SURVEY OF IMPACTS ON THE ANDAMAN COAST, SOUTHERN THAILAND FOLLOWING THE GREAT SUMATRA-ANDAMAN EARTHQUAKE AND TSUNAMI OF DECEMBER 26, 2004.

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SUMMARY

This report on the Sumatra-Andaman great earthquake and tsunami of December 26, 2004 describes the event and its impacts in southern Thailand. It includes the observations of the New Zealand Society for Earthquake Engineering Reconnaissance Team gathered one month after the event. The report covers the effects of the tsunami on the natural and built environment, and the recovery process in relation to social and economic issues. Lessons applicable to the understanding and potential mitigation of tsunami risk in New Zealand are presented and discussed.

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1. INTRODUCTION

On December 26, 2004, the boundary between elements of the Indo-Australian plate and the Eurasian plate, offshore northern Sumatra, Indonesia ruptured in a great (moment magnitude 9.3) earthquake - second only to the 1960 Chilean earthquake in recorded magnitude (Stein and Okal, 2005). Up to 15 m of thrust movement on the plate interface caused a massive shift of the seafloor and displaced tens of cubic kilometres of seawater, generating tsunami waves that radiated across the Indian Ocean (Ni *et al*., 2005; Lay *et al*., 2005). The earthquake was widely felt throughout South Asia and was locally destructive in Sumatra and the Andaman and Nicobar Islands that parallel the plate boundary. However, it was the tsunami that transferred energy with efficiency and devastating effect from the remote epicentral region to densely populated coastal communities thousands of kilometres away.

In Sumatra, where the tsunami made landfall within 10-15 minutes, run-up heights[1] of over 30 m (Banda Aceh) were recorded. Run-up heights of more than 10 m were also documented in Thailand (12–14 m) and Sri Lanka (11 m). Documented fatalities eventually exceeded 283,000 with the heaviest losses concentrated along the west coast of Sumatra, but more than 40,000 were also accounted for on distant shores around the Indian Ocean. More than 1 million people were displaced (USGS, 2005).

The scale and impact of this disaster is unparalleled in recent history. It occurred suddenly and affected many nations distant from its direct physical effects. In addition to the heavy casualties in densely populated local communities, many of those affected in Thailand, Sri Lanka and the Maldives were foreign tourists.

In Thailand, the tsunami death toll climbed to around 5,300 of which around 50% were foreign nationals, a majority from northern Europe. A further 3,000 persons were missing or unaccounted for in the aftermath (Guy Carpenter, 2005). At the request of the Thai Government several nations, including New Zealand, provided specialised medical and police forensic expertise to assist with disaster victim identification and repatriation (NZ Government, 2005)

As the disaster response moved from the heavy rescue phase to relief and initial reconstruction, the Society (NZSEE) assembled an inter-disciplinary team to survey the impacts and recovery operations in southern Thailand[2]. Similarities to New Zealand infrastructure and topography and some shared principles of civil defence and emergency management in Thailand made this a region of interest for lessons applicable to New Zealand.

Topic areas of interest and expertise included:

- Assessment of variable wave recession and attack time-lapse at different localities based on interviews with survivors, and relationship to coastal geometry, bathymetry and extent of inundation;
- Engineering assessment of impacts of waves and transported debris on built structures and engineering lifelines along the coast (roading, bridges, communications, water and waste, coastal piers or jetties);
- Assessment of the challenges related to management of the rescue and recovery efforts at a national and local level, including the demands that arise from world-wide interest and concern;
- Preliminary assessment of the socio-economic impacts on local communities, particularly disruption to businesses and primary-production.

The team visited Thailand from 24 January to 1 February, four weeks after the event. Discussions were held among representatives of Thai institutions and government departments in Bangkok before proceeding to affected areas along the Andaman coast. This timing enabled both the damage to be surveyed (despite extensive clean-up operations) and an appraisal of how the recovery operations and community response was progressing.

This paper discusses our insights into the physical damage inflicted by the tsunami through to lessons from the initial emergency response and the subsequent socio-economic recovery—which will continue for several years.

The team was led by Hugh Cowan, a geoscientist with experience of hazard monitoring systems and post-earthquake reconnaissance. Rob Bell, a coastal engineer and scientist documented hydraulic effects of the tsunami on the natural and built environment. Noel Evans, a structural engineer and lifelines group coordinator observed the damage to engineered structures and lifelines, Erica Dalziell, a risk management specialist, assessed the impact of the disaster in terms of pre-event vulnerability and post-event reconstruction. Mike O'Leary, national controller for the Ministry of Civil Defence and Emergency Management (MCDEM), and Bernie Rush, an emergency management advisor to MCDEM, researched the organisation and control of regional and national coordinating structures for response and recovery and the management of international assistance. Lawrence Yule, Mayor of Hastings and member of the National Council of Local Government New Zealand, took special note of potential lessons for

[1] Tsunami run-up is the vertical distance between the maximum height, reached by the water on shore and the mean-sea-level surface.

[2] The Society also sponsored Dr James Goff who participated in a United States tsunami reconnaissance mission to Sri Lanka (Liu *et al*., 2005).

planning and risk management in New Zealand coastal communities.

The team was guided by colleagues in Thailand. Ms Kamolrat Saringkarnphasit, a seismologist with the Thai Meteorological Department, accompanied the mission. Dr Adichat Surinkum, geologist and Director of the Geotechnical Division of the Department of Mineral Resources, contributed valuable additional guidance in the field during part of the mission.

2. THE SUMATRA-ANDAMAN EARTHQUAKE SEQUENCE AND TSUNAMI

The great Sumatra-Andaman earthquake of December 26, 2004 initiated at a depth of about 30 km beneath the Sunda Trench off the west coast of Sumatra, Indonesia [3.244°N; 95.825°E] at 00:59 UTC[1] (Stein and Okal, 2005). The rupture propagated upwards on a shallow-dipping (8°) fault plane and northward along the Nicobar and Andaman islands that delineate the boundary between the Indo-Australian plate and the southern edge of the Eurasian plate (Ni *et al*., 2005; Bilham, 2005), (Figure 1 and 2).

Up to 15 metres of thrust displacement was accommodated at the plate interface within a few minutes, offshore from Banda Aceh, Sumatra where the strongest excitation of the tsunami occurred (Figure 2) (Lay *et al*., 2005). Farther north, the rupture slowed considerably and for the last five of its eleven minutes duration, no further tsunami waves were produced. During the following hour, however, this northern section of the rupture accumulated many metres of slip, which contributed perhaps a third of the total energy released. This slow slip accounted for a three-fold upward revision of magnitude from 9.0 to 9.3 (Bilham, 2005). Later analysis of continuous-recording GPS stations revealed that co-seismic horizontal displacements had occurred over a vast region – from decimetre-scale shifts at the nearest stations (e.g. 270 mm at Phuket, Thailand, 400 km to the east) to several millimetres measured at points in southern China, the Philippines and India (Vigny *et al*., 2005).

The total length of the rupture is comparable to the distribution of aftershocks, which is more than 1,200 km for the December 26 event. This increases to more than 1,600 km when the contiguous Nias earthquake (moment magnitude M_w 8.7) of March 28, 2005 is included (Figure 2). The March 28 earthquake indicated further rupture of the plate interface to the southeast and raised concern about the altered state of stress and possibly heightened tsunami hazard on adjoining sections of the plate boundary.

Large earthquakes are known to have ruptured the Andaman section of the over-thrust plate boundary in 1847 (M_w 7.5), 1881 (M_w 7.9), 1941 (M_w 7.7) and, in the northern Andaman Sea, a section of the Andaman Ridge-Transform boundary near the coast of Myanmar, in 1930 (M_w 7.3) (Nutalaya *et al*., 1985; Ortiz and Bilham, 2003; Bilham et al., 2005) (Figure 1). Those historical events produced tsunami that, while locally destructive in the islands, had limited regional impact, probably due to their involving slip on deeper parts on the plate interface than occurred on Dec. 26, 2004. The earthquakes of 1930, centered in the far north of the Andaman Sea on a section of the plate boundary characterised by right-lateral strike-slip faulting, destroyed the ancient seaport of Pegu. Tsunami associated with those events caused severe flooding and fatalities in Myanmar (Nutalaya *et al*., 1985).

Farther south, offshore from Sumatra, the potential for great earthquakes has long been recognised from historical events with estimated magnitudes even larger than those mentioned above (Newcomb and McCann, 1987). Earthquakes there, in 1797 (M_w 8.4), 1833 (M_w 9) and 1861 (M_w 8.5) generated large tsunami. The waves of the 1833 event probably made landfall nearby with heights in the range 5-10 m (Cummins and Leonard, 2004). A smaller event (M_w 7.8) in 1907 just south of the December 26 rupture zone also produced a locally destructive tsunami in northern Sumatra (Newcomb and McCann, 1987). The inferred rupture area of that and the adjoining 1861 event were broken again by the recent (March 28, 2005) Nias earthquake.

3. TSUNAMI INUNDATION

The December 26, 2004 tsunami made landfall along the northwest coast of Sumatra and its offshore islands within tens of minutes after the earthquake. During the ensuing hour or so, flow depths of between nine and fifteen metres flooded coastal regions to a maximum extent of inundation, that in some areas reached 3-4 km inland (Borrero, 2005; Yalciner *et al*., 2005). Run-up heights ranging from 2-3 metres to more than 30 metres were later documented. The impacts were generally catastrophic although there were local examples of effective self-evacuation that averted significant loss of life[2].

In Thailand, the tsunami wave train first reached the nearshore waters off Phuket Island (Figure 2 and 3) around 1.7 hours after the earthquake, initially as the negative part of the wave (trough). This trough was the first visible sign of the tsunami observed as coastal waters quickly receding offshore to below the low tide mark[3]. This occurred over a period of about eleven minutes, exposing rocks that are normally submerged and stranding fish (and yachts). Unfortunately, many people

[1] (7:59am local time and 12:59pm NZST)

[2] Yalciner et al. (2005) reported that inhabitants of Simuelue, an island in the epicentral region, self-evacuated the coast immediately following the earthquake and suffered only eight fatalities from a total population of ~78,000. This successful action was attributed to retained community learning from the destructive impact of tsunami that accompanied the M_w 7.8 earthquake of 1907.

[3] The opposite occurred in countries to the west e.g., Sri Lanka and India, where the damaging wave crest arrived first (i.e. not heralded by receding waters).

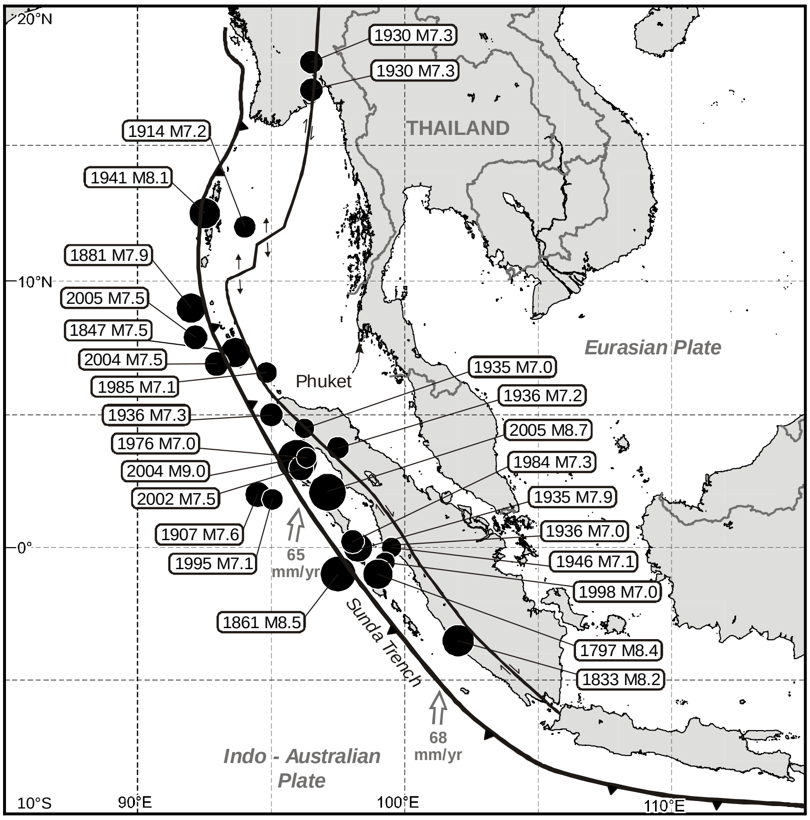

Figure 1. Historical large and great earthquakes of the Andaman plate boundary and region adjacent to the December 26, 2004 and March 28, 2005 earthquakes. Events of magnitude 7.0 or greater and depth < 100 km. Compiled from catalogues of the International Seismological Centre (ISC) and the National Earthquake Information Center (NEIC) Preliminary Determination of Epicentres (PDE).

were enticed by this unusual phenomenon and tragically drowned simply unaware of what was really happening.

The first tsunami peak (wave crest) arrived around two hours after the earthquake (~10:00am local time), initially striking the west-coast beaches of Phuket Island. Twenty five minutes later the waves rolled ashore at Khao Lak, 70 km farther north (Thompson, 2005). At around the same time, Phi Phi Island, located to the southeast of Phuket, was hit and a little later, the mainland of Krabi province farther to the southeast (Figure 1).

The best documented sea-level measurement on the open coast was obtained by a sounder on the yacht *Mercator* one nautical mile off Phuket beaches (Siffer, 2004). Three main waves were recorded at 12-13 minute intervals —the first was the largest (6.6 m trough-to-crest), while the third wave reached the highest elevation (5 m above the tide). Unfortunately, the waves arrived right on high tide for the Andaman coast (these would have been 1.2 m lower if arrival was at low water). Based on several post-event field surveys conducted by various international teams (e.g. NOAA, 2005; Tsunami Lab, 2005; Kyoto University, 2005), including our own measurements, the peak tsunami run-up heights are summarised in Table 1.

TABLE 1: Peak tsunami run-up heights (m) above mean sea level for Andaman Coast (north to south on Figure 1).

Location	Peak run-up height (m)
Ban Nam Kem	8–9
Khao Lak	12–14
Kamala Beach	5–5.7
Patong Beach	5–5.5
Karon Beach	4–5
Kata Beach	5.5
Phi Phi (north)	7–8
Phi Phi (south)	4–5
Krabi	4.3

Our tsunami reconnaissance surveys covered three main areas: Khao Lak region of Phang-Nga Province, Phuket Island (west coast) and the island of Koh Phi Phi in Krabi Province (Figure 3).

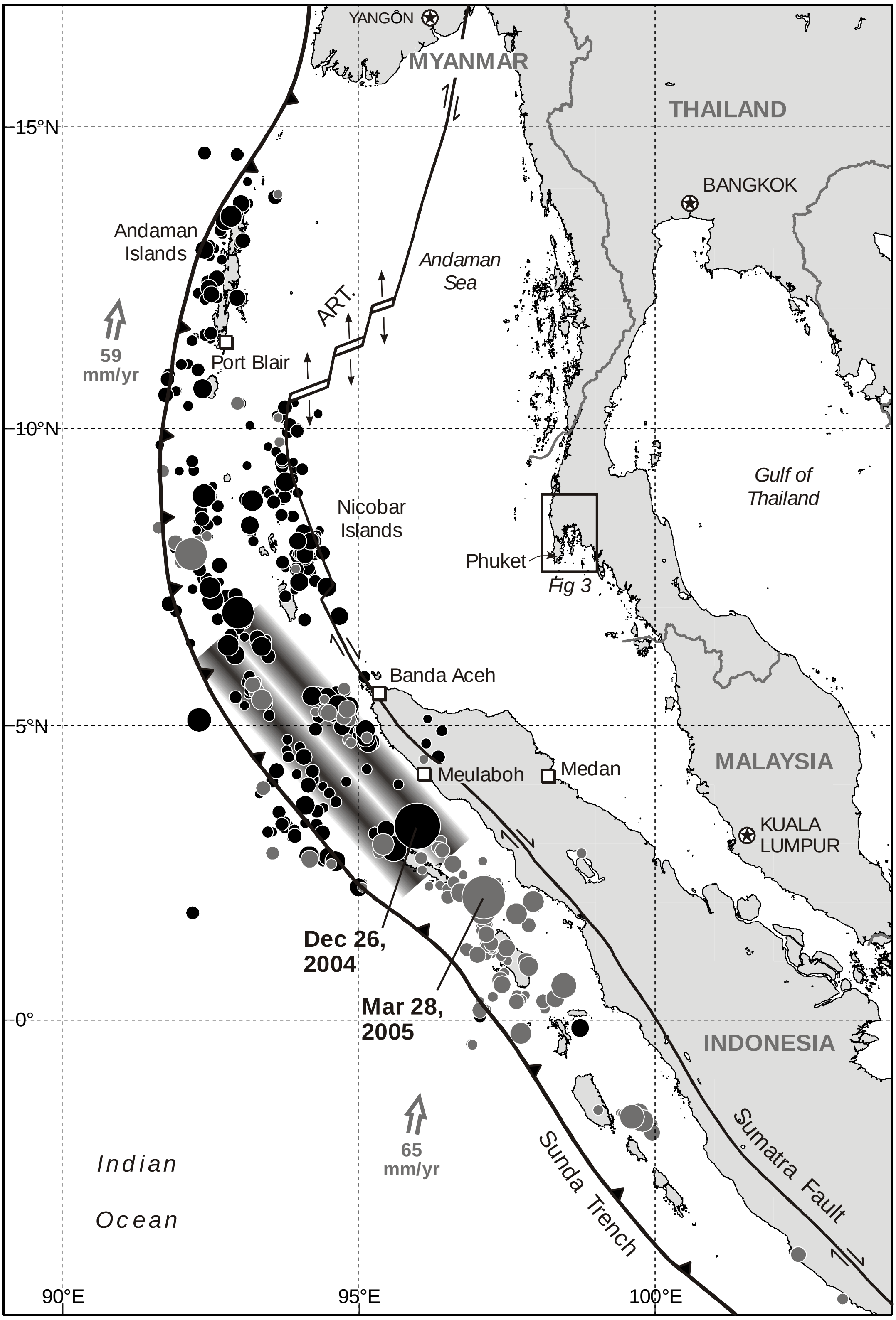

Figure 2. Major structural elements of the Indo-Australian and Eurasian plate boundary, showing the mainshock and aftershocks for the December 26, 2004 Great Sumatran-Andaman earthquake (M_w 9.3) (black symbols), and the contiguous Nias earthquake (M_w 8.6) of March 28, 2005 and combined aftershocks thereafter (grey symbols). The earthquake sequence encompasses a rupture zone 1,600 km long and 200 km wide. Strong excitation of the December 26 tsunami occurred between the mainshock epicentre, offshore Sumatra and the Nicobar Islands (shading) within the first four minutes of the rupture (Lay et al., 2005). All aftershocks shown are for events of magnitude 5 or greater from the PDE catalogue of the NEIC; ART=Andaman Ridge-Transform zone.

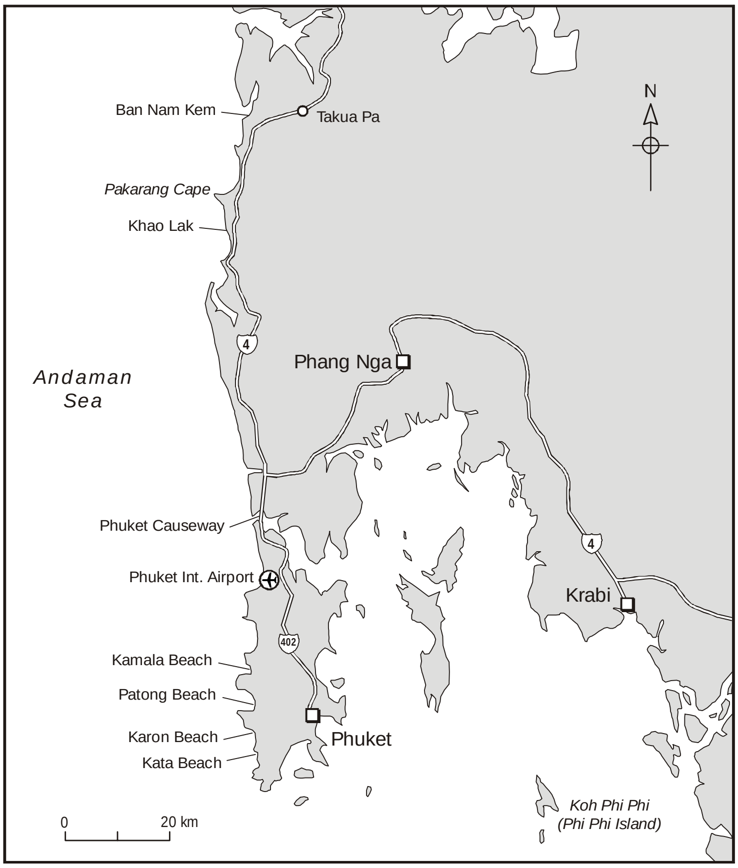

Figure 3. Simplified map of the Andaman Coast, Thailand showing localities mentioned in the text.

Khao Lak (Phang-Nga province)—the Khao Lak area is 70 km north of the Phuket causeway on Highway 4 (Figure 3). In between there is limited coastal population and development. The "Khao Lak tourist region" is located on a narrow coastal beach strip 15–20 km in length bounded by mountainous terrain. Feeder roads of a few hundred metres to a few kilometres off Highway 4 lead to individual or clustered resorts fronted by golden sandy beaches. This region had grown to become a booming tourist destination in the last five years.

Khao Lak was hit by tsunami waves with measured run-ups varying from 4 m up to 14 m, suffering the most serious devastation in terms of people killed and hotel/resort damage (Figure 4 and 5). Few of the hotels or resorts in Khao Lak, which had a total of around 5,500 rooms, were left standing. It is estimated that more than 1,000 people died in Khao Lak and 80% of the coastal facilities suffered serious damage. It is estimated that the lethality ratio in the impacted coastal strip was around 25% of people (EEFIT, 2005). Penetration inland was up to 3 km in the widest part of the coastal strip at Pakarang Cape (Figure 3). In central Khao Lak, a police patrol boat off Bang Niang Beach was driven by the tsunami 1.2 km inland, narrowly missing a shopping complex (Figure 6). While damage was severe to resorts along the coastal strip, the town of Khao Lak and the main road farther inland suffered only moderate damage in low-lying areas and adjacent to rivers. The reason for the tsunami run-up height being so much higher at Khao Lak was due to wave amplification across the broad shallow shelf offshore of Khao Lak compared with the more steeply rising seafloor off the coast of Phuket Island (Royal Thai Navy, 1981)

Koh Phi Phi (Krabi province)—Phi Phi is a butterfly-shaped island, with a low-lying narrow strip of sand (tombolo) formed over thousands of years between the lee of two steep rocky outcrops (Figure 7). The strip is only 150 m wide at its narrowest, increasing to 1,000 m at the base of the cliffs at each end. Further the sandbar is only one metre above high water in the narrowest section. Following a large recession of the sea (especially in the shallower northern bay), the tsunami wave peak arrived first in the northern bay inundating the entire sandbar to a depth of 7–8 m, washing debris into the southern bay (Ao Ton Sai). The island was then hit by the wave refracting around the island from the south a few minutes later. The refracted wave was half the height due to the deeper water present in Ao Ton Sai (where the wharves are located).

On Phi Phi, about 1,400 resort rooms in 34 facilities were lost or damaged and up to 70% of the island was severely damaged (Guy Carpenter, 2005) as shown in Figure 8. The devastation witnessed at Phi Phi provided a salutary lesson of the vulnerability associated with extensive development on tombolos and sand spits in areas exposed to tsunami hazard.

Figure 4. Tsunami wave heights were inferred from strand-lines and watermarks on buildings. In this case a car was lifted above the roofline of a resort in Khao Lak (Photo Thai Meteorological Department).

Figure 5. Missing roof tiles indicate the tsunami torrent depth exceeded nine metres at this location in Khao Lak (Photo ED).

Figure 6. One of two police patrol vessels caught by the first tsunami wave off Khao Lak – this one was carried 1.2 km inland narrowly missing a shopping complex; the other vessel rolled and sank near the coast. (Photo RB).

Figure 7. Phi Phi Island viewed from the air as the team approached by helicopter from the southeast. The tsunami wave traversed the sand-spit at depths of up to nine metres, first from the north and a few minutes later again from the south (Photo ED).

Figure 8. The hospital on Koh Phi Phi was set back from the shore but situated close to sea-level. It was rendered inoperable by the tsunami, highlighting the critical need to locate such facilities outside potential inundation zones (Photo LY).

Phuket Island (Phuket Province)—western beaches of Phuket were the first areas in Thailand to be impacted by the tsunami (Figure 3). Inundation heights varied considerably along the coast (Table 1) due to variations in the wave shoaling from sand bars and reefs on a coast with beaches aligned at different orientations. Beach condition was also a factor, with Karon Beach less affected because the foredune had been kept intact. Kamala Beach, with its extensive nearshore rock platform, was the location most seriously affected by the tsunami in Phuket and experienced significant loss of life.

Although hotels and businesses in Kamala and Patong Beaches were heavily damaged, mainly the ground floors, initial surveys of hotels around the island indicated that less than 20% suffered serious damage (Guy Carpenter, 2005). Penetration of the tsunami inland was constrained by the density of buildings, but side roads leading off the main coastal road being perpendicular to the beach and parallel to the flow direction became swift torrents, transporting lethal volumes of debris. Vehicles were piled up in stacks at the ends of these roads, whereas the alleyways off these side roads (being perpendicular to the flow and sheltered by buildings) incurred much less damage. A recurring theme of survival among those we interviewed involved split-second, counter-intuitive decisions to enter side alleys instead of running farther inland along the main side roads. Sheltered by buildings the side alleys afforded protection from high flow velocities and torrent depths encountered in the main streets.

4. RESPONSE OF LIFELINES

While the damage to engineering lifelines in the inundation zones was catastrophic the major arterial lifelines on the mainland were mostly located away from the coast and suffered relatively minor damage.

Reinstatement of services to the coastal resort areas was progressively undertaken, based on need and the availability of resources. Lifelines on Koh Phi Phi were almost totally destroyed and even a month after the event, were operating on a temporary basis.

4.1 Phuket International Airport

Phuket International Airport, which quickly became the key lifeline for much of the response effort, had seawater break through its protective seawall and flood the runway. The transformer for runway lights was damaged and debris was transported in through an open channel (Ruangsassamee and Lukkunaprasit, 2005). However, airport emergency crews quickly re-established control and the airport reopened by early evening on the day of the tsunami to allow flights to and from Bangkok.

4.2 Water Supply

Many of the water supplies in the affected areas operate on a combination of reservoirs and underground aquifers. In some locations water towers are used to provide adequate pressure. With water supplies initially disrupted, response organisations relied on stocks of bottled water that is used extensively by the tourist industry.

Water towers suffered damage (but seldom total collapse) and damage to pumps, in addition to water contamination, was widely observed.

During the mission it was noted that HDPE pipe had been used extensively to reinstate water mains. This had the advantage that it could be laid in long lengths with relatively easy fusion jointing. In some cases it appeared that existing HDPE water mains had remained intact in locations where roads had been scoured out and retaining walls had failed.

4.3 Power Supply

The main electrical transmission conductors extend down the centre of Phuket Island and were undamaged. A new distribution main conductor was under construction along the Phuket coastal resorts. At the time of the tsunami the damage to local distribution networks was extensive. Authorities moved very quickly to effect repairs, however. An example of quick repairs was the reinstatement of supply in parts of Phuket within one day and the submarine supply to offshore islands from Ban-Nam-Kem in Khao Lak was reinstated within five days of the event.

4.4 Hospital Services

Most major hospitals and clinics were located away from the inundation zones. However the hospital at Koh Phi Phi was located on the low lying tombolo at its narrowest width.

The Phi Phi hospital was inundated by the first wave and rendered completely inoperable (Figure 8). Being the only emergency medical centre this meant that there was no medical treatment available until sufficient clearance of debris allowed emergency services to arrive from the mainland by helicopter.

The example of Phi Phi hospital clearly demonstrates the need for planners to locate critical emergency response services in areas not at risk to tsunami (or flood) inundation or to make provision for the loss of such service centres.

4.5 Sewerage Systems

The Bangkok Post (30 Dec., 2004) reported that authorities were concerned about the massive amount of untreated municipal wastewater being discharged from the Phuket community of Patong into the Andaman Sea. The town's sewerage treatment plant was unable to treat its normal 10,000 cubic metres of wastewater each day as the pump and regulator controls had failed. Many wastewater ponds and treatment tanks were also flooded, killing bacteria used for waste treatment.

This was repeated at the many affected resort areas along the Thai coast. In some cases even though the plant (e.g. pumping stations) was not physically damaged, it was rendered inoperable by the tsunami having inundated the control electrics and mechanisms at various collection points (Figure 9a and 9b).

A month after the tsunami, minor sewer overflow discharges were still continuing at some beaches while authorities were waiting for repairs and replacement components. They were very aware of the need for speedy repairs to preserve the pristine image for the numerous resorts.

4.6 Roads

Damage to coastal roads in Phuket appears to have been quickly repaired with access still available by numerous roads from the unaffected eastern coast.

One of the two bridges connecting the main Highway 402 of Phuket Island to the mainland and Phang Nga Province, was closed for three or four days while repairs were effected.

One road bordering the coast at Kamala Beach (Phuket Island) suffered extensive damage. Here the impact of the tsunami destroyed the protecting seawall and bodily shunted the asphalt of a section laterally by about 600 mm so that it was forced over the concrete roadside stormwater drain cover (Figure 10).

In Khao Lak, Highway 4 runs close to the coast and was inundated in many places. Thus it was some time before access to this area was reinstated and news of the greater losses and more extensive damage to the Khao Lak area became known.

At a number of Khao Lak coastal resorts the outgoing sea waters (following each wave inundation) caused extensive and deep outwash scour channels causing numerous coastal side-road dropouts. Since these resorts were far from re-establishing at the time of our visit, these dropouts had yet to be repaired.

Figure 9a and 9b. Inspecting damage to a sewerage pumping station at Kata Beach, Phuket Island. Electrical control systems were damaged beyond repair, causing sewer overflows into the adjacent stream, and discharge onto the nearby beach (Photos RB and HC).

Figure 10. Damage to roads was locally severe due to scouring. At Kamala Beach, Phuket Island, where the torrent depth was 3-4 m, the beach-front road pavement was shifted landward 600 mm onto the adjacent stormwater drain cover.

5. PERFORMANCE OF STRUCTURES

5.1 Thai Building Regulations

Locating definitive information on the Thai building regulations and codes during the visit was limited to a few documents available in English. General descriptions were provided however, as the tour proceeded.

The Bangkok Metropolitan Authority Building Regulations (2001) that were adopted by most provinces are mostly descriptive planning rules. The only structural items specifically covered include wind loads, minimum concrete cover thicknesses, and the need to fix reflective glass enclosures.

A seismic loading code, Ministerial Building Control Regulation No 49 (dated 1997) applies only to larger and public buildings, in the seismically-active northern provinces of Thailand. The provisions of this code did not apply to Bangkok nor to the south-western coastal provinces that we visited.

During 2003 – 2004 the National Earthquake Committee of Thailand included a study of the dynamic response of structures in Bangkok and other cities in the Seismic Hazard and Mitigation of Seismic Risk Project (Phase 1). It was anticipated that Phase 2 of this project would lead to the development of seismic requirements for Bangkok and the other cities.

During our tour we were informed that a conference of representatives of the Thai construction industry in mid-January 2005 reviewing damage to buildings from the tsunami recommended the adoption of Ministerial Building Control Regulation No 49 in all provinces of Thailand.

Under prevailing building regulation requirements, much appears to have been left to building owners and developers to set their own levels for design and construction monitoring. Foreign investors in Thailand, however, tended to insist that suitable internationally recognised standards were followed.

Thus we observed the performance of hotels and resorts where the major buildings had generally been designed to recognised standards but had not been designed for lateral loads such as earthquake loadings. The standard of design and construction of older buildings, local residences, small shops, restaurants and some resort bungalows varied widely. Many were non-engineered structures.

5.2 Typical Construction Systems

The tourist resorts and hotels had developed at a phenomenal rate over the last few years particularly along the coast at Khao Lak. The resorts were mostly modern structures that included a combination of single storey bungalows and two or three storey blocks.

The multiple-storey buildings generally consisted of reinforced concrete frame structures with reinforced concrete floor slabs cast over prestressed concrete planks. Casting the slabs in with the beams was shown to provide good diaphragm action. The details of reinforcing were as would be expected for non-seismic design detailing, especially beam/column junctions, lap lengths and confining reinforcing. In a number of cases these would not have complied with the requirements of ACl non-seismic design (Lukkunaprasit and Ruangsassamee, 2005).

Exterior and partition walls were generally 100 mm thick and consisted of plastered unreinforced masonry. The roofs were either galvanised iron or tiles supported by timber framing. Extensive use was made of light suspended ceilings.

Single storey buildings generally consisted of a basic frame of 100×100 mm lightly reinforced concrete columns on a concrete slab with similar sized beams at eaves level. Walls were also plastered unreinforced masonry. Galvanised iron or tiled roofs were supported on timber framing (and more recently light gauge structural steel).

5.3 Damage to Buildings

The December 26 earthquake was felt in southern Thailand but was not sufficiently strong to cause structural damage. The tsunami torrents, however, generated very high dynamic face loading pressures on buildings, assessed by Thai engineers as high as 20 to 30 kPa. (Dr P. Warnitchai, pers. comm). These pressures were sufficient to blow out unreinforced masonry walls, sweep bungalows off their slab foundations and collapse many buildings. Damage was often initiated by the impact of trees, boats and cars that were engulfed by the tsunami.

Within the Khao Lak area about 100 of the 143 hotels or resorts sustained damage and almost 80% of the room capacity was lost (EEFIT, 2005). This is reflected in the high casualty figures with about 70% of the life loss and missing persons for Thailand occurring in this region.

Most of the damaged and collapsed single storey buildings had been cleared by the time of the visit. The extensive areas of cleared sand gave an indication of the large number of buildings that had been destroyed. These buildings included detached bungalows, bars, restaurants and those associated with the resorts. Those that remained standing through the torrent appeared to have been either well sheltered by buildings in front or were very well tied at foundation and eaves levels, with numerous partition walls (Figure 11).

The remaining damaged single-storey buildings that we observed demonstrated a wide variety of failure mechanisms associated with inadequate detailing of reinforced concrete to sustain high lateral loads. For many the basic structure was a simple mechanism with little lateral bracing and inadequate jointing (Figure 12).

The multi-storey buildings were extensively damaged in the ground floors with walls facing the torrent blasted through (Figure 13). Once the tsunami was able to flow through the lower storeys the loadings on the building would have been significantly reduced and the remaining walls, generally in the direction of flow, were able to provide in-plane resistance. An extreme example of the difference of impact forces occurred at Kamala Beach School, Phuket where a new school two-storey block under construction with no ground storey infill walls survived while two completed similar buildings were destroyed.

The collapse of ground storeys of buildings created significant volumes of debris, which when added to furniture, building fittings picked up in the torrent and other debris made survival extremely difficult for anyone caught in it.

Figure 11. View to seaward at one of the coastal resorts in Khao Lak. Foundations are all that remains of the single-storey buildings closest to the beach. A gradation in the severity of damage owed more to the protection afforded by adjacent structures than to the absolute distance inland (Photo HC).

Figure 12. Damage to reinforced concrete frame structures was only locally severe, where exposed structural elements were impacted by entrained debris (Photos NE and RB).

Figure 13. One of resorts at Khao Lak located a few hundred metres from the shoreline, where the highest tsunami run-up (12 m) occurred. Water entered rooms even on the third floor, and in-fill block walls and windows on the first and second floors were punched out (Photo ED).

Ten to twelve metre run up heights in Khao Lak meant that for many buildings the inundation extended to the second, and locally the third, storey. While the damage to partition walls was significantly less in the higher storeys, ceilings and furniture and fittings were caught up in the torrent and damage was frequently initiated by the impact of projectile logs and other debris (Figure 14).

What had not been expected by our team was the extent of damage caused to buildings by the outwash flows in between incoming tsunami torrents. The inundations from the tsunami surge lasted for up to 10 minutes. After that the retreating water flowed to rivers, streams or the nearest low-lying area, scouring wide deep channels that undermined buildings, bridge abutments and roads (Figure 15a and 15b). While buildings on piles remained stable, in some locations the scouring undermined buildings that led to collapse, especially for those on spread footings. In other locations well connected new structures on spread footings were bodily moved up to six metres and were left partially collapsed and leaning at odd angles. In one instance, in-ground swimming pools were fully exhumed and unevenly displaced. The sand around some buildings showed signs of having liquefied leading to underground services tanks floating up above ground level (Figure 16).

5.4 Damage to Wharves

The benefit of well tied structures was demonstrated at Ban-Nam-Kem fishing port where the wharf slabs were not constructed monolithically with the supporting beams. The tsunami lifted the slabs off the beams and then started a progressive collapse of the other structural elements (Figure 17).

5.5 Damage to Seawalls

A number of seawalls were constructed to provide wave and storm-tide protection and retain land up to about a metre above beach level. These non-engineered walls collapsed seaward onto the beach during the outwash of the retreating waters (Figure 18). Typically these structures had no spread footing or deep piling. The combination of scour, possible liquefaction and the outgoing water tipped many lengths of wall seaward, enabling more scouring of the land and buildings behind.

5.6 Damage to Bridges

Damage to bridges was reported at low lying locations up to 1.3 km inland from the coast. Side barriers were impacted and bent or sheared. We were unable to obtain details of the number of bridges that were damaged or needed replacement.

The damage caused by scouring during the outwash phase exposed pilecaps and undermined stream protective works, particularly on the downstream side of bridges and culverts.

Figure 14. Extraordinary volumes of debris were entrained by the tsunami and contributed to its destructive impact. This coconut palm trunk penetrated the roof and internal ceiling of a hotel on Koh Phi Phi (Photo ED).

6. EMERGENCY PREPAREDNESS AND RESPONSE

6.1 Emergency Management in Thailand

The National Civil Defence Committee, chaired by the Minister of Interior, coordinates all activities relevant to civil defence and disaster management at a national level in Thailand. The committee consists of representatives from a number of national agencies, with its secretary the Director-General of the Department of Disaster Prevention and Mitigation (DDPM).

Regional Disaster Prevention and Mitigation Centers (12) are organised beneath the DDPM to render technical and auxiliary assistance to provincial civil defence committees, the latter chaired by the Governor of each province. These provincial organisations directed much of the emergency response to the tsunami impact.

Figure 15a and 15b. The receding waters after each wave caused substantial scouring of small streams and low-lying depressions, as shown here at Khao Lak. The scoured "channel" (15a) is 50 m wide and up to 3 m deep, completely undermining the resort buildings (15b) nearby (Photos RB).

***Figure 16.** Liquefaction of soils appears to have occurred during the surge and withdrawal of tsunami waters at Khao Lak, with underground services such as this tank floating to the surface (Photo NE).*

***Figure 17.** Severe damage to the wharf piles and topping at Ban Nam Kem, a fishing port north of Khao Lak, where the tsunami height reached nine metres (Photo HC).*

Figure 18. Receding waters (out-rush) caused collapse of most seawall defences from behind due to scouring (Photo RB).

6.2 Emergency Response to the Tsunami

One month after the tsunami the response phase was completely over. The Emergency Operation Centres (EOCs) established for this purpose had been dis-established so there was no opportunity to view them in operation to assess their effectiveness. However, two of our team (MOL and BR) met the Director of the Policy Bureau of DDPM, Mr. Jakarin Hongsahul, in Phuket, to discuss aspects of the emergency response to the tsunami disaster.

The emergency response structure depicted in papers provided by DDPM is very similar to the New Zealand CIMS (Coordinated Incident Management System) model. However, Thailand has a centrist command and control ethos backed by significant Government resources. The Thai approach could be compared with what New Zealand would have done under the old Civil Defence Act 1983, with government resources as they were before 1984.

We understood that the EOCs had been multi-agency, with effective sharing of information between all of the organisations. Initially there were three EOCs operating. This was later expanded to six. The Prime Minister appointed a Minister to perform an equivalent role to that of National Controller in New Zealand. The Minister in turn appointed regional governors to local controller roles.

Initially, resources were overwhelmed, but machinery and manpower in the form of Defence Force, DDMP and private contractor resources had allowed Thai authorities to clean up many areas that were inundated by the tsunami within a few weeks.

The same resources had constructed 16 substantial, fully-serviced temporary residential camps for displaced persons and to begin the construction of more substantial transit accommodation for displaced families living in those camps. Our team observed armed forces personnel carrying out reconstruction work in the devastated fishing village of Ban Nam Kem.

Most international response aid agencies only remained in Thailand for a very short time. Of those we knew of remaining in the country most appeared to be involved in disaster victim identification or advising(?) on risk mitigation and recovery issues.

Near Khao Lak the team encountered a group of local and international volunteers, established in a resort complex. They appeared to be attracting more people to join them through a website www.tsunamivolunteer.net under the auspices of a local Thai NGO.

As a result of talking with this volunteer group we identified a number of issues. There was no formal leadership of the group. Strong-willed individuals appeared to be making decisions following informal daily meetings. Each day at these meetings the approximately 100 volunteers discussed among themselves what activities they would undertake that day. Money was also collected from the volunteers at the conclusion of the meeting. There appeared to be no forward planning, nor any link with other organisations to ascertain how best they could assist the community. Many of the volunteers we spoke to had arrived in the country hoping to get work with international NGOs such as Red Cross, but had been turned away.

These people were both a significant positive resource and a significant burden on the local Thai community. We judged their contributions would have been far more effective had they been integrated into formal relief efforts. The lesson for New Zealand should a major disaster strike, would be to identify this volunteer resource (international and national) at points of entry and channel it into appropriate relief activities.

7. CASUALTIES AND HEALTH

Casualties from Khao Lak and Koh Phi Phi were taken to hospitals at Takua Pa and Krabi, respectively. From Takua Pa, patients with serious injuries were evacuated to larger hospitals elsewhere. As mentioned in Section 4.4 the hospital on Koh Phi Phi was completely destroyed by the tsunami and injured survivors had to wait hours for evacuation by helicopter before receiving medical attention.

A surgeon at the Takua Pa district hospital explained that during December 26 more than two thousand people arrived at the emergency department where seven doctors and ten nurses treated more than one thousand patients, including approximately 300 foreigners. The most common injuries were respiratory insufficiency, lacerations and lower limb fractures. Many of the wounds were described as “extremely dirty” requiring extensive irrigation. Infections were common with many tsunami survivors readmitted for debridement of wounds and treatment with potent antibiotics. Aspiration pneumonia related to near drowning in contaminated seawater presented in numerous cases at Takua Pa and elsewhere (Kateruttanakul *et al*., 2005) posing additional challenges for casualty planning.

Prior to the December 26 event, a commonly-used rule-of-thumb based on past events was that most deaths and injuries in a tsunami are caused by debris entrained by the tsunami torrent. However, in Thailand, based on interviews with hospital authorities and disaster victim identification teams, drowning was by far the most common cause of death and aspiration pneumonia the most common injury/illness. It appears that this shift in type of casualties was due to the sheer depth of water that inundated the land, particularly in the Khao Lak area.

8. SOCIAL ISSUES

Besides the resort areas, a fishing village called Ban Nam Kem north of Khao Lak was largely destroyed with heavy loss of life. More than 5,000 survivors were distributed among 16 temporary camps managed by the Department of Social Development with assistance from the Ministry of Defence, Ministry of Health and the Ministry of Interior.

8.1 Distribution of Aid

In the days shortly following the tsunami, the Thai government set up a disaster assistance programme which provided immediate humanitarian aid such as food and shelter, and an initial lump-sum payment of 2,000 baht/person (approx USD$50) as well as 40,000 baht (USD$1,000) for each family with members dead or missing (FES and MAC 2005). Of the 120,000+ Burmese migrant workers in the area, 10,000 were estimated to be directly affected but only 20% were believed to be registered with the authorities (Bangkok Post, 27/01/2005).

8.2 Looking to the future

We talked with many local Thais about their plans for the future. At that time, one month after the tsunami, we struck people at differing stages of coping with the tragedy. Some were still in a state of shock; like a couple at Kamala beach, whose house and small beachside restaurant had both been destroyed. They had no plans or ideas on what the future might hold. Others, who had similarly lost both home and business, were further along in the grieving process, already looking to find alternative futures for themselves and their families. A significant challenge for these affected communities will be finding ways to support each other when all are suffering. Keeping the community together over the long recovery process ahead will also be challenging. Particularly in areas like Khao Lak, where the tourist economy is unlikely to resume at pre-tsunami levels for at least 12 months, possibly longer, people may move from the area either temporarily or permanently.

9. IMPACT ON BUSINESSES

Though the financial implications of the 2004 earthquake and tsunami pale in comparison to the human death toll, economic losses arising from the catastrophe are still expected to be substantial in several countries (including Thailand). According to Munich Re (2005), the economic damage from the disaster may total more than 10bn Euro (USD$13bn). This would make the event the fourth costliest disaster of 2004, behind the Japanese earthquake in October (USD$28bn), hurricane Charley (USD$21.3bn) and hurricane Ivan (USD$20bn).

9.1 Tourism Industry

The regions affected by the tsunami were significant in terms of Thailand's overall tourist economy. According to Tourist Authority Thailand (TAT) statistics (TAT, 2005a), in 2003 the six affected provinces earned USD$1.9bn accounting for 25% of Thailand's total tourism revenue. Nearly 80% of this sum was earned in Phuket alone. The tsunami struck right at the start of the peak tourist season, when the area generates two-thirds of its annual income.

The Tourism Council of Thailand estimates that Phuket Province lost at least USD$500m in revenue in the three months following the tsunami (Phuket Gazette, 17/05/05). The Tourism Ministry estimates that about 180,000 people in the tourism industry have lost their jobs and another 80,000 are at risk (UNDP, 2005a).

The recovery of tourism infrastructure and services is expected to vary along the affected coast. At the time of our visit, only one month after the tsunami, there were already distinct differences in the recovery rate of different areas. Areas such as Patong beach in Phuket, where wave heights reached 5-5.5 m, were already well on the way to recovery. Many businesses had reopened, albeit in the midst of ongoing construction, and tourists were slowly filtering back into the area. Several factors contribute to this rapid recovery. In Patong Beach a relatively low proportion of resorts were seriously damaged (estimated at less than 20%, Guy Carpenter, 2005). Patong Beach also had a well established and thriving tourism economy, meaning businesses near the beach were likely to have been in a strong financial position prior to the event.

Relatively quickly after the event, TAT also embarked on significant marketing strategies to restore the confidence of domestic and international travelers, with targeted marketing campaigns to promote the Andaman Coast as "open for business". They also facilitated Agent Education visits, where media and travel operators were invited to visit affected areas and conduct site inspections of hotels and attractions that had re-opened (TAT, 2005b).

In other regions, the recovery is proceeding at a much slower rate. The scene at Phi Phi Island was one of near total destruction. Very little clearing work had been undertaken after four weeks, with streets and shops piled high with debris. One of the major challenges for recovery on Phi Phi is that all debris must be removed from the island by barge. At the time of our first visit, there was only one backhoe and two dump trucks working on the island. The psychological impact this had on the population was significant. However, on a subsequent visit one week later, substantial clean-up was underway with a noticeable rise in optimism.

In Phi Phi many of the business owners we talked to had no indication of how long it might take to clear and rebuild their properties. An estimate for Charlie's Resort (one of the larger businesses) was to re-open in two years. The future prospects for Phi Phi business owners however remain positive. The topography of the island and its unique natural beauty are likely to ensure it remains an attractive tourist destination. If anything, the devastation at Phi Phi may provide an opportunity to correct previous over-development which led to significant environmental pressures on the area. This aspect is discussed in more detail in Section 9.6.

The Khao Lak area suffered substantial devastation with nearly all tourist infrastructures in the region affected to some degree. The recovery of repairable resorts in the Khao Lak area is expected to take at least one year. A major issue for the Khao Lak community will be the interdependent nature of tourism recovery, with few tourists attracted back into the area so long as a critical mass of tourist facilities remain closed. There is also the potential for a change in the character of the area, which before the tsunami had a high proportion of small, family run tourist hotels and restaurants. The capital requirements for reconstruction, long timescales for recovery, and large areas of cleared land now available (where earlier buildings have been destroyed) has led to speculation of a future Khao Lak with a high proportion of large, internationally owned hotel chains (Bangkok Post, 13/01/05).

These longer term impacts and the characteristics of business that survive and those that do not will be explored in a return visit to Thailand by one of the authors (ED) in August 2005.

The tsunami has also meant a change in clientele for those businesses in the heavily affected areas that were able to reopen soon after the event. Relief volunteers and those attracted back to the area by cheap hotels and travel deals tend not to be the big spenders. Devastated areas such as Khao Lak have also seen a growing trend of local and international 'disaster tourists', wanting to see the devastation for themselves; this is providing a much needed boost for those businesses able to reopen soon after the event (Phuket Gazette, 18/01/05).

9.2 Fishing Industry

Thailand is the world's largest shrimp exporter. Although, at a macro scale, some have estimated that the tsunami will have little impact on the overall industry (EIU, 2005), the local impact is significant. Our team observed a large number of damaged shrimp farms. The Thai Shrimp Association estimates that the tsunami has caused USD$500m damage, and killed more than 100 hatchery workers. Shrimps, which are raised in seaside man-made saltwater lagoons, were washed away along with a great deal of equipment. The jobs of up to 300,000 shrimp workers are at risk as a direct result of the tsunami (Thai Embassy DC, 12/01/05).

The tsunami also caused significant damage to the local fishing industry (Figure 19), with around 20% of officially registered boats suffering damage (EIU, 2005). The Department of Fisheries estimates that a total of 7,446 fishing boats were lost (UNDP, 2005a).

The fisheries industry contributes only about 1.7% of total GDP so represents a much smaller macro economic impact than Tourism. The wide-scale devastation of whole fishing communities, and the loss of small boats used locally for transport and small scale fishing is likely to have significant social impacts for the affected communities though. The capital required to repair or rebuild lost boats, as well as the loss of skilled fishermen with local knowledge of the fishing grounds, will have impacts for many years to come. Of particular note is Ban Nam Kem Village in Khao Lak District which was particularly hard hit by the tsunami, with early estimates of up to half of the population dead or missing (WHO, 04/01/05). It should be noted that boats well offshore at the time the tsunami struck suffered no damage. We spoke to one local fisherman who was approximately 10 km offshore when the tsunami struck, where he felt the tsunami as a 1 m high long-period swell.

***Figure 19.** At Ban Nam Kem, fishing and port facilities were destroyed, many lives were lost and the ecology of coastal fishing grounds altered. The economic recovery from the tsunami poses a significant challenge to this community and others like it along the Andaman coast (Photo ED).*

9.3 Insurance Coverage

The overall picture of insurance coverage for affected businesses is complex. Many of the large tourist resorts, particularly those owned by multinational chains, either have insurance cover or because of their size, self insure against smaller losses. During our visit however we spoke with many small business owners who either had no insurance cover, or whose insurance cover was limited primarily to fire damage and did not cover tsunami. On Phi Phi Island none of the business owners we spoke to had insurance. We were told that it is not possible to buy insurance cover for property on Phi Phi Island, but were unable to verify the reason for this.

9.4 Business Recovery

On the 12th of January the Thai Government approved more than 69 billion Baht in financial aid and credits for individuals and businesses affected by the tsunami.

Soft loans (with interest rates lower than market values) and tax breaks which allow business owners to claim tsunami losses against tax have been offered to businesses in the affected area (Jantraprapaweth, 2005). For example, our team spoke with a business owner in Patong Beach who had just secured from the bank a 24-month loan at a 2% rate of interest. The capital for these loans was provided by the Government at 1% interest, with the bank adding on to this a 1% transaction management fee.

As part of the recovery package, small business owners were also entitled to financial support of 20,000 baht, and fishermen with registered vessels damaged or lost were entitled to compensation of 10,000 and 66,000 baht respectively (FES and MAC, 2005). Nearly five months after the tsunami, however, there is concern that aid packages for small business owners are still taking too long to process, with latest reports of 968 small businesses owners still awaiting any compensation (Phuket Gazette, 13/05/05). The processing of compensation claims is complicated as many business owners have lost all documentation, creating difficulties in verifying losses and confirming people's identities.

9.5 Flow-on Economic Effects

The tourism industry accounts for around 6% of Thailand's national GDP. The impact of the tsunami is expected to be felt right across Thailand as discretionary spending is reduced. One month after the tsunami some Thai industries, including car manufacturers, were predicting a substantial short-term slump in sales (EIU, 2005).

In addition to those businesses directly affected by tsunami damage, businesses beyond the immediate damage areas also experienced a severe reduction in business. One month after the tsunami, undamaged hotels were reporting only 10% occupancy in what would normally be their peak tourist season. Four months on from the tsunami, international passenger arrivals at Phuket airport were down 56% on the previous year (Phuket Gazette, 04/06/05). This reduction in general tourist trade has flow-on effects throughout the general business community—reducing demand for other tourist services such as taxis, bars and souvenir sellers and in turn reducing the disposable income and spending of locals.

Although the economic impact for the Andaman Coast region is significant, the macro economic impact for Thailand as a whole is much less severe. The eastern coast of Thailand, which was unaffected by the tsunami, has a large number of tourist resorts, and many tourists can switch to these eastern resort areas (DCOMM, 2005).

9.6 'Building Back Better'

The tsunami has devastated communities; but at the same time the devastation wrought on these communities opens up opportunities for change—change that prior to the event would not have been politically feasible. In disaster literature, this concept is referred to as "Building Back Better" (Monday, 2002, UNDP, 2005b) where the community seeks not to simply rebuild what was, but to look for opportunities to reduce future vulnerability to hazards. The application of this concept was observed on Phi Phi Island, which prior to the tsunami had been intensively developed with shops encroaching right onto the beach frontage. In the aftermath of the tsunami, local government officials indicated that encroached land would be reclaimed, and core areas of the beach would be re-planned and re-zoned to ensure that replacement architecture is to a lower density (Cummings, 2005).

At Patong Beach there is a move to limit the number of beach chairs and umbrellas allowed to return onto the beach margin. These moves however have been met with significant public resistance, and prior to the March national elections few decisions were being made. This left the affected community with significant uncertainties as to how the recovery process would proceed.

This highlights a tension for any community faced with recovering from major disaster. On the one hand the community will want to get the recovery process underway as quickly as possible, whilst on the other hand time is needed to evaluate options and opportunities to build back better. Talking about these issues beforehand and agreeing a decision making process in advance that will be effective in a response and recovery setting is needed to negotiate through these often conflicting objectives.

10. CONCLUSIONS

The tsunami in Thailand was not a single breaking wave – rather it was a raging torrent or wall of water that surged repeatedly onto the land. Prior to the landfall of the first tsunami torrent the sea receded to below normal low tide levels for a period of several minutes – some witnesses claim up to 15 minutes. The opposite occurred in countries west of the rupture zone, where no initial recession was observed and the tsunami made first landfall as a wave crest. The waves off Thailand travelled obliquely along the coast from south to north, hitting the Phuket coast almost 25 minutes before they arrived at localities in Phang-Nga province farther north.

In places the water level was between one and three storeys high. Wave heights at individual localities varied according to the near-shore bathymetry; the highest waves occurring where the bays had a broad, shallow sea floor or extensive reefs or rock platforms. The outrush as the inundating waters retreated produced as much devastation as the incoming wave, causing deep scouring of the coast and sucking survivors out to sea.

The main conclusion from these observations is that on a low-lying coast, over a distance inland of hundreds of metres to several kilometres, tsunami damage can be catastrophic. There are usually several waves—not just one—and this caught many unawares.

Modern engineered multi-storey structures will usually survive, although many engineered single-storey structures along the Thai coast were completely destroyed. Damage to non-structural elements, especially partition walls, cladding, roofing and coastal drainage and protection works, is extensive. Huge volumes of debris are created.

Mortality rates are high due to the momentum of flows, the over-pressures, impact of entrained debris and the duration of the inundation. Catastrophic damage and high mortality were characteristic impacts of the tsunami torrent in Thailand wherever the waters exceeded several metres depth.

No single measure can be expected to provide complete protection. Countervailing measures need to balance detection, warning, response, refuge and long-term planning for the siting of essential facilities. Saving lives is the key objective for future events and will be achieved principally by inland or vertical evacuation before a tsunami makes landfall. However, the required distance inland or above wave height will depend on the local geography and the depth of the torrent.

Uniform setback distances for development on a coast may be ineffectual because the momentum of a tsunami torrent causes damage for a considerable distance inland and especially at estuaries and along rivers.

New Zealand may never experience a tsunami event with consequences of such severity as the December 26 event, but the Thai experience indicates some shared vulnerabilities in coastal communities exposed to tsunami hazard including:

- extensive development close to beaches, on sand spits and narrow coastal corridors;
- no high ground for refuge in many of these areas
- foreshores modified for coastal development by removing trees, lowering dunes to enhance ocean views and hardened coastal defence structures which could exacerbate wave run-up.

Observations in Thailand suggest that green belts such as dunes, mangroves and dense coastal trees can significantly reduce the force of impact where tsunami water depths do not exceed a few metres.

Previous assessments of tsunami hazard in New Zealand were based on static inundation levels (elevation) only. They are likely to underestimate the risk close to the coast because they do not account for the potential momentum of the flows—neither do they account for the sheltering effect of buildings and vegetation. Furthermore, while many of the affected localities in Thailand were holiday resorts, in New Zealand most coastal towns support permanent settlement with integrated economic activities and services. A tsunami striking a populated coastal area in New Zealand could therefore overwhelm local response and recovery arrangements.

No changes to the New Zealand building codes are considered relevant for mitigating vulnerability to tsunami, but planning and emergency management requirements for low-lying areas should be reviewed, especially for essential facilities.

Better understanding of the unique nature of tsunami hazards and the types of vulnerability will be crucial to minimizing the effects of future tsunami. Preparedness factors include capacity for self-evacuation, knowledge of designated routes and alternative refuges, training for those responsible for visitors or dependants in vulnerable locations and where practicable, sufficient warning.

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