Analysis of Tsunami Culture in Countries Affected by Recent Tsunamis

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Abstract

Since 2004 there is a growing global awareness of the risks that tsunamis pose to coastal communities. Despite the fact that these events were already an intrinsic part of the culture of some countries (such as Chile and Japan), in many other places they had been virtually unheard of before 2004. Nevertheless, the frequent reoccurrence of these events in recent years has led to the emergence of a “tsunami culture” in many areas of the world, which has resulted in increased awareness, disaster preparedness and willingness of local populations to evacuate when the threat of these events arises. This paper will explore these cultural issues using as a basis questionnaires carried out by the authors during their own field visits to the last three major events (in Japan, Chile and Indonesia), and interpret these through the willingness of coastal communities to build protection measures along the shore and the impact that these can have on sustainable development.

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1. Introduction

As greater numbers of people move to coastal areas due to the expanding world’s population, the potential human and financial consequences of a tsunami are increasing. Nevertheless, there is an increasing world-wide awareness of the risk associated with tsunamis, which is mainly due to the fact that many catastrophic tsunamis have been documented by the world’s media within a reasonably short time period (from 2004 in Indonesia to 2011 in Japan). This has led many countries to develop tsunami warning systems and evacuations plans (an example can be found in the development of the Indian Ocean Tsunami alarm system following the 2004 tsunami). Although these might make little sense in the short-run (due to the low frequencies of these events in many parts of the world) in the long-run if they are maintained they could drastically reduce the mortality due to these events. However, for this to happen it is imperative that a “tsunami culture” is created and kept, which requires important investments in education, infrastructure and drilling exercises.

The authors of the present paper, as part of the WASEDA-YNU Advanced Coastal Environment and Management Group (WAYCEM) research network led by Prof. Shibayama at Waseda University (Japan), routinely carry out tsunami surveys of all major tsunami events. In the present research the authors will thus discuss the emergence of a local and global “tsunami culture” through their own field trips to inspect the last major tsunamis throughout the planet. The research will first describe these field trips and then analyse the protection measures and preparedness of the communities in each of the three countries visited (Indonesia, Chile and Japan). In understanding these protection measures the concept of Multi-Layer Safety (MLS) as a means of classifying the various risk-reduction measures is important. The attitude of the local population when faced with a tsunami will be investigated, regarding when and why the residents chose to evacuate.

Following each tsunami event there is typically a major drive to increase disaster preparedness, through the construction of defence structures, relocation of communities away from danger zones and the improvement of evacuation systems. By analysing all these elements, it is possible to gauge to what extent each of these countries possessed a “tsunami culture” prior to each tsunami, and to what extent the events have increased awareness and promoted improvements in future disaster preparedness.

2. The concept of Multi-Layer Safety (MLS) from a tsunami disaster point of view

Multi-layer safety is a concept in flood risk management that introduces the integration of flood risk probability-reducing measures and loss-mitigating measures in a flood protection system. Essentially the role of the former is to prevent inundation, while the latter are meant to function only in case that an extreme event exceeds the expectations of the prevention lines, and inundation occurs.

Based on the National Water Plan of the Netherlands [1], three safety layers can be distinguished in a multi-layer safety system as follows:

- **Layer 1 - Prevention**: this is defined as preventing seawater from inundating areas that are usually dry, by building flood defences such as dykes or breakwaters.
- **Layer 2 - Spatial Solutions**: This means using spatial planning and adaptation of buildings to decrease the loss if a flood does occur.
- **Layer 3 - Emergency Management**: This layer focuses on the organizational preparation for floods such as disaster plans, risk maps, early-warning systems, evacuation and medical help.

Whether multiple layers of safety are present in a system, and which ones are prioritized, can vary significantly in different countries and regions. This generally depends on two parameters, the frequency and effect of extreme events that can cause a water disaster over time, and the economic resources available for
investments in infrastructure for flood protection [2]. Developing countries, whose resources for the protection against flooding are limited, often compromise by using only loss-mitigating measures, which can be much cheaper and of smaller scale than prevention structures. In richer countries like Japan, the existence of economic resources for flood protection makes prevention much more important than in developing countries, while it creates more options for the distribution of investments in different layers.

In the present paper we will analyse each of the three target countries in terms of whether any safety measures existed to attempt to understand to what extend a tsunami culture was present in each country, how this influenced the development of a multi-layer safety strategy, and to what extent this was deliberate or not.

3. Chile

Chile has suffered from tsunami events regularly throughout its history, such as the major event in 1960, which was still present in the minds of many members of the older generation. At 3:34 local time on February 27, 2010, a large earthquake of magnitude Mw 8.8 generated a tsunami that caused heavy damage to the coastal area. The tsunami survey was conducted from the 2nd to the 7th of April 2010 [3].

At each survey point (shown in Fig. 1), tsunami inundation heights and run-up heights were measured and information from local residents was collected by means of structured interviews (which covered information about tsunami heights, evacuation and life after the disaster)

The team visited a number of villages and town along the coastline, covering hundreds of kilometres of Chilean coastline. In the area surveyed many buildings and villages were destroyed, shipping containers and ships were carried away by the waves and damage was caused to a variety of coastal infrastructure.

Tsunami inundation height was 4-10 m in a wide area of Chilean coast, with a maximum recorded run-up height of over 20 m. The reflection at the edge of a continental shelf caused several waves to attack the coast.

Generally speaking it could be said that tsunami counter-measures were not adequately developed in Chile. Protection measures were virtually non-existent, and where they existed they appeared not to have been there to prevent the damage due to any natural disaster, but more as an accidental feature of the terrain. For example, in the village of Llolleo sand dunes protected part of the coastline. These sand dunes were effective at blocking the tsunami, at least in the side of the village were the sand dune was continuous and thus the tsunami could not enter through any gaps in it. The southern half of the village, however, only had a broken sand dune to the west side of it, and was completely open to the sea on its southern half, and thus this part of the village was almost completely wiped out.

Figure 1. Run-up and inundation heights along the Chilean Coastline
The only indication of some layer 2 measures that were attempted on purpose were houses on stilts that survived in some other locations (as seen in Fig. 3), which point towards the existence of a “cultural” layer 2, whereas some of the villagers might have built their houses higher as a consequence of a “tsunami culture”, learnt by previous events. However, this culture clearly does not exist at institutional levels, as can be seen by the fact that a village existed in such a potentially hazardous area, and built out of wooden materials, without any consideration of any other counter-measures. Layer 2 measures were thus absent throughout most of the country, and when they did appear to have been established through historical events rather than presently planned (famously, the present location of the regional capital of Concepcion was relocated after the previously capital on the seaside was destroyed several times by historical tsunamis). This would point out to the existence of not only a “tsunami culture” but also to a “tsunami cultural legacy”.

Regarding level 3 measures, little existed in terms of evacuation buildings or other evacuation plans. The survey conducted by the authors indicated that around 50% of residents of coastal areas appeared not to have ever taken part in evacuation drills (see Fig. 4). A tsunami warning system did exist, though the authorities failed to act correctly and a tsunami alert was not issued. Despite this, residents evacuated most coastal areas, and especially fishermen (and in some cases local policemen) instructed residents to leave due to the danger of an incoming tsunami, as can be seen from Fig. 5. It is important to understand that the residents of many coastal areas were fishermen, and amongst them there is widespread knowledge about tsunamis (which are referred to as “maremotos”, which could be translated as “sea quakes”). Most residents of these areas actually decided to evacuate to surrounding hills immediately after the earthquake, though some did wait till after the first tsunami wave, as seen in Fig. 6. Fortunately in many cases the first wave appeared not to have been as strong as the second wave, as shown from the results of computer simulations by Mikami et al. [3]. Thus ultimately, and despite the lack of warning by the authorities, the evacuation was generally successful and casualties due to the tsunami were very low. The main exception was an island off the coast of Constitucion where dozens of people had been camping, all of whom perished. In this case local fishermen normally ferried people to the island, and thus those camping at the island were unable to escape the incoming wave (which barely above the level of whatever, and made it impossible to attempt any means of vertical evacuation).

The limited number of casualties and the speed with which local residents evacuated to nearby mountains when prompted by fishermen or local authorities (who were acting independent of a tsunami alert, and in the context of often incorrect or confusing information from central authorities) point out to the existence of a strong tsunami culture. This has been reinforced in the aftermath of the event, and the authors understand that at present various studies are being commissioned throughout Chile to improve disaster preparedness. Particularly priority is being given to areas where there is a “seismic gap”, and it is expected that as a result mortality levels will decrease in future events.

Figure 2. Unprotected part of Llolleo village
Figure 3. Surviving house on stilts and the fishing village of Iloca
4. Mentawai

At 21:42 local time on October 25 (14:42 UTC on October 25), 2010, a large earthquake of magnitude $M_w$ 7.7 occurred off the coast of the Mentawai Islands in Indonesia, generating a large tsunami that struck the coastal area of these islands (including the islands of North Pagai, South Pagai, and Sipora, as shown on Fig. 10). To measure tsunami trace heights and to gather information from residents, a field survey was conducted on November 19 and 20, 2010. The main area of the field survey was the south coast of Sipora Island, Mentawai where the tsunami damage was severe.

The team visited four villages (Bosua, Old-Gobik, Masokut, and Bere-Berilou), with Fig. 7 showing the results of the measurement surveys. The tsunami trace heights on Sipora Island were converted to the heights above the estimated tide level according to WXtide at the tsunami arrival time on Siberut Island. Tsunami inundation heights exceeded 3 m in all villages that were surveyed. In all of these the houses located closer to the sea (and which were generally wooden constructions) were washed away, with damage gradually decreasing as the wave progressed inland. The areas surveyed generally possessed little in terms of modern infrastructure, and thus most of the recorded damage was to housing.

For the case of the Mentawai Islands it is clear that an adequate tsunami multi-layer protection system was not in place. The only layer 1 feature in this area were the coastal forests in front of the villages, though these were not sufficiently wide to provide much in terms of protection. It is not clear why villages were situated somewhat inland from the water edge, which did give residents some extra time to escape after hearing the approaching tsunami. It could be possible that prior events throughout time had constantly destroyed the
houses located closer to the water, and thus the fact that the main side of most villages was far from the edge was a sort of “tsunami cultural legacy”, even if local residents were unaware of it. This could constitute some sort of “layer 2”, though it was clearly not due to careful planning, and it could have been just coincidental. The distance to the beach also varied from village to village, indicating a general lack of planning of layer 2 measures.

For the case of layer 3, it appeared that some measures had been taken. A tsunami warning system had been put in place, including a tsunami buoy, though it had not worked properly (apparently due to vandalism). Residents were reasonably well aware of the threat of tsunamis (through events such as the 2004 Banda Aceh tsunami) and thus evacuated the area when prompted, mainly after receiving information from the radio or from aid organizations present in the area (42% of respondents) or by their own initiative (42% said that they evacuated the area after feeling the earthquake). They also reported how the thundering noise of the approaching tsunami also encouraged them to evacuate. Residents in some of the areas visited explained also how they had take part in tsunami drills, and thus were aware of what to do in the case of a tsunami, though these tsunami drills were not conducted in all locations. Nevertheless in the areas surveyed the evacuation was often successful, as the local residents had enough time to evacuate and they did evacuate (though casualties were higher in areas surveyed by other teams).

All of this points to the existence of a tsunami culture, though maybe not as developed as in the case of Chile, and which appeared to be the consequence of education (tsunami drills) rather than the experiences of previous generations. The reason why a stronger tsunami culture, based on previous events, was not captured by the surveys is unclear. It could be due to remoteness of the islands, which means that education did not reach the islands till recently, and thus information was not adequately transmitted from generation to generation. It is also possible that, despite the islands being located in an area of high tsunami risk, no tsunami occurred in the islands for a long period of time, and that the villages surveyed were “relatively new”, formed by descendants of people who lived on other parts of the islands that are not usually affected by tsunamis. Clearly, more research is needed to ascertain this, though it is clear that there a tsunami culture does exist now, and that it will be reinforced by this event, which has led to some villagers to relocate further inland (such as the movement of people from the “old” Gobic to the “new” Gobic, further inland).

Figure 7 Map of surveyed location and distribution of tsunami trace heights
5. Japan

On March 11, 2011, a large earthquake of magnitude 9.0 on the Richter scale occurred offshore the northeast coast of Japan. This very strong earthquake generated a major tsunami which devastated large parts of Japan’s north-eastern coastline and causing large numbers of casualties [4].

In order to comprehensively record tsunami inundation and impacts along the coastal regions affected, the 2011 Tohoku Earthquake Tsunami Joint Survey Group was immediately organized following this disaster. The authors of the present article were also part of these field surveys [5]. Inundation heights were measured to be in the range of more than 10 m in the north part of Miyagi, 5 to 10 m along the coast of Sendai Bay and around 5 m along the shores of Ibaraki and Chiba. On the Sendai plain, the maximum inundation height was 19.5 m, and the tsunami propagated as a bore more around 4-5 km inland [4]. Fig. 8 shows the points that were surveyed along the coast by the authors [5] and the Joint Survey Group [4], with the inundation heights and run-up heights at each location.

Buildings, including many well-engineered reinforced concrete structures, were washed away or suffered extensive damage, while numerous ships as well as large boats were left stranded inland. Coastal protection works such as dikes, tsunami walls, breakwaters and coastal forests also suffered heavy damage. Even breakwaters specifically designed to protect against tsunamis were either damaged or completely destroyed. The tsunami had been widely anticipated, as frequent tsunamis have hit the area in the past, with three major ones taking place since the beginning of the Meiji Era (1868–), which are known as the Meiji-Sanriku (1896), Showa-Sanriku (1933) and Chile (1960) tsunamis. In fact, the Great Eastern Japan Earthquake and Tsunami has been described as one in several thousand years event, resembling thus the Jogan Tsunami which occurred in A.D. 869 [6] and thus constituting one of the worst events in the history of the country.

This was actually the first time in history that a tsunami had encountered a modern well-developed tsunami counter-system method (Mori, 2012). Before the Great Eastern Japan Earthquake and Tsunami, a
large variety of tsunami countermeasures, representative of all three layers of multi-layer safety, could be found along the coast of Tohoku. This clearly indicates that a tsunami culture clearly existed in Japan.

The type of tsunami counter-measures, however, were not uniform along the entire affected coast, and varied along with the requirements of the coast in each area. Generally speaking, layer 1 measures included offshore breakwaters and tsunami walls along the northern part of the coastline (known as the ria area) and coastal levees and sandy frontages on the southern part (known as the Sendai coastal plain). Most of these structures suffered extensive damage, as can be seen in Fig. 9.

The spatial arrangements that are part of layer 2 measures are the placement of important social infrastructure buildings on higher grounds, and the flood proofing of high buildings by accommodating the most important functions on higher floors. A general remark about layer 2 measures is that although they are distinct in Tohoku, they were not within the framework of a general strategy for mitigation of tsunami damage. There were schools and hospitals located on high enough grounds that stayed unaffected or less affected than the majority of buildings, such as the hospital of Onagawa on a ground elevation of 15m, where only the ground floor was inundated (see Fig. 10). On the other hand, there were important administration buildings that were destroyed, such as the Disaster Prevention Centre of Minamisanriku, located close to the waterfront. Thus, although the need for such layers was clearly imprinted into Japanese minds, the scale of the disaster was clearly much greater than what was expected.

Due to the high frequency of tsunamis in Tohoku layer 3 measures, like early-warning and evacuation schemes, were well developed in the area, with local residents and children frequently taking part in evacuation events. Only three minutes after the earthquake a tsunami warning was issued in Tohoku, arguably the fastest response of any such system in any country in the world. However the expected tsunami wave and inundation height was underestimated in the original alert (though corrected in subsequent alerts), and this might have contributed to the loss of some lives. Moreover, time available for evacuation in some areas was too short, and many people perished while attempting to move to higher grounds. It is also apparent that despite instruction not to use vehicles, in some areas residents tried to escape using their cars, and this might have created traffic jams. Despite all these shortcomings, Tohoku could be considered as one of the most well prepared coastal areas in the world for a tsunami emergency, and tsunami preparedness was clearly taken seriously by local authorities and residents, highlighting the high level of tsunami culture present in the area. Throughout the region, numerous tsunami memorials, tree lines and marks of the inundation level of previous events could be find, which keep alive the memory of previous events for the local population. Following this last event, other monuments, marks and symbols will be created, though it is too early to know what shape they will take. Nevertheless, this will surely help the transmission of a tsunami culture to later generations.
6. The Reinforcement of the “Tsunami Culture” after these events

After a tsunami event the damage to coastal areas generally leaves an important imprint in the minds of those who experience it, which means that (at least in the short term) buildings are often not rebuilt close to the sea, and when they are sometimes improvements are made to them. For the case of the Mentawai Islands, the residents of village of Gobic started to take refuge and rebuild in another area on higher ground (“new Gobic”). In the mid-term, of course, many of these inhabitants may return to more coastal areas, and arrivals from different areas or the descendants of those who experience the tsunami might “forget” the event.

This highlights the importance of decisive institutional actions to establish effective layer 2 measures, were the inhabitants of an area do not “forget” past events and the construction of housing in areas that are at high risk are prevented. One such example is given by Suzuki [7] for the case of Toni-Hongo village in Japan. The village was completely destroyed by the 1896 Meiji-Sanriku Tsunami, with 88% of its inhabitants perishing, which prompted the survivors to relocate to the hillside, though only 5 houses actually did this, due to the inconvenience of this for the fishermen and their families. Relocation thus failed, and the village was once again destroyed by the tsunami of 1933, though this time only 53% of the inhabitants died. Although the mortality rate did go down, it was still high as not many individuals had survived the 1896 event. Nevertheless, as a result of the 1933 tsunami the residents decided to relocate to a terraced land on the hillside, and the construction of houses was prohibited in the inundated area. Following the 1960 Chilean tsunami the construction of tsunami counter-measures were started, with a first 5m high wall finished in 1969, which was then elevated to 11.8m in 1980. However, after the 1960 Chile tsunami some houses were gradually built in the lower areas of the village, and the 2011 tsunami destroyed 50 of these houses (though mortality in the village was only 0.7%, as many villagers still lived in the higher areas and there was a clear indication that the villagers should evacuate there in the case of a tsunami.

It is important to note that it is possible that the population that will live in tsunami prone areas in the future will decrease in the Tohoku region, mainly due to the effect that the tsunami has had on the local population. Fig. 11 shows the relationship between the number of inhabitants who would like to move to safer areas as a proportion of the population that perished in various localities in the Rias coastline in Tohoku [8]. Fig. 12 shows also the relationship between those who would like to leave compared to the proportion of population that lived in areas that were inundated, for each city. These graphs clearly show how there is a very clear relationship between these factors, and generally speaking it could be concluded that those that lived in areas that were inundated would like to relocate to safer areas. In addition to this, there is anecdotal evidence that many of the younger members of the communities, and especially those with children, have typically relocated to other areas, often because of the lack of schools. Indeed, one year after the disaster very few houses have been built in the areas that were inundated, and much of the population appears to remain in temporary housing or to have left the area. If this is compounded with an expected demographic decline due to population aging (and particularly around the smaller towns and villages), then it is clear that far less people will probably live around these areas. In fact Japan has already entered the era of population decline, as the fertility rate has been far below the level required to maintain the stationary population since the mid-1970s. This makes continuing depopulation almost inevitable due to the low levels of immigration allowed into the country, with the Japanese National Institute of Population and Social Security Research [9] forecasting that the population in the year 2100 will have decreased to just over 64 million from its level of around 128 million in 2009.
7. Conclusions

Recent tsunami events have increased tsunami awareness throughout the world, leading to the emergence of a “global tsunami culture”. Such tsunami cultures already existed in a number of countries, such as Japan or Chile, due to the numerous events that took place in the past, and which continue to be alive in people’s memory either through oral transmission or education. In other places, such as Mentawai, the cultural link to past events is less clear, though a tsunami culture is starting to exist through improvements in education and recent events. Nevertheless, it is imperative that the awareness about disasters continues to increase in the future, so that multi-layer safety measures are promoted throughout all areas at risk of tsunamis.

References