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Tsunamis

Some pre-emptive disaster planning and management issues for consideration by the construction industry

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Abstract

Purpose – Tsunamis are a rare but devastating form of natural disaster that has been documented since early civilization. Throughout history, many major tsunamis have impacted on the world's coastlines, causing heavy loss of lives and damage to properties. While the Sumatran tsunami in December 2004 demonstrated the sheer scale of destruction, there remains little understanding of the implications such obliteration have for disaster planning and management in the construction industry. The purpose of this paper is to raise the awareness of these implications and address some of the pertinent issues.

Design/methodology/approach – The threat from tsunamis for an island state like Singapore cannot be ignored. A general study of tsunami dynamics is carried out and applied to model the worst scenario if tsunamis were to hit Singapore. Unique problems relating to such a scenario are subsequently highlighted to extrapolate an understanding of how the construction industry should now react even before the disaster strikes.

Findings – There appear to be some potential danger and immense uncertainties to the immediate coastline of Singapore in the event of a tsunami. Faced with these uncertainties, the local construction industry needs to recognise such challenges and develop appropriate policies and strategies way ahead to account for disaster planning and management.

Practical implications – While tsunami warning systems have been put in place, tsunamis cannot be stopped. The construction industry has a significant role to play in minimising destruction through appropriate building codes, materials, designs, enforcement and preventive maintenance of infrastructure.

Originality/value – The paper raises the issues of disaster planning and management caused by tsunamis and prompts the construction industry into taking appropriate and timely action to ward off what can be an extremely threatening event to both lives and properties.

Keywords Tidal waves, Earthquakes, Natural disasters, Contingency planning, Construction industry, Singapore

Paper type General review

Introduction

The massive undersea earthquake of Richter magnitude 9.0 near Aceh, West Sumatra, Indonesia on 26 December 2004 created a tsunami that caused nearly 200,000 deaths in about a dozen countries fringing the Indian Ocean – Indonesia, Thailand, Sri Lanka, India, Maldives, Bangladesh, Malaysia, Myanmar and Somalia. This was one of the worst disasters in recent history. Tsunamis can cause great destruction and loss of life within minutes on shores near their source, and some tsunamis can cause destruction within hours across an entire ocean basin (NOAA, 2005). Hence, it demands coastal countries, such as Singapore, to examine and evaluate the impacts of tsunamis and develop plans to mitigate and reduce any apparent hazards.

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Many existing publications are based on general disaster management strategies. Apart from the systems developed by the United Nations Human Settlement Programme (UN-Habitat, 2003) and the World Bank (2006), Stallen *et al.* (1994) and Trim (2004) have presented some practical issues pertaining to disaster management. In particular, Oloruntoba (2005) has specifically touched on tsunamis and the unique issues and challenges in the management of this form of catastrophe. Ofori (2002) has highlighted some important strategies to prepare the construction industry for disaster prevention and response.

The objective of this paper is to explore and describe the general characteristics of tsunami waves and, using Singapore as a hypothetical case, recommend a suitable tsunami disaster management plan for implementation by the construction industry. It is also to raise awareness among professionals in the construction industry that mitigating measures can be taken to pre-empt the destructive forces of tsunamis that may potentially occur in the future. The discussion on tsunami characteristics will require some description and elaboration on the general dynamics and concepts of waves. It will look into common causes of the origin, its propagation mechanisms along the water column and the effects of devastation as it moves inland. In particular, some risk prone locations will be identified.

The approach to tsunami management will be separated into two areas – post- and pre-tsunami. As part of the post-tsunami management plan, some general disaster management issues will be elaborated. Subsequently, some strategies for the local construction industry to mitigate tsunamis will be recommended.

Origin and causes of the great waves

Giant sea waves or tsunamis had repeatedly swept over coastal communities every few years without warning, causing countless deaths and immeasurable damages. From records of about 65 million years ago (the same time as the demise of the dinosaur species) to the recent South-Asia disaster, the effects of tsunamis are clearly demonstrated (see Plates 1 and 2).

Therefore, there is a pressing need to understand the geological processes behind this natural phenomenon to better predict the intensity of inundation and take preventive measures to mitigate the hazards caused by this ever-changing and

Source: Channel NewsAsia (2005)

Plate 1.
Flattened houses near Band Aceh

Plate 2.
Destruction by running tsunamis

Source: Singapore Red Cross Society (2005)

dynamic planet. With advances in science and engineering, such proliferation of knowledge is plausible. The word "tsunami" is derived from Japanese words "*tsu*" which means harbour and "*nami*" which means wave (IOC, 2005). Formed as a result of a large-scale disturbance of the water column, tsunami is a system of ocean gravity waves of extremely long wavelength and period (IOC, 2005, 1999).

Very often, people use seismic or tidal sea wave to illustrate "tsunami". This is incorrect because tsunamis are absolutely unrelated to astronomical tides and have different physical characteristics from the latter (IOC, 2005). Hence, the Japanese word "tsunami" has been internationally accepted to cover all forms of impulsive harbour wave generation.

Tsunamis are seismic sea waves that are generated by the sudden displacement of a large volume of water (Kusky, 2003). When the water is being displaced from its equilibrium position, waves will be formed as the water column attempts to regain its equilibrium under the influence of gravity (IOC, 1999). This violent and impulsive undersea disturbance is usually caused by earthquakes, occasionally by submarine landslides, infrequently by volcanic eruptions and rarely by large cosmic impacts in the ocean (IOC *et al.*, 2005). These forces will create energy through the waves to produce an extremely damaging effect along the shoreline. The origins and causes of tsunamis are discussed below.

Earthquake

Earthquakes have been, by far, the most prevalent form of tsunami generation mechanism (Kusky, 2003). These usually occur in regions where there is a high seismicity characterised by tectonic subduction along plate boundaries. As these plates collide, they tilt, offset or displace large areas of the sea floor and cause sudden displacements of the ocean water that produces tsunami waves. However, it should be noted that not all earthquakes generate tsunamis (Prager, 2000). According to IOC (2005), the earthquake should have a Richter magnitude exceeding 7.5 to produce a destructive tsunami. An increase in one unit of magnitude corresponds to a factor of ten increments in seismic wave amplitude and a 30-fold increase in released energy (IOC *et al.*, 2005).

Triggering a tsunami requires the vertical movement of up to several metres of the sea floor over a large area of up to 10,000 km^2 (IOC *et al.*, 2005). When the ocean floor lifts up or drops down, it pushes large volumes of water upward or downward, resulting in a wave motion that eventually becomes a tsunami. The focus in the earth where the rupture occurs has to be shallow (less than 70 km below the earth's surface) and located underneath or near the ocean (IOC *et al.*, 2005). It is only shallow offshore earthquakes that can cause enough deformation to generate tsunamis over the water column above it. Nonetheless, sufficiently strong inland earthquakes can also produce the same effects in the sea nearby (Prager, 2000). Hence, in order for an earthquake-induced tsunami to be generated, the fault has to lie within a certain depth below the sea and create a vertical displacement over a large region. The Sumatran earthquake on 26 December 2005 is a typical example of such tsunami generation mechanism.

Landslide

Displacement of water caused by sudden submarine landslides or slumps that fall from great heights into the sea can generate tsunamis (IOC, 2005). Since these are usually bulky materials such as sedimentation from eroding rivers and glacier or avalanche formed from rocks or ice falls, they are able to produce a significant impact on the surrounding water column. Usually, landslides are triggered as a consequence of land mass being disturbed. Based on records, the most common factors include earthquakes, storms and human activities such as construction works. The occurrences of such events have shown to cause instability and abrupt failure of the slopes, leading to the eventual collapse of large amounts of sediments.

However, landslides can also happen without any stimulation (Kusky, 2003). When sediments rest unstably on slopes that are over-steepened, there is a high probability of them falling and sliding downhill. Also, porous sediments that are saturated with water may give way under their own weight. Recent evidence suggests that almost one-third of tsunamis in the 1990s were generated by quake-induced landslides (Prager, 2000). A falling rock in Lituya Bay, Alaska on 9 July 1958 caused one of the largest tsunami that reached 520 m high on the island. Thus, we should not underestimate the role of landslides in tsunami generation.

Volcanic eruption

Tsunamis can also be generated by volcanic eruptions offshore (IOC, 2005). Violent eruption can create impulsive disturbances which displace a large volume of water in the immediate vicinity. Based on information from ITIC, this mechanism can trigger tsunamis in three ways. The first method is cause by submarine eruptions underneath the sea. As these volcanoes erupt, they displace massive amounts of water above it with an explosive force (Kusky, 2003). The energy that is released by the volcano will be transmitted to the water, producing a series of waves that eventually become a tsunami. Likewise, volcanic eruption above the sea level will produce pyroclastic or lava ejections from the summit of the volcano. As these ash and debris flow down the volcanic slopes and plunge into the sea under gravity, they spread out rapidly and can create enormous energy that generates huge waves into massive tsunami (Bryant, 2001).

The last and most destructive cause is a consequence of the collapse of offshore volcanic slopes. After numerous large explosions, the magmatic chamber becomes partially vacated and leads to the collapse of the unsupported volcanic slopes into the empty hole underneath (George, 2005). This falling back of the eruption column beneath the sea displaces large amounts of water and generates a tsunami. In short, a tsunami is usually produced as a result from a combination of submarine eruptions, flow of pyroclastic materials and collapse of volcanoes. One of the largest tsunami was generated from the eruption of Krakatoa, Indonesia on 26 August 1883 where the joint effects of the explosion and collapse of the volcano killed 36,417 people along the Sunda Strait in both the islands of Java and Sumatra (George, 2005).

Asteroid or meteorite impact

The discovery of huge submarine impact craters has offered some form of evidence suggesting that large asteroids or meteorites have hit the Earth's surface in the past (IOC, 2005). Since four-fifths of our planet is covered with water, the potential of them falling in the oceans and seas are high. Recent studies by scientists have indicated that the impact of a moderately large asteroid, 5-6 km in diameter, in the middle of the large ocean basin will generate a tsunami of cataclysmic proportions (IOC, 2005). In particular, they have found evidence of a devastating tsunami generated by an enormous asteroid/meteorite impact in the Gulf of Mexico about 65 million years ago that may have led to the extinction of the world's dinosaurs (Prager, 2000).

Fortunately, the occurrence of such an asteroid or meteorite impact is very rare since most will have been burnt down as they pass through the Earth's atmosphere (IOC, 2005). Yet, the risks of such random asteroid or meteorite impacts are still present and will continue to pose a threat to the present-day civilization.

Movements of tsunamis

Once tsunamis have been generated by any of the mechanisms illustrated above, they start to travel outwards in all directions from the origin as a series of waves. As they propagate towards any land mass, they are characterised by various unique features that are substantially different in the deep ocean and along the shoreline.

Deep ocean

Unlike ordinary wind-driven ocean waves, tsunami behaves as shallow-water waves with long wavelengths (DESS, 2005). Hence, the depth of water (i.e. height of water level from ocean floor) is less than half the wavelength (i.e. distances between successive wave crests). In general, the wavelength of a tsunami can be as much as 200 km or longer while ocean depth averages about 4 km only (IOC, 2005). With the prevalence of such long wavelengths, there is a subsequent lag time between individual wave crests. Thus, the period (i.e. time between the passages of successive wave crests) of tsunami waves can be as long as 100-2,000 seconds (Bryant, 2001). As a result, many people have perished because they did not foresee the arrival of subsequent waves many minutes and indeed hours later.

As a guide, tsunami waves travel at an average speed of 200 $\mathrm{ms^{-1}}$ in the Pacific Ocean where the typical water depth is about 4 km (IOC, 2005). The recent Sumatra earthquake has shown us that tsunami waves can travel through the Indian Ocean from the west coast of Sumatra to the east coast of Africa in just seven hours! Tsunamis can travel at high speeds for long periods of time due to the extensive energy carried throughout the water column from the ocean surface to the seabed (IOC *et al.*, 2005). In fact, the wave loses energy at a rate inversely proportional to its wavelength (Prager, 2000). Hence, large amounts of energy are carried by the sea from the source area toward the shore because there is a very minimal energy loss in the process. Most tsunami waves travel in the deep ocean with an amplitude (i.e. half the height from trough to crest) of less than 1 m (Kusky, 2003). With this gentle rise and fall of the sea surface, it makes detection difficult except with the aid of sophisticated equipment (IOC *et al.*, 2005). Hence, many people out at sea do not see or feel the passage of the killer waves underneath them.

Shore and coast

When tsunami waves from deep ocean enter the shallower coast, bay or harbour, friction from the shallower sea bed causes their speed to reduce dramatically to about 50-60 km/h (IOC, 2005). As later wave trains continue to travel in deep water towards the same shore at high velocities, it results in a rapid compression of waves near the shoreline (IOC, 2005). As the energy is directed upwards, the water columns start to bunch and pile up on themselves (Kusky, 2003). Once a tsunami reaches dry land, the wavelength is significantly reduced to not less than 10 km and the wave may reach more than 30 m tall (IOC, 2005).

Effects of destruction

Once this wall of water is smashed onto the built-up areas inland, the energy being released can result in a potentially destructive impact on life and property. In addition to such destruction caused by the in-coming flood or tide, their retreat from land also create serious erosion problems in the affected areas (Kusky, 2003). When tsunami waves run up onto land, the first group of fatalities arises from those people who are playing along the coast or shoreline. These fast moving waves will usually out-run and drown many people in their path. Also, they can sweep individuals away from buildings and even unleash whole villages with many people still residing within them. Despite the initial death toll, this strong hydrodynamic force will continue to erode and disintegrate most property, such as buildings, cars and infrastructure. Subsequently, this large amount of floating debris carried by the water will become even more dangerous projectiles that may create further damage inland (IOC, 2005).

Besides direct damage, secondary problems can result from fires and pollution following the initial destruction. Ruptured fuel facilities, wrecked ships or damaged cables may result in fires, leading to injuries; damaged piping may bring about sewerage and chemical pollution that promotes the spread of diseases (IOC, 2005). Finally when the flood water recedes, it carries most displaced debris (people and properties) on its path back to the ocean. This enormous erosion by the withdrawing waters will not only displace the populace, but also permanently alter various natural and developed features of the land mass (Wong, 2005). In a nutshell, all these effects of destruction can be quantitatively described by two types of measurements – inundation and run-up (IOC *et al.*, 2005).

Run-up elevation

Run-up is defined as the maximum vertical height above mean sea level at the farthest point on the shore that the sea surface attains during a tsunami (IOC *et al.*, 2005; Kusky, 2003). Due to its correlation with the tsunami intensity, it has been frequently used to describe the tsunami magnitude along a particular coastline. As most dwellings are situated on low-lying coastal areas, any tsunami run-up over 1 m can be dangerous (IOC, 2005). For example, the December 2004 tsunami generated a run-up of nearly 34 m in local Sumatra Island, killing almost 170,000 people and sustaining an estimated US$4.5 billion worth of damages (UN Special Envoy, 2005). Basically, the height of run-up is affected by numerous factors (Kusky, 2003). It will depend on energy and travel direction of the wave, coastal configuration (e.g. shape of the shoreline) and offshore topography (e.g. depth of the seabed). Typically, steep-sided islands with fringing or barrier reefs are better protected from tsunami inundations.

Inundation distance

Inundation, also known as inland penetration, is defined as the maximum horizontal distance that tsunami run-up can penetrate inland (IOC *et al.*, 2005; Bryant, 2001). As a general rule, the extent of inundation is an indication of the volume of water carried onshore and the extent of damage along the coastline. In reality, tsunamis may penetrate inland by as much as 300 m or more, flooding many areas with water and debris (IOC *et al.*, 2005). The area of damage can be easily mapped from satellite images that clearly show the location of sediment deposits and dead vegetation. The flow direction can also be determined from the items broken and bent by the waves (Wong, 2005). However, the inundation distances are not similar throughout the shoreline and are dependent on the elevations and terrain of the land, wave intensity and undersea features. In general, lower ground experiences relatively more flooding but such penetrations can be reduced by developing closely spaced structures or planting dense stands of trees.

Locations at risk

Looking at past records, it has been universally recognised that the probability of tsunami inundation becomes higher when the shoreline is situated near the tsunami source. In fact, cities that are located along fault zones associated with converging or diverging plate boundaries are highly prone to tsunami attack, for example, the so-called Pacific Ring of Fire. From these observations, tsunamis are probably the greatest threat to every developed or developing coastal city. With most cities being located close to the coastline and an increasing number of city dwellers, the risks cannot be ignored. Imagine the death tolls and economic impact if a tsunami were to strike cities such as Tokyo, New York or Bombay with populations of over 15 million people!

Nevertheless, not all locations along the coast may be afflicted with the same extent of destruction even though they are of the same distance from the tsunami source. These can be attributed to the difference in topography or coastal configurations of individual shorelines. They have been classified into nine types (Bryant, 2001):

1. Exposed open beaches without any protection from sea-walls or reefs are more easily inundated.
2. Smooth cleared land with low friction allows waves to penetrate further inland. This can be minimised with a densely treed landscape or close-proximity development.

(3) River deltas characterised by steep bathymetry and modest sedimentations permit the waves to cover long distances inland.

(4) Resonance of waves within harbours and bays can excite and amplify the water against infrastructure built along the shoreline.

(5) Rivers provide a path for tsunami waves to travel upstream. When these rivers turn shallow or narrow, a typical tsunami inundation is imminent.

(6) Headlands are susceptible to high waves due to the convergence of wave energy through extensive refraction.

(7) Gullies may funnel the tsunami energy further inland and transform the water into hazardous waves.

(8) Cliffs and steep slopes are not efficient in deterring tsunamis from surging inland as their heights are so minuscule in comparison with the long wavelengths of the waves.

(9) Lee sides of islands are more vulnerable because tsunami waves flow around natural barriers and flood the areas behind them (Bryant, 2001).

Hypothetical case of Singapore

Singapore is a nation state that comprises one main island and some 63 offshore islands (Singapore Department of Statistics, 2005). Of the 699 km^2 that make up the total land area, about 620 km^2 are within the main island of Singapore where almost 4.24 million people reside. With the exception of Pulau Tekong and Pulau Ubin (the two largest outlying islands), the rest of the offshore islands are mainly found along the south-western strait (see Figure 1). The country is located near the equator between latitudes 1° 09′ N to 1° 29′ N and longitudes 103° 36′ E to 104° 25′ E (Singapore Department of Statistics, 2005). As shown in Figure 2, Singapore has a peculiar geographical location surrounded by Peninsular Malaysia in the north and the Indonesian archipelago on the sides (Sumatra in the west, Java in the south and Borneo in the east).

Based on the plate tectonic theory, Singapore is situated in a low seismicity region of the smaller Sunda plate within the larger Eurasian plate. The Eurasian plate borders with the Indo-Australian plate on the western side of Sumatra and continue beneath Java to reach the Philippine plate on the eastern side of the Phippline Islands. Although the plate boundaries do not cross Singapore, the nearest fault and trench are located more than 350 km away at the west coast of Sumatra across the Straits of Malacca (Pan *et al.*, 2005). Generally, most people perceive Singapore as a geologically safe country because of the distant plate boundaries and the shelter provided by the surrounding land masses. Even the perceptibly pro-active Government of Singapore has reiterated that the risks of Singapore being affected directly from any regional tsunamigenic events would be very low (MSD, 2005). Despite the assurance from the government of Singapore, people cannot ignore the possibility of a local tsunami inundation. This is especially relevant as Singapore is just a small island completely enclosed by the sea situated in the Pacific Ring of Fire. Hence, there is a need to recognise the major historic events for better tsunami prediction.

History of regional tsunamis

Although MSD (2005) has no record of any tidal-surges affecting Singapore, the NOAA (2003) does provide data on historical tsunamigenic events and run-ups everywhere in

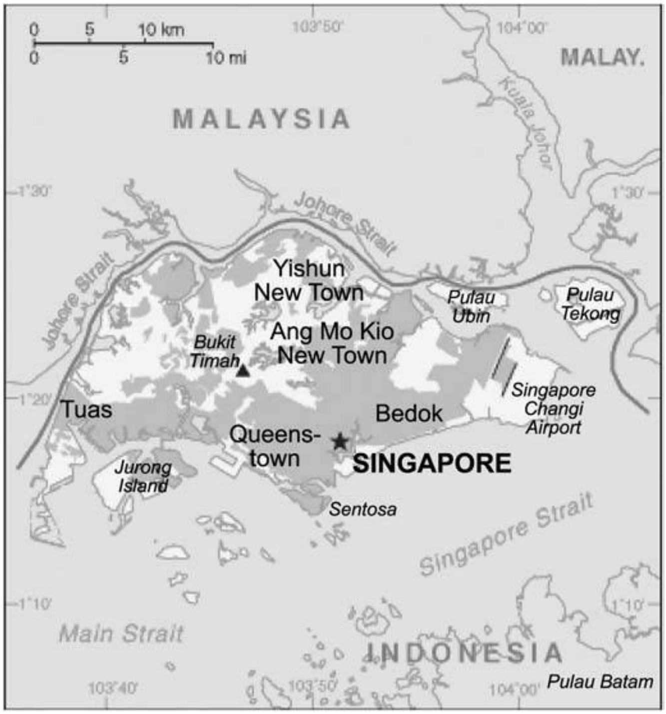
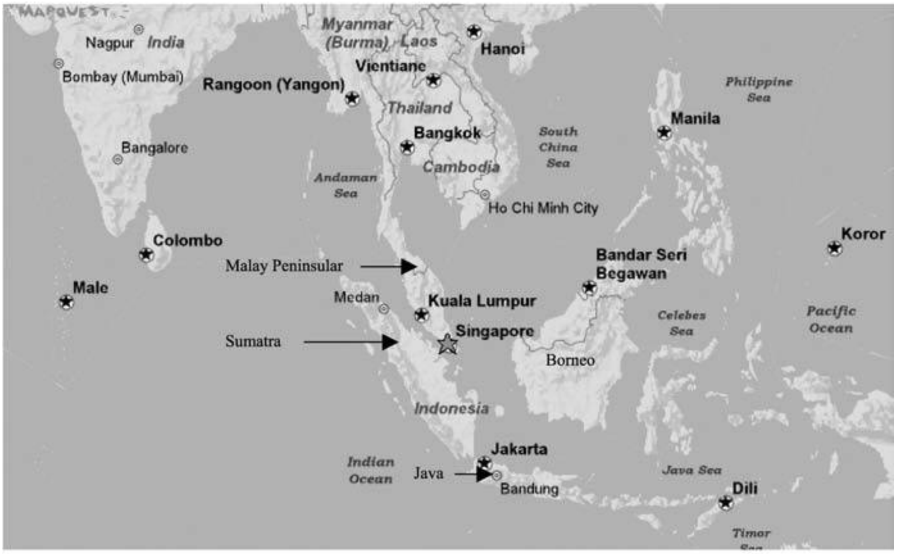


Figure 1.
Map of Singapore

Source: Central Intelligence Agency (2005)

the world. In order to look into the effects on Singapore, it is important to analyse the trends and patterns from the Indonesian region. Through an analysis of the database, there are a total of 269 tsunami events and 675 tsunami run-ups recorded in this region from 416 to 2005AD. By reference to these historical data, a big earthquake and tsunami will occur in either 50-, 80- or 100-year cycles (Raymondjose, 2005). For instance, the last major tsunami before the 26 December 2004 disaster happened 122 years ago with the volcanic eruption of Krakatoa.

Interestingly, the database shows records of one tsunami event and two tsunami run-ups in Singapore. The tsunami event is due to an earthquake in "Malaysia: Singapore" (1.2° N 103.5° E) on 26 August 1883 that resulted in 36,000 deaths. Likewise, the two separate tsunami run-ups are caused by a magnitude 7.2 volcano-earthquake at "Indonesia: Banda Aceh" (5.5° N 96.0° E) on September 1837 and a magnitude 7.5 earthquake at "Malaysia: Malay Peninsula" (2.5° N 99.5° E) on 17 May 1892. The existence of such data would appear to show the presence of a significant threat in Singapore and a need for further studies on the probability of such a catastrophe. According to historical trends, there exists a high possibility that another great tsunami, equivalent to or larger than the Sumatran tsunami on 26 December 2004, might just hit the region unexpectedly in the future. Regardless of whether the disaster reaches Singapore, it is of paramount importance to recognise the potential tsunami risks in this part of the world.



Source: Adapted from MapQuest (2005)

Figure 2.
Map of the region around Singapore

Lisitsyn (1988) mentioned that up to 76 per cent of the total bulk of sediments delivered to the ocean is accumulated at the equatorial humid zone. In the Indian Ocean, sediments from the Indian rivers of Ganges and Brahmaputra are transported from the Tibet mountain area to the Java trench at the western part of the Indonesian region. This higher sedimentation rate will have a considerable effect towards an impending regional landslide and tsunami.

Besides landslides, earthquakes also contribute actively to tsunami generation. According to Gusiakov (2005), the ratio between the number of tsunamis and the total number of earthquakes with magnitude greater than 7.0 and depth less than 100 km is termed tsunami efficiency. From 1901 to 2000, the tsunami efficiency of the Indonesian region is 79 per cent, which is much higher than the average value of 57 per cent for the whole Pacific. It would appear that with three major historic earthquakes in the Sumatran island, another potential earthquake is highly probable and with a 79 per cent chance of generating a tsunami.

Based on such historical seismological data, Dr Smith Dharmasaroja, a Thailand meteorologist, believed that the epicentre of future earthquakes will shift northwards from Sumatra to the Andaman and Nicobar Islands. If a tsunami is generated, it can move downwards through the narrow and shallow Straits of Malacca, swamping Malaysia and Singapore (Ghosh, 2005). According to Professor James R. Rice, a seismological expert, this risk might become even greater during periods of high tides and monsoon winds (Lin, 2006).

Effect of local topography and coastal landscape

As these waves travel through the Straits of Malacca, they are likely to flow past Malay Peninsular and create destruction on the lee sides of the island. With a relatively low-lying and flat terrain, especially some areas barely above the high-tide level, it is not realistic to expect Singapore to be completely safe from tsunami. Nevertheless, the northern part of Singapore is adequately sheltered by the Malay Peninsular and any tsunami inundation will most likely affect the southern shoreline only. The southern shoreline of Singapore can be basically separated into East and West Coasts. West Coast is largely sheltered from inundation by the offshore islands, such as Jurong Island and Sentosa; East Coast is protected by the treed landscape of the East Coast Park. However, East Coast has a higher risk of inundation because the buffer zone provided by the park is so minuscule in comparison with the larger offshore islands of the West Coast (see Figure 3).

In the middle of East and West Coasts lies the Marina Bay of the Singapore River. There are two problems with Marina Bay. First, the waves within the semi-enclosed bay might undergo resonant amplification against Raffles Place which is built along the coastline. Second, the waves can travel up the river and intensify where the passage shallows or narrows. The latter effect might also be observed in the Straits of Malacca. Being situated in an open coastal area that is relatively unsheltered, the south-eastern shoreline of Singapore is fairly vulnerable to tsunami inundation. In order to understand the impact of tsunami along this area, three essential features of the waves – speed, run-up and inundation – need to be considered.

The south-eastern part of Singapore is primarily a residential area built on reclaimed land (URA, 2003). As a framework to initiate the study on the built environment, this section will merely analyze the distance and elevations of the developments along a segment of East Coast between the shopping mall of Parkway Parade and Victoria Junior College (see Figure 4).

The discussion will start from the beachfront to (Upper) East Coast Road at almost 1,000 m inland. The elevation of the area and the buildings were studied through topographical maps published by the Mapping Unit (1995) of the Ministry of Defence

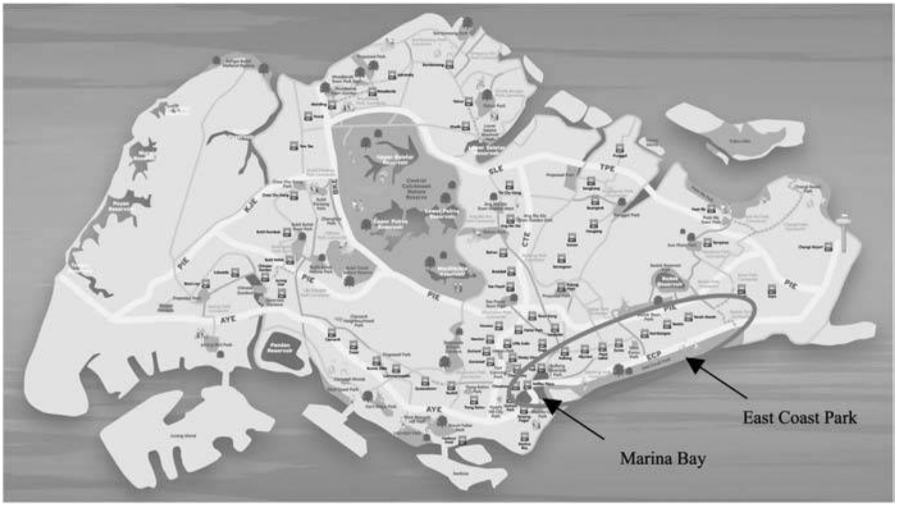


Figure 3.
Parks and gardens in Singapore

Source: Adapted from National Parks Board, Singapore (2005)

Source: Adapted from Google (2005)

Figure 4.
Aerial view of Marine Parade

and planning maps from the Survey Department (2001), Ministry of Law. The immediate shoreline comprises the East Coast Park at some 2 m above the mean sea level, stretching over 20 km from Marina East to Tanah Merah on a land area of 186 ha. It is a man-made beach that offers a wide range of facilities from bowling alleys, golf range and holiday chalets to restaurants and hawker centres. However, most of the buildings in this zone are relatively low and will not be able to withstand any tsunami run-up of more than 32 m. At about 300 m to 600 m from the beach, separated by the East Coast parkway (an expressway), the land is at a height of between 2 m and 3 m above the mean sea level. Besides high-rise housing characterised by the Housing and Development Board estates and private condominiums, this region also houses the Marine Parade town centre. Assuming the level of each storey to be 3 m, the units must be above the eleventh storey to be absolutely safe from a 32 m high tsunami.

From about 600 m to 1,000 m inland, the area is made up of low-rise developments that consist of shop-houses along Upper East Coast Road and high-class bungalows, terrace and semi-detached houses in Telok Kurau. Although tsunamis are unlikely to reach almost 1,000 m inland, these low-rise developments may still be vulnerable to tsunami inundation because the height of the land is just a mere 3 m to 4 m above the mean sea level. Therefore, Marine Parade appears to be at a high risk of tsunami obliteration due to its predominantly residential characteristics – many people might be displaced or killed in the event of such a disaster. Furthermore, this place also poses serious problems in disaster management and rescue operation because most of the developments, such as those along the shoreline and those located further inland, are considered low-rise.

Operational readiness

While the pro-active Government of Singapore has repeatedly assured the public that Singapore has an extremely low risk of being directly affected by tsunamis, there remains a need for a comprehensive tsunami warning and evacuation system that is able to put into operation as and when required. The relevant authorities in Singapore believed that tsunamis have an extremely low probability of hitting Singapore. Nevertheless, it was understood that an initiative to simulate possible tsunami obliteration locally was underway. This includes studying the likelihood of an inundation using models and worst case scenarios and developing a monitoring and early warning system for the region. Apart from the important roles played by the Ministry of Home Affairs and the Meteorological Services Division, it would appear that the best action plan in the event of a tsunami will be through the implementation of the civil emergency operation plan by the Singapore Civil Defence Force (2002) for accidents such as fire, building or infrastructure collapse.

Disaster management and the construction industry

Regardless of the type of catastrophe, the general disaster management strategies are often classified into four main phases – emergency, relief, recovery and reconstruction (Tan, 2005). Emergency operation takes place almost immediately following the disaster where search and rescue are initiated to save and protect lives. This is continued with the relief work to provide the displaced people with food, shelter and medical assistance. The commencement of the recovery phase begins with the restoration of essential infrastructural services and rehabilitation to assist the victims in returning to their pre-disaster livelihood. Finally, long-term reconstruction measures aim to develop buildings and infrastructures that have been destroyed in the disaster.

Given the enormous amount of effort needed in the various stages of disaster management, it requires a holistic response from many different fields and varied disciplines. For the construction industry, these include professionals, practitioners and volunteers from international institutions, voluntary welfare organisations (VWOs) or non-governmental organisations (NGOs) that specialise in building, civil engineering, architecture, urban planning and environmental studies. With the rapid socio-economic progress resulting in massive globalisation, settlements are being more inter-connected and reliant on each other (Ofori, 2002). Consequently, the ever-extending distribution networks of resources such as utilities and food supplies are becoming more vulnerable to disruption when one area is affected by any disaster.

The 2004 Sumatran Earthquake and Tsunami is a typical example of a disaster that led to the destruction of 141,000 houses, 2,240 educational facilities and 592 health centres in Aceh/Nias within Sumatra (UN Special Envoy, 2005). According to the World Bank (2006), between 80,000 to 110,000 houses, 335 new schools and 89 health centres are needed to be rehabilitated or rebuilt in this area to return the people to their normal livelihoods. Despite records showing Singapore being struck by tsunamis in the nineteenth century, there was never any tsunami being documented in modern-day Singapore. Hence, instead of focusing on recovery and reconstruction efforts, the construction industry must set their sights towards improving local mitigation and preparedness level. By doing so, Singapore will be better positioned to respond to a tsunami if and when it happens.

In order to be tsunami ready, it is necessary for the local construction industry to appreciate the importance of the building delivery process and its life cycle from planning, design, construction to operation and maintenance. At each stage, a deliberate, planned, strategic and systematic process must be established to improve the capacity and capability of the industry to respond effectively to disasters (Ofori, 2002). Although the current local framework has an elaborate process of checks and balances, there are still many opportunities to develop the construction industry further with regards to disaster management. Table I shows how a pre-emptive industry can respond efficiently and effectively in dealing with tsunamis at various stages of the building delivery process and life cycle through the proposed mitigating measures. Yet, it is even more pertinent to develop the necessary proficiency and expertise in tsunami preparedness amongst the various industry players.

Appropriate business and operating environment

A conducive business and operating environment aids the adoption of a disaster management plan in the construction industry. Based on professional hazard and vulnerability assessments, the government can enact suitable laws, regulations and codes for planning, development and building control. These standards will establish a proper framework of documentation, procedures and practices to guide and facilitate the continuous development of the companies in the various aspects of tsunami management.

In Singapore, the Urban Redevelopment Authority (URA, 2004) and Building and Construction Authority (BCA, 2005) can give practical effect to the policies by supporting and enforcing the regulatory framework on disaster management in every development works (see Table I). The public sector can also take the lead to embrace this concept in their contract forms and project procedures. These strategies will help to set the stage for future industry-led developments to nurture the capability of the local players in this area.

Institutional, corporate and human resource development

Professional institutions and trade associations can help to promote tsunami awareness and develop a proper tsunami action protocol among developers, consultants, contractors and facility managers. In this regard, training programmes should be provided to future and current professionals of these organisations for them to upgrade their knowledge and skills in response to disasters which might happen anytime in the future. Not only can the educational institutions redevelop their curricula to include specialised disaster management modules, but the professional institutes can also mandate its members to take up disaster management courses as part of their continuous professional development scheme. This educational process will provide opportunities for the industry to upgrade their capacity and capability to undertake works that may require special precautionary measures.

Research and development (R&D)

The vulnerability of constructed facilities has long been considered a risk in every country. In fact, numerous historical tsunamigenic events have created extreme

Table I.
Mitigating measures for the construction industry

Stages	Administrative procedures	Special features of procedures	Potential mitigation measures against tsunamis
Planning	Urban Redevelopment Authority (URA) issues the "Development Planning Approval"	Applications to be made by qualified persons, i.e. registered architects and engineers Payment of development charges if the gross floor area exceeds the prescribed baseline	A higher gross plot ratio or storey height to permit safe evacuation above the maximum run-up height (especially for developments near the shore) A suitable buffer zone from the coastline to restrict developments along the inundation distance
Design	Building and Construction Authority (BCA) and other technical agencies including Fire Services Bureau and Ministry of the Environment issues the "Building Plan Approval"	Design should be done by qualified persons Accredited Checker must scrutinise submitted calculations and drawings of structural engineer	Improve the structural systems of buildings to resist the lateral forces and vertical loads of the incoming waves Examples include the use of transfer girders, braced frames, belt or outrigger trusses, shear walls and tubes
Construction	Building Control Act/Regulations and codes of practice specify detailed requirements for construction activities For public-sector buildings, contractor must be registered (i.e. satisfy personnel, financial and track record criteria) Qualified persons must supervise construction Workers on the plumbing and electrical installations must be licensed	Building activity can only begin after the issuance of a Building Permit. Construction site deemed as a factory for health and safety reasons Client must pay for full-time resident engineer or clerk of works on the site to act as client's representative Temporary Occupation Permit (TOP) is given after all the installations and systems are tested at completion Certificate of Statutory Completion must be granted. Requirements are even more stringent than those for TOP	Periodic inspections to ensure the contractors endorse tsunami mitigation measures in the construction process Organisations to incorporate tsunami mitigation systems for their buildings in their ISO 9000 and OHSAS 18001 standards Ensure building complies with the relevant standards of safety, amenities and matters of public policy with regards to tsunami before the issuance of TOP
Operations and maintenance	Building can only be utilised for the approved purposes	Annual certificate of inspection required for all buildings with lifts Five-yearly inspections of structural efficacy for commercial buildings; and ten-yearly inspections for residential buildings	Prepare a tsunami evacuation plan (*vis-à-vis* the current fire emergency plan) for the occupants and building management to follow in the event of a tsunami disaster Regular servicing and proper maintenance of coastal protection infrastructure

Source: Adapted from Ofori (2002)

devastation of the built environment in coastal communities. Ofori (2002) has attributed the cause to the following five distinct features of the constructed items and their associated vulnerabilities:

1. *Location specific and immobile* – items are exposed to disasters where they are located; they cannot be moved as a precaution.
2. *Highly expensive* – impossible to test the constructed facility by exposing it to the full force of a possible disaster. Thus, simulations and tests may not fully reflect the actual situation.
3. *Long development process* – planning, design and construction involve multiplicity of operations, with dispersed control.
4. *Durable* – durability is both a requirement and a feature. When the item is exposed to natural elements, wear and tear may weaken it.
5. *Usage* – items are occupied and utilised for livelihood. Thus, disasters affecting them can lead to loss of lives (Ofori, 2002).

Given the inherent weakness of the current constructed facilities, academia needs to embark on extensive R&D programmes to investigate the relationships between tsunamis and the built environment. Until there is more in-depth understanding of the impact of tsunamis, researchers will be ineffective in coming up with appropriate building designs and suitable materials that are both high-performing and tsunami-resistant.

Conclusion

At the local level, the problem with tsunamis is that most people never really experience these events. Consequently, they believe it is not going to happen and ignore the associated risks involved. However, such major natural catastrophes have occurred throughout the geological history and it is not going to stop happening just because of the advancement in scientific knowledge. It is not a question of if, but a question of when.

The dynamics of tsunamis from commencement to termination have been systematically discussed and explained. Basically, they can be caused by earthquakes, landslides, volcanic eruption and asteroid impacts. Once generated, they can travel at great velocities in a ripple effect to create much devastation on the shoreline. Often, this is measured by the run-up height and inundation distance. In fact, special features of the geographical landscape can either promote or dampen the effects of tsunamis. Based on the preliminary analysis of the historical data from NOAA's (2003) database and geographical data from local maps, there appears to remain some potential risks of tsunamis to Singapore. It would seem that Singapore is not absolutely safe from tsunami attacks and the effects can be beyond the imagination of the local populace.

Studies have shown that the post-disaster management process is often plagued with problems that have led to increased cost and delays. In order to bring about a more effective and efficient relief and reconstruction process, issues such as logistic and organisational coordination, strategies for cooperation, accountability and transparency and political and security issues have to be seriously considered at the outset. A tsunami management system is proposed at every stage of the building delivery process and life cycle to better prepare the nation against any tsunami disaster. Through integrated efforts by the government, corporate and academic institutions, the local construction industry can also improve its management capacity and capability to prepare for and mitigate the risks from tsunamis. There is certainly a role which the construction industry can play to pre-empt the destructive forces of tsunamis before they hit.

Finally, it is noteworthy that Chhibber and Parker (2006), both from the World Bank's Independent Evaluation Group, have argued that the ghastly impact on lives from natural phenomenon such as tsunamis could have been avoided if disaster risk had been an integral part of long-term development planning. In short, it is lamentable that disasters are predictable, but countries do not plan for them. The World Bank's duo opined that prevention is more cost-effective than response, and that poor construction quality is a major reason why so many people lost their lives when disasters strike in developing countries. This could be caused by lax building codes, weak enforcement of construction standards, and corrupt procurement practices. Upstream in the construction supply chain, better land use planning is important to ensure that people are not housed in risky areas. In arguing that building materials and design are closely related and small changes can either save thousands of lives or put many more at greater risks, Chhibber and Parker (2006) noted that it actually costs very little, an estimated 10 per cent increase, to make structures safer. Preventive maintenance of key protective infrastructure is also of critical importance for protection against future catastrophes, as vividly shown by the costly neglect of levees designed to protect the city of New Orleans when Hurricane Katrina struck the USA. Although studies have shown that $1 spent on prevention can save up to $40 of damage, Chhibber and Parker (2006) lamented that countries are still reluctant to invest in more risk management when funds might be diverted to meet other developmental needs. In their fitting conclusion, Chhibber and Parker (2006) warned that unless the world rigorously changes the way disaster risk is brought into developing thinking, mankind will remain in a vicious and expensive cycle of quick fixes, provoke donor fatigue and continue to jeopardise the lives of poor people in disaster hotspots!

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