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# PERFORMANCE OF BUILDINGS IN PORT BLAIR (INDIA) DURING THE GREAT SUMATRA EARTHQUAKE OF 26 DECEMBER 2004

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## ABSTRACT

The great Sumatra earthquake of 26 December 2004 caused substantial damages to reinforced concrete (RC) buildings at Port Blair in the Andaman Islands in India. On the other hand, traditionally constructed timber buildings performed extremely well in response to ground shaking. The RC buildings were damaged primarily because of improper design and reinforcement detailing at the design phase and improper workmanship and quality control at the construction phase. Performance of buildings during 26 December earthquake shaking, and historical and predominant construction practices in one of the most seismically active regions in India are discussed in the paper. Peak ground acceleration at Port Blair is estimated by analysis of a collapsed RC scooter stand.

## Introduction

The great mega-thrust M9.0 Sumatra earthquake at 06:28:53am (Indian Standard Time) on 26 December 2004 and the resulting tsunami waves caused extensive damages in Port Blair (Jain et al. 2005a, 2005b). Port Blair is the capital city of Andaman and Nicobar (A & N) Islands in India and is located at about 1000 km NNW of the epicenter (3.307°N 95.947°E). A & N Islands are one of the most seismically active regions and are placed in seismic zone V, the most severe seismic zone as per the Indian code. Maximum intensity of shaking at Port Blair was VII on MSK scale. Tsunami reached Port Blair within 45 minutes of the event and the maximum height of waves recorded was about 4.5 m. Because of thrusting of Indo-Australian plate beneath the Burmese micro-plate, the A & N Islands sustained uplift on the western side and subsidence on the eastern side (Malik and Murty 2005). At Port Blair, situated on the eastern coast of the A & N Islands, rise in sea-water level by 0.9-1.2 m suggested considerable subsidence of the Island after the event.

The present paper is concerned with the performance of buildings in Port Blair primarily due to ground shaking. A digital strong-motion instrument installed at Port Blair by the India Meteorological Department failed to record the main event perhaps because of improper maintenance. Hence, peak ground acceleration (PGA) during the event is estimated by an

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approximate analysis of a collapsed reinforced concrete (RC) scooter stand.

## Construction Practices in Port Blair

Masonry was the primary construction material on the islands till 26 June, 1941, when a severe earthquake (M7.7) struck the region and damaged several masonry buildings perhaps including a part of the Cellular Jail (Jhingran 1953). The Cellular Jail was constructed in Port Blair over a period of ten years from 1896 to 1906 using solid brick masonry. It was a huge structure with a 5-storey central controlling tower and seven 3-storey wings containing 696 cells emanating from the tower (Fig. 1a). The construction was in very high quality masonry prevalent in India at that time. The masonry structure of Cellular Jail performed well during the shaking of 26 December.

After the 1941 earthquake, masonry constructions went out of vogue and it became a common practice on the islands to construct flexible wooden buildings using locally available timber. However, because of some major fire incidents, perceived superiority of RC construction, and because of restriction on use of timber due to environmental reasons, construction of the timber building was discontinued in the nineties. Nowadays, RC frame buildings with masonry infills are the prevalent mode of construction. Most commonly used bricks currently are light-weight hollow concrete blocks and solid clay bricks.

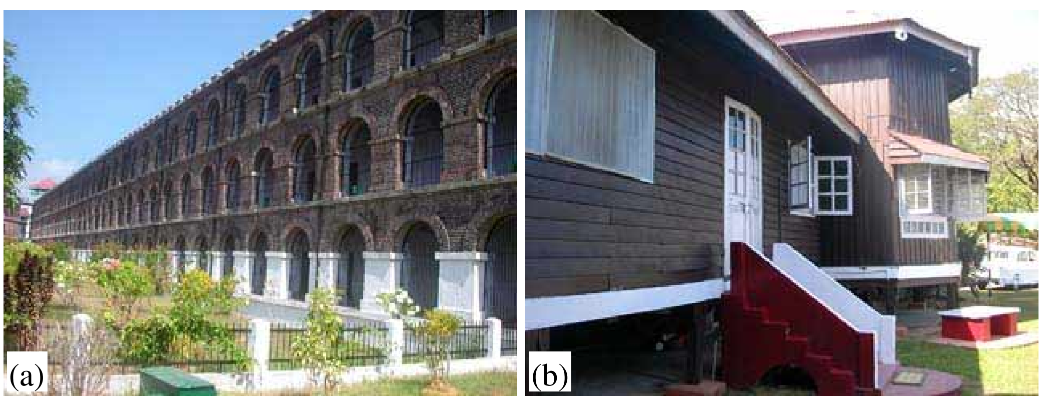


Figure 1. Undamaged historical and traditional construction in Port Blair: (a) masonry structure of Cellular Jail, and (b) timber house at Marine Hill, Port Blair.

Due to the shaking induced by the earthquake of 26 December, traditional timber buildings in Port Blair performed extremely well (Fig. 1b), while the RC buildings had varying levels of performance depending upon the quality of construction. Serious deficiency was observed in design and construction expertise for RC buildings at all levels. Common men are constructing these without involving engineers. Even when engineers are involved, earthquake resistant design and construction features may or may not be followed. For example, performance of several privately built RC buildings in Port Blair was disastrous. On the other hand, several Government buildings in Port Blair constructed by engineers using consultants also suffered extensive damages and partial collapse. For example, at Marine jetty dry dock, recently an office complex was being shifted from a 50 year old timber building, which was considered to be dilapidated (Fig. 2a) to a newly constructed 3-storey RC building (*Siddhartha*) situated right across the road (Fig. 2b). In 10 years of its existence, severe corrosion was observed in *Siddhartha* building due to poor quality of construction (Fig. 2c). However, the timber building performed well during the shaking. Damages were also observed in *Siddhartha* building because of earthquake shaking in the form of cracks in RC columns, crushing and out-of-plane failure of infills at several locations, etc. As a result, *Siddhartha* building had been vacated while the old timber building was being used as the office complex.

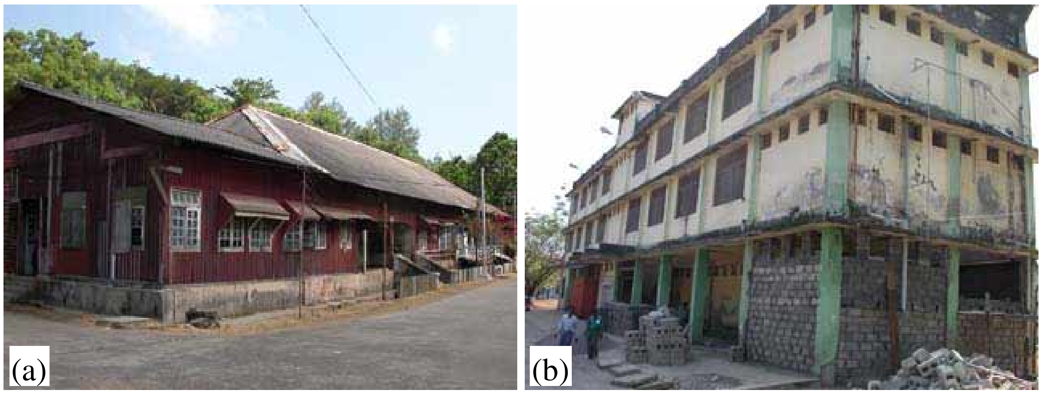



Figure 2. Performance of a 50 years old timber building vis-à-vis RC *Siddhartha* building at Marine Jetty Dry Dock: (a) undamaged timber building, (b) damaged *Siddhartha* building, and (c) Severe corrosion in *Siddhartha* building.

RC framed buildings require considerable sophistication in design, detailing and construction phases. Strict quality assurance and engineering inputs are absolutely necessary for good performance of RC buildings. When Government organizations are themselves not able to incorporate and adhere to the standards in construction of RC buildings; it would be highly unrealistic to expect this from common men who construct 1-2 storey buildings with the help of masons. This emphasizes the need for philosophical changes at the grass-root level in design and construction of buildings in higher seismic zones in India. Instead of low quality RC frame buildings, alternate typologies that do not require much engineering inputs and yet could perform well in earthquakes, need to be encouraged.

## Type of Damages Suffered by RC Buildings

Most RC buildings in Port Blair are 2 to 3 stories high, supported on columns on sloping ground because of significant variation of ground level on the islands. RC frame buildings in Port Blair suffered a variety of damages due to earthquake shaking, such as, collapse of whole building, severe damages to frame members and masonry infills, frame-infill separations, etc.

Various types of damages suffered by the RC buildings are discussed in the following.

**Collapse of Buildings with Open First Storey (Buildings on Stilts)**

Several buildings on stilts in and around Port Blair suffered severe damages or complete collapse due to shaking (Fig. 3). Most of these buildings were privately owned and constructed without engineering supervision and lacked proper seismic design and ductile detailing. In some of the buildings which did not collapse, the stilt storey columns suffered extensive damages. In a collapsed 3-storey building at Naya Gaon, the upper stories suffered only nominal damages in the RC frame and masonry infill (Fig. 3a). Some recently constructed buildings on stilts at Bamboo Flat collapsed completely (Fig. 3b). A 2-storey Police-Barrack Government owned building in which the open first storey was used for storage purpose collapsed at Haddo wharf (Fig. 3c), whereas the adjacent buildings with infills in the first storey survived the shaking.


Figure 3. Collapse of RC buildings at (a) Naya Gaon, (b) Bamboo Flat, and (c) Haddo wharf, and (d) partially collapsed Passenger Terminal Building at Haddo wharf.

The partially collapsed Passenger Terminal Building at Haddo wharf (Fig. 3d) was formally designed by a structural engineering firm in Chennai and constructed by contractor with engineering supervision. This is a newly constructed important building with heavy usage on a busy wharf. Because of large openings provided for ventilation, nominal masonry infill walls were present in the RC frames on periphery of the building; however, infill walls were not present in the inner frames to generate open space. Ductile reinforcement detailing was not found in RC columns of the building. The building was partly supported on RC piles on the sea-side and partly on spread footing on relatively soft soil, which aggravated the damages in the building.

**Damages due to Poor Shear Design**

Predominant construction practice in Port Blair is to provide a very light lateral reinforcement in columns (6-8 mm diameter with 90° hooks at about 200-250 mm spacing). Therefore, stilt storey columns of several buildings suffered extensive damages in brittle shear mode resulting into complete collapse of some buildings (Fig. 3). In several columns in buildings at Bamboo Flat, the 90° hooks of the shear reinforcement opened up leading to buckling of longitudinal bars and subsequent crushing of concrete (Fig. 4). In the Passenger Terminal Building at Haddo wharf, several columns and beams sustained extensive damages in shear and flexural modes due to inadequate design (Fig.5).

Figure 4. Poor shear design attributed to several column failures in buildings at Bamboo Flat.

Figure 5. Severe cracking in RC members of Passenger Terminal Building at Haddo wharf.

**Damages associated with Short Column Effect**

In several buildings, masonry infills were used in RC frames only up to partial heights because of functional requirements, such as, ventilation. In addition, openings are generally provided in the infills for provision of doors and windows, which created *short column effects* and significantly increased shear demands in the columns. Several short columns in buildings at Bamboo Flat and in Passenger Terminal Building at Haddo wharf suffered extensive damages at the locations where partial height infills were provided (Fig. 6).

## Out-of-Plane Failure of Masonry Infills

Out-of-plane failure of masonry infills was observed in several RC buildings primarily due to poor quality of masonry, and inadequate and loose joint between RC frame and masonry walls. In a three-storey school building at Mohunpura in Port Blair, long infill walls tilted out-of-plane (Fig. 7a). The collapsed 3-storey building at Bamboo Flat had out-of-plane collapse of several infill walls (Fig. 7b). Similar damages in masonry infills were also observed in the Passenger Terminal Building at Haddo Wharf (Fig. 7c).

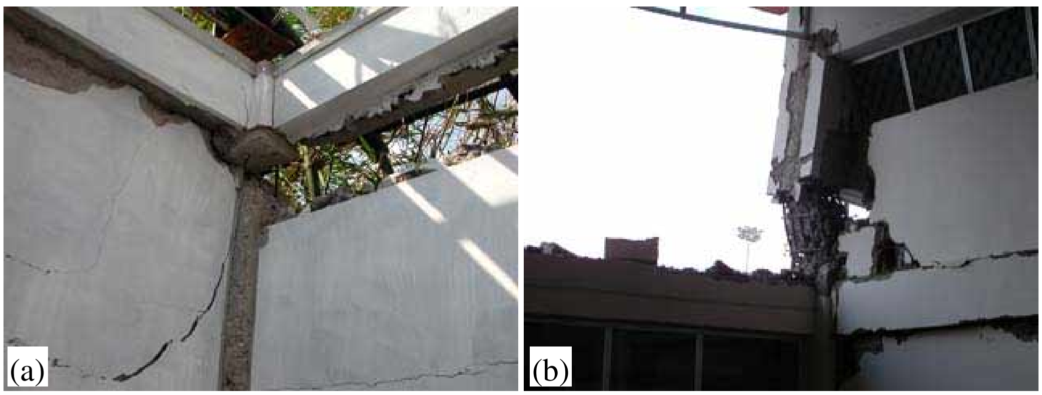

Figure 6. Damages associated with short column effect in buildings at (a) Bamboo Flat, (b), and (c) Passenger Terminal Building at Haddo wharf.

Figure 7. Out-of-plane failure of masonry infills in buildings at (a) Mohanpura (school building),

(b) Bamboo Flat, and (c) Passenger Terminal Building at Haddo wharf.

## Pounding Damages

Several buildings in the Bamboo Flat shopping complex and Passenger Terminal Building at Haddo wharf suffered substantial cracking and damages at the floor levels in slabs, and in columns and masonry infills because of pounding with adjacent blocks (Figs. 8a, 8b, 8c). An L-shaped 3-storey RC school building at Mohanpura constructed in stages between 1986 and 1989 was damaged at the expansion joints provided between different blocks (Figs. 8d and 8e).

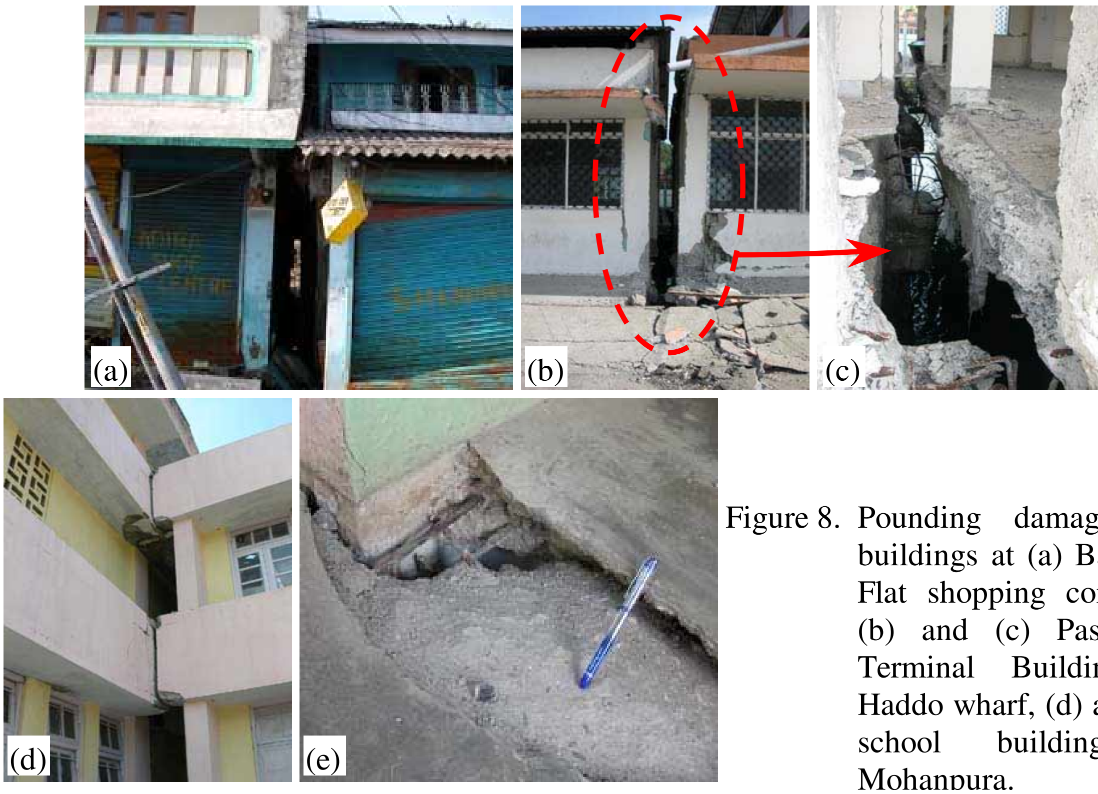


Figure 8. Pounding damages in buildings at (a) Bamboo Flat shopping complex, (b) and (c) Passenger Terminal Building at Haddo wharf, (d) and (e) school building at Mohanpura.

## Ground Sliding/Failure

Many RC buildings in Port Blair are constructed on sloping ground. Ground sliding along the slope up to about 50-75 mm was observed at plinth level of several buildings at Aberdeen Market and Dilanipur (Fig. 9). Fig. 9a shows a marking on a masonry wall produced by a steel gate in front of Police station building at Aberdeen Market before the earthquake. During the earthquake, the 3-storey building moved along the slope by about 75 mm, while the steel gate connected to a retaining wall did not slide with the building. Figs. 9b and 9c show lateral movement of about 50 mm at the plinth level of a 3-storey RC building at Dilanipur.

## Foundation Failure and Settlement of Buildings

Several buildings in Port Blair settled possibly due to foundation failure, erosion or settlement of underlying soil due to inundation of the region by tsunami waves, and liquefaction.

In most of such cases buildings located near the sea settled down and signs of liquefaction, if any, were washed away by the tsunami. At least two RC buildings (Fig. 10a, 10b) and several shops in the shopping complex (Fig. 10c) at Bamboo Flat settled down possibly due to liquefaction. Several buildings located in harbor area in Port Blair settled down due to structural failure of some of the foundation piles, e.g., Operation Wing building at Marine jetty (Fig. 11a) and Passenger Terminal Building at Haddo wharf (Fig. 11b). Damages were observed at the junction of a RC pile and pile cap supporting a RC storage building at Haddo wharf (Fig. 11c).


Figure 9. Ground sliding along slopes resulted in permanent lateral movement in (a) Police station building at Aberdeen Market, (b), and (c) residential building at Dilanipur.


Figure 10. Settlement of several buildings at Bamboo Flat (a) 2-storey RC building, (b) 3-storey RC building, and (c) shopping complex.

**Peak Ground Acceleration (PGA) during the Earthquake**

The digital strong-motion instrument installed at Port Blair by the India Meteorological Department failed to record the main event; therefore, PGA is estimated by an approximate analysis of a collapsed RC scooter stand. The scooter stand in the Port Management Board office complex was 20 m long, 3.3 m wide, and 2 m high supported on six columns spaced equally at 4 m without any filler walls or non-structural elements (Fig. 12a). All the columns (size: 200×300 mm) failed causing collapse of the entire structure. The columns had 4 bars of 16 mm dia. and 2 bars of 12 mm dia. as longitudinal reinforcement, and most of the bars were found to be severely bent. Transverse reinforcement in the columns consisted of 8 mm dia. bars at 150 mm spacing.

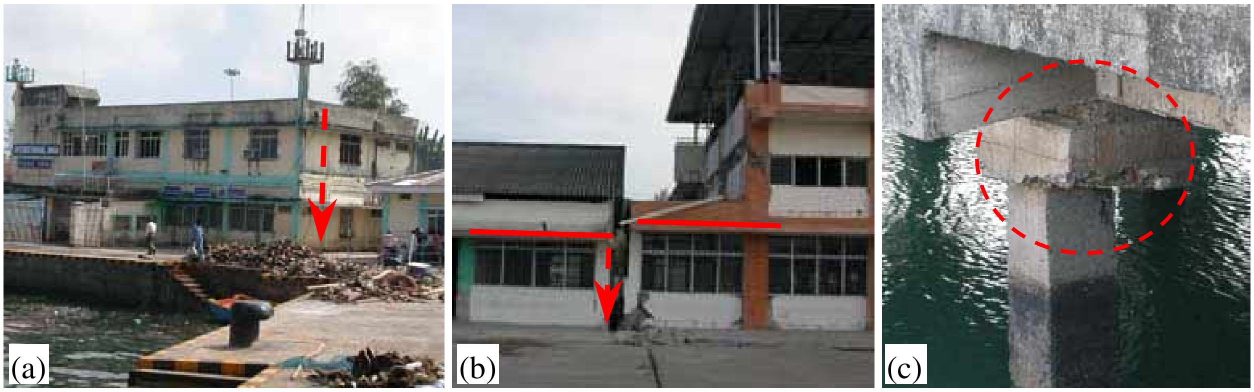


Figure 11. Foundation failure resulting into settlement of buildings (a) Operation Wing building at Marine Jetty, (b) Passenger Terminal Building at Haddo wharf, and (c) RC storage building at Haddo wharf.


Figure 12. Collapsed RC scooter stand at Marine jetty office complex: (a) collapsed structure, (b) longitudinal rebars of at least two end columns were continued only up to soffit of the top beam, and (c) shear reinforcement was not present in at least one interior column.

It was observed that the longitudinal rebars of the two end columns were continued only up to the soffit of the top beam (Fig. 12b). Therefore, it is assumed in the analysis that the plastic hinges will form at only the bottom of both the end columns. On the other hand, plastic hinges are assumed to form at both the top and bottom of the inner columns. Also, shear reinforcement was not found in about half the height in one of the interior columns (Fig. 12c). Thus, concrete is considered to be unconfined in the analysis and the columns were assumed to have negligible ductility. A rough calculation indicates that the lateral load capacity of the structure was about 25% of its self weight, which suggests that the PGA in the region may have been at least 0.1g.

## Concluding Remarks

There was no or very limited damage to the traditionally constructed wooden buildings using locally available timber. Old masonry buildings also performed well during the shaking, indicating a very high quality of masonry construction in India. On the other hand, significant damages were observed in several RC buildings constructed in recent years. An approximate analysis of a collapsed RC scooter stand indicates that the peak ground acceleration in Port Blair during the earthquake was at least 0.1g. Poor quality control and non-adherence to the basic earthquake resistant features was one of the major reasons of unexpectedly poor performance of RC buildings. Alternate construction practices, which require little engineering expertise and still can provide resistance to lateral seismic forces, are required in seismically active regions in India.

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