Assessment of
Banda Aceh, Sumatra, Indonesia
following the earthquake and
tsunami of 26th December 2004

For and on behalf of:-

Tsunami Safe Hills &
Other interested parties

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CONTENTS

1 Introduction

On Sunday 27th and Monday 28th February 2005, I, Mr Richard Feilds Bate, Chair of Tsunami Safe Hills travelled around Banda Aceh, Sumatra, Indonesia, a city extensively damaged by the 26th December 2004 tsunami[1]. My mother in law Threesnogindarty Usmin and my wife Rosa assisted me with the organisation and translation.

The survey work, discussions and eyewitness reports were arrange with the support of the Indonesian Ministry's Emergency Team in Banda Aceh. The Team also provided all accommodation and transport.

This report is to assist the development of sustainable infrastructure capable of withstanding any potential future tsunami, during the reconstruction of the city.

2 Chronology of Events

At 3.3 N 95.8 E (just north of Simeulue island, off the western coast of northern Sumatra, Indonesia ~ 300km south of Banda Aceh), 07:58:53 local time (00:58:53 GMT) on 26th December 2004 a series of earthquakes began. The estimated intensity of the earthquake was 9.0 (on the Richter Scale); this is thought to be the fourth or fifth largest earthquake since 1900, and by far the most destructive. Since information regarding precisely what happened and when is not available, some of the subsequent descriptions are approximate or based upon sources which cannot be confirmed.

An initial estimate of the size of the rupture that caused the earthquake is obtained from the length of the aftershock zone, the dimensions of historical earthquakes, and a study of the elastic waves generated by the earthquake. The aftershocks suggest that the earthquake rupture had a length of ~1200 km parallel to the Sunda trench and a width of over 100 km perpendicular to the earthquake source. Early estimates from the study of elastic waves show the majority of slip was concentrated in the southernmost 400 km of the rupture. The rupture started close to Aceh and progressed northwards towards the Andaman Islands. The seabed is thought to have altered by up to 15 meters in places, the alteration of the seabed caused the following tsunami.

The earthquake was at a depth of 30 km (18.6 miles) below mean sea level. This is at the extreme western end of the *Ring of Fire*, an earthquake belt that accounts for 81 percent of the world's largest earthquakes (USGS). The earthquake itself (apart from the tsunami) was felt as far away as Bangladesh, India, Malaysia, Myanmar, Thailand, Singapore and the Maldives.

The earthquake lasted for some 3 – 4 minutes at source, although the time varied at other locations. The energy released was approximately 2x10^18 Joules, or the equivalent of 23,000 Nagasaki atomic bombs. The tsunami energy was approximately 100 times less.

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[1] Tsunami is a Japanese word that means, "harbour wave". A tsunami is a wave train, or series of waves, generated in a body of water by an impulsive disturbance that displaces the water column.

Eyewitness reports indicate, in Banda Aceh, that the earthquake lasted ~10 minutes and that ~10 minutes following the earthquake the sea drained away from the coastline. After a further ~10 minutes the sea returned with the first tsunami. The depth and damage caused by the first tsunami cannot be precisely determined, however it is thought to be local and minimal. The first tsunami drained away into the sea after ~10 minutes more. Presumably whilst the first tsunami was draining into the sea, the second tsunami wave arrived taking ~30 minutes to achieve its maximum depth. The final water level of the tsunami may be approximated by subsequent level survey work; the final water level of the second tsunami is thought to be between 7 – 10 metres above mean sea level (depending upon location). It took approximately a further 120 minutes for the water to drain away into the sea.

During my survey, 9 weeks after the tsunami, it was noted that some areas still had standing saline water (lagoons), which had not drained into the sea.

From eyewitness reports there were two separate tsunami. Evidence suggests that the tsunami approached Banda Aceh from the northwest. The city is partially sheltered by a high ridge of land to the west of the city so that the full force of the tsunami was not felt. On the far western side of Banda Aceh (close to the high land) the water is estimated to have reached more than 13m (including run up effects). Some sources estimate the maximum water height adjacent to the epicentre of the earthquake (on the west coast of Sumatra) as 40m (possibly including run up effects).

Other eyewitness reports indicate that in Banda Aceh, the sea withdrew from the land up to 1.5km from the established coastline. This caused interest among some young residents (and others) who noticed a large amount of fish trapped on the seabed. Unfortunately the people attempting to catch the fish were unable to flee the ensuing tsunami. However, reports from other areas indicated that locals were aware of tsunami from traditional folklore. The folklore (among other things) told the story of the importance of evacuation to high ground following a rapid and unusual lowering of the sea level, casualties were reported less in such areas.

The formal emergency response rapidly followed the tsunami event, by the Indonesian Government, who managed relief via the Ministry of Settlement and Regional Infrastructure and other departments. Large-scale international and charitable assistance has also supported the Indonesian efforts. The emergency response is being superseded on the 7th March 2005 by a reconstruction effort.

The response has several features:-

- Attending urgent medical needs such as injuries.
- Locating and burying the deceased.
- Providing food, water and shelter.
- Providing semi-permanent accommodation with supporting infrastructure.
- Providing sustainable long term planned solutions, which reflect the local and environmental needs, and any potential earthquake or tsunami.

A *Draft Master Plan*, has been designed by the National Development Planning Board (Bappenas) in early March 2005, for the reconstruction of the city. Public input has been invited by 25th March 2005, and it is hoped that some of the comments raised in this report are included in the *Final Master Plan*. In particular the development of *Tsunami Safe Hills* (analogous to the Escape Hill System) at key locations.

3 Site Field Survey

My initial survey commenced shortly after arrival at the Banda Udara Sultan Iskandarmuda Airport; although a selection of aerial photographs were also taken prior to landing.

Most photographs were taken on the afternoon of Sunday 27th February 2005.

Weather conditions were dry, warm and sunny, with ~1/8 cloud cover. No precipitation had been recorded for two weeks. There was a significant amount of airborne dust encountered during the visit this reduced general visibility.

During the survey the various structures and features were indicated to me, by the Indonesian Ministry's Emergency Team, in Banda Aceh, who accompanied me.

Following survey work I was invited to share my thoughts regarding the appropriate use of *Tsunami Safe Hills* and other features in the form of a discussion with Bapak Hari, Bapak Kris and Bapak Toto of the Indonesian Ministry's Emergency Team.

4 Early Warning

No evidence of early warning systems was discovered. Eyewitness and secondary sources indicate that a variety of responses occurred, although very few people realised in Banda Aceh that a large tsunami had occurred until after the inundation.

It is recommended that an adequate early warning system be incorporated in any final planning scheme, which clearly alerts people at risk, and is integrated with other infrastructure developments. Education at primary and secondary school level should form an important role in explaining some of the prerequisite features of tsunami.

5 Earthquake Damage

The earthquake conspicuously damaged a number of buildings in the city of Banda Aceh, possibly up to 10% of buildings suffered extensive damage. Due to the subsequent tsunami it is not possible to determine precisely the quantity of damaged buildings alone, since the tsunami also caused extensive damage. Damage varied from notional cracking, to failure of sections of buildings, to complete destruction. Some collapsed buildings were suspected to still contain victims.

Owing to the scale of devastation some of the buildings I saw were still structurally unstable and either partial or complete demolition is recommended. In view of the seismic activity of the area this work should be completed as soon as practically possible.

The earthquake has caused some local changes in ground level; some reports indicate that the level may have changed by up to 2m. It is unclear whether the subsidence resulted in general lowering, rising or both. Further investigations should try to establish the new topography this could involve Lidar Radar mapping.

Shopping Mall extensively damaged Banda Aceh **©Richard Bate2005**

6 Tsunami Damage

The damage caused by the tsunami is difficult to calculate precisely, although the destruction varies from slight water-debris damage to complete eradication (including the foundations) to buildings. The coastline has been radically altered in places by the tsunami, with beaches removed of material, and new features created by deposited material inland.

The Cost

In Sumatra alone ~200,000 people died with 400,000 to 700,000 displaced. Additional people are at risk from outbreaks of disease. Many of the survivors and external assistants are experiencing trauma. The precise extent of human losses and suffering cannot be determined.

Economic impacts result from loss of infrastructure, fishing interests, tourism and saline contamination of drinking water and farmland. The Indonesian Emergency support teams have met most essential needs, although key services – such as 24-hour water and electrical supply have yet to be comprehensively restored. A range of economic values have been suggested for the total cost, this report does not seek to comment upon total economic cost values.

Law enforcement appears to be applied in general, despite obvious difficulties; although reports of land parcel boundary and resource distribution disputes have been noted.

Deposited debris Banda Aceh **©Richard Bate2005**

Environmental damage included the complete removal of mangrove forest swamps in a number of areas. Other sources indicate that coral reefs and other sensitive ecosystems may have been permanently damaged.

Initially the tsunami flowed inland as the water level rose. The evidence from video footage appears mixed, some indicate that the rise in water level was not instantaneous, rather a gradual increase, possibly as high as 10cm per second, others show a breaking wave (almost vertical). In any event the water rapidly collected and contained material as it moved inland. The extent of debris contained within the water is noted from three separate sources:-

1. The primary video footage.
2. The removal of material (buildings, vegetation, etc).
3. The evidence of the debris after the water had receded.

The debris present in the water reduced the ability of people in the water to swim or attempt coordinated movements. The debris, which was deposited after the tsunami water subsided, also hindered the initial emergency response, as it blocked roads, covered bodies, prevented proper drainage and generally reduced movement. In addition removal of the debris also was an important component of daily activities in the beginning of the reconstruction period. Since debris may be deposited up to 1m deep in places, some of the debris may still contain human remains.

Some of the debris may be used (after an initial sorting) in creating *Tsunami Safe Hills* or other elevated structures designed to cope with potential tsunami affects.

Infrastructure damage

In general damage was most severe near the coast and low-level areas. Some damage occurred by the earthquake vibrations and the debris contained within the tsunami; most damage was caused by the tsunami seawater flow.

6.1 Roads

Most main roads have now been cleared of debris, so that most vehicles can travel without too much difficulty. Some minor roads have not been cleared of material and are not defined. Occasionally new tracks have been formed where appropriate. Some roads have been damaged or destroyed, particularly those sections near the most devastated areas of Banda Aceh.

In order for a suitable response to future tsunami all roads should permit freedom of movement, so that evacuations may be carried out as efficiently as possible.

Road and flood barrier damaged Banda Aceh **©Richard Bate2005**

6.2 Bridges

Most main roads have connecting bridges over land drainage channels. These bridges are higher than adjacent areas, some offered refuge areas to people nearby. Some bridges suffered some cracking and widening over the expansion joints. Occasional bridge sections were destroyed, although most were able to withstand the tsunami.

Bridges structures were able to withstand the combined earthquake and tsunami affects most effectively. Most bridge abutments have been able to withstand tsunami scour, whilst easily coping with the earthquake vibrations. The bridges themselves have been able to move slightly during the earthquake (with minor widening of expansion joints) while permitting the flow of water either beneath or through the structure proper although some bridge decks failed, probably as a result of debris causing displacement by hydraulic forces.

Bridge Banda Aceh **©Richard Bate2005**

Any future development of bridge structures should reflect their inherent ability to function either during or after the tsunami event. Preferably all new bridges should be constructed above the height of the tsunami water level, so that they may also serve as emergency safe areas during a future tsunami.

<u>6.3 Buildings</u>

Almost all buildings adjacent to the coastal zone (within 1km) were destroyed above foundation level. Some locations indicated that even foundations and floor slabs had been removed. Approximately 90% of buildings within 3km of the coastline were destroyed, assuming that the coastline is 10km long – this equates to a comprehensive destruction area of $30km^2$. A similar area between this and the rear higher grounds was also directly inundated with the tsunami, although damage to buildings was more mixed, with partial failures and debris impacts becoming more common.

There appeared to be two types of buildings, which were able to withstand the tsunami relatively successfully, mosques and open low-level column supported buildings. A comprehensive description of why the various buildings did not catastrophically fail is not included here, although a general discussion is included.

Mosques were the buildings, which performed the best under the extreme conditions. Earthquake damage appears to minimal, and the tsunami water appears to have either passed around the mosques or through open areas internally. The reasons for the success are complex, but probably include; a high quality construction, thick walls, strong smooth columns, raised ground and open areas immediately adjacent.
Other buildings were also partially successful under the extreme conditions tended to be two (or more) storey buildings, on raised ground, of high quality construction, strong and smooth with open areas immediately adjacent.

In general successful buildings were able to cope with the violent earthquake and the complex hydraulic forces. Future designs and constructions should reflect both these features.

6.4 Flood Prevention Structures

The height of flood barriers (walls and embankments) was in general, significantly exceeded by the tsunami. Only a small number of flood prevention structures were studied. However, floodwalls of reinforced concrete were noted to have been partially successful in withstanding the earthquake and tsunami. Earth embankment structures were less successful and most were observed to have been obliterated beyond recognition.

Land drainage channels were noted to be filled with large quantities of debris, during the survey most drainage channels were not performing as intended, instead holding large quantities of water within the drainage channels and adjacent land areas. Most land drainage channels were not damaged by either the earthquake or the tsunami.

Pumping Station Banda Aceh **©Richard Bate2005**

A single pumping station was observed during the survey, which was extensively damaged. It is unlikely that the pumping station could be repaired. Gravity sluices gates performed better, some appearing in good order, with others clearly damaged.

Most drainage channels have been significantly altered in coastal areas. It is possible that some of the drainage characteristics have changed following the removal and deposition of sediments, combined with the ground subsidence.

Flood prevention mechanisms should be comprehensively assessed and reinstated prior to major reconstruction phases.

6.5 Coastal Structures

Some coastal structures (reinforced concrete seawalls, jetties, etc.) performed relatively well, suffering damage equivalent to a severe storm. Some sections experienced total failure with other observed sections having repairable damage. Only limited survey work was completed of coastal structures, and a comprehensive survey should be undertaken at the earliest opportunity.

Beaches, dunes, earth embankments and lagoons have been extensively changed, moved or destroyed. Some areas of land have disappeared completely. Very little fine material has been unaffected by the tsunami. Aerial photographs comparisons before and after indicate a general migration of the coastline in the landward direction, with lagoons extended or now part of the open sea.

It appeared that only a small number of seaworthy vessels were still available for daily use. Harbouring and port facilities appeared to be improvised from the remaining infrastructure.

A large number of sea vessels were carried inland by the tsunami. The extreme instance of this was the ship PLTD APUNG 1, a vessel ~20m wide, >40m long, 15m high, which was carried ~3km inland. The vessel is in substantially good condition, although several attempts to return the ship to the sea have been unsuccessful.

Coastal structures should be comprehensively assessed and reinstated where appropriate prior to major reconstruction phases.

6.6 Other Structures and Services

Other structures and services have been extensively disrupted, following a similar pattern to building structures. Approximately 90% of structures and services within 3km of the coastline were destroyed or rendered useless. A similar area between this and the rear higher grounds was also directly inundated with the tsunami, although damage was more mixed.

Electric and water supplies Banda Aceh **©Richard Bate2005**

Water supply has been contaminated, by seawater and debris, with some pipelines damaged. Therefore a significant portion of the city does not have a piped water supply. Mobile water tanker provided water supplies where appropriate.

Most electrical supplies are distributed from overhead power cables, with very few underground cables being used. A significant portion of the city does not possess any electrical supply, and night illumination levels are correspondingly low.

It is not known how the telephone network has been affected.

6.7 Mangrove Forests and Vegetation

Most of the mangrove forests observed were completely destroyed, with only occasional root structures remaining. It has been suggested that the presence of mangrove forests could potentially reduce the impact of tsunami. No evidence was observed that mangrove forests reduced or increased the impact of the tsunami.

The remains of mangrove forests Banda Aceh **©Richard Bate2005**

However, it would be prudent to permit the establishment of mangrove forests in low level areas, as the presence would prevent or reduce residential development, and enhance the local environmental features.

Most vegetation appeared unaffected by the earthquake. However the tsunami has caused land based plant life a variety of problems. Problems include:-

- Stripping of leaves and bark
- Removal of upper portions of trees
- Complete removal
- Poisoning from the salt water

Some limited plant growth was observed, and this is expected to accelerate once most of the seawater has been washed away by rainfall.

7 Conclusions

The earthquake and tsunami events of the 26th December 2004 have left an indelible scar upon the communities of the Indian Ocean. Significant international support and intervention have provided some semblance of normality to the affected areas; however key aspects of reconstruction will take many years to accomplish.

Whilst a general overview of events is available, precise details are still subject to change or amendment. Understanding definitively what happened should form a prerequisite to any strategic approaches to addressing the issues. Clearly the combination of the massive earthquake with the subsequent tsunami has resulted in widespread destruction. Any future developments should reflect the potential of the forces at play.

The city of Banda Aceh was actually sheltered from the epicentre of the earthquake, and could experience even larger tsunami in the future. The return period for the tsunami has not been calculated, although nothing similar in the Indian Ocean has occurred for at least 200 years.[2]

Emergency responses appear to have been completed relatively successfully, given the enormity of what happened. It is difficult to describe the extent of devastation, since little exists for comparison.

Immense amounts of material have been transported by the tsunami. This material is now being processed and transported in an orderly fashion. Some of the material is being recycled.

Reconstruction appears to arise from a variety of sources, including previous land occupiers (and their next of kin), local government, national government, non-governmental and international organisations.

City bridges are the structures, which have been able to withstand the combined earthquake and tsunami most effectively. All bridges seen showed little scour to the abutments, and aerial photographs show that failure only occurred on some span sections.

Mosques were the buildings, which performed the best under the extreme conditions. Earthquake damage appeared minimal, and the tsunami water appears to have either passed around the mosques or through open areas internally, causing only minor damage.

[2] The eruption of Krakatau in 1883 caused a tsunami between Java and Sumatra.

Buildings seemed to successfully survive by having a combination of the following properties:-

- high quality construction
- thick walls
- open low-level areas to allow water to pass through
- high or multi storey
- located on raised ground
- low resistance to water flow
- having open space around to allow debris to pass unhindered

The reasons for each individual structure's survival are thought to be complex, and may never be properly understood.

Drainage channels may have been significantly altered throughout the city. It is possible that some of the drainage characteristics have changed following the removal and deposition of sediments, combined with the ground subsidence.

The existing coastline is potentially unstable, since major changes in sediment depositions could take years for more stable beach equilibria to be achieved.

Water and electrical supplies, and telephone communications are under additional strain with important areas without constant resources.

Soil pollution from the salt water may take many years to fully recover. Large areas of mangrove forest have been destroyed or extensively damaged.

8 Recommendations

This report is to assist the development of sustainable infrastructure capable of withstanding any potential future tsunami.

A *Draft Master Plan*, has been designed by the National Development Planning Board (Bappenas), for the reconstruction of the city. Public input has been invited by 25th March 2005.

The conclusions and recommendations of this report are presented as a public contribution to the *Draft Master Plan*. The key recommendations are as follows:-

1. An adequate early warning system is incorporated into any area where tsunami risk exists.
2. Adequate protection should be made available to people living in tsunami risk areas.
3. People living in tsunami risk areas should be aware of the alleviation measures available and the early warning system.

An element of the early warning system should be rooted in local knowledge. People in risk areas should be aware of how a tsunami can form, and what a tsunami does. Some of the peoples of Indonesia already have good traditional knowledge that identifies the key points of note. Measures should be taken for remembering what happened, and how people survived.

A variety of protection measures are potentially available, although cost plays an important limiting factor. Apart from *Tsunami Safe Hills* (see appendix A), an Escape Hill System, multi storey buildings should be built on stilts (with open low level areas) and embankments, have also been suggested. The *Draft Master Plan* attempts to locate key city features away from coastal and low-lying areas; this is a sensible approach, but may not be practical in all cases.

The *Tsunami Safe Hills* charity should be used where appropriate in the reconstruction of affected areas. The *Tsunami Safe Hills* concept may be used with other remedial works, to create the best environment for the people concerned.

Any major changes in topography either from subsidence (caused by the earthquake) or from erosion or deposition (caused by the tsunami) should be established as soon as possible.

In order for a suitable response to future tsunami all roads should permit freedom of movement, so that evacuations may be carried out as efficiently as possible should the need arise.

Any future development of bridge structures should reflect their inherent ability to function either during or after the tsunami event. Preferably all new bridges should be constructed above the height of the tsunami water level (~10m), so that they may also serve as emergency safe areas during a future tsunami.

In general, a number of buildings were able to cope with the violent earthquake and the complex hydraulic forces. Future designs and constructions should reflect both these features.

Flood prevention mechanisms and coastal structures should be comprehensively assessed and reinstated prior to major reconstruction phases.

It would be prudent to permit the establishment of mangrove forests in low level areas, as the presence would prevent or reduce residential development, and enhance the local environmental features and also to some degree, slow up and moderate future tsunami wave effects.

This document has been prepared by:-

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Signed…………………………………………………Dated:- 11th March 2005

with assistance from:-

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