ANALYIS OF THE 2011 TOHOKU TSUNAMI.

Análisis del tsunami de Tohoku de 2011.

A. Santos [(1)], J.L. Zêzere [(1)]

(1) RISKam. Centro de Estudos Geográficos, Instituto de Geografia e Ordenamento do Território, Universidade de Lisboa (Portugal). email: angela.santos@campus.ul.pt

Resumen: El tsunami del 2011 fue responsable de muchas víctimas y daños significativos a lo largo de la costa de Tohoku. Provocó varios incendios y la inundación de la central nuclear de Fukushima Daiichi dando lugar a un apagón en toda la región y al accidente nuclear. En este estudio, se analiza la combinación de varios desastres y se concluye que las consecuencias han sido catastróficas: en varias localidades la altura máxima de las olas del tsunami fue de 10 m, superando todas las medidas de protección costera. La inundación del tsunami superó largamente los límites previstos en los mapas de peligrosidad; 19.089 muertos y desaparecidos y más de 380.000 personas fueron evacuadas; problemas de salud ambiental y pública. Sin embargo, la preparación del Japón a los desastres naturales, junto con la firme determinación de los japoneses para volver a su vida cotidiana ha permitido una rápida recuperación en la región.

Key words: Tohoku tsunami, multi-disaster, tsunami warning system (TWS), tsunami hazard maps, recovery
Palabras clave: Tsunami de Tohoku, multi-desastre, sistema de alerta de tsunami, mapas de peligro de tsunamis, recuperación

1. INTRODUCTION

On the March 11, 2011 a magnitude 9.0 earthquake occurred offshore the Tohoku region (Figure 1). The tsunami generated by this earthquake was the responsible for most of the damages and victims. As of February 10, 2012 the number of dead was 15,787 and missing 3,302 (NHK World, 2012).
In this study, the earthquake and its consequences are briefly presented. In addition, the role of the media is discussed. On the other hand, tsunami data (travel times and maximum water level) allow the validation of the tsunami numerical model. Finally, the mitigation of the tsunami disaster is discussed, which include analysis of tsunami hazard maps, details of evacuation process of the populations and summary of the progress in the recovery of the Tohoku region.

2. THE EARTHQUAKE AND CONSEQUENCES

The earthquake occurred offshore the northeast region of Japan, in the sudbuction zone between the Pacific and North American plates (Figure 1).
Immediately after the earthquake the Fukushima Daichii nuclear power plant (FDnpp) stopped production, with minor damage. However, when the tsunami inundated the facility caused permanent damage on the plant that triggered a massive blackout on the Tohoku region and the nuclear accident.
The immediate consequence of the non-operation of the plant was the lack of both seismic and tsunami data. Therefore, there is a large uncertainty about the detailed focal mechanism of the earthquake. Nevertheless, it was estimated that the rupture is 500 km length and 200 km width Santos (2011). The author conducted a preliminary tsunami numerical simulation by considering these dimensions, and in this study the same fault parameters will be used to validate the tsunami data.
Other immediate consequence of the malfunction of the plant was the lack of communications. Fix phones, mobiles and fax machines couldn't be used. In addition, television and radio could not be used. The earthquake also caused subsidence of

the soil mainly in the Ishinomaki–Yuriage zones (see Figure 1 for location).

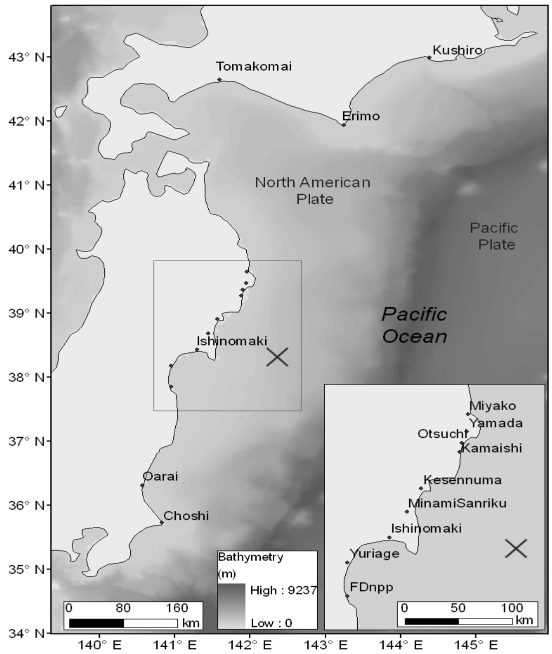

Fig.1: Location of the epicenter and the places where travel times are considered.

3. THE ROLE OF THE MEDIA

Media in Japan is fundamental to disseminate information about the tsunami disaster on 2 major levels: before the disaster, by the tsunami warning system, and after the disaster, by long term broadcast.
The tsunami warning system showed many weaknesses and was not effective to inform accurate information about tsunami arrival times and maximum water level high. As a consequence, many people were confused about what to do.
The Japanese television NHK has been broadcasting daily information about the disaster. In this study some witness's accounts reporting the tsunami travel times were compiled in order to validate the tsunami numerical model.

4. TSUNAMI DATA

4.1 Travel times

Japan Meteorological Agency (JMA) is responsible for the management of tsunami gauge stations. However, due the malfunction of the FDnpp, there is no data from Miyako to Yuriage. Therefore, tsunami travel times on these areas were reported by the witnesses, and compiled as presented in Table 1.

Table 1: Observed tsunami travel times

Place	Travel time in minutes
Kushiro	48, JMA(2011)
Erimo	32, JMA (2011)
Tomakomai	54, JMA (2011)
Miyako	At least 20, Tanoya (2011
Yamada	40, Tarou (2011)
Otsuchi	30, Usuzawa (2011)
Kamaishi	39, Inoguchi (2011)
Kesennnuma	40, Ito (2011)
MinamiSanriku	40, Oikawa (2011)
Ishinomaki	40, Takahashi (2011) 30, Jou (2011)
Yuriage	70, NHKWorlda (2011)
FDnpp	51, NHKWorldb (2011)
Oarai	29, JMA (2011)
Choshi	27, JMA (2011)

4.2 Maximum water level

Post-tsunami field survey is an *in-situ* survey conducted by tsunami experts with the aim to collect clues in order to understand the tsunami features.

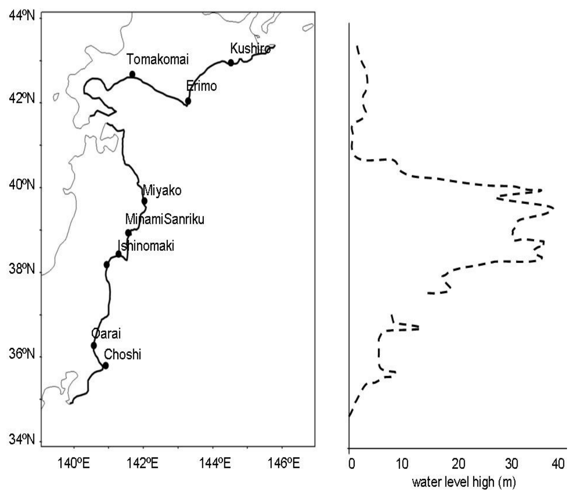

Fig. 2: Measured water level on the Hokkaido and Tohoku regions, except in the exclusion zone of the FDnpp *(modified from TSJ (2011)).*

When there is no tsunami gauge stations available, this technique is fundamental to provide important scientific data.
Figure 2 shows the maximum water level measured by tsunami experts (*TSJ (2011)*) on the coastal areas of Hokkaido and

Tohoku regions, as of August 26, 2011. The figure may not represent the final report however as of August 16, 2011 the tsunami run-up was measured at Miyako with 39 m.

5. RESULTS OF THE TSUNAMI NUMERICAL SIMULATION

The lack of both seismic and tsunami data makes the determination of the earhtquake's focal mechanism difficult. Nevertheless, Santos (2011) considered a fault 200 km by 500 km. Figure 3 shows the modelled and observed travel times. The Figure shows that in general, the model is in agreement with both tide gauge stations and witness's accounts.

Figure 3 also shows that the tsunami hit most of the affected coastal areas between 30 to 40 minutes after the earthquake. The modeled maximum water level is represented on figure 4. Although the model results are slightly overestimated at Erimo Cape and Miyako, the overall tsunami behavior is well represented by the tsunami numerical model. These results show that the tsunami was higher than 10m on most of the coastal areas on the Tohoku region.

6. MITIGATION OF THE TSUNAMI DISASTER

6.1 Tsunami hazard maps

All coastal areas are provided with tsunami hazard maps. The construction of disaster supporting buildings like schools, hospitals and evacuation centers are located outside of these areas. However, on the March 11 most of these facilities were inundated by the tsunami, causing many people to parish.

6.2 Evacuation procedures

It is estimated that 2/3 of the victims are older than 65 years old. From several witness' accounts most of the elderly people refused to leave their homes. Therefore, most of the victims did not even try to evacuate. However, many people escaped either by their own judgment or by the emergency call of the local wireless disaster prevention system.

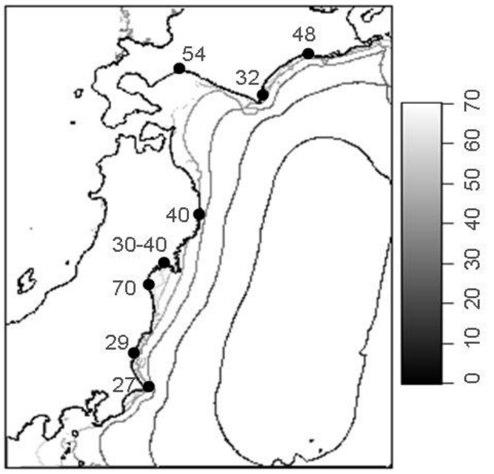

Fig. 3: Modeled and observed tsunami travel time in minutes.

On the other hand, at the time of the earthquake it was snowing on most of the affected areas. Some survivors admitted they were reluctant to go outdoors because it was cold. In addition, the coastal areas are protected by breakwaters, seawalls and gates; some survivors also admitted they were confident in the coastal defense mechanisms, since in previous large earthquakes they didn't had to evacuate due to tsunami. They only realized the urgency to evacuate when they saw the tsunami waves overtopping the seawalls.

6.3 Recovery

Since March 11, Santos et al. (2011) compiled daily information for the first 6 months, showing the recovery process started immediately after the disaster. The rescue and support to the survivors was the immediate priority, by providing shelter, food, water and medicine to those in need. Cleaning and repair of the roads and railways was another priority measurement, as well as to keep the FDnpp under control. The affected region has a long recovery process: on February 9, 2012 the repair of damaged roads and sewage systems was underway in the devastated areas. On March 7, 2012 new guidelines for buildings used as emergency tsunami shelters were drawn. Full-scale breakwater repair work started on April 6, 2012.

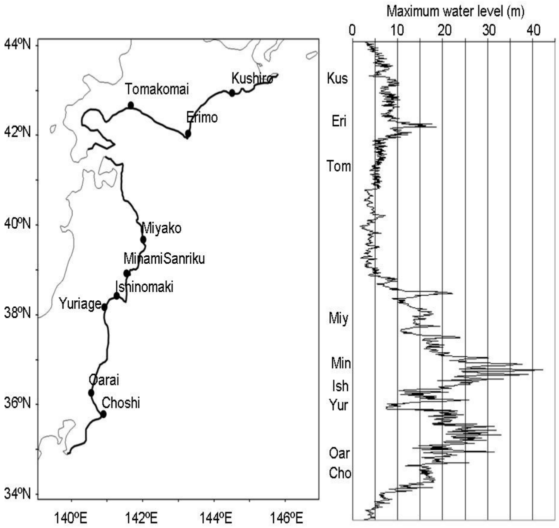

Fig. 4: Modeled maximum water level.

7. CONCLUSIONS

The tsunami caused an elevated number of casualties mainly due to: aging population, too many false alarms and over confidence in coastal defense mechanisms, lack of action from the persons (because of weather conditions at the time of the earthquake) and vulnerability of communications systems to lack of electricity.

The tsunami caused significant damage mainly because tsunami hazard maps and all the coastal mechanism defenses were not prepared for the worst case scenario.

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