DEVELOPMENT OF PLANNING AND DESIGN GUIDANCE FOR TSUNAMI VERTICAL EVACUATION STRUCTURES IN NEW ZEALAND

Jenni Tipler, Sarah-Jayne McCurrach
Ministry of Business, Innovation and Employment, Ministry of Civil Defence and Emergency Management
Wellington, New Zealand

Abstract

New Zealand's entire coastline is at risk of tsunami from local, regional and distant sources. With more than 75% of New Zealanders living or working within 10 km of the coast, the tsunami risk is significant. Conditions that might prevent timely evacuation, including geographic settings, infrastructure, and demographic barriers mean timely evacuations out of tsunami zones may not be possible for at-risk communities. These barriers result in differing evacuation planning requirements and vertical evacuation has been identified as a possible solution to these challenges. The Ministry of Civil Defence & Emergency Management (MCDEM) and the Ministry of Business, Innovation and Employment (MBIE) have established a project to develop guidance for tsunami vertical evacuation structures (purpose built and retrofitted), appropriate to New Zealand's requirements. The first phase of the project will provide territorial authorities with the tools to assess their tsunami residual risk and need for vertical evacuation. It will also provide options for planning for the designation of such structures, including public education, welfare considerations and access.

The second phase of the project is to develop technical guidance for the design and evaluation of vertical evacuation structures. There are currently no standards or guidelines that can be used by engineers for New Zealand application to design a vertical evacuation structure or evaluate the suitability of an existing building for vertical evacuation. Existing international design standards are being used to inform the development of New Zealand specific guidance, which will support ongoing discussions about tsunami risk management in New Zealand. This paper presents an overview of the Phase 1 guidance and an update of the process underway to develop technical guidance for Phase 2.

Introduction

New Zealand sits at the convergent boundary of the Pacific and Australian Tectonic Plates, known as the Kermadec-Tonga subduction zone, located in the southwest of the Pacific Ocean in the Pacific 'ring of fire' (Figure 1). The Kermadec-Tonga Trench is one of earth's deepest oceanic trenches. It is thousands of kilometer's long and subduction occurs along the trench to the east of the North Island of New Zealand. This is known as the Hikurangi Trench, which comes within 80 km's of New Zealand's coastline. The trench is comparable to the Japanese Trench, and is capable of generating tsunamigenic earthquakes, similar to that of the devastating 2011 Tohuku earthquake and tsunami. The Puysegur Trench and the Alpine Fault (Southern/Northern Fiordland) are associated with the subduction of the Australian Plate under the Pacific Plate to the south of New Zealand. Both the Puysegur and the Hikurangi trenches are capable of generating tsunami causing significant land inundation.

The tectonic setting and New Zealand's location in the Pacific, puts the country at risk from distant, regional and local source tsunami. These sources are defined by a tsunami originating from a location, more than 3 hours travel time, 1-3 hours travel time, and less than 1-hour travel time from New Zealand's coast, respectively. Exposure to multiple tsunami sources is not unusual for a Pacific nation. However, New Zealand faces a unique combination of challenges concerning tsunami risk management.

The historical tsunami record suggests New Zealand has experienced multiple, very large tsunami in the past, and since 1840 there have been 10 recorded tsunami with wave heights >4 meters at our coastline, sources of which were from local and distant source earthquakes (80% local, 20% distant). Smaller tsunami from distant sources occur with high frequency but are typically confined to marine disturbance only, rather than land-based impact. Very large tsunami has the potential to significantly inundate multiple coastal areas. Tsunami can therefore cause widespread loss of life, injuries, and cause physical and environmental damage and disruption across multiple regions simultaneously, and can trigger other hazards e.g. infrastructure failure. A 2015 New Zealand Institute of Economic Research (NZIER) Report reviewed and discussed New Zealand's tsunami risk and the gaps in addressing these through current risk management practices. The NZIER report estimated that a 1/500-year tsunami event could lead to between 4,000 and 33,000 fatalities (NZIER, 2015).

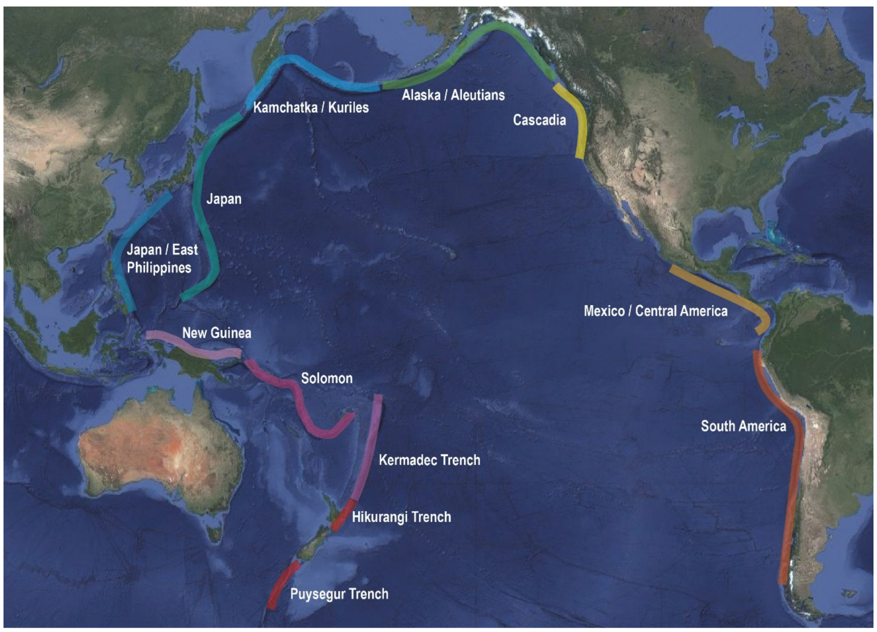

Figure 1. The Pacific Ring of Fire & significant subduction zones identified (GNS Science).

It is therefore important to understand the national, regional and local risk from tsunami to inform the decision-making required for effective tsunami risk management across the 4R's of reduction, readiness, response, and recovery. Tsunami risk management in New Zealand involves a broad range of activities at the national, regional and local level. Traditionally, this has focused strongly on life safety preparedness, evacuation planning, warnings, and response planning, including but not limited to; public education, insurance cover (private and government) for losses and business interruption to reduce financial risk.

A critical tsunami risk management measure is the timely evacuation of people when a tsunami threat is present. New Zealand Civil Defence Emergency Management (CDEM) Groups are responsible for coordinating local evacuation planning and the associated activities, including public education. The Civil Defence Emergency Management Act (2002) and the National Civil Defence Emergency Management Plan Order (2015) provide the legislative framework for "all hazards" risk management. MCDEM is the custodian of these legislative instruments and coordinates the national tsunami risk management program, working with central and local government agencies, researchers, the media, the private sector and communities. Under a devolved accountability model for emergency management, policy and guidance is developed at the national level and in most cases, implementation occurs at the regional or district level by CDEM Groups.

Some CDEM Groups face particular challenges with regard to timely evacuation of at-risk communities; therefore, additional measures such as tsunami vertical evacuation may need to be considered. Their use is most appropriate during local source tsunami events, when the evacuation time can be minutes. It is important that tsunami vertical evacuation is recognized as a supplementary risk management measure of last resort, to meet a clear need, when all other risk management measures have been assessed and implemented. In New Zealand, it is intended that tsunami vertical evacuation structures are for those people who may live, work or recreate in tsunami inundation zones, where timely evacuation is not possible.

MCDEM and MBIE have initiated a two-phase project to develop bespoke guidance that will enable CDEM Groups to consider using tsunami vertical evacuation as an additional measure to manage tsunami risk, appropriate to New Zealand's requirements.

Project Phase 1: Assessment and Planning for Tsunami Vertical Evacuation

The Phase One guidance aims to provide nationally consistent advice on assessing, identifying, planning and designing for tsunami vertical evacuation in New Zealand. The guidance presents a risk-based approach for CDEM groups to determine whether tsunami vertical evacuation should be considered for their region, or at-risk communities.

The guidance follows a three-step decision-making framework which includes:

- Step 1 Tsunami hazard risk assessment provides information on the requirements and methods for completing tsunami risk assessment.
- Step 2 Tsunami residual risk assessment describes the process and provides methods for assessing, evaluating and managing tsunami residual risk.
- Step 3 Tsunami vertical evacuation describes the key principles and considerations for implementing tsunami vertical evacuation.

The purpose of establishing a staged, risk assessment and evaluation approach is to enable CDEM groups to truly understand their hazard, exposure and vulnerability. This approach requires robust, transparent and well supported decisions to be made with regard to the design and implementation of tsunami vertical evacuation structures.

Step 1: Tsunami hazard risk assessment. Effective tsunami risk management begins with assessing tsunami risk through the process of identification, analysis and evaluation. The approach developed by MCDEM provides a standard approach to tsunami risk identification and analysis, and determines the current tsunami risk for an area of interest, such as a community or region.

The purpose of Step 1 is to understand the total tsunami risk in terms of population exposed to tsunami hazard on land. The tsunami sources that are included in the hazard assessment require characterizing to understand their contribution to overall tsunami risk. Consideration must be given to local, regional and distant sources that contribute to the hazard and to the minimum arrival time from tsunami generation to shore for each of these sources. Tsunami risk evaluation must include understanding the likelihood of a particular hazard occurring and the consequences of that hazard in terms of the extent of land inundation.

Exposure to tsunami hazard is defined as the number of people present in tsunami zones, which depends on daily, weekly and seasonal fluctuations in the population. In order to estimate the degree of damage experienced by a tsunami hazard, the vulnerability of the at-risk population must also be considered.

Evacuating people from exposed areas is the most fundamental method for managing tsunami risk. However, there may be conditions or characteristics of the people exposed that reduce their inherent ability to evacuate. For example, people are more vulnerable if they cannot understand that there is a threat (either from natural or official warnings). There are various reasons why vulnerabilities may be present in individuals or parts of the populations such as age, impaired mobility or language barriers.

Quantitative tsunami hazard risk assessment involves modeling the tsunami risk, often through scenario-based assessments of tsunami inundation and calculating the population in the exposed areas for that particular scenario. Our approach in calculating tsunami risk does not include evacuation. It determines the maximum consequences; in this case, the number of people killed or injured with no measures in place to reduce exposure.

Step 2: Tsunami residual risk assessment. Step 2 of the tsunami vertical evacuation decision-making framework describes the process for considering tsunami residual risk assessment and residual risk management. This includes modeling residual risk, determining risk acceptance levels, evaluating the level of residual risk, evaluating options for improving risk management and implementing new risk management measures.

The purpose of modeling residual risk is to determine the risk that remains after risk management measures have been implemented. The process involves comparing evacuation-modeling results with minimal wave arrival time of waves capable of inundating the land, to determine the number of people who cannot evacuate before the first wave arrives. Evacuation models are designed to calculate the time required for all people within an evacuation zone to reach safety. This takes into account different movement rates, route availability and terrain by incorporating data on terrain, population exposure, people's decision-making, and population vulnerability.

Residual risk to life-safety must be evaluated to determine if it is acceptable, tolerable or intolerable. It is almost certain that some residual risk will remain, regardless of the effectiveness of tsunami risk management and the preparedness of the population. Therefore, it is likely that some residual risk must be managed. Residual risk can be managed by; reducing long-term exposure through measures such as land-use planning; reducing short-term exposure through measures that could contribute to more timely evacuations, and; reducing vulnerability through public education or training exercises and drills.

If tsunami residual risk is below the acceptable threshold, additional risk management measures are not required, but may be beneficial in the long term. If residual tsunami risk is determined to be tolerable, some additional risk management measures are likely to be required. If tsunami risk is determined to be intolerable, new or improved measures to reduce the risk must be implemented. The expectation is that residual risk will be reduced to at least tolerable and ideally acceptable levels. If all other practical options for reducing residual risk are exhausted and risk is intolerable, then tsunami vertical evacuation may be considered as a risk management measure.

Following implementation of any risk management measure, the changes to residual risk must be re-modeled and the residual risk re-evaluated. The process of assessment, evaluation, and managing residual risk continues until the risk is tolerable, or all risk management improvement measures are exhausted.

Tsunami vertical evacuation should only be considered when all other practical measures for managing risk have been implemented and evaluated. The most effective method to ensure the safety of people is to move them from the hazard zones to safe locations. Tsunami vertical evacuation is a measure that is designed to offer temporary refuge; however, people will still be physically located within the hazard inundation zone, so it is considered a measure of last resort.

Step 3: Tsunami vertical evacuation. Step 3 of the of the tsunami vertical evacuation decision-making framework describes the considerations and principals of planning for tsunami vertical evacuation, and includes the factors that may prohibit the designation and use of tsunami vertical evacuation structures. These include:

- the cost to build a new, or retrofit an existing structure, is prohibitively expensive
- the available locations for a structure are unsuitable for the at-risk community
- the community or stakeholders do not want to use vertical evacuation as a measure to reduce the residual risk

In New Zealand, vertical evacuation structures should be designed and built to provide a short-term refuge from tsunami, for the purpose of life safety only. Vertical evacuation structures are not intended to provide long-term refuge and are not Civil Defence Centers. Implementation of these structures should be accompanied by a robust public education strategy and communication plan/community engagement plan, to ensure the context, use and limitations of tsunami vertical evacuation are understood. If tsunami vertical evacuation is to be adopted as a risk management measure, then challenges are likely to arise over the alignment of local and national tsunami safety messaging and campaigns. Other considerations include regularly testing tsunami vertical evacuation structure(s) through exercises and drills.

The location of a tsunami vertical evacuation structure, within the tsunami inundation zone is one of the most important considerations for both purpose built and retrofitted structures. A detailed location(s) assessment should be completed as part of the planning process. The assessment should ensure a number of locations are evaluated with the main objective of ensuring timely, safe and efficient evacuation. The location of a tsunami vertical evacuation structure should not pose further risk to evacuees, who will be using the structure for refuge.

Accessibility to a vertical evacuation structure is an important consideration and not only includes the structure's 'business as usual' usage (private vs public), but anything that may prohibit use of the structure in times of an emergency. This may include, but is not limited to, the structures accessibility 24/7, 365 days of the year, the access for varying community needs, and have the capacity of the structure clearly identified.

Phase 1 is currently in the review and implementation process. We anticipate this to be completed and in use during October 2018. Following the detailed process and clear documented of the assessment, if the use of vertical evacuation is determined as the only effective measure for reducing tsunami risk to tolerable levels, the Phase 2 technical guidance (to be developed in Phase 2 of the project) will be used to inform the structural design of vertical evacuation structures.

Project Phase 2: Technical Design Guidance for Tsunami Vertical Evacuation Structures

Phase 2 Project Approach. The project approach is to utilize existing international design guidance as a baseline for the development of NZ-specific guidance. This includes FEMA P-646 *Guidelines for Design of Structures for Vertical Evacuation for Tsunamis* (ATC, 2012) and ASCE 7 – 16 Chapter 6 *Tsunami Loads and Effects* (ASCE, 2016). The proposed content of the New Zealand guidance document covers a range of specialized disciplines including: tsunami wave modelling, hydrodynamics, structural engineering and, geotechnical engineering.

For this reason, it is appropriate that specific sections of the existing international guidelines are reviewed by different parties with the relevant specialist expertise (rather than having all parties review all sections). A technical working group will review particular sections of the existing guidance as described in Table 1.

Phase 2 of the project will be staged as follows:

1. A straw-man guidance document will be developed by combining existing international design guidance
2. This document will be reviewed, in sections, by relevant technical experts in the technical working group (refer to Table 1) who will help develop the content further
3. The developed document will be workshopped in full by the technical working group
4. MBIE and MCDEM will further develop the draft guidance document. Where insufficient evidence exists to justify a deviation from the straw-man, the straw-man content will prevail
5. The developed draft document will be reviewed by the technical working group and independently reviewed by the relevant technical societies including the New Zealand Society for Earthquake Engineering (NZSEE), Structural Engineering Society (SESOC), the New Zealand Coastal Society (NZCS)
6. The document will be published
7. Implementation of the guidance will be facilitated through a series of training workshops

The proposed participants in the technical working group include GNS Science, the National Institute of Water and Atmospheric Research (NIWA), the University of Auckland (UoA) and a structural engineering consultant.

Table 1. Proposed Structure of the Phase 2 Design Guidance

Section/Chapter	*Proposed Lead reviewers*
1. Introduction	
1.1 Purpose and Scope of the Guide	MBIE
1.2 Background	MBIE
2. Tsunami Load Determination and Structural Design Criteria	
2.1 Performance Objectives	All
2.2 General Design Criteria	All
2.3 Design Inundation Depth and Flow Velocity	GNS/NIWA
2.4 Hydrostatic Loads	UoA
2.5 Hydrodynamic Loads	UoA
2.6 Debris Impact Loads	UoA/Structural Engineer
2.7 Structural Design Procedure	Structural Engineer/UoA
2.8 Foundation Design	MBIE/UoA
3. Structural Design Concepts and Additional Considerations	All

Current Status of Phase 2. MBIE and MCDEM have developed the straw-man document and are currently working with specialist consultants and technical experts to review this document and help further develop the content for specific New Zealand application.

Considerations in the Development of Guidance for the Design of Vertical Evacuation Structures in New Zealand. The Phase 2 design guidance outlines the process for determining the tsunami demands on structural elements and the structural performance acceptance criteria.

Vertical evacuation structures are expected to be designated as Importance Level 4 structures in accordance with AS/NZS 1170.0 (SNZ, 2002). For a design life of 50 years, the structures will need to be designed for the 2500 year tsunami event. Near-source generated tsunamis are expected to create severe ground shaking prior to the arrival of the tsunami. The performance of vertical evacuation structures subject to this shaking must ensure that there is sufficient residual capacity to resist the ensuing tsunami loads and that any damage to the structure, including that of any non-structural components, during the earthquake does not affect building access or otherwise compromise it's use as an evacuation structure.

The focus of the Phase 2 guidance is on the design of new, purpose-built structures although the concepts described in the guidance could be used as the basis for assessing the suitability of existing buildings for vertical evacuation. In New Zealand the prevalence of precast concrete floor systems in modern multi-story buildings means that many of these buildings will be unsuitable for use as vertical evacuation structures. This is due to the vulnerability of the floor systems in these buildings, particularly in relation to uplift forces due to buoyancy that may result during the tsunami event.

New Zealand Building Code Requirements for Tsunami Loading. The New Zealand Building Act (2004) requires that all new building work comply with the Building Code Clause B1.3.3. This Clause relates to structural stability and states that "account shall be taken of all physical conditions likely to affect the stability of buildings… including… earthquake, snow, wind…". This Clause provides examples of physical conditions that must be considered but is not an exhaustive list. This implies that tsunami loads should be considered if they are likely to affect the stability of a structure, regardless of whether tsunami is explicitly named as a physical condition. MBIE, as the building regulator, is in the process of reviewing the current interpretation of the Building Code with regard to when tsunami loading should be considered more specifically in new building design.

In practice, compliance with the Building Code is usually achieved by referral to Acceptable Solutions and Verification Methods that provide deemed-to-comply solutions with the Building Code. The New Zealand Building Code is performance-based; therefore, designers can also apply an Alternative Solution to demonstrate compliance with the Building Code. To date, the Acceptable Solutions and Verification Methods for structural stability have not considered tsunami loads, yet they are valid compliance paths for buildings constructed in inundation zones. This has contributed to the pervasive practice of omitting tsunami considerations for new building design. Furthermore, there are currently no New Zealand standards or guidelines that can be used by engineers to design a structure to withstand tsunami loads.

Summary

- Phase 1 is currently in the review and implementation process. We anticipate this to be completed and in use during October 2018. The guidance describes the process for assessing the need for tsunami vertical evacuation, and highlights its use should only be considered when all other practical measures for managing risk have been implemented and evaluated.

- Phase 2 of the MCDEM/MBIE vertical evacuation structures project is currently underway. A straw man proposal for the guidance document has been developed and specialist technical experts are in the process of reviewing the straw man document and helping to further develop the content.
- MBIE, as the building regulator, is in the process of reviewing the current interpretation of the Building Code with regard to whether and when tsunami loading should be considered more specifically in new building design.

References

Applied Technology Council (ATC), 2012, "FEMA P-646 Guidelines for Design of Structures for Vertical Evacuation from Tsunamis: Second Edition", Federal Emergency Management Agency (FEMA), retrieved from https://www.fema.gov/media-library-data/1426211456953-f02dffee4679d659f62f414639afa806/FEMAP-646_508.pdf

ASCE/SEI (American Society of Civil Engineers, Structural Engineering Institute), 2016, "Minimum design loads and associated criteria for buildings and other structures", *ASCE/SEI* 7-16, Reston, VA

Australian Standard / New Zealand Standard 1170.0:2002 (AS/NZS 1170.0:2002), 2002, "Structural design actions – General Principles". Standards New Zealand, 40 pages.

Civil Defence and Emergency Act, No. 33. 2002, retrieved from http://www.legislation.govt.nz/act/public/2002/0033/48.0/DLM149789.html

Civil Defence Emergency Management Plan Order, 2015, retrieved from http://www.legislation.govt.nz/regulation/public/2015/0140/latest/DLM6486453.html?src=qs%20

Fraser, S. A., 2014, "Informing the development of tsunami vertical evacuation strategies in New Zealand: A thesis presented in fulfilment of the requirements for the degree of Doctor of Philosophy in Emergency Management at Massey University Wellington, New Zealand," Palmerston North: Massey University.

Ministry of Civil Defence & Emergency Management (MCDEM), 2018,"Assessment and planning for tsunami vertical evacuation. Director's Guideline for Civil Defence Emergency Management Groups [DGL 21/18]", Wellington, New Zealand, 36 pages

New Zealand Institute of Economic Research (NZIER), 2015, "Tsunami risk facing New Zealand: NZIER report to the Earthquake Commission," Wellington, New Zealand, 38 pages