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Insight on seismic hazard studies for Egypt

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ABSTRACT

The seismic hazard studies for Egypt have been initiated a long time ago aiming to predict the ground motion parameters at different geographical scales; their review process had been routinely performed due to the increase of available instrumental observations rather than from methodological advances.
For the comprehensive understanding of the development of seismic hazard assessment (SHA) studies in Egypt, we properly collect and test the existing SHA maps, computed at different geographic scales, against the available observations, data quality, physical assumptions and adopted methodology. Most of these SHA studies are probabilistic and the mapped ground motion acceleration values have been often largely exceeded by the observed values due to earthquakes occurred after their publication. For each study, we discuss and evaluate the input data, methodology and the results obtained in order to understand the reasons behind the bad performance of the available seismic hazard maps and to avoid such shortcomings in future seismic hazard assessment. Finally, we formulate suggestions that could be considered before new seismic hazard maps are released and then adopted, for the real benefit of society.

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1. Introduction

The main aim of seismic hazard assessment (SHA) is the reliable characterization of the possible effects, and their geographical distribution, from local and regional earthquakes and to present them in a form, useful for practical and effective reduction of seismic risk.

It is clear that the most important input parameters for seismic hazard computation, whatever approach is considered, are: the seismotectonic sources, the set of controlling earthquakes (e.g. Maximum Credible Earthquake (MCE)), the ground motion prediction equation (GMPE) in the case of Probabilistic Seismic Hazard Analysis (PSHA) or DSHA (Deterministic Seismic Hazard Analysis) and lithosphere structure in the case of Neo-Deterministic Seismic Hazard Analysis (NDSHA). The first two sets of parameters (seismotectonic sources and the earthquake potential) are not easy to define, especially for intraplate regions, where the earthquake generation process is poorly understood and occasionally there is a poor correlation between the observed seismicity and the geologic structures or active faults (e.g. Egypt). Moreover, the identification of the controlling earthquake for these regions (i.e. intraplate regions) is

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not a handy way because of the limited seismicity record, very variable length of occurrence time interval, lack of our understanding about earthquake generating process and characteristics of seismotectonic earthquake: the subsurface active faults "blind faults" in mid-continental regions are a good example of the active seimotectonic structure that is capable to produce strong earthquakes, despite it is not characterized properly (e.g. Western Australia; Cairo-Suez shear zone in Egypt). Therefore, the incorporation of all available information from different multidisciplines e.g. Morphostructural Zonation (MZ), paleoseismological, geodesy investigations, will be necessary in the proper identification and characterization of active seismic sources, since using the available instrumental and historical earthquake records alone can incorrectly define (underestimate) the hazard level in the studied area. Moreover, the available strong motion databank for regions of scarce seismicity (e.g. Northeast Africa; Arabian Peninsula) and low occurrence rate for large earthquakes is not sufficient to establish or explore a proper GMPE for the prediction of the ground motion parameters. Consequently, it is better to resort to scenario-based techniques (e.g. NDSHA) or to use a GMPE that is developed from reliable source and propagation modeling and then validated using the available ground motion data instead of using imported ones.

In fact, there is the crucial need for a formal procedure for the proper collection and rigorous testing of newly developed seismic hazard maps before they can be accepted and then adopted, so that the society may benefit from such scientific studies and will not be deceived by the existing incorrect SHA results (Kossobokov and Nekrasova, 2012; Panza et al., 2012).

This work aims at giving a detailed insight on the available seismic hazard studies carried out at different geographic scales in Egypt, and finally to come out with some suggestions, comments and conclusions that could help in improving and enhancing the effectiveness of the future studies. To do this, we will start by showing shortly the performance of seismic hazard maps on global scale and an explanation about the SHA methods, their shortcomings and the alternatives; then we will focus on the existing seismic hazard studies for Egypt, describing the approaches that have been used, the input data and models, the dispersion in the obtained results, the testing of the results against the available macroseismic data and discussing the possible shortcomings. In Egypt the available seismological data is not sufficient for a sophisticated testing, but the result of the current testing cannot be overlooked.

2. SHA performance, advances and shortcomings

After the recent destructive earthquakes, e.g. Sumatra 2004, Wench China 2008, Haiti 2010 and Japan 2011, that took by surprise the global existing maps (see Kossobokov and Nekrasova, 2012; Panza et al., 2014), there is the urge to identify the causes of such failures and to improve the procedure of seismic hazard analysis, so that hazard maps possess, at the time they are published, some reliable predictive content and do not need to be revised after each major earthquakes occurrence, as it often happened till now. Stein et al. (2012) studied the causes of the failure of seismic hazard maps related with the Tohoku 2011 (March 11, M ~ 9.0) event and identified four overlapping factors that can cause a hazard map to fail: bad physics, bad assumptions, bad data and bad luck, and introduced suggestions that could improve the performance of such a map.

Intensive debate and criticisms on the traditional PSHA method and its global performance in the last decades has demonstrated the fallacy of its estimates (e.g. Molchan et al., 1997; Castaños and Lomnitz, 2002; Klügel, 2007a,b; Geller et al., 2015). These authors evidenced substantial limits in both theoretical and practical bases of PSHA, including their dangerous effects on seismic codes. Traditional PSHA-based seismic hazard maps are: (1) strongly dependent on the length, completeness and the quality of earthquake database being used; (2) do not adequately consider the seismic source process, seismic wave propagation model and local site condition; (3) do not appropriately consider the temporal properties of earthquakes occurrence, since they are based on the assumption of random occurrence of earthquakes, that implies the independent occurrence of earthquakes in both time and space; this means that the probability of occurrence of two events at the same time and space is about zero, contrary to what sometime observed; (4) do not adequately consider the available information from paleoseismological, morphostructural and GPS based studies. In fact, the number of records of large earthquakes is too limited to attempt to describe the probability of occurrence and ground motion particularly for mid-continental regions. So far, there is no a formal approach that allows for the use of this kind of aforementioned data (item 4) in the computation of the Gutenberg-Richter (GR) relation (Gutenberg and Richter 1956) that is at the base of any traditional PSHA estimate.

The modern PSHA approach (for the complete description see e.g. Petersen et al., 2008; Atkinson and Goda, 2011) could implement data about active sources and has some improvements relative to the traditional one, as: a) the adoption of active fault databases; b) point and finite source modeling can be frequently used in developing a GMPE and generating the time histories from a control fault for structural dynamic analysis; c) Morpho-tectonic and paleoseismological studies, as well as GPS and InSAR measurements are used in the determination of fault segmentation, attitude, depth, and slip-rates of fault sources; d) to characterize the distribution of earthquake magnitudes, GR relationship was commonly used for a relatively big regional sources in PSHA, but for small sources it resort to Characteristic Earthquake (CE) model which refers to the characteristic magnitude occurs more often than predicted by the GR models proposed above; e) weights in a logic tree are commonly determined by a large group of experts instead of "the author's experience and judgment"; f) residuals in GMPEs are decomposed into epistemic uncertainty and aleatory uncertainty. Only aleatory uncertainty was included in the integration for annual rates of exceedance. Epistemic uncertainty is moved to the logic tree; g) Seismotectonics and crustal structures as well as seismicity were commonly used in delineating the regional source zones and focal depth distribution function. Basin depth and Vs30 were used in developing the GMPE; h) Output ground-motion level is not a single value, but a spectrum covering 0 s to 10 s. PGV, PGD, and Arias intensity may also be included.

According to the Multiscale Seismicity (MS) model (Molchan et al., 1997), the GR relation is valid as a law only for the earthquakes that have a linear dimension of the surface rupture small compared to the dimensions of the analyzed region, i.e. in the point source approximation. When focusing on a relatively small site, the point source approximation may no longer be valid and therefore GR is not applicable as a law. For example, an event with M ≥ 7, whose rupture length can be estimated around 50 km (Wells and Coppersmith, 1994), can be considered a point only if the studied seismogenic zone has linear dimensions larger than 500 km (Panza et al., 2014). The use of small areas has given rise to the CE model (Schwartz and Coppersmith, 1984), but this model has been strongly questioned by several authors (e.g. Molchan et al., 1997; Geller et al., 2015) which cast severe doubts on the CE model reliability.

In view of the theoretical and practical limits and errors in basic assumption of traditional PSHA estimates, it appears urgent to resort to a scenario-based approach to SHA. NDSHA approach is a scenario-based method for seismic hazard analysis, where realistic synthetic seismograms are used to construct earthquake scenarios. NDSHA is best suited to compute the ground motion parameters at 1 and 10 Hz cut-off frequencies for different geographic scale studies. The two frequency thresholds are chosen depending upon the quality of the available input data; cutoff frequency increases with increasing quality. Starting from the available knowledge about the mechanical properties of the Earth's structure, seismic sources and seismicity of the study region, it is possible to realistically compute the synthetic seismograms from which quantify peak values of acceleration, velocity and displacement or any other ground motion parameter relevant to seismic