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M 6.7, 4 January 2016 Imphal earthquake: dismal performance of publicly-funded buildings

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The *M* 6.7 Imphal Earthquake of 4 January 2016 caused devastation in Manipur state and adjoining areas. This event presented another opportunity to understand the earthquake risk of the affected region as well as of the North-Eastern Himalayan region, which have similar patterns of seismicity, built environment and construction practices. Many dramatic collapses and damages, especially to publicly-funded buildings were disproportionate to the observed intensity of shaking. This was primarily due to poor compliance with seismic codes, inferior quality of raw materials and shoddy workmanship. Consequently, the seismic risk in the region is growing at an alarming pace with increasing inventory of vulnerable construction. This article discusses seismic performance

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of three publicly-funded buildings in the recent earthquake and highlights the vulnerability of such inventories along with the below par preparedness of the government agencies in dealing with such calamities. This event should be regarded as a preview of what is likely to happen in the event of a greater shaking expected for the region and should hasten the community to take necessary steps to identify seismic vulnerabilities and improve construction practices through effective intervention.

Keywords: Earthquake effects, reinforced concrete frame, seismic vulnerability.

THE *M* 6.7 earthquake of 4 January 2016 struck at 04:35 am IST with its epicentre located in the Tamenglong district (24.83°N 93.66°E) of Manipur about 30 km west of the state capital Imphal (Figure 1). The earthquake was strongly felt in all northeastern states of India, Bangladesh and Myanmar. The worst affected regions were Imphal, Tamenglong, Noney and Thoubal. A few aftershocks of magnitude less than 4.0 were also felt within a day of the main shock. A part of north-east India, especially Assam, Nagaland and Mizoram also experienced intense shaking during this earthquake. Eight people were reported dead in India, five in Bangladesh, and nearly 200 people were injured. We undertook a reconnaissance survey of the earthquake affected regions during 14–17 January and visited Imphal and adjoining areas. We visited the affected areas again after three months to see the condition of the damaged structures and whether any restoration work was taken up by the authorities.

The earthquake occurred as a result of strike–slip faulting in the plate boundary region between the Indian and Burmese plate. A recent study showed that this event could be an extension of the Kopili fault (see Figure 1) running from the Bhutan Himalaya between the Shillong plateau and Mikir Hills[1]. The boundary region has a history of experiencing large earthquakes: 19 earthquakes of magnitude larger than 6 have occurred within 250 km of this earthquake over the past century. The largest event was *M* 8.0 in 1946 (ref. 2) on the Sagaing fault, about 220 km to the southeast of the 2016 earthquake. Another event of *M* 7.5 in January 1869 (ref. 3), referred to as '1869 Cachar earthquake' and located ~110 km northwest of the 2016 event caused widespread damage in Imphal City (Figure 1). Based on the paleoseismological studies, this event was also related to the Kopili fault[4]. Other nearby damaging events included a *M* 7.3 earthquake, 150 km to the east of the 2016 event in the Indo-Burma region in August 1988 (refs 3, 5), and a *M* 6.0 earthquake 90 km to the southwest in December 1984 causing several fatalities and injuries[6].

Even though the Indian standard code for seismic design, IS 1893 (ref. 7), has identified the northeastern part of India, including Imphal, as the zone of most severe seismic hazard (i.e. zone V), it was rather perplexing to discover that a great majority of buildings seriously lacked earthquake-resistant features, which are essential for satisfactory seismic performance in the design level shaking. The shaking intensity in Imphal city and adjoining areas during the 4 January event varied from VI to VII on the Mercalli scale. Unfortunately no ground motion data is available till date. However, using various empirical relations between peak ground acceleration (PGA) and intensity, the PGA due to this event could be predicted in the 0.11–0.34 g range[8,9]. During this earthquake several RC buildings in Imphal suffered varying degree of damage, from minor to complete collapse. (Figure 2 shows the complete collapse of two private buildings in Imphal.) In such earthquake-prone areas, the built structures must comply with seismic code of practices. However, the general lack of enforcement of existing regulations/codal provisions and negligence of good construction practices were major factors behind the observed damages in the region. Not many wooden houses were seen in Imphal, but as expected, all performed extremely well during the earthquake and thus, once again proved their superiority (Figure 3 *a*). Similar wooden houses made using bamboo/wood, known as Shing-Khim, that is commonly found in rural areas (for example, at the epicentral region, Noney) reported no damage (Figure 3 *b*).

It was surprising to observe that a number of publicly-funded buildings, which are supposedly designed and constructed properly under strict technical supervision, performed rather poorly. For example, damage to two five-year-old RC buildings in the famous Ima Keithel (New Market and Laxmi Market) left large number of vendors without facilities to conduct their business. Similarly, the families had to take shelter elsewhere when the

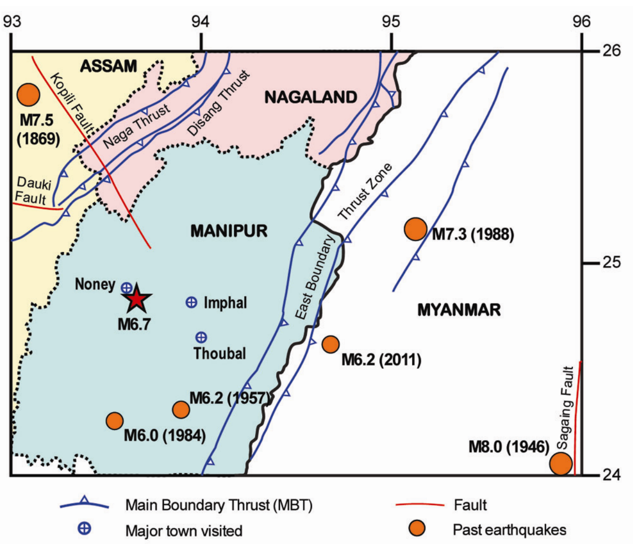

Figure 1. Location of epicentre of the January 4, 2016 earthquake and past earthquakes of magnitude greater than *M* 6.0.

Figure 2. ***a***, Collapse of a 3-storey building in Keishampat, Imphal; ***b***, Collapse of a 4-storey building in Dewlahland, Imphal.

Figure 3. Good performance shown in traditional construction. ***a***, 2-storey wooden house (known as Shing-Khim) at Dewlahland in Imphal; ***b***, single storey Shing-Khim at Noney Bazaar near Epicentral region.

newly constructed three-storey RC building staff quarters in the complex of Sports Authority of India (SAI) was damaged so badly and unexpectedly that it had to be demolished within a few months of its completion. Buildings at the Inter State Bus Terminal (ISBT), Government Polytechnic and Central Agriculture University (CAU) are a few other government funded and supervised constructions that were expected to perform satisfactorily during design level earthquakes, but experienced moderate to severe damages. Moreover, large building campuses, such as, buildings at CAU and those shown in Figure 2, were constructed on landfill soil and performed extremely poorly during the earthquake shaking. This shows that geotechnical study is generally not carried out even for important projects in Manipur. This communication will discuss the performance of three publicly-funded buildings to highlight major errors and omissions that led to such poor performance which confound the common man in success of earthquake-resistant construction in particular and structural engineering, in general.

The famous Ima Keithel (meaning Mother's Market is one-of-its-kind, more than two centuries old all-women market in Imphal) was provided with three reinforced concrete (RC) buildings in November 2010: Keithel-1 (also famously known as Ima market or Nupi market), Keithel-2 (Laxmi market), and Keithel-3 (New market). Construction of these RC buildings was started in 2006, to replace the older Ima Keithel which consisted of unreinforced masonry buildings and a large number of tin sheds supported on steel trusses and pillars or bamboo posts (similar to that shown in Figure 4 *a*). Though older buildings and sheds of the Ima Keithel were functional, the Government decided to dismantle them because they were in dilapidated condition due to negligence and poor maintenance. Three RC buildings were constructed in the Ima Keithel complex. All three buildings have similar elevation and plan (Figure 4 *b*). However, Keithel-1 showed much better performance during the earthquake; compared to the other two buildings in which several columns were severely damaged. After the damage, the vendors in Laxmi and New Market evacuated the buildings and started to operate their business outside the buildings, resulting in severe traffic jams in the area (Figure 4 *c*). On the other hand, vendors in the Ima

Figure 4. ***a***, Old buildings in Ima Keithel complex were primarily steel truss sheds supported over steel or bamboo posts (http://www.trekhub.in/blog/a-trek-through-old-bazaars-of-india/); ***b***, Newly constructed RC building in Ima Keithel complex (Keithel-1 or Ima Market is shown here); ***c***, Vendors doing routine business outside the damaged building of New Market; ***d***, Vendors doing routine business inside the undamaged Ima Market.

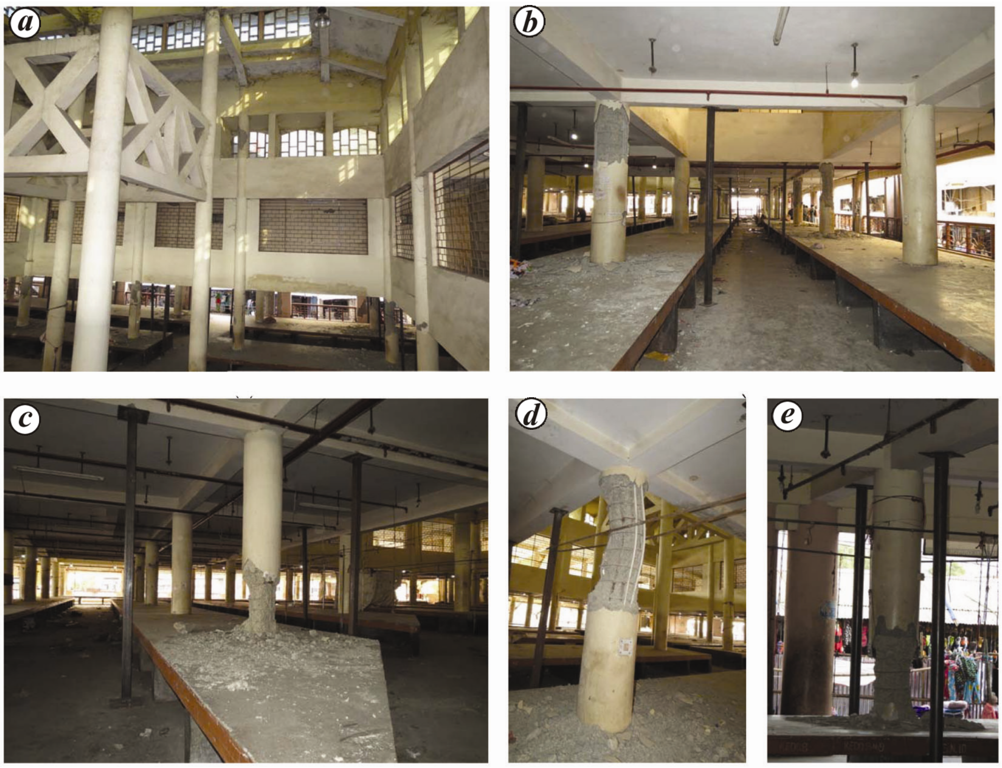

Figure 5. ***a***, Soft first storey in Laxmi Market; ***b***–***e***, severe damage to the RC columns of Laxmi and New Market.

Figure 6 *a–c*. Concealed drain water pipes inside the exterior columns further compromised the confinement of core concrete in the circular columns of the buildings.

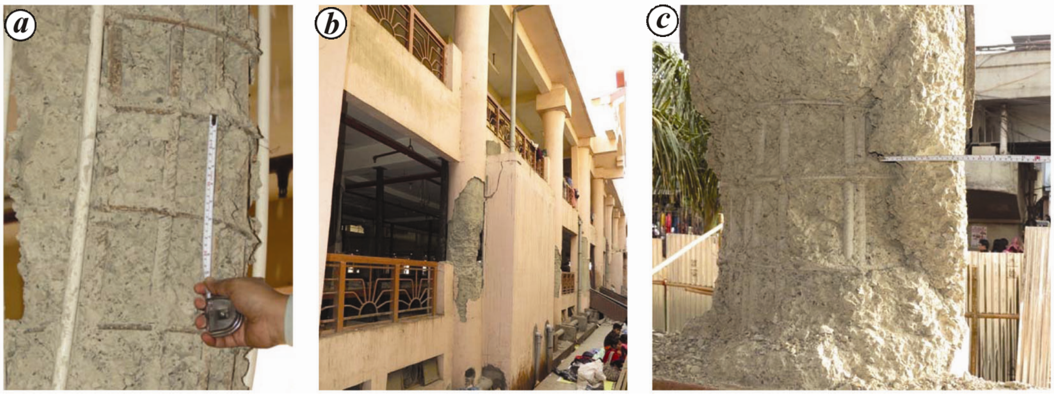

Figure 7. ***a***, Non-ductile detailing in columns of the buildings; ***b***, Short column effect in columns due to presence of parapet walls; ***c***, Irregular concrete cover in columns.

market operated their business inside the building as usual (Figure 4 *d*).

Though the structural plan of all three buildings was more or less symmetric and regular, the masonry infill walls were placed un-symmetrically in the upper floors (other than the basement and the first floor). The concrete and workmanship used in the buildings appeared to be of poor quality. RC retaining walls were provided at the periphery in the basement of all the three buildings. All three buildings were supported on RC raft foundation. The presence of RC walls in the basement and masonry infill walls in the second and third storey resulted in the formation of a soft first storey (Figure 5 *a*). Moreover, since the infills in the second and third storeys were provided un-symmetrically, the heavier and stiffer side of the buildings attracted more lateral force. Hence, the columns in the eastern side of the first floor of the two buildings suffered more damage during the earthquake (Figure 5 *b*). Some columns were so badly damaged that the longitudinal bars underwent buckling, resulting in large axial deformation (Figure 5 *c–e*).

All columns in the buildings have circular cross-section. Thicker columns were provided on the periphery to conceal PVC rain water pipes (RWP) of 150 mm diameter inside the columns. This further compromised the confinement of core concrete in these columns (Figure 6). In most exterior columns, the RWP were provided along the periphery of the circular hoops (Figure 6 *a*). In

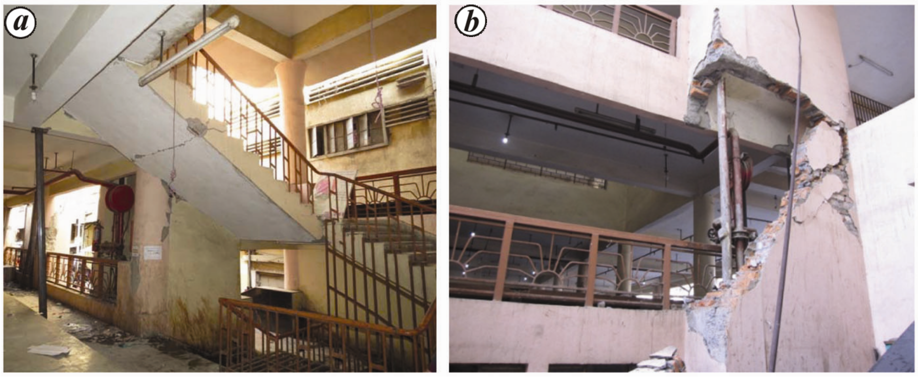

Figure 8. ***a***, Severe damage to waist slab of RC staircase in Laxmi market; ***b***, severe damage to masonry infill walls.

Figure 9. ***a***, A view of Inter-State Bus Terminal at Imphal; ***b–d***, severe damage to RC columns; ***e***, non-ductile detailing in columns.

some locations, where two adjacent columns were closely constructed, the RWP were provided at the centre of one of the columns and along the periphery of hoop reinforcement in the other column.

In addition to poor material quality used in the building, it was observed from the damaged regions of the columns that, the reinforcement details did not comply with the ductile detailing provisions of IS 13920 (ref. 10). The spacing of circular stirrups was as high as 200 mm in some locations and 135° hooks were not provided in the stirrups (Figure 7 *a*). Vertical alignment of longitudinal steel bars was not maintained at several places, which resulted in unequal stress distribution in the stirrups. All longitudinal reinforcing bars were spliced at the same level in the columns, resulting in a weaker section where most damage took place. Short column effect was observed in several first storey columns due to the presence of RC slab at 450 mm height (provided for displaying items for sale in the market) and also due to the provision of parapet walls along the periphery between the columns in the first storey (Figures 5 *c* and 7 *b*). Short column effect damaged several columns in the first storey of the buildings. Provision of irregular cover to concrete (as thick as 150 mm in some cases) resulted in spalling of cover concrete in several columns (Figure 7 *c*). In addition to the columns, severe damage was observed in staircases and several masonry infill walls of both buildings (Figure 8 *a* and *b*). The staircase and masonry

Figure 10 ***a***, ***b***. Retrofitting of RC column by replacing circular ties with helical reinforcement and addition of longitudinal bars along with ties in the existing concrete core; ***c***, view of retrofitted column wrapped with plastic sheet for curing.

Figure 11. ***a***, Damage experienced by hostel building in SAI complex; ***b***, repairing of crack with plaster reinforced with steel wire mesh.

infill walls were in fact hanging precariously during our visit.

Interestingly, the beams and slabs of any of the buildings were not damaged during the earthquake. Further, no damage was observed in any members in the basement. Only some columns in the second and third storey suffered moderate damage signifying the soft storey effect in the first storey. Clearly, a combination of these deficiencies, poor detailing, and poor construction practices resulted in extremely poor performance of the two buildings during the earthquake. The buildings were lying in the same condition three months after the earthquake, during our second visit. By then, the vendors had already started occupying most parts of the damaged buildings.

On the other hand, there was no noticeable damage to the RC structure of Keithel-1 (Ima market) building. This may possibly be due to use of better quality materials, better workmanship and provision of good ductile detailing in columns. Manipur PWD engineers also reported that the RWP were not concealed in the columns of Ima market. Moreover, in this building, the short column effect in the external columns along the periphery was avoided by not providing masonry infill walls up to sill level. Instead only steel grills were provided along the periphery and the grills were not laterally connected to the peripheral columns. Another important difference in the Ima market building is that the columns in the central cut-out regions were connected to the rest of the structure at all floor levels. However, in the other two buildings, these columns were connected to the rest of the structure at ground floor and roof levels only. Further, PWD engineers reported that helical reinforcement (instead of circular hoops) was provided as shear reinforcement in the

Figure 12. ***a***, Minor to moderate damage experienced by staff/coach quarters in SAI complex; ***b***, View of demolished quarters after three months.

columns of this building. The helical reinforcement is known to provide better shear strength and ductility to the column section.

The Inter-State Bus Terminus (ISBT) built with the North Eastern Council (NEC) funding for the benefit of not only Manipur but also people of other north-eastern states, experienced major damage in many RC columns during the earthquake. ISBT was one of the many projects inaugurated in December 2011. However, even after 5 years, the ISBT complex was not fully functional (Figure 9 *a* shows the current status of ISBT). The RC columns in the buildings also have circular cross-section and consist of similar design and detailing defects as observed in Laxmi and New markets. Thus, many of these columns suffered severe damage during the earthquake as shown in Figure 9 *b–e*. It was surprising to notice that such an important publicly-funded building with simple and regular structural configuration had experienced this intensity of damage during a moderate level shaking. This level of shaking is significantly less than what is expected in the design level earthquake in highest seismic zone V of the Indian code.

During the next visit to ISBT after three months, we observed that the retrofitting of the damaged RC columns was in progress (Figure 10). The retrofitting work involved replacing of circular ties with helical reinforcement and adding another layer of longitudinal reinforcement along with ties inside the original concrete column core. Though some steps were taken by the state PWD for restoring the structure from its damaged state, the effectiveness of this retrofitting technique is suspect and open to discussion. First, proper assessment is required to determine the performance level of the damaged building. Then an appropriate strengthening scheme should be developed, provided that the building achieves an adequate level of performance related to life-safety of occupants. The concerned authorities should follow the Indian code IS 15988 (ref. 11) and IS 13935 (ref. 12) for seismic evaluation and strengthening of buildings.

Another government construction which experienced extensive damage was in the complex of SAI. The major part of SAI complex at Imphal was constructed in 2010, ahead of the Commonwealth Games in New Delhi. However, few buildings such as residential quarters for coaches and staff were recently constructed, which are yet to be handed over to SAI. The SAI complex hostels and newly built staff quarters that suffered cracks during the 4 January earthquake were deemed unsafe and forced most hostellers and staff to leave for their homes (Figures 11 *a* and 12 *a*). The authorities, however, started repairing the damaged portions within a week after the earthquake. The repair work only included covering of cracks with plaster, reinforced with steel wire mesh (Figure 11 *b*). This impromptu restoration work cannot ensure acceptable performance of the structure in case of another earthquake. However, no such repair work was taken up for the newly constructed three storey quarters built for the accommodation of staff coaches (Figure 12 *a*).

It was rather disturbing to see during the next visit, that the three storey building (Figure 12 *a*) which experienced minor to moderate damage was completely demolished (Figure 12 *b*). The visible details of RC columns in Figure 13 clearly indicate that the columns were unnecessarily over/heavily reinforced. For the sake of ductile detailing, huge amount of confining and longitudinal reinforcement was provided in column. Generally such large amount of reinforcement in small size columns is not recommended to achieve good compacted concrete. The column sizes for the demolished building vary from 230 mm × 300 mm to 230 mm × 500 mm and longitudinal bar of 25 mm diameter was used in these columns. The percentage of longitudinal reinforcement appears to vary from 4.5 to 5.8, which is higher than the recommended limit of 4% prescribed in the Indian code IS 456 (ref. 13).

Summarily, earthquakes occur quite frequently in and around Manipur because of the strike–slip motion in the plate boundary region between the Indian and the Burmese plates. The likelihood of major earthquakes is reflected by assigning most severe seismic zone V to the region in the Indian seismic code. Therefore, earthquake-resistant construction has to be a non-negotiable practice

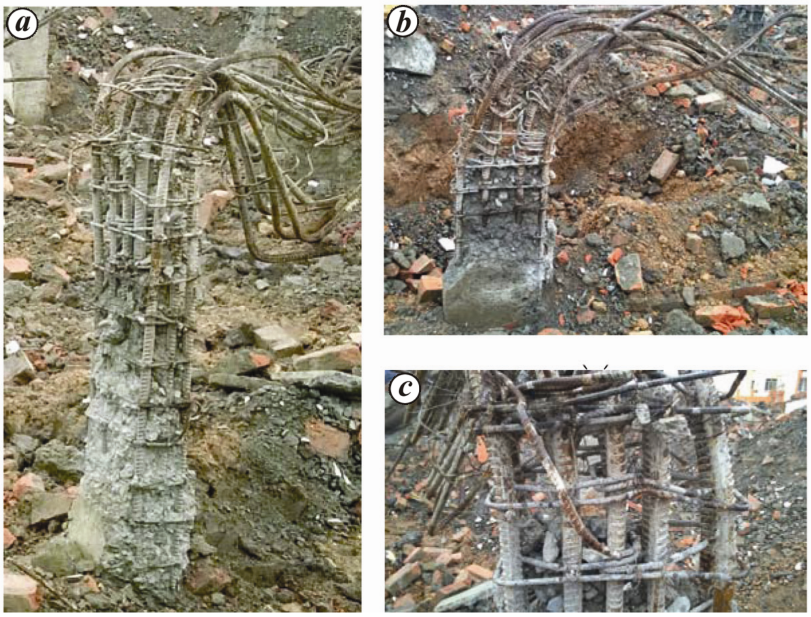

Figure 13 *a–c*. Huge amount of reinforcement provided in concrete columns of staff quarter building at SAI, Imphal.

Figure 14. A message on a wall facing street in Imphal reminds that there is earthquake awareness in the region due to frequent shaking.

in Manipur along with superior quality of materials and workmanship. Despite considerable awareness in the public about earthquakes and associated risks (e.g. the old message on a wall shown in Figure 14), it appears that the public, as well as the administrators, chose to ignore the threat and continued to build structures which were not earthquake-resistant. Such ignorance has already been reported from other areas of north-eastern India that have also suffered huge loss during recent earthquakes[14,15]. Due to such negligence, many publicly-funded buildings suffered severe damage even during the moderate level earthquake of 4 January 2016. The damages to these structures under shaking intensity of VI–VII are not only ironic but also represent the utter betrayal of the public trust brought into by total failure of the structural engineering profession. Such negligence must not be ignored any further and the structural engineering community should act rather responsibly to ensure that such shameful performance of structures is not repeated in future earthquakes. Despite the available knowledge base, it is unfortunate that society is not adequately prepared due to lack of implementation. Therefore, the seismic risk in the region capable of large earthquakes, has risen to unacceptable levels which may lead to a large-scale disaster, if not mitigated soon.

The most surprising fact relates to arbitrary decisions taken by the concerned authorities on whether to retrofit or demolish the damaged structures. The reality of subjective decisions is quite obvious from the current state of three publicly-funded buildings discussed in this article. In the case of ISBT, the authorities were pro-active in restoration work. However, the staff quarters at SAI complex with moderate damage were demolished right away. Before taking such decisions no proper seismic evaluation and analysis of these structures was performed as per Indian code. In contrast to such quick and abrupt measures, no concrete steps were taken by the state and central authorities to restore/retrofit the damaged buildings of New and Laxmi market.

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Negative allometry for egg size in ladybeetles (Coleoptera: Coccinellidae): Trade-off between egg hatch time and size

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Similar to a wide range of other organisms, large species of predatory ladybeetles lay proportionally small eggs when compared to smaller species. This study determines whether egg size in aphidophagous lady beetles is constrained by the time it takes for the eggs to hatch. The eggs of the large species, *Anisolemnia dilatata* (168 mg), and small species of ladybeetle, *Coccinella septempunctata* (27 mg), were collected immediately after they were laid, separated from one another and weighed. The time for the egg to hatch was determined at 22°C. As predicted, the eggs of the large species were a smaller proportion (0.0048) of their mother's weight when compared to the eggs of the small species (0.0061). On an average, the eggs of the large species were about 4.9 times heavier and took 1.31 times longer to hatch than those of small species. These results indicate that in insects and aphidophagous ladybeetles, in particular, egg hatch time is not directly proportional to the egg size and reproduction may involve more than a trade-off between the number of eggs and size. It is likely that egg hatch time is a constraining factor and an important determinant of the inter-specific negative allometry for egg size in this group of insects.

Keywords: Egg size, inter-specific negative allometry, ladybeetles.

NEGATIVE allometry for egg size represents a relationship in which the eggs of species with the biggest adults tend to be larger than those produced by smaller adults, but the eggs become proportionally smaller as the adult size increases[1]. Such a relationship is recorded in many groups of animals (spiders[2], insects[3,4], fish[5], turtles[6], snakes[7], lacertid lizards[8], birds[9]). This has mainly been discussed in terms of a trade-off between egg number and size[9,10] according to which bigger adults, within or between species, tend to produce more eggs directly proportional to their body mass and length of reproductive life but invest less in egg size because of ecological and physiological constraints[11,12].

Here, predatory ladybeetles (Coleoptera: Coccinellidae) were used to explain the interspecific allometric relationship between egg size and adult size. Available

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