coast. In general, there was enhancement of Chl *a* concentration by middle of October (Figure 1 *d*) with a maximum (>8 mg/m^3) off Gopalpur–Visakhapatnam coast which could be due to the influx of waters from the adjacent Rushikulya estuary and Chilka Lake. The high concentrations observed during post-monsoon season compared to pre-monsoon may be due to combined effect of biological productivity and anthropogenic inputs, in addition to the physical processes.

A comparison between the *in situ* estimations and satellite-derived values of Chl *a* for pre-monsoon (I) and post-monsoon seasons (II) for the year 2000 are presented in Table 1. Average values at the surface (from the coast to 12 km) are shown. There is reasonable agreement between the *in situ* and satellite estimations of Chl *a* off Puri, Visakhapatnam and Kakinada while the errors are large off Gopalpur, Bheemunipatnam and Gauthami Godavari during the pre-monsoon season. The error is maximum off Puri during post-monsoon season. Satellite estimates are lower than the *in situ* values off Bheemunipatnam, Visakhapatnam and Kakinada during post-monsoon season. Hence it is inferred that there is a need to improve and develop site-specific algorithms for different coastal waters off the east coast of India.

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Need for earthquake-resistant design of harbour structures in India in view of their performance during the 2004 Sumatra earthquake

Harbours and jetties are lifeline structures as they provide a cost-effective method for transporting large quantities of goods and raw materials into and out of a region. These are important structures especially in islands like the Andaman and Nicobar (A&N), where the main mode of transportation is the sea, since these are a set of 572 islands separated by channels and creeks. These structures also play a significant role in the transportation system in terms of evacuation of people before or after natural disasters, e.g. earthquakes and tsunamis. Further, these are useful to supply relief materials after the natural disaster when other transportation systems fail to deliver. Similar roles were accomplished by some of the less damaged ports and jetties in the A&N Islands after 26 December 2004, when the great Sumatra earthquake of magnitude M_w 9.1 caused a devastating tsunami in the Indian Ocean. Some damaged, unserviceable offshore and foreshore harbour structures, north of Port Blair (capital of A&N Islands, India), caused total disruption of sea transport that caused a delay in the supply of relief work in the earthquake and tsunami-affected areas[1]. This underlines the need to design these structures so that they can withstand earthquakes.

According to the Indian seismic hazard zone map[2], the entire A&N Islands lie in the most severe seismic zone, i.e. zone V, where the expected intensity of shaking is IX or greater on the MSK intensity scale. However, in the case of the 2004 Sumatra earthquake, it was observed that the intensity of shaking in the Andaman Islands, located about 1000 km northwest from the epicentre (03.295°N 95.982°E according to USGS) was between VI and VII. Performance of the structures could have been better than what was observed if these were designed and detailed properly. In India, currently there is no code for earthquake-resistant design of such structures. The existing earthquake-resistant design codes i.e. IS 1893 (ref. 2) and IS 13920 (ref. 3) are intended for building systems and are not sufficient for harbour structures which behave differently than buildings and bridges.

Based on the reconnaissance study conducted by the authors immediately after the earthquake, damages to harbour structures located north of Port Blair are described here along with their possible causes and remedies. Jetties at Rangat Bay and Mayabandar Harbours in the Middle Andaman Islands, and at Diglipur and Gandhinagar in the North Andaman Islands were severely affected, while Kalighat Jetty in North Andaman and Uttara Jetty in Middle Andaman sustained only minor damages (Figure 1). Berthing jetty and a portion of the approach jetty at Sagar Dweep totally collapsed during this earthquake and the jetty was not operational for post-earthquake relief operation (Figure 2).

The most common damages of jetties resulted from the pounding at the construction joint of two portions of the jetties supported by piles. Pounding can occur between two adjoining structures due to out-of-phase horizontal vibrations during earthquake shaking, if sufficient spacing is not provided to accommodate the lateral displacements. Such damages were observed between two portions of berthing jetties of Mayabandar Harbour, Diglipur Harbour and at the junction of the approach jetty and berthing jetty of Mayabandar, Rangat and Diglipur harbours and Sagar Dweep Jetty (Figure 3). Similar pounding damage was noticed at the Diglipur Harbour during the 2002 Diglipur earthquake[4,5]. Pounding damages could have been prevented or minimized by providing sufficient gap at the location of construction joints of the jetties. It appears that the structures were not designed for earthquake-induced lateral displacement and forces.

Generally berthing jetties are constructed away from the shoreline inside the sea to get sufficient water depth for anchorage of ships. These are connected to the shore by approach jetties supported by piles, which generally are embedded in the sloping ground and therefore, the unsupported length of the piles varies along the length of the approach jetty (Figure 4 *a*). The piles mostly affected by this earthquake were those having comparatively shorter unsupported length (short piles) towards the shoreline. These comparatively stiffer, short piles attract more shear forces during earthquakes than those with relatively longer unsupported length and hence more flexible. Such damages were observed in the piles of the approach jetty of Mayabandar where the approach slab fell-off from the ends due to damages to the short piles (Figure 4 *b*), while little or no damage was found in the relatively longer piles. Therefore, either proper dredging of seabed should be done to increase the unsupported length of the shorter piles or the shorter piles should be designed to withstand large amount of shear forces to prevent short-column failure during an earthquake.

Poor performance of several ports during the past earthquakes throughout the world has been primarily due to liquefaction of the soil[6]. During the Sumatra earthquake, the approach pavement and seawall around the slipway at Mayabandar Harbour were severely damaged due to liquefaction of soil (Figure 5 *a*). Some soil improvement technique, e.g. vibro-flotation, dynamic compaction can be used to overcome the problem of soil liquefaction. Further, installation of compaction piles also can reduce the possibility of soil liquefaction.

Severe damages were observed at the top of the piles in several jetties due to inadequate shear reinforcement, improper detailing at the pile head and beam connections, and poor maintenance of jetty structures against corrosion of reinforcement. Failure of the piles required the closure of the Mayabandar harbour as it could not be approached by vehicles. The 90° hooks (instead of 135° hooks, recommended by IS 13920)[3] were clearly visible in the piles of the approach jetties at Mayabandar and Rangat. This type of reinforcement detailing is undesirable in highly seismic regions (zone V in Indian seismic zone map)[2]. This inadequate detailing of transverse reinforcement may lead to shear failure at the top of the piles of the approach jetty at Diglipur Harbour. These piles were also affected during the 2002 Diglipur earthquake[4,5] and some cosmetic retrofitting was done with 10 to 15 cm thick micro concrete. No assessment was made of the ability of the structure to resist strong earthquake shaking in future. A part of the berthing jetty at Diglipur Harbour sunk due to pile failure underneath (Figure 5 *b*).

In some cases, poor maintenance of these structures was primarily responsible

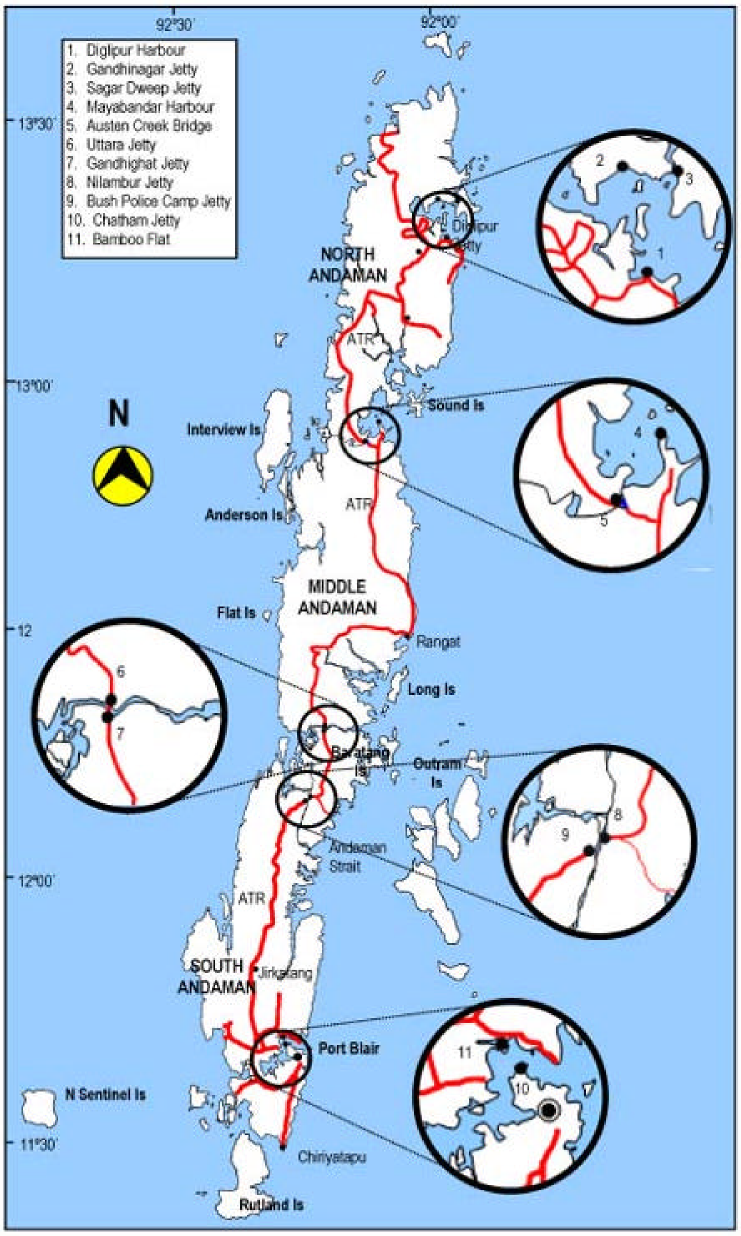

Figure 1. Schematic diagram of Andaman Islands showing locations of harbours and jetties.

for the severe damages. Jetty structures are continuously in contact with severe and very severe coastal environment (IS 456: 2000)[7], which led to the deterioration of concrete and steel reinforcement by chemical, electrochemical and mechanical processes. The common deterioration mechanisms are corrosion of steel reinforcement, alkali-aggregate reaction (AAR), carbonation, abrasion, scour and cracking. Steel corrosion is caused by electrochemical processes, AAR and carbonation result from the chemical reaction between the marine environment and concrete, and the rest are mechanical processes. Corrosion of steel reinforcement is prevalent in the splash and tidal zones where alternate wetting and drying takes place. It deteriorates the cover concrete, exposing the reinforcement of piles and deck slabs. Corrosion of the exposed reinforcement in some piles at Rangat Bay Jetty was so severe that the transverse ties were practically missing, which led to the failure of these piles during the earthquake (Figure 6 *a*). Use of galvanized or plastic-coated reinforcing bar along with periodic maintenance of these piles may reduce the risk of such damages. Carbonation and AAR are common in submerge and tidal zones. In the tidal and splash zone, abrasion of concrete piles takes place by the repetitive impact of waves, and the water-borne sands and floating debris which destroy the concrete cover and expose the steel reinforcement. Wave action also increases strain in the piles and thereby causes cracks, which in turn accelerate corrosion of the steel reinforcement by permitting the ingress of chloride, water and oxygen. High performance epoxy-coating materials may be used to protect concrete and steel from such mechanical attack in marine environments.

Apart from jetties, other harbour structures that were affected are breakwater, slipway, passenger hall, etc. The Breakwater at Rangat Bay consists of 100 m long RC-pile trestle followed by rubble mound portion (length 375 m) which was covered with four-legged 'tetrapods' of 4 to 10 tons capacity each, to protect rubble from rough sea waves. Several piles of the reinforced concrete trestle were damaged exposing the steel reinforcement, while the deck slab of the trestle was not damaged. Some tetrapods on the sea side of the breakwater were dislocated due to the tsunami. Longitudinal cracks were developed at the centre at different places along the length of the rubble mound portion of the breakwater (Figure 6 *b*). Typical failure mode of such breakwaters during earthquakes is 'settlement associated with significant foundation deformation beneath the rubble mound'[8]. Stability against horizontal forces, e.g. sea waves, earthquake loading, etc. is maintained by shear resistance of the rubble, resistance to overturning and bearing-capacity failure.

Minor damage was noticed in the wall of passenger halls at Mayabandar and Diglipur harbours. The out-of-plane failure of hollow block wall was observed in the passenger hall at Mayabandar harbour. Out-of-plane failure of the wall can be prevented by providing reinforcement inside the wall and anchoring these to beams and columns.

RC columns of Port Control Tower (PCT) at Rangat and Diglipur harbours were damaged, exposing the steel reinforcement. Cracks were observed in RC tie beams at different places of the Port Management Board (PMB) office building at Rangat and Diglipur. At Mayabandar Harbour, no damage was noticed in the Electrical Level Luffing crane (6 ton capacity) over the jetty while the counterweight frame suffered damages and fell down.

There are a few codes and guidelines for the seismic design of various ports around the world[8–13]. Comparison of seismic design strategies of different codes and guidelines have been discussed in the report of PIANC[8]. Currently, two-level approach is used to design port components. In level-1 design, operating level earthquake is considered which has a 50% probability of exceedance in 50 years which is roughly 72 years of average return period. Operation of ports should not be interrupted under this level of earthquake shaking. All damage that occurs should be easily detectable and accessible for inspection and repair. Level-2 or contingency level earthquake (CLE) motions, should be resisted by jetties, retaining structures/dykes and critical operational structures, so as to prevent major structural damage and collapse. Location of

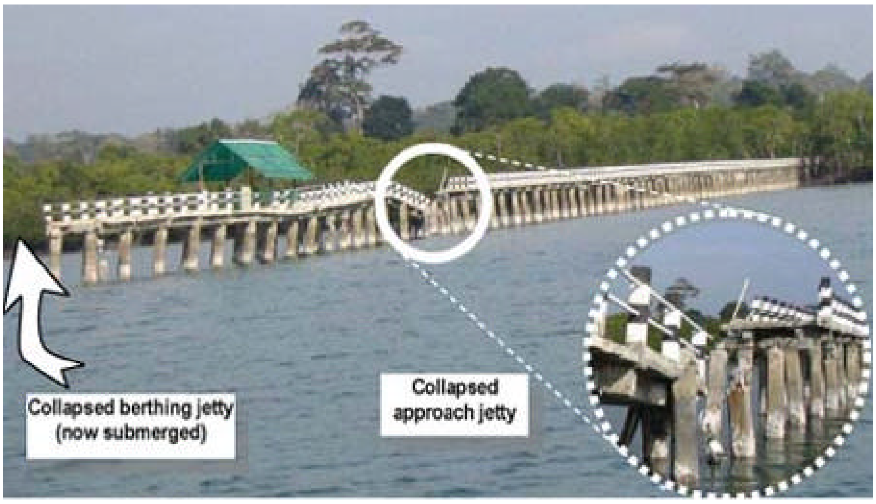

Figure 2. Gandhinagar Jetty in North Andaman: Total collapse of berthing jetty and partial collapse of approach jetty.

Figure 3. Pounding damage to jetties in Middle Andaman (***a***) at the junction of solid jetty and RC piled approach jetty at Rangat and (***b***) in the berthing jetty at Mayabandar.

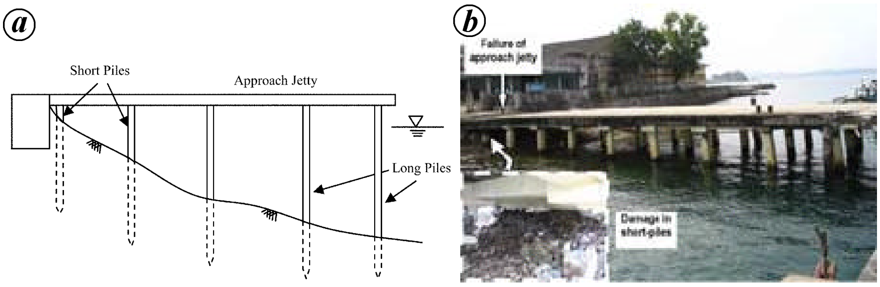

Figure 4. ***a***, Pile-supported approach jetty. ***b***, Damage in short piles of the approach jetty at Mayabandar Harbour in Middle Andaman Islands.

Figure 5. ***a***, Damaged side bund of slipway at Mayabandar Harbour in Middle Andaman due to liquefaction of soil. ***b***, A portion of the berthing jetty at Diglipur Harbour sunk due to failure of piles. This portion of the jetty cannot be approached by the vehicle for loading/unloading of goods.

Figure 6. ***a***, Severe corrosion led to damage of columns of approach jetty at Rangat Bay Harbour in Middle Andaman. ***b***, Rangat Bay Harbour in Middle Andaman, longitudinal cracks on top of the breakwater.

damage should be such that it is visually observable and easily accessible for repairs, e.g. damage to foundation elements below ground level is not acceptable. Under this level of shaking, collapse of wharf/jetty must be prevented while controlled plastic deformation which is economically repairable within an acceptable period of time and is not a threat to life is considered acceptable. Container cranes and any other critical components should be operational with only minor repairs. CLE motions are defined to have a 10% probability of exceedance in 50 years (or 475 years of average return period).

The method of seismic analysis of port structures depends on the type of structure. Analysis methods available for this type of structures can be classified as simplified analysis, simplified dynamic analysis and dynamic analysis. In simplified analysis, the pile deck system of pile-supported wharves/jetties or frames of cranes, are modelled by single degree of freedom (SDOF) or multi degree of freedom (MDOF) system. Earthquake motions are generally represented by the response spectrum method. In simplified dynamic analysis, pushover analysis is performed by modelling the pile-supported wharves or cranes as SDOF/MDOF system for evaluating ductility factor/strain limit. Soil–structure interaction (SSI) effects are not considered in the analyses. Displacement, ductility factor, location of plastic hinge and buckling in the structures can be obtained from such analysis. In dynamic analysis, SSI is considered using finite element method or finite difference method.

Several harbours and jetties were damaged in the 26 December 2004 Sumatra earthquake in the Andaman Islands (north of Port Blair) located about 1000 km northwest of the epicentre of the earthquake. These damages to critical transportation facilities underline the extreme vulnerability of port structures in the region. Two most common damages were the pounding between the two portions of deck slabs of jetties and damages to short piles supporting them. Inadequate shear design of piles, improper detailing (mainly inadequate lapping of longitudinal bars) and inadequate anchorage length resulted in damage of several piles under the wharves. Liquefaction of underlying soil was also responsible for damages to sea walls. Apart from the offshore structures, there were damages to different foreshore structures related to harbour, i.e. passenger hall building, PCT, PMB office building, etc. Similar damage was also noticed in harbour structures of Kandla, Navlakhi, etc. in Gujarat after the 2001 Bhuj earthquake[14]. Therefore, it is necessary to develop codes and guidelines for the seismic design and retrofit of harbour structures in India to minimize economic losses in future earthquakes.

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Impatiens clavata Bhaskar *sp. nov.* – a new scapigerous balsam (Balsaminaceae) from Bisle Ghat, Western Ghats, South India

The species of *Impatiens* L. (family Balsaminaceae) are extremely difficult to classify as they exhibit few distinguishing key characters[1,2]. There are only a few authentic and monographic studies on *Impatiens* of South India[1–4]. The latest monographic work on South Indian *Impatiens*[1,5–7] has revealed one new species (*I. agumbeana*) and a new 'pollen variety' (*I. acaulis* var. *granulata*) in the Section 'Scapigerae'. Another new scapigerous species (*I. chandrasekharanii*) was reported from Akkamalai, Annamalai in Coimbatore District[8]. Among the known South Indian species of *Impatiens*, there are three Scapigerous species which exhibit somewhat clavate-shaped spur in the flower, viz. *I. clavicornu*, *I. laticornis* and *I. dendricola*. But in all these species the wing petal does not have a dorsal auricle, which is an appendage of the anterior lobe. The new species now reported has a sickle-shaped spur, uniquely clavate (most unique and prominent than in the other three species) and wings have a long and distinct dorsal auricle produced into the clavate spur. The clavate spur measures nearly 18 mm long and 5–7 mm wide at one-fourth distance from the bulged tip and is characteristically flattened and tape-like. Besides, the taxon exhibits several other differences which warranted describing this as a distinct species.

This new species was collected by the author on large trees (epiphytic plant) from Pushpagiri Hills, about 8 km from Bisle (Bisle–Subramanya Road), Sakleshpur taluk, Hassan district, Karnataka on 24 September 1972 and 1 October 1973. Recently, on the basis of location details given by the author, W. D. Theuerkauf (Gurukula Botanical Sanctuary, Wynad) also collected this plant from this locality during September 2006. While working on the flora of Hassan district, C. S. Saldana collected exactly similar specimens from Bisle on 18 September 1969, but he identified it as *I. barberi* Hk.f. based on his authentication made at Kew Herbarium. The present author had also accordingly followed his identification. But only recently, after having got the access to the type material of *I. barberi* Hk.f., which is preserved at Madras Herbarium, Coimbatore (Figure 1), it was confirmed that the specimen from Pushpagiri Hills, Bisle is not *I. barberi* but a distinct species having a prominent clavate shaped spur and a 13 mm long dorsal auricle, endemic to this locality.

I. barberi was named after its collector C. A. Barber by Sir J. D. Hooker (JDH) and it was collected from Cadamany (adjoining Bisle) in the erstwhile Mysore State on 8 September 1903. JDH has made a sketch of the floral parts on the type sheet, according to which the spur is short and not clavate. Unfortunately, in the type sheet of *I. barberi*, the flowers and plants are not properly spread and pressed. Therefore, the drawings left on the type sheet are the only basis for comparison. JDH did not give any description for *I. barberi*, but only gave a key character that the spur is small compared to *I. scapiflora* and *I. acaulis* and grouped it under the scapigerous balsams having

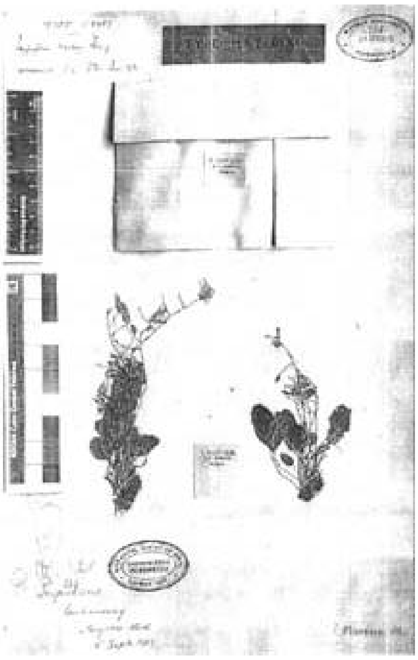

Figure 1. Type sheet of *Impatiens barberi* Hk.f. preserved at Madras Herbarium, Coimbatore. Note the sketch of floral parts made by JDH.