International Journal of Disaster Risk Reduction 31 (2018) 275–280

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Multi-hazard analysis of earthquake shaking and tsunami impact

João Bonacho*, Carlos Sousa Oliveira

Instituto Superior Técnico (IST), ICIST/CeRIS, Universidade de Lisboa, Lisbon, Portugal

ARTICLE INFO

Keywords:
Tsunami
Earthquake
Damages
Aggregated damages
Simulator
GIS

ABSTRACT

Tsunami damage on buildings in regions subjected to shaking is commonly modeled disregarding the occurrence of a previous earthquake and damages that have already occurred at those buildings.

In Portugal, there are studies for the regions of Lisboa, Setúbal and Algarve that access damages or vulnerability of buildings due to the action of tsunami waves. Even so, they never took into account that, if near to the epicenter, usually prior to the tsunami, there was an earthquake shaking capable of provoking some level of damages to the building stock in the affected area.

In this paper, we propose a way of combining earthquake shaking damages with tsunami damages – the aggregated damage. This is defined as an additive function. The aggregated damage of a building is the sum of damages caused by the earthquake plus those caused by the tsunami.

As for earthquake shaking damage assessment, we use a home-developed software model based on standard vulnerability indexes conveying fragility curves for 5 different damage states (DS_i), for reinforced concrete and other building typologies (only masonry is considered in the present case). The tsunami fragility curves corresponding to similar DS_i, were obtained from recent published literature where the main variable was the water maximum height reaching each building which was estimated using a Geographic Information System (GIS) approach.

1. Introduction and objectives

Damage on building stock and impact on humans (displaced persons, injured and deaths) has been widely studied and applied all over the world, where earthquake-prone zones and civilization are present [1,2].

When tsunami damage estimation is to be determined (through simulators or numerical modeling), buildings are often considered to be “as new”, i.e. damages caused by the previous earthquake are not considered.

Off-shore earthquakes can generate large tsunamis that aggravate the effects of ground shaking alone. Yet, the analysis of tsunami impact without consideration of shaking is made frequently. A clear example of a multi-hazard influence goes back to early times such as the 1755 Lisbon earthquake which caused 3 types of action: shaking, tsunami and fire [3].

Tsunami damages should only be estimated after the earthquake shaking ones, taking in account that usually there is an earthquake shaking before the tsunami waves reach the shore, at least for tsunamis generated by earthquakes having epicenter sufficiently close to the target area.

Adding damages caused by the tsunami to the earthquake shaking ones is a natural approach, as occurs in the real world.

The impact of tsunami waves on structures is a new area of research involving, in a first step, the wave propagation from source to shore and the study of inundation, the height of water in a “populated” area and the flow velocity. In a second step, there is the physical interaction of the wave field with the stock of buildings and other obstacles. Waves transporting solid elements (vehicles, debris, etc.) pose an additional difficulty to analyze the problem [4].

The existence of shaking prior to the tsunami arrival is the problem we want to address in a multi-hazard perspective. Goda and De Risi [5] propose a model to study the impact of shaking and tsunami considering the seismological and geologic hazard, but they do not contemplate the interaction that aggravates the final damage state as we propose.

Structural damages to buildings can be estimated by the use of fragility curves, which represent~~s~~ a cumulative distribution of probability of reaching a certain Damage State, for some demand parameter. This is true in the case of earthquake shaking and for tsunamis, the difference being made by the demand parameter. The former uses ground shaking and the latter one uses inundation depth.

The effect of shaking in the housing stock and other constructions in terms of Damage States has a long tradition which goes back to early

---

* Corresponding author.
E-mail addresses: joaocbonacho@hotmail.com (J. Bonacho), csoliv@civil.ist.utl.pt (C.S. Oliveira).

https://doi.org/10.1016/j.ijdrr.2018.05.023
Received 22 October 2017; Received in revised form 25 May 2018; Accepted 28 May 2018

Table 1
Correspondence between damage states (Nanayakkara and Dias [19] and EN 1998–1 [16]).

Nanayakka and Dias	EN 1998-1	Description
DS03	DS4	collapse
DS02b	DS3	heavy
DS02a	DS2	moderate
DS01	DS1	non-structural
DS00	DS0	no damage

Table 2
Median inundation depth by construction material and damage state (adapted from Nanayakkara and Dias [19]).

Damage level	RC (m)	Masonry (m)
DS03 - collapse	5.4–7.3	2.3–2.5
DS02b - heavy	~3.5	~1.9
DS02a - moderate	1.4–1.9	1.3
DS01 - non-structural	0.3–0.5	0.3–0.5

eighties in Europe and even before in the USA and Japan. Firstly, the vulnerability functions were developed from observed damage in historical events and, later on, for fragility curves associated to six Damage States: DS_0- no damage; DS_1- slight damage; DS_2- moderate damage; DS_3- heavy damage; DS_4- partial collapse; and DS_5- total collapse. For a comprehensive development of such curves, one may refer to the work of Benedetti et al. [6] and Lagomarsino and Giovinazzi [7] and, more recently, to analytical models based on capacity curves [8]. Fragility curves were developed for different building typologies, essentially taking into account the number of stories, the construction material, the epoch of construction, the codes which were enforced, and some specific indicators related to geometry, quality of construction, etc. For a detailed analysis of the earthquake shaking simulators developed after 2000, see Oliveira et al. [2]. The European Macroseismic Intensity Scale (EMS-98) [9] has also followed similar steps, linking intensity to vulnerability and Damage States for different building typologies. Consequently, along tradition exists in this area of knowledge.

On the other hand, the derivation of fragility curves for the tsunami impact only recently has drawn the attention of the scientific community, essentially after the Sumatra 2004 and the Great East Japan (Tohoku) 2011 events. This is the main reason for not having at our own disposal settled and consistent information in this topic.

In relation to the multi-hazard and multi-risk approaches, we are also giving the first steps. The methods for these analyses can be assessed in authors such as Garcia-Aristizabal and Marzocchi [10], Lui et al. [11], and Zschau [12].

The aggregated damage function will result from adding damages,

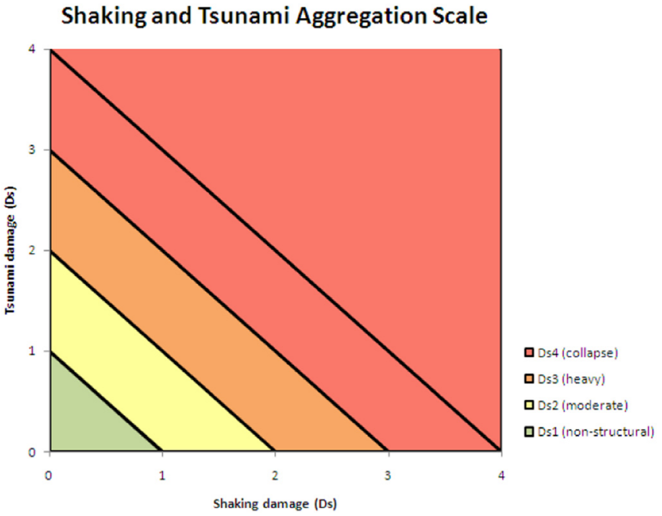

Fig. 2. Aggravation due to shaking and tsunami, using $DS_{[AGG]} = DS_{[Shaking]} + DS_{[Tsumani]}$.

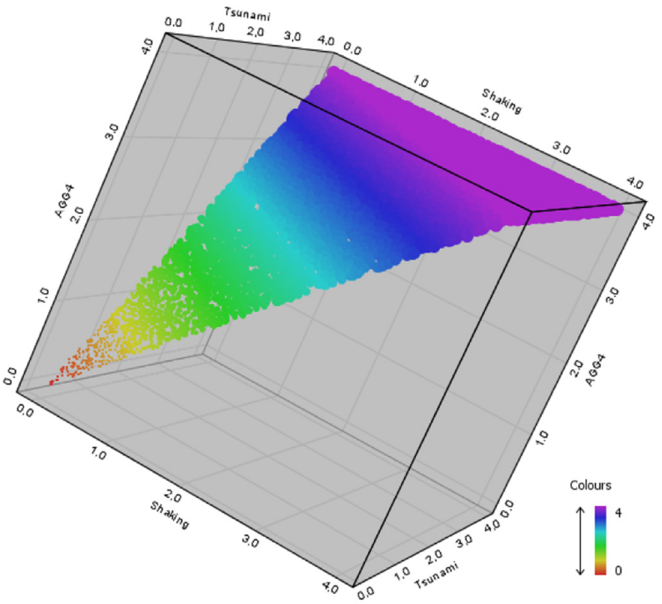

Fig. 3. 3D representation of $DS_{[AGG]}$ as a function of $DS_{[Shaking]} + DS_{[Tsumani]}$.

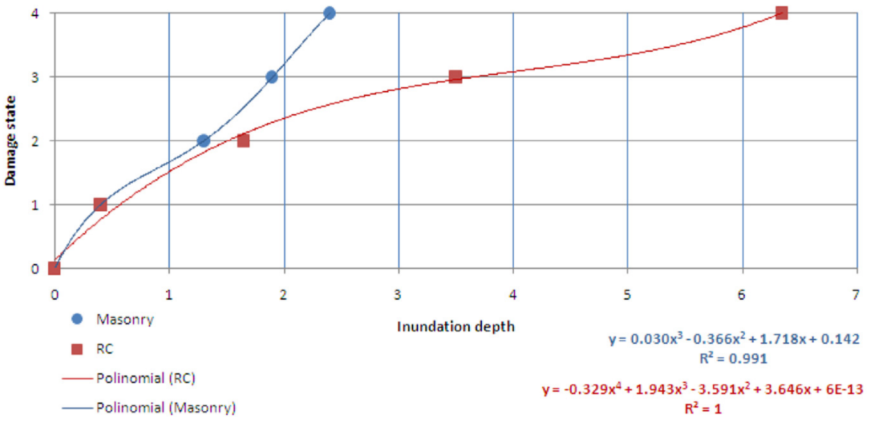

Fig. 1. Fitting curves for RC and masonry (fitted from Table 2 data).