4th International Conference on Building Resilience, Building Resilience 2014, 8-10 September 2014, Salford Quays, United kingdom

Post tsunami rehabilitation in the context of national initiatives Case Study-Port City of Galle Sri Lanka

Prof Samantha Hettiarachchi\textsuperscript{a} and Kushani De Silva\textsuperscript{b}

\textsuperscript{a,b}University of Moratuwa, Katubedda, 10400, Sri Lanka

Abstract

The paper describes the investigative studies conducted for the post tsunami rehabilitation and conservation for the port city of Galle in Sri Lanka. The said studies include, field investigations on the impact of inundation, mathematical modeling of scenarios, assessment of vulnerability and preparedness and the development of mitigation measures, in particular integrating hazard mitigation and breakwater construction for ports.

© 2014 Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

Selection and/or peer-reviewed under responsibility of the Centre for Disaster Resilience, School of the Built Environment, University of Salford.

Keywords: Tsunami Risk Assessment and management; Scenario Modelling; Tsunami Breakwaters

1. Introduction

The Sri Lankan coastline was devastated by the Indian Ocean Tsunami of December 2004, which was caused by a massive submarine earthquake west of northern Sumatra, measuring 9 on the Richter Scale and a fault length exceeding 1000 km. The entire coastline with the exception of parts of the north-western coastline was severely affected.

Post-disaster planning has been undertaken within the framework of multiple coastal hazards including tsunamis, however remote the chances of a very extreme event taking place. Mitigation options must consider the full spectrum of coastal hazards, both episodic and chronic, important aspects of vulnerability and overall risk assessment.
It was evident that some cities were severely affected by the tsunami in view of their increased exposure arising from the coastline geometry. In particular cities located within bays and around headlands were subjected to extensive damage due to the concentration of wave energy. This included principal coastal cities of Galle, Matara and Hambanthota. In addition tsunami waves caused changes in the bottom bathymetry leading to changes in the near shore wave climate which in the long term will affect coastal erosion trends. For purpose of coastal rehabilitation, conservation and mitigation it was decided to conduct detailed risk assessment studies following which risk management options were considered.

2. Increased exposure of the city of Galle

On 26th December 2004, the city of Galle Galle received the severe impact of tsunami waves, their magnitude having increased due to near-shore transformations. The tsunami waves, which reached the offshore waters of Galle were primarily diffracted waves, diffraction taking place around the southern coast of Sri Lanka. In the context of tsunamis the location of Galle is extremely vulnerable. It lies besides a wide bay and a natural headland on which is located the historic Galle Fort with very reflective vertical non-porous walls on all sides. Furthermore, there exists the Dutch Canal to the west of the headland, conveying water through the city centre. The waves in the vicinity of Galle, which were increasing in height due to reduced water depths were further subjected to a series of near-shore processes which increased their heights even further. The wide bay in Galle further contributed to the increase in wave height by modifying the shoaling process via reduced wave crest width to accommodate the bay shape. The combined effect of the bay and the headland led to a high concentration of wave energy leading to large tsunami wave heights.

3. Investigations implemented for the Galle city

Soon after the tsunami disaster Hettiarachchi et al (2009) conducted investigations focusing on risk assessment and management. These investigations were revisited and extended recently. The investigations included,

1. Detailed field investigation to identify the height and the extent of inundation, qualitative assessment of currents, damage profile of infrastructure and factors leading to loss of human life, and impacts of near shore bathymetry.
2. Analysis of data from field instruments which captured the tsunami in action, and information from satellite images.
3. Hazard assessment via probabilistic and deterministic tsunami hazard analysis, with the examination of a number of scenarios for the latter.
4. Vulnerability assessment based on critical parameters identified via a process of consultation with stakeholders.
5. Preparedness assessment via consultation with the community and disaster managers.
7. Identification of Risk Management Measures based on
   -Mitigating the tsunami hazard (reducing the impact of the tsunami wave)
   -Reducing the exposure and vulnerability
   -Enhancing preparedness and evacuation
   -Risk transfer via insurance
8. Hazard mitigation measures with respect to the development of a tsunami breakwater as part of strategic port development and coast conservation via revetments and bio-shields.
9. The development of building codes for new construction, enhancing the strength of existing buildings and their field applications.
10. Improving public knowledge on Tsunami Early Warning Systems and on Disaster Management Maps for the benefit of the community covering evacuation maps and evacuation zones and shelters.

The paper highlights some of the above investigations and outcomes.
4. Hazard and Vulnerability Analysis

4.1. Hazard Analysis

Tsunami hazard analysis focuses on three areas namely,
- tsunami hazard sources,
- exposure in relation to the said sources and
- potential impact on land.

It is important to initially understand the principal phases of the tsunami wave from generation, propagation to inland dissipation. In this respect it is necessary to be fully aware of the physics of the phenomenon associated with each stage.

Tools and methods available to study the hazard include, instrument measurements which captured the event (if any such data is available), field investigations, image analysis and mathematical modelling. The latter includes both deterministic and probabilistic tsunami hazard modelling (Burbidge et al. 2009).

With respect to tsunami hazard sources attention is focused on previous events (their location, magnitude and sequence), seismic gaps and the identification of potential ‘credible scenarios’.

Mathematical modelling is widely used to simulate tsunami wave propagation. Deep water modelling is used until the interaction with the continental shelf and thereafter near-shore and inundation modelling are used. The latter is challenging in view of data requirements and simulation of rather complex phenomena.

When examining its exposure at a specific location on the coastline, for a given hazard source, due attention must be focused on submarine geological features, regional location which will identify the influence of key wave transformation processes, location with respect to continental shelf and shoreline geometry. Depending on these aspects the amplitude of the tsunami wave may be enhanced. Wave reflection from coral atolls and concentration of wave energy within bays and headlands are typical examples of this category.

Investigating the impact of tsunami on land after an event can be studied by measurements from field instruments (if any which has captured the event), post event field observations and satellite images.

Prediction of possible impacts of tsunamis can be achieved by investigating historical records, paleo-tsunami research work and mathematical modeling. The need for reliable, calibrated models with quality data on near-shore bathymetry and onshore topography is considered important for modeling.

Analysis of information from instruments which captured the tsunami, post tsunami field measurements, analysis of satellite images and mathematical modelling of credible scenarios were extensively used to study the impacts of the Indian Ocean tsunami on the City of Galle.

4.2. Vulnerability Analysis

Vulnerability represents characteristics and circumstances of a community, a system or an asset that make it susceptible to the damaging effects of a hazard such as tsunami, an earthquake, a flood, etc. It arises as a consequence of conditions determined by physical, social, economic, political, institutional and environmental factors that characterize the framework of development employed in every society. The basic components of vulnerability can be broadly classified as human, physical, socio-economic, environmental, functional and administrative (Villagran 2006) and is therefore dependent on several factors related to the said components. These include, among others, population characteristics and density, degree of poverty, livelihoods, building types their strength (structural vulnerability), and a variety of other factors.
Detailed assessment of vulnerability remains a complex area in view of the widely varying parameters which have to be analysed and in view of the difficulties in defining and quantifying certain parameters. Assessment of vulnerability can therefore be implemented at different levels using varied approaches from simplified to highly sophisticated, commencing from very basic data bases to highly sophisticated data bases both referral and relational. Description of approaches and models on vulnerability analysis is presented in detail by Birkman (2006) and a summary is available in UNESCO (2009a).

A simplified approach for vulnerability assessment would focus on critical parameters of interest from the broader components of human, physical, socio-economic, environmental, functional and administrative and this should be identified in consultation with all stakeholders. Typically they cover population (characteristics, distribution, location and livelihood), status of infrastructure, exposure and preparedness for effective safe evacuation in response to warning. This approach is primarily a one dimensional approach of susceptibility. Reviews of recent post tsunami vulnerability studies indicate that the greater focus have been on potential loss of life and damage to houses and dwellings. Only a few studies have considered other aspects in detail.

A framework to breakdown vulnerability assessment into components by analyzing how disasters can impact the different sectors which comprise society was proposed by Villagran (2008) thereby moving from single dimension of susceptibility to three dimensional sector approach. The sector approach identifies dimensions of vulnerability in three dimensions, namely dimensions of susceptibility, sectors and scale of consideration. In effect dimensions of sectors and scale are added to the existing dimension of susceptibility. Typical sectors identified are, housing, communications, education, health, energy, government, industry, commerce, finance, transportation, public infrastructure, environment, tourism etc. The advantage of this approach, in particular from a policy point of view, is that it promotes the effective assignation of responsibilities relating to the reduction of vulnerabilities.

A detailed sector approach for vulnerability was also applied in a benchmark project for the City of Galle, Sri Lanka by Villagran (2008) and its advantages were clearly observed. In particular it is easy to understand the factors which maintain existing levels, reduce and increase vulnerability. The application of this method requires vast amount of data and consumes time. However, one of the important strengths of the study was that it provided guidance in identifying the critical parameters which could be adopted for a simplified approach on vulnerability.

Having reviewed all relevant information including the detailed study of Villagran (2008) it was decided to adopt a simplified approach giving attention to the identification of relevant parameters via stakeholder consultation. It was evident that simplified approaches based on relevant critical parameters provide effective vulnerability analysis on which risk assessment can be undertaken with confidence.

During the consultation it was important to present a strategic approach, commencing from the exposure of vulnerable systems, their sensitivity and resilience where applicable.

Systems exposed, primarily include the population (human), buildings and infrastructure (physical), socio economic fabric of society (socio economic), ecosystems/ natural environment (environment). Services and infrastructure essential for the functioning (functional) and administering (administrative) of society are the other two important aspects.

A community which is well informed of the hazards and prepared are less vulnerable because they are able to move away from prior to the hazard sets in or in a better position to respond intelligently to emergency situations.

The important categories are listed below

- Population (human)
- Buildings and Infrastructure (physical)
- Socio economic activities
- Environment
- Functional
- Administrative
- Capacity and Preparedness
Based on the review of above parameters, the following broad groups were identified to accommodate the relevant parameters relating to the vulnerability of the City of Galle.

- Population, its profile and geographical distribution
- Socio-economic profile of residents including livelihood
- Buildings, infrastructure and its status,
- Ecosystems and areas of environmental importance.
- Capacity to evacuate, within the broader framework of awareness, preparedness, early warning, response and safe evacuation

It is noted that factors relating to exposure of vulnerable elements to hazards, presence of existing protection, distance from sea and elevation were duly accounted in the hazard analysis.

Critical elements identified for City of Galle included

- Train Station
- Bus Terminal.
- Area of congregation in front of Post Office.
- Houses
- Schools (4)
- Mahamodera Teaching hospital
- School of Nursing
- Sambodhi Children Home
- Main Street – Trade and Commerce.
- Fish market, vegetable and fruit market
- Fuel stations
- District Administrative Building.
- Municipal Council Building.
- Coastline road network, Colombo to Matara
- Commercial Port
- Fishing harbour and boat landing sites (3).

In the final analysis it is important adopt weightage factors for relative importance after reaching agreement in consultation with stakeholders.

5. Approaches to Risk Management and their applications

There are many approaches that could be adopted when planning for a tsunami and other coastal hazards that accompany high waves and high inundation. Measures for risk management can be broadly classified into four categories, namely, those which mitigate the impact of the hazard, mitigate exposure and vulnerability to the hazard, improve preparedness and response and risk transfer via insurance.

5.1 Measures that mitigate the impact of hazard (Physical Interventions)

1. The implementation of artificial measures for protection including offshore breakwaters, dikes and revetments
2. The effective use of natural coastal ecosystems including coral reefs, sand dunes and coastal vegetation

5.2 Measures that mitigate the exposure and vulnerability to the hazard

1. Land use planning
2. Regulatory interventions such as set back of defense line, in particular for critical infrastructure for sustaining society and those infrastructure to be used by highly vulnerable groups
3. Adaptation of building codes to incorporate guidelines related to coastal hazards for a variety of infrastructure and enforcement regarding the adoption of such building codes leading to hazard resilient buildings and infrastructure.
4. Other regulatory interventions to reduce the level of vulnerability to acceptable levels.

5.3 Measures that improve preparedness and response
1. Early warning systems (local and regional)
2. Public warning systems
3. Evacuation routes and structures
4. Community education, using a variety of aids including maps

5.4 Risk Transfer via insurance
1. Development of appropriate mechanisms for risk transfer for different hazards, insurance, catastrophe bonds or funds

It is emphasised that Hazard, Vulnerability and Risk Maps play a vital role in Risk Management. In fact it is important to upgrade these maps regularly considering the beneficial aspects of risk management measures adopted. These maps lead to the production of Disaster Preparedness/Management Maps.

6. Integrating Mitigation with development of port of Galle

There are many hazard mitigation measures that could be adopted in coastal zone management when planning for tsunamis and other coastal hazards that accompany high waves and high inundation. In 2000, Japanese Port Consultants (JPC) developed a Master Plan for the development of the Port of Galle. In view of environmental concerns it was recognized that the development should be restricted to a two berth medium size harbour. In order to maintain healthy exchange of tidal flow for the well being of the coral reef system, JPC in consultation with the environmental specialists incorporated an offshore detached breakwater, which coincidentally has all the characteristics of an effective Tsunami Breakwater (Figure 1). It is admitted that tsunamis were not part of the agenda of the engineering and environmental designs at that stage.

The design of the Galle Harbour was revisited to examine the potential impact of tsunamis on the said offshore breakwater and the extent to which it would afford protection to the City of Galle. Deterministic tsunami hazard modelling with and without the offshore breakwater indicated a reduction in both tsunami wave height and the speed due to the presence proposed offshore breakwater. In effect the offshore breakwater would provide significant protection. The inundation area was reduced by nearly 20% and due to the energy dissipation of the breakwater, the dynamic characteristics of the incoming waves were greatly reduced. This level of protection could be further enhanced by providing front line protection on the coastline via a hybrid approach using both artificial and natural methods.

7. National initiatives on enhancing Disaster Management Capabilities

With the tsunami of 2004, the government and the society had to take the challenge of assisting the victims. Since then activities have taken place such as, enactment of the Disaster Management Act of May 2005, after which the
National Council for Disaster Management (NCDM), Disaster Management Centre (DMC) and the Ministry of Disaster Management have been established for implementing provisions of the Act.

Apart from the rare disasters such as tsunami, the more common disasters affecting Sri Lanka are flood, drought, landslide, Lightning, High winds/cyclones, animal attacks etc. At present, in addition to these, climate change induced events and improper land use in the recent past has influenced the disaster patterns.

Based on the country experience, global developments in DRR and, recommendations of UNDAC Assessment 2011, in May 2012 the NCDM has approved the development of this “Sri Lanka Comprehensive Disaster Management Programme (SLCDMP), 2014 – 2018”, with the goal of ensuring safety of Sri Lanka by reducing the direct and associated potential risk of the country and minimizing impacts on people, properties and economy, and the overarching objective of creating and facilitating an enabling environment for multi hazard, participatory and partnership oriented disaster management programmes using risk knowledge as the base, in line with global conventions and frameworks.

With the advance knowledge on the spatial distribution of key hazards and the availability of all island census data in 2012 the country can develop the risk profiles and start using a “risk base” approach in investments on risk reduction and investments. High risk areas should receive high priority. While supporting the “Risk Profile” development process the SLCDMP can promote the enabling environment for professionals in various development sectors to be aware and use of the available risk information including appropriate training. Urban and high risk areas may need hazard, vulnerability and risk maps for frequently occurring hazards. Availability of risk information may help expand the insurance industry and policy development related to land use, construction guidelines and dwelling in high risk areas.

A number of programmes to promote the use of hydro- meteorological models to forecast floods and inundation areas are underway. Potential also exist to enhance the use of watershed models in integrated water resource management and pollution control. There are a number of coastal models being tested for sea level rise, storm surges and tsunami. These modelling efforts will add value to in the risk assessment processes. In that context it is necessary to provide opportunities via SLCDMP for capacity building and including the applications of simulation models in national and sub national level land use and investment planning towards risk reduction. Also the SLCDMP may play a key role in knowledge management and transferring best practices from other countries and vice versa in the area of hazard profile development, risk assessment and related mitigations.

8. Conclusions

The paper presents a summary of the investigative studies conducted for risk assessment for the City of Galle and focuses attention on the development of risk management measures and their implementation. It was evident that in the case of coastal cities of Sri Lanka the tsunami hazard is of low frequency with potentially high impacts. In that context to invest in costly coast protection measures seems irrelevant unless integrated with national development projects such as port development and therefore attention was focused on harnessing the full potential of bio-shields, community preparedness and resilience. The paper also focuses on national initiatives on enhancing disaster management capability.

References


