SOME REFLECTIONS ON THE STRUCTURAL ENGINEERING ASPECTS OF TSUNAMI DAMAGE

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1. INTRODUCTION

The Great Indian Ocean Tsunami on 26 December 2004 caused massive damage and a great deal of it was structural. Furthermore a large proportion of the loss of life could be ascribed to this structural failure, since it prevented vertical evacuation, and the resulting debris became an added hazard. However although structural failure was widespread, many structures did survive inundation by the tsunami, particularly if it was only partial inundation, suggesting that if communities are going to be built in tsunami prone areas there may be structural solutions that could be expected to provide a safe refuge in all but the most extreme events. There is also a need for critical infrastructure in tsunami prone areas to be resilient to tsunami inundation.

To date there has been very little research undertaken on the design of structures to resist tsunamis, primarily because major tsunamis were perceived as being so rare as not to warrant attention from the point of view of public safety. However public perceptions in this regard are changing. If suitable structural solutions are to be found they will need to be based on a fundamental understanding of the forces imposed on structures by tsunami inundation, and the response of structures to them. This will require considerable knowledge about the physical characteristics of the tsunamis as they penetrate over land. Three important variables are penetration, depth and velocity. Some information is available on penetration and depth, but very little is known about velocities during inundation, and the effect of the entrained debris, which are critical to estimating forces.

2. COASTAL DISASTER REDUCTION GUIDE

The catalyst for this paper has been the Joint Working Commission on Disaster Reduction on Coasts of the Indian Ocean established by the first author following the 2004 Great Indian Ocean Tsunami with the endorsement of the International Association of Bridge and Structural Engineering and Engineers Australia, and the support of many other organisations and engineers. The objective of the Commission is to develop a Guide to disaster reduction in coastal communities at risk from inundation from floods, storm surges, tropical cyclone generated storm surges and tsunamis. As an essentially civil engineering approach to disaster reduction it will primarily focus on reduction of vulnerability of the built environment, not emergency management issues such as warnings, response and recovery when an event occurs. It is also intended for primary use by communities and individuals on coastlines bordering the Indian Ocean, which with the exception of Australia and South Africa are not generally regarded as highly developed parts of the world.

The Guide will be based on a Limit State approach with three limit states being identified:

- A serviceability limit state based on the need to survive inundation without loss of life or injury, and minimal physical damage to buildings and infrastructure, from events with a return period of the order of 50 years;
- A normal code ultimate limit state based on the need for minimal loss of life and injury, and minimal damage to essential services, while accepting significant physical damage to normal buildings and infrastructure, from events with a return period of the order of 300 years;
- A post-code ultimate limit based on the need to minimise life, injury and asset damage, as well as maintaining essential services through the incorporation of robustness in the design of buildings and infrastructure from events with a return period of the order of 1000 years or more.

It will also need to be in such a form that communities and individuals will be able to use it.

The development of the Guide is primarily being undertaken as a voluntary activity by concerned engineers from academia and the profession within the region of intended application with the support of the various professional engineering bodies serving the region. A key activity is a planned international symposium on the subject of the Guide to be held at Monash University in November 2005, which it is hoped will provide the information base for the production of the Guide during 2006.

3. STATE-OF-ART OF TSUNAMI RESISTANT DESIGN

Currently there are no well established procedures, soundly based on engineering science, for the structural design of buildings and infrastructure, which a design engineer can use with confidence. In the absence of these, however, there are some empirical approaches which have been proposed for the establishment of design loads for use in conjunction with the normal material design codes.

The derivation of design loads is commonly a three stage process

- Determination of design event
- Derivation of the design values of basic design action parameters arising from the design event
- Derivation of design forces acting on the structure based on the basic design action parameters

In the case of tsunamis the design event may be the estimated 300 year return period tsunami height in the offshore deep ocean. The basic design action parameters might be the estimated depth and velocity of the tsunami overland flow impinging on the structure from the design tsunami. The design forces will be the pressures and forces exerted on the structure by the tsunami flow.

Little information is currently available on tsunami risk on which to base design events, so a nominal design event is likely to be adopted.

The wave height of a tsunami approaching the shore will depend on the bathymetry and coastal geometry. By using formulae derived for solitary waves approaching a long straight coastline, empirical formulae have been developed for estimating the breaking wave height and the associated velocity (Murty 1977, Muir Wood & Fleming, 1981, Mader, 1988).

Overland flow of tsunamis has been observed to be either in the form of a surge following breaking of the primary tsunami wave in the vicinity of the coastline, or a more gradual flow of water inland as the sea-level gradually rises. Major tsunamis appear to primarily give rise to overland flow of the first type. Togashi (1976) and Bryant (2001) have provided procedures and empirical formulae that could be used for determining the depth and inland penetration of the overland flow from tsunamis.

In a recent paper Okada, et al (2005) have proposed an empirical method for estimating the forces exerted on structures by tsunami overland flow based on the methods used for estimating wave forces on structures. This method assumes that the seaward face of the structure will be loaded by a hydrostatic pressure based on an immersion depth of three times the design inundation depth, with no load on the landward face of the structure. Other procedures have also been advocated based on assumptions of the depths and velocities of the overland flow – eg Murty (1977)

4. DEVELOPMENT OF A RATIONAL DESIGN APPROACH

The Great Indian Ocean Tsunami is already generating a much greater interest in the characteristics of tsunamis required for rational structural design. This is likely to lead to significant improvements in the design of structures to resist tsunamis in the future.

A recent paper by Thio, Ichinose and Somerville (2005) describes a method of probabilistic tsunami hazard analysis (PTHA), which is equivalent to probabilistic seismic hazard analysis (PSHA), the primary technique underlying the determination of the design earthquake events.

Sophisticated simulation modelling of tsunamis, including the use of supercomputers, and the generation, propagation and interaction with coastlines of tsunamis is being undertaken at a number of centres around the world. Some of this work was underway before December 2004, but it was primarily directed towards warning systems.

Chanson (2005) has postulated that the overland flow is similar to dam break and provided an analytical technique for estimating overland flow depths and velocities based on this approach. The work described is based on normal fluid flow, but he indicates in reality the entrained debris makes the problem much more complex. The flow will become non-Newtonian and the effect of debris impact can not be ignored.

The Limit State approach described above provides a logical framework for the development of rational procedures for structural design. Where the risk is very low, but the probability of a significant event nevertheless exists, which is probably the Australian situation, it may be that only the post-code ultimate limit state would be adopted for most structures. For critical facilities whose continued performance would be important if a major event occurs then the adoption of the normal code limit state, with a check to ensure satisfactory performance at the post-code ultimate limit state may be more appropriate.

5. CONCLUSIONS

The design of structures is currently focussed on events which have a return period of the order of 500 years or less. Tsunamis severe enough to threaten the safety of structures have been traditionally assumed to be less frequent than this and consequently have been ignored in structural design. The recent 2004 Great Indian Ocean Tsunami is changing community attitudes in this respect.

The current approach is an outcome of the Limit State design approach introduced in Australia in the 1970's, with two primary limit states being adopted for structural design, the serviceability limit state, and the ultimate limit state. To cope with the tsunami type problem it is proposed that a third limit state be introduced – a post-code ultimate limit state – requiring structures to be assessed for their resilience to an event greater than that assumed for normal ultimate strength design.

Currently a rational approach to the design of structures to resist forces exerted on them by tsunamis based on sound engineering science does not exist, and where design is required recourse has to be made to empirical approaches. However the increased level of research on tsunamis that is expected to result from the impact of the Great Indian Ocean Tsunami on the world is expected to provide the required information to develop a rational approach.

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