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LESSONS LEARNED FROM ELE STUDIES IN URBAN EARTHQUAKE-PRONE AREAS

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ABSTRACT

Predicting the likely consequences of an earthquake to a nation, a city or an individual facility is generally covered by the scientific field of earthquake loss estimation (ELE). Traditionally, ELE studies have been conducted empirically (e.g. Risk-EU approach) mainly because of a lack of instrumental ground motion data and the limitations of structural analysis techniques. However, with the advent of nonlinear structural analysis tools (e.g. the nonlinear static pushover analysis) and the introduction of Capacity Spectrum Methodologies (CSM), ELE studies have been more and more conducted in an analytical-predictive way.

Analytical ELE studies for a test bed, i.e. a city or a region, require estimates on the expected ground-motion characteristics including effects of local subsoil conditions, vulnerability of the prevalent building and infrastructure typologies, as well as exposure of the same. The paper at hand discusses the challenges and the associated uncertainties that are inherently connected to each of the three components, ways to either minimize or handle these uncertainties, and how the final results of analytical ELE studies can still be considered as valuable output given the involved uncertainties. More importantly, the paper will shed light onto the technical and nontechnical problems and challenges involved during the practical conduct of ELE studies. These challenges may not only affect the practical conduct of the data collection, but also increase the uncertainties of collected input and inventory data, and not the least hamper the practical implementation of results and the initiation of mitigative actions. The paper will thereby relate to various ELE studies and risk mitigation initiatives that were conducted during past years mainly in developing countries.

INTRODUCTION

Earthquake damage and loss estimation (ELE), often also referred to as earthquake risk estimation, is a comparably young research discipline, which basically began with the seminal works on earthquake hazard by Luis Esteva (1967; 1968) and Cornell (1968). Earthquake hazard, however, represents only one of the three main components that are required for a proper damage and loss assessment. The other main components are the collection of inventory data of all assets that are to be covered by the study (e.g. buildings, infrastructure facilities, population) as well as the provision of vulnerability estimates for these assets, i.e. to describe their damageability as a function of ground motion intensity.

The main aim of ELE studies is therefore more on predicting the likely consequences an earthquake, represented by a certain ground motion level, may impose on a certain test bed of varying spatial dimension. These consequences are basically the extent of damage the seismic ground motion is able to cause to various types of buildings and infrastructure facilities as well as the connected economic and social losses.

The present article discusses the various types of uncertainties that are inherent to the different components of ELE as well as the reliability of the loss predictions at the end. As the individual, partly large uncertainties that stem from the different components stack up for the final loss estimates, a critical evaluation of the final outcomes of an ELE study may be legitimate.

CHALLENGES AND UNCERTAINTIES INVOLVED IN ELE STUDIES

From the viewpoint of the 18th century classical determinism, when probability connoted only lack of knowledge, to the current state of the art in science, when randomness is needed as a statistical perspective to characterize the physical world, the term “uncertainty” is necessary associated to both events: lack of knowledge and randomness (Woo, 1977). In the context of ELE, the term uncertainty thus refers to a large variety of unknowns starting with the uncertainties connected to the occurrence of a certain earthquake or the exceedance of a certain ground motion shaking level, via the uncertainties connected to the physical (and geometrical) parameters of the building stock inventory to the uncertainties that are connected to the unknown, e.g. how the building stock inventory will change over time (Lang, 2013). It is therefore of utmost importance that ELE models consider the local peculiarities as well as spatial variations of the three main components, i.e. hazard (earthquake), exposure, and vulnerability of the assets at risk (Erduran and Lang, 2012). Hence, the final results of an ELE study will also carry a certain level of uncertainty, both of aleatory and epistemic character (Budnitz, 1997). In the following, the various sources of uncertainty are briefly addressed.

GENERAL APPROACH FOR ELE

In general, various approaches exist for ELE. The approaches mainly differ in the way earthquake ground motion (hazard) is provided and/or how building damageability (vulnerability) is represented. Traditionally, ELE relied on empirical studies mainly focusing on macroseismic intensities in order to characterize earthquake shaking as well as statistical damage observations to describe building vulnerability.

On the other hand, with the advent of nonlinear analysis techniques (e.g. the nonlinear static pushover analysis; e.g. Krawinkler and Seneviratna (1998)) as well as the introduction of capacity spectrum methodologies (CSM; Freeman et al. (1975)), analytical ELE gained greater attention. The analytical approach for ELE is purely theoretical as it based on simulation of the structure’s damaging behavior under earthquake loading. In case that both approaches are combined or used to complement each other, the study is conducted in a hybrid way (e.g. (Dolce et al. 1995)). As a fourth approach, expert opinion studies may be mentioned, which is purely based upon the subjective opinion or decision of a group of experts.

While the final decision which one of these four approaches to select will mainly depend on the type and format of available data, each approach is connected to certain uncertainties with respect to how hazard and vulnerability are represented. Figure 1 graphically illustrates the four different approaches for ELE in terms of their respective uncertainty.

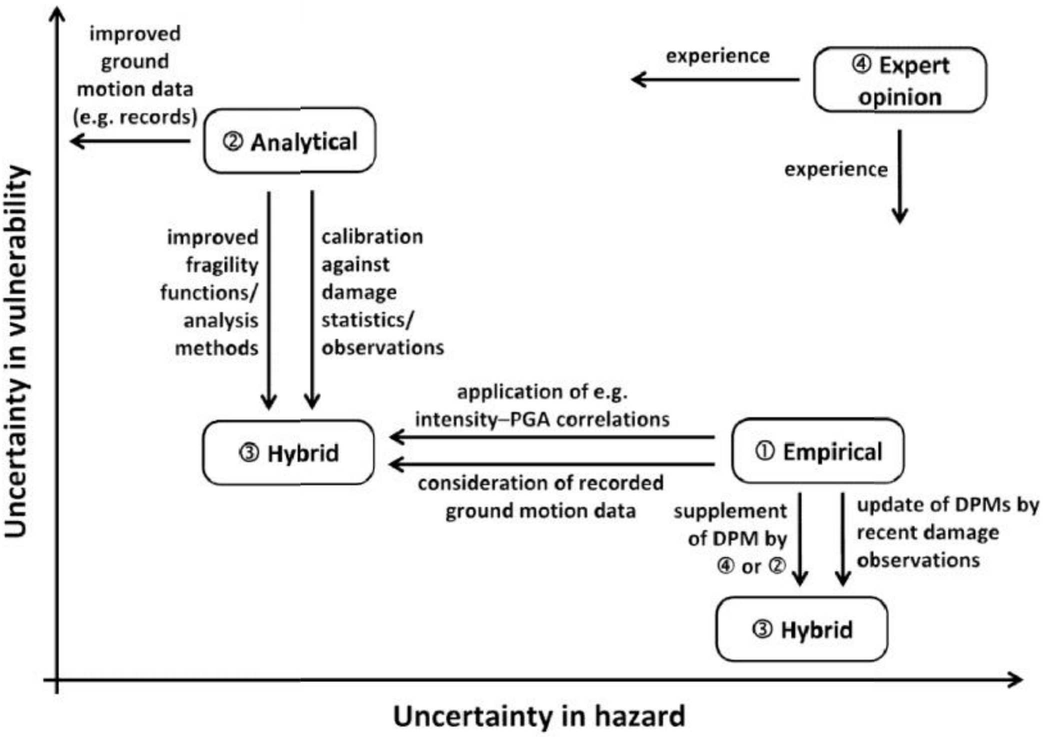

Figure 1. Qualitative ranking of the four different approaches for ELE addressed here with respect to their uncertainties in hazard and vulnerability (Lang, 2013)

SCALE AND RESOLUTION OF THE ELE

ELE studies can be conducted for any scale and resolution though there are certain restrictions with respect to the maximum size of the study area under consideration. However, uncertainties in final loss estimates may more depend on the spatial resolution of the study area, hence the detailedness of exposure data, and how much effort is spent on collecting this data.

In general, ELE studies are not related to the level of individual buildings but geographical units which cover a certain area with homogenous soil conditions, same era of construction, etc. The spatial extent (size) of these geounits mainly determines the study's level of information, hence affect the dispersion of the inventory database and later the uncertainties in loss results.

EXPOSURE

The collection of inventory data and the compilation of an exposure database is probably the most cumbersome task of an ELE study. Not only because it is time consuming, but also because it should cover a variety of structural and socioeconomic data on the physical assets and the population which is often hard, if not impossible, to obtain in sufficient quality.

In some cases, already existing databases (e.g. census data) may help to reduce the effort of data collection, but often may provide unfortunate restrictions on the study, e.g. with respect to the clustering of the study area, the classification of building typologies, which may not be optimal for the good of the study. It may also be considered that existing databases may already be outdated (census data, e.g. is usually collected every 10 years), which can have serious implications in many parts of the world with extreme population growth and building development.

HAZARD

Analytical ELE studies make use of a demand response spectrum to represent the seismic ground motion input. The spectral and amplitude characteristics of the response spectrum are determined by the considered seismic hazard which may include local soil (and site) conditions. The uncertainty related to hazard comes from the fact that there are different ways to model it and hence to derive these input parameters for ELE studies (i.e. deterministic events, hazard maps or curves, probabilistic events-based ground-motion fields).

On the other hand, the majority of ELE studies are of deterministic character, so another source of uncertainties are related to provide the ground motion estimates at the site of interest using suitable ground-motion prediction equations (GMPE) or which were taken from empirical or probabilistic ground motion shake maps. But also single deterministic events are connected to sources of epistemic uncertainties which stem from the variations in source parameters.

VULNERABILITY

Vulnerability functions represent the structural behavior of the respective building typology and define the probability of suffering a certain level of damage along a given ground motion intensity parameter.

In many cases, ELE studies are conducted by selecting existing vulnerability functions that had been originally derived for similar building typologies in other parts of the world rather than to develop customized functions that address the peculiar structural and non-structural characteristics of the respective building stock. The reasons for this are either to reduce the calculation efforts, especially when studies are conducted for large portions of the building stock, lack of available resources, or lack of information which does not allow for a detailed survey and data acquisition (D'Ayala and Meslem 2013).

However, the selection of vulnerability functions that represent the peculiarities of the building stock can be the most challenging task in order to ensure a reliable earthquake loss assessment. For instance, HAZUS vulnerability functions (FEMA 2003) that were derived for buildings in the U.S. only, have been used in conducting ELE studies in many parts of the world: Romania (Vacareanu et al., 2004), India (Gulati, 2006), Algeria (Boukri et al., 2013), Venezuela (Bendito, 2014), among others. Typically, differences in construction techniques and detailing between different countries are significant, even when buildings are nominally designed according to similar code provisions.

Furthermore, most of these existing vulnerability functions from literature were generated using different methodologies which employ a variety of approaches and assumptions when deriving the vulnerability functions (Meslem et al., 2014). Hence, there will be a question on the reliability of obtained ELE results due to significant uncertainty.

In general practice, analytical vulnerability functions are generated through a process which essentially is based on two main components (Figure 2), i.e. the ground motion intensity parameter-to-structural response functions, P(SR|IM), and the structural response-to-damage state functions, P(DS|SR).

The functions are the products of two independent processes, i.e. the structural analysis and the damage analysis. At the level of the structural analysis process, the uncertainty mainly depends on the choice of structural modelling assumptions, definition of structural characteristics-related parameters (how close/representative are the chosen parameters to the assessed building class), method of analysis, as well as how record-to-record variability is taken into account. For the damage analysis process, uncertainties mainly stem from the choice in characterizing and determining the damage thresholds, i.e. the selection of damage model and damage scale.

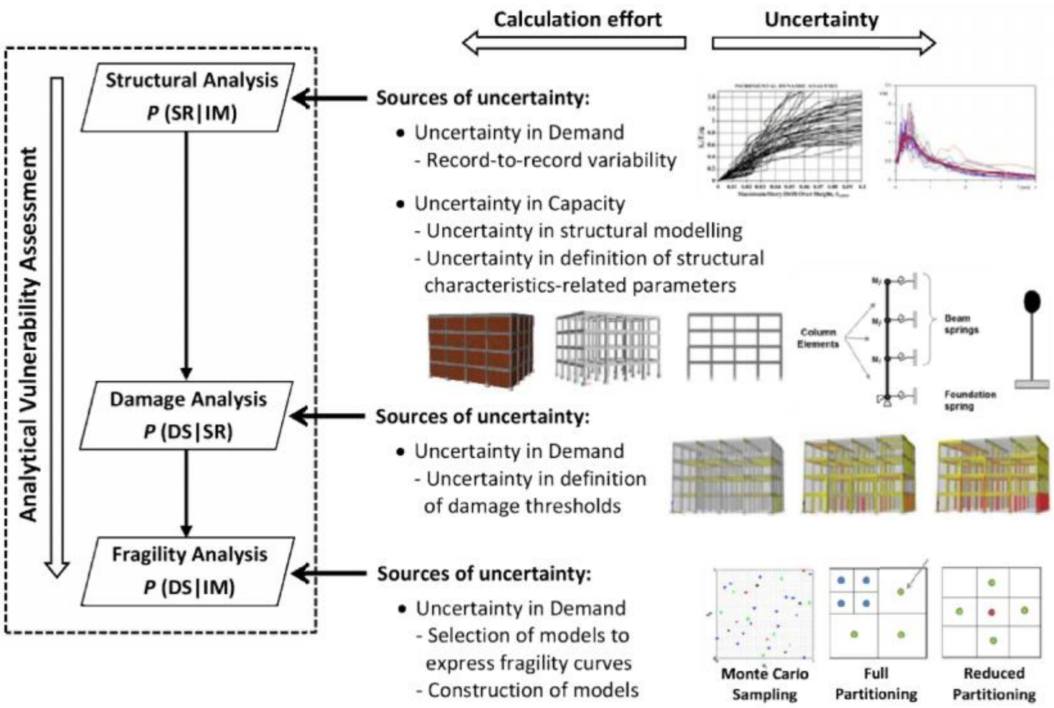

Figure 2. Process of analytical vulnerability assessment with respect to calculation effort and uncertainties (Meslem et al., 2014)

CONCLUSIONS

To come up with appropriate predictions of expected damage and loss, reliable risk models have to be generated, which consider the local peculiarities as well as spatial variations of the three main components: earthquake hazard, exposure and vulnerability of the available assets at risk (Erduran and Lang, 2012). Each one of these three components is associated with an intrinsic uncertainty. As such, the final risk results will also carry a certain level of uncertainty, both of aleatory and epistemic character (Budnitz, 1997). Aleatory uncertainties are those that are due to randomness and cannot be improved. The most common example for aleatory uncertainty is probably the intrinsic uncertainty in GMPE that is caused by the randomness of earthquake events and the great dispersion of median ground motion values (Douglas, 2010a; 2010b). However, the majority of the uncertainties associated with earthquake risk analysis are epistemic (due to lack of knowledge), which means that they can, in theory, be reduced if sufficient resources are allocated to improve the models (Crowley et al., 2005).

In seismic hazard analysis, a proper treatment of epistemic uncertainty that is related to the use of different ground-motion prediction relations can be achieved through the use of a logic-tree approach (Bommer et al., 2005; Bommer and Scherbaum, 2008). Nowadays, this treatment is also used in ELE estimation allowing the user to consider epistemic uncertainties of any type of input data (Molina and Lindholm, 2007; Molina et al., 2010). The diversification of each input type leads to a sudden increase in the number of logic tree branches. This, in turn, leads to an increase in damage and loss computation runs and hence computation time which nowadays can be handled easily.

As the uncertainties in final damage and loss estimates will come with only one variation range, it should be considered which of the single input parameters and their intrinsic uncertainty contributed to a lesser or greater extent to the final uncertainty level.

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