Disaster Reduction on the Coasts of the Indian Ocean

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Summary

The Indian Ocean Earthquake and Tsunami of 26th December 2004 has resulted in a massive and generous response for disaster relief and reconstruction, together with plans to be more prepared next time. Disaster reduction, a program delivered before disaster strikes, is the best long term means of reduction of poverty but it receives less attention in the aftermath of a major disaster. An effective disaster reduction program must address all risks, not just tsunamis. For some regions tropical cyclones and storm surges are more frequently deadly than tsunamis. The two can be combined in the assessment of inundation. The program must be one which is affordable in regions of poverty, and it must be one which is implemented by the communities themselves. A procedure is given whereby a "disaster reduction limit state" is added to the procedures of risk assessment. Based on these principles, a *Guide to Disaster Reduction on the Coasts of the Indian Ocean* is proposed.

Introduction

When a major natural disaster strikes, such as the Indian Ocean Tsunami of 26th December 2004, there are four phases of response.

The first phase is emergency relief – food, shelter, medical services, evacuation, counselling.

The second phase is rebuilding habitat and infrastructure, and rehabilitating ecosystems. In poor regions the resources are perceived to be insufficient to make habitat and infrastructure disaster proof. The reconstruction is made accepting that lives, livelihood and buildings will be lost next time a similar disaster strikes. Poor communities, challenged to rebuild the social order as well as the physical order can do little about disaster reduction, especially when there is no expert coordinated guidance available.

The third phase is the introduction of a disaster management plan. This addresses mitigation of the disaster through early warning systems and community education, with a view to saving lives, but it does not provide the habitat and infrastructure with the physical planning and robustness to reduce the impact of the disaster on them. It also provides strategic planning for a more effective and rapid response in phases one and two.

The fourth phase is disaster reduction. This consists of modifying the planning, strengthening and protection of the infrastructure, so that, in conjunction with a disaster management strategy, all survives with minimum loss of life, livelihood, assets and facility. This is the most important phase in the global effort to reduce poverty. A disaster is a temporary setback to economic growth in rich countries, but a permanent setback in poor countries.

"Like slavery and apartheid, poverty is not natural. It is man-made, and it can be overcome."

Nelson Mandela,
4th February 2005

The great Indian Ocean Tsunami gives us a pause to think how we can best reduce the impact of great natural disasters. Structural engineers, with their understanding of risk and mathematical modelling of physical systems, are well placed to provide an answer in appropriate consultation with other experts. It requires an extension of their thinking about design and lifetime performance of structures and systems. This paper explores the methodology for disaster reduction on the coasts of the Indian Ocean. Coastal communities have the added vulnerability of inundation from the sea and winds stronger than inland, putting them at greater risk of disasters than other communities.

This paper addresses the development of a Guide for Disaster Reduction on

Fig. 1: The Indian Ocean basin showing 17 significant tsunami events in 280 years and tropical cyclone frequency (compiled primarily from Wikipedia [4] and US Geological Survey [5, 6] sources)

the Coasts of the Indian Ocean as an aid to disaster reduction on a global scale. It is restricted to disasters arising from natural hydro-meteorological and geophysical events, excluding drought. Human health, activity and commerce will only be considered insofar as they exacerbate or mitigate natural disasters.

Disaster Reduction

There are several remarks to make about disaster reduction:

- It applies to all regions, not just those recently affected by a disaster.
- It addresses all known hazards, including earthquakes, tropical cyclones, storm surges, wind storms, floods, volcanic activity, tsunamis and rising sea levels.
- It addresses human activity such as inappropriate land use and coastal development which exacerbate disaster.
- It requires knowledge of risk of all hazards in terms of intensity and return period.
- It requires affordable strategies for implementation.
- It requires community awareness and participation in disaster reduction program.
- Implementation is most obstructed by poverty.

Risk

A key to successful disaster reduction is the identification and quantification of risk to establish priorities for action to reduce loss of life, livelihood and assets from disasters. A UN report on reducing disaster risk [1] is a valuable source of risk identification nation by nation in terms of type of disaster, death and injury, and social and economic loss. Only some of the disasters relate to hydro-meteorological and geophysical events. The information is not presented in an engineering format of intensity of the hazard and return period. Such information must be compiled from other sources. This report targets the exacerbation of disasters by human developments so that it is directed to governments, which can exert control over development.

The UN International Strategy for Disaster Reduction bureau has launched Know Risk [2] at the Kobe conference in January 2005. This informative publication takes a holistic approach to disaster reduction with appropriate emphasis on the social dimension. A major obstacle to achieving disaster reduction is the mindset that disasters are inevitable and irreducible. However, quantified risk requires further research from many sources, including UN-ISDR [3].

The Indian Ocean Tsunamis of 2004 brings the issue of risk into focus. Inspite of the huge number of fatalities, deaths from tsunamis averaged over time are fewer than deaths from tropical cyclones, including storm surge, in the Indian Ocean. In 1970 a tropical cyclone and storm surge killed an estimated 300 000 to 500 000, mostly in Bangladesh – more than the tsunamis of 2004. Intense tropical cyclones occur much more frequently than major tsunamis. *Fig. 1* depicts historical data of intense tropical cyclones and tsunamis in the Indian Ocean, (other sources of disasters such as earthquakes without tsunamis are not shown). Tsunamis affect almost all the coasts of the Indian Ocean but mostly originate from earthquakes in the subduction zone of the Indian and Australian tectonic plates under the Eurasian Plate. All listed tsunami events except Krakatoa (1883) were due to earthquakes. Intense tropical cyclones, which occur in latitudes 10°–40° north or south of the equator do not necessarily have landfall, when the disaster strikes. In other parts of the world locally intense tsunamis have been the result of subsea landslides, often triggered by relatively small earthquakes.

This information has to be converted into site specific risk. This is a function of local topology onshore and offshore and local features of the landscape such as forestation. For individual buildings it further depends on distance from the shoreline, elevation above sea level and type, form and orientation of the structure.

Inundation

The additional hazards confronting communities on coasts compared with inland are associated with inundation from tsunamis and storm surges. The latter are accompanied by exceptional winds with higher speeds than inland. Wave and current theory have been applied to model tsunami inundation [7]. Storm surges are accurately modelled for some regions of the world. Shallow and wide continental shelves are conducive to higher elevations of storm surge, but might reduce the onshore effects of a tsunami.

Although storm surges can be accompanied by waves, even breaking, which add to the destruction, tsunamis although rarely breaking waves, are very destructive because of the much higher water velocities. Not only do these result in high lateral pressure on buildings, they also lead to scour which undermines otherwise robust buildings and

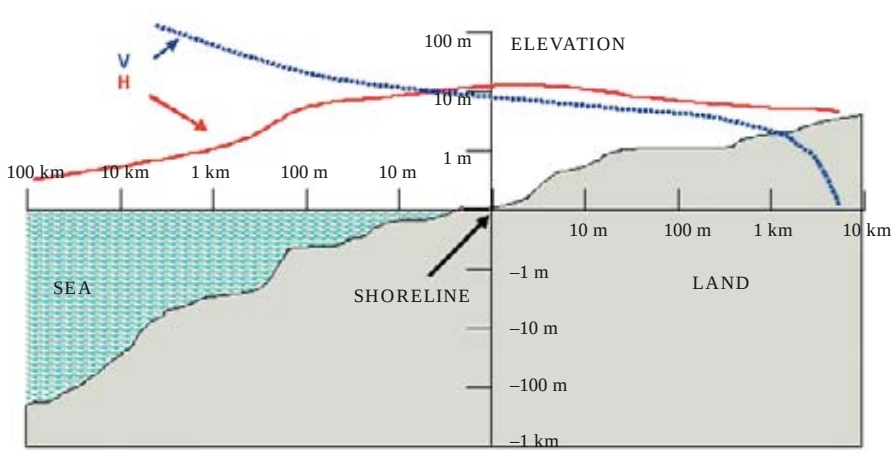

Fig. 2: Inundation maximum height and velocity (conceptual)

infrastructure. The worst scour sometimes occurs during backwash, undermining buildings, burying coral reefs in sand and destroying marine habitat.

Ideally a model could be developed to estimate the depth and speed of inundation from both storm surge and tsunami, using an elevation of the water depth and the land elevation on a section normal to the shoreline. Data for this profile is both regional and site specific. A hypothetical case is shown in *Fig. 2*.

Regional data alone combined with the derived profile should be sufficient to estimate the extent of inundation and velocity for the "design" storm surge and the "design" tsunami. The maximum height and water velocity of a tsunami crossing the shoreline is indicated conceptually in *Fig. 2*.

The profiles on shore can be extensively modified by breakwaters, embankments on land, terrain roughness in the form of assemblies of buildings, "tsunami forests" and mangroves. When slope increases and land elevation rises above the height of the approaching tsunami, the tsunami can "run up" the slope, achieving a height up to three times the depth on arrival at the slope.

Storm surges require low water depth extending many kilometres offshore for maximum effects, and water velocities are much lower. A breakwater could have a mitigating effect on tsunamis and on the waves superimposed on a storm surge, but not on the storm surge itself.

In addition to the sectional view, consideration must also be given to the shoreline topography, which can have a converging or diverging effect, particularly on tsunamis.

Any individual building can be positioned on this diagram to assess the significance of immersion and the need to raise occupied floors above a certain height.

Limit State	Serviceability	Ultimate Strength	Disaster Reduction
Nominal Return Period	50 years	500 years	5000 years
Performance criteria	Zero deaths Zero injuries Zero damage	Zero deaths Accept some injuries Accept some damage No collapse	Resilient community Accept some deaths Accept many injuries Accept damage
Design parameters and processes	Limit deflection Limit vibration Limit cracking Durability No flooding of utilities and essential services	Collapse load Fatigue failure No flooding of utilities and essential services	Robustness Non-structural disaster reduction measures

Note: The annual probability of an event is the reciprocal of the return period in years.

Table 1: Limit states for inundation

Disaster Reduction Methodology

Structural engineers can extend limit state design methodology to incorporate disaster reduction. Normally the principal limit states considered are serviceability and ultimate strength. A client might wish to achieve disaster reduction against exceptional events such as being struck by a meteorite or subjected to an unimaginable earthquake. For ordinary structures the only option is insurance, but if the structure or utility must be functional after the disaster then appropriate extension of design performance is made – at a cost.

The poor coastal communities hit by the recent tsunami, an event with a return period almost certainly shorter than 500 years, are threatened with complete destruction of their social fabric as well as the physical infrastructure. Insurance, if they could afford it, cannot replace these intangibles. Therefore we have to go beyond the ultimate strength limit state to a "disaster reduction" limit state where non structural methodologies must be employed to minimise death and destruction and to sustain and maintain the social fabric beyond the disaster. The principles are set out in *Table 1*.

The more important the building or facility, e.g., hospital, place of worship, school, factory, road or bridge, the more stringent the requirements in the disaster limit state (Table 2).

Perhaps the most immediately effective process is community education, especially for saving lives. Some island communities in India and Indonesia with a memory of tsunamis following earthquakes in the distant past survived without loss of life.

Early Warning

An early warning system is part of the disaster reduction process, but often of limited value. In the Indian Ocean it can become dysfunctional through lack of activation, and – when it is activated – through false alarms. In Bangladesh it has been proposed to integrate the tsunami early warning system into the existing, though incomplete, telephone/fax warning system for tropical cyclones and storm surges, now in continuous operation.

For any warning system to work there must be public escape routes, refuges which can be reached in time, a system for disseminating the early warning to the community, community education and evacuation drill. These are all necessary for an effective early warning system.

Early warnings will not reach communities close to the epicentre generating the tsunami in time to act. For these, community education to seek a refuge as soon as a strong motion earthquake

The disaster reduction parameters will include some of:		
Relocation on high ground	Set back from the coast	Scour protection
Elevation of floor levels	Refuges	Escape hills
Escape routes	Levees	Breakwaters
Upper floor refuges	Changed orientation	Modified construction methods
Wave transparency	Wall stabilisation	Bracing systems
Early warning systems	Community education	Public notices

Table 2: Disaster reduction parameters

is felt is the practical solution. A strong motion earthquake is defined more by duration and acceleration, as it might be some distance away. Duration of more than 15 seconds has been suggested as an indication of an earthquake of sufficient magnitude to generate a tsunami.

Disaster Reduction Guide

The possibility of producing a Guide *for Disaster Reduction on the Coasts of the Indian Ocean* as an aid to disaster reduction on a global scale was presented at a conference hosted by the Indian Group of IABSE, February, 2005 [8]. The idea was prompted in part by the possibility that concentration on the tsunami to the exclusion of other natural hazards would leave communities with a false sense of security after dealing with effects of the tsunami.

This *Guide* is to be based upon the principles outlined above. An important principle for the document to become effective is that it be drafted so that local communities could use it without recourse to special external engineering services in its interpretation. Thus it will go further than a conventional code of practice in incorporating all the technical data needed to reach the options and recommendations for disaster reduction for particular communities.

It is planned to provide the *Guide* in a form that the user can input the latitude and longitude of the coastal strip in question. This is to be sufficient for the "design" earthquakes, tropical cyclones, and tsunamis to be extracted. This will be supplemented by user input data on local topography, refuges, location of building or facility, type of structure, materials, availability of an early warning system, etc. The output will be a series of recommendations with alternatives deemed sufficient to reduce risk to an acceptable level.

Seven principles for planning and designing for tsunami hazards have been presented in a US publication [9]. This is a good, practical guide, appropriate in an affluent society where individuals can afford to hire professionals to address their particular risks from tsunamis. It also makes suggestions to prevent inappropriate development along coasts at risk of tsunamis. It is fair to say that a different document is required for the coasts of the Indian Ocean where the community risks are evidently higher than that in the USA, and they are exacerbated by poverty and lack of public funding.

Implementation

The production of a Guide, difficult as it might be, is relatively easy compared with having it used effectively where it is needed. The implementation will require recognition of the risks of living on the coast at the regional government and local community level, the realisation that these risks can be reduced in an affordable way, and the knowledge of how to do it. At government level the political will to face something which might happen in the future is weak. At village level the community leaders must somehow become aware of the possibilities. It would seem that the best option is to introduce disaster awareness and the commitment to disaster reduction is through community school curricula and the development of teams to inform community leaders and regional governments. Without the support of aid groups such as the UN International Strategy for Disaster Relief and various NGOs this is unlikely.

Conclusion

Disaster reduction is the most effective way of reducing poverty and saving lives and livelihoods. It needs implantation before a disaster occurs, not after. Disaster reduction in relation to natural hazards is risk based design and modification of buildings and infrastructure and community practice to achieve acceptable levels of risk in preserving lives and infrastructure. An extension of structural limit state design principles of serviceability and ultimate strength to include a disaster limit state is proposed. Coastal communities have the added hazard of inundation from tsunamis or storm surges requiring particular analytical and numerical modelling techniques to quantity risk and impact. The local community must understand and be involved in the choice of the disaster reduction program and its implementation. A Guide is proposed as an aid to disaster reduction.

Acknowledgements

The development of the concept of the Guide has been greatly enhanced by discussions with the Joint Working Commission, and a wider circle of active contributors. Special appreciation is extended to Jon Hinwood for articulating tsunami as load.

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