Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 123 (2015) 599 – 605

Procedia Engineering

www.elsevier.com/locate/procedia

Creative Construction Conference 2015 (CCC2015)

Assessment of casualty and economic losses from earthquakes using semi-empirical model

Hsi-Hsien Wei[1,*], Igal M. Shohet[2], Mirosław J. Skibniewski[3], Stav Shapira[4], Robert Levy[2], Tsafrir Levi[5], Amos Salamon[5], Moti Zohar[5]

[1]*Department of Civil and Environmental Engineering, University of Maryland, College Park, 20742, U.S.A., Email: hw2208@umd.edu*
[2]*Department of Structural Engineering, Ben-Gurion University of the Negev, Beer Sheva, 84105, Israel*
[3]*Department of Civil and Environmental Engineering, University of Maryland, College Park, 20742, U.S.A.*
[4]*Emergency Medicine Department and PREPARED University center for Emergency Response Research Faculty of Health Sciences, Ben-Gurion University of the Negev, Beer Sheva 84105, Israel*
[5]*Division of Engineering Geology and Geological Hazards, Geological Survey of Israel, Jerusalem, 95501, Israel*

Abstract

A complete seismic risk assessment generally takes into consideration the interaction of three components – hazard, exposure and vulnerability – and after these three components are well defined for the purpose of interest, the risk can be assessed by the intersection of these three components, and in turn risk can controlled by countermeasures to each aspect of risk. The goal of this study is to develop and implement a semi-empirical model for casualty estimation that will enable to forecast the extent, types and severity of casualties that may happen in Israel and its surroundings in the case of several scenarios of given earthquakes. The expected deliverables will enable the research team to assess the risk, and develop strategies for retrofitting the vulnerable structures, and improve preparedness of the population in the case of destructive earthquakes.

Peer-review under responsibility of the organizing committee of the Creative Construction Conference 2015

Keywords: seismic risk assessment; seismic hazard

1. Introduction

Mitigating the results of potential earthquakes requires an estimation of the casualties that may incur, and accordingly an appropriate response model can be developed. Based on an extensive literature review of the consequences of earthquakes, the following parameters were identified as significant in estimating human casualties: (1) the earthquake hazard in the designated area, such as active faults, liquefactions, landslides and ground motion amplifications; (2) building and structural vulnerabilities to seismic hazards, assessed by an empirical or analytical

Peer-review under responsibility of the organizing committee of the Creative Construction Conference 2015
doi:10.1016/j.proeng.2015.10.113

approach combining simulation of seismic events with the data bases of structures, geological data, seismic data; and (3) assessment of the socio-economic conditions in the designated area, in order to estimate the potential population that was present in different building types at the time of the shake-out.

Many studies have focused on the extent of fatalities incurred from the numerous earthquakes that occurred in different parts of the world. In contrast, only a limited number of studies focused on surviving casualties depicting different extent, types and severities of injuries. Generally, the number of casualties and the level of injury are not easily attainable due to the limited quality and lack of information in earthquake casualty data. However, several studies that established casualty rates with respect to various building types and damage levels were published during the last two decades. There are four common approaches that have often been utilized to estimate casualties that might be caused by earthquakes: 1) an empirical approach consists of direct correlation between ground motions and the population that was present in the area at time of earthquake occurrence, based on historic earthquake statistics; 2) a semi-empirical approach takes into account the types of buildings that characterize the area and estimates damage rates according to the different structures; 3) pure analytic approach predicts behavior of buildings and their effects on individuals that are inside them, based on seismic hazard analysis; and, 4) hybrid approach consists of estimating the fraction of the population killed due to collapse of different types of buildings, considering macro-seismic intensities.

The empirical analysis ignores many relevant variables, such as building and structural vulnerabilities, as well as the presence of the population inside the structures during the event. The hybrid and analytic approaches do not address behavior of the numerous types of buildings that might be situated in the area struck by an earthquake and necessitate accumulation of data that are usually difficult to obtain due to inconsistent and poorly characterized historical earthquake casualty data. Therefore, a semi-empirical approach can more effectively estimate the damage and casualties that might be caused by a given earthquake, as it includes the identification of different types of buildings, the presence of the population during different time-frames, and the types of injuries that might be caused taking into account different socio-economic condition. Israel is situated in an area prone to earthquakes. To present, the estimation of casualties that might be incurred during an earthquake in the region has not taken into consideration the different types of buildings and the presence of the population in the different structures at different time-frames. The research employs the semi-empirical approach to estimate the surviving casualties and fatalities that might be caused by a potential earthquake. The city of Tiberius and its surroundings are used as the case-study to develop the model that will then serve as the basis for estimating the overall number of casualties that might be caused in the country.

2. Background

2.1. Natural Risk Assessment and Management

In general, risk mitigation actions include risk avoidance, reduction, transfer and acceptance, which lessen the impact of risk by dealing with its corresponding components of the risk. A large number of researches have studied the loss estimation and corresponding risk mitigation actions in seismic-active areas. For instance, risk avoidance is to reduce the impact of risk by the means of shunning the exposure at risk, as depicted in Fig.1 through actions such as urban plans by not allowing properties to be built on the areas which is consider as being at high risk [1]. For another example, as also depicted in Fig.1, one of the common countermeasures of risk reduction is to reduce the vulnerability of building stock by retrofitting structures to higher standard [2]. However, risk reduction can also be conducted by non-engineering means to lower social vulnerability such as enhancement in public education and awareness of risk [3,4].

For an area with low hazard (e.g. infrequent severe earthquakes), it in fact could be exposed to high risk as a result of its high vulnerability of built environment due to the lack of seismic design and mitigation actions, and lack of public perception and preparation. In addition, the high exposure of interest at risk like population and assets also is another reason making the area at high risk. Therefore, it is obvious that even a low hazard would cause disastrous consequences in terms of social and economic losses. Due to implementation of risk mitigation actions, such as upgrade building seismic resistance, community one has lower risk comparing to community two which has no mitigation action, although community one has higher potential impacts from earthquakes. Fig.1 also shows how mitigation actions can help reduce risk in the areas subjected to significant risk, and also how areas with moderate hazards could be subjected to significant loss due to a lack of mitigation plan.

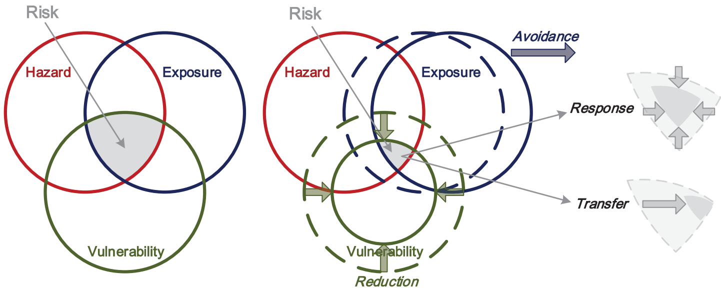

Fig. 1. Risk Assessment Model

2.2. Seismic Hazard in Tiberias, Israel

Tiberias was reported to have been hit by earthquakes several times in its history. Much of the damage had been documented in historical sources that were written by different authors and in many languages (e.g. [5,6]). Ideally, comprehensive characterization of past events is better achieved if based on reliable and complete historical sources. However, this is almost never the case whereas considerable share of the sources are doubtful and ought to be screened carefully with a critical approach. Thus, we have graded the reliability of the historical reports and apply a level of authentication to each entry of the events and the damage it caused [7]. The result is a compiled list of events that probably hit Tiberias and its close vicinity during the last 2,000 years (Fig.2). The list shows seven reports (363, 749, 1546, 10/1759, 11/1759, 1837, 1927) that mention damage in Tiberias, as well as four others between the 8th and 16th centuries (1033, 1057, 1070, 1202) that do not mention Tiberias but affected strongly nearby locations and thus may be considered as if having hit Tiberias as well. Overall, it is reasonable to assume that Tiberias was most probably damaged at least eleven times since its establishment in 19 CE with irregular intervals of time between the events. The average repeat time would be at the range of ~185 to 150 years, depending whether the counting starts from the first event in our list (31 BC) or the first mention of reported damage in Tiberias (363 CE), respectively (Fig.3). Since there is no sign of change in the geology and tectonics of the region, it is reasonable to assume that the seismic activity of the last two millennia will continue in the near future. Thus, the experiences of the past damaging earthquakes are extrapolated for hazard and risk assessment to the future.

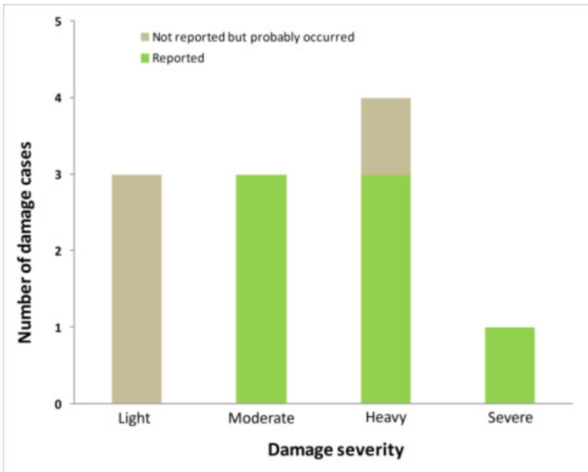

Fig. 2. Damage Recurrence and its Severity in Tiberias during the Last 2000 years

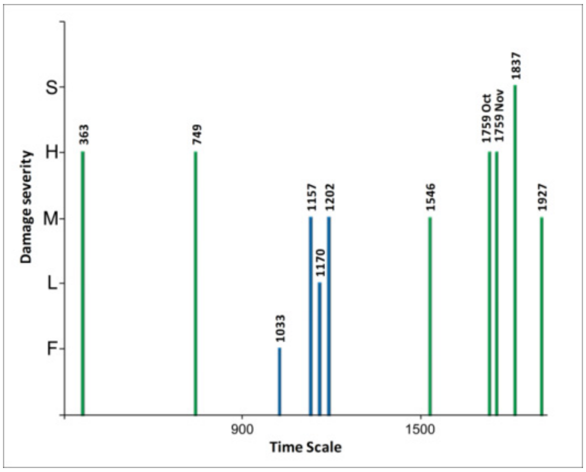

Fig. 3. Temporal distribution of damage in Tiberias during the last 2,000 years. (Green bars represent events that reported to damage Tiberias while the blue bars represent events that caused damage around Tiberias but Tiberias was not mentioned explicitly.)

3. Methodology

3.1. Risk Assessment Models and Tools

Loss estimates are a key tool in prioritizing the allocation of limited resources, as well as preventing the cascading effect of events, which can exacerbate the initial effects of a disaster. Hypothetical scenarios provide references for emergency response training exercises, response plans, and resource assessment. Effective emergency response depends on quick and precise estimates of extent of damage and magnitude. Advanced loss estimation programs can provide managers with quantitative loss projections for planning purposes, including cost benefit analysis of building codes and proposed mitigation efforts. After an event, loss estimation programs can provide answers at the critical time when the damage extent and distribution are unclear [8]. Earthquake risk is defined by 1). the occurrence probability of a seismic event, 2). the exposure of people and property to the event, and 3). the consequences of that exposure. Based on this definition of risk, several earthquake losses estimation tools, integrated with geographic information system (GIS) has been developed for three different models for their use of purposes [9]. These three models of earthquake risk assessment may be classified into three categories 1). Real-time, 2). Scenarios, and 3). Probabilistic. Real-time loss assessment model helps to obtain estimates of seismic hazards and losses soon after the occurrence of earthquakes [9]. These involve the generation of real time ground motion estimation maps as products of real-time seismology and/or generation of alarm signals directly from on-line instrumental data [10]. Many real-time loss assessment tools have been developed for rapid loss assessment to assist emergency decision-making, such as PAGER [11] and NERIES-ELER [12]. Secondly, scenario assessment tools, such as HAZUS, help to simulate earthquake scenarios and to provide useful estimates for local governments or public services to propose their seismic disaster mitigation plans. Third, probabilistic tools, like TELES [9], helps to provide catastrophic risk management tools, such as proposing the seismic insurance policy for residential buildings and developing public policy towards the preparedness to seismic scenario.

3.2. Casualty Loss Assessment

To estimate the casualties in earthquakes, three common approaches have been developed and partially used in different tools mentioned above, which includes 1) empirical, 2) analytical, and 3) semi-analytical models. In regions that have experienced numerous earthquakes with high fatalities history, typically in developing countries with dense populations living in vulnerable structures, enough data exist to calibrate fatalities from the historical earthquake record alone [13]. In such regions, building inventories are typically lacking, as are systematic analyses of their vulnerabilities; hence, analytical tools are inadequate for loss estimation. In contrast, in the most highly developed countries, particularly those with substantive building code implementation, structural responses are more easily characterized analytically and their distributions and occupancy are more readily available [14]. Due to the success of such building codes, for the purpose of fatality loss model, this category of countries typically has had relatively few fatal earthquakes, making it difficult to use empirical calibration from past events alone. In such cases, fatality estimates are largely informed from analytically-derived collapse rates and inferred fatality ratio given a structural collapse [15]. The key distinction between the semi-empirical and analytical methods is that the semi-empirical method uses intensity-based, collapse-probability functions primarily derived from expert opinion while the analytical method uses physics- and engineering-based collapse-probability functions obtained using spectral response and the capacity-spectrum approach.

4. Results

A case study was conducted to illustrate the proposed methodology. The case study illustrates its application to the evaluation of number of fatalities and repair cost at the four possible seismic-damage states of an individual RC building. Meanwhile, HAZUS seismic-loss estimation was employed to obtain the expected number of buildings, within the inventory of RC buildings in the city of Tiberias, which would be in each of these four damage states following each of 12 hypothetical seismic events [16]. The casualty and economic losses were evaluated for a typical three-story, two-bay old RC residential building with a total floor area of 600 m2 in the city of Tiberias. We chose this building type for our first case study because, having been built before 1980 when the first Israeli national seismic building code was enacted, it embodies a high level of seismic risk.

Accurate and well organized demographic data is the basis for proper casualty estimations. Casualties are calculated at the census tract level. The building stock for each tract is distributed into basic groups of residential, commercial, educational, industrial, and lodging. Specific information on the demography, such as the number of the residential population during the day and that at night, enables a better estimate of the expected casualties. In order to provide advance estimates of the demographic (e.g., number of shelter needs) and economic losses, it is necessary to assign complete demographic data to the census tracts [13]. Since the demographic data available in Tiberias were incomplete (e.g., distribution in the census tracts of those working in commercial and industrial occupancies based on time of day), the process of completing the demographic data was carried out by data collection from the Central Bureau of Statistics calculations based on a number of statistical parameters (e.g., population density and population working in the commercial and the industrial sectors; number of visitors in the hotels). The number and severity of casualties are strongly related to the extent of both the structural and non-structural building damage. Therefore, in HAZUS and in other kinds of such a software, one of the major inputs necessary for earthquake casualty estimation is the correlation between the number and severity of injuries and the damage level of the structures. As a result, Fig.4 shows the Average annual losses by building-damage states; Fig.5 shows the average annual losses by repair costs attributed to damaged buildings, and Fig.6 displays the average annual losses by number of fatalities.

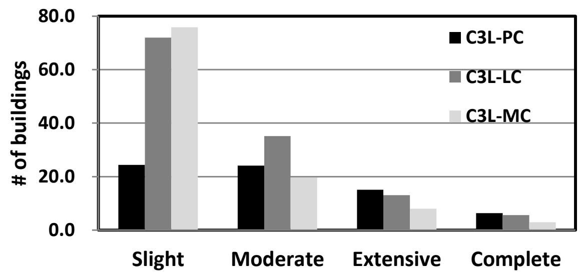

Fig. 4. Average annual losses by building-damage states

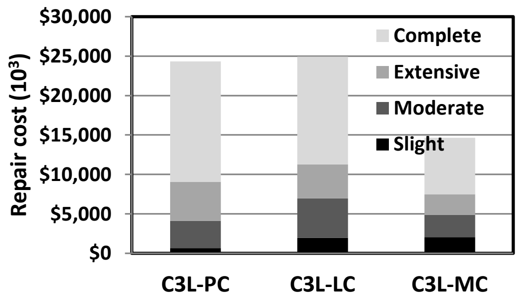

Fig. 5. Average annual losses by repair costs attributed to damaged buildings

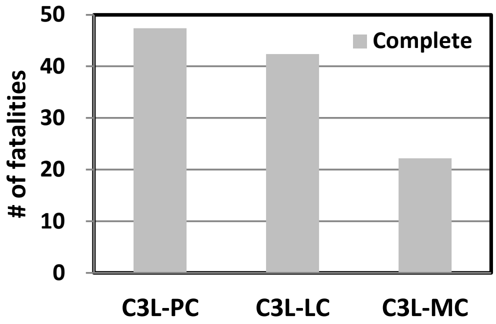

Fig. 6. Average annual losses by number of fatalities

References

[1] Wang, J.-J. (2012), "Integrated model combined land-use planning and disaster management: The structure, context and contents", *Disaster Prevention and Management*, Vol. 21 No. 1, pp. 110-23.

[2] Erdik, M., Rashidov, T., Safak, E. and Turdukulov, A. (2005), "Assessment of seismic risk in Tashkent, Uzbekistan and Bishkek, Kyrgyz Republic", *Soil Dynamics and Earthquake Engineering*, Vol. 25 No. 7, pp. 473-86.

[3] Nirupama, N., and Maula, A. (2013). "Engaging public for building resilient communities to reduce disaster impact." *Natural Hazards*, 66(1), 51-59.

[4] Siagian, T. H., Purhadi, P., Suhartono, S., and Ritonga, H. (2014). "Social vulnerability to natural hazards in Indonesia: driving factors and policy implications." *Natural Hazards*, 70(2), 1603-1617.

[5] Ambraseys, N. N. (2009). Earthquakes in the Mediterranean and Middle East. A Multidisciplinary Study of Seismicity up to 1900 (1 ed., pp. 947). New York: Cambridge University Press.

[6] Guidoboni, E., & Comastri, A. (2005). Catalogue of Earthquakes and Tsunamis in the Mediterranean Area from the 11th to the 15th Century. Bologna: INGV-SGA.

[7] Zohar, M., Salamon, A., and Rubin, R. (2013). Damage patterns of past earthquakes in Israel – Preliminary Evaluation of historical sources (pp. 37). Jerusalem: Geological Survey of Israel.

[8] Levi, T., Tavron, B., Katz, O., Amit, R., Segal, D., Hamiel, Y., Bar-Lavi, Y., Romach, S., and Salamon, A. (2010). "Earthquake loss estimation in Israel using the new HAZUS-MH software: preliminary implementation." Ministry of National Infrastructures Geological Survey of Israel, Jerusalem, Israel.

[9] Yeh, C.H., Loh, C.H. and Tsai, K.C. (2006), "Overview of Taiwan earthquake loss estimation system", *Natural hazards*, Vol. 37 No. 1, pp. 23-37.

[10] Erdik, M., Şeşetyan, K., Demircioğlu, M., Hancılar, U. and Zülfikar, C. (2011), "Rapid earthquake loss assessment after damaging earthquakes", *Soil Dynamics and Earthquake Engineering*, Vol. 31 No. 2, pp. 247-66.

[11] Earle, P., Wald, D., Allen, T., Jaiswal, K., Porter, K., and Hearne, M. (2008) "Rapid exposure and loss estimates for the May 12, 2008 MW 7.9 Wenchuan earthquake provided by the US Geological Survey's PAGER system." Proceedings of the 14th World Conference of Earthquake Engineering, Beijing, China.

[12] Earle, P. S., Wald, D. J., Jaiswal, K. S., Allen, T. I., Hearne, M. G., Marano, K. D., Hotovec, A. J., and Fee, J. M. (2009). "Prompt Assessment of Global Earthquakes for Response (PAGER): A system for rapidly determining the impact of earthquakes worldwide." US Geological Survey.
[13] Federal Emergency Management Agency (2008), "HAZUS-MH MR4 Earthquake Model Technical Manual", FEMA Washington, DC.
[14] Jaiswal, K., Wald, D., and Porter, K. (2010). "A global building inventory for earthquake loss estimation and risk management." *Earthquake Spectra*, 26(3), 731-748.
[15] Jaiswal, K., Wald, D., and D'Ayala, D. (2011). "Developing empirical collapse fragility functions for global building types." *Earthquake Spectra*, 27(3), 775-795.
[16] Wei, H. H., Skibniewski, M. J., Shohet, I. M., and X., Y. (2015). "Life cycle environmental performance of natural hazard mitigation for buildings." *Journal of Performance of Constructed Facilities*, 10.1061/(ASCE)CF.1943-5509.0000803 , 04015042.