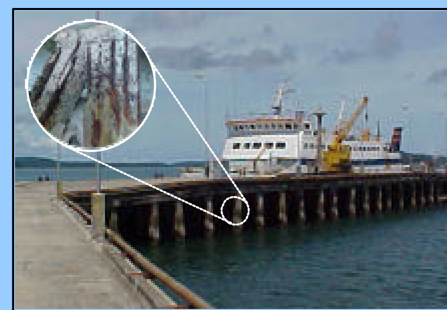
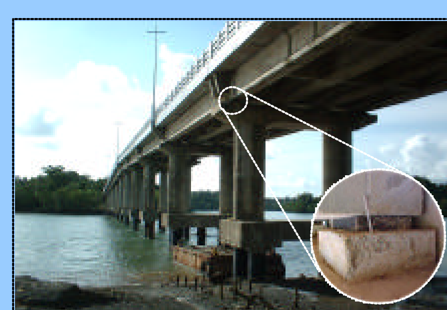
Reconnaissance Report

North Andaman (Diglipur) Earthquake of 14 September 2002





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RECONNAISSANCE REPORT

NORTH ANDAMAN (DIGLIPUR) EARTHQUAKE OF 14 SEPTEMBER 2002

by

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April 2003

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NORTH ANDAMAN (DIGLIPUR) EARTHQUAKE OF 14 SEPTEMBER 2002

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On 14 September 2002, at 03:58:31 AM a M_L 6.0 (IMD) M_w 6.5 (USGS) earthquake struck the Northern Andaman Island region of the Andaman & Nicobar Islands (Union Territory) of India (Figure 1). The epicenter is about 165 km NNE from Port Blair, the administrative head quarters of A&N Islands, in the sea about 24 km SSE of Diglipur, a town with a population of about 30,000. The location of the epicenter is 13.013°N 93.147°E (USGS), and the focal depth is 33 km. The main shock was followed by many after shocks, the largest of them being M 5.3 on 14 September at 04:44 hours and M5.2 on 15 September at 01:29 hours. In the two days following the main shock, 20 after shocks of M>3 were recorded at IMD Observatory in Port Blair; a list of these is given in Table 1. Aftershock activities were noted even till 24 September 2002.

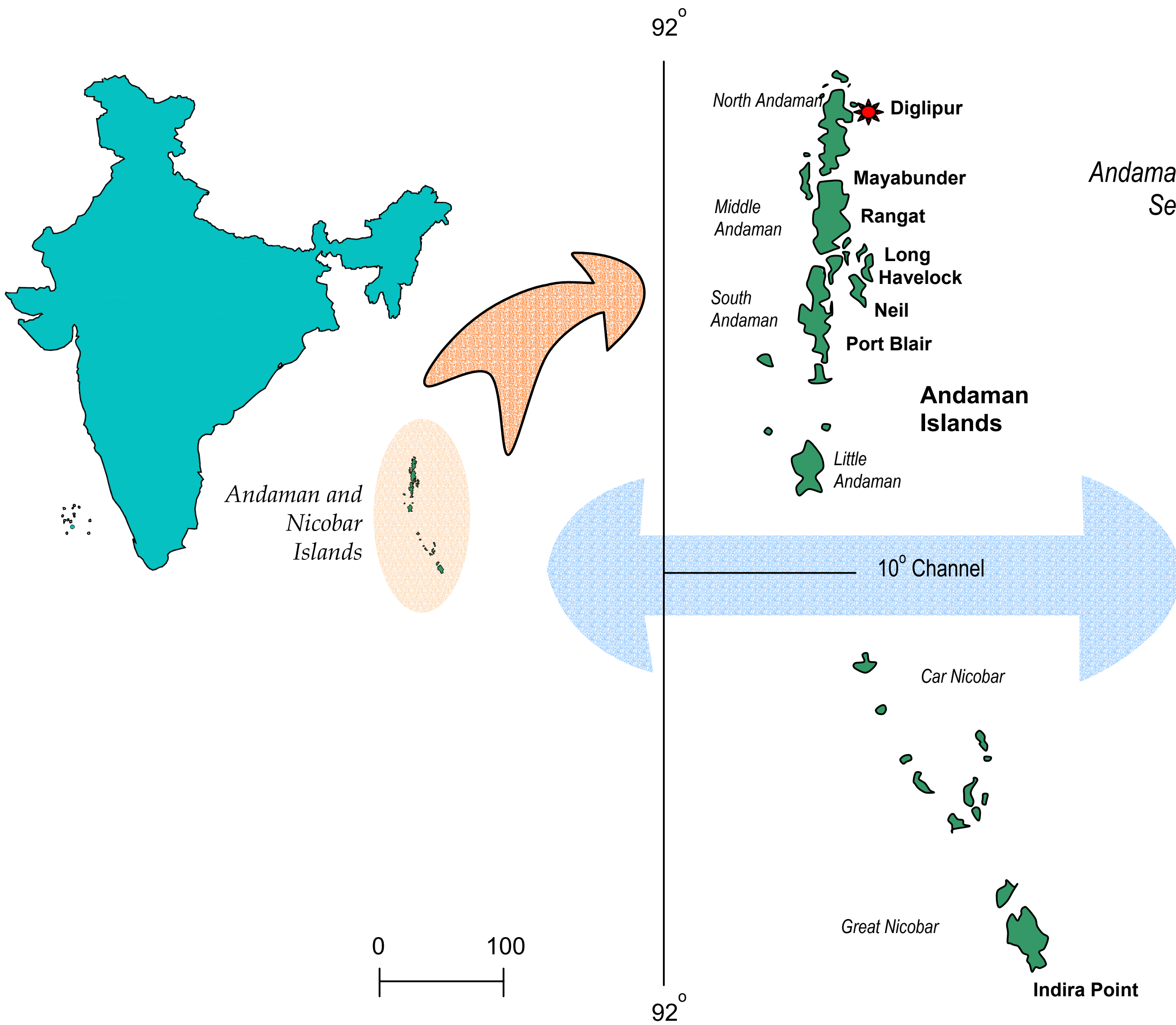


Figure 1: *Index Map of the Andaman & Nicobar Islands showing epicenter of the earthquake*

Table 1: *Aftershock activities on the first two days following the main shock on 14 September 2002. (Source: IMD)*

Date	**Time**	**Local Magnitude**
14 September 2002	03:59	6.0 Main Shock
	04:44	5.2
	10:49	3.2
	12:27	3.2
	14:50	3.5
	15:19	3.0
	16:34	3.3
	20:40	3.2
	22:10	3.0
	23:06	3.2
15 September 2002	00:21	3.0
	01:28	5.3
	03:43	4.7
	04:34	3.1
	05:09	3.2
	05:15	3.1
	06:21	3.2
	06:24	3.1
	06:59	3.0
	07:12	3.0

No strong motion data is available for this earthquake. However, one tri-axial strong motion accelerograph (Make: *GeoSIG*) was installed in the IMD Observatory at Port Blair after about three weeks of the occurrence of the main shock of September 14.

The Andaman & Nicobar Islands have been regarded as one of the most active seismically regions in India. They are placed in most severe seismic zone V of the Indian Seismic Zone map (Figure 2), with expected MMI of IX or greater. The arcuate line of Andaman and Nicobar Islands are said to be located on a small tectonic plate and is referred as Andaman Plate by Dasgupta (1993) and Burma Plate by Curray et al (1982). This tectonic plate, which forms the ridges of the islands, is sandwiched between the Indo-Australian plate on the western side and the Eurasian plate in the north and the east. On the eastern side of the Islands arc lies the spreading centers. The Indian lithosphere on the western side subducts below the Andaman (Sunda) Plate (Fitch 1970, Dasgupta and Mukhopadhyay 1993, Rajendran and Gupta, 1989). The subduction at this interface causes regular seismic shaking of moderate earthquakes in this region.

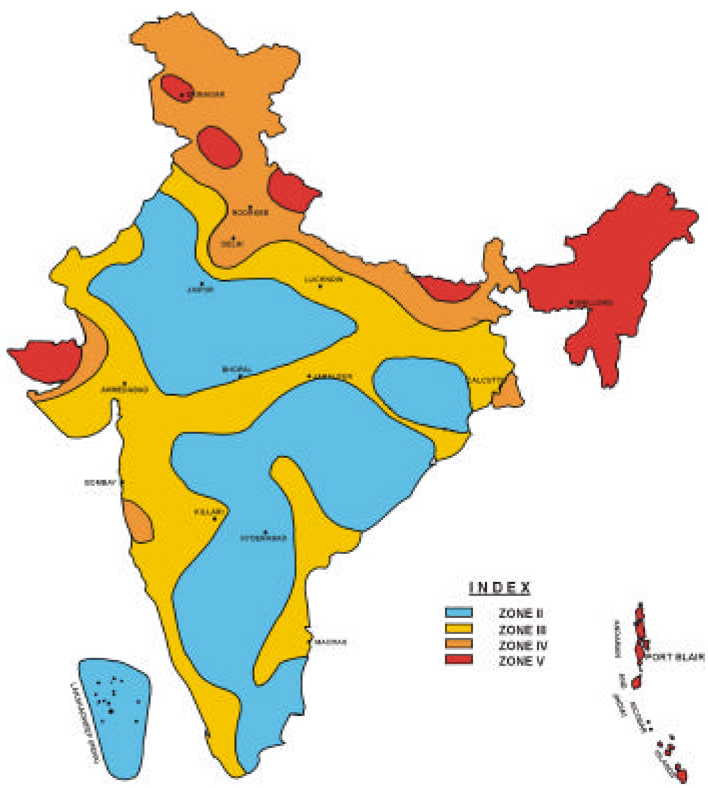


Figure 2: *Seismic Zone Map of India showing the Andaman & Nicobar Islands region in Seismic Zone V (Source: GSI)*

Many large earthquakes visited the region in the past (Table 2). The most significant one in the recent times was on 26 June 1941. This great earthquake of M 8.1 (M_W 7.7 USGS) is the strongest recorded event in this region centered in the west of Middle Andaman Island (12.50°N 92.50°E). It caused extensive damage in the Andaman Islands, including at Port Blair. The maximum MM intensity of VIII$^+$ was observed in Baratang Island, Port Blair, Shaol Bay Creek, and near Port Anson (Dasgupta et al 2000). The resulting tsunami in the Bay of Bengal caused flooding of the Port Blair and recorded along the eastern Coromandel Coast of Peninsular India.

An earlier event on 31 December 1881 was known to have caused even greater damage. This event is estimated to have a magnitude of about Mw 7.9 (Ortiz and Bilham 2002) and caused significant damage to masonry buildings in Port Blair, and the tsunami generated by this earthquake had a maximum run-up of about 1.2 m on the eastern coast of India (Oldham 1884). A summary of the epicenters of the earthquakes greater than M6 in the region since 1973 is shown in Figure 3 (NEIC, USGS). Rajendran et al (2003) have observed that since 1973 nearly a dozen earthquakes have occurred in the region with at least one event greater than M6 and suggest that the region is witnessing a new phase of seismic activity. The earthquake of September 14, 2002 is probably a result of the ongoing post-seismic relaxation associated with the 1941 event and can lead to a prolonged inter-seismic phase for a large-thrust type earthquakes (Rajendran et al 2003).

Table 2: Significant earthquakes of M=6.0 in Andaman & Nicobar Islands. (*Dasgupta et al 2000, Bapat et al 1983, Ortiz and Bilham 2002*)

Date	**Magnitude**	**Location**	**Remark**
31 December 1881	M_w 7.9	Between 8.5°N to 10 .5 °N off Car Nicobar Island	Based on a recent study by *Ortiz and Bilham (2002)*
16 November 1914	M_s 7.2	12.00°N 94.00°E	SW of Barren Island
28 June 1925	-	10.20°N 92.80°E	SE of Little Andaman Island
19 May 1928	M_s 6.2	13.00°N 93.00°E	
01 August 1929	M_s 6.5	12.00°N 95.50°E	Andaman Sea, ESE of Barren Island
09 December 1929	M_s 6.7	04.50°N 94.50°E	SSE of Great Nicobar islands
19 March 1936	M_s 6.5	10.50°N 92.50°E	Little Andaman Island
14 September 1939	M_s 6.0	11.50°N 95.00°E	SE of Barren Island
26 June 1941	M 8.1 (IMD); M_w 7.7	12.50°N 92.50°E	W of Middle Andaman Island
14 July 1941	M_s 6.0	12.40°N 92.50°E	
9 August 1941	M_s 6.0	12.40°N 92.50°E	
08 August 1945	M_s 6.7	11.00°N 92.50°E	N of Little Andaman Island
23 January 1949	M_s 7.2	09.50°N 94.50°E	E of Car Nicobar Island
17 May 1955	M_s 7.2	07.00°N 94.00°E	Off E coast of Great Nicobar Island
18 June 1957	M_s 6.5	14.00°N 96.00°E	ENE of Narcodam Island
16 November 1962	M_s 6.1	13.50°N 93.20°E	
14 February 1967	M_s 6.8	13.70°N 96.50°E	Andaman Sea, W of Mergui Archipelago
20 January 1982	M_w 6.2	06.95°N 94.00°E	Great Nicobar Island, E of Bananga
	M_w 6.1	07.12°N 93.90°E	Great Nicobar Island, SE of Laful
24 January 1983	M_w 6.1	12.91°N 93.59°E	

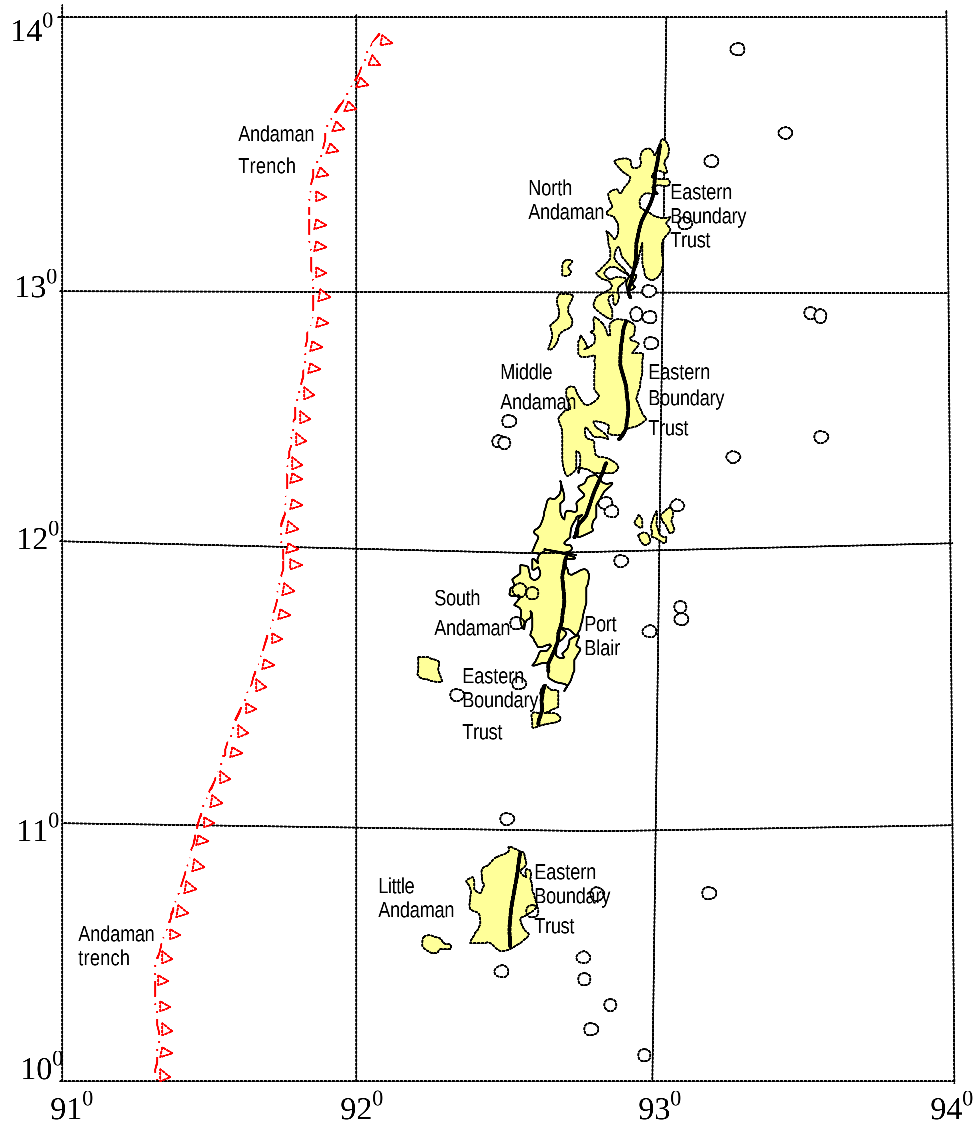


Figure 3: *Map of Seismicity in the Andaman & Nicobar Island region since 1901, showing locations of earthquakes of M>5 (Dasgupta et al 2000)*

The maximum intensity of shaking was observed in the Shibpur, Aerial Bay Jetty and Kerala in the neighbourhood of Diglipur town towards shoreline and was estimated to be VII on MSK scale (Figure 4). Many masonry and reinforced concrete structures suffered minor damage which varied from purely cosmetic to serious structural damage. Most of these damages were primarily due to poor architectural configuration and serious deficiency in reinforcement detailing. Lateral spreading near shoulders of roads were observed and similar damage was noted in the newly constructed runway (Figure 5). Most of the North Andamn island experienced a shaking of intensity VI and light traditional structures made using timber and bamboo suffered no visible damage. However, a few of masonry and RC structures with significant seismic deficiencies experienced damage which was not proportionate to the observed level of shaking.

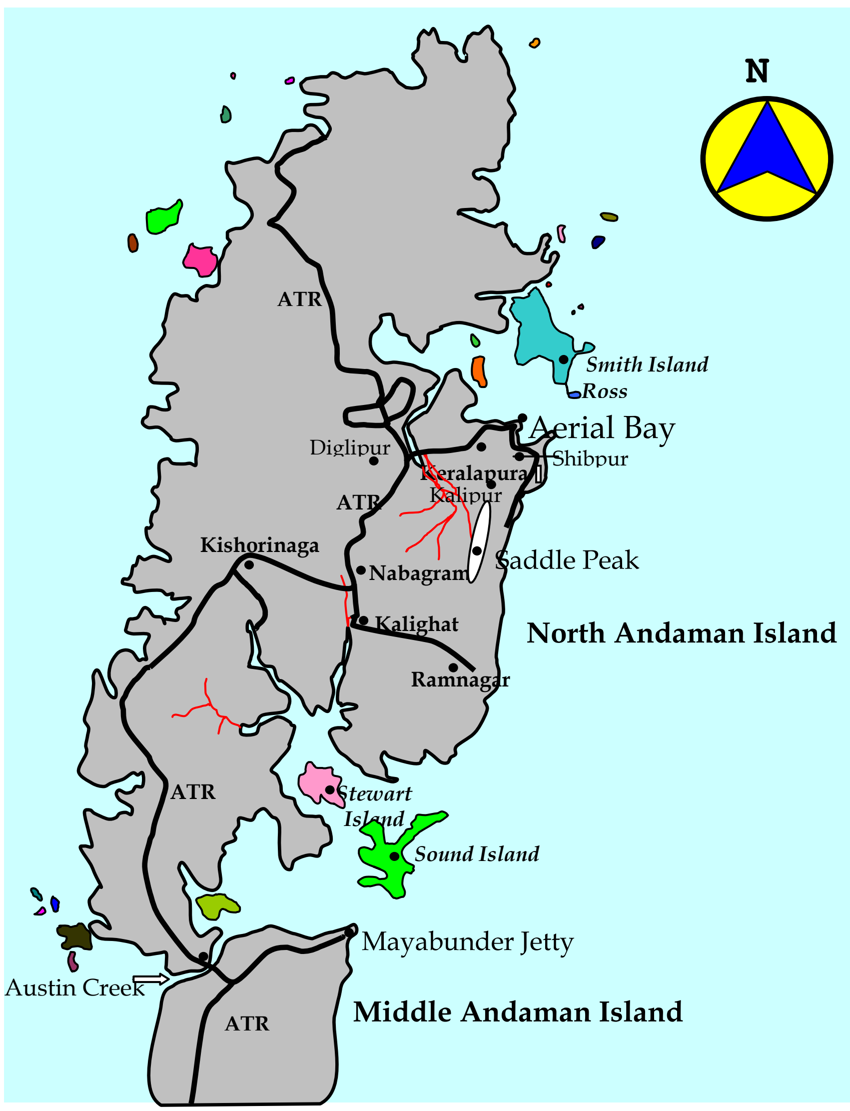


Figure 4: *North Andaman Island and Northern tip of the Middle Andaman Island that experienced significant shaking of MSK VI with small area in the proximity of Arial Bay where shaking intensity reached a maximum of VII.*

a) Passenger shelter at bus stop b) RC sign post c) Longitudinal cracks along ATR

Figure 5: *Damage due to significant shaking in Shibpur area near shoreline in Diglipur.*

In the North Andaman Island, the other population centers which were affected by the earthquake lie southward along the Andaman Trunk Road (ATR). Many school, community and residential buildings in Nabagram, Kalighat, Ramanagar and Kishorinagar suffered damage. In the northeast of Arial Bay, on largely uninhabited Ross and Smith islands, a strong shaking was also reported, which is consistent with the location of epicenter in the sea off Diglipur.

Mayabunder which is located on the northern tip of the Middle Andaman Island was shaken to the intensity of VI. Pounding damage was noted to jetty slabs. Truss members in the old cargo shed at the jetty and their connections failed. Many buildings in Mahatma Gandhi Degree College, about 12 km from the Mayabunder town, developed cracks in their seismic deficient masonry and RC buildings. Further southward on Middle Andaman Island from Mayabunder, the intensity of shaking was less; the earthquake was felt upto Port Blair at the southern end of south Andaman island. Traditional timber and bamboo structures were not affected to any noticeable degree on these islands, even in the areas of stronger shaking.

A seismic intensity map is shown in Figure 6; this is based on the broad observations of effects of the earthquake along the main artery of the Islands namely, the ATR. Major population centers are located along ATR. However, many villages in remote places are not easily accessible. A great majority of structures are indigenous houses that are constructed with timber and bamboo. These structures, in general, fared well in the earthquake and bore no visible sign of structural distress to help clearly assess the intensity of shaking.

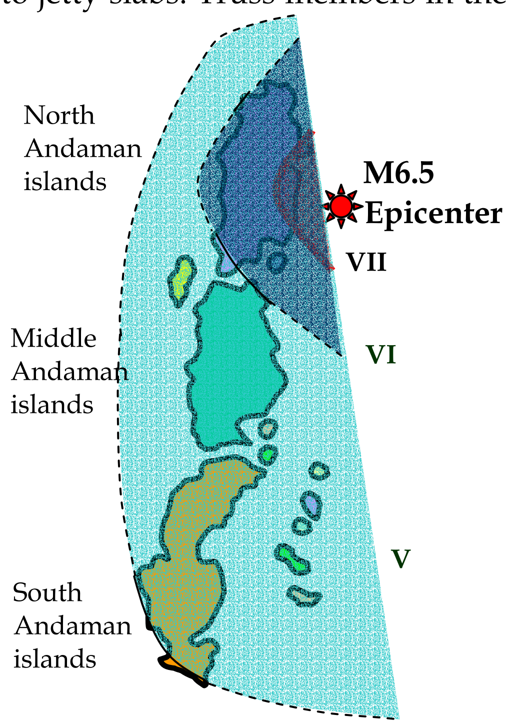


Figure 6: *An iso-seismal map of the Andaman earthquake of 14 September 2003*

4. Geology and Soil Conditions of the Region

Andaman islands are a group of about 200 islands spread along a curved line of 1200 km long in the Bay of Bengal. They are mass of hills marked with exceedingly narrow valley and are thickly covered with tropical forest; the longest island (namely the Southern Andaman Island) is 350 km long and 50 km in width at its widest stretch. These islands are part of submarine mountains, which are geologically similar to Arakon Yoma of Burma range in the north. The Saddle Peak (728 m above MSL) in North Andaman Island is the highest point of this region. The older rocks are of early Tertiary or late Cretaceous period (Figure 7).

The thrust faulting between the Indo-Australian Plate and the micro-Burmese plate has resulted in the formation of the Andaman & Nicobar Islands. Currently, the landmass of the Andaman & Nicobar Islands has a maximum elevation of about 700 m above mean sea level (MSL), the average elevation being about 40 m above MSL (Figure 8a). This elevation causes gentle hill slopes along the islands. Also, the topsoil in the Andaman & Nicobar Islands is usually made of soft disintegrated sedimentary rock (murrum) and clayey silt (Figure 8b). Further, the annual rainfall in the Andaman & Nicobar Islands is about 3000 mm. This level of saturation coupled with the weak murrum/silty top soil at low lying land makes the constructions along these slopes the most vulnerable structures from the foundation point of view.

Figure 7: *Vertical cut exposures in the town of Port Blair showing highly fragmented rock structure with interstice loose sediment layers.*

(a) (b)

Figure 8: *Soil strata in the Andaman & Nicobar Islands has two dominant features, namely (a) soft disintegrated murrum or silty soil along the hill slopes, and (b) high water table due to extensive water body around the low-lying islands. Both these contribute to making the hill slopes vulnerable to the expected strong seismic shaking in the region.*

The area is primarily under the threat of rains for most part of the year. Thus, pitched roofs are common. In early buildings, timber was used extensively in the form of frames, beams, posts, trusses, and walling. However, these days it is more common to see reinforced concrete frames and floors in buildings, with steel tubular trusses supporting light roofing made of asbestos or corrugated galvanized iron sheets. Some recent constructions even use pitched RC roofs. The restriction on the felling of trees for timber and the high maintenance cost of timber structures has further accentuated this change. Table 3 and Figure 9 summarize the variety of materials that have been used in constructing walls and roofs of houses and their evolution with time. Many of earlier types are still preferred because of economy of construction.

Nowadays, the prevalent construction has reinforced concrete (RC) stiffener frame and solid/hollow concrete block infills. Even load bearing constructions use these concrete blocks as walling material. However, a variety of roof types is in use - from tubular truss to RC slab (sloping or flat slab).

Earlier, sea sand was used in the making of concrete, but nowadays, pulverized quarry dust is being used as fine aggregates (Figure 10a) which is a by-product from crushing of boulder stones at local quarries to obtain coarse aggregates (Figure 10b). The quarries use the

Table 3: *General pattern of evolution of housing types in the region based on the material and construction technique used for walls and roofs*

<table>
<tr><th colspan="2">Housing type</th><th>Material for Wall</th><th>Material for Roof</th></tr>
<tr><td rowspan="10">Traditional construction

Modern construction</td><td>1</td><td>Thatch and wooden posts for support</td><td rowspan="2">Thatch as roof cover on informal wooden truss</td></tr>
<tr><td>2</td><td rowspan="2">Bamboo mats and wooden posts</td></tr>
<tr><td>3</td><td rowspan="4">Asbestos/CGI sheets on wooden truss</td></tr>
<tr><td>4</td><td>Wooden planks and wooden posts</td></tr>
<tr><td>5</td><td>Masonry upto plinth level is added</td></tr>
<tr><td>6</td><td>Hollow block wall masonry and wooden posts</td></tr>
<tr><td>7</td><td rowspan="4">RC stiffener frame and hollow block infill masonry</td><td>Part in timber and part in RC frame roof with light asbestos/CGI sheets as roof cover</td></tr>
<tr><td>8</td><td>Part steel tubular truss and part RC frame roof with light asbestos/CGI sheets as roof cover</td></tr>
<tr><td>9</td><td>RC sloping slab</td></tr>
<tr><td>10</td><td>RC flat slab</td></tr>
</table>

Figure 9: *Transition of constructional strategies in Andaman & Nicobar Islands from traditional wooden construction with thatch roof to modern reinforced concrete frame buildings with sloped/flat RC slab roof.*

(a) (b)

Figure 10: *Fine and Coarse Aggregates obtained from crushing the sedimentary and basalt rocks available in the region.*

locally available sedimentary and basalt rocks, which have very high water absorption capacity. Thus, the concrete obtained from these aggregates also has very high permeability.

Burnt–clay bricks are non-existent in the Andaman and Nicobar Island region primarily because of the non-availability of good clayey earth and the difficulty to manufacture because of less sunshine and almost daily drizzles/showers. Instead, concrete blocks are widely used for masonry in the region. Two sizes of hollow concrete blocks are normally used; namely: (a) 200 mm thick block with nominal plan dimensions of 400 mm length and 200 mm width, in exterior walls and (b) 100 mm thick block with the same nominal plan dimensions, in interior partition walls (Figure 11). They are made by mixing Portland cement, sea sand and 12 mm stone chips in the proportion of 1:3:6 by volume. Usually, they are not adequately compacted and cured, and therefore their compressive strengths are usually as low as 3 MPa. These low strengths do not meet requirements of the relevant Indian Standards. Solid concrete blocks were used in place of hollow concrete blocks, where higher compressive loads were anticipated. Cement–sand mortar is used for the masonry; the mortar mixes vary from 1:3 to 1:6.

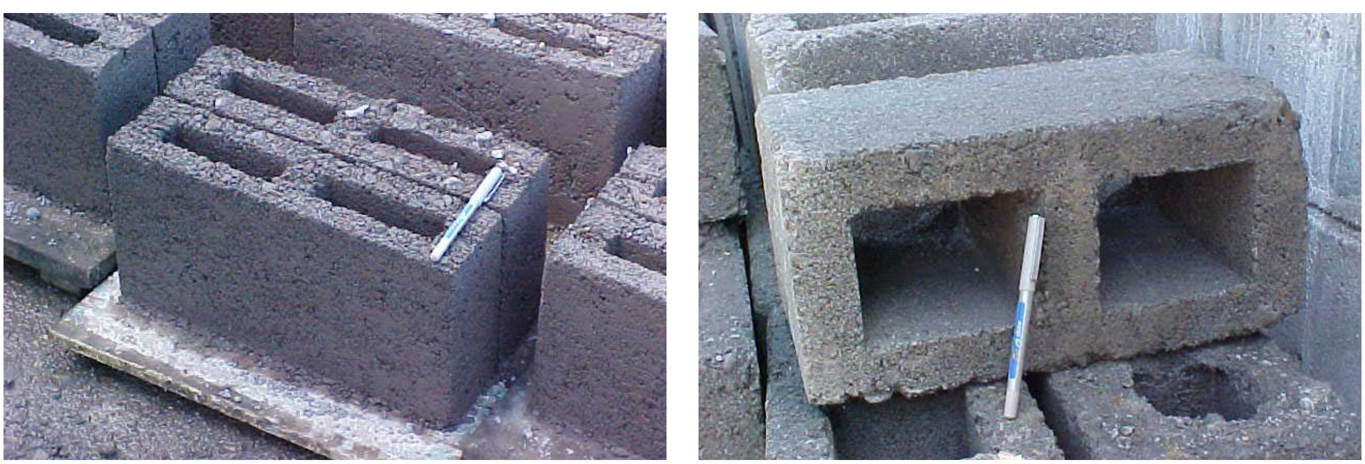


Figure 11: *Hollow concrete blocks used for masonry wall are characterized with a very low compressive strength due to poor compaction, curing, etc.*

Though only a small area of North Andaman Island was subjected to strong shaking, disproportionately large damage was observed in certain masonry and modern RC buildings that suffered from numerous seismic deficiencies. These deficiencies ranged from those involving planning and layout to those involving design and construction aspects of earthquake resistant structures. Despite Andaman and Nicobar Islands being in seismic Zone V, little attention was paid to ensure good seismic features in structures built in the region, including many major building projects under taken in the recent past. In other words, the contemporary constructions are adding to the seismic vulnerability of the region rather than mitigating it.

In contrast, traditional structures using lightweight materials such as timber, bamboo mats, thatch, asbestos and CGI sheets have performed satisfactorily. Some of the earlier wood constructions though suitable for seismic conditions, were found to be highly vulnerable to strong seismic shaking due to their poor present condition; lack of maintenance, degradation of timber, and weakening of joints were observed as some reasons for this. (Figure 12). Figure 13 shows a wooden frame house constructed on stilts, a representative of the buildings of the colonial period. The building had a history of settlement and movements at stilt level, which was not adequately addressed and was in poor general maintenance. During this earthquake, the building was severely shaken and rendered unsafe for further occupation. Such a performance of buildings of this type was an exception in the area and many took the shaking without any visible distress.

Figure 12: *An old 2-storey timber house in dilapidated condition; numerous such constructions stand vulnerable under expected strong shaking in the region.*

Figure 13: *An old and poorly maintained wooden frame building on stilts on slope with a long history of soil movement and settlement rendered unsafe for further occupation in Diglipur.*

The islands have a large inventory of buildings that have masonry load bearing walls and light roof truss made of either steel pipes or timber. Often these walls are not tied together to create the necessary box-action in masonry construction required for lateral resistance. No positive connection is provided between the wall and truss members resting on them. In figure 14 is an example of such structures; wherein the masonry wall was pushed out-of-plane during large movement of flexible roof that consists of poorly jointed wooden truss members. Presently, steel trusses involving hollow circular pipes are fast replacing the older practice of timber trusses. However, connections between truss members are purely ad-hoc as shown in Figure 15 a. Figure 15 b shows the straining of seating connection at the column top caused by large movements of the flexible truss.

(a) (b)

Figure 14: *Masonry bearing wall dislodged out-of-plane due to large movements of flexible roof structure.*

(a) (b)

Figure 15: *Poorly detailed joints between truss pipe members, and between the truss and the supporting RC column.*

In the last few years, many Panchayat buildings have been constructed in the region based on the type design developed by the Andaman Public Works Department (APWD). A typical plan and elevation of such a building is shown in Figure 16. However, significant variations from the approved drawings were noticed, such as creation of open ground story for meeting assemblies by not raising masonry walls to the full story height. The first story becomes heavy and stiff due to presence of large amount of masonry wall to create office space. Obviously, this top-heavy-bottom-flexible structure would result in large seismic demands on the column members for which they might not have been designed.

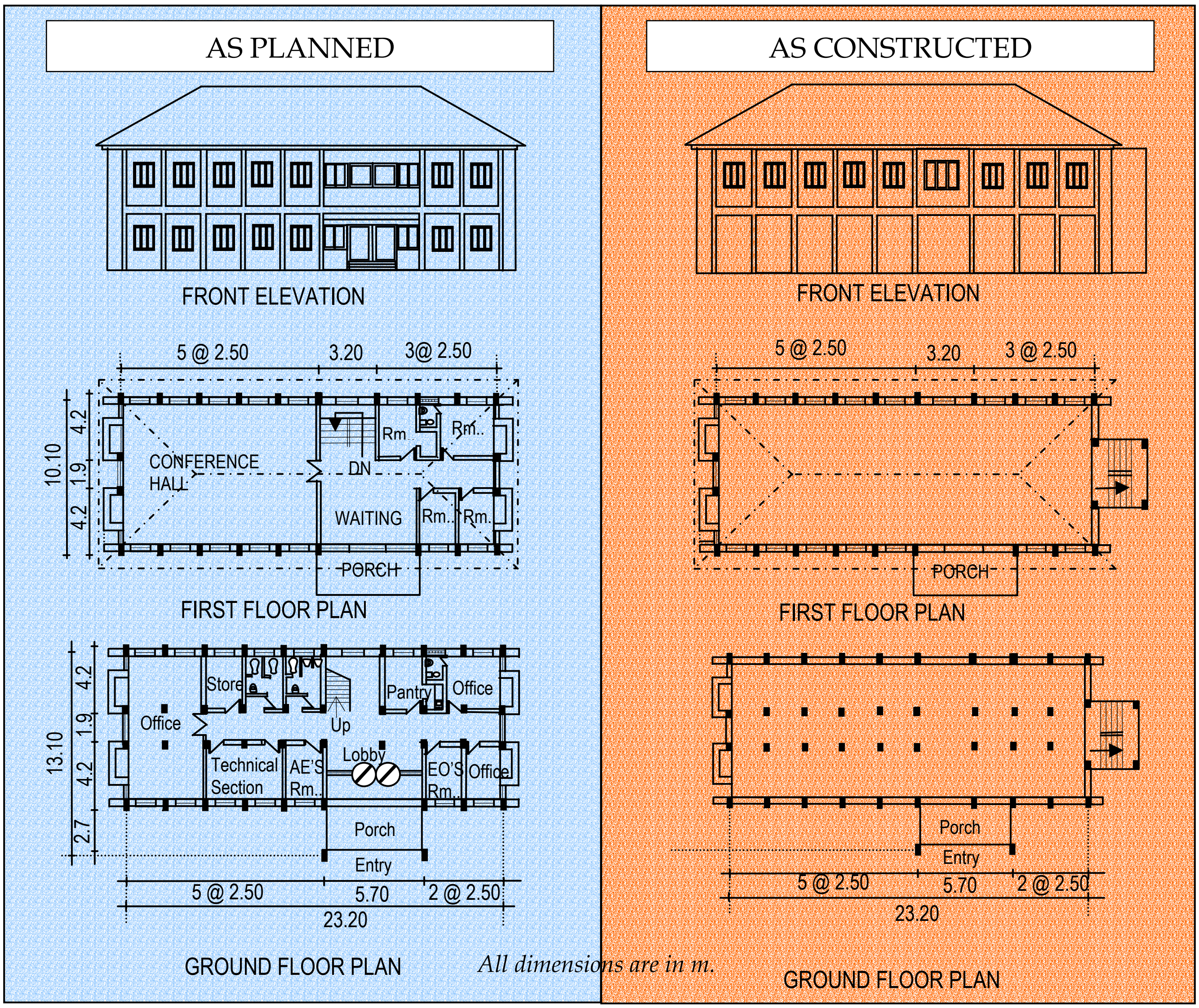


Figure 16: *Typical plan and elevation of Panchayat buildings in the region. The 23.2 m by 13.1 m building in the plan was originally designed with office spaces on the ground floor, which was altered when built. Also, the stair case block was relocated at the end of the building.*

One such building, the Nabagram Panchayat building, suffered extensive damage to its ground floor columns near the side farthest from the stiffer side near the stair case block. Many of the columns were severely cracked and damaged near beam-column joints and at mid-heights (Figure 17). A close inspection revealed that no transverse stirrups (ties) were present over a length greater than 350 mm for the 200 mm wide columns. The ties were not securely held in place and as a result slipped from their position while placing concrete. Two-to-three tie rings were found stacked at one place. Absence of ties rendered these relatively short columns extremely vulnerable to shear forces generated during the earthquake and even a general shaking of intensity VI was serious enough to damage the structure and undermine its safety. The RC columns were not designed for earthquake forces and required ductility to begin with. Further the building was made susceptible to poor seismic performance by creating the open first storey and by the lack of transverse stirrups in that storey where shear resistance is most needed.

(a)

(b) (c) (d) (e)

Figure 17: *Severe cracking and damage to the soft first storey columns of the Nabagram Panchayat building due to 'missing' ties.*

Similar constructional errors were responsible for damage to columns near beam-column joints in the main building of Mahatma Gandhi College near Mayabunder, which also received a less than moderate shaking of VI on MSK scale. As shown in Figure 18, the deep cracks were noticed in beam-column joint regions in one wing of the 'donut' shaped building which was constructed at a later date. Upon chipping away the concrete cover, no stirrups were found in the column for entire beam depth for a distance in excess of 450 mm. Such a reinforcement detailing in joints is not even appropriate for gravity loads and is a clear violation of the design practices specified by Indian Standards. Obviously, the performance of the building in the earthquake was not satisfactory; in far greater damage would have resulted in the event of greater shaking which is probable in this highly seismic Andaman and Nicobar Island region.

Figure 18: *Cracking in critical beam-column joint regions due to 'missing' ties for entire beam depth (more than 450 mm) in the main building of Mahatma Gandhi College in Mayabunder.*

Similar omissions in reinforcement detailing and serious errors on part of architectural layout and planning of structures in high seismic zones was vividly illustrated in recently completed Turtle Resort building at Shibpur, near Diglipur. The building is a two-storey RC frame building with concrete block masonry infills, as well as load bearing one in some parts of the building. The building is highly irregular not only in the plan but also vertically with floors at various levels connected through lobbies and walkways (Figure 19). The building developed cracks in columns and in the large number of partition and bearing walls. The cracking near the column tops were primarily due to absence of transverse stirrups over a length greater than two times the column width. The building suffered damage disproportionate to the observed shaking primarily due to poor layout of structural elements causing additional forces, irregularities in strength and stiffness, discontinuities in the load path, and absence of column ties (Figure 20). The seismic vulnerability of this building was sufficiently illustrated during this earthquake and its performance provides enough clues to predict its behaviour in the event of greater shaking.

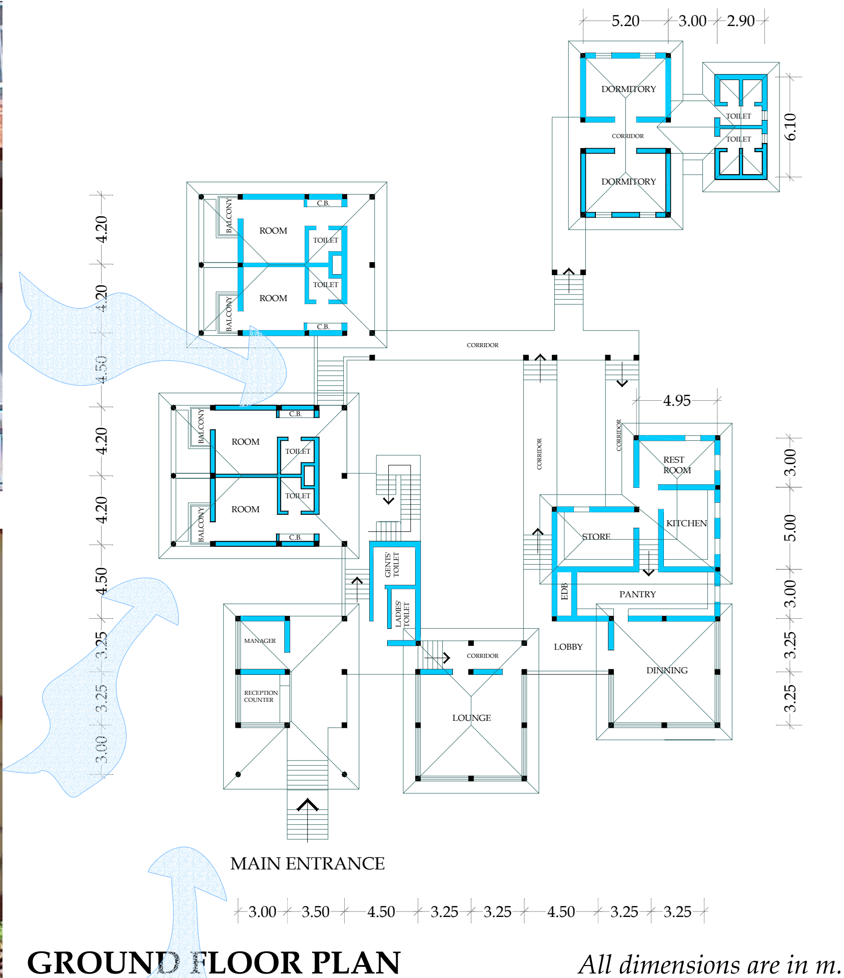


Figure 19: *Turtle resort building and highly irregular and asymmetric arrangement of structural members.*

Figure 20: *Damage to columns, which reveal absence of transverse ties over a length of about 450 mm from the beam soffit. This omission during the construction compounded with poor architectural planning and configuration resulted in significant damage in an area that sustained less than moderate shaking.*

Another interesting example of poor layout and planning consideration from the point of view of earthquake resistance was observed in the newly constructed library building of Mahatma Gandhi College in Mayabunder (Figure 21). This three-storeyed building is asymmetric in plan and has a high ceiling over a part of the building. Besides cracking to infill walls, cracking was also noticed in the beam-column joint region. Inadequate shear resistance due to possible absence of ties is likely suspect.

Figure 21: *Cracking in the joint region of columns in the asymmetric library building at Mahatma Gandhi College in Mayabunder.*

The practice of earthquake resistant design and construction is practically non-existent in building construction in the Andaman and Nicobar Island region. A two-storey building in Keralapuram under construction presented a interesting example of the kind of damage to columns that is likely if the columns are are not provided adequate confinement at the column ends. As shown in Figure 22, the top storey columns (in the absence of masonry walls) acted as 'cantilever' supports and could not respond satisfactorily to the seismic moments and shears produced in it during the earthquake. At the base of majority of the upper storey columns, flexural cracking was noticed as 'plastic hinges' were formed. Clearly, the usual practice of providing 90^0 hook ties at 150 mm centres is not adequate for the necessary confinement for stable and ductile behaviour. Similar reinforcement detailing could not safely hold the columns supporting slab over the stair case, and the columns failed in shear at the in mid-height.

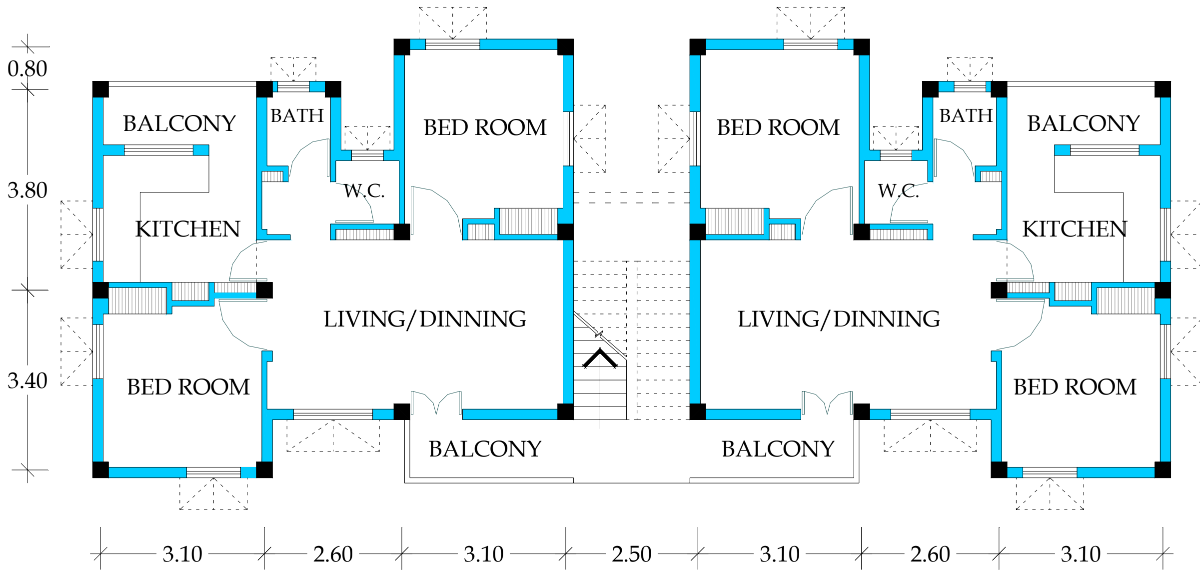
(a)

(b)

(c)

Figure 22: *(a) Unfinished residential building, (b) and (c) Cracking at the base of second story column as 'plastic-hinges' were developing, and shear failure of columns supporting staircase slab, due to inadequate the transverse confinement less than required from seismic consideration.*

Buildings that are properly constructed with simple and symmetric planning, a primary requirement of earthquake resistance, have performed satisfactorily. As shown in Figure 23, two-storey load-bearing buildings with relatively light truss roof, constructed for government employees in Diglipur, came out of this earthquake without any need for major repair. The minor damage that were observed could have been reduced had these buildings received regular maintenance and upkeep.



FLOOR PLAN

All dimensions are in m.

Figure 23: *Two storey load bearing masonry building for Govt. employees in Diglipur performed satisfactorily despite poor maintenance and upkeep, primarily due to better structural layout and relatively light roof.*

There are nine major harbours in the Andaman and Nicobar Islands, of which three suffered damage during this earthquake. Arial Bay Jetty at Diglipur in the North Andaman Island was the most affected, while the Sagar Dweep and Mayabundar in the Middle Andaman Island Jetties sustained only minor damage.

7.1 Diglipur Harbour (Arial Bay Jetty)

The Arial Bay jetty structure consists of approach segment meeting the main berthing structure of at 120^0 angle as shown in Figure 24. Figure 25 shows the plan of various structures at the Diglipur harbour. The berthing structure was originally constructed in 1968 and extended in 1999. The entire approach and berthing structure consists of 400 mm square reinforced concrete piles connected at the top by a box-type pier cap made of beams, columns, braces and slabs. Pounding damage was observed at the intersection of the approach segment and the main berthing structure; the wearing coat was broken (Figure 26). Also, a portion of the main berthing structure that protrudes into the longitudinal direction of the approach segment around the bollard was sheared off during the shaking. The pier components suffered significant spalling during the shaking and the reinforcements were exposed. An inspection of the piles and the pier cap elements indicated that it was not adequately protected against the corrosive marine environment; the transverse ties were either missing or severely corroded as shown in Figure 27.

Figure 24: *Approach jetty meeting an angle with the main berthing jetty at Diglipur harbour. The damage to jetty slab was concentrated at the intersection.*

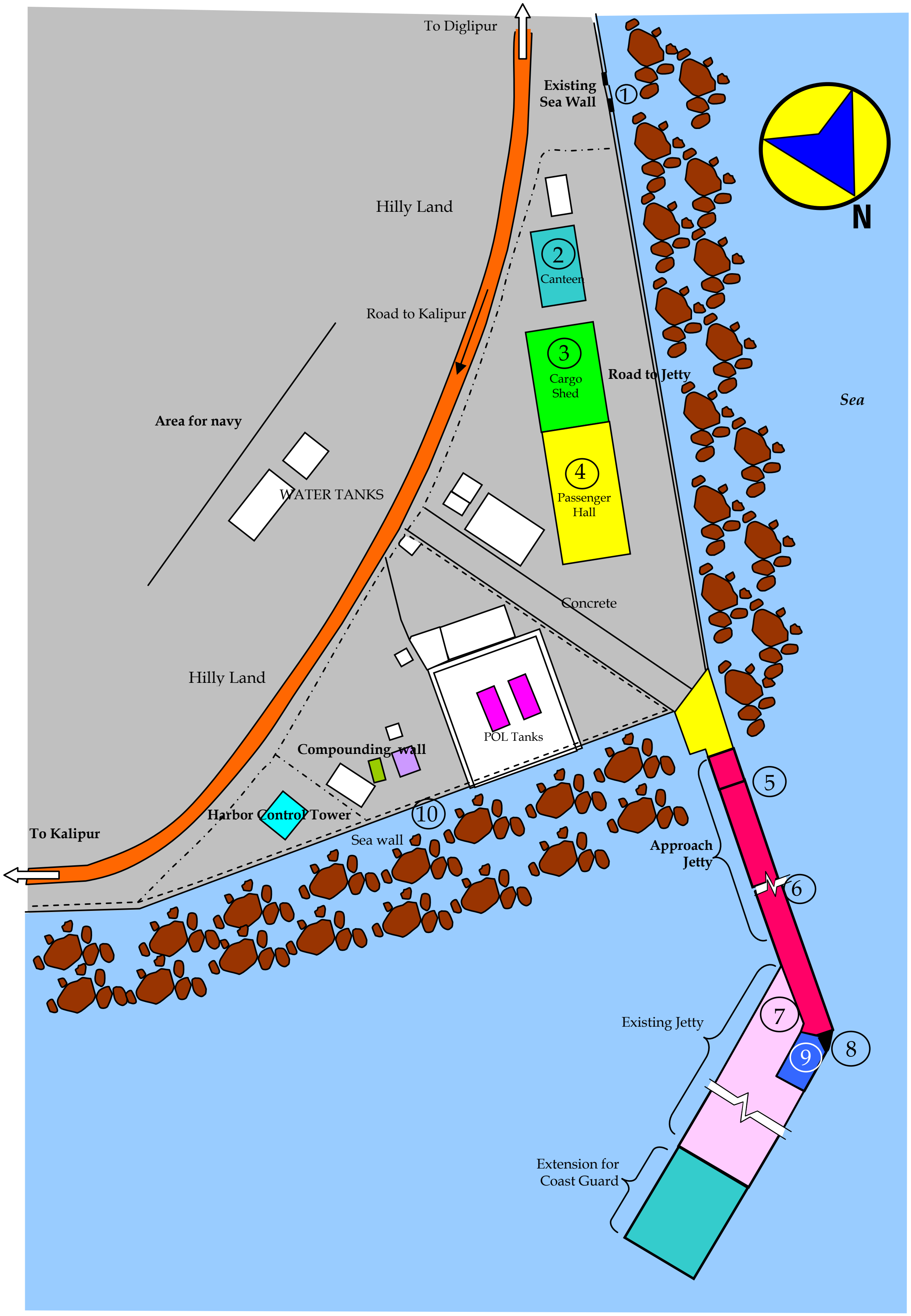


Figure 25: *Map showing various structures and their arrangement at the Diglipur harbour.*

(a)

(b)

Figure 26: *(a) Pounding damage at the intersection of approach to main jetty at the top, and (b) exposed slab reinforcement underneath due to heavy corrosion.*

(a)

(b)

Figure 27: *Severe corrosion of reinforcing bars and spalling off cover concrete from beams, and (b) columns and batters.*

At the Arial Bay, there are two POL (petrol oil and lubricants) tanks (Figure 28). These cylindrical tanks are made of welded mild steel plates of diameter 3m and length 7.5 m supported horizontally on masonry pedestals performed satisfactorily. They contained only 50% of the 50kl capacity of the High Speed Diesel oil.

The control tower of the Arial Bay is a three-storey RC frame structure with a 10m high steel mast (Figure 29). In the lower portion, it has a single room of 5mX5m plan with eight columns along the perimeter. It has no major damage. Only the infill was separated from the frame in the ground storey of the RC frame building. Similar minor cosmetic damage was noted in other masonry structures of canteen, passenger waiting hall and cargo shed.

Figure 28: *Cylindrical tanks for Petrol, Lubricants and Oil (POL) at Diglipur harbour.*

Figure 29: *Three-stroreyed RC frame structure for Control Tower building at Diglipur harbour.*

7.2 Mayabunder Harbour

The Mayabunder harbour is a major facility for sea transportation among the islands and to the main land. The arrangement of the harbour is shown in Figure 30. Pounding damage was afflicted to the jetty slab across at expansion joints, which was later repaired (Figure 31). Subsequent to the earthquake, vertical cracks were noticed on the piles supporting the jetty; some horizontal cracks in the slab were also visible from the underside. The bottom tie of wooden roof trusses in the cargo shed broke causing sagging of ridgeline.

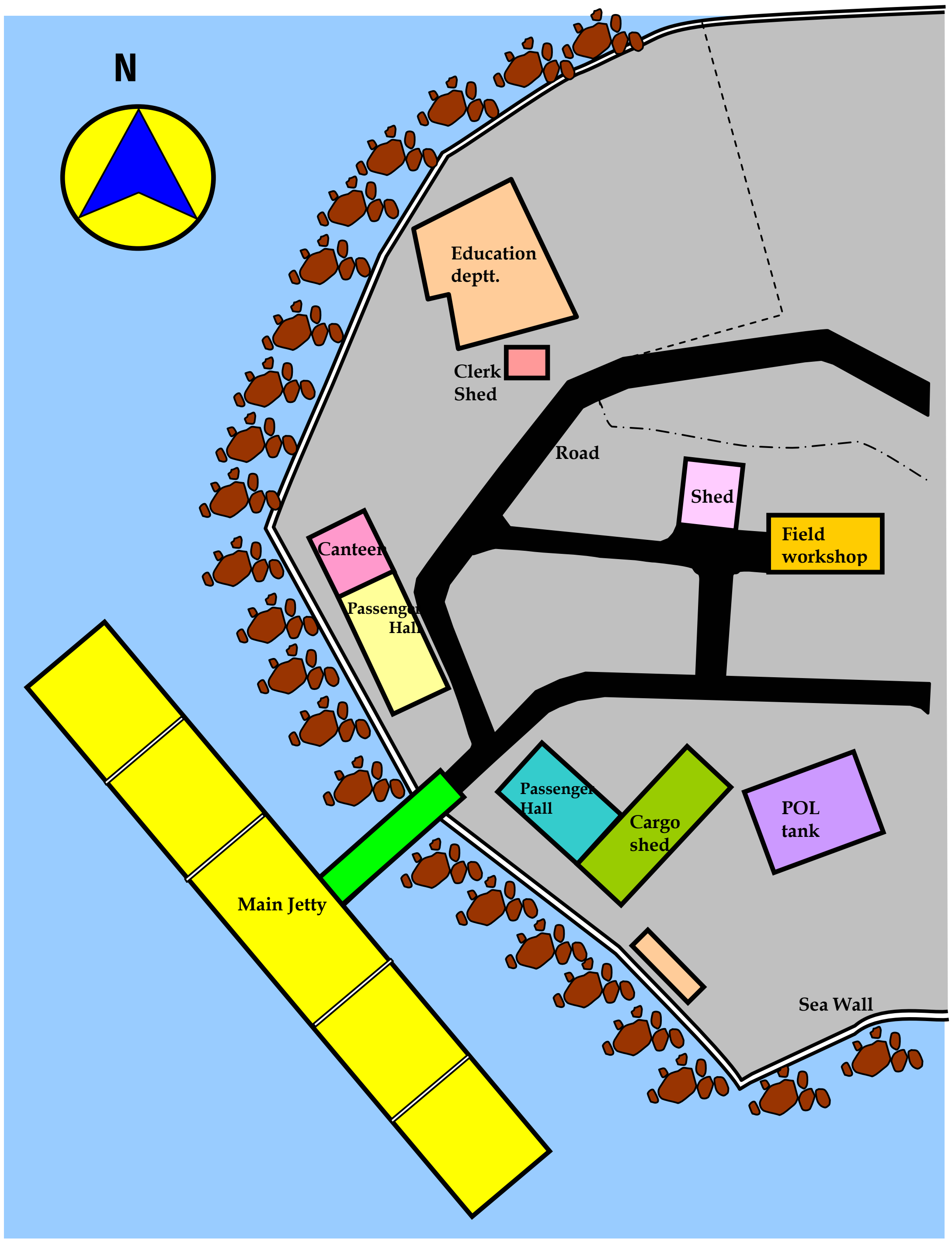


Figure 30: Map of Mayabunder harbour

Figure 31: *Pounding damage at the expansion joints on the main jetty.*

The Kalpong hydroelectric project is only such project in the Andaman and Nicobar Islands and has been completed about one year ago. The project is over the Kalpong river which is the main stream of North Andaman Island which joins the Arial Bay creek near Diglipur after traversing a length of 35 km. Both forks of the river were used in the project by constructing a concrete dam on the left fork and a rockfill dam on the right fork of the river (Figure 32). The concrete dam is 24 m high and 138 m long whereas the rockfill dam is 27 m high and 146 m long (Figure 33). A 300 m long link channel connects reservoirs formed by both dams. The project also involves a number of earthen dykes over the natural drains in the reservoir area. The 1.2 m diameter and 650 m long penstock leads to the power house which has an installed power generation capacity of 5.25 MW.

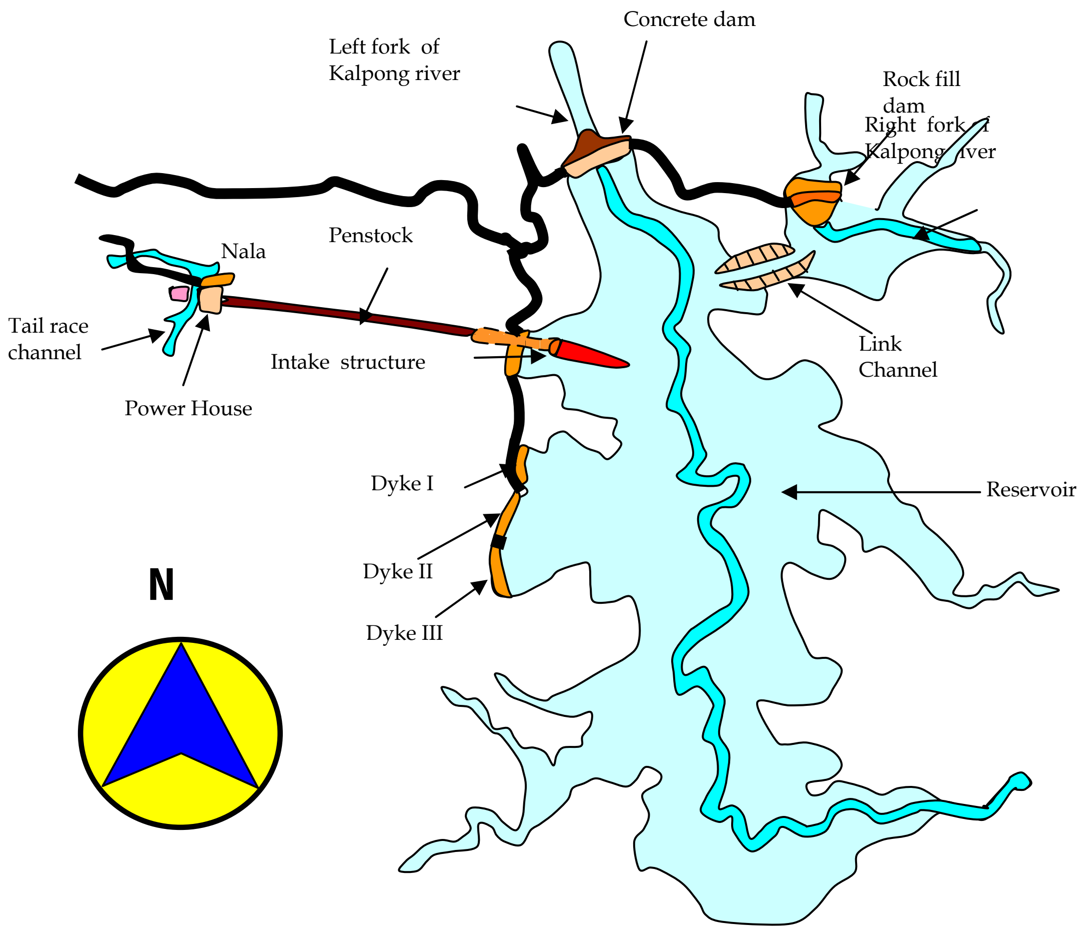


Figure 32: *Schematic map of Kalpong Hydroelectric Project, near Diglipur*

No damage was noticed in the dam structure. However, peeling off of paint across construction joints in the observation gallery of concrete dam suggested that dam structure was shaken during the earthquake. A marginal increase in the seepage flow from *55 lpm* to *60 lpm* was noticed after the earthquake. However, the readings of joint meters and pressure meters recorded no change before and after the earthquake. The powerhouse building is a 2-storey RC frame structure where separation of infill masonry from the surrounding frame was noticed in the high ceiling area of generator room.

Figure 33: *Concrete and rockfill dam on the left and right fork of the Kalpong river.*

9.1 Bridges

The newly constructed bridge over the Austin Creek at Mayabunder that connects Middle Andaman Island to North Andaman Island along the Andaman Trunk Route (ATR) was not open to traffic at the time of the earthquake (Figure 34). 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 is merely rested on the pier caps with no fastening between any of them. No damage was noticed to the bridge structure in this earthquake. However, inadequate seating of bridge deck over piers and abutment 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 the 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.

(a)

(b)

(c)

Figure 34: *(a) Newly constructed RC bridge at the Austin Creek, and (b) and (c) inadequate seating for bridge deck and absence of restrainers to prevent the unseating of deck during probable strong motion at the site.*

The earthquake affected region has many small bridges over natural drains which are in poor condition and pose serious safety threat in the event of greater shaking. The Kalpong bridge on ATR between Diglipur and RK Gram is a 30-year old structure and was in poor state of health (Figure 35). No serious damage was noticed to the steel superstructure of the 20 m main span. However, timber beams of approach spans supported on RC frame piers appeared to have moved. The seating of beams at 6 m tall piers may not be adequate in the event of stronger shaking and needs to be retrofitted urgently. The poorly maintained masonry and RC piers of the main and approach spans indicate significant deterioration n their strengths, raising concerns on the residual strength of the bridge.

Figure 35: *Kalpong bridge north of Digliour town has no earthquake resistant features. This deficiency is further accentuated by its poor maintenance.*

9.2 Airport

Port Blair airport provides the only civilian air link to the Andaman & Nicobar Islands from the main land. The newly constructed airstrip in Shibpur (south of Diglipur) is meant for light aircrafts. The flexible airstrip developed on unconsolidated marshy land developed cracks near the centerline. The cracks were filled with Grade 80/100 bitumen as seen in Figure 36. The terminal building under construction did not experience damage. However, the 1.5 m high boundary wall of the airport premises fell at many places.

Figure 36: *Longitudinal fissures of the flexible pavement of the airstrip at Diglipur, which were closed with bitumen pours.*

9.3 Telecommunications, Electric Power and Drinking Water Supply

There was disruption of telephone link for two days due to uprooting of telephone poles in the Diglipur area. Drinking water supply was affected in Diglipur town due to landslides at Lamia Bay, where surface run-off water is collected and distributed after treatment. Electric power supply was also affected due to damage to 50 poles over 8 km stretch between Arial Bay and Kalipur. The reinforcement in the precast RCC electric poles was corroded and concrete cover had fallen off. These already environmentally weakened poles were easily overwhelmed by ground shaking (Figure 37).

Figure 37: *Deteriorated RCC electric poles gave way in the area of major shaking disrupting power supply.*

10. Government Response and Socio-Economic Issues

Immediately after the earthquake, the government deputed a team consisting of the Member of Parliament (Mr. Bishnu Pada Ray), the Commissioner (Revenue), Deputy Commissioner (Andaman Administration), Superintending Engineering (Andaman Public Works Department (APWD)) and Assistant Commissioner (Mayabunder). By mid-day of 14 September 2002, the team visited the affected area including Kalipur, Keralapuram, Arial Bay Jetty and some villages of Diglipur Tahsil and Diglipur.

After assessing the overall situation, the team reported that the earthquake caused moderate damage, and instructed the APWD to conduct a survey of the damaged houses in the area. The field survey team consisted of APWD engineers and revenue officials headed by the Assistant Commissioner (North and Middle Andaman). Based this survey, 65 houses were declared to have suffered marginal damage. A relief of Rs.800 per house was sanctioned to the affected persons from the Lieutenant Governors Relief Fund as per the approved norms of the Ministry of Agriculture, Government of India. The Lieutenant Governor and the Member of Parliament distributed this relief.

A task force including the local heads of department of Diglipur Tahsil was constituted and was headed by Tahsildar (Diglipur). This task force regularly visited the affected areas and carried out relief work. They also conducted publicity campaign to allay fears of future shocks and instill confidence among the people. An ambulance with medicines was sent every day to the affected areas to attend to the needs of the people. The police department installed a VHF set at the school building in Kalipur to relay emergency information. By 09 October 2002, the bus service to the affected villages was restored. The marine department stationed two boats, one at Arial Bay Jetty and the other at Smith Island for emergency evacuation.

After the earthquake, major government departments present in the islands, namely Andaman Public Works, Andaman Harbour Works and Military Engineering Services carried out a survey of damage to the structures under their care. APWD prepared a list of buildings under the following categories: (a) buildings to be repaired/restored, (b) buildings to be retrofitted, (c) buildings to be reconstructed, and (d) buildings that are seismically deficient. However, the Department appeared not equipped with proper technical knowledge to undertake these projects successfully. For example, the damaged columns of Nabagram Panchayat building will be just restored to the original without addressing the seismic deficiency of the structure and its components in any comprehensive manner (Figure 38).

Figure 38: *Inadequate repair of damaged columns of the Panchayat building at Nabagram village.*

The Mw 6.5 North Andaman Earthquake of September 14, 2002, had its epicenter located off the coast of Diglipur in the North Andaman Island about 24 km in SSE direction. An area of about 40 km^2 adjacent to Shibpur and Arial bay jetty was subjected to a maximum shaking of intensity VII on MSK scale. However, the remaining Island up to Mayabunder in the south on the Middle Andaman Island experienced a shaking intensity of VI. These islands have a long history of earthquakes, as the region is a subduction zone, which is continuation of the Burmese range in the North.

The traditional structures in the region used light building materials such as timber, bamboo, thatch, etc. and were largely unaffected. Even modern day variations of these older housing types where timber has been replaced by light steel sections of angles and pipes, have performed mostly satisfactorily.

However, the performance of recently constructed buildings in reinforced concrete and masonry was rather unexpected, as these materials are regarded superior to low strength materials of traditional construction. These structures suffered damage even when the shaking intensity was less than moderate (VI on MSK scale), whereas a much greater shaking, in the excess of intensity IX on MSK is expected in the region. Clearly, these structures have added to the seismic vulnerability of the region rather than mitigating it. They will be seriously affected in the event of greater shaking causing loss of lives and damage to property.

Based on this field observation, a number of critical issues are identified that were not addressed adequately considering high seismicity of the region:

1. **Architectural and structural issues:** A structure located in the high seismic region should be of simple geometry and symmetric configuration of structural elements avoiding eccentricities and irregularities in the uniform distribution of strength and stiffness. Most of the constructions are on hill slopes, some of which are even known to be deforming. But, sufficient attention was not paid to this aspect. Many of these *must-do's* have been given no consideration at the planning stage and structural configurations provided were not known for superior seismic performance. BIS codes on seismic design and construction were also not adhered to.
   Many well-known problems such as open-first-storey, shear-critical short-columns, discontinuous load paths for lateral loads due to offsets in plan and in elevation, which seriously undermine seismic resistance of structures were repeated in many of newly constructed buildings.

2. **Construction and detailing issues:** Many RC members suffered unexpected damage primarily because they were not constructed properly. Carelessness in ensuring proper placement of transverse stirrups (ties) in the columns led to many 'missing' column ties, rendering them vulnerable to shearing forces due to the earthquake. Further, ductility provisions as stipulated in IS 13920 for RC structures resisting earthquakes were simply not followed. There were many other problems related to reinforcement detailing, such as insufficient lapping of rebars, bent longitudinal bars, and open hooks. Steel trusses

made from hollow circular tubes are becoming popular in the recent time, but the ad-hoc arrangement of the bolted connection among truss members is matter of serious concern.

3. **Building Material issues:** The quality of concrete and masonry blocks is in general very poor. Non-availability of a good quality raw material is the primary obstacle, which is further compounded by unsound field practices. Concrete masonry blocks used in construction yield a very low compressive strength, because the manufacturing process is inadequate. They were not compacted enough and the required density and strength as per BIS codes are not achieved.

The design and construction practices in the Andaman and Nicobar island region in general do not seem to be too different from those in the mainland India. The vulnerability of the constructions in the mainland Indian has been adequately emphasized by the 2001 Bhuj (Gujarat) earthquake disaster. Considering the high seismicity of Andaman and Nicobar Islands, only the earthquake-resistant constructions in the region can mitigate a disaster due to a future earthquake. Unmitigated risk leads to a disaster, and the seismic risk can be controlled only if the seismic vulnerability of the structures is reduced. The performance of vulnerable structures in the earthquake of September 14, 2002 which caused a low to moderate shaking only, should serve as a preview of what can happen in the event of a bigger earthquake that is likely in this highly seismic region.

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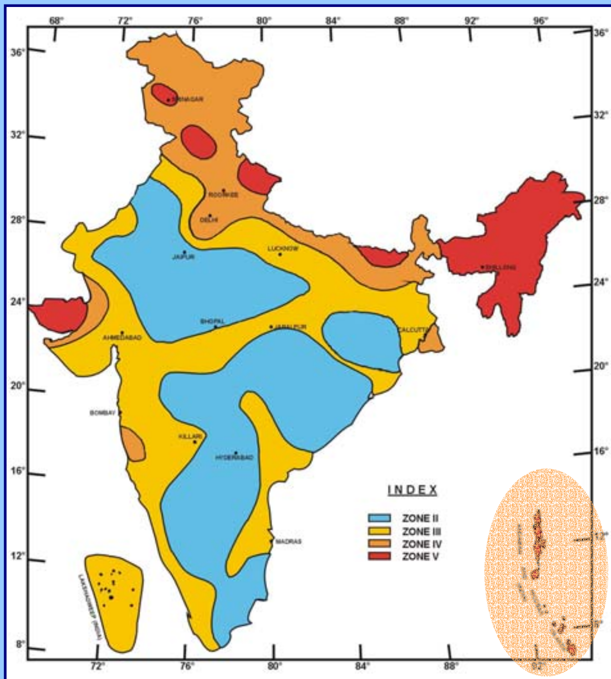

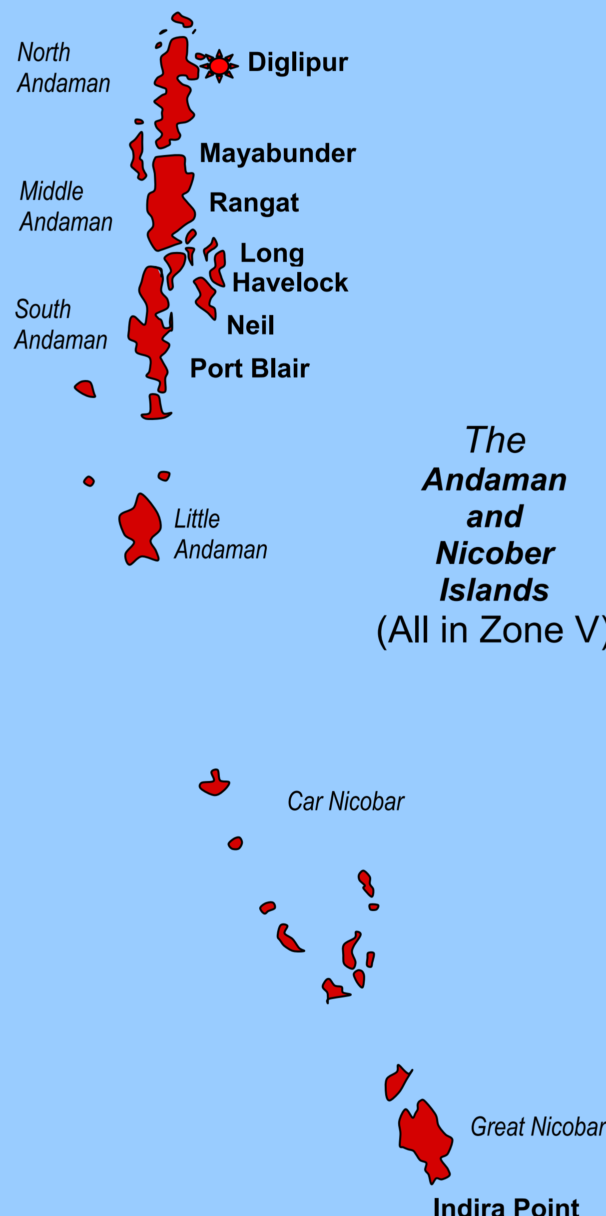

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