interspersed with plain lands of black cotton soil and gentle valleys in which flow the rivers Terna, Bheema and Manjra. The predominant local building material in the rural areas is the freely available trap stone from the mounds (Figure 3).

The maximum damage due to the earthquake is generally identified as being in Khilari which is on the northern side of the river Terna. The nearby villages of Mangrul and Nandurga which are on the same side of the river and the villages of Rajegaon, Ekkundi, Kavatha and Pethsanghavi on the southern side of the river have also been devastated by the earthquake. However, the damage has decreased by an order of magnitude beyond a distance of about 15 km from Khilari.

Seismic intensity evaluation

The effects of a seismic event at any given location on man-made structures, natural objects and also on public mind can be quantified using well established earthquake intensity scales. The intensity is a descriptor

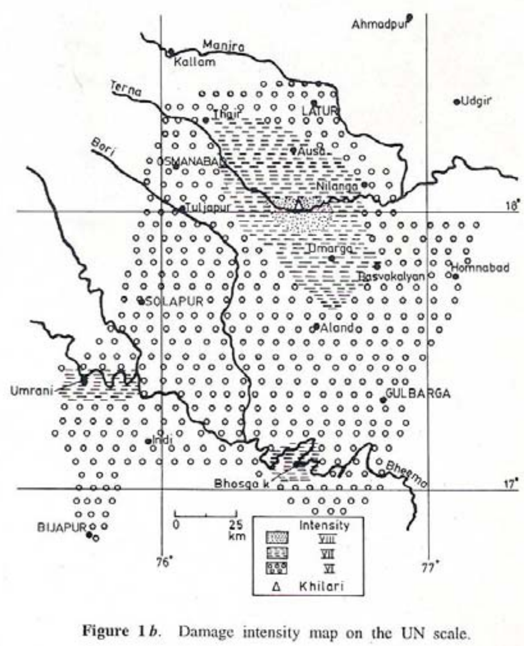

Figure 1*b*. Damage intensity map on the UN scale.

Figure 2. Terrain view.

Figure 3. Soil section of a mound.

of the earthquake at a particular location. This depends not only on the site and earthquake source parameters, but also on the construction quality prevailing in the region. Presently, there are two widely accepted intensity scales, namely, the modified Mercalli intensity (MMI) scale and the UNESCO intensity scale[3] (same as MSK scale). On both these scales there are twelve ratings. For an earthquake of magnitude 6 to 7, the epicentral intensity can be expected to be in the range of VII–X on either of the above scales[4]. Of the two scales, the UNESCO scale is more precise and measures the damage to buildings on a finer scale. This scale has been adopted in the present study. The UNESCO scale classifies buildings into three groups, measures damage levels on five grades and quantifies damage ratios at three percentages. On the basis of all these three informations and a few others, the intensities are worked out (Table 1). The intensity map, according to the present field study, is shown in Figure 1*b*. The epicentral intensity is estimated to be VIII. This drops by one unit beyond about 15 km from the epicentre.

Figures 4–10 and Figures 11–15 show, respectively, the scenes of damage observed in the epicentral region and in the region within about 120 km from the epicentre. The arrangement of these figures follows the UNESCO classification of building types and damage levels as given in Table 1. While categorization into building type and damage levels was reasonably straightforward, assigning damage ratio, on the other hand, has been difficult outside the epicentral region. The damage pattern observed in the epicentral region (Figures 4–10), satisfies the criteria outlined in Table 1 for an earthquake intensity of VIII. Apart from damages to buildings, the UNESCO intensity scale also lists effects which might be observed on watertables and earth slopes. There were many reports of anomalous behaviour of watertable in the epicentral region. This also points towards an intensity of VIII. The damages shown in Figures 11–15 are at places away from the epicentre. The extent of damage observed indicates an intensity of VII. Figures 11 and 12 refer to damage in Umerga and Basavakalyan at a distance of 25 km and 55 km from Khilari respectively. In this region four landslides on a steep cutting adjoining a road near Basavakalyan in Bidar district were also observed (Figure 13). This observation also supports assigning an intensity of VII to this region. Figures 14 and 15 show damage in Bhosga-K, a village on the banks of Bheema river at a distance of 120 km from Khilari. Similarly, a small region around Umrani in Bijapur district on the bank of Bheema river shows an intensity of VII. In Figure 1*b*, the region of intensity VI has been marked up to what has been surveyed by the authors. Thus, the actual boundary of region of intensity VI is not limited to what has been shown in Figure 1*b*. An interesting feature of this earthquake was that it was felt more widely and severely to the south of the epicentre than to the north. This fact is reflected in Figure 1*b* with two small regions of VII intruding into the bigger region of intensity VI. Unusual local geology and soil conditions might have led to this anomaly.

Non-residential structures

We inspected several engineered structures such as water tanks, earthen dams, hydraulic works, bridges, industrial structures and electric substations in the affected area. Figures 16–19 show some of the conspicuous scenes of damage observed. Among these, the catastrophic failure of the overhead water tank at the epicentral village of Kavatha is the most striking (Figure 16). This structure had a spiral staircase adjoining the circular tank portion which made the structure asymmetric in plan. Further, the tank was reportedly partially filled at the time of the earthquake. It is of interest to note that a water

Table 1. UNESCO (MSK) intensity scale (abridged)

Type of structures

Structure A	Buildings in field-stone, rural structure, unburnt brick houses, clay houses.
Structure B	Ordinary brick buildings, buildings of large block and prefabricated type, half timbered structures, buildings in natural hewn stone.
Structure C	Reinforced buildings, well-built wooden structures.

Damage to structures

Grade 1	Slight damage	Fine cracks in plaster, fall of small pieces of plaster.
Grade 2	Moderate damage	Small cracks in walls, fall of fairly large pieces of plaster, pantiles slip off, cracks in chimneys, parts of chimney fall down.
Grade 3	Heavy damage	Large and deep cracks in walls, fall of chimneys.
Grade 4	Destruction	Gaps in walls, parts of buildings collapse, separate parts of building lose their cohesion, inner walls collapse.
Grade 5	Total damage	Total collapse of buildings.

Definition of quantity

Single, few	About 5%
Many	About 50%
Most	About 75%

Expected damages to buildings at different intensities

Intensity	VI	VII	VIII	IX	X
Building type					
A	Many grade 1 Few grade 2	Most grade 3 Few grade 4	Most grade 4	Many grade 5	Most grade 5
B	Few grade 1	Many grade 2	Most grade 3	Many grade 4 Few grade 5	Many grade 5
C	–	Many grade 1	Most grade 2 Few grade 3	Many grade 3 Few grade 4	Many grade 4 Few grade 5

Other effects

Intensity	Effects on persons and surroundings
VI	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 a few instances dishes and glassware may break, books fall down. Heavy furniture may possibly move and small steeple bells may ring. In a few cases cracks up to a width of 1 cm possible in wet ground; in mountains, occasional landslips; change in flow of springs and in level of well water are observed.
VII	Most people are frightened and run outdoors. Many find it difficult to stand. The vibration is noticed by persons driving motor cars. Large bells ring. In single instances landslips of roadway on steep slopes; cracks in roads; seams of pipelines damaged; cracks in stone walls.
VIII	Fright and panic; persons driving motorcars are disturbed. Here and there branches of trees break off. Even heavy furniture moves and partly overturns. Hanging lamps are damaged in parts. Small landslips in hollows and on banked roads on steep slopes; cracks in ground up to widths of several centimeters. Water in lakes becomes 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. Occasional breaking of pipe seams. Memorials and monuments move and twist. Tombstones overturn. Stone walls collapse.

Figure 4. Khilari; Type A structures, grade 5 damage.

Figure 5. Khilari; Type A structure, grade 4 damage.

Figure 6. Rajegaon; Type B structure, grade 4 damage.

Figure 7. Kavatha; Type B structure, grade 4 damage.

Figure 8. Khilari; Type C structure, grade 3 damage.

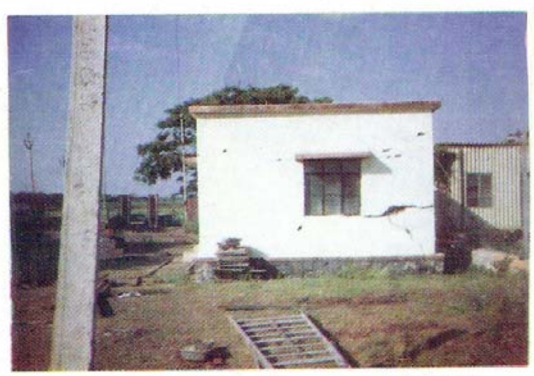

Figure 9. Sastur; Type C structure, grade 3 damage.

Figure 10. Khilari; Type C structure, grade 2 damage.

Figure 11. Umerga; Type C structure, grade 1 damage.

Figure 12. Basavakalyan; Type C structure, grade 1 damage.

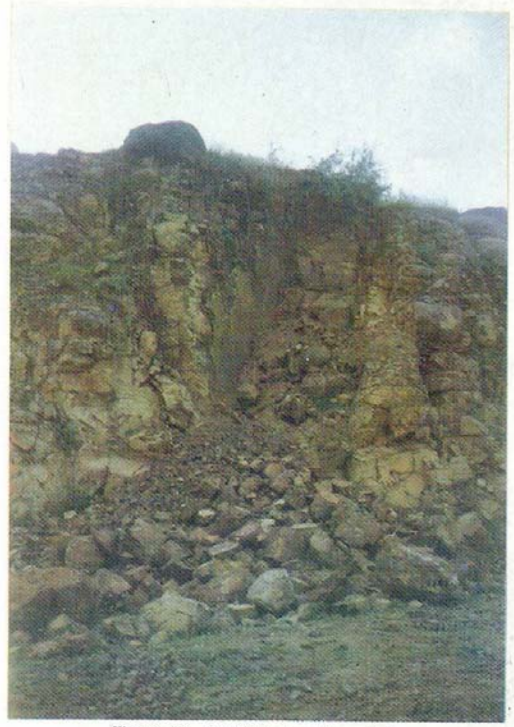

Figure 13. Landslide near Basavakalyan.

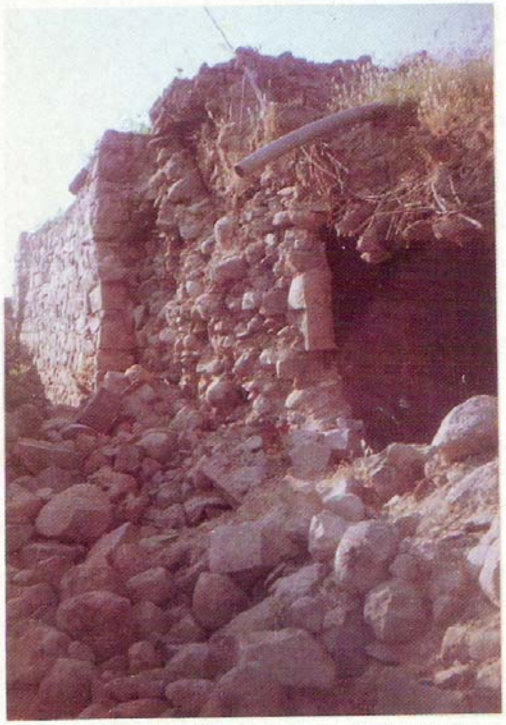

Figure 14. Bhosga-K; Type A structure, grade 4 damage.

Figure 15. Bhosga-K; Type A structure, grade 3 damage.

Figure 16. Circular water tank at Kavatha.

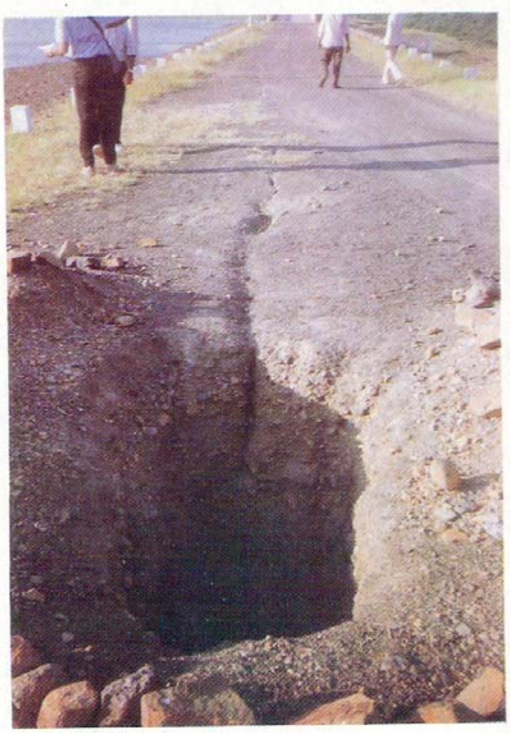

Figure 17. Crack on the top of the Makni dam (pit was dug for inspection).

Figure 18. Retaining wall failure at Kohinoor Pahad near Basavakalyan, Bidar district.

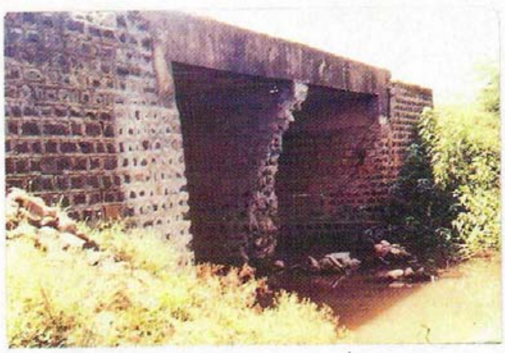

Figure 19. Damaged pier of Rudrawadi culvert near Aland, Gulbarga district.

Figure 20. Hydraulic control structure near Rajegaon.

Figure 21. MSEB substation at Umerga.

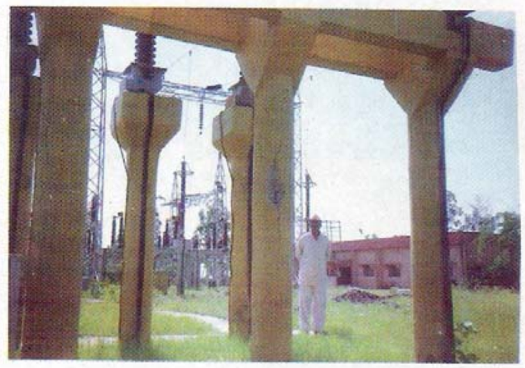

Figure 22. MSEB substation at Umerga.

Figure 23. Broken idols in Kavatha temple.

Figure 24. Clockwise rotation of stone block in Kavatha temple.

Figure 25. Cracked stone wall in Kavatha temple.

Figure 26. Broken stone beam, Ambabhavani temple, Khilari.

Figure 27. Fractured column, Ambabhavani temple, Khilari.

Figure 28. Old fault on Lamjan–Nilanga road.

tank of similar design has survived the earthquake in the town of Umerga 20 km away. Also, rectangular overhead water tanks in the epicentral villages of Khilari and Sastur are still safe. The earthen dam at Makni, about 15 km away from Khilari, developed a 15 m long, 1.2 m deep and 10 to 15 cm wide longitudinal crack at the top (Figure 17). This dam is about 15 m tall, 1.5 km long and has a central concrete masonry control structure of about 400 m long flanked by earth sections. In the top portion of the dam, junctions between the masonry and earth parts showed signs of severe distress. The earthen dam at the Upper Mullamari project near Hallikhed-K, in Bidar district, about 70 km away from the epicentre has remained unaffected. On the other hand, a 200-year-old stone masonry earth-retaining structure collapsed in the village of Kohinoor Pahad, Bidar district, at an epicentral distance of 50 km (Figure 18).

Cracks were observed at the abutments of a few bridges on the national highway between Humnabad and Umerga. The central pier of the Rudrawadi culvert near Aland, about 55 km away from Khilari was considerably damaged (Figure 19). Several culverts and parapets of small bridges in the epicentral region have also suffered damage. Near Khilari, cement concrete pipes of small culverts were damaged. The piers of a stone masonry hydraulic control structure, which was under construction near Rajegaon, have extensively cracked at about mid-height (Figure 20). The RC pads on the top of some of the piers have also cracked exposing the reinforcement at a few places. About 50 km away from the epicentre, RC aqueducts of the Upper Mullamari irrigation works near Hallikhed-K have cracked leaving open the steel at a few places. Some minor distress was also observed at aqueduct canal junctions.

By and large, there was no significant damage to industrial plants in the epicentral region. However, minor damage to brick chimneys and machine foundation bolts was observed in the khandsari factories near Basavakalyan and Humnabad. Signs of land settlement leading to structural damage were observed in the 132 kV electric substation in Umerga. Here, the ground floor within a RC frame structure had subsided by about 2 cm over an area of 5 square meters. In the same place, the foundation slab of a transformer had also cracked due to ground subsidence (Figure 21). Damage to RC columns supporting the insulators can be seen in Figure 22. In the 33 kV electric substation in the epicentral village of Sastur, RC structures suffered considerable damage. In addition, the contact plates in the isolators were broken and also bolts at the joints reportedly came out. In the epicentral region, the electric poles, transmission and communication towers were largely unaffected. At a few places, however, I-section steel poles were seen to have buckled at about 1.5 m from the ground. A few poles running in the fields near Khilari were also observed to have tilted by about 15° to the vertical. There was no damage to railway tracks and roadways. Interestingly, trains which were running in the Sholapur–Gulbarga section at the time of earthquake faced no problems.

Estimation of ground acceleration

As already mentioned, there are no strong motion records available on this earthquake. Consequently, it is of interest to estimate ground motion parameters based on field observation of free standing rigid objects. These could be, for example, idols in temples, tomb stones in graveyards or other objects. We have made several observations on toppling and rotations of such objects in the earthquake-affected areas. Figure 23 shows two idols, in a temple complex of Chalukyan period, in the epicentral village of Kavatha which toppled during the earthquake and broke on impact. It is noted that the idols were restored to their original positions after the event. Based on principles of mechanics, it can be shown that the ground acceleration required to initiate tilting (not necessarily leading to toppling) of these idols should be between $0.14\,g$ and $0.17\,g$. A summary of inferences drawn from similar observations made in the epicentral area is given in Table 2. It may be noted that the acceleration levels are arrived at based on the assumption that the objects do not slide and that they are acted upon by only horizontal ground acceleration. Hence the values reported should be treated as order of magnitude estimation of the ground acceleration.

We also made a few observations on rotations of rigid blocks. Figure 24 shows a 3° to 4° clockwise yaw motion of a stone block in the Chalukyan temple complex in Kavatha village. About 200 m away in the same village, another stone block of a later period has yawed in the same fashion. Similar clockwise rotation was also observed in a stone block in front of the Vitoba temple in the river bed near Rajegaon. From the sense of these observed rotations, it may be surmised that both Kavatha and Rajegaon are located on the same side of the rupture plane. If more objects which have rotated in plan can be reliably located, it may be possible to fix up approximately the location and direction of the rupture.

Discussion

Field studies of earthquake effects are useful in several ways. The most obvious one is in understanding the behaviour of structures. This, in turn, indicates the kind of construction to be adopted in future. The field survey

Table 2. Field observation of overturned/tilted objects

Place	Distance from Khilari (km)	District and Taluk	Description	Horizontal acceleration to initiate tilting (g)
Khilari	–	Latur Ausa	Roadside boundary stone near post office Roadside marking stone near main square	0.18 0.24
Kavatha	< 5	Osmanabad Umerga	Idol in Hanuman temple on 2 m high platform Surya idol kept on pedestal in Vishnu temple Vishnu idol kept on ground	0.16 0.17 0.14
Sarwadi	7	Latur Nilanga	Idol in Vishnu temple on 1.5 m high platform	0.13
Sirur-G	30	Gulbarga Aland	Idol in Hanuman temple on 1 m high platform Idol in Hanuman temple on 1 m high platform	0.16 0.24
Thair	50	Osmanabad Osmanabad	Idol in Laxmi temple on 1.5 m high platform	0.1
Umerga	25	Osmanabad Umerga	Steel cupboard in 3rd floor of MSEB quarters	0.25
Kohinoor Pahad	50	Basavakalyan Bidar	Stone block in graveyard on 1 m high platform	0.12

supports the media reports that the large number of house collapses was due to the poor quality of construction. The local material freely available is the heavy deccan trap stone which is mostly rounded and smooth. Construction of walls with these stones without an interlocking arrangement may be stated as the root cause of the destruction. The binding agent used has been invariably mud, mixed with organic materials. This, over the years, had lost its strength and hence the walls with their heavy roofs were already in a precarious condition. The large number of foreshocks might have also helped weaken the construction joints. There were a few cases of collapsed RC roofs which were supported on dressed stone or brick masonry in cement mortar. In these cases, lack of corner interlocking, loosening of lintel beams had led to the initial failure of walls. The loosened bricks and stones had fallen due to lateral dynamic forces during the seismic action. This in turn led to a chain reaction bringing down the roof as a sheet (Figures 6 and 7). The buildings which withstood the shock with minor distress, are stone masonry with good corner details and brick masonry with continuous lintel bands. Occasionally, old construction with wooden columns, even though carrying heavy roofs, are seen to be standing. Modern RC frame-type construction was quite rare in the epicentral region, and wherever found, performed well. Among non-residential structures almost all the engineered construction withstood the shock with repairable damage except for the water tank at Kavatha. The electric substations in Umerga, Sastur and near Khilari did suffer varying levels of damage. However, all of them could be made functional very quickly. Similarly, there was visible distress in the form of a crack and subsidence in the Makni dam. But these were again repairable damages. The culverts and road bridges near the epicentre did show small movements of the piers and abutments. All these structures are still functioning satisfactorily.

The monumental structures in and around Khilari are mostly temples built during the Chalukyan period. The exact dates of these temples, called locally Hemadpanthi temples, are not readily available. We have been able to gather from historians that these might have been built during 1000–1300 AD. Study of these temples was scientifically, and otherwise, quite revealing. The study of free standing objects such as lamps, idols and marking stones was useful in gaining some idea about the level of ground acceleration. The Chalukyan temple complex at Kavatha (Figure 23) with broken idols was also the site of rotation of a massive well dressed stone block (Figure 24). In the same temple complex, dressed rectangular stone blocks in three parallel walls got sliced between the joints (Figure 25). There is a huge stone inscription outside the temple wall in Kannada script. We have not been able to decipher whether any date is mentioned in this. However, based on the photographs, a few historians suggested that the temple could belong to 11–12 century AD. From local inquiries it was learnt that at least the southernmost shrine was functional and regularly visited by worshippers. The present earthquake left this structure badly damaged. The brick-in-mortar spire had collapsed along with the metal cap. The integrity of the outer walls is drastically lost, with the corners looking out of plumb. A few stone lintels are broken giving a feeling of precariousness to parts of the structure. There is a temple of similar style in Khilari town which perhaps belongs to the same period. This is called the Ambabhavani temple, where again the lintels are broken (Figure 26). The remarkably beautiful stone columns are fractured at the bottom due to the earthquake (Figure 27). Thus, even though it is not possible to say when a past earthquake of magnitude greater than 6 *M* occurred in this area, we may make an educated guess. Had an earthquake of the same or higher intensity visited this place in the past, it probably dates back to a period preceding the construction of these temples, which remained intact till the present earthquake occurred. If this argument is accepted, it follows that in the last 600–700 years no strong earthquake has visited, at least, the present epicentral tract of the Marathwada region. This, to some extent, explains the prevalence of local construction practices which do not take cognisance of possible seismic activity. However, this may not mean that there have been no strong earthquakes in historical times. For example, the village of Thair, which is 50 km NW of Khilari, is historically a most interesting place. Here, the damage from the present earthquake is not at all severe. Archaeological excavations have revealed that this place, formerly called Tagarpura, was a flourishing town some 2000 years ago, but then got ruined. Local villagers talk of earthquakes as being the cause of ruination. While this at present is merely speculation, palaeoseismic investigations are called for to ascertain this possibility.

The effect of the earthquake on the natural relief could not be studied in detail. At Khilari and Rajegaon, there were reports of ground cracks, which got closed due to the heavy rains which followed the earthquake. Thus, we could not verify these reports. However, away from the epicentre, we observed two instances of ground cracking. The first was in Gulbarga district in village Alanga in Aland taluk. A nearly 30 m long, 2 cm wide crack could be seen on the ground ending up at a nearby borewell. In the village of Thair, the floor in a hut showed a crack running nearly in the NW-SE direction. The crack was nearly 5 cm wide and was visible for about 30 m in the open field also. An interesting geological feature near the epicentral region is an old fault with a vertical uplift of the ground (Figure 28). This can be seen in the fields to the right of the road connecting Lamjan and Nilanga. The vertical face of the exposed part is considerably weathered. On both sides of this East-West running fracture, the ground is nearly level and is cultivated. Local people call the place Kengal, which means red stone. The soil nearby looks brick red, with a large number of pebbles strewn out of the vertical face of the uplifted ground. No fresh movement of the fault is apparently visible to the eye. Geological study of this feature is essential to understand the tectonics of the region.

Conclusions

The present field study motivated from the engineering point of view leads to the following conclusions.

(1) The estimated intensity of the earthquake in the epicentral region on the UNESCO scale is VIII. On the MMI scale, too, this intensity is nearly VIII.

(2) Ground acceleration near the epicentre is estimated to be of the order of 0.2 *g*.

(3) The large number of house collapses during the earthquake was caused by the poor quality of construction with random rubble masonry. Even simple measures like corner interlocking, avoidance of rounded stones, provision of better bonding, lintel bands, etc. as described in standard guidelines[5] would substantially reduce the vulnerability of non-engineered construction to possible future earthquakes in this region.

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