Engineering lessons not learnt from 2002 Diglipur earthquake – A review after 2004 Sumatra earthquake

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A moderate earthquake in 2002 damaged newly built masonry and RC buildings and structures in North Andaman Island; these damages were disproportionate to the intensity of shaking in the area (VII on MSK scale). But the public and professionals ignored the lessons learnt and continued to design and construct without accounting for earthquake effects. And, the 2004 Sumatra earthquake caused a similar intensity of shaking in the same region: buildings and structures that were affected in the 2002 event were once again damaged, and in many cases more severely, rendering them unusable and irreparable. This article identifies factors that led to this repeat occurrence of structural damages and suggests that urgent remedial measures are required to prevent such unsatisfactory structural performance in future earthquakes.

Keywords: A&N Islands, bridge, buildings, earthquake, jetty.

THE Andaman and Nicobar (A&N) Islands are formed as a consequence of the subduction of the Indian plate under the micro-Burmese plate[1] along the Sunda arc. Hence, the Indian seismic hazard zone map[2] places these islands in the most severe seismic zone, namely zone V. Notwithstanding this earthquake hazard, over the last decade, construction strategies in the A&N islands have moved away undesirably from the traditional earthquake-resistant practices (i.e. light structures using timber, bamboo and thatch) to a special class of cheap and vulnerable structures (i.e. heavy and brittle structures using unreinforced masonry and reinforced concrete (RC)), thereby increasing seismic risk of the built environment.

This negative transition in the engineering practices was exposed by two recent earthquakes, namely the M_w 6.5 earthquake on 14 September 2002 and the M_w 9.3 Sumatra earthquake of 26 December 2004. The intensity of ground shaking in the North Andaman Island in both these events (Figure 1) was about the same, ~VII on the Medvedev–Sponheuer–Karnik (MSK) scale. Seismic performances of the same set of structures in the North Andaman Island were studied after both these earthquakes[3,4]. The studies reveal the same lessons: the most striking feature was brittle and undesirable performance of recently constructed unreinforced masonry and RC buildings and engineered structures, versus the good performance of indigenously built structures without any visible sign of structural distress. Damages during the earthquakes to these structures were no surprise, because these were similar to the non-seismic constructions that collapsed during the 2001 Bhuj earthquake in Gujarat.

Figure 1. North Andaman Island experienced significant shaking of MSK VI to VII in the 2002 and 2004 earthquakes.

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Even though the performance of structures in the 2002 earthquake served as a preview of what would happen in a future earthquake of similar or higher intensity of shaking, those lessons were not internalized by the professionals and public, and thereby inviting yet another disaster in 2004, when the Great Sumatra earthquake with epicentre over 1100 km away, produced shaking similar to the 2002 event. These two earthquakes in the same region causing similar intensity of shaking and affecting same structures in such a short interval of time provided a unique and rather rare opportunity for a comparative study on the performance of built environment. This article presents case studies of seismic performances of select structures (representative of the range of the affected structures) during the 2002 and 2004 events, prevailing design and construction practices that perpetrated risk to the built environment, and measures that are necessary to bring the agenda of seismic safety into focus for the seismically threatened A&N Islands.

Poor performance of structures – unexpected in 2002 but expected in 2004

The M_w 6.5 North Andaman (Diglipur) earthquake of 14 September 2002 was centred in the sea at 13.01°N 93.15°E (United States Geological Survey, USGS), about 24 km SSE of Diglipur town in the North Andaman Island and about 165 km NNE from Port Blair. The worst affected regions of the 2002 earthquake lie mostly in a small area of about 40 km^2 around Diglipur town, where maximum intensity of shaking of VII was noted on MSK scale. Other parts of the North Andaman Island experienced a less than moderate shaking of VI. On the other hand, the earthquake of 26 December 2004 had its epicentre located at 03.30°N 95.87°E (USGS). The MSK intensity of shaking due to this earthquake is estimated to be about VII+ in the regions around Diglipur, which is over 1100 km from the epicentre. However, this time the ground shaking was not only of longer duration than that during the 2002 earthquake, but was also dominated by long period waves; eyewitnesses described it as slow-moving rolling-type of shaking (as opposed to ground vibration changing direction rather rapidly during 2002).

According to the Indian seismic zone map[2], the entire A&N Islands lie in the most severe seismic zone V, where the expected intensity of seismic shaking is IX or greater on MSK intensity scale. Hence, during both these earthquakes, the intensity of shaking was less than the maximum expected. In the 2002 earthquake, the performance of masonry and RC structures is described as poor, as these structures suffered damage even when the shaking intensity was less than moderate. However, traditional structures in the region that used light building materials were largely unaffected, though they used materials which are generally regarded inferior to the modern high strength masonry and reinforced concrete. Even modern-day variations of these older housing types wherein timber was replaced by light steel angle and pipe sections, performed satisfactorily. In the 2004 earthquake, once again a similar performance was observed; however, in some cases, the structural damage was more severe.

A field reconnaissance after the 2002 earthquake, identified a number of critical issues related to earthquake resistance of the structures, which were not addressed adequately before the event. The authors also made a technical presentation to the engineering community in Port Blair immediately after the earthquake highlighting these issues, in addition to recording it in the reconnaissance report and circulating the same. Unfortunately, no effort was made to remedy those errors and/or omissions. Even the so-called retrofitting work carried out on damaged structures after the 2002 earthquake, amounted to mere cosmetic repair, rather than to ensuring the required lateral strength, stiffness and ductility through proper re-design and detailing of structural elements. Many such inadequately retrofitted structures were severely damaged again in the 2004 earthquake. In the following sub-sections, case studies of poor performance of structures are illustrated through their observed behaviour in the last two earthquakes.

Buildings

In the A&N Islands, many private dwellings and community buildings, such as school and health centres, are built in masonry-load-bearing walls and light roof (steel pipe/timber truss clad with corrugated galvanized iron sheets). Often, these walls are not tied together to create the box-action required to improve lateral resistance. Also, positive connection is not provided between walls and roof trusses resting on them. An example of such a structure is shown in Figure 2: the masonry wall collapsed out-of-plane when the flexible roof consisting of poorly jointed wooden truss members moved by large amounts. Similar damages were observed on a much larger scale in most school buildings, wherein long slender partition walls separating two classrooms were either severely damaged or collapsed due to out-of-plane instability.

In the last few years, many two-storey Panchayat Bhavan buildings constructed in the region were based on a type-design developed by the Andaman Public Works Department (APWD). Significant variations were noticed in these RC structures from the approved drawings. For instance, infill walls were eliminated in the ground storeys, especially in the interior bays, to create large spaces for assembly of villagers during public meetings, and many infill walls were added in the upper storey to create smaller office room spaces. This made its ground storey relatively flexible and weak, and the upper story stiffer and heavier. Obviously, such top-heavy bottom-flexible structures would draw large seismic displacement demands on the ground storey columns for which they may not have been designed.

Figure 2. Slender masonry walls dislodged due to out-of-plane instability and poor or no connection to the surrounding structural elements.

Figure 3. ***a***, Severe cracking and damage to soft first storey columns of Nabagram Panchayat Bhavan building primarily due to 'missing' ties in the 2002 earthquake. ***b***, More severe damage in the 2004 earthquake to the same columns which were 'retrofitted'.

In many instances, the masonry walls in the ground storey were discontinued at the sill level instead of being raised to the full storey height. This created the short column effect, an additional abnormality that was also not accounted for in the design. An example of such a structure is the Panchayat Bhavan building at Nabagram, about 25 km south of Diglipur (Figure 1). The ground storey columns of this building suffered extensive damage in the 2002 earthquake. Many columns were severely cracked and damaged near beam-column joints and at mid-heights (Figure 3). First, a close inspection revealed that no transverse stirrups (ties) were present over a length greater than 350 mm of the columns in the ground storey from the soffit of the beam. The code (IS 13920 : 1993) for detailing of earthquake-resistant RC frame requires the stirrup spacing[5] in such locations to be no more than 75 mm. Even if such a building is located in the lowest seismic zone II, the code (IS 456 : 2000) requirement for these 200 mm wide columns would be no more than 200 mm for the spacing of stirrups[6]. This is a construction error: the ties were not securely held in place during concreting, slipped from their position, and three ties stacked one on top of the other.

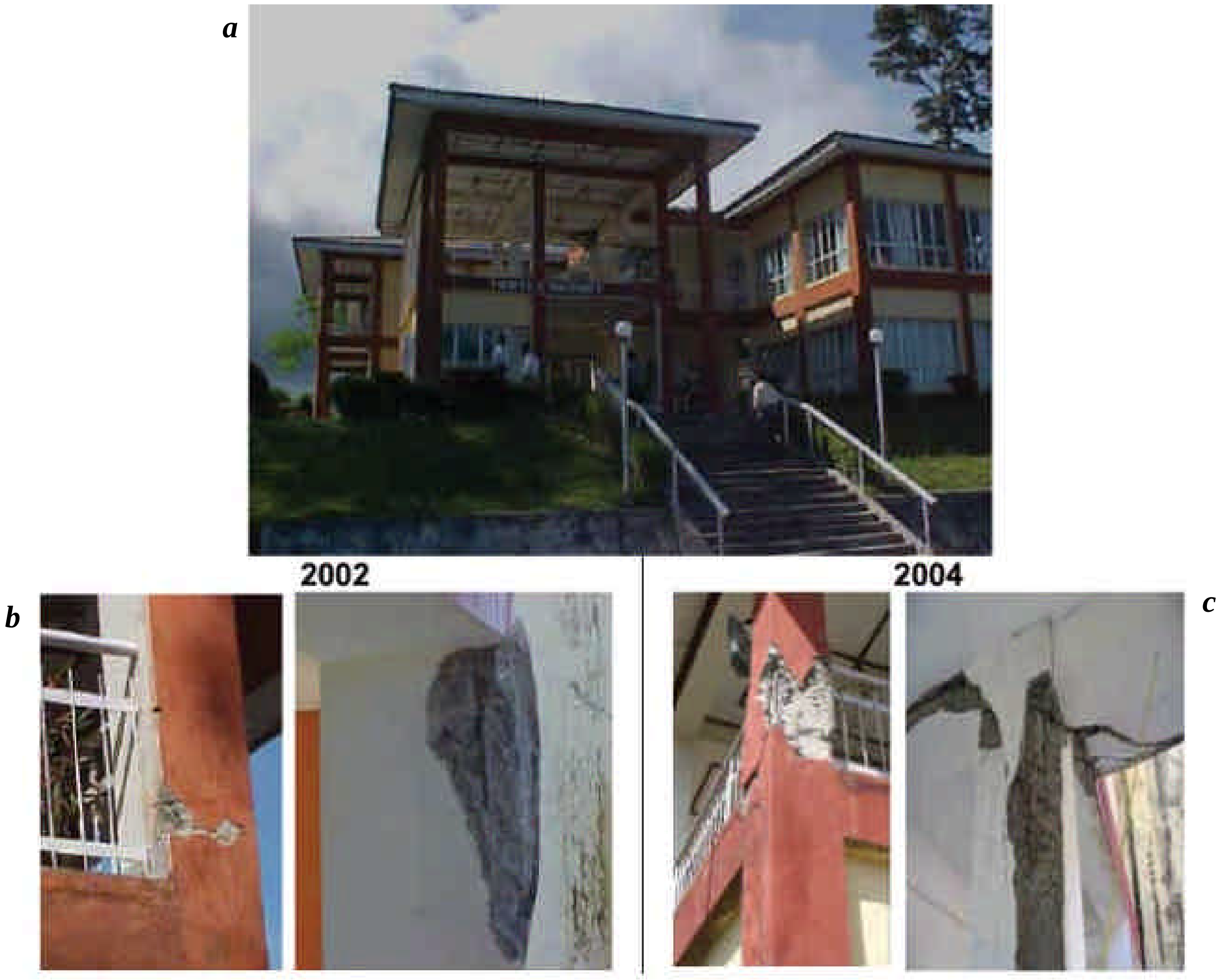

Figure 4. ***a***, Turtle Resort building and highly irregular and asymmetric arrangement of structural members. ***b***, Damage to columns which reveals absence of transverse ties over a length of about 450 mm from the beam soffit. This omission during construction compounded with poor structural configuration resulted in significant damage in less than moderate shaking of the 2002 earthquake. ***c***, Repeat damage to columns in the 2004 earthquake, as no attempt was made to remedy the underlying structural deficiencies.

Secondly, the building was made susceptible to poor seismic performance by creating the open ground storey. Thirdly, the infills of partial height created short columns effect. Fourthly, the RC columns were not designed for earthquake forces and required ductility, particularly in the ground storey, where it was most needed. As a consequence, even a low intensity (VI on MSK scale) ground shaking was sufficient to seriously damage the structure and undermine its safety. The severely damaged columns of the building were simply repaired after the 2002 earthquake: the fine cracks were filled with mortar and the crushed concrete was replaced with hand-placed new concrete. No attempt was made to evaluate and remedy its overall seismic deficiencies; this left the building especially vulnerable to future earthquake shaking. And, during the 2004 earthquake, the building was again severely damaged and many columns in the ground storey were damaged. Further, the portion of the building close to the stiff stairwell was heavily damaged.

Similar serious errors were committed while conceiving the architectural layout, deciding the structural frame of structures in high seismic zones, and drafting reinforcement detailing in the Turtle Resort building at Shibpur, near Diglipur (Figure 1). One portion of this two-storey building has RC frame with concrete block masonry infills, and the other has load-bearing masonry with RC slab. This building is highly irregular not only in plan, but also in elevation; floors are at different levels, interconnected through lobbies and walkways (Figure 4). In the 2002 earthquake, the building sustained cracks in columns and in a large number of partition and load-bearing walls. Cracks at the top ends of the columns were primarily caused by the absence of transverse stirrups over a length greater than twice the column width. The high damage despite low intensity of shaking was primarily due to poor structural layout resulting in additional torsion-induced forces, irregularities in strength and stiffness, discontinuities in load path and absence of column ties. Even though the 2002

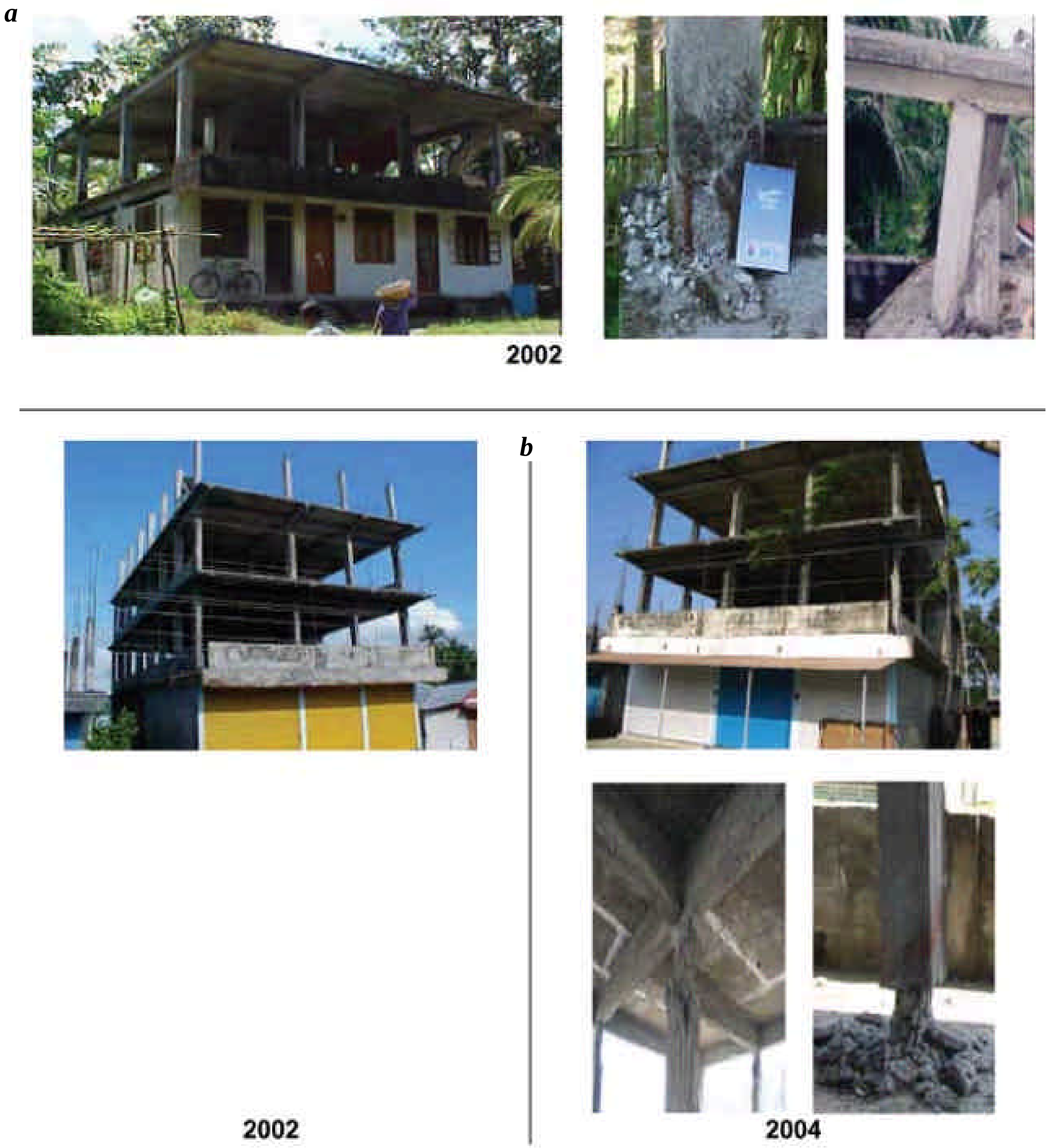

Figure 5. Weak RC columns cannot safely resist even less than design level earthquake forces. ***a***, Unfinished residential building in Keralapuram damaged in the 2002 earthquake developing 'plastic-hinges' at the base of second story column due to inadequate strength. ***b***, Unfinished three-storey building in Diglipur market which escaped damage in the 2002 earthquake, had severe damage to most of its columns in the second storey in the 2004 earthquake.

earthquake vividly illustrated the seismic vulnerability of this building to future shaking, no effort was made to remedy its seismic deficiencies; the damaged portions were simply 'repaired' after the 2002 earthquake. And, in the 2004 earthquake, the story was repeated.

A two-storey building under construction in 2002 presented another interesting example of the kind of damage to columns that is likely if columns are not provided adequate lateral strength and confinement at their ends, in Keralapuram, near Diglipur on the way to Aerial Bay jetty. As shown in Figure 5 *a*, the top storey (in the absence of masonry walls) acted as a vertical 'cantilever' and could not respond satisfactorily to the seismic moments and shears produced during the earthquake for the roof slab alone. Flexural crack-

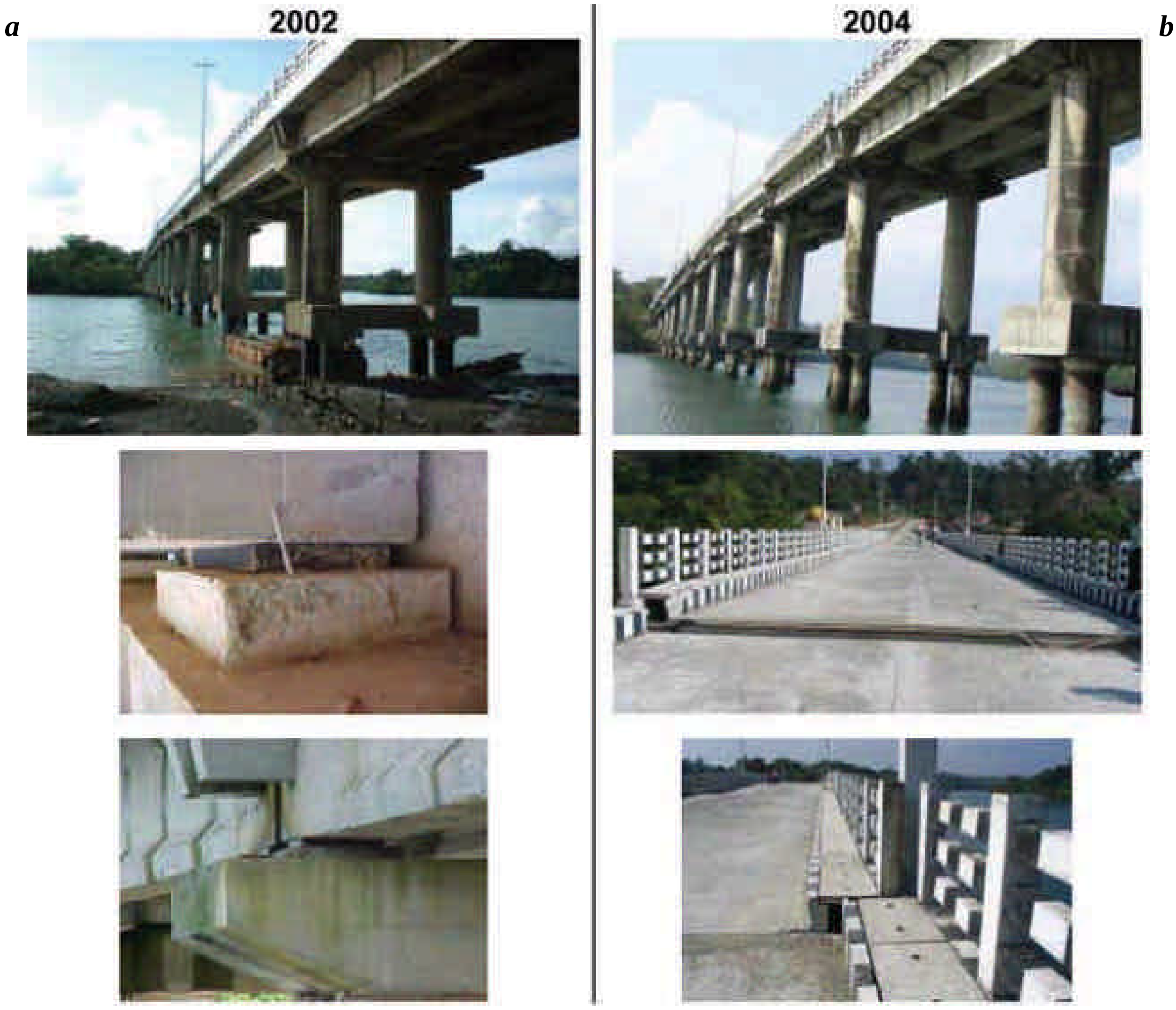

Figure 6. Newly constructed Chengappa RC bridge at the Austen Strait on ATR connecting North and Middle Andaman Islands. ***a***, Bridge after 2002 earthquake where inadequate seating for bridge deck and absence of restrainers had raised concern for unseating of deck during probable strong motion at the site. ***b***, Decks of three middle spans fell off the bearing, got displaced laterally about 700 mm and closed for even light vehicles.

ing (due to formation of plastic hinges) was noticed at the base of most columns of the upper storey. Clearly, the prevalent practice in the A&N Islands of providing 90° hooks in column ties at 150 mm centres in all building columns does not guarantee the confinement required for ensuring stable and ductile behaviour under strong seismic shaking expected in the region. Similar reinforcement detailing led to the failure of staircase columns at mid-height, and to the subsequent collapse of the slab supported over the staircase. Another building with similar details which escaped major damage in the 2002 earthquake (Figure 5 *b*), was badly damaged in the 2004 earthquake, in the same fashion with plastic hinges formed at one or both ends of most columns. Clearly, the RC columns designed only for gravity forces can be easily overwhelmed by lateral forces even under moderate shaking, and could collapse if masonry infills are absent.

Chengappa bridge at Austen Strait

The newly constructed bridge over the Austen Strait near Mayabunder that connects the Middle Andaman Island to the North Andaman Island along the Andaman Trunk Route (ATR), was not open to traffic at the time of the 2002 earthquake (Figure 6). This 268 m long RC bridge is simply supported over 13 cast-in-place piers. The bridge deck is 9.3 m wide and is made of pre-cast girders and cast *in situ* slab. The superstructure merely rested on elastomeric bearings placed on the pier caps, with no fastening between any of

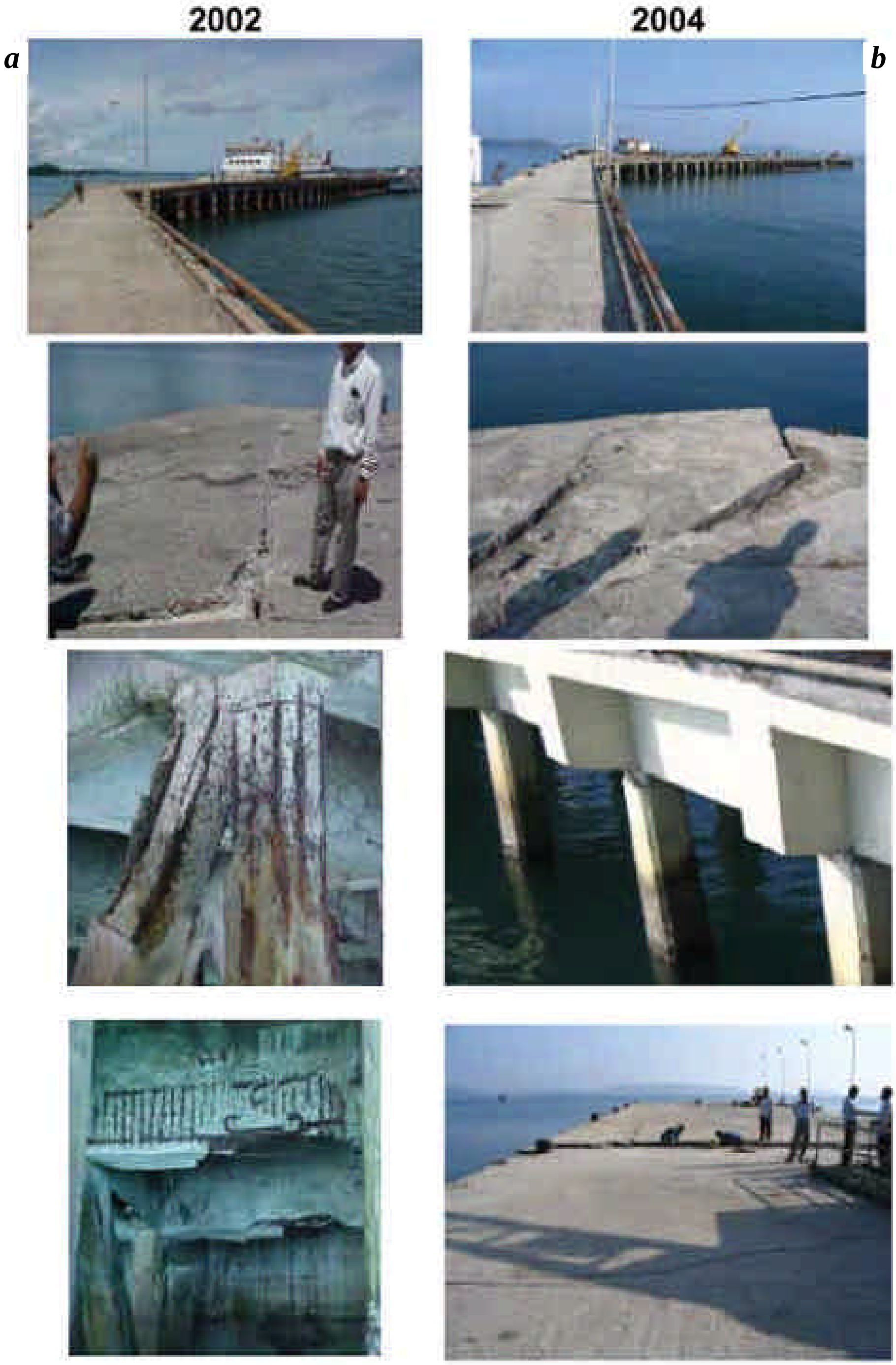

Figure 7. ***a***, Approach jetty meeting an angle with the main berthing jetty at Diglipur harbour and pounding damage to jetty slab was concentrated at the intersection in the 2002 earthquake. Severe corrosion of reinforcing bars and spalling of cover concrete from beams, columns and batters. ***b***, Besides pounding damage of slabs, the old berthing jetty 'sank' and cracked as piles at top failed in shear in the 2004 earthquake.

them. No damage was noticed to the bridge structure in the 2002 earthquake; however, in their reconnaissance report, the authors had expressed concerns about this bridge as follows[3]:

'Inadequate seating of bridge deck over piers and abutments is a serious concern for its safety during a stronger earthquake in future. The bearings are simple neoprene pads which are far from satisfactory for a bridge located in seismic zone V. Bridge deck restrainers are the minimum that need to be provided to ensure that the spans are not dislodged from the piers in future earthquakes.'

In the 2004 earthquake, the sixth, seventh and eighth spans from Mayabunder side abutment were displaced horizontally by about 700 mm and vertically by about 220 mm from their original positions and were off-seated from their bearings. Also, the second, third, fourth, fifth, ninth and tenth spans from Mayabunder side abutment moved horizontally by about 20–150 mm. As a result, the bridge had to be closed even for light vehicles after the 2004 event, particularly when it was needed most for facilitating post-earthquake emergency services across the islands. The bridge could have been easily retrofitted in the intervening period of two years, which would have prevented unseating in this and the future earthquakes.

Aerial Bay jetty at Diglipur harbour

The Aerial Bay jetty structure consists of an approach segment meeting the main berthing structure at 120° angle (Figure 7). The berthing structure was originally constructed in 1968 and extended in 1999. The approach and berthing structures are supported by 400 mm square RC piles connected at the top by a box-type pier cap made of beams, columns, braces and slabs. In the 2002 earthquake, pounding damage was observed at the junction of the approach segment and main berthing structure; the wearing coat was broken. The piles suffered significant spalling of cover concrete at their top ends, and the reinforcements there were exposed. After the 2002 earthquake, these damaged top ends of the piles of the approach jetty were simply covered with micro-concrete for the lost reinforcement and cover; no assessment was made of the ability of the structure to resist strong seismic shaking in future. And, in the 2004 earthquake, besides the pounding damage at junctions, damage was noticed at the same top ends of piles of the approach jetty, which were covered up. However, piles of the older section of the berthing jetty failed in shear at the top ends and these were not addressed after the 2002 earthquake. This led to the sinking and cracking of the jetty slab, which is not easy to repair and is currently not being used.

Summary – lessons not learnt

Many well-known unfavourable structural features that seriously undermine seismic resistance of structures, e.g. open-ground-storeys, out-of-plane instability of unsupported slender walls, short-column effect, and discontinuous load paths for lateral loads due to offsets in plan and elevation, were repeated in many of the newly constructed buildings. Non-seismic design and construction practices added to the seismic vulnerability of the built environment in the region (be it in buildings, bridges or jetties). Non-compliant constructions were being built in the region. When this was exposed in the 2002 earthquake, it should have been taken as an opportunity for corrective actions. Two years was not too small a time interval to remedy the glaring errors of constructions existing in 2002 for the new constructions. However, a number of RC and masonry buildings constructed after 2002 were also made vulnerable, with no attention to lateral loads due to earthquakes.

The engineering lessons from the 2002 and 2004 earthquakes show that these lessons were not being internalized by the public and professionals for a variety of reasons. These include:

(a) Widespread ignorance of earthquake-resistant design and construction among the civil engineering community.
(b) Lack of accountability for the non-performance of structures.
(c) Absence of structural codes and guidelines for seismic evaluation of existing structures and their strengthening, if found deficient.
(d) Lack of professional experience and expertise to carry out such seismic upgrades.
(e) Above all, a general lack of genuine desire and concern for seismic safety in the region which is highly seismic active.

Now, the 2004 earthquake offers fresh reminders of the lessons, and another opportunity for corrective action. In the absence of proactive efforts, these lessons could be wasted yet again. In the past, we have wasted away such opportunities on many occasions, only to be reminded again with a heavy penalty of large-scale damage and destruction. For example, before the 2002 earthquake, the 2001 Bhuj earthquake of Gujarat vividly illustrated the seismic vulnerabilities of modern constructions. However, despite some successes, these events have largely been unable to stir desired participation from the professionals and public towards ensuring earthquake-resistant constructions in the country.

Conclusion

The art and engineering of designing structures to resist earthquakes has come long way in the last four decades in India and is mature enough to create structures that will not only survive strong earthquake shaking, but also remain functional after the event. One cannot afford to ignore the lessons of past earthquakes if such disasters are not to be welcomed in the future. This is especially important in the A&N Islands, because, in future, earthquakes of more damaging ground shaking are probable than those of 2002 and 2004.

Urgent steps are required in the A&N Islands to create safer built environment. First, a technical awareness campaign must be urgently undertaken on the vulnerability of certain types of constructions currently being practised in the A&N Island region. Secondly, a comprehensive programme needs to be undertaken for technical training of the engineers of the A&N Islands; these engineers must include those from all government departments (e.g. APWD, Andaman & Lakshadweep Harbour Works, Military

Engineering Service, Airports Authority of India, and Indian Coast Guard), public sector (e.g. Indian Oil Corporation) and teachers of the local polytechnic. Thirdly, pilot projects must be started to demonstrate the processes involved in the seismic design of new constructions and in the seismic strengthening of older constructions. Fourthly, the bye-laws in the Islands need to be re-looked at to identify provisions that are detrimental to good seismic behaviour of structures, and such lacunae, if any, be eliminated in a revised draft for approval of the authorities. Each of these items requires careful long-term planning and systematic implementation. Individuals who can champion these efforts need to be identified, funds be provided and a reasonable time target be placed.

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