

ANALYSIS OF MULTI-LAYER SAFETY IN COUNTRIES AFFECTED BY RECENT TSUNAMIS: EMERGENCE OF A GLOBAL TSUNAMI CULTURE

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ABSTRACT: Since 2004, there is a growing awareness of the risks that tsunamis pose to coastal communities globally. Despite the fact that these events were already an intrinsic part of the culture of some countries such as Chile and Japan, many other places had virtually not heard about such phenomenon before 2004. Nevertheless, the frequent reoccurrence of major tsunamis 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. However, evacuation during a tsunami is still not successfully carried out by the different elements of society, pointing to lack of awareness, an over-reliance in defence mechanisms or lacking in the transmitting of knowledge from previous events. 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 (Chile in 2009, Indonesia in 2010 and Japan in 2011), 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. The existence of a “traditional tsunami culture” will be explored through an analysis of the existence of multi-layer safety system constructed by previous generations, and whether this is being preserved nowadays or past lessons are being forgotten.

Keywords: Tsunami, counter-measures, culture, Banda Aceh, Tohoku, Chile

INTRODUCTION

There is an increasing world-wide awareness of the risk associated with tsunamis due to high number of severe events documented by the world’s media within a reasonably short period (from 2004 in Indonesia to 2011 in Japan). This has led many countries to develop tsunami warning systems and evacuations plans (such as 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 rates due to these events. However, for this to happen, it is imperative that a “tsunami culture” is created and kept, requiring important investments in education, infrastructure and drilling exercises.

The present paper will discuss the emergence of a local and global “tsunami culture” through the last 3 major tsunamis (Indonesia in 2004, Chile in 2010, and Japan in 2011). The attitude of the local residents when faced with a tsunami will be investigated, regarding when and why the residents chose to evacuate. Following each

tsunami event typically there is 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 interpreting all these elements from the point of view of a multi-layer safety risk management strategy, it is possible to gauge to what extent each of these countries possessed a “tsunami culture” prior to each tsunami, and how this might influence future disaster preparedness.

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 (see the National Water Plan of the Netherlands). Essentially the role of the former is to prevent inundation while the latter is meant to function only in case an extreme event exceeds the expectations of the prevention lines and inundation occurs. The multi-layer safety system can be distinguished three safety layers 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.

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- *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 (Tsimopoulou, 2012). Developing countries, whose resources for construction infrastructure are limited, often compromise by using only loss-mitigating measures, which can be much cheaper and smaller in scale than prevention structures. On the other hand, richer countries such as Japan have more financial resources for flood protection.

In the present paper, the authors will analyse each of the three target countries in terms of whether any safety measures existed before their respective tsunamis in order to attempt to understand to what extent a tsunami culture was present, how this influenced the development of a multi-layer safety strategy, and if this was a deliberate risk management strategy or not.

CHILE

Chile has suffered from tsunami events regularly throughout its history. The last major one was in 1960, and therefore the threat that they pose was still present in the minds of the older generation. On February 27, 2010, a large earthquake of magnitude Mw 8.8 generated a tsunami that caused heavy damage to the coastal area (Mikami et al., 2010). 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 (Mikami et al., 2010). Structured interviews were carried out to collect information regarding the tsunami heights, evacuation and life after the disaster.

Generally speaking, it could be said that tsunami counter-measures were not adequately developed in Chile. Prevention measures were virtually non-existent, showing how little effort was made to develop layer 1 measures. Where present, they appeared not to have been there to prevent the damage due to any natural disasters, but more as an accidental feature of the terrain. For example, in the village of Llolleo sand dunes protected parts of the coastline (see Fig. 1).



Fig. 1 Partially degraded sand dunes at Llolleo



Fig. 2 Destroyed houses behind the sand dunes

These sand dunes were effective in blocking the tsunami, at least on the side of the village where the sand dune was continuous. 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. This part of the village was consequently almost completely wiped out (see Fig. 2)

The houses on stilts that survived were the only indication of some of the layer 2 measurements. This does point out to the existence of a “tsunami culture.” However, this culture clearly does not exist at institutional levels as such a settlement should not exist in a potentially hazardous area, especially considering no tsunami warning system or other counter-measures were in place. 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 as part of a modern risk management strategy (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. A structured survey conducted on the local residents by the authors indicated that around 50% of the residents of coastal areas appeared not to have ever taken part in evacuation drills. A tsunami warning system did exist, though the authorities failed to act properly and a tsunami alert was not issued. Despite this failure, 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. 3. It is important to understand that the residents of many coastal areas were fishermen, and amongst them, there was a widespread knowledge about tsunamis. Most residents actually decided to evacuate to surrounding hills immediately after the earthquake, though some did wait until after the first tsunami wave. Fortunately, in many cases, the first wave appeared not to have been as strong as the second wave. Ultimately, and despite the lack of warning made by the authorities, the evacuation was generally effective and casualties were low. The main exception was an island off the coast of Constitución where dozens of people had been camping, all of whom perished. In this case, local fishermen normally ferried people to the island; and hence, those who were camping on the island were unable to escape.

The limited number of casualties and the speed in which local residents evacuated to nearby mountains when prompted by fishermen or local 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 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 disaster preparedness will significantly increase in the future.

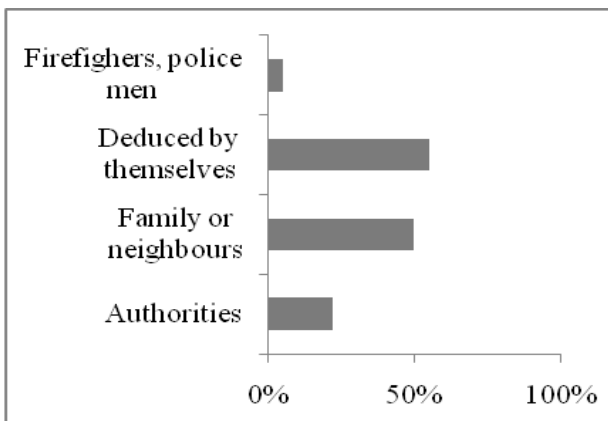


Fig. 3 Source of information that prompted local residents to evacuate

INDONESIA (MENTAWAI ISLANDS)

At 21:42 local time on October 25, 2010, a large earthquake of magnitude M_w 7.7 occurred off the coast of Mentawai Islands in Indonesia, generating a tsunami that struck the coastal area of these islands. Houses located near to the sea (generally wooden constructions) were washed away with damage gradually decreasing as the wave progressed inland. The areas generally possessed little in terms of modern infrastructure, and thus most of the recorded damage was to housing (See Fig. 4)

In 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 that could be observed was the coastal forests in front of the villages, though these were not sufficiently wide to provide much 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 is possible that prior events 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.

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 was not operational at the time of the event. Residents were reasonably well aware of the threat of the tsunamis; and evacuated the area when prompted, mainly after receiving information from the radio, aid organizations present in the area (according to 42% of respondents) or by their own initiative (another 42% said that they evacuated the area after feeling the earthquake).



Fig. 4 All wooden houses were destroyed in Gobic

In terms of evacuation preparedness, residents in some areas visited by the authors explained how they had take part in tsunami drills, and that they were aware of what to do in the case of a tsunami. However, these tsunami drills were not conducted in all locations. Nevertheless in the areas surveyed the evacuation was often successful, as local residents had enough time to evacuate.

This indicates the existence of a tsunami culture, though maybe not as developed as in the case of Chile, which appeared to be the consequence of education (tsunami drills) rather than the knowledge transmitted by 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, even though it was evident that a certain tsunami culture does exist now, and that it will be reinforced by this event. For instance, some villages have decided to relocate further inland, like the movement of people from the “old” Gobic to the “new” Gobic, further inland.

JAPAN

On March 11, 2011, an earthquake of magnitude 9.0 on the Richter Scale took place off the northeast coast of Japan, generating a major tsunami which devastated large parts of the coastline and caused large numbers of casualties (Mori et al., 2012). Inundation heights were measured to be in the range of more than 10 m in the northern 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 19.5m, and the tsunami propagated as a bore more around 4-5km inland (Mikami et al., 2012).

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, were overwhelmed and suffered heavy damage. 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 2011 *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; and constituting one of the worst events in the history of the country (Sawai, 2006)

This was actually the first time in history that a tsunami had encountered a well-developed modern tsunami counter-system method (Mori et al., 2012). Before the *2011 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 existed in Japan prior to the event. However, the type of tsunami countermeasures employed were not uniform along the entire affected coast. Generally speaking, layer 1 measures included offshore breakwaters and tsunami walls along the northern part of the coastline (known as the rias area) and coastal levees and sandy frontages on the southern region (known as the Sendai coastal plain). Most of these structures and the area behind them suffered extensive damage, as can be seen in Fig. 5.

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 placing 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 higher grounds that were unaffected or affected less than the majority of buildings, such as the hospital of Onagawa on a ground elevation of 15m, where only the ground floor was inundated. 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.



Fig. 5 Extensive failure of coastal dykes

Due to the high frequency of tsunamis in Tohoku layer 3 measures (such as early-warning and evacuation schemes) were well developed with local residents and children frequently taking part in evacuation exercises. Only three minutes after the earthquake, a tsunami warning was issued. People knew how to and where to evacuate as a result of having been verbally warned by those around them, official evacuation orders, or warning messages.

However, the time available for evacuation in some areas was too short, and many people perished while attempting to move to higher grounds, or for a variety of other factors (Yun and Hamada, 2012). 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. Nevertheless, Tohoku could be considered as one of the most 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. Throughout the region, numerous tsunami memorials, tree lines and marks of the inundation level from previous events could be found, which kept the memory of previous events alive (Suppasri, 2012). Following this last event, other monuments, marks and symbols are also being created, which will surely help the transmission of a tsunami culture to later generations. What is particularly interesting is the placement of inundation signs along all major roads, showing the beginning and end of the inundated sections, which means that drivers will be constantly reminded of this past event in the future.

DEVELOPMENT OF A GLOBAL “TSUNAMI CULTURE”

After a tsunami event the damage to coastal areas generally leaves an important imprint in the minds of those who experienced it, often discouraging the construction of new buildings close to the coastline, at least in the short term. In the case of the Mentawai Islands, the residents of Gobic village started to take refuge and rebuild on higher grounds (“new Gobic”) in a different area. In the mid-term, of course, many of these inhabitants may return to more coastal areas, and arrivals from different regions 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 (2012) 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. This prompted the survivors to relocate to the hillside, though only 5 houses actually did so due to the inconvenience this caused to fishermen and their families. It could be said that relocation 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, residents decided to relocate to a terraced land on the hillside, and the construction of the houses was prohibited in the inundated area. Following the 1960 Chilean tsunami the construction of tsunami counter-measures was started, with the 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 on the lower areas of the village, and the 2011 tsunami destroyed 50 of them (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. 6 illustrates 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 (Oyama, 2012). Fig. 7 shows also the relationship between those who would like to leave compared to the proportion of the population that lived in areas that were inundated, for each city. If this is compounded with an expected demographic decline due to population aging, then it is clear that far less people will probably live around these areas (Japanese National Institute of Population and Social Security Research, 2012).

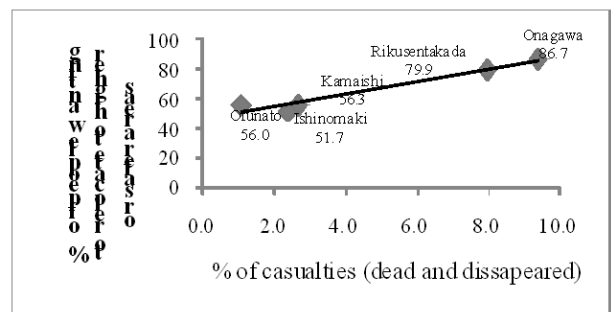


Fig. 6 Relationship between number of inhabitants who would like to depart from each population centre and the proportion of casualties

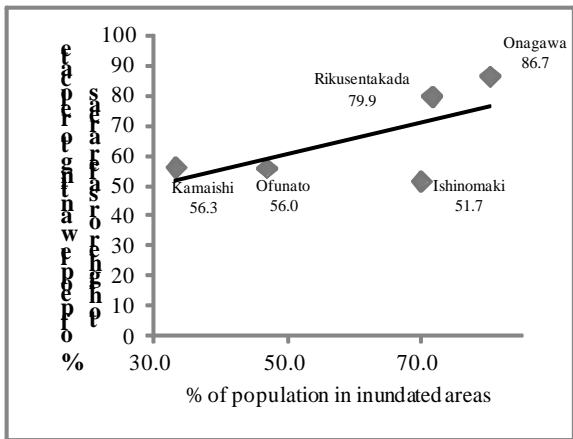


Fig.7 Relationship between number of inhabitants who would like to depart and the proportion of the population in each of the inundated areas

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 be created through improvements in education and recent events. Nevertheless, it is imperative that the awareness about coastal disasters continues to increase in the future, so that multi-layer safety measures are promoted throughout all areas at risk of tsunamis and storm surges. This awareness needs to be coupled with efficient and well designed evacuation strategy that targets the worst case events (Level 2 events, as defined in Shibayama et al., 2013) so that the entire population of each settlement can reach safe areas. The emergence of a “tsunami culture” is a great opportunity for states to proceed on formalizing/improving their flood risk management practice. In this respect multi-layer safety is one choice, but other strategies need to be considered too.

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