Tsunami evacuation: Lessons from the Great East Japan earthquake and tsunami of March 11th 2011

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ABSTRACT

The Great East Japan moment magnitude (Mw) 9.0 earthquake occurred at 14:46 (Japanese Standard Time) on March 11th 2011. Significant seabed displacement generated the subsequent tsunami, which caused significant damage in Iwate, Miyagi, Fukushima and Ibaraki Prefectures. As a result of this event over 19,000 people are dead or missing, with over 295,000 collapsed buildings along 600 km of affected coastline.

Reconnaissance-level analysis of evacuation preparedness and actions related to the tsunami has been carried out using semi-structured interviews with local disaster prevention officials and emergency services officials. Interviews were carried out in Tarō Town, Kamaishi City, Ōfunato City (Iwate Prefecture) and Kesennuma City, Minami-Sanriku Town, Ishinomaki City and Natori City (Miyagi Prefecture). The interviews covered tsunami awareness, observations and response to natural and informal warnings; style and derivation of evacuation maps; official warning timing and dynamics; evacuation timing, mechanisms and issues; and vertical evacuation buildings – availability, designation, public awareness, utilisation, relationship to maps, and post-event review. The report also presents examples of hazard and evacuation maps and signs employed in the Tōhoku region.

Experiences in Tōhoku during this event are relevant to tsunami mitigation activities in the State of Washington and in New Zealand, which co-funded this research. These areas have local earthquake and tsunami risk posed by the Cascadia Subduction Zone and the offshore Hikurangi subduction margin, respectively. This report provides recommendations for further development of tsunami mitigation activities in these areas, based on findings from the interviews.

Overall there was a 96% survival rate of those living in the inundated area of the municipalities visited. This can be attributed to mostly effective education and evacuation procedures. Schools education, hazard maps and exercises appear to be the most common forms of education. Community involvement in planning of evacuation maps, routes and buildings is common, with many places conducting regular community-level exercises. Hazard and evacuation maps lacked consistency and both maps and safe locations were generally designed for a tsunami height that under-represented the worst case scenario.

The natural warning of long ground shaking (reported as more than two minutes, and often more than three) was widely agreed as enough by itself to have triggered evacuation. Sea walls reduced effective observation of the natural warning of unusual ocean behaviour in many places, and fostered a false sense of security in some locations.

Although an early warning system is often seen publicly as key infrastructure in enhancing tsunami resilience, the expectation of official warnings (and their content) may have slowed the time taken for people to initiate evacuation in Tōhoku, compared to if there had been total reliance on natural warnings. Exposure to previous false 'major tsunami' warnings apparently led to complacency in this event, despite this earthquake feeling much larger than anything previously experienced. The philosophy of *tsunami tendenko* was shown to be a positive education tool which promoted immediate self-evacuation and save many lives.

Peoples' movements during and after evacuation reveal that many people died unnecessarily due to delayed evacuation or non-evacuation as a result of social or parental responsibility, lack of education or scepticism of warnings. Widespread use of motor vehicles caused traffic

congestion in some areas, when walking, running or cycling would have been much more effective and saved lives.

Many people returned to the evacuation zone too early in some places because they had not seen the wave arrive at the expected time given in official warnings, or because they expected no more waves to arrive. It is critical that people have the awareness that the first wave may come later than estimated by rapid scientific analysis, and the largest wave may not be the first.

The evacuation strategy in place at March 11th 2011 was appropriate in that it sent people to safe locations, used maps and community involvement and was regularly exercised in many places. Some evacuation centres were not located far enough inland or on high enough ground because they were not designated using the worst-case tsunami inundation.

There was extensive effective use of both designated and informal vertical evacuation buildings. The most important considerations for effective use are sufficient height (in relation to expected inundation depth), reinforced concrete construction, community engagement, owner agreement, signage, 24-hour access and evacuee welfare. More than one building owner considered use of their building in evacuation as corporate social responsibility. To enhance evacuee safety it is prudent to minimise the opportunities for spilled accelerants such as oil, and debris such as logs in tsunami-prone locations.

KEYWORDS

Great East Japan earthquake and tsunami, evacuation planning, evacuation response, vertical evacuation, natural warning, tsunami warning.

1.0 INTRODUCTION

1.1 Background to the event

The moment magnitude (Mw) 9.0 Great East Japan earthquake occurred at 14:46 (Japanese Standard Time) on March 11th 2011. The earthquake mechanism was reverse faulting at a depth of 24 km on the subduction zone plate interface at the Japan Trench, with the epicentre at N38.1, E142.9, 130 km offshore of the Oshika Peninsula (Japanese Meteorological Agency, 2011a). The total rupture area is estimated to be 380 km long and 90-130 km wide (Geospatial Information Authority of Japan (GSI), 2011a). Strong ground shaking was felt across Japan, and while Japanese Meteorological Agency (JMA) shaking intensity 7 was recorded at one location (Kurihara City, Miyagi Prefecture), locations in Iwate and Miyagi Prefectures generally experienced maximum JMA intensities of 5 Lower to 6 Upper (the perception and impacts of which are described in Table 1). This level of shaking corresponds approximately to Modified Mercalli Intensities 7 to 10 (Table 2), used in New Zealand and the U.S.

Seafloor geodetic data indicates co-seismic displacement of up to 3 m in an upward direction (Sato et al., 2011), which was sufficient displacement to generate the tsunami that caused damage along the entire east coast of Honshu, and particularly significant damage in Iwate, Miyagi, Fukushima and Ibaraki Prefectures. Coastal towns were afforded a minimum of around 20-25 minutes between the earthquake and arrival of the first significant (inundating) tsunami waves. Some areas, such as Ishinomaki City, experienced five significant waves, the latest of these arriving at least 2 hours and 15 minutes after the earthquake. Many areas (for example, Natori City and Kesennuma City) remained inundated with standing water until at least March 12th 2011, with frequent subsequent flooding due to co-seismic subsidence at the coast of up to 1.2 m (Geospatial Information Authority of Japan (GSI), 2011b). In Kesennuma, fires that had ignited during the initial tsunami waves continued to burn on March 12th.

There are some similarities between this event and expectations of a Cascadia tsunami in Washington State (WA). According to simulations by Venturato et al. (2007), expectations in Washington are for 1-3 m of seafloor deformation and 1-2 m co-seismic subsidence – similar to that experienced in Tōhoku. Tsunami waves are expected to arrive within as little as 20 minutes and the second wave to reach shore has been modelled at 5-6 m height for Ocean Shores, WA and 7-8 m at Long Beach, WA. These wave heights are sufficient to inundate the 2nd and 3rd storeys of reinforced concrete (RC) or steel buildings and destroy timber buildings near the coast.

The extent of destruction that this magnitude of event can cause is highlighted by damage statistics from the National Police Agency of Japan (2012): 118,810 structures suffered total collapse, 176,964 partial collapse and 479,429 partial damage in Iwate, Miyagi, Fukushima and Ibaraki Prefectures. Life loss from this event at February 14th 2012 stood at 19,263 dead and missing (Fire and Disaster Management Agency of Japan, 2012). Fatality rates were variable between the cities and towns affected – Table 3 shows that the fatality rate for the locations visited in this research range from 2% to 8%. The highest recorded fatality rate exceeded 11.5% in Onagawa Town (not visited during this reconnaissance).

Table 1 Human perception and indoor/outdoor effects at JMA intensity 5 Lower to 6 Upper. Extract from Japanese Meteorological Agency (2011b).

Seismic intensity	Human perception and reaction	Indoor situation	Outdoor situation
5 Lower	Many people are frightened and feel the need to hold onto something stable.	Hanging objects such as lamps swing violently. Dishes in cupboards and items on bookshelves may fall. Many unstable ornaments fall. Unsecured furniture may move, and unstable furniture may topple over.	In some cases, windows may break and fall. People notice electricity poles moving. Roads may sustain damage.
5 Upper	Many people find it hard to move; walking is difficult without holding onto something stable.	Dishes in cupboards and items on bookshelves are more likely to fall. TVs may fall from their stands, and unsecured furniture may topple over.	Windows may break and fall, unreinforced concrete-block walls may collapse, poorly installed vending machines may topple over, automobiles may stop due to the difficulty of continued movement.
6 Lower	It is difficult to remain standing.	Many unsecured furniture moves and may topple over. Doors may become wedged shut.	Wall tiles and windows may sustain damage and fall.
6 Upper	It is impossible to remain standing or move without crawling. People may be thrown through the air.	Most unsecured furniture moves, and is more likely to topple over.	Wall tiles and windows are more likely to break and fall. Most unreinforced concrete-block walls collapse.

Table 2 Correspondence between JMA instrumental intensity and Modified Mercalli intensity (after Kunugi, 2000). IJMA is JMA instrumental intensity ('L' denotes Lower, 'U' denotes Upper). IMM is instrumental Modified Mercalli. IMM1 is Modified Mercalli intensity, which corresponds to the same values for New Zealand MMI scale of Dowrick (1996). Thresholds are determined according to the comparison of the description of the intensity at each level.

I_{JMA}	0	1	2	3	4	5L	5U	6L	6U	7	
I_{MM}	1	2	3	4	5	6	7	8	9 ~		
I_{MM1}	1	2	3	4	5	6	7	8	9	10	11 ~

Table 3 Casualty statistics at locations investigated in this report. JMA intensity source: Japanese Meteorological Agency, 2011c. Total population source: Statistics Bureau, 2010. Casualty statistics source: Fire and Disaster Management Agency of Japan, 2012 (except Tarō Town – from Ichiro Matsuo, personal communication). These figures do not account for daily movement of population and fatality rate may have been affected by daily commuting patterns (after EEFIT, 2011)

Municipality	JMA intensity	Total population	Population residing in inundated area	Percentage of total pop. Residing in inundated area	Dead and missing (at 14 feb 2012)	Fatality rate (population of inundated area)
Tarō Town	5L to 5U	4,876	3,000	62%	185	6%
Kamaishi City	5U to 6L	39,578	13,164	33%	1,047	8%
Ōfunato City	6L	40,738	19,073	47%	425	2%
Kesennuma City	6L	73,494	40,331	55%	1,368	3%
Minami-Sanriku Town	6L	17,431	14,389	83%	875	6%
Ishinomaki City	6L	162,822	112,276	69%	3,739	3%
Natori City	6U	73,140	12,155	17%	966	8%
All areas	-	412,079	214,388	52%	8,605	4%

1.2 Goals, methodology and report structure

Many of the issues experienced in terms of evacuation preparedness and response in Tōhoku during this event are extremely relevant to tsunami mitigation activities in the State of Washington owing to local earthquake and tsunami hazard posed by the Cascadia Subduction Zone, and in New Zealand due to similar earthquake hazard on the offshore Hikurangi subduction margin.

This research set out to investigate key lessons from Japan that are pertinent to emergency management and tsunami preparedness in Washington and New Zealand under the following categories:

- Characteristics of tsunami from a high magnitude local subduction zone earthquake (Section 1.1)
- Level of tsunami preparedness in affected communities and its role in mitigating life loss (Sections 2.1 and 3.1)
- Effectiveness of tsunami warnings and evacuation strategies (including maps and signs) (Sections 2.2 to 2.6 and 3.2 to 3.6)

- Factors affecting emergency response (Sections 2.3 to 2.5 and 3.3 to 3.5), and
- Performance of structures under earthquake shaking and subsequent tsunami loading, particularly those designed for/designated as vertical evacuation (Sections 2.7 and 3.7)

The research was commissioned by Washington Military Department Emergency Management Division (Washington EMD) and supported by New Zealand Ministry of Science and Innovation core geohazards funding to GNS Science, and was conducted in collaboration with local Japanese colleagues. The report focusses on lessons for Washington and New Zealand.

This report provides a reconnaissance-level analysis of the themes which arose during interviews of disaster prevention officials and emergency services officials at seven tsunami-affected locations in Iwate and Miyagi Prefectures. We discuss these themes in Section 2.0, and provide recommendations in Section 3.0 for furthering tsunami preparedness and mitigation in the Washington and in New Zealand. Interview data has been augmented with discussion of local maps, posters, reports, documents and signs in both Japanese and English. Appendices 1 and 2 show the interview questions in English and Japanese and Appendix 3 gives a summary of the key points that were raised during interviews. Appendix 4 provides a summary of vertical evacuation buildings in the locations visited, including information on construction, signage, inundation on 11th March, and number of people who took refuge there.

1.3 Interviews

The field survey was carried out from October 19th to 28th 2011 in collaboration with Mr Ichiro Matsuo of NPO-CeMI, and Professor Hitomi Murakami of Yamaguchi University. Due to the timing of the survey 7 months after the tsunami, the interviews draw on information gathered through many surveys carried out by local researchers in the interim period.

Semi-structured interviews with city officials (civil protection, emergency management, fire department and police department staff) and some local residents were carried out in seven locations in Iwate and Miyagi Prefectures: Tarō Town, Kamaishi City, Ōfunato City, Kesennuma City, Minami-Sanriku Town, Ishinomaki City and Natori City. These locations comprise variable topography of rias and plains, and among them experienced a wide range of impacts and evacuation issues on March 11th 2011. A map of the locations investigated is presented in Figure 1 and a summary of casualty statistics is provided in Table 3.

The focus of interviews was:

- Natural and informal warnings: awareness, observations/experience and response
- Style and derivation of evacuation maps
- Official warning timing and dynamics
- Evacuation timing, mechanisms and issues
- Vertical evacuation buildings – availability, designation, public awareness, utilisation, relationship to maps, and post-event review

The interview questions were translated into Japanese (see Appendices 1 and 2) and circulated to interviewees in the days ahead of our meetings. Note that during interviews the ordering of interview topics naturally fell in the sequence given above, rather than the written sequence given in Appendices 1 and 2. Sections 2.0 and 3.0 of this report have been structured according to that natural ordering.

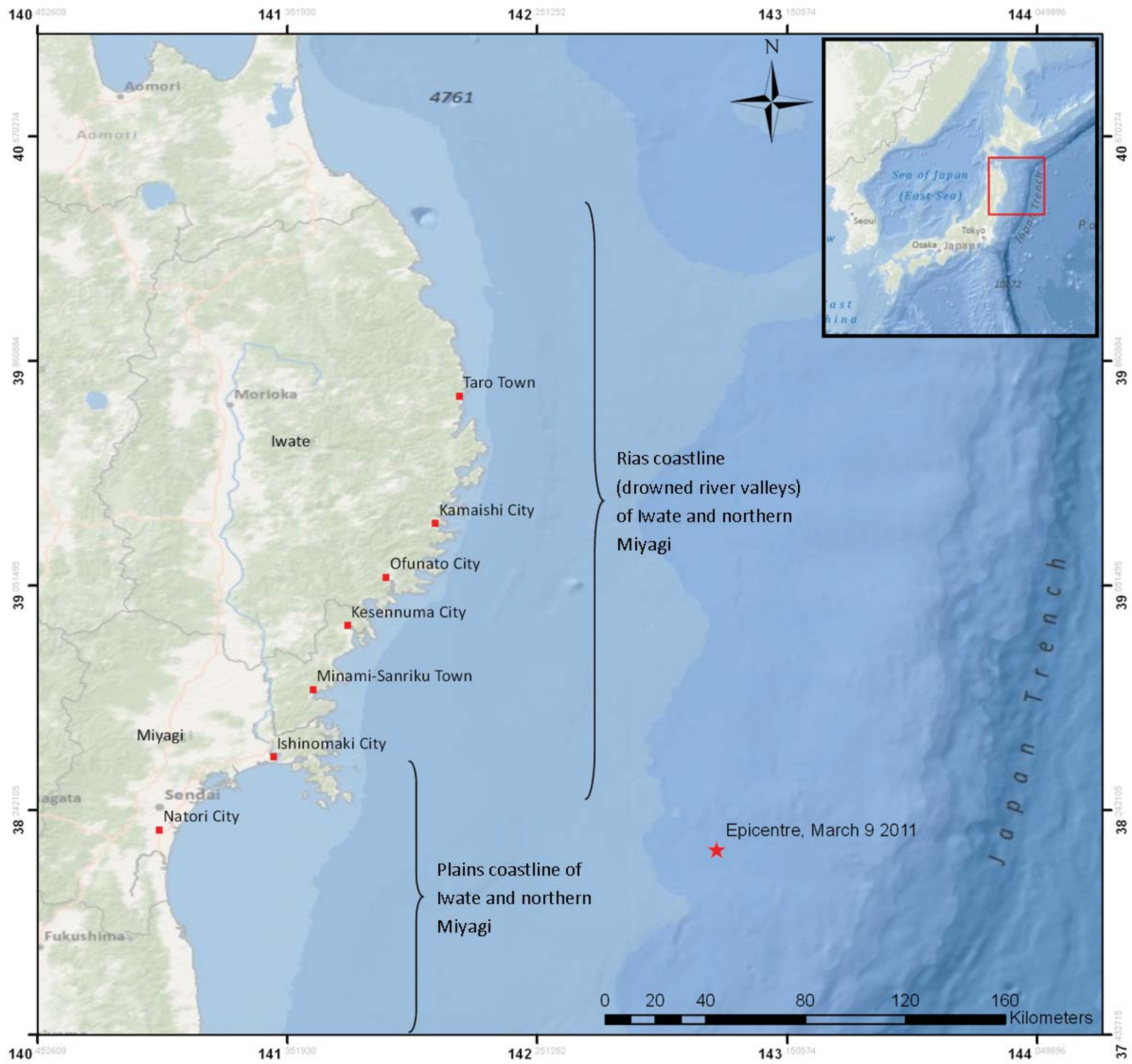


Figure 1 Map of locations investigated in this report, with coastal topography and epicentre of March 11th main shock indicated. Note the grey lines delineate prefectures. All of the locations investigated lie within Iwate and Miyagi prefectures (labelled), which received the largest tsunami wave heights and most of the casualties. Base map credits: GEBCO, NOAA, National Geographic, DeLorme, Esri.

1.4 Tsunami preparedness in the Tōhoku region of Japan

1.4.1 Previous events and hazard estimation

Tsunami preparedness in Japan is addressed in the Basic Disaster Plan as a subsection of Earthquake Countermeasures, which is summarised in a plan report from the Cabinet Office Government of Japan (2007). The Cabinet Office has produced guidelines for the creation of tsunami hazard maps and designation of tsunami evacuation buildings (Hiroi et al., 2005). These are followed by prefecture and municipality governments under their responsibility to formulate and implement local disaster management plans, based on the national plan.

Tsunami preparedness in the Tōhoku region is borne out of well-recorded impacts of previous events, primarily the 1896 Meiji Sanriku, 1933 Shōwa Sanriku and the 1960 Chile tsunami. A technical investigation to define characteristics of expected earthquakes of the Japan Trench was carried out between 2003 and 2006, in which the expected damage from these events was estimated and necessary mitigation strategies developed. Eight earthquake scenarios were examined for the northeast of Japan, and their estimated impacts used to develop strategies for mitigation of economic damage and life loss (Central Disaster Prevention Council, 2008). Analysis of these eight separate events formed the basis of hazard assessment from Japan Trench tsunami until early 2011, with no consideration for the rupture of multiple segments at once (Expert Committee on the Working Group on Tsunami disaster evacuation, 2010), as occurred on March 11th.

Preparedness prior to March 2011 focussed on the locally recurrent Miyagi-ken-oki (“Offshore Miyagi Prefecture”) tsunami, which has been consistently used as the basis for numerical tsunami simulation, hazard mapping and determination of the design-level tsunami for structural defences. The Miyagi-ken-oki earthquake is a recurrent earthquake event of around magnitude 7.5 with a source area off the Oshika Peninsula, Miyagi Prefecture (in the same area as the epicentre of March 11th event, Figure 1). This size of earthquake has occurred five times since 1835, the most recent occurrences in 1978 and 2005, with no significant tsunami. The event was estimated to have a mean recurrence interval of 35.2 years and an estimated 97% probability of occurrence in the period 2002-2032 (Ohtake and Ueda, 2002). Due to the frequency of this type of event and knowledge of the source area, this scenario is the one most often simulated to map tsunami hazard, while inundation heights and extents of the Meiji and Shōwa era tsunami are often also delineated on hazard maps (see Section 2.2).

The absence of the 869 Jogan Tsunami in informing preparedness activities is surprising given that it has been demonstrated inundation extended more than 4 km inland (Minoura, Imamura, Sugawara, Kono, and Iwashita, 2002). This extent is similar to the inundation extent on March 11th 2011 in the same area. This extreme event was not included in hazard modelling and mapping due to it being perceived as an outlier (Earthquake Engineering Research Institute, 2011a), and perhaps also due to a lack of knowledge of the potential source area and absence of tsunami deposit data on the inundation extent on other sections of the Tōhoku coast.

1.4.2 Hazard estimation and mapping

Hazard estimation is consistent at prefecture level as it is the prefectural government who carry out the tsunami estimation for all coastal municipalities within their prefecture. The delineated hazard is provided to the individual municipality governments, who produce hazard maps and evacuation maps as part of their local disaster management plan. Community engagement with evacuation mapping is discussed in Section 2.1, which includes examples of hazard maps from the locations visited. The inconsistencies between municipalities in representation of hazard and evacuation routes or refuges are shown in Section 2.2 and in the Miyagi Prefecture online database of maps (Miyagi Prefectural Government, 2004).

1.4.3 Education and evacuation exercises

Regular education and evacuation drills are conducted by municipal governments to maintain disaster prevention awareness. A national "Disaster Reduction Day" is held annually, during which every prefecture carries out large-scale decision-making simulations. There is also an annual tsunami evacuation drill held in Miyagi and Iwate prefectures on the anniversary of the 1960 Chile tsunami. In addition to this, disaster prevention activities are carried out by local groups at the city or neighbourhood level for tsunami in addition to other perils.

The philosophy of *tsunami tendenko* relies on the trust that every person in a community knows what to do in the event of a tsunami to self-evacuate immediately (rather than helping or waiting for others) and get to an evacuation refuge according to a home or work evacuation plan. This philosophy is described very well in a video documentary by D. Harding and B. Harding (2011).

Despite these exercises and the well-known history of tsunami in Japan, a review of evacuation in Kesennuma City following a local offshore earthquake in 2003 (causing JMA shaking intensity up to 6 Lower) showed that almost 86% of residents, including those in the tsunami hazard zone, did not evacuate (Suganuma, 2006) and a low rate of evacuation also occurred following a tsunami warning in 2004 in the Tokaido region. Suganuma (2006) describes a decline in disaster prevention awareness over time since the 1995 Hanshin-Awaji (Kobe) earthquake. A survey of 1,808 residents in areas of Sendai subject to a tsunami warning on May 28th 2010 (following the Maule, Chile earthquake) shows only 53.9% of residents evacuated (City of Sendai, 2010).

1.4.4 Earthquake early warning system and rapid official tsunami warnings

Another high-profile tool in the preparedness framework for Japan is the JMA-operated earthquake early warning system. A network of seismometers allows rapid detection of earthquakes and analysis of the magnitude and hypo-central location. P-wave arrival time near the epicentre allows estimation of arrival for the more damaging S-waves. This system can provide tens of seconds warning ahead of damaging ground shaking, allowing time for people to find cover, and also facilitates rapid estimation of tsunami generation.

Within 2-3 minutes of a tsunamigenic earthquake occurring, estimated tsunami wave heights and arrival times can be provided in a tsunami advisory or warning, based on the estimated earthquake magnitude (Japanese Meteorological Agency, 2011d; Ozaki, 2011). Tsunami warnings are issued to 66 individual regions by JMA with a level of severity determined by expected tsunami height at the coast (Table 4). Observations at offshore GPS buoys are used to revise earlier estimates as water level or pressure changes at the buoy (Ozaki, 2011). JMA disseminates advisories and warnings to TV and media, and to local governments using a combination of dedicated online, radio, and satellite wireless networks.

Municipality governments are then responsible for issuing evacuation orders to the public on receipt of a warning from JMA or national government (Suganuma, 2006), which is achieved via roof-top or street-based loud speakers and indoor receivers.

Table 4 Specifications of tsunami warning/advisory issued by JMA (Source: Japanese Meteorological Agency, 2006).

Category		Indication	Forecast tsunami height
Tsunami **Warning**	**Major tsunami**	Tsunami height is expected to be **3 meters or more**.	Forecast heights are specifically indicated for every region; namely 3 m, 4 m, 6 m, 8 m and 10 m or more.
	Tsunami	Tsunami height is expected to be **up to 2 meters**.	Same as above, but 1 m or 2 m.
Tsunami **Advisory**		Tsunami height is expected to be **about 0.5 meters**.	0.5 m

1.4.5 Coastal defences

'Hard' coastal defences are a common feature of the Japanese coastline, and at a given location may include a combination of offshore breakwaters, groynes, seawalls (at the shoreline, or further inland), concrete revetments and river-mouth flood gates. The design-level tsunami for these defences is often those that have been previously experienced: Kamaishi breakwaters are based on the 1896 Meiji tsunami; the Tarō seawall was constructed as a result of the effects from the 1896 and 1933 tsunami. Other defences are designed according to the Miyagi-ken-oki tsunami scenario.

1.5 Tsunami preparedness in the State of Washington and New Zealand

The authors have previously undertaken numerous social research projects on tsunami preparedness and evacuation in United States (specifically the State of Washington), New Zealand and Japan. These projects have been in collaboration with local and national level emergency managers in New Zealand, Washington EMD, and CeMI (an environmental planning non-profit organisation) in Japan. They have included studies of public perception, tourism preparedness, warning system effectiveness, evaluation of evacuation plans, and standardisation of mapping and signage.

1.5.1 Washington

For over a decade the State of Washington has developed a programme of tsunami understanding and preparedness, through a combination of state initiatives and wider national programmes. This occurred in response to the increased awareness among scientists of the tsunami risk posed by the earthquakes along the Cascadia Subduction Zone, offshore of the Pacific Northwest states. As part of an integrated evaluation program, Johnston et al. (2005) carried out several surveys and focus groups between 2001 and 2003 to evaluate tsunami preparedness in Washington. This work found that earlier initiatives had been "moderately to highly effective in raising public awareness of the tsunami hazard", but that this awareness did not necessarily translate into preparedness, which was recorded as "low to moderate". Awareness among visitors was much lower than that of residents, and Johnston et al. (2007) followed up these findings with an assessment of preparedness in the tourism sector. This work, carried out in 2005, found a low level of staff training on tsunami hazards, and little provision of hazard information to guests. In response to the findings of

Johnston et al. (2005), various outreach initiatives and educational tools were developed to increase preparedness in Washington, while staff training, workshops and a guidebook were developed specifically for the tourist sector in response to the findings of Johnston et al. (2007). The most recent follow-up research in this series of evaluations, Johnston et al. (2009), noted that high staff turnover remains a challenge to achieving high levels of preparedness in the tourism sector although there have been improvements. It was also recognised by Johnston et al. (2009) that improvements have been made in the provision of loudspeaker warning systems and community-based evacuation drills, although participants from both Ocean Shores and Long Beach expressed concern over the available evacuation routes. Further evaluations of siren tests and community-based evacuation exercises were carried out in September 2010; the findings showed mixed levels of siren audibility in the current system, but highlighted the effectiveness of siren and evacuation drills as a means of hazard education (Leonard et al., 2011).

The Washington EMD program focusses on education and preparedness of both the resident public and the tourism sector. This is achieved in part through public forums, town hall meetings in collaboration with local Emergency Managers, and training of local volunteers to serve as community tsunami educators. Tsunami information, preparedness and evacuation educational materials are provided via internet, brochures, fact sheets, video, resource guides, guidebooks, childrens' cartoon books, trivia sheets, games, and evacuation maps are available (http://www.emd.wa.gov/hazards/haz_tsunami.shtml). Evacuation signage is widely deployed in tsunami hazard zones.

Tsunami warning infrastructure includes All Hazard Alert Broadcast (AHAB) to radios and free-standing siren towers and NOAA weather radios are provided to low income families and schools. Twelve communities in Washington are recognised as 'Tsunami Ready' under the National Oceanic and Atmospheric Administration/National Weather Service (NOAA/NWS) 'Tsunami Ready' program, which helps communities increase tsunami preparedness (NOAA/NWS, 2011).

The provision of evacuation maps is a major initiative covering over 20 different locations. Some maps use three zones of 'greatest risk', 'marginal risk' and 'higher ground', evacuation routes, assembly areas, roads, rivers and place names (Figure 2). Other maps use only two zones: 'tsunami hazard zone' and 'outside of hazard zones', for example in Clallam County (Figure 3). These maps are provided with additional information as part of a short brochure. In the planning of evacuation routes and assembly areas, Washington EMD and the Department of Natural Resources assess landslide and liquefaction hazards which may impede evacuation.

There are inconsistencies between maps produced by different state authorities in the U.S. and Kurowski, Hedley, and Clague (2011) discuss this issue in their evaluation of tsunami evacuation maps in Washington. New National Tsunami Hazard Mitigation Program (NTHMP) guidelines have been released to ensure there is enhanced consistency in this respect from January 2012 (NTHMP Mitigation and Education (MES) Subcommittee, 2011).

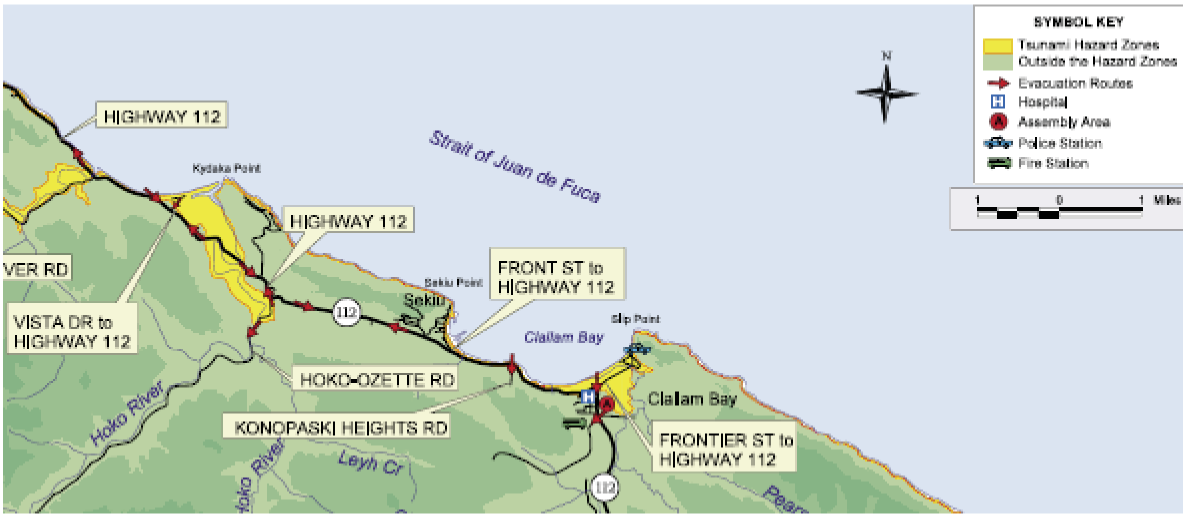


Figure 2 Excerpt from the tsunami evacuation map Clallam Bay, Clallam County, Washington. This map uses 2 zones, local sites of importance (fire department, etc.), evacuation routes and assembly areas (Clallam County Emergency Management, n d).

Figure 3 An example evacuation map in Washington. This map is for Long Beach and Ilwaco, Pacific County, and illustrates the use of 3 zones, evacuation routes and assembly areas (Pacific County Emergency Management, 2007).

Signs for hazard zones and evacuation routes are standardised along the Pacific Coast, with signs indicating the tsunami hazard zone with brief instructions regarding natural warnings (Figure 4) and evacuation route signage (Figure 5).

Figure 4 ‘Tsunami Hazard Zone’ sign with instructions to evacuate to high ground or inland in response to an earthquake.

Figure 5 ‘Tsunami Evacuation Route’ sign with arrow depicting the direction of evacuation. These signs are placed regularly along roads in tsunami hazard zones.

1.5.2 New Zealand

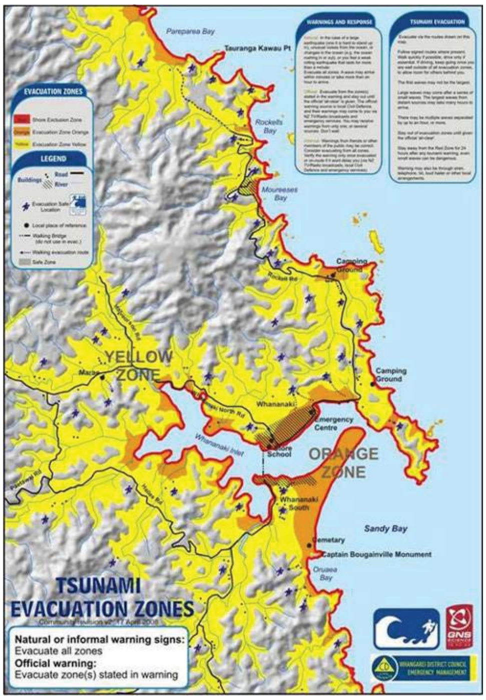
The risk of tsunami from the offshore plate boundary has been apparent to scientists in New Zealand for well over a decade, but political and public traction for mitigation only increased following the Indian Ocean tsunami in 2004. Guidance for New Zealand is now in place for tsunami warning (MCDEM, 2010a), evacuation mapping (MCDEM, 2008a), signage (MCDEM, 2008b), land use planning (Saunders et al., 2011), and guidance for official CDEM messages (MCDEM, 2010b).

The standard base map for evacuation maps shows three evacuation zones: a coastal exclusion zone that can be placed off limits when only the foreshore is at risk, an orange zone that intends to cover most distant sources, and a larger yellow zone that includes the local and regional sources (Figure 6). The maps are then developed in discussion with the local community with respect to what is depicted on the map – e.g. road names and key infrastructure.

Standard signs include an ‘evacuation zone sign’, information boards which include the evacuation map, various ‘evacuation route’ signs, an ‘evacuation safe location’ sign, and a ‘previous event’ sign (which is unused and may be re-considered in light of Tōhoku events). The first two signs are shown on the information board (Figure 7), while the latter two have not yet been implemented in New Zealand.

Neither Washington nor New Zealand employs large amounts of ‘hard’ coastal defences for coastal protection – sea defences are typically placed in ports and are designed to protect against storm waves, not tsunami waves. Beach and dune environments dominate the shoreline in low-lying areas of both regions.

Currently there are no early warning systems in place for Washington or New Zealand for local source tsunami. Local tsunami warning would be natural and informal warnings, whereas regional to distant tsunami allow warnings to be disseminated through official channels. It is known that there is public misunderstanding that official warnings and warning hardware (e.g. sirens) will cover local sources – this is an ongoing issue for public awareness and preparedness.



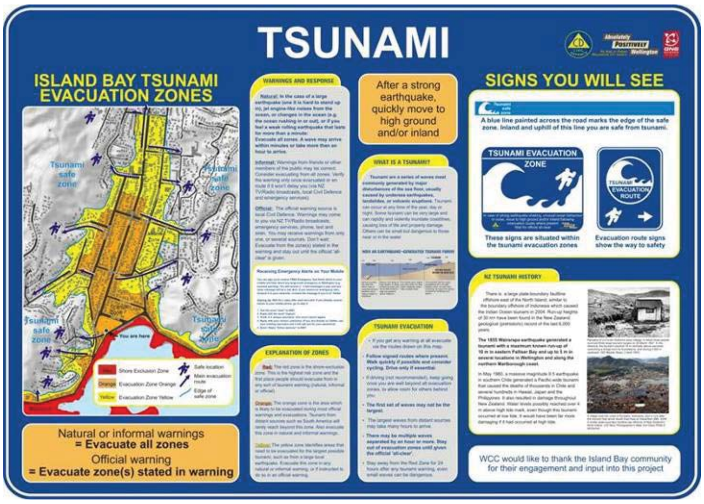


Figure 6 An example tsunami hazard map from Whananaki, New Zealand.

Figure 7 An example tsunami evacuation map and information board as displayed outdoors (1.2 m wide) in the Island Bay community, Wellington, New Zealand.

2.0 INTERVIEW OUTCOMES

This section discusses emergent themes from the interviews with disaster prevention and emergency service officials in the Tōhoku region, and relates these issues to Washington and New Zealand. Each sub-section contains information which has some cross-over to other themes, and several themes may be inter-related or influenced by the same factors. No theme or event highlighted here should be considered in isolation. A summary of the key points raised in interviews at each location is presented in Appendix 3 for quick reference. Recommendations for Washington and New Zealand are given separately in Section 3.0 in consistent sub-sections.

2.1 Community involvement in evacuation planning and preparedness

Community disaster groups are common in Japan and many cities and towns have multiple disaster prevention groups who are engaged with local government in awareness and education activities at the neighbourhood level.

High levels of community engagement were apparent in most of the interviews, particularly with residents being involved in production of evacuation maps in Kamaishi, Ōfunato, Kesennuma, and Minami-Sanriku. In these locations, the prefectural government provides hazard mapping to the municipal government who then work with community groups to develop the evacuation maps and identify suitable (or historical) places of refuge. This approach is not ubiquitous – in Natori City, the development of evacuation mapping was said to be the responsibility of local government who then provide the finalised evacuation map to the public.

The local community was involved in identification of potential buildings for vertical tsunami evacuation in Ōfunato, Kesennuma and Kamaishi. Community members had either approached building owners about the potential use of a building, or approached municipal government with suggestions of potential buildings. There have been mixed outcomes regarding the eventual official designation of buildings where the community have been involved in this process, but it is clear that community engagement in vertical evacuation strategies is beneficial, as discussed in Section 2.7.

In addition to the nationwide tsunami disaster drill carried out annually on the anniversary of the 1960 Chile tsunami, community groups in Natori City, Ishinomaki City and Miyako City carry out more regular drills for tsunami, as well as other hazards. The officials we interviewed were not able to provide data on the levels of resident participation in such drills.

Community involvement in planning and preparedness is well-established in Washington, where the Emergency Management Division engages with coastal communities through county level emergency management groups, who co-ordinate community education sessions and evacuation drills. There has previously been a high level of community interest in participating in focus groups on tsunami risk and preparedness, with proactive preparation among many hotels in coastal Washington (Johnston et al., 2005). An AHAB siren test and evacuation drill on September 21st 2011 achieved 100% participation of schools in Grays Harbor County, although participation was lower in other counties (J. D. Schelling, personal communication, December 17th 2011), illustrating the high levels of engagement which have been achieved. Project Safe Haven is a current vertical evacuation strategy development project, in which the community drives discussion of conceptual facility locations, design of facilities, and development of a preferred strategy (Project Safe Haven, 2011a, 2011b). This project provides raised awareness in the coastal communities and is an excellent model for developing and enhancing community-based evacuation strategies.

In New Zealand, national guidelines and standards for maps and signs have existed since 2008, but the application of these guidelines at community level is just developing momentum in 2012. Locally specific evacuation maps have been developed across several New Zealand regions, with varying approaches to community engagement. Most local authorities at least consult the community on appropriate evacuation routes at community meetings. Whangarei District and Wellington City have developed maps with some communities as part of all hazard community response planning, with full ownership of maps, plans, sign locations and exercise planning lying with the community planning group. Evacuation drills presently only occur in a few communities nation-wide. Civil Defence and Emergency Management (CDEM) Groups of emergency services and disaster managers are mandated through legislation in all regions, and community-based planning for tsunami is expected to continue to grow in coming years.

2.2 Hazard/evacuation maps and signs

2.2.1 Hazard/evacuation maps

Maps depicting tsunami hazard (with or without evacuation facilities and routes) had been developed prior to 2011 for all of the communities visited during this research. The content and style of evacuation maps therefore varies greatly between municipalities in terms of both hazard used and features pertaining to evacuation. Community involvement in defining evacuation routes was a feature of map development in Kamaishi, Ōfunato, Kesennuma and Ishinomaki, but in Natori City the definition of refuges and evacuation routes was carried out by the municipal government.

Although a full evaluation of evacuation maps is outside of the scope of this report, notable variations in the maps for locations visited (Figure 8 to Figure 14, obtained from local officials or government websites) are summarised below.

The inclusion of previous or modelled events is inconsistent. To delineate the tsunami hazard, most municipalities map recorded inundation heights or extents of one or more of four key tsunami scenarios: the 1896 Meiji tsunami, 1933 Shōwa tsunami and 1960 Chile tsunami, and the modelled extent or heights of tsunami from the expected Miyagi-ken-oki earthquake. The hazard map for Ishinomaki City used the modelled Miyagi-ken-oki earthquake and the official recognises that the consideration of source events in their approach was not robust enough. It appeared that several emergency managers interviewed may not have had a clear idea of which data originated from modelling, and which represented historic events, but this may have been uncertainty related to language translation. We were unable to discuss clarity of the maps with members of the public.

Hazard or evacuation zone style varies between maps. Some maps use variable colouring to indicate modelled inundation depth (Figure 10, Figure 11, Figure 13); others provide only a single colour delineation of inundation extent in historic events (Figure 8, Figure 12).

Generally maps appear quite crowded with a range of topographic, cultural as well as tsunami evacuation related content. In some cases additional historic event lines are present as well as coloured zones. However, the location of at least one tsunami hazard zone stands out well in all maps.

All of the evacuation maps that we observed show refuge locations although, the symbols used are inconsistent between maps. Definitions of refuges vary and include generic ‘safe refuge’, ‘tsunami-specific refuge’, ‘vertical evacuation building’ (Figure 11) or ‘welfare location’s, with some maps using different symbols to define refuge type. Many of the refuges shown on maps were designated based on community function and capacity and were typically schools or community centres. During the evacuation on March 11th many people evacuated directly to designated shelters.

There is limited illustration of evacuation routes on the maps. Ōfunato (Figure 10) and Kesennuma (Figure 11) use arrows indicating the approximate best route out of the inundation zone, but there is no prescriptive route marked. Other maps do not include any graphical indication of evacuation route.

Text-based evacuation or preparedness information is provided on most maps, but the content of this information varies. The Tarō Town map includes information on previous tsunami events, while the maps for Ōfunato and Natori have advice on preparedness and space for residents to fill out important information.

The interviews carried out in this study did not provide sufficient insight into the impact of inconsistent evacuation maps on evacuation on March 11th 2011. This requires further research as Japan amends and enhances its hazard modelling and evacuation mapping in light of the Tōhoku tsunami. Recent work by Kurowski et al. (2011) highlighted that some similar inconsistencies occur in evacuation mapping in Washington and Oregon (see Section 1.5), and any research in Japan into the impacts of variable evacuation maps on the response of transient populations or different levels of risk perception in Japanese coastal communities could provide additional guidance as to enhancing the approach taken in Washington. Consistency in evacuation mapping is already recognised as an issue in the United States and all maps produced after January 1st 2012 are subject to guidelines set out by the NTHMP Mitigation and Education Subcommittee (2011) to ensure minimum requirements in evacuation mapping. Updating of current maps to ensure consistency is expected to be complete by the end of 2012 (J. D. Schelling, personal communication, March 9th 2012).

Consistent evacuation mapping in New Zealand is being achieved by following the guidelines set out in MCDEM (2008a). Some variation still exists in terms of the delineation of the location of evacuation zone boundaries, where local CDEM group members are responsible for producing their own mapping of zones from hazardous wave heights e.g. Hawke’s Bay CDEM Group (2011). In New Zealand there is a strong emphasis on simple maps showing zones, routes and safe locations, and as concise as possible messaging focussing on the required response to natural and informal warnings (evacuate all zones) vs. official warnings (the warning will state the zone(s) to evacuate). One community group, in conjunction with Wellington Emergency Management Office, has delineated the beginning of the mapped safe zone with a blue line painted across roads throughout the suburb. This has generated very high public awareness and is planned to be rolled out city-wide.

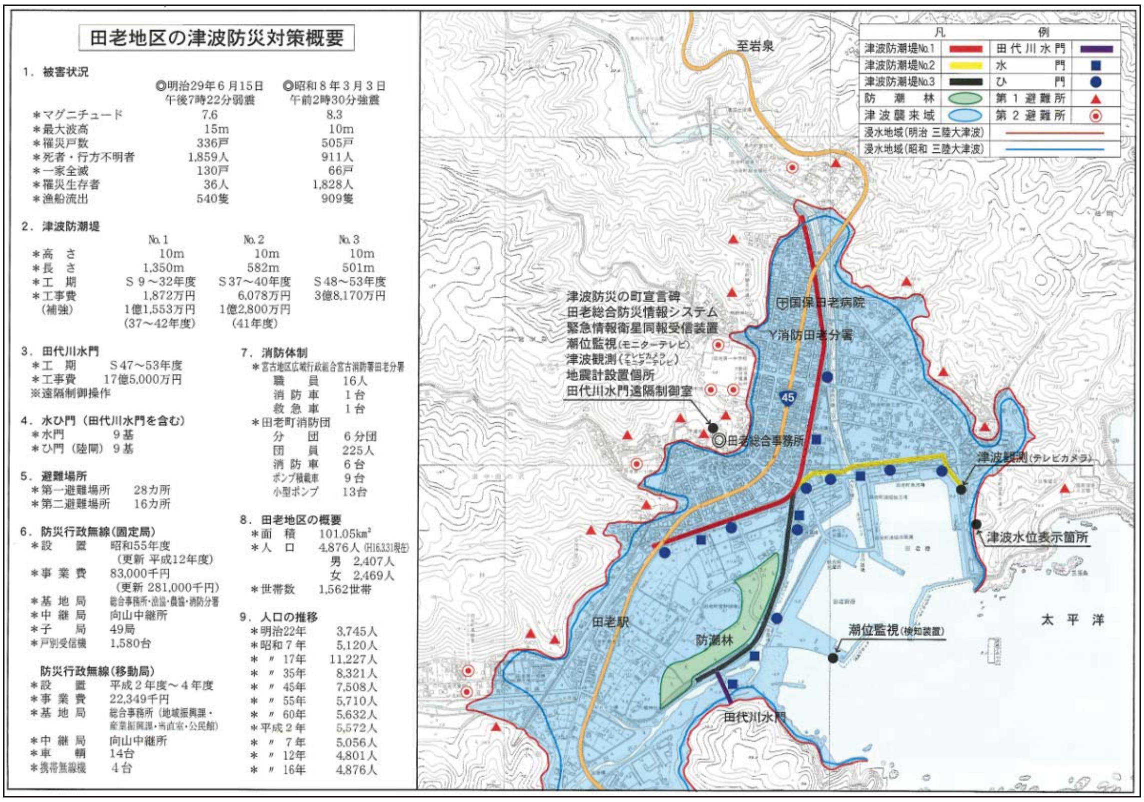


Figure 8 Extract from Tarō tsunami hazard map, indicating three sections of tsunami wall (red (1958 section), black and yellow thick lines), tsunami gates (blue triangles and circles). The inundation extent of the 1986 Meiji (thin red line) and 1933 Shōwa tsunami (thin blue line). Evacuation refuges are marked as red triangles and welfare centres as red circles. Source: Tarō Town Disaster Prevention Office.

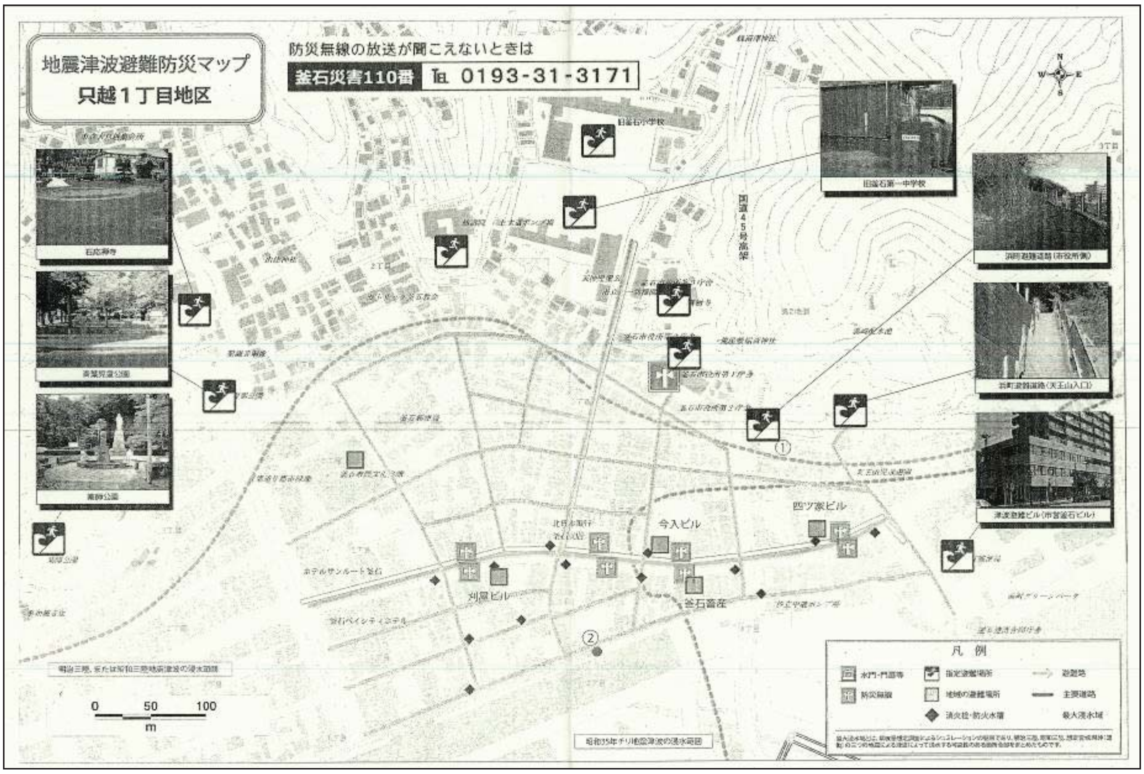


Figure 9 Kamaishi City evacuation map (Source: Kamaishi City Disaster Prevention Office).

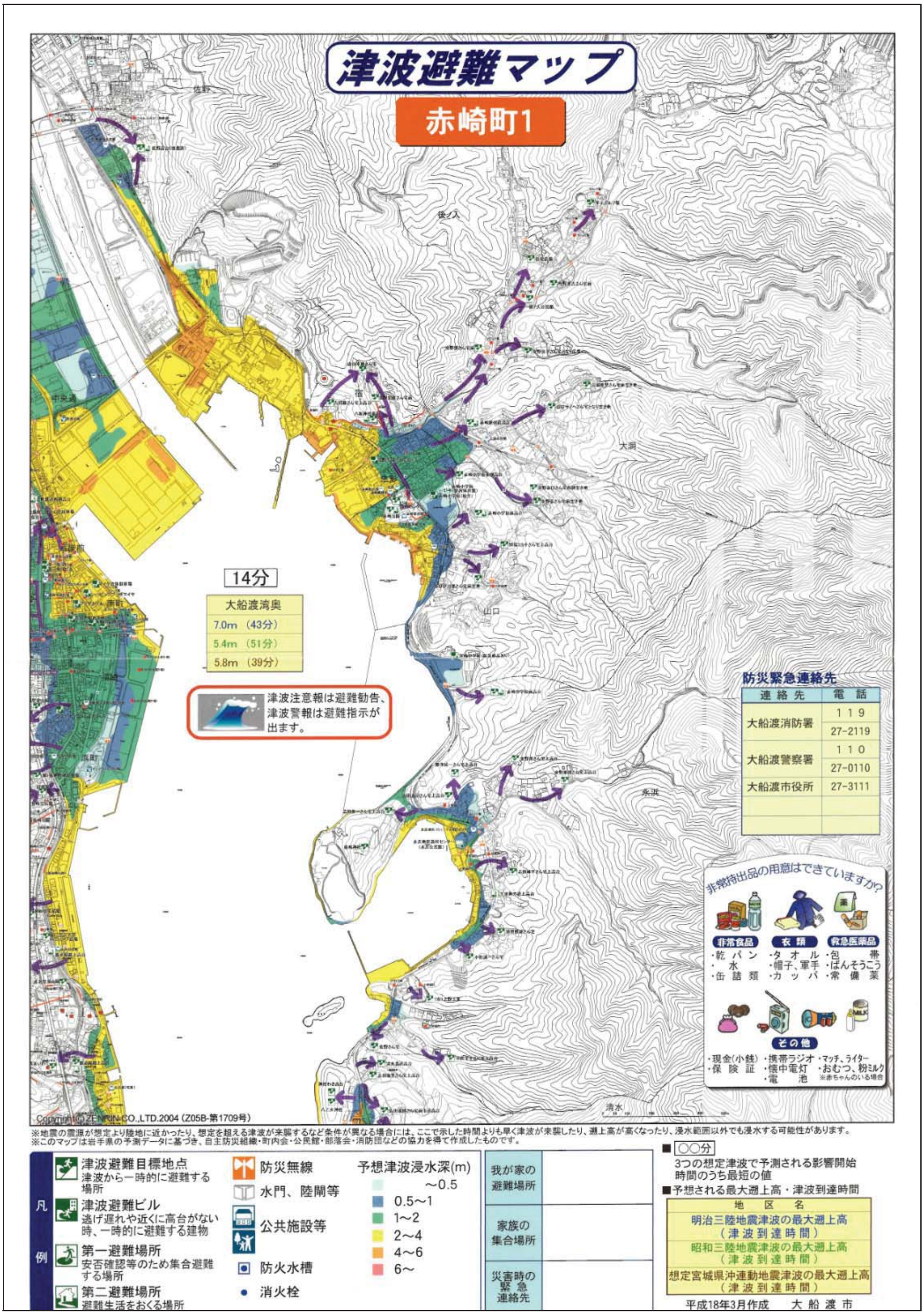


Figure 10 Ōfunato City evacuation map (Source: Ōfunato City Disaster Management).

Figure 11 Excerpt from Kesennuma City evacuation map (Source: Kesennuma General Affairs Department).

Figure 12 Minami-Sanriku hazard map with evacuation refuge locations indicated by numbered red circles (Miyagi Prefectural Government, 2004).

Figure 13 Excerpt from the Ishinomaki tsunami hazard map with evacuation refuges (Ishinomaki City, n d).

Figure 14 Natori City hazard map (Source: Natori City Disaster Prevention Office).

2.2.2 Hazard/evacuation signs

Road signs indicating evacuation routes or extent of inundation zones are inconsistent between prefecture and municipality, however, they form a key part of tsunami preparedness and are commonly seen. This sub-section demonstrates the range of information displayed on signs in Iwate and Miyagi.

Road signs indicating the estimated extent of tsunami inundation zones (Figure 15 and Figure 16) are present along the coast in Kamaishi district. On roads out of Tarō, similar signs mark the extent of inundation in the 1933 Shōwa tsunami.

Figure 15 A sign displayed above the road indicating to drivers that they are entering an estimated tsunami inundation area. These signs were seen on roads within Kamaishi district.

Figure 16 A sign displayed above the road indicating to drivers that they are exiting an estimated tsunami inundation area. These signs were seen on roads within Kamaishi district.

Evacuation route signs in Miyako City and Matsushima Town commonly include the distance to safe places, in addition to a directional arrow. There is consistent use of the green symbol depicting evacuation to high ground (Figure 17 to Figure 20). Matsushima Town also has information boards displaying a schematic map of the entire evacuation route and location of the designated assembly point on the evacuation route (Figure 19) in addition to signs painted onto the pavement in town (Figure 20). This style is not consistent for all signs in Matsushima, however: Figure 21 shows a more basic sign indicating just the direction of evacuation. The inclusion of distance on evacuation route signs is not currently included in signage standards for New Zealand (MCDEM, 2008b) or Washington.

Figure 17 Tsunami evacuation route direction and distance sign displayed on a sign in Hitachihamacho, Miyako City.

Figure 18 Tsunami evacuation route direction and distance sign displayed on a lamp-post in Hitachihamacho, Miyako City.

Figure 19 Tsunami evacuation route information board and directions (with distance to safe location) in Matsushima Town, Miyagi Prefecture.

Figure 20 Tsunami evacuation route sign with direction and distance to safe location painted on the pavement in Matsushima Town, Miyagi Prefecture.

Figure 21 A sign in Matsushima Town, displaying the tsunami evacuation route.

Figure 22 Tsunami evacuation route sign with solar powered lamp, on a road leading to high ground out of Tarō Town.

Tarō Town has signs posted regularly at short distances (20-30 m) along the road out of the Town towards high ground. These signs are mounted on posts with solar powered lamps for night-time use (Figure 22).

Ōfunato City uses signs indicating the walking route direction and distance to safe refuges, providing the name of the refuge in English and Japanese (Figure 23). The city also uses signs which light up at night.

Figure 23 Evacuation route sign in Ōfunato City, indicating the distance to a "tsunami emergency place of refuge". Photo courtesy of EEFIT.

In addition to the information boards and pavement-mounted signs in Matsushima Town, we also observed an example of natural warning education in the centre of town, situated close to several tourist sites (Figure 24). This sign displays the standard green icon representing evacuation to high ground.

Another style of tsunami warning sign was observed on a road out of Kamaishi (Figure 25); this symbol is consistent with other signs observed in the district in terms of the yellow and black icon used, but this symbol not seen in any other districts, which appear to only use the green evacuation symbols. Both the green and yellow symbols have been accepted as ISO international standards after being proposed by Japan. However, both New Zealand and Washington use a blue sign style very similar to each other, which is common in other countries. All signs discussed above have bilingual text for at least the basic information, enhancing understanding further than recognition of the tsunami symbol for people with little understanding of Japanese text.

A muster point for use in evacuation of children was seen in Hitachihamacho, Miyako City (Figure 26, Figure 27). This sign is located on the wall of a house on the road at the base of a hill. The owner of the house told us that children are instructed to gather at this sign and evacuate up the hill together.

Figure 24 A sign in the centre of Matsushima Town, advising evacuation on experiencing an earthquake.

Figure 25 A sign indicating tsunami hazard, on a road out of Kamaishi City. Translation reads: “Tsunami Attention! Tsunami inundation hazard zone”.

Figure 26 Tsunami evacuation muster point for children in Hitachihamacho, Miyako City.

Figure 27 Close-up view of tsunami evacuation muster point for children in Hitachihamacho, Miyako City. Translation reads: “Tsunami shelter (Kuwagasaki elementary school)”.

Signs or plaques marking inundation depth in previous tsunami were seen in Minami-Sanriku (Figure 28 and Figure 29) and Ōfunato City (Figure 30). These markers do not indicate maximum inundation extent in the 1960 Chile event; rather indicate depth at a particular location. The marker in Figure 28 indicates the tsunami inundation depth was 2.4 m at this location in the 1960 Chile tsunami; inundation depth at this point was at least 10 m on March 11th 2011. It was not clear from interviews with emergency officials, whether these signs caused under-estimation of tsunami hazard in the local population, but the authors believe that this sort of demonstrative information should be reserved for maximum events, and in the case of these locations should have more appropriately reflected the larger 1896 or 1933 tsunami flows if known. Ancient stones have been reported in the media, which indicate the extent of historic tsunami; these were not observed by the authors.

Figure 28 A marker post indicating past inundation height in central Minami-Sanriku Town. The Japanese text gives notification that the Shizugawa hospital is a designated vertical evacuation building. The Japanese text informs people to evacuate to designated evacuation places such as parks, highlands, and Shizugawa elementary school and Shizugawa hospital.

Figure 29 A marker post indicating past inundation height in central Minami-Sanriku Town. This marker was found close to a care home (1 km inland), and displays the standard icon representing evacuation to high ground.

Figure 30 Tsunami height marker on a building wall in Ōfunato City, indicating the maximum inundation height at this point during the Chile tsunami on May 24th 1960. Photograph courtesy of EEFIT.

In Ishinomaki, we observed a map which focussed on the local landslide hazard and evacuation routes designed for landslide only (Figure 31). This map shows evacuation routes to shelters which are away from steep hillsides, but encourage evacuation into areas close to the banks of the Kitakami River. On March 11th 2011, the specified evacuation shelters were inundated by tsunami flow from the river channel. This illustrates the need for information boards and signs to include multiple hazards where this is appropriate.

Figure 31 Landslide hazard and evacuation map on an information board in Ishinomaki City.

2.3 Response to natural and informal tsunami warnings

2.3.1 Natural warnings

The officials interviewed in Tarō, Kesennuma, Minami-Sanriku and Natori reported that ground shaking lasted longer than 2 minutes (most reported as long as 3 minutes) and in Kesennuma, Minami-Sanriku and Ishinomaki the interviewees acknowledged that this earthquake felt unusual or stronger than they had ever experienced previously (including previous Miyagi-ken-oki events in 1978 and 2004). Most interviewees, when questioned further, felt that they could have stood up in the earthquake and that ‘stronger’ generally referred to the length of shaking and the long and variable period of the shaking. As a result of the ground shaking, they recognised that this could be the recurrent Miyagi-ken-oki event and there was recognition of the potential for tsunami. The JMA shaking intensity at each location is given in Table 3. Drawdown of the tsunami was only cited in our interview at Minami-Sanriku.

Public response to the natural warning of strong and long ground shaking was variable. In Tarō, most people in the town are believed to have evacuated in response to ground shaking and although an audible tsunami warning was broadcast by the disaster prevention officials, this was broadcast while people were already running. Tarō Town officials describe a history of strong communication of tsunami risk from parents to children, with a tradition of telling stories about tsunami, education in school on tsunami including communication on the subject between local and visiting schoolchildren. The official himself told us how he was often told as a child to “run straight away, even if the ground shaking is small” in an earthquake. Local tradition in Minami-Sanriku encourages evacuation from coastal areas when an earthquake occurs or when drawdown of the sea occurs. It appears that in both Tarō and Minami-Sanriku traditions and education were heeded as they suffered fatality rates of only 6% despite inundation of more than 10 m.

A study of 113 residents in Kamaishi showed that 66.4% of the population evacuated immediately, and 72% of those evacuated directly as a result of the natural warning (NPO CeMI, 2011). This immediate action is a result of education and previous experience. Tsunami education efforts by local government stress the importance of natural warnings and this event has re-affirmed to the disaster prevention office in Kamaishi the importance of this education.

Local disaster prevention officials believe that “most people” evacuated coastal areas of Ōfunato as a result of ground shaking, while it is estimated that 20-30% did the same in Kesennuma (the majority, however, waited for an official “formal” warning before evacuating). The response of many people to natural warnings – overwhelmingly in this case being the strength and especially duration of ground shaking – can be attributed to the history of significant tsunami impacting the rias locations, and the resultant education to run to high ground in the case of strong ground shaking.

Unfortunately, the immediate evacuation of low-lying areas was not ubiquitous. Ground shaking did trigger evacuation in Ishinomaki, although this appears to be in response to education for earthquakes rather than tsunami, and people evacuated to local parks, rather than specifically uphill. Evacuation training and schools disaster education in the city was focussed on earthquake events without consideration for tsunami.

In Natori, young people were said to have evacuated inland on feeling the strong ground shaking (JMA intensity 6 Upper) but many older people did not believe a tsunami would affect them from this earthquake, as they had no experience of tsunami reaching the residential areas after previous earthquakes. The survey by NPO-CeMI shows that 57.1% of evacuees interviewed did evacuate immediately, although there was only 56.7% of those who evacuated due directly to the natural warnings (NPO CeMI, 2011). Due to the lack of recognition of subsequent tsunami hazard, 30% of residents stayed to clear up earthquake debris, and 40% tried to ensure the safety of family and neighbours. As result, 54.5% of those who delayed evacuation evacuated between 20-60 minutes after the earthquake.

The immediate reaction of large numbers of people to ground shaking has a cumulative “cascading effect” on increasing the overall evacuation rate, as other people (who may be confused or unsure of what action to take) see people running and as a result begin to evacuate. This effect was reported in Kamaishi, Natori and Ōfunato.

Current advice in New Zealand for local tsunami, which are not expected to provide sufficient time to an issue official warning, is that:

“*Persons in coastal areas who experience strong earthquakes (hard to stand up); experience weak earthquakes lasting for a minute or more; or observe strange sea behaviour such as the sea level suddenly rising and falling, or hear the sea making loud and unusual noises or roaring like a jet engine should not wait for an official warning. Instead, let the natural signs be the warning. They must take immediate action to evacuate predetermined evacuation zones, or in the absence of predetermined evacuation zones, go to high ground or go inland.*” (MCDEM, 2010a)

This advice is appropriate for the reported experiences in Iwate and Miyagi on March 11th 2011 and it is encouraging that for a similar event in New Zealand, the current education is appropriate.

Likewise, advice given by Washington EMD and West Coast and Alaska Tsunami Warning Centre (WCATWC) instructs people to evacuate coastal areas immediately when ground shaking is felt, although there is no clear qualification (stating what sensation people might experience) of the level of ground shaking that might be followed by tsunami:

"*If you feel the ground shake, evacuate inland or to high ground immediately and return only after officials say it is safe to do so.*" (Washington Military Department Emergency Management Division, 1999)

"*A strong earthquake felt in a low-lying coastal area is a natural warning of possible, immediate danger. Keep calm and quickly move to higher ground away from the coast.*" (West Coast and Alaska Tsunami Warning Center, 2011)

This is in contrast to the unsuitable advice given on the FEMA ready.gov website:

"*If an earthquake occurs and you are in a coastal area, turn on your radio to learn if there is a tsunami warning.*" (FEMA, 2011)

2.3.2 Informal warnings

In addition to peoples' reaction to seeing others evacuating, informal warnings in other forms were effective in saving lives. These warnings include hotel owners instructing or guiding guests to high ground (e.g. in Tarō and Unosumai, Kamaishi). In Ōfunato, the disaster prevention official cited business owners who warned employees to evacuate and a resident who drove north up the valley to warn his colleagues. At Minato High School in Ishinomaki, a teacher used the school announcement system to warn the area around the school that a tsunami of over 6 m was coming; it is estimated that over 100 people were saved due to this warning.

Events in Natori City show that informal warnings (or confirmation of warnings) from the media cannot be relied on following a strong local earthquake. Tsunami arrival at Natori was 60 minutes after the earthquake, and around 30 minutes after arrival of the first waves at locations further north. Due to power outages, television and telephones were not functioning, so residents could not receive information that these locations that had been affected, thus indicating the possibility of Natori being affected. Residents did talk to one another and encourage others to evacuate, but many were still reluctant to leave.

Given the potential for electronic media channels (television, radio, cell phone, fixed line telephone, internet) to be disrupted following a strong local earthquake (directly or due to loss of the electricity they rely on), these media should not be expected to be available to provide informal warnings or confirm the occurrence of a tsunami. This increases the importance of education to heed natural warnings.

Recommended guidance in New Zealand includes public response to informal warnings is as follows, and appears on tsunami evacuation information boards:

"Warnings from friends, other members of the public, international media, etc. may be correct. If you feel the threat is imminent, quickly get to high ground. Consider evacuating from all zones. Verify the warning only once evacuated or if you can do so quickly via radio, television, internet, or through your nearest civil defence emergency management office." (MCDEM, 2008a)

2.4 Formal warning messages and systems

2.4.1 Warning messages

The sequence of formal warning broadcasts from JMA in Iwate and Miyagi on March 11th 2011 is presented in Table 5. This sequence shows the significant increase in expected wave heights (at the shore) in the first 41 minutes following the earthquake using the framework discussed in Section 1.4. In addition to JMA warnings, there are some local arrangements for providing early tsunami warnings. For example, in Ōfunato a tsunami warning is disseminated by the disaster prevention office if shaking intensity registers greater than 4 on their own intensity meter.

Although an early warning system is often seen publicly as key infrastructure in enhancing tsunami resilience, the expectation of official warnings (and their content) may have slowed the time taken for people to initiate evacuation in Tōhoku, compared to if there had been total reliance on natural warnings. The broadcast of estimated tsunami heights had negative consequences in Kamaishi, as the disaster prevention office continued to broadcast the JMA estimate of 3 m even after JMA had released an updated estimate of 6 m, resulting in the under-estimation of the tsunami threat by some of the public. In Kesennuma, the first waves had already begun to arrive by the time updated wave heights were received by disaster prevention officials, which somewhat negated the updates. In the case of Tarō, expectation that the 10 m high protective wall would protect the town from the expected 3 m high waves may have slowed evacuation response times. Initial underestimation of the tsunami threat was unavoidable due to the method used to estimate tsunami magnitude being reliant on preliminary estimates of earthquake magnitude – preliminary earthquake magnitudes are often revised upwards as more data becomes available. The difficulties in producing accurate tsunami estimates from rapid estimations of earthquake magnitude were recognised prior to this event and discussed by Imamura and Abe (2009).

Exposure to previous false 'major tsunami' warnings apparently led to complacency on March 11th 2011, when wave heights commensurate with the 'major tsunami' warning actually arrived. The evacuations of both Kesennuma and Natori were negatively affected by complacency which resulted from a 'major tsunami' warning being issued following the Maule, Chile earthquake of 2010. In that event, wave heights that occurred at Kesennuma were 0.5-0.6 m and were approximately 0.5 m at Natori. The officials interviewed believe that this led to subsequent underestimation by residents of the tsunami threat on March 11th 2011. This suggests some apparent confusion in public perception of anticipated tsunami magnitude from local and distant tsunami sources. The threat of tsunami from the felt local earthquake of March 11th 2011 was not perceived differently to the officially-warned distant tsunami that had been expected from the 2010 Chile earthquake. Local officials do not believe that an event two days prior, on March 9th 2011, contributed to this complacency – despite the proximity of this event, the corresponding warning was for a lower level than on March 11th.

Table 5 Time sequence of JMA tsunami warnings from March 11th to 13th, indicating the change in estimated tsunami height for Iwate and Miyagi Prefectures. Between warning #3 and #10, the major tsunami warning remained in place for these prefectures (Source: Japanese Meteorological Agency, 2011e).

Time	Level for Iwate	Level for Miyagi
March 11th, 14:49 (warning #1)	Major tsunami: 3 m	Major tsunami: 6 m
March 11th, 15:14 (#2)	Major tsunami: 6 m	Major tsunami: 10 m
March 11th, 15:30 (#3)	Major tsunami: 10 m	Major tsunami: 10 m
March 12th, 20:20 (#10)	Downgraded to tsunami warning	Downgraded to tsunami warning
March 13th, 07:30	Downgraded to tsunami advisory	Downgraded to tsunami advisory
March 13th, 17:58	Advisory cancellation	Advisory cancellation

2.4.2 Warning systems

Japanese towns typically have extensive networks of speakers in the streets, which are used daily for official announcements. In the event of a tsunami, these systems can be used to broadcast a warning to the whole town, including spoken messages in addition to a siren tone. The system often requires manual operation from a central broadcast point, such as the city office. Ōfunato City had a broadcast system comprising over 120 mobile, portable and fixed stations, some with visual alerts (Disaster Mitigation Section Ōfunato City, n d). As is already widely recognised, warning systems are vulnerable to loss of power in local earthquakes, an effect which was seen in Tarō when broadcasts ceased shortly after the audible warning broadcast began. Wireless transmission of warnings was also reported to be ineffective in Natori City due to power outages.

Although the primary use of tsunami warning sirens is for warning of the tsunami risk, their use in Japan for post-event welfare announcements or tsunami warnings in aftershocks puts extra emphasis on their survivability, although further natural warning signs would be expected in any large aftershock. Tsunamigenic aftershocks are a very real possibility following a significant subduction zone event, as shown by the aftershock record around Tōhoku which shows an offshore M7.3 event 3 months later on July 10th 2011 (Japanese Meteorological Agency, 2011f). This is an interesting concept for further use of speakers and siren towers. Scour, debris strike and inundation of electrical systems are all issues for survivability of these networks – in Ōfunato, the systems failed when tsunami water inundated battery power packs mounted on the siren towers.

A significant amount of information transfer in Minami-Sanriku is conducted by wireless digital radio system. There were 105 speakers throughout the town and wireless radio receivers are rented to every household by the municipal government. Public offices, schools and factories also had wireless receivers (Figure 32), which cost JPY 50,000 (USD 640; NZD 850) per unit. They function on mains power with a battery in case of power outage and are designed to remain on standby most of the time, automatically receiving the tsunami warning. The tsunami warning was disseminated very effectively via this network on March 11th 2011.

The original broadcast point of tsunami warnings in Minami-Sanriku was the disaster management office, but due to severe tsunami damage to that building, a backup system at the relocated town office was used for three days to announce welfare information and aftershock warnings. This back-up system was only suitable for three days of use for welfare announcements because the temporary facility did not have sufficient capacity for continued operation. This illustrates the need for comparative redundancy in warning systems.

Figure 32 A wireless receiver shown by civil protection officials in Minami-Sanriku. These units are rented by the local government to every household in the town, and resulted in effective warning dissemination on March 11th 2011.

2.5 Movements during and after evacuation

Observations and reports of peoples' movements during and after evacuation reveal that many people died unnecessarily during the tsunami inundation, through social or parental responsibility, lack of education or scepticism of warnings.

2.5.1 Delayed evacuation or non-evacuation

Delayed evacuation and non-evacuation were significant in influencing life loss of the individual and of emergency responders or other community members. The importance of immediate evacuation is highlighted by figures presented by Sagara (2011): only 1 person died out of 33 who evacuated Rikuzentakata immediately. In contrast, 42 people died out of 147 people who did not evacuate immediately. Immediate evacuation increases chance of an individual successfully evacuating. Emergency personnel such as fire-fighters, who have responsibilities for specific tasks such as closing tsunami gates, may have very little time in which to complete those tasks on behalf of the community. However, their lives were further endangered when they remained in the hazard zone to mobilise people who had chosen not to evacuate immediately.

As introduced in Section 2.3, older people in Natori City did not believe a tsunami would affect the residential areas of Yuriage as they had no experience of tsunami reaching the residential areas after previous local earthquakes. Others remained in the town to clear up earthquake debris or to check on family members or neighbours, rather than evacuating. Volunteer fire department personnel went to elderly peoples' homes in order to persuade residents to leave. This approach had some success as some residents decided to leave at that point; however, as a result of their actions some volunteers were delayed from evacuating the inundation zone and were killed in the tsunami. Natori City is a key example of a location which suffered from a lack of recent experience, and underestimation of the hazard through numerical modelling, which resulted in complacency and delays in evacuation on March 11th 2011 despite the natural warnings. The issues caused by lack of experience of local tsunami are likely to also affect Washington and New Zealand for the same reasons, where emergency officials are working hard to prepare communities with no previous experience of such an event.

Non-evacuation in Tarō was reportedly caused by the communication of information that the expected tsunami was only 3 m – this led to public perception that the town would be protected by its tsunami defences, and some were sceptical that a tsunami would arrive at all. Following the natural and formal warnings, some residents in Tarō waited in the town for family members to drive home from elsewhere in order to evacuate together. This had not only the effect of delaying the person in Tarō, but encouraging those in other locations to drive into the hazard zone, with the result that some were unnecessarily killed during inundation. The desire to evacuate with family was also reported in Kamaishi, where residents are reported to have died while driving through the city having collected family members.

In Kesennuma the disaster prevention official we interviewed believes that people should be encouraged to help others in the stages of disaster preparation and post-evacuation, rather than during the event when they should be concentrating on evacuating the hazard zone themselves. In this way, people would be encouraged to not return or travel through evacuation zones to help people prior to imminent tsunami arrival. He is considering adopting the *tsunami tendenko* philosophy that was taught in Iwate Prefecture and attributed to successful evacuations of schools in Kamaishi City.

These examples are important for Washington and New Zealand to consider, as delays in evacuation are likely to cause many deaths in a local tsunami event, and education should be put in place specifically to reduce this potential issue. Adoption in Washington and New Zealand of a *tendenko*-like strategy encouraging self-evacuation and not stopping to help others would be a significant change from current advice, which emphasises the importance of immediate evacuation but does not explicitly advise “leave others behind” or “look after only yourself”. In fact, advice from FEMA (2011) states the opposite, which may result in further deaths from people remaining in the inundation zone too long:

“Remember to help your neighbors who may require special assistance - infants, elderly people, and individuals with access or functional needs.”

Delays in evacuation were also caused by perceptions of safety close to the edge of the recognised hazard zone. In Ōfunato City, most people in the official (and mapped) hazard zones evacuated quickly, whereas those just outside the mapped hazard zone tended to not evacuate until they saw the tsunami coming close to their immediate location. This effect was seen in Minami-Sanriku, where neighbourhood fatality rates are higher in neighbourhoods immediately inland of the mapped tsunami hazard zone, where people perhaps perceived themselves to be safe. Murakami and Kashiwabara (2011) also suggest this effect occurred in Natori City, where fatality rate in Yuriage 2 chome is 22%. In comparison areas closer to the fishing harbour, suffered 11-12% a lower fatality rate (Figure 33).

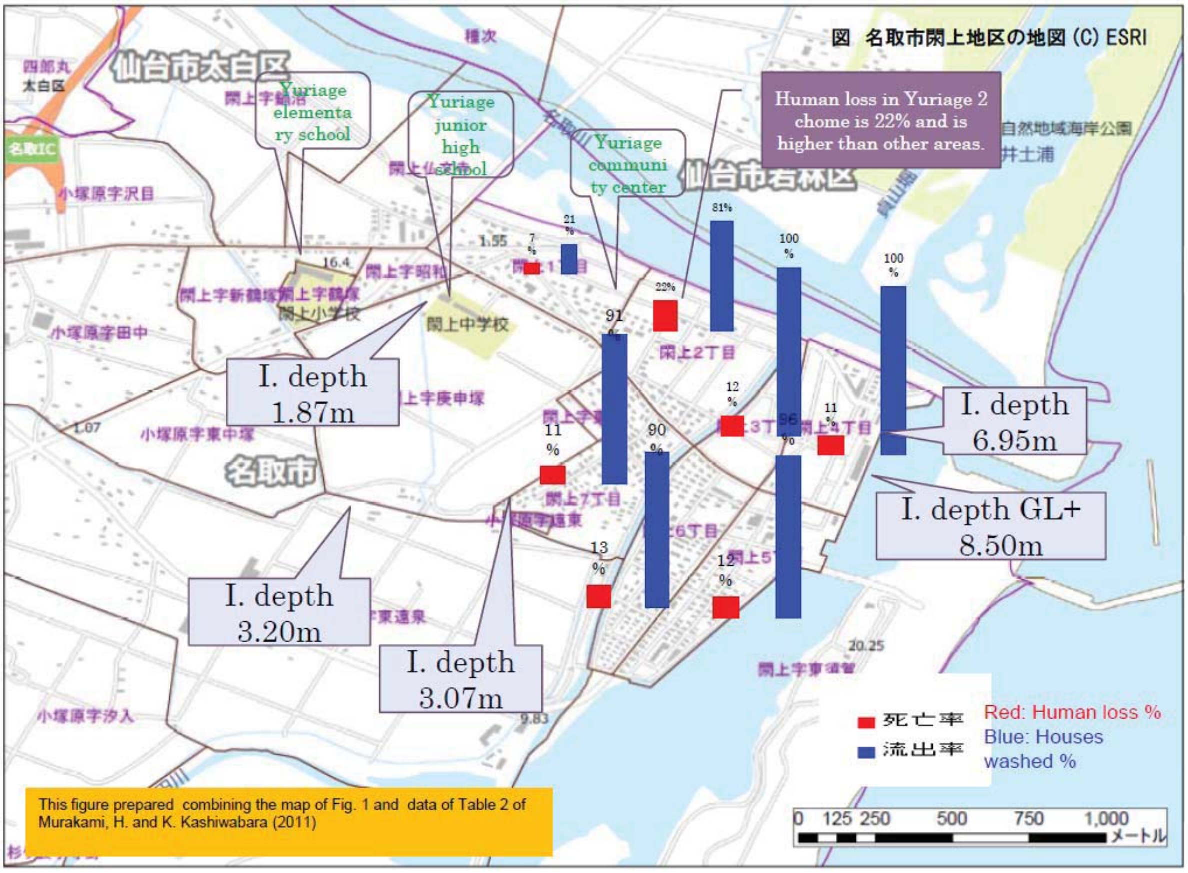


Figure 33 Building damage and fatality rate for seven areas of Yuriage, Natori City. Source: (Murakami and Kashiwabara, 2011).

2.5.2 Use of motor vehicles during evacuation

Traffic congestion was a significant issue in several locations during the evacuation on March 11th 2011, although other locations reported minimal congestion and attributed this to previous guidance to evacuate the hazard zone by foot rather than motor vehicles.

In Tarō, most people arrived at evacuation centres on foot, apparently following official guidance to walk, rather than using motor vehicles. As a result, congestion was not a problem in Tarō. In Minami-Sanriku there was a limited amount of vehicle use in the evacuation, which caused minor congestion initially but by 15:10 the roads were clear. Use of vehicles during tsunami evacuation is prohibited in Minami-Sanriku due to (i) the possibility of traffic congestion, (ii) failure of traffic signals during a power outage, (iii) poor road conditions immediately following an earthquake, and (iv) evacuation locations may quickly fill up with vehicles if they are used. During the annual evacuation drill, use of vehicles is forbidden and despite the public here arguing that they should be able to use cars for families and elderly to evacuate their homes, it remains prohibited.

The disaster prevention office of Kamaishi recognises that the importance of evacuating on foot had not been impressed enough on residents. On March 11th traffic congestion occurred on the Highway 45 Bridge at the port front, which forced some drivers to abandon their vehicles and use the nearby government building as an ad-hoc vertical evacuation refuge. In the February 2010 Chile tsunami, officials closed roads in the city to prevent people driving into the hazard zone, but there were complaints from the public and people drove through town anyway.

In order to combat traffic congestion in the town of Ryoishi, Kamaishi district, the town put in place a scheme to designate certain vehicles and drivers to transport vulnerable people to high ground in case of tsunami. The physical labelling of designated vehicles is aimed at raising awareness of who is responsible for returning to the town and limiting the number of vehicles being used in evacuation. On March 11th 2011 all designated drivers were out of town at the time of the tsunami and the scheme could not be actioned before tsunami arrival.

Heavy use of vehicles in Ishinomaki led to road congestion and many deaths on March 11th, despite repeated official messages at the time via loudspeaker not to use vehicles. Following the April 7th 2011 aftershock, heavy use of vehicles occurred again, despite the impacts this had during the previous evacuation.

The flat agricultural plains around Yuriage have no high ground for several kilometres and a survey carried out in Natori determined that 65% of residents evacuated by motor vehicle (Murakami and Kashiwabara, 2011). Many routes lead inland via a gridded network of roads, suggesting many possible evacuation routes. However, these roads are all single-track and deep ditches along road edges prevent two vehicles passing each other. For this reason, residents of Yuriage chose to use main roads to evacuate in their vehicles. It is this type of local knowledge that is invaluable in establishing suitable evacuation routes. The large distances to safety across flat plains such as those surrounding Natori, provide a persistent problem because people perceive that there is no other way to evacuate other than by car. Murakami and Kashiwabara (2011) recommend the promotion of the use of bicycles to reduce the amount of congestion in future tsunami evacuations.

A traffic accident occurred on the Yuriage Bridge – a major crossing point over the Natori River – when a lorry shed its load, causing closure of one lane of traffic. This incident illustrates the potential for unforeseen delays during vehicle-based evacuation, in addition to traffic volume alone. Following a strong earthquake, falling debris or damage to roads or bridges only increase the likelihood of such incidents. Experience of the Christchurch earthquakes rendered many bridges unpassable for a short time and the potential for many blocked roads following an earthquake in Wellington show that this is a very real problem for major urban areas of New Zealand.

Education in Kesennuma has consistently stated that people should not use vehicles during tsunami evacuation. However, this approach is under review following the March 11th event in spite of traffic congestion prompting the fire department to instruct people to abandon their cars. Due to there being some successful use of vehicles in this event and the recognition that it is impossible to stop vehicle use entirely, the disaster prevention official stated that a possible future approach in the city might be to accommodate vehicular transport by widening roads or develop a road system that is designed specifically to cope better in an evacuation situation. The installation of evacuation towers at junctions, or overhead pedestrian walkways were suggested as potential vertical evacuation options in case of traffic congestion and the need to abandon cars. This combination of developments is seen by the authors as an unsuitable option, as this is likely to encourage people to use vehicles, resulting in even more vehicles on the road and exacerbating current problems with congestion. In addition the knowledge that evacuation towers are abundant may encourage people to leave their vehicles at the earliest sign of congestion, thus blocking all vehicles behind them. The authors believe it is more effective to emphasise evacuation on foot to keep roads as empty as possible, as is current practice in Washington and New Zealand. In recognising that some vehicles will be used, New Zealand advice is that if you have to use a vehicle, drive as far as possible out of the evacuation zone to allow room for other people to drive out, rather than stopping immediately outside the evacuation zone (MCDEM, 2010a).

2.5.3 Use of boats during evacuation

Residents of Hitachihamacho, Miyako City reported using fishing boats as a means of escaping the tsunami and preventing damage to their boats. Many people sailed out of the harbour at this location on feeling ground shaking, with the intention of sailing far enough into deep water that the tsunami would not affect them. Once in deep water, a large group of boats gathered together until the next day, as it was impossible to return to shore at night through the large amounts of debris that had collected in the harbour. Some people travelled out to sea in very small boats that had no means of shelter, and these boats were unsuitable for the overnight weather conditions. It was reported that many other boats were still trying to leave the harbour when strong currents of the initial waves prevented further progress. In this location, deep water is only 1 km offshore, and the fishermen felt they would be safe there, but it is clear that this approach is fraught with issues of precise timing before wave arrival and debris fields, and is not a course of action to recommend to the general public onshore. The International Tsunami Information Center advises evacuation by boat only in the case of a distant tsunami (International Tsunami Information Center, 2006). New Zealand tsunami advisories and warnings advise people to stay out of the water, including any “boating activities” (MCDEM, 2010a), but there is no explicit mention of evacuation by boat.

2.5.4 Schools evacuation

The interviews highlighted several examples of parents travelling unnecessarily to schools to collect children following the tsunami warning, with fatal consequences. In Tarō, parents are required to collect their children from school in the event of a tsunami warning. The school was not inundated on March 11th, but parents are said to have died while driving through the town on their way to or from the school as tsunami waves arrived. Deaths of parents and children were also reported in Kesennuma City during collection from schools. In Ishinomaki, some parents collected children from schools and lost their lives while driving through an inundated zone, whereas the children who remained at those schools survived on upper floors of the buildings.

At Unosumai, Kamaishi City, all children successfully evacuated the Kamaishi Higashi Middle School and Unosumai Elementary School, located 800 m inland from the pre-tsunami shoreline following the earthquake. Tsunami evacuation training had been conducted in Kamaishi schools since 2005 and 5-10 hours of annual class time was spent on learning about the tsunami hazard (D. Harding and B. Harding, 2011; MSN Sankei News, 2011). Due to the unexpected height of the tsunami, the children abandoned plans to stay on the 3rd floor of their school building to evacuate uphill, and then had to relocate further uphill twice more during the event. Their training had stressed that they should assess the situation as they see it and be able to respond to changing events, and this most likely saved many lives on March 11th. This is an excellent example of effective education in schools.

A recent study of schools disaster preparedness education in New Zealand showed that there is no requirement for tsunami exercises in schools, and although most schools understand their responsibility to care for their students until parents or an appropriate guardian collect them, many schools (including in coastal locations) have not carried out tsunami drills (Johnson, 2011). There is also no specific advice around the actions of parents following an earthquake – i.e. collection of students from school, or organised rendezvous at a specified safe location.

In the United States, FEMA advice states:

"*If the school evacuation plan requires you to pick your children up from school or from another location. Be aware telephone lines during a tsunami watch or warning may be overloaded and routes to and from schools may be jammed.*" (FEMA, 2011)

This advice makes no mention of the potential that parents may have to travel through potential inundation zones to get to or from the school. Education in Washington encourages parents to travel to the schools designated assembly point rather than collecting children directly from school.

2.5.5 Necessary relocation from evacuation refuges

It has been reported in the media that over 100 evacuation centres were inundated on March 11th 2011 (Unknown, 2011a). In Kamaishi, nine of a total of 96 refuges were inundated. It should be noted that these refuges were not vertical evacuation facilities designed to provide refuge above the inundation height within the inundated area; rather they were evacuation centres which had been incorrectly perceived to be *outside* of the tsunami hazard zone. In Tarō, evacuation centres had been located outside of the 1896 and 1933 inundation extent, believed to be the maximum possible inundation (Figure 8). Unfortunately one of these refuges was inundated, killing people who had travelled there.

The case of Unosumai has already been discussed, where evacuating school staff and pupils were required to reassess their situation and evacuate to a different place according to the evolving hazard. In this case, they evacuated further uphill several times (I. Matsuo, pers. comm., October 20th 2011). In Ishinomaki, people left the Kadonowaki Elementary School when the school building became inundated. They were able to exit to the rear of the school and immediately climb to higher land, due to the location of the school. This school later caught fire while inundated with tsunami water. The response of evacuees in these cases shows that judging the evolving situation and being able to make further decisions is a worthwhile education strategy, although this should not be at the expense of ensuring that any evacuation centres are certainly outside of the maximum tsunami inundation, and any vertical evacuation buildings are designed to remain safe in the worst tsunami.

2.5.6 Leaving evacuation refuges too early

In Tarō, a town with high awareness of tsunami risk and a history of tsunami education, many residents died on returning to the town a short time after arriving at a refuge, because they had seen no wave eventuate. This occurred in spite of local government advice that once a tsunami advisory or warning is issued, people should remain on high ground until that advisory or warning is lifted. The disaster prevention official noted that there is no legal recourse for not following the advice, so people are legally entitled to return to low-lying areas at any time.

The Ishinomaki City disaster prevention official also reported deaths which occurred when people had successfully evacuated to uphill refuges, only to leave the refuge when the JMA-estimated time of wave arrival had passed with no apparent realisation of the tsunami. Some people who had stayed at high ground while inundation occurred returned to low-lying areas around 17:00, when tsunami waters receded, only for the fourth and fifth waves to inundate parts of the city and kill many more people. A similar effect was observed during the event in Yuriage, Natori City, where people who were in evacuation buildings left those buildings after the first waves receded. Subsequent waves resulted in the deaths of many of these people.

The occurrence of deaths in this manner can be seen as an issue for education and understanding of uncertainty in i) arrival times, ii) the time of first [t] wave versus the largest waves, and iii) education of people in the fact that tsunami are a series of waves often occurring over many hours.

In New Zealand, language broadcast in a *National Warning: Tsunami Threat to New Zealand* is as follows, including a brief statement to clarify the uncertainty of arrival time:

"If a tsunami has been generated, the first wave may arrive in New Zealand in the areas around [insert place] at [insert NZDT/NZST on insert date]. The first wave may arrive later and may not be the largest" (MCDEM, 2010a)

Recommended text for warning and evacuation information covers the other issues, stating:

"There may be multiple waves separated by up to an hour, or more. Large waves may come after a series of smaller waves. The largest waves from distant sources may take many hours to arrive." (MCDEM, 2008a)

"Stay OUT of evacuation zones until given the official 'all-clear' from Civil Defence Emergency Management. Stay away from the Red Zone for at least 24 hours after any tsunami warning – even small waves can create dangerous currents." (MCDEM, 2008a)

In Washington, advice in evacuation brochures give consistent advice to wait for an 'all-clear' message before returning to the shore. Washington Military Department Emergency Management Division (1999) states:

"Do not return to shore after the first wave. Wait for Emergency Management officials to give the "All Clear" before you return."

A later map for Ocean Shores published by Washington State Department of Natural Resources covers several points in this statement:

"The first wave is often not the largest; successive waves may be spaced many minutes apart and continue to arrive for several hours. Return only after emergency officials say it is safe" (Washington State Department of Natural Resources, 2007)

2.6 Impacts of coastal defence on warning response and evacuation

Japan spends a significant amount of resource on 'hard' coastal defence, and some of the most formidable sea walls and breakwaters of the Tōhoku region were adversely affected during the tsunami of March 11th. It is recognised that these substantial defences can prevent damage in small to moderate events, and may allow extra time for evacuation in such extreme tsunami. The breakwaters at Kamaishi are estimated to have reduced inundation height by 40%, and delayed onshore arrival by approximately 6 minutes (Takahashi et al., 2011). Despite the physical benefits, our interviews also indicate some negative impacts of significant hard defences, which can induce false impressions of safety and an inability to see the natural warning of a disturbed ocean. Even in small events, unforeseen issues (e.g. break-down and non-closure of gate systems/earthquake damage) may result in unexpected inundation.

The tsunami impacts in Tarō have been widely reported due to the damage the town sustained, despite having a concrete sea wall of 10 m height, in three sections with a combined length of 2,433 m (Tarō Town Municipal Government, n d). This sea wall prevented damage in the town due to the 1960 distant Chile tsunami, and would likely prevent damage to the main town in the vast majority of tsunami in its design lifetime. However, on March 11th, the perceived safety in which residents lived may have contributed to a number of deaths – as already discussed in Section 2.5, the presence of the wall and the estimated 3 m tsunami height combined such that some people believed they would be unaffected behind the wall. Sixteen people died while driving through Tarō, possibly as a result of not feeling the earthquake or at least not being able to sufficiently recognise the arriving tsunami due to their views of the sea being obstructed. The disaster prevention official also reported that some people believed that the tsunami spray hitting the wall was fire rather than waves arriving.

This issue was also apparent in Ryoishi, where several vehicles were observed driving along the coastal road immediately adjacent to a sea wall (Bombaadi, 2011). At the time these vehicles were on the road, the tsunami was rising rapidly on the other side of the wall unseen by the drivers before it poured over the top of the wall, which was several metres tall. The reduction in visibility out to sea also endangered the lives of fire-fighters in Setai, Miyako City, who were manually closing tsunami gates when they saw the tsunami at the last minute through a small window in the gate and were able to drive away.

New Zealand and Washington presently have sea walls (mostly around harbours) designed only to mitigate normal storm waves and prevent long-term erosion. On coastlines at risk of a local subduction zone earthquake, it is unlikely to be feasible to construct a defence of sufficient size to protect against the maximum potential events – exactly as shown in Tarō. Sea walls may reduce tsunami velocity and wave heights even if breached or damaged, however, the population of the area ‘protected’ by the defence must be suitably educated to know that the defence is not a 100% guarantee of safety.

2.7 Vertical evacuation buildings

Vertical evacuation buildings are designed to provide refuge in the inundated area by providing sufficient elevation above the maximum water level. This type of refuge proved to be extremely valuable in reducing life loss on March 11th 2011. These buildings are different to regular evacuation centres, which are generally designated in Japan for use in multiple hazards, and are located outside of the previously estimated tsunami hazard zone.

The consistent education message delivered to the public in Tōhoku was to evacuate inland or to high ground as priority, but the presence of vertical evacuation buildings was valuable in situations where people were unable to get inland or to high ground prior to tsunami arrival. The successes are numerous; however, some important lessons can also be learnt from the experiences of evacuees who used these buildings. Appendix 4 provides a list of vertical evacuation buildings in the locations visited, with details on construction, signage, access, inundation level on 11th March and number of people saved.

Section 2.1 introduces the Project Safe Haven initiative underway in Washington to develop vertical evacuation strategies. Evacuation buildings are not currently designated in New Zealand, but some existing buildings could be considered suitable. An initial scoping study was recently completed and the Ph.D. thesis work of Stuart Fraser is focussing on developing guidelines for vertical evacuation in New Zealand; this report forms part of the basis of that research.

2.7.1 Building specification and levels of damage

The requirements of buildings to be designated for vertical evacuation by local government in Japan are that they meet adequate construction standards and minimum heights as specified by Hiroi et al. (2005). In consideration of local sources, these buildings must conform to sufficiently high seismic standards to provide life safety following a significant local earthquake. The seismic safety requirement of vertical evacuation buildings in Japan was achieved by designating buildings constructed to post-1981 seismic standards. Although some of the vertical evacuation buildings observed suffered damage from ground shaking, none suffered sufficient damage to prevent use in the subsequent tsunami evacuation. Detailed structural analysis is out of the scope of this report.

The key criteria from the 2005 guideline for official designation of buildings as tsunami evacuation buildings are that they:

- Are of a minimum height according to estimated maximum inundation depth
  - Less than 1 m depth = 2-storeys or higher required
  - 2 m depth = 3-storeys or higher required
  - 3 m depth = 4-storeys or higher required
- Are reinforced concrete (RC) or steel reinforced concrete composite (SRC) construction
- Were constructed after 1981 (the latest significant update of building codes in Japan)

Building damage surveys following this event underline previous observations that reinforced concrete structures are the most effective buildings in tsunami, as they are the most resistant to tsunami loading, and debris impact. Structural members of observed steel buildings generally survived tsunami loading very effectively but high levels of damage to cladding and other non-structural elements (EEFIT, 2011), and high potential for significant damage from debris strike makes them unsuitable for use as a safe refuge.

There are cases of some vertical evacuation buildings being overtopped (e.g. Fisheries Cooperative in Minami-Sanriku) and in other cases the maximum inundation height was close to the building roof when the tsunami arrived at low tide. This has prompted some of the interviewed officials to call for a minimum height of 5-storeys for designated facilities. Despite this, there were some 2-storey buildings that proved sufficient as a refuge in places where flow depths were relatively low in 2011 (e.g. Yuriage).

2.7.2 Observed examples of vertical evacuation buildings

There were 3 designated vertical evacuation buildings in Kamaishi district at the time of this event: an 8-storey RC frame apartment block and a 2-storey RC government building (Figures 34, 35 and 36) in the city, and a 4-storey steel frame hotel near Unosumai (Figure 37). An estimated 50 people evacuated to the apartment block and government building.

Damage was limited to glazing and very minor cladding damage on the government building. Damage to glazing and non-structural RC-infill panels was common at the apartment block, which was inundated to the 3rd storey, while debris impact had damaged a steel-frame vehicle parking elevator (EEFIT, 2011). People were trapped in this building until March 12th due to silt blocking the stairwells (EEFIT, 2011). The owner of the Hotel Horaikan at Unosumai directed guests to high ground behind the hotel, rather than staying in the building. The hotel suffered non-structural damage at the ground floor only, and at the time of our visit the hotel was being refurbished internally.

There were plans for further tsunami evacuation buildings and towers close to the Kamaishi Port, but these had not yet been constructed.

Figure 34 Designated evacuation locations in Kamaishi City. An estimated 50 people evacuated to this apartment block (A) and government offices (B). The entire area shown was inundated; inundation depth was 8 m in the vicinity of building (A).

Figure 35 Apartment block in Kamaishi City, which was inundated to the 3rd storey

Figure 36 Government offices in Kamaishi City. This building is raised several metres above sea level and sustained damage to only the 1st storey windows

Figure 37 The Hotel Horaikan at Unosumai, Kamaishi City, with official signage displayed at the 3rd floor and very little external damage. The hotel was inundated to the ceiling of the 2nd storey

Figure 38 Locations of 5 designated vertical evacuation location visited in the downtown area of Ōfunato City: (A) Plaza Hotel; (B) Yasuka office/apartment buildings; (C) Maiya Shopping Centre and car park.

Seven buildings in Ōfunato City were recognised by the community and municipal government as vertical evacuation buildings, five of which we visited during our field visit (Figure 38). These were not officially designated as they did not meet the standards set by the 2005 government guidelines due to their construction prior to 1981. As result, the buildings are defined through informal arrangements with the building owners. This arrangement is in place for the Maiya shopping centre and adjacent multi-storey car park (Figure 39 and 40), Yasuka private commercial and apartment blocks (Figures 41 and 42), Plaza Hotel (Figure 43 and 44), Fukutomi Hotel, Kesennuma Banking building, Nokyo Credit Co-operative building, and the Wedding Plaza. Despite the construction of these buildings prior to latest seismic requirements, they were not significantly damaged in this earthquake. The only structure less than 4-storeys in height is the RC construction Wedding Plaza, which was inundated almost to its roof but survived intact. Inundation height in the vicinity of these buildings was around 3-storeys (9-10 m height; EEFIT, 2011).

Figure 39 Maiya shopping centre, which was inundated to the 3rd storey

Figure 40 Maiya multi-storey car park showing damaged railing at the 2nd storey.

Figure 41 Yasuka private commercial and apartment block number 1 shows very little exterior damage.

Figure 42 Yasuka private commercial and apartment block number 2 is adjacent to block number 1 and was being refurbished at the time of our visit


Figure 43 The Plaza Hotel, which was being refurbished at the time of our visit

Figure 44 External stairs giving access to the 4th storey of the Plaza Hotel

Twelve buildings were designated for vertical evacuation by Kesennuma City in 1982 with a further three added later. Nine of these buildings are shown in Figure 45, and individual photographs are shown in Figures 46 to 53. These buildings provided refuge to 2,326 people on March 11th. With the exception of the car park deck over the fish market (which was constructed with vertical evacuation as a planned function) these buildings were all existing structures that met the 2005 guidelines. Being constructed over a fish market, parts of the car park structure are open with steel columns and no walls, enabling flow through the structure.

Consideration is being given to changing the requirements for buildings used for vertical evacuation in Kesennuma, as several buildings were close to being overtopped. The tsunami arrived at low tide, and it is estimated that overtopping of vertical evacuation buildings would have occurred if the tide and tsunami combined had been just 1 m higher. In recognition of this, the fire department believes that buildings designated for vertical evacuation in future should be 5-storeys or greater. Additional features under consideration include night-time lighting to indicate evacuation routes, and emergency power supplies in vertical evacuation buildings. Fires were a significant issue in Kesennuma, after 51,000 litres of oil was spilt from ruptured oil tanks. Many buildings burned and some evacuation centres narrowly avoided catching fire while occupied by evacuees. A government committee has been set up to prevent such a spillage of oil occurring again, and the fire-proofing of evacuation structures was raised as a consideration for future design of such facilities.

Scour of vertical evacuation buildings was common in Kesennuma and was observed at the office building (Figure 46), welfare centre (Figure 48) and Prefectural Office (Figure 50). The buildings were generally undamaged by debris strike despite their location in a busy port, with damage from debris only observed at the office building in Figure 46.

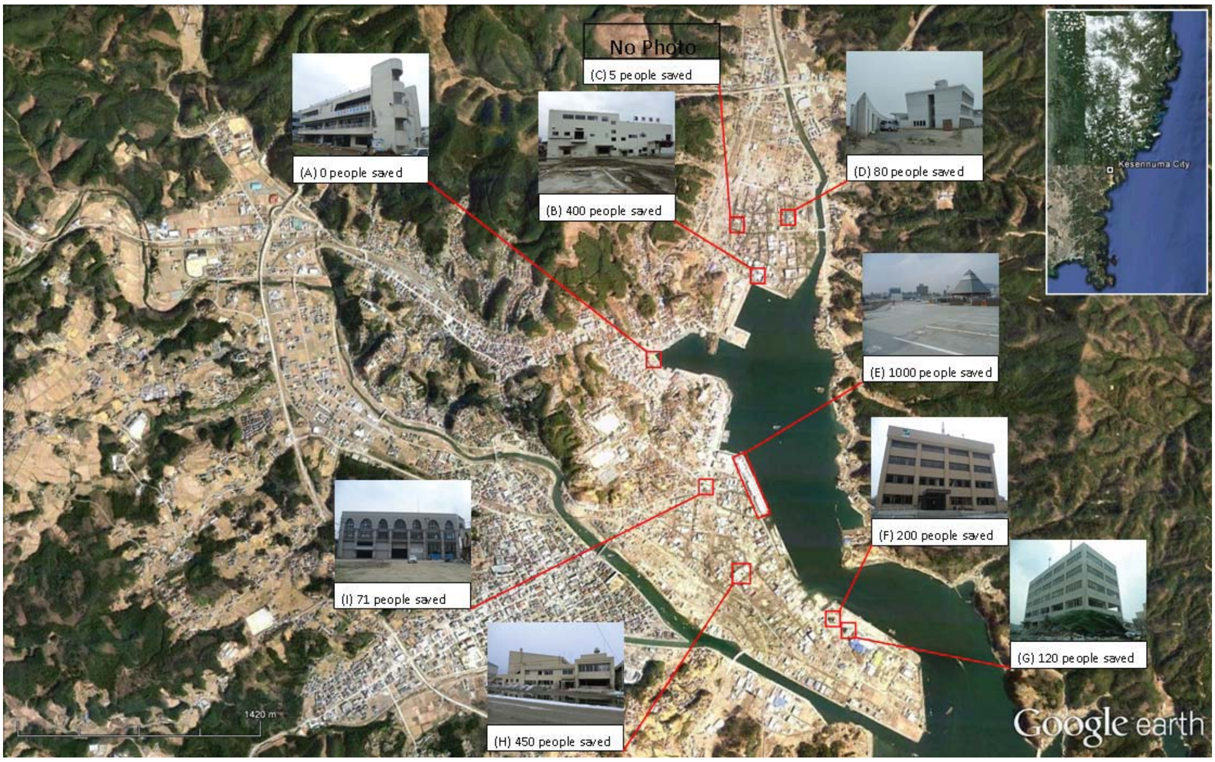


Figure 45 Locations of designated tsunami evacuation buildings in Kesennuma City (Data from Kesennuma City General Affairs Department). (A) Office building; (B) Yoyoi food factory; (C) Shoe store; (D) Elderly welfare centre; (E) Tourist Pier and fish market; (F) Prefectural Office; (G) National government office; (H) Central Community Centre; (I) Kahoku Newspaper office

Figure 46 An office building in the inner harbour was unused on March 11th. This building sustained debris damage to the external stairs (front right) which face the harbour. Minor scour occurred along the seaward face of the building, and around the base of the external stairs.

Figure 47 The Yoyoi food factory, where 400 people took refuge. Inundation height was around 8 m here.

Figure 48 An elderly persons' welfare centre which was inundated to around 8 m height. Scour up to 2 m deep occurred on the near side of the building in this photograph. Extensive damage occurred immediately inland of this building, while 80 survived on the upper floors.

Figure 49 The large open car park roof space above the fish market provided refuge to 1000 people. This structure is at the harbour front and inundation almost reached roof level. The open steel structure enabled tsunami flow at the 1st storey.

Figure 50 The Prefectural Government offices suffered extensive scour and heavy in inundation of 8 m. This building was constructed after 2004 and displays tsunami vertical evacuation signage at roof level. 200 people survived the tsunami in this building

Figure 51 The National Government office, where 120 people took refuge from the tsunami. This building is adjacent to the Prefectural Government offices and was left undamaged when light steel structures were washed into it. The lower two storeys were inundated.

Figure 52 Kesennuma central community centre, where 450 people took refuge when they evacuated nearby buildings

Figure 53 The Kahoku Newspaper offices were inundated to at least the ceiling of the 1st storey. 71 people took refuge here.

There were four designated tsunami evacuation buildings in Minami-Sanriku in the near shore area (Figure 54) which was inundated to 11 m above ground level:

- The Matsubara community apartment block (Figure 55), which is owned by the town, is located at the harbour front. It is RC construction, 4-storeys in height, and 44 people survived on the roof, despite inundation to the 4th storey. This building was constructed in 2007 and planned as a vertical evacuation structure to provide refuge to large crowds at the adjacent sports ground. This is the only building in Minami-Sanriku with tsunami evacuation signage, due to its construction after use of common signage began in 2004. Due to its location, there were initial public concerns about the building being used for tsunami evacuation, but it was agreed the roof level would constitute safe elevation. Significant scour occurred around this building, with at least 2 m of scour around the foundations (EEFIT, 2011).

- The Takano Kaikan wedding ceremony building (Figure 56) provided refuge to 330 people, most of whom were elderly and attending an assembly at the time of the earthquake. The building owners considered use of this building in evacuation as corporate social responsibility.

- Shizugawa Hospital is a site comprising two buildings of 4- and 5-storeys in height (Figures 57 and 58). Most of the 320 people who were in, or evacuated to this building prior to the tsunami survived on the roof but 71 people were killed, the majority of whom were patients who could not relocate to the top storey due to illness/weakness.

- Despite being only 2-storeys in height, the fishing co-operative building (Figure 59) was designated for vertical evacuation use through its ownership by a public organisation looking to protect its workers. The building was unused on March 11th.

Following experiences of March 11th, the disaster prevention official in Minami-Sanriku recommends that all vertical evacuation buildings should be higher than 5-storeys. Evacuation towers may be considered in the town for the future but as was the case before March 11th, primary advice will be to evacuate to higher ground rather using buildings or towers. These should remain a last resort due to the potential for people to become isolated in buildings and require rescue later.

Figure 54 Locations of designated tsunami evacuation buildings in Minami-Sanriku Town: (A) Matsubara apartments; (B) Takano Kaikan building; (C) Shizugawa Hospital; (D) Fisheries Co-operative. Significant scour can be seen where seawater is encroaching around building (A) and to the east of building (D).

Figure 55 Matsubara apartment block viewed from the seaward side with waterborne debris to the 4th storey. The low seawall has been destroyed in the tsunami return flow and was sheltered in part by the apartment building. The foundations of this building are exposed above the water level due to extensive scour.

Figure 56 The Takano Kaikan building 160 m inland of the Matsubara apartment block. Little damage aside from glazing was observed here, despite heavy damage and collapse of RC buildings immediately seaward.

Figure 57 Shizugawa Hospital (west building) – the taller of the 2 hospital buildings at 5-storeys, this section suffered less debris damage than the east building.

Figure 58 Shizugawa Hospital (east building) viewed from the seaward side which suffered debris damage at the 1st and 2nd storeys.

Figure 59 Minami-Sanriku fisheries co-operative building which was overtopped on March 11th. Image credit: Google Streetview, August 2011.

There was widespread use of buildings for informal (unplanned) vertical evacuation in Ishinomaki on March 11th, 2011. Following production of the 2005 government guidelines on vertical evacuation, Ishinomaki City office reached agreement with three private companies in the Minato-machi district of the city to use their facilities for evacuation. On March 11th, a total of around 500 people sought refuge at these three buildings: York Benimaru shopping centre (Figure 60), Homac hardware centre (Figure 61), and Hotaru funeral facility (Figure 62). Although these buildings are only 2-storeys in height, they were deemed appropriate for the city's level of tsunami risk and were sufficient for the tsunami inundation which occurred. Two of the buildings (Homac and Hotaru) have external vehicle ramps leading to rooftop car parking areas; the funeral facility appeared not to have external access to the 2nd storey, and it is unclear whether 24 hour access is available.

There was no disagreement from the building owners when they were approached by the city. Once the use of these buildings had been agreed, the agreement was broadcast on local news but their function was not publicised widely and no signage was applied. It is agreed that the city will pay compensation to the building owners in the event of damage or costs incurred to the property when people evacuate to the property – for example, people having to break in or occupy the building for long periods of time.

In addition to these three designated buildings, almost any building that is higher than a 2-storey residential structure was used for vertical evacuation in this event. About 260 official and unofficial evacuation places were used in total, providing refuge to around 50,000 people. These included schools, temples, shopping centres and housing. In addition to this, there were another 50,000 people trapped in the upper storeys of houses. Due to the effects of this tsunami, it is recognised that more evacuation structures are required west of the Kitakami River. Relocation of evacuees was required in some locations, for example at Kadonowaki Elementary School (Figure 63), which was inundated at the first floor and was subsequently affected by fire within 1 hour of the earthquake. Those people that had evacuated to the school were able to leave the school prior to the fires, moving further inland and uphill to another school.

Figure 60 York Benimaru shopping centre, Minato-machi, Ishinomaki City. The rooftop car parking area is accessible by vehicle ramp and was successfully used for vertical evacuation on March 11th.

Figure 61 The Homac hardware store is a single storey building with car parking on the roof, which is accessible by vehicle ramp. Image credit: Google Streetview, August 2011

Figure 62 The Hotaru funeral facility. This is an unlikely vertical evacuation facility given the lack of obvious roof space or external access, but successfully provided refuge on March 11th.

Figure 63 Kadonowaki Elementary School was damaged by fire while inundated during the tsunami. People who had sought refuge hear were able to leave the building and evacuate further uphill at the rear of the school. This building is a typical school structure in Japan; these buildings are commonly used as evacuation or emergency welfare centres.

Four tsunami buildings in Natori City had been specified by the municipality government as evacuation places: Yuriage Community Centre (Figure 65), Yuriage Junior High School (Figure 66), and Yuriage Elementary School (Figure 67). These buildings are situated outside of the previously estimated tsunami hazard zone, so it is believed that these buildings had been identified as regular evacuation centres, rather than specifically for vertical evacuation. Sendai International Airport in Kitakama was also an evacuation location, through an existing agreement with local residents that it would be used in the event of a tsunami. These buildings were the destination for many people evacuating Yuriage (Murakami and Kashiwabara, 2011) and a total of 3,285 people evacuated to these buildings (Unknown, 2011b), but other 1 to 2-storey buildings between Yuriage and the airport, such as a pump-house and a university boat club building were also successfully used for refuge. People also survived on a pedestrian footbridge close to the Yuriage Bridge. The designated schools in Yuriage are 3-storeys in height and the community centre is 2-storey. In this event a small amount of water reached the 2nd storey but people survived at that level.

Figure 64 Locations of designated evacuation buildings in Yuriage, Natori City: (A) Yuriage Junior High School; (B) Yuriage Elementary School; (C) Yuriage Community Centre. Sendai International airport is to the south of the area shown here.

Figure 65 The Yuriage Community Centre was inundated to the 2nd storey but 43 people survived in the building.

Figure 66 Yuriage Elementary School. 870 people took refuge here, where the large roof area and 3rd storey were above inundation. Direct external access to the 3rd storey is available from the stairs shown here.

Figure 67 Yuriage Junior High School is constructed on ground which is raised 1.8 m above the surrounding fields. This helped to mitigate damage from the tsunami flow and only contents damage was observed (EEFIT, 2011). 823 people took refuge here.

2.7.3 Community engagement

Community-led identification of buildings that may be suitable for vertical evacuation was common in the locations visited, particularly in Ōfunato City where all vertical evacuation buildings were originally proposed by the community, but did not meet the age requirements set by the government guidelines. In Kamaishi, the community identified several buildings that they believed could be used in a tsunami, additional to the three officially designated buildings. The suggested buildings did not meet the government requirements and the local authorities do not advise their use during tsunami. Only the building owners used these buildings on March 11th 2011, and although the lowest 3-storeys were damaged, the occupants survived.

Community disaster prevention groups in Kesennuma approached the owners of the Yoyoi food factory in the Hamacho neighbourhood about using it for vertical evacuation, after which the building owners and the city came to an agreement to designate it as a vertical evacuation building. The building has signage over the doors and is used in ongoing training as part of the evacuation drill held at the factory twice a year with the local fire department and residents.

2.7.4 Evacuation building signage

Consistent vertical evacuation signage for buildings was introduced in 2004 and in general only buildings constructed after 2004 have this signage in place on their exterior (e.g. Figures 68 and 69). The only observed buildings with official signage in place are the apartment block in Kamaishi; Hotel Horaikan in Unosumai; Matsubara apartment block in Minami-Sanriku; the Prefectural Office in Kesennuma City; and Yoyoi food factory in Kesennuma.

Figure 68 Official vertical evacuation signage, as photographed on the apartment block in Kamaishi.

Figure 69 Sign indicating the entrance to external stairways at the apartment block in Kamaishi (Translation: "*Evacuation building entrance (stairways)*".

2.7.5 Owner agreement

During designation of buildings, disaster prevention officials found building owners to be "extremely cooperative" in Kesennuma, and this is also seen in other locations where interviews were carried out. The owner of the Hotel Horaikan in Kamaishi district proposed that her own building be designated as an alternative option to defences blocking beach access. She had previous experience of evacuation into a building following a tsunami warning, so built her hotel as a 3-storey building so it could be used in tsunami. The owners of the Takano Kaikan building in Minami-Sanriku were said by disaster prevention officials to recognise the corporate social responsibility of agreeing to this use. The Minami-Sanriku fisheries co-operative was interested in designation to protect its workers.

In Ōfunato, the disaster prevention official reported some initial resistance from building owners when they were first approached about the potential use of buildings in evacuation. The owners' concerns focussed on night-time access and who would be responsible for evacuees while in the building, but following discussions with the community the owners agreed to their buildings being used. We were unable to confirm through our interviews, the reasons for final agreement. The issue of responsibility for evacuees remains a key issue here: employees at the Credit Co-operative chose to leave the building on hearing the tsunami warning on March 11th, and it is unknown what impact this had on people trying to access the building in this case.

2.7.6 24-hour access

A vital issue in the effective use of vertical evacuation buildings is guaranteed access 24 hours a day, on any day of the year. Access to upper floors of buildings in Japan is often provided via external stairs, which exist on many buildings for emergency egress in fire or earthquakes. These stairs may not always lead to the roof, but do at least give access to upper floors. Where access is not available by external staircases, several other methods of access are available in the locations visited (see also Appendix 4):

- Owners of private buildings have security staff present overnight to allow people in (e.g. Prefectural Office in Kesennuma)

- Building owners agree to breakage of doors and windows to allow emergency access (e.g. Kesennuma Junior High School and National Office in Kesennuma)
- Due to day to day use, the building is staffed, or has residents in a night-time 24-hrs a day (e.g. Shizugawa Hospital, Hotel Horaikan, Matsubara apartments)
- Representatives of local residents have keys to enable access outside of office hours (e.g. two representatives living near to government building, Kamaishi; Yuriage schools and community centre, where the key holders are informed by telephone that they need to open the facility).

2.7.7 Evacuee Welfare

Welfare of evacuees is another important issue in considering use of vertical evacuation buildings. Evacuees had been stranded in many buildings for up to 2 days following the earthquake, due to remaining tsunami waters or debris blocking egress from the building. Welfare considerations are primarily provision of food and water, shelter, warm blankets or clothing, sanitation facilities and a means of emergency communications with disaster prevention headquarters or emergency services.

Provisions were available at the Prefectural Office in Kesennuma and South Kesennuma Elementary School but these were appropriate to a 6 hour occupancy period only. It had been assumed that after 6 hours residents would be able to get to welfare centres where more long-terms provisions are stored prepared in the event of a disaster. However, some residents had to remain in these buildings until the March 13th, when they were either rescued by helicopter or by road once debris had been cleared. Other examples of evacuees having to remain in evacuation buildings until March 12th were at Yuriage Elementary and Junior High schools, and the apartment block in Kamaishi, when evacuees had to leave through tsunami water or dig silt out of stairwells to exit the building. Evacuees remained in the airport terminal until March 13th until they were rescued. The Yuriage community centre and Junior High School both had some provisions for evacuees, but there was very little at the school and storage of provisions in the community centre was on the ground level, which became inundated. There was no emergency communications equipment in the schools.

In Ōfunato, provisions were available at the shopping centre due to the day-to-day function of the building, but no specific arrangements had been made to provide short-term support for occupants in the event of a tsunami. Apartment buildings are also likely to have some provisions and shelter, given the regular residential use of the building. The disaster prevention official here raised the provision of a communications link in all refuges as an important resource, to enable evacuees to contact help in case of requiring urgent rescue (for example if threatened by fire or serious illness) when cell phones or other radio systems are not functioning.

The disaster prevention official in Minami-Sanriku re-affirmed an important challenge when planning resources for evacuation buildings: it is difficult to say how many people will use any given building. More work is required on resource planning, but it is clear from the events of March 11th that basic resources are highly desirable for a few days of occupancy. However, this issue is secondary to the provision of life-safety, and designation of suitable buildings should not be delayed or prevented as a result of inadequate welfare facilities.

3.0 RECOMMENDATIONS

This section presents recommendations for Washington and New Zealand, as a result of the authors' observations and information from interviews. These recommendations refer to the themes discussed previously in Section 2.0 under corresponding headings.

3.1 Community involvement in evacuation planning and preparedness

There is well-developed community engagement in tsunami preparedness in Tōhoku. This is extremely positive for perpetuating community awareness of hazard and appropriate response, and increasing community ownership of disaster planning. In the municipalities we visited, 96% of people living in the inundated area survived. This is a very positive result in the context of such a large magnitude earthquake and tsunami, and the high rate of survival can be attributed to this high awareness and subsequent effective evacuation.

Community engagement should continue to be encouraged as it currently is in Washington and New Zealand, through projects emphasising community input and ownership.

3.2 Hazard/evacuation maps and signs

3.2.1 Maps

The maps provided to coastal residents in Tōhoku show some of the same inconsistency issues recently highlighted in the Pacific Northwest by Kurowski et al. (2011). More focussed research of map content and style (and their impact on evacuation response in Tōhoku) has the potential to provide recommendations of regional scale evacuation mapping best practice. This can benefit programs that are already under way in Washington and New Zealand to enhance tsunami evacuation mapping standards. Researchers should monitor any Japanese research on the impacts of hazard and evacuation mapping styles and inconsistencies had on evacuation response on March 11th 2011 and assimilate research findings into current efforts to improve consistency.

It is encouraging that the U.S. and New Zealand have already taken steps to improve consistency and clarity of their mapping. At this time when Japan needs to revisit its mapping, there should also be opportunity U.S. and New Zealand guidelines to positively inform the next generation of maps in Japan.

Showing evacuation shelters and/or assembly areas on maps is recommended but maps should only show those sites which have been officially designated as being at sufficient elevation to ensure safety in tsunami, and of sufficiently strong construction to survive a local earthquake and tsunami. Evacuation routes should be shown to encourage people to evacuate out of the evacuation zone as soon as possible and then to shelters, rather than travelling extensively within the evacuation zone. Confusion among evacuees may arise where shelters or assembly areas are designated for use in the occurrence of different hazard events (e.g. landslide), and may be located within the tsunami evacuation zone. These should not be included on tsunami evacuation maps, and there should be clear, specific education informing the community about whether or not that facility is suitable for use in tsunami evacuation.

3.2.2 Hazard/evacuation signs

Washington and New Zealand already have well-developed tsunami signage guidelines and our observation of similar signage in Japan suggest only a minor addition. It is recommended that consideration be given to including on signs the distance to safe location, in order to provide some perspective of the distances people would be required to cover in an event.

3.3 Response to natural and informal tsunami warnings

Education that people should evacuate coastal areas if they experience a strong or long earthquake was an appropriate concept for Tōhoku and the benefits of this education were shown on March 11th 2011 with high proportions of the population evacuating immediately. This is an example that the message currently given in New Zealand is the correct one for local tsunami, and should continue to be used.

Relevant agencies should continue education which encourages immediate evacuation upon experiencing natural warning signs. Particularly encouraging is the fact that immediate evacuation can have a cascading effect on influencing others (who may be disoriented or unaware of appropriate action) to evacuate.

An important point to note is that personal or community experiences appeared to negatively affect the proportion of people evacuating immediately. Due lack of experience of local tsunami in Washington and New Zealand education must be made more effective to counter this and achieve high proportions of immediate evacuation.

In the United States, preparedness advice from relevant agencies on the West coast varies but maintains the core message to evacuate on feeling ground shaking. This message is unfortunately not replicated by the message given by FEMA (2011), whose current advice is to listen to the radio upon feeling an earthquake. A subsequent FEMA statement advises immediate evacuation upon receiving an official warning. Even if the radio is still working during the earthquake, strong or long ground shaking is by far the fastest warning and advising people to monitor the radio will likely (a) slow evacuation and (b) reduce public confidence in their ability to act on natural warnings in the absence of official warnings. Given the short expected arrival times (20-30 mins) of the first waves at the Washington coast, the FEMA advice should be made consistent with that provided by Washington EMD and WCATWC, to evacuate to high ground upon experiencing a strong earthquake.

It is recommended that additional clarification be added to provide a clear statement of what people can expect to experience in a strong earthquake – i.e. experiencing difficulty in standing up. Additional consideration should also be given to the occurrence of long periods of sustained ground shaking (longer than a minute), when people may experience lower levels of shaking that do not trigger response to the earthquake strength.

Education in New Zealand states that informal warnings from friends and members of the public may be correct and that people should not wait but rather evacuate and then confirm the warning once at a safe location. Informal warnings were valuable in Japan and discussion supporting informal warnings should be included alongside any education around formal and natural warnings.

Communications channels can be disrupted in a local earthquake event, and the population should be encouraged to recognise the unreliability of these communication channels in such a situation and respond to the natural (or informal) warning without scepticism or hesitation.

3.4 Formal warning messages and systems

3.4.1 Warning messages

In general there is a high expectation in Japan that official warnings will be provided for local tsunami, in addition to regional or distant tsunami. In Washington and New Zealand there is a much longer response time for the broadcast of official warnings, precluding their use in local events. In addition, the high monetary cost of implementing technology required for a Japanese-style early warning system means that at present, more effective evacuation of the population in local source events can be achieved in Washington and New Zealand if people are educated to evacuate independently of formal warning (i.e. in response to natural warnings).

At a time when official hardware-based warning systems are growing in scale and apparent technological advancement, there is increased potential for people to be less likely to respond to natural warnings. While recognising the benefits of tsunami warnings for regional and distant tsunami, there should be continued investment into education of the different response issues for local tsunami versus regional and distant tsunami.

Reliance on early warnings for local source events in Japan has previously caused frequent false alarms (and unnecessary evacuation), which in some areas led to complacency and meant some people delayed or declined to evacuate on March 11th. By comparison, earthquakes that are long (lasting more than a minute) or strong (enough that people can't stand up) are rarely felt in a person's lifetime in Washington and New Zealand and any use of official warnings should not detract from public response to this unmistakable natural warning. Education material and especially community planning and exercises that clearly identify the difference in size between expected distant source and local source tsunami are required to minimise normalisation bias that occurs from experience of more frequent 'small' distant tsunami.

The use of broadcasts explicitly stating expected wave heights should be considered extremely carefully before implementation. Miscommunication occurred in Tōhoku when communications systems failed. Inaccurate estimates and failure in the system was shown to result from technological failure, human error, and due to reliance on preliminary earthquake parameters to estimate tsunami height. A more conservative approach should be adopted in the time period where accuracy cannot be guaranteed, through publication of worst-case scenario wave heights or by avoiding any discussion of size for local sources and advising that people evacuate the largest (most conservative) zone. If wave heights are to be broadcast, the receiving audience must be educated effectively that wave heights are given at the shore, and that on-shore inundation height and run-up is likely to be much greater.

The ideal situation is to avoid any expectation that official warnings will occur in a local source event at all, thus encouraging total evacuation in response to natural warnings.

3.4.2 Warning systems

Any tsunami warning system in place in Washington or New Zealand that is intended for use in local warnings must have sufficient redundancy to allow full functionality following a local earthquake. The experience of effective warning transmission in Minami-Sanriku via household wireless radio receivers illustrates the effectiveness of a system such as the NOAA Weather Radio system.

The Japanese approach of utilising siren towers and speakers for post-event announcements of further events or welfare advice (i.e. locations to receive supplies or medical treatment) should be considered for post-event response in the United States and New Zealand where such systems are available. Additional redundancy and resilience is required in the warning broadcasting system if it is required for further warnings and welfare announcements. This must be applied to the broadcasting source point, any telemetry, and the public notification point.

Siren towers and radio-receiver systems are expensive and can be too slow in a local source event, compared to the natural warning from long or strong earthquakes. These official warning mechanisms should be treated very cautiously and not expected to be a reliable solution for local earthquake and tsunami.

3.5 Movements during and after evacuation

3.5.1 Delayed evacuation or non-evacuation

Tsunami education in Washington and New Zealand aims to achieve widespread immediate evacuation and can benefit from using examples of *tsunami tendenko* in education programs, to encourage people to evacuate immediately on experiencing a natural warning. Whether or not official advice should follow *tsunami tendenko* in explicitly recommending that people do not stop to help others is an emotionally and culturally sensitive question and would require careful consideration before deciding whether or not to implement such advice in Washington or New Zealand. Assisted evacuation of immobile people or groups requires careful planning within realistic timeframes for tsunami arrival, and should be regularly exercised as part of tsunami preparedness activities. There should be clarification of current FEMA advice (see Section 2.5) to help neighbours evacuate – it is unclear whether this advice relates to distant tsunami when there would be time to help others without endangering yourself, or local tsunami when there may not be.

The *tsunami tendenko* message should be delivered alongside education showing that delayed evacuation or refusal to evacuate places additional burden on emergency services or neighbours. The key message is that immediate self-evacuation and prior planning are the most effective ways to ensure that the maximum number of people survive a tsunami.

3.5.2 Use of motor vehicles during evacuation

Events on March 11th provide support for the approach currently taken in Washington and in New Zealand, which is to encourage tsunami evacuation on foot wherever possible. Vehicle congestion was a significant problem in some areas investigated, even where previous education had encouraged evacuation on foot. Tsunami drills, in which use of vehicles is banned, appear to have been an effective method of encouraging evacuation on foot and this should continue to form a key part of education.

Motivating people not to use vehicles is a significant challenge. One strategy in use in Ryoishi involved 'stickering' approved vehicles for the transport of special needs groups, such as disabled and elderly people. While this is unlikely to be able to be policed in an event it may well act as a strong education medium (both through selection discussions and visibility of stickers) and awareness trigger for the need to otherwise avoid cars.

Social responsibility should be harnessed to reduce use of motor vehicles in evacuation by communicating that use of a motor vehicle puts those in the vehicle and others in danger by causing congestion and slowing evacuation, and that motor vehicle evacuation should be reserved for evacuation of immobile residents only.

The emphasis on pedestrian (and bicycle) evacuation in Washington and New Zealand should be continued, unless a location is a considerable distance from high ground, in which case, vehicles may be the only way to evacuate coastal zones rapidly enough. In these cases an efficient scheme is required to streamline large-scale evacuation in vehicles, but observations from this event have not suggested such a scheme.

3.5.3 Use of boats during evacuation

Further discussion is required to determine the most appropriate recommendation regarding use of boats to evacuate out to sea. However, Washington and New Zealand should aim to provide explicit advice to the public on this issue.

It is likely that in many situations following a local tsunami, there would be insufficient time to launch a boat and reach the open ocean before wave arrival (while likely to be experiencing very strong currents) and this course of action should not be recommended. Additional considerations for evacuation by boat are: difficulties returning to port through debris fields or to damaged moorings, and the ability to stay at sea for many hours.

3.5.4 Schools evacuation

It is vital that the lessons of unnecessary deaths during evacuation of parents and children are learned and incorporated to current school evacuation advice. The example of children successfully evacuating Kamaishi City schools provides an excellent example of the benefits of tsunami education (in this case *tsunami tendenko*), and this should encourage New Zealand and Washington to make tsunami education in schools a priority.

Schools should have a school-community approach to tsunami evacuation training, inclusive of staff, children and parents. All schools in, or in the vicinity of a tsunami hazard zone should have a tsunami evacuation plan, which is practised regularly with schoolchildren and teachers, and communicated effectively and regularly to the parents. In this way, all parties can be educated as to whether a school is at risk of tsunami or not, and what actions should be taken in the event of a tsunami.

The ideal situation is one in which parents trust that their children are safe while at the school either because i) they are aware that the school is in a safe location, or ii) they have confidence that the school staff and their children are all well-trained in evacuation procedures. This trust could prevent many deaths by removing the requirement or desire for parents to travel into or through the potential inundation zone when tsunami is imminent. In the course of reducing the number of parents travelling to schools, potential traffic congestion and contraflow of traffic can also be reduced.

This school-community approach can also have additional benefits in the education of the wider community by getting adults involved in disaster education when they might not otherwise attend community meetings. As one disaster prevention official in Tōhoku stated, "*The key to effective education is to have everyone envisage the tsunami together and individuals must take responsibility for their decision of where to go in a tsunami*". He believes that education in schools in Japan is vital as many children do not attend disaster workshops in the community, and while there is interest in disaster curriculum in some schools it is not compulsory; he considers the best way to reach children being through the curriculum with parents involved in order to create a type of *"knowledge permeation strategy"*.

3.5.5 Necessary relocation from evacuation refuges

Tsunami are a dynamic and rapidly evolving hazard, such that a location that at first appears safe can very quickly become inundated, so people should be empowered to use their evacuation training and initiative rather than follow a prescriptive evacuation plan to a certain location and remain there. Personal responsibility is the important factor, and it should be a key component of education to train people in assessing the changing situation during evacuation and take action where appropriate.

This education should not come at the expense of ensuring hazard modelling is as accurate as possible and that any evacuation centres are located outside of the maximum tsunami inundation extent. Likewise, all vertical evacuation buildings should be designed to remain safe in the maximum tsunami so that where relocation is not possible, life-safety is still ensured.

3.5.6 Leaving evacuation refuges too early

Education around the interpretation of arrival times in tsunami warning messages must continue to stress that arrival times are approximate and that people should not return to low-lying areas, even if the arrival time has passed without wave arrival. The most important message is that it may take hours for a tsunami to arrive and the largest wave may be hours after the first wave.

The importance of receiving an official 'all-clear' message must continue to be emphasised strongly in a consistent fashion across tsunami evacuation literature, particularly in cases where people may have evacuated due to natural warning and been unable to confirm the occurrence of a tsunami through official or informal channels.

3.6 Impacts of coastal defence on warning response and evacuation

In Washington and New Zealand it is unlikely that substantial coastal tsunami defences would be constructed, due to the nature of the coastline and people's high value on coastal amenities (e.g. sea views, beach access). The construction of hard defences in response to a plate boundary local source tsunami hazard should be carefully considered, with the negative social and environmental impacts, the significant financial investment required, as well as the estimated levels of physical protection included in any cost-benefit analysis.

Where 'hard' defences are considered at even small scales, it should be effectively communicated to the public that this infrastructure should not be seen as a guarantee of life safety in any tsunami, and that evacuation remains the appropriate action to take. The issue of coastal walls blocking the ability to see natural warning signs in the ocean remains.

3.7 Vertical evacuation buildings

The use of vertical evacuation buildings has undoubtedly shown its value in providing safe refuge during the Great East Japan tsunami. In the locations visited during this research, 37 designated buildings provided refuge to at least 5428 people (see Appendix 4). The use of buildings is not a replacement for evacuation to high ground, but it does provide effective alternative options to those unable to evacuate the inundation zone prior to tsunami arrival. Key lessons can be learnt from the experience of March 11th, for implementation in current development of vertical evacuation projects in New Zealand and Washington.

3.7.1 Building specification and levels of damage

The specifications for vertical evacuation buildings in Japan, set by Hiroi et al. (2005) were sufficient in this event with respect to construction type, with damage to designated buildings in the earthquake and tsunami generally limited to non-structural damage. Along with FEMA (2008) these guidelines provide a standard for appropriate construction of vertical evacuation structures, and observations from this event support continuation of the focus on using reinforced concrete buildings for vertical evacuation. Heavy damage to glazing and contents should be expected at any inundated facility, while observations in Tōhoku support the need to find solutions for minimising spread of fire and preventing fire damage.

The appropriate height of buildings is being called into question following instances of waves almost overtopping buildings. The recommendation of a minimum number of storeys relies on the underlying hazard modelling for an area, and in order to gain maximum confidence that a building is tall enough, detailed site-specific tsunami modelling must be carried out at the site of any proposed facility, using the maximum credible local event. The application of a factor of safety, such as that applied in FEMA (2008) is still required in addition to the model-derived estimated maximum tsunami height to account for uncertainty in such estimates. A blanket requirement for a single minimum height may not be the right approach, given the varying flow depth with onshore topography seen in Japan.

3.7.2 Community engagement

Community engagement on the selection of vertical evacuation buildings should be encouraged. It is vital that members of the local community are familiar with the buildings as part of the community preparedness plan, and are aware that the buildings are proposed as a secondary option to evacuation to high ground. If a project has the support of the community it will likely increase co-operation with building owners who may initially be reticent about the designation of their building.

Designated facilities should be incorporated into tsunami evacuation drills to foster familiarity with their use. Care should be taken to continue to prioritise evacuation to high ground, but evacuation to vertical evacuation facilities should be practised where a local tsunami is known to be likely to prevent people in certain locations reaching high ground.

3.7.3 Evacuation building signage

Consistent signage should be adopted and applied to all buildings designated for vertical evacuation use. These signs should be clearly displayed at the top of buildings and above entrances, indicating the most appropriate access route to upper stories. The signage should be consistent with current styles and messages in use in the local area. The signage is intended to allow easy identification for local people and visitors to the area (or emergency responders), and enhances awareness of the facilities.

3.7.4 Owner agreement

Owner agreement is likely to be a significant issue in New Zealand and Washington if private buildings are considered for use. Owner agreement issues generally focus on responsibility or liability for evacuees and issues of access. Leveraging community interest and encouraging owners to see the provision of the facility as a benefit to the community has been shown in Japan to be an effective way to gain agreement of building owners.

3.7.5 24-hour access

The ability to quickly access vertical evacuation buildings at any time of day or night is vital. The community should be aware that facilities are available at night, and building owners should be prepared to allow access to the building at any time. Direct external access from the ground floor to upper storeys (above 3rd or 4th storey) or the roof should be provided where possible, but where this is unfeasible, agreement should be sought between the building owners and the community in recognising that in an emergency, people may need to gain access by other means.

Promoting the use of “key-holders” – representatives who have keys with which to access designated buildings in the case of an emergency when the building is locked appears to be an effective method, but requires responsibility on the part of key-holders to go to the building in the event of a tsunami. These people would ideally be civil defence volunteers or people in a similar role. Allowing evacuees to enter by force should be investigated as a possibility, but is likely to be an inappropriate solution for buildings containing sensitive data such as public offices or commercial premises. In each case, dialogue between building owners and the community is encouraged in order to find the most appropriate solution.

3.7.6 Evacuee welfare

In any vertical evacuation building, there should be provision of shelter, food and water, and communication links to civil defence and emergency services at upper storeys. Provision of dedicated supplies has been shown to be extremely important given the potential for refuges to be in use for up to a few days if tsunami waters subside slowly or debris traps evacuees. Adequate provisions may help reduce any need or urge of evacuees to leave the refuge earlier than necessary. The amount of provisions should be commensurate with an estimated number of occupants, which should be researched through a combination of evacuation mapping and travel time mapping to estimate the likely level of occupancy. However, these provisions should be managed in a way so as not to not lessen the need for the public to prepare personal emergency kits with their own supplies.

3.8 Additional recommendations from observations and interviews

It is important to provide education on tsunami risk and response to people living inland, as well as those living at the coast. Everyone should have the awareness to be able to take responsibility for their own actions when in a tsunami-risk area. If the awareness exists in visitors, it is likely they will be able to respond to any warnings and signage more effectively, even in an unfamiliar area.

Landslide hazard should be taken into account for tsunami evacuation, in areas where high ground is reached by steep inclines or up narrow valleys. This is important for the occurrence of local tsunami with significant prior ground shaking, which could trigger landslides which block evacuation routes. The awareness to respond and use an alternative evacuation route could save many lives.

The response of some volunteer fire-fighters in Japan was to wait to confirm the occurrence of tsunami arrival on television before responding to the emergency. The previous repeated closure of tsunami gates with no subsequent event may have contributed to some complacency among fire-fighters in Tōhoku. It is unclear whether this slowed the fire services response to closing tsunami gates in this event, but this effect must be mitigated to ensure the most rapid response possible following every warning or significant local earthquake. Training of emergency personnel must emphasise the need for immediate response to natural warnings.

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APPENDICES

APPENDIX 1 INTERVIEW QUESTIONS (ORIGINAL ENGLISH VERSION)

Research questions to be used in interviews with disaster management officials in Tōhoku, Japan.

The aim is to get an understanding of the role of natural and informal warnings, and vertical evacuation buildings in the tsunami mitigation strategy of several municipalities, and to understand their performance in the March 11th 2011 Tōhoku tsunami. Lessons learned will inform further work on tsunami evacuation in Washington State, U.S., and New Zealand as part of an on-going Ph.D. project and collaboration between GNS Science and Washington State Emergency Management Department.

<u>Preparedness – Vertical Evacuation ('V.E.')</u>

1. Was V.E. available in the city prior to the 2011 tsunami?
    a. Was this in response to national or prefectural government directive – as part of the Basic Disaster Plan, or municipality initiative?

2. How many buildings were designated for use as a V.E. facility?
    a. When were the buildings designated?
    b. How were buildings chosen? *(basis of height and material, or detailed analysis by engineers?)*
    c. What design tsunami was for used basis of hazard in the designation process? *modelled Miyagi-ken-oki, Chile 1960, Meiji Sanriku 1933?*
    d. Has there been resistance from building owners when designating buildings as V.E. buildings?
    e. Were additional modifications made to any of these buildings when designated? *(retrofit of structure, fitting of railings, external stairs, sirens)* Is this a condition of them being designated for vertical evacuation?
    f. Are there other styles of vertical evacuation facilities? *(Artificial berms, towers)*

3. What style of evacuation map is available for the city? *(see example and obtain copy where available)*
    a. When were the evacuation maps developed?
    b. What was the design tsunami? *Miyagi-ken-oki, Chile 1960, Meiji Sanriku 1933?*
    c. Were these developed with V.E. in place, or was development separate?
    d. Are V.E. facilities explicitly marked on the evacuation maps? *(e.g. Ishinomaki has a single symbol, Kesennuma are different)*

4. How are the public made aware of V.E. facilities?
    a. What is the educational advice given to the public? *("high ground first, then V.E. building…"?)*
    b. Is V.E. included in tsunami literature provided by management office?
    c. Do evacuation drills involve the use of V.E. buildings?

<u>Preparedness – Natural/Informal Warnings</u>

5. How are natural warnings signs presented in tsunami education and mitigation?
    a. Are the public aware of the importance of natural warnings signs?
    b. Does literature use an event of certain duration/level of ground shaking as a threshold for when people should evacuate?

6. Are the public made aware of the possibility of informal warnings in the event? *(warnings from neighbours…)*

<u>On 11 March 2011 – Warnings and evacuation response</u>

7. How long did ground shaking last in the town?
    a. Does this satisfy advice given for reacting to natural warnings?

8. What was the JMA intensity in the town, or personal experience of ground shaking?
    a. Does this satisfy advice given for reacting to natural warnings?

9. What was the arrival time of first wave in the town?
    a. How large was this first wave?
    b. Arrival times of larger waves?

10. What time did the official warning commence, and how was this communicated?

   a. How did the disaster management initiate the warning? *(official message from JMA/government, or as a result of natural/informal warnings?)*
   b. Were there power outage issues, any other issues that prevented communication of the warning?

11. When did people begin to evacuate?
    a. Was there a large response to ground shaking or did people wait until wave arrival?
    b. At what point do people report beginning evacuation – ground shaking commencing, ground shaking ceasing or tsunami wave arrival?
    c. What proportion of the population ignored natural warning signs and waited for the tsunami warning, or did not evacuate?

12. Where did the population evacuate to? *(get proportions and age distribution if possible)*
    a. How many people evacuated to designated high ground?
    b. Other high ground?
    c. Vertical evacuation buildings?
    d. Upper floors of other buildings?

13. How did people evacuate? *(car, on foot, bicycle).*

14. How far did people travel to each evacuation place?
    a. Were evacuation times/distances consistent with estimations of average walking times?

15. Where were issues of congestion observed, and did this result in further casualties *(i.e. were many people killed in their cars?)*

<u>On 11 March 2011 – Vertical Evacuation (V.E.)</u>

16. How many designated V.E. structures were available in the town in March 2011?
    a. Which had signage indicating their emergency use?
    b. Were all of these buildings used?
    c. Were additional (non-designated buildings) used by large groups of people?
    d. What is the nature of arrangements with buildings owners, and who is liable for safety of evacuees in the building?
    e. Are there official personnel at each building in the event, to direct/help evacuees?

17. During tsunami warnings, were the public specifically advised to evacuate to any vertical evacuation building? *(or to "upper floors of a tall building")*

18. How many people evacuated into each of the vertical evacuation buildings (designated/non-designated)?
    a. How long did people remain in the buildings?
    b. What distances did they travel to each building?
    c. Do any of the buildings have provisions for medium-term occupancy? *(timeframe: days; provisions: food and water, radio communication, shelter)*

19. Issues with the evacuation buildings
    a. Was there any overcrowding reported in a building?
    b. Were there any buildings that were inaccessible prior to inundation? *(due to being locked, or earthquake-damaged)*
    c. How many of the buildings are estimated to be locked and inaccessible at night?
    d. Did any buildings suffer damage/flooding that caused further evacuation? *(i.e. fire damage, debris impact)*
    e. Did any buildings suffer damage/flooding that caused deaths of occupants?
    f. Did people refrain from using such buildings following such a large earthquake? *(what is public perception of safety of such buildings post-earthquake)*

<u>Since March 2011 – Vertical Evacuation (V.E.)</u>

20. Has there been a review of vertical evacuation facilities since March 2011?
    a. Is this municipality level review, or national, prefectural?
    b. Is there any national/uniform guidance from national government on application of vertical evacuation?

21. Are there plans in place to change the (vertical) evacuation strategy for the town? *(new structures being built, re-assigning building use, more emphasis on vertical evacuation in the evacuation strategy)*

APPENDIX 2 INTERVIEW QUESTIONS (JAPANESE TRANSLATION)

Research questions to be used in interviews with disaster management officials in Tōhoku, Japan. These questions were translated and provided to interviewees in preparation for the interviews.

垂直避難（耐震基準を満たしたビルへの避難/略V.E.）の準備について

１．２０１１年の津波以前に、この町で垂直避難をすることは可能でしたか？
  ・可能だとしたら、それは基本災害計画の一環として、国家または県の政府による指示によるものでしたか？または自治体独自によるものでしたか？

２．垂直避難用に指定されたビルは何件ありましたか？
- そのようなビルに指定されたのはいつ頃ですか？
- 垂直避難用ビルはどのように選ばれましたか？ビルの高さ、使用されている建築資材、または技術者による詳細な分析によるものですか？
- 垂直避難用のビルを指定する上で、どのような災害を考慮されましたか？想定宮城県沖津波、１９６０年のチリ地震、または１９３３年の明治三陸津波などでしょうか？
- 垂直避難用ビルに指定する上で、ビルの所有者から反対を受けることはありましたか？
- 垂直避難用のビルに指定された際に、ビルに変更を加えることはありましたか？（構造上の改築、柵を立てる、外側にも階段を作る、サイレンを付けるなど）
- ビルに変更を加えられることが、垂直避難用ビルに指定する条件でしたか？
- その他、垂直避難用ビルにはどのような特徴がありますか？（人口の小段やタワーなど）

３．この町ではどのような避難用地図が使用されていますか？（サンプルがあればみせて頂き、可能であればコピーを入手）
- 避難用地図ができたのはいつ頃ですか？
- 避難用地図を設計する際に、どの津波が考慮されましたか？想定宮城県沖津波、１９６０年のチリ地震、または１９３３年の明治三陸津波などでしょうか？
- 避難用地図は、垂直避難用ビルの指定に伴って作られましたか？もしくは２つは別々に設計されましたか？
- 避難用地図には、垂直避難用ビルが明確に表示されていましたか？（石巻では統一されたシンボルが使用されていたが、気仙沼では使用されていなかった）

４．垂直避難用ビルに関して、人々はどのように知らされているのでしょうか？
- どのような避難に関する指針がありましたか？（“高台に避難し、その後垂直避難用ビルに移動する”など）

・ 災害対策本部による津波に関する文献の中に、避難用ビルについて記載されていますか？
・ 避難訓練の際に、垂直避難用ビルへの避難も行いますか？

自然からの警告、非公式な警告に関する準備について

５．津波教育、また災害被害を軽減するために、自然からの警告について、どのように表現されていますか？
・ 人々はそのような自然からの警告を深刻に受け止めていますか？
・ 津波に関する文献の中で、地震がある一定の長さや震度に達すれば避難すべきだと書かれていますか？

６．このような地震・津波の際に、近所の人からの警告など、非公式な形の警告にも人々は注意を払っていますか？

２０１１年３月１１日から　警告及び避難行動について

７．この町では、揺れはどのくらい続きましたか？
・ この長さは、避難すべき自然からの警告だと感じましたか？

８．この町で気象庁が観測した震度はいくつでしたか？また、個人的にはどのくらいの強さに感じられましたか？
・ この地震の強度は、避難すべき自然からの警告だと感じましたか？

９．この町を最初に津波が襲ったのは何時ですか？
・ 最初の津波の規模はどのくらいですか？
・ より大きい津波が到達したのは何時ですか？

１０．正式な津波警報が出されたのは何時ですか？また警報はどのような形で伝えられましたか？
・ 災害対策本部は、どのようにして警報を出しましたか？（気象庁による通達を受けて、政府による通達を受けて、または自然及び非公式の警告を受けて出しましたか？）
・ 停電による問題、または警報を阻止するようなその他の問題はありましたか？

１１．いつ、人々は避難を始めましたか？
・ 地震の後に大勢が避難を始めましたか？または最初の津波が到達するまで待っていましたか？
・ どの時点で避難を始めたと報告されていますか？地震が起きたとき、揺れがおさまったとき、または津波が到達したときでしょうか？
. 自然からの警告を無視して津波が到着するまで待機した人、また避難しなかった人は人口の何割くらいでしたか？

１２．人々はどこに避難しましたか？（その割合、年代の分布などが分かるものがあれば入手）
指定された高台に何人くらいの人が避難しましたか？
- その他の高台に避難した人はいましたか？
- 垂直避難用ビルに避難した人はいましたか？
- 垂直避難用ビル以外の建物の上階に避難した人はいましたか？

１３．人々はどのように避難しましたか？（車、徒歩、自転車など）

１４．避難場所までどのくらいの距離を移動しましたか？
- 避難時間と避難距離は、平均的な歩く早さと矛盾はありませんでしたか？（アメリカ合衆国連邦緊急事態管理局：；日本）

１５．渋滞・混雑の問題はどのような場所で見られましたか？この問題によって、死傷者数は増えましたか？（例えば、大勢の人が車の中で亡くなりましたか？）

２０１１年３月１１日から　垂直避難用ビルについて

１６．２０１１年３月に時点で、この町には垂直避難用ビルが何件ありましたか？
- 緊急時に避難する建物であることが表示されているビルはありましたか？
- これら全てのビルは避難に使われましたか？
- 避難用に指定されていないビルにも、大勢の人々が避難しましたか？
- ビルの所有者とはどのような取り決めがありますか？ビルへの避難者の安全は、誰が責任を負いますか？
- それぞれのビルには、避難者に指示を出したり助けたりする、公の責任者がいますか？

１７．津波警報の際に、特に垂直避難用ビルまたは高層ビルの上層階に避難するよう、避難指示が出されましたか？

１８．垂直避難用ビルに避難したのは何人でしたか？（垂直避難用ビル、及びそれ以外のビルそれぞれ何人でしたか？）
- どれくらいの期間、人々はビルにいましたか？
- ビルまでの移動距離はどのくらいありましたか？
- 避難者が数日の期間滞在する場合、食料や水、ラジオや避難所など、支給物資等を提供するビルはありますか？

１９．避難用ビルの問題について
- 混雑しすぎていると報告されたビルはありましたか？
- 浸水前に、鍵がかかっていた、地震で壊れていたなどの理由で、入れないビルはありましたか？

- 夜間に鍵がかかっていたるなどして入ることのできないビルは何件くらいあると見積もられていますか？
- 火事や瓦礫による損傷など地震や津波による被害を受け、避難してきた人々がさらに避難しなければならない状況になってしまったビルはありましたか？
- 地震や津波による被害を受け、避難者が亡くなってしまったビルはありますか？
- あれほどの大地震の後、人々はこのようなビルに入るのをためらいましたか？（地震後、このようなビルの安全性に関する意識はどのように変わりましたか？）

２０１１年３月から　垂直避難（V.E.）について

２０．２０１１年３月から、垂直避難用の施設について再調査されましたか？
- その再調査は、自治体によるものですか？または県、国によるものですか？
- 垂直避難用の施設を設定する際に、日本政府による国レベルの統一された指針はありますか？

２１．この町において、（垂直）避難の戦略を変更する予定はありますか？（新しい構造を設計している、ビルの使用に関して再割当をしている、避難戦略において垂直避難をより重視するようになった等）

APPENDIX 3 SUMMARY OF KEY POINTS MENTIONED IN INTERVIEWS

The following tables provide a summary of points that were raised in each location during our interviews. Due to the nature of semi-structured interviewing, the absence of a point being raised does not necessarily mean that it does not apply in that location, rather, this point did not emerge from that particular interview. It is common for topics to emerge in early interviews, which then appear in later interviews. The order of locations in this table reflects the order of interviews during our investigation; our first interview took place in Tarō Town and the final interview in Natori City.

Earthquake and tsunami	Tarō Town	Kamaishi City	Ōfunato City	Kesennuma City	Minami-Sanriku Town	Ishinomaki City	Natori City
Recorded JMA seismic intensity (Japanese Meteorological Agency 2011c)	5- to 5+	5+ to 6-	6-	6-	6-	6-	6+
Earthquake felt more than two minutes long *Reported as longer than 1 minute of shaking	●	●	●	●	●	*	●
Earthquake felt unusual or strongest ever **a question asking what the earthquake felt like emerged after the first few interviews*			●	●	●	●	●
Expectation among officials that it was Miyagi-ken-oki				●	●		●
Reported public did not expect large tsunami, despite strength	●			●		●	●
Drawdown observed **this was not an interview question, but was offered as an observation by the interviewee*					●		
Stated first tsunami waves arrived in under 30 mins	●		●	●	●		
Mentioned largest waves were not first	●	●	●		●	●	

Preparedness	Tarō Town	Kamaishi City	Ōfunato City	Kesennuma City	Minami-Sanriku Town	Ishinomaki City	Natori City
Significant damage to city/town in previous events	1896 1933	1896 1933 1960	1896 1933 1960	1896 1933 1960	1896 1933 1960		
Interviewee felt there was high awareness that EQ means tsunami	●		●		●		
Stated previous events/evacuations with small or no tsunami –leading to complacency and normalisation			●	●		●	●

Earthquake and tsunami	Tarō Town	Kamaishi City	Ōfunato City	Kesennuma City	Minami-Sanriku Town	Ishinomaki City	Natori City
Interviewee pointed out that local and distant source events are differentiated in preparedness activities		●	●				
Reported education encourages response to natural warnings	●	●	●		●		
Mentioned local volunteer disaster groups operate			●		●		●
Stated drills held, additional to annual national tsunami drill			●	●			●
Reported community involved in making evacuation maps		●	●	●		●	

Tsunami Warning	Tarō Town	Kamaishi City	Ōfunato City	Kesennuma City	Minami-Sanriku Town	Ishinomaki City	Natori City
Reported loss of power for warning system * due to inundation, rather than earthquake	●	●	●*	●*			●
Mentioned estimated wave height included in warning		●		●			
Stated estimated wave height specifically not included in audible warning			●			●	
Stated informal warnings (e.g. one person mentioned to another) saved people * including seeing others running		●*	●*		●	●	●

Evacuation	Tarō Town	Kamaishi City	Ōfunato City	Kesennuma City	Minami-Sanriku Town	Ishinomaki City	Natori City
Reported significant numbers evacuated due to ground shaking	●	●	●	●		●	
Stated significant road congestion due to vehicle use		●		●		●	●
Mentioned people returned home before warning cancellation	●						●
Reported parents collected children from school resulting in deaths	●	●		●		●	

Earthquake and tsunami	Tarō Town	Kamaishi City	Ōfunato City	Kesennuma City	Minami-Sanriku Town	Ishinomaki City	Natori City
Mentioned people waited for family members before evacuating	•						
Reported deaths of citizens checking on others	•	•		•			
Discussed deaths of people with responsibilities - carer, firemen	•	•					•
Reported people close to the inland hazard boundary evacuated late or didn't evacuate			•		•		•
High ground exists within 1km of inundated area (approx. 15 minutes walking time for an able person – a conservative approach to values from FEMA 2008)	•	•	•	•	•	•	
Reported relocation of evacuees after reaching first refuge	•	•				•	
Mentioned people returned to low-lying areas when no wave arrived by estimated arrival time	•					•	
Stated defences caused complacency in response *Converse applied – low walls did not give impression of safety	•				•	*	
Mentioned defences obstruct view of water	•	•					

Vertical Evacuation	Tarō Town	Kamaishi City	Ōfunato City	Kesennuma City	Minami-Sanriku Town	Ishinomaki City	Natori City
Stated existing buildings officially designated		•		•	•	•	•
Mentioned new buildings constructed with V.E. planned				•	•		
Noted inconsistent signage of buildings		•		•	•		•
Noted that community suggested additional bldgs. *officially designated, ^ not officially designated		•^	•^	•*	•*		
Mentioned community-recommended buildings were successfully used in vertical evacuations		•	•	•			
Reported vertical evacuation saved lives	•	•	•	•	•	•	•
Recognition that water/food stocks required			•	•	•		•

Earthquake and tsunami	Tarō Town	Kamaishi City	Ōfunato City	Kesennuma City	Minami-Sanriku Town	Ishinomaki City	Natori City
Reported that required height for vertical evacuation should be >5-storeys, due to inundation close to roof level of some vertical evacuation buildings				●	●		
Mentioned people remained in buildings for >24 hours		●		●			●
Reported 24-hr access by building function/structural feature		●	●	●	●	●	
Noted 24-hr access by community arrangement		●		●		●	●
Reported overtopping of an officially designated vertical evacuation building overtopped					●		
Recognition that emergency communications links to civil protection are required in vertical evacuation buildings			●				●

APPENDIX 4 SUMMARY OF VERTICAL EVACUATION BUILDINGS IN LOCATIONS VISITED

City/town	Building	Construction	Height	Inundated storeys	People saved	Signage	24-hour access
Minami- Sanriku	Shizugawa Hospital	RC	5-storey	4	320	No	Open 24-hrs
Minami-Sanriku	Matsubara community apartment block	RC	4-storey	4	44	Yes	Residents open
Minami- Sanriku	Takano Kaikan	RC	4-storey	3	330	No	External stairs
Minami- Sanriku	Fishing cooperative	RC	2-storey	2	-	No	Unknown
Ishinomaki	York Benemaru	RC	1-storey	1		No	External stairs
Ishinomaki	Homac	Steel frame	1-storey	1	500	No	External stairs to roof car park
Ishinomaki	Hotaru funeral centre	Unknown	2-storey	1		No	Unknown
Ōfunato	2 private commercial and apartment blocks	RC	3-storey	Unknown	Unknown	No	Unknown
Ōfunato	Wedding Plaza	Unknown	3-storey	3	Unknown	No	Unknown
Ōfunato	Nokyo credit co-operative	Unknown	<4-storey	Unknown	Unknown	No	Unknown
Ōfunato	Kesennuma banking building	Unknown	Unknown	Unknown	Unknown	No	Unknown
Ōfunato	Maiya shopping plaza (and adjacent multi-storey car park)	Car park steel frame	5-storey	3	Unknown	No	24hr access to car park only
Ōfunato	Fukutomi Hotel	Unknown	Unknown	Unknown	Unknown	No	Unknown

City/town	Building	Construction	Height	Inundated storeys	People saved	Signage	24-hour access
Ōfunato	Plaza Hotel	RC	4-storey	3	22	No	External stairs
Natori	Yuriage Community Centre	RC	2-storey	1	43	No	Staff to bring key and open buildings
Natori	Yuriage Elementary School	RC	3-storey	1	870	No	External stairs, staff to bring key and open buildings
Natori	Yuriage Junior High School	RC	3-storey	1	823	No	External stairs, staff to bring key and open buildings
Natori	Sendai International Airport	RC (note lots of external glazing)	2-storey	1	Unknown	No	Unknown
Kamaishi	Apartment block	RC	8-storey	3		Yes	Unknown
Kamaishi	Government building	RC	2-storey	Unknown	50	No	Local residents provided with a key for night-time access
Kamaishi (beach loc. Unosumai)	Hotel Horaikan	Steel frame	4-storey	2	-	Yes	External stairs
Kesennuma	Government building	RC	5-storey	2	120	No	Public instructed to break windows to gain access when closed

City/town	Building	Construction	Height	Inundated storeys	People saved	Signage	24-hour access
Kesennuma	Prefectural building	RC	5-storey	2	200	Yes	Security staff to let people enter
Kesennuma	Central community centre	RC	3-storey	2	450	No	External stairs
Kesennuma	Centre for working young	RC	2-storey	2	1	No	Unknown
Kesennuma	Fish market	Steel frame	1-storey	1	1,000	No	External stairs, vehicle ramp to car park on inland side
Kesennuma	Park Hotel	Unknown	Unknown	Unknown	-	No	Open 24-hrs
Kesennuma	Kahoku newspaper building	RC	3-storey	1	71	No	Unknown
Kesennuma	Minami Kesennuma elementary school	Unknown	3-storey	1	Unknown	No	Unknown
Kesennuma	Jonan Junior High School	Unknown	Unknown	Unknown	-	No	Public instructed to break windows to gain access when closed
Kesennuma	Ace Port	RC	3-storey	1	-	No	Unknown
Kesennuma	Welfare centre	RC	3-storey	2	80	No	Unknown
Kesennuma	Shoes store	Unknown	Unknown	Unknown	5	No	Unknown
Kesennuma	Yayoi food factory	Steel frame	4-storey	4	400	Yes	Open 24-hrs
Kesennuma	Koyo High School	Unknown	Unknown	Unknown	49	No	Unknown

City/town	Building	Construction	Height	Inundated storeys	People saved	Signage	24-hour access
Kesennuma	Iwaizaki Centre	Unknown	Unknown	Unknown	-	No	Unknown
Kesennuma	Ikkeikaku Hotel	Unknown	Unknown	Unknown	50	No	Unknown
Totals	37 buildings	5428 people					

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