



Updated Seismic Input for Next Generation of the Egyptian Building Code

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Abstract. Egypt is prone to earthquakes of moderate and strong size from inland and distant seismogenic sources. The seismicity and seismic hazard studies have indicated that the country face moderate seismic hazard. Current practice in the Egyptian building code considers seismic load using seismic input from old seismic zonation map that go back to the late 90's. Although, this map was developed using a traditional seismic hazard approach, the seismic design strategy, as well as the building code and its update; rely upon it. Also, despite the several developments in the understanding of seismicity, crustal deformation and earthquake mechanics in Egypt that have been achieved in the last two decades, also the presence of theoretical and practical developments, the current seismic load computation of the code is still dangerously adopt and recommend this map. Therefore, the current practice needs an urgent revisit and update. The main aim of this work is to estimate the ground motion parameters in the form of accessible digital maps or databases (e.g. Peak Ground Acceleration, velocity, displacement, response spectra, and time histories) that can be used as input for the next generation of the Egyptian Building code. Physics-based seismic hazard maps and/input are computed where uncertainties are properly evaluated and communicated to the end users. Also, the newly developed maps or input provide a wide range of ground motion parameters in the form of digital databases, not only limited to peak ground motion values, but comprise also excitation records, response spectra or any other ground motion parameter relevant to seismic engineering. The main delivers of this work will be archived and presented using GIS tool that covers whole Egypt with several thousands of sites (nodes), at each node/site. A geospatial database of computed time histories (seismograms and accelerograms) due to all possible seismic sources that can affect those sites are provided. In addition, at each site a representative response spectrum that envelopes all possible ground motion parameters with different percentiles are given.

1 Introduction

For most countries, building codes, either for construction and urban planning, define the minimum requirements or recommendations for a “good performance” in the face of a possible future seismic action that may occur during the life-time of a given construction (e.g. residential buildings, infrastructure, lifeline).

Generally, the concept of Performance Based Design (PBD) consists in designing a system so that it behaves in a desirable way when subject to a certain action (e.g.

earthquakes, wind). The key points in such procedure are the identification of a procedure which relates the behavior/response of an object to the applied action, the identification of the limit beyond which the behavior of the object is unacceptable and the correspondent strength of that action. The Performance Based Seismic Design (PBSD) is the application of the PBD in the field of earthquake resistant structure design. Seismic design codes have been developed since the beginning of 1900 in Italy, U.S. and Japan (BSSC 2015; Fasan 2017). The main purpose for which is to mitigate a building's collapse due to earthquake impact, which was evaluated, as introduced in Italy in 1909, through applying lateral forces proportional to the gravitational load of the building. This is the origin of the lateral force method still used today. Such a procedure, neglecting for a moment the problem of the definition of the seismic load, was merely focused on the collapse prevention.

These considerations arise from the fact that, after some small earthquakes, evidence showed that even although buildings did not collapse an extensive non-structural damage was observed.

At present, a modern PBSD process includes mainly the following steps (Bertero and Bertero 2002):

- Seismic Hazard Assessment (SHA);
- Definition of Building Performance Levels (PLs);
- Selection of acceptable Performance Objectives (POs);
- Structural analysis and POs check.

The concept of PBSD was first imbedded into building design guidelines in 1978 with the ATC-06 publication (ATC 1978). The assessment of seismic hazard was based on a single map and the achievement of adequate performance of a building under risk was reached by classifying the buildings in four different Seismic Performance Categories. Each category requires different levels of security and anti-seismic details. The hazard map was defined probabilistically since it was “*policy decision*” of the ATC-06 committee that “*the probability of exceeding the design ground shaking should – as a goal – be roughly the same in all parts of the country*” and “*there is no workable alternative approach to the construction of a seismic design regionalization map which comes close to meeting the goal*” (ATC 1978) even if it was well recognized that the “*assumption [of Poissonian distribution of earthquakes in time and space] is of limited validity*”. Hence, for consistency with a priori decisions, the ATC-06 committee adopted a method known to be based on wrong assumptions (Fasan 2017). It worth to say, at that time deterministic seismic hazard approaches were developed and well known “*based upon estimates of the maximum ground shaking experienced during the recorded historical period without consideration of how frequently such motions might occur*” but “*considering the significant cost of designing a structure for extreme ground motions, it is undesirable to require such a design unless there is a significant probability that the extreme motion will occur*”. In other words, ATC committee decided to lower the ground motion level just for cost reduction, so the probabilistic method was used to give an appearance of rationality to the choice does not matter how robust the method was.

This position is supported by the fact that a seismic hazard map was first drafted for ATC 3-06 “*having literally been drawn by a committee*” based on expert judgment and subsequently since this map “*appeared to agree reasonably well with the level*

of acceleration determined by Algermissen and Perkins [...] their map was used as a guide for the rest of the country". It happened that the map of Algermissen and Perkins (Algermissen and Perkins 1976) was based on a "mean return period" of 475 years, so a 10% probability of exceedance in 50 years map was adopted in ATC-06 and subsequently became a standard number all over the world. So the use of an "average life" of 50 years is explained as "*a rather arbitrary convenience*" and the 10% probability of exceedance as a number often taken by statistician "*to be meaningful*" (Bommer and Pinho 2006).

Historically, the same target probability of exceedance PEY of 10% in 50 years has been used worldwide as a reference to design ordinary buildings without any validation or clear risk-based rationale and regardless of differences with the U.S.A. in terms of seismicity, construction practices and economic prosperity (Bommer and Pinho 2006). Consequently, the computed ground motion values, as it could be expected given their probabilistic nature, have been systematically exceeded by earthquakes occurred after the publication and adoption of the standard probabilistic hazard map as pointed by Kossobokov and Nekrasova (2012). Moreover, the comparison between different probabilistic hazard maps computed at regional or national scales reveals how the peak ground motion values (e.g. PGA with $PEY = 10\%$ in 50 years) are not consistent from map to map of the same area of interest, and large differences have been found (Nekrasova et al. 2014; Hassan et al. 2017a) due to many factors (e.g. preconception of the seismic hazard analyst, assumptions). Hassan et al. (2017a) indicated that the comparison among different probabilistic seismic hazard maps for Egypt (at national and local scales) for the same site reveals that the PGA values are not consistent and considerable differences are found; the local studies can be more detailed, though not necessarily more reliable (e.g., Klügel 2008). For example, the PGA values for Aswan vary in the range from 0.005–0.2 g, showing a large scatter in the expected values. So, it could be difficult for the potential users to decide what ground motion value to rely on in the design or retrofitting of the built environment. Furthermore, there are substantial differences between PGA values determined by the same study at the same site, but using different GMPEs (e.g., Abdel-Fattah 2005). Those observations and other engineering considerations have resulted in, in some countries (e.g. U.S.A), a change in the value of PR from 10% to 2% in 50 years (Fasan 2017), "*In part, 2% in 50 years was selected because USGS had already produced maps for this hazard level*" (BSSC 2015).

The main contribution in the development of the PBSO philosophy of design has been done by the Vision 2000 report (SEAOC 1995) which firstly introduced a multi performance levels check. This report defines a series of performance levels (in terms of acceptable level of damage) that a building should achieve during earthquake actions of different strength. These performance levels are usually defined as: Operational Limit (OL), Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP). The "mean return periods" arbitrarily associated with them are 43, 72, 475 and 970 years and correspond to a probability of exceedance of 69%, 50%, 10% and 5% in an interval of 50 years, respectively (Fig. 1). The mean return periods corresponding to the four performance levels have been arbitrarily selected for California (Bertero and Bertero 2002) and it has never been motivated (Bommer and Pinho 2006).

Nowadays, the most advanced seismic codes change what is called the reference average life (Y) with the change of the importance of the structure (risk category), which

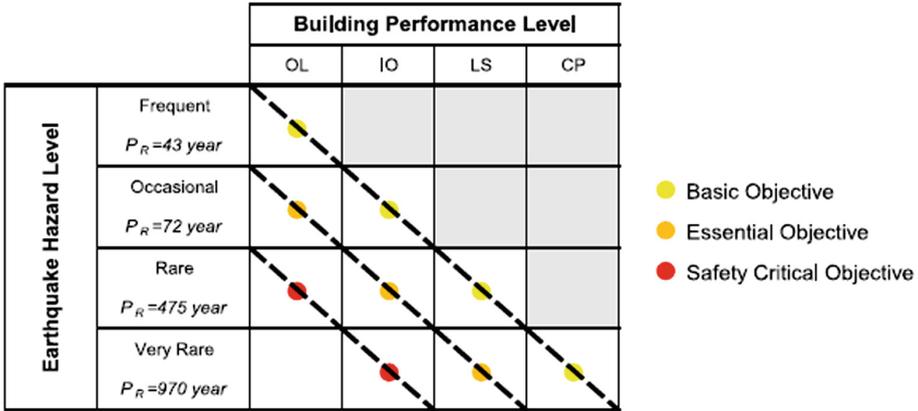


Fig. 1. Vision 2000 conceptual performance objectives matrix (SEAOC 1995).

is controlled by the (hypothetical) consequences of its failure (the more dangerous the consequences, the longer the “average life”) (e.g. NTC08 (C.S.L.P. 2008)). This leads the codes to increase the expected structural performance with increasing importance of the structure. Indeed, proper structural performances in case of occurrence of frequent earthquakes (i.e. for low intensities) and, on the other hand, high damages for a very rare earthquake can be accepted.

However, the standard breakdown of the overall cost of a modern building is: 8–18% for structural components, 48–62% for non-structural components and 20–44% for contents (Miranda and Aslani 2003). According to Fasan (2017) the costs optimization using a probabilistic value of ground motions when evaluating the Collapse Prevention Level appears to be unreasonable, at least for three reasons: 1) the fallacy of the “mean return period” concept; 2) the benefits (reduction of costs) due to a PSHA decrease of ground motion involve a very small percentage of the overall cost (the structural components); 3) it does not take into account the post-earthquake recovery costs.

Actually, the PBSO procedure should aim to build an earthquake resilient system. An earthquake resilient system is a system with the following characters (Bruneau et al. 2003):

- reduced failure probabilities of a system;
- reduced consequences from failures, in terms of lives lost, damage, and economic and social consequences;
- reduced to recovery time by increasing resilience (restoration of a specific system or set of systems to their design level of performance).

In fact, the losses due to earthquakes occurred during this decade (e.g. Christchurch (New Zealand) and Tohoku (Japan) earthquakes in 2011), demonstrated that a PBSO procedure based on PSHA is neither reliable nor cost effective. The acceleration response spectra nor 2500 years return period prescribed by the New Zealand seismic code was exceeded by the Christchurch earthquake (22 February 2011, $M_w = 6.2$) that caused 181 deaths. It was estimated that at least 900 buildings in the business district and

over 10 thousands homes had to be demolished. The restoration cost was estimated in about US\$15--20 billion, the highest cost ever caused by an earthquake in New Zealand (Kaiser et al. 2012; Morgenroth and Armstrong 2012). In the Tohoku earthquake (Japan, 11 March 2011, $M_w = 9$), followed by a devastating tsunami that cost the government about US\$260 billion (Iuchi et al. 2013). The Wenchuan earthquake (China, 12 May 2008, $M_w = 7.9$) resulted in about US\$124 billion of direct losses and at least other US\$100 billion of indirect losses due to production interruption (Wu et al. 2012). Fasan (2017) pointed that Italy has spent from 1944 to 2012 almost €181 billion, only in public funding, because of earthquakes Code. Between August and October 2016 a sequence of devastating earthquakes struck the country of much higher spectral accelerations than those with a “mean return period” of 2475 years given by the Italian Building Code (Fasan 2017).

Consequently, it seems obvious that the claim of the ATC-06 committee “*considering the significant cost of designing a structure for extreme ground motions, it is undesirable to require such a design unless there is a significant probability that the extreme motion will occur*” is no longer valid or acceptable in order to create a resilient system. In addition, the progresses in engineering knowledge and the developments of new methods and technologies, such as the use of seismic isolation and/or dissipative systems, make the statement obsolete and even incorrect. According to Sawires et al. (2016a) first version of the Egyptian Concrete Code was developed in 1930, and then it was followed by successive updates in 1962, 1969 and 1988...etc. The Egyptian building codes lacked the guidelines for seismic action till 1988. According to that buildings were typically designed to stand gravity (vertical) and wind (lateral) loads. The first building code of practice to admit and recommend to consider seismic actions in the designing of buildings was published by the Ministry of Housing, Utilities and New Communities in 1988, the Reinforced Concrete Code as pointed by Sawires et al. (2016a) (ESEE 1988). After the occurrence of 1992 Cairo earthquake ($M_w = 5.8$) the Egyptian Code for Loads and Forces was motivated and issued on December 1993 (ECP-201 1993). More than ten years later, a new code (ECP-20 2004) was developed in order to address the shortcomings presented in preceding standards, particularly in the seismic hazard definition. The 2004 code seems to be a copy from the Eurocode 8 version of 2004 with minor changes for making it applicable in Egypt. Most recently, the Egyptian code gradually introduced ductility concepts and detailing procedures through its successive versions (ECP-201 2004, 2008, 2012), although these aspects of the code still need considerable improvement and development at least from the earthquake loading side (Raheem 2013, Sawires et al. 2016a). Reaheem (2013) indicated that the traditional engineering approach aim to employ equivalent static analysis methods, while current design practice is moving toward an increased emphasis on the nonlinear analysis method. In fact, earthquake time histories may be not crucial for the land use and urban planners, but are of a great importance for structural and technical engineers willing to design a new structure and/or evaluate the seismic performance of the existing built environment, and to investigate the non-linear behavior of soil at the site of interest. So, it is crucial to exploit the current methodologies for modeling the generation and propagation of seismic waves, as done with multi-scenario seismic hazard analysis approaches, can to

provide a comprehensive database of computed seismograms for Egyptian territories that suffer from the lack of useful strong motion databases.

NDSHA approach is a scenario-based method for seismic hazard analysis, where realistic synthetic seismograms are used to construct earthquake scenarios. In the NDSHA, the knowledge gaps can be appropriately treated, either by incorporating available data from seismology, paleoseismology, morphostructural, geodetic, and related studies or by performing extensive parametric and sensitivity analysis to better and accurately define and addressing the effect endemic lack of knowledge, analyst preconceptions and insufficient data and uncertainties on the resultant hazard maps.

2 Challenges for Seismic Hazard in Egypt

Egypt is well defined as a relatively moderate seismicity country, although it has experienced strong earthquake effects through history from distant (Hellenic arc, Cyprian arc, and the Dead Sea fault system) and nearby (e.g., North Red Sea, Gulf of Aqaba, Gulf of Suez, South-West Cairo (Dahshur Zone), and the continental margin of Egypt) earthquake sources. The reasons behind the strong risk from modest seismic hazard are the high population density, the proximity of some seismic sources to urban cities, profound effect of the path and local site condition, the deterioration of the buildings, absence of maintenance, and the poor design and construction practice. According to the macroseismic data, the 365 Crete, 1303 Rhodes, 1969 Shadwan Island (entrance of the Gulf of Suez), and 1992 Cairo (Dahshur) events are examples of earthquakes that generated the strongest impacts in Egypt. If earthquakes with similar magnitudes happen shortly, a high seismic risk in Egypt is expected due to the increase of exposure and vulnerability, which are the main elements in the risk concept. Therefore, the reliable seismic hazard assessment (SHA) to mitigate the possible losses in the future is a due.

Although many lessons learned through the time, most of the existing seismic hazard studies for Egypt failed to predict the ground motion parameters for earthquakes had occurred after their publication. The failure is evidenced by merely comparing the expected ground motion parameters by different studies with the macroseismic intensity, which is shown and discussed by Hassan et al. (2017a). The failure may be due to the fact that, to identify the location and characteristics of seismotectonic sources for Egypt, only seismological observations (about 120 years) have been considered, while paleoseismological and Morphostructural Zonation (MZ) investigations or similar studies that are suitable to identify seismotectonic sources that may be active over a time scale that is larger (long recurrence) than the instrumental database time span have been not investigated yet or ignored or unappreciated.

Although the importance of the new developments in SHA methodology and practice, it is worth to mention that, most of the available SHA maps for Egypt are based on the traditional approaches and have not implemented the newly proposed improvements in their computations, so far. Approximately, 80% of all SHA studies conducted until now about Egypt at different geographic scales are based on the traditional PSHA and it is still in use in the construction of newly developed SHA maps at different scales (e.g., EzzElarab et al. 2016; Sawires et al. 2016b) upon which the current Egyptian building code is dangerously based.

It worth mention that, the recently released studies have adopted the traditional PSHA method and mainly focus of the collection, update, and revision of the earthquake catalog rather than to the critical review and improvement of the methodology and other elements that are crucial to reach a reliable, as much as possible, estimate of hazard. Moreover, a recently released PSHA study for Egypt has been done by Gaber et al. (2018) has admitted that “*the update of the PSHA maps due to the occurrence of few earthquakes of moderate size and without any real advancement in methodology or inclusion or development of a new investigation will not cause any significant changes in the ground motion values and the pattern of the isocontour maps*”.

It worth to mention that, most of the available SHA studies for Egypt (e.g., Ibrahim and Hattori 1982; Abdel-Fattah 2005; Mohamed et al. 2012; EzzElarab et al. 2016) have limited the output of the seismic hazard assessment to one or two value(s), i.e., peak ground acceleration (PGA) for the horizontal component and response spectrum (RS) rather than the complete frequency content, effective acceleration, bracketed duration, incremental velocity and damaging potential (e.g., Decanini and Mollaioli 1998; Bertero and Uang 1992). Also, they did not give the due attention, in a sound and physically correct way, to the so-called “site-effects”, that may be not persistent when earthquake source changes (Molchan et al. 2011). Actually, the sediments of the Nile Valley and its Delta can have a substantial impact on the polarization (also defined amplification/de-amplification) of seismic waves in the horizontal plane and on ground failure or soil liquefaction (e.g., El-Sayed et al. 2001).

In fact, earthquake time histories may be not crucial for the land use and urban planners, but are of a great importance for structural and technical engineers willing to design a new structure and/or evaluate the seismic performance of the existing built environment, and to investigate the non-linear behavior of soil at the site of interest. So, it is crucial to exploit the current methodologies for modeling the generation and propagation of seismic waves, as done with scenario-based approaches, can to provide a comprehensive database of computed seismograms for Egyptian territories that suffer from the lack of useful strong motion databases.

It seems that one of the major problems in the seismic hazard studies carried out for Egypt, is that how much the used earthquake catalogs are representative of the real seismicity of the study area (e.g., Badawy 1998; Saleh 2005). So, it is required to use all available information (e.g., geodesy) and to plan new comprehensive investigations where crucially necessary (e.g., paleoseismology) to better identify and characterize the seismic sources for Egypt. The appropriate incorporation of aforementioned information is an essential factor in SHA by whatever approach and may help in improving the performance of the SHA maps, since the use of historical earthquake records alone may not yield a hazard map of appropriate performance. Badawy (1998) has mentioned that before the 1960s the earthquake location accuracy is not adequate for the analysis. The catalog used in this study is too short and insufficient to reliably estimate the seismic hazard, mainly when the assessment is carried out using PSHA methods, which strongly depend on the amount of data available (35 years of seismological observations are useless in the hazard estimation because of the undue extrapolation to large earthquake occurrence rate). Also, some of the existing studies do not communicate the characteristics of the earthquake catalog being used (e.g., Sabry et al. 2001).

The second important factor is the ground motion prediction equation (GMPE) in the case of PSHA or DSHA and the lithosphere structure in the case of scenario based approaches. In fact, most of the GMPEs used in the calculation of ground motion parameters for Egypt have been developed for other regions that differ, for instance, in the tectonic setting and crustal structure, thus they can be called as imported GMPEs. The reason behind the adoption of imported GMPEs is insufficient strong motion database, which is not sufficient to construct an empirical relationship for Egypt or to explore and evaluate the suitable GMPE (Hassan et al. 2017a, b).

Moreover, the critical review of the seismic hazard maps for the country by Hassan et al. (2017a) has revealed that there is no a clear and proper communication for the characteristics of the GMPEs being used and sometimes is difficult to figure out how those studies have defined a rock site regarding shear velocity. Abdel-Fattah (2005) for example, gives the priority to the results based upon the imported GMPE of Atkinson and Boore (1995, 1997) because, from his point of view, there is a proper consistency between the local and regional seismicity and tectonics of the region (i.e., North America), for which the Atkinson and Boore (1995, 1997) GMPE was estimated, and the local and regional seismicity and tectonics of Egypt. Moreover, the inclusion of various GMPEs for hazard estimation for Egypt has been done in some studies without particular caution for the possible incompatibility between different equations.

Most of the estimated ground motion maps for Egypt are not validated against the available observation or the macroseismic data. Also, the uncertainties associated with the computation of ground motion parameters are neither sufficiently assessed nor presented to the different potential users. The PGA values estimated using the NDSHA approach represent the upper boundary for the different seismic hazard maps in the different regions in Egypt; thus, they turn out to be conservative and physically reliable. Also, there is no significant change in PGA values from El-Sayed et al. (2001), Mourabit et al. (2014), and Hassan et al (2017b) this may be due to the fact that, NDSHA needs only earthquake catalogs with $M \geq 5$ (during the period from 2001 to 2014 occurred just a few events of moderate magnitude). It is worth to mention that, the computation of NDSHA maps available for Egypt is carried out using the earthquake catalog and no information about the control faults or MZ has been used, so far. Although, the fact that the earthquake catalogs for Egypt used in Mourabit et al. (2014), which is an NDSHA based study, and Mohamed et al. (2012) "PSHA studies" are almost the same, the predicted ground motion values obtained from NDSHA are more significant and comparable with the observed intensities.

Base on the reasons mentioned above, it is essential to resort to a more reliable solution for modeling the generation and propagation of seismic waves (e.g., the structural models and related computation of realistic broadband signals as done with scenario based approaches (e.g. Neo-Deterministic Seismic Hazard Analysis approach NDSHA). In fact, the regional structural models are an important input in SHA computation based on NDSHA and have a profound effect on the resultant ground motion maps, although, all of the existing models for Egypt are too simple, and the revision of the crustal models is needed taking into account all the crustal studies available for different regions of the Egyptian territory, and eventually, to plan new comprehensive studies over a regular grid where crucially necessary.

In spite of, the poor performances and fundamental shortcomings of existing PSHA studies available for Egypt, the seismic design strategy as well as the building code and its update still rely upon the maps from those studies. In order to overcome the limits of design procedures based upon PSHA seismic input (Fasan et al. 2015; Rugarli 2014), it is necessary to resort to a new seismic design strategy based upon the NDSHA definition of the seismic input in Egypt.

3 Methodology

Multi-Scenario Seismic Hazard Assessment approach is best suited to compute the ground motion parameters at 1 and 10 Hz cut-off frequencies for a set of 1D structural models and multi-earthquake scenarios at different spatial scales.

In the framework of default procedure (Fig. 2), the study region is covered by a regular grid (usually $0.2^\circ \times 0.2^\circ$). The earthquake sources are centered in the grid cells that fall within the adopted seismogenic zones, while the computation sites are placed at the nodes of a grid that is staggered by 0.1° with respect to the sources' grid. For a site-specific analysis, the computation can be preformed for selected observation points instead of the default grid as shown for the study site. A smoothing procedure for the definition of earthquakes location and magnitude, M , is then applied to account for spatial uncertainty and for source extension. After smoothing only the cells (earthquake sources) located within the seismogenic zones are retained. The smoothing process makes Multi-Scenario Seismic Hazard Assessment approach robust and prevents it from the possible uncertainties in the earthquake catalog, which is not required to be complete for $M < 5$. A double-couple point source is placed at the centre of each cell, with a representative focal mechanism which is consistent with the present-day dominant tectonic regime of the corresponding seismogenic zone. Source depth is taken into consideration as a function of magnitude.

The standard method used in Multi-Scenario Seismic Hazard Assessment is the modal summation technique (MS) that is very fast and provide an accurate simulation of ground motion in far source condition. It can be applied only when epicentral distance is greater than focal depth. So, MS is not appropriate for hazard scenario in near source and near field condition. To overcome this limit the discrete wave number technique (DWN) is used where it is numerically accurate over wide range of frequencies and distances but it is more time consuming than MS. In the near field, the discrete wavenumber (DWN) technique is used (Pavlov 2009), while for epicentral distances larger than the hypocentral depth the modal summation technique is adopted. The DWN in the implementation of Pavlov (2009) gives the full wave field, including all body waves and near field effects.

The structural model of interest is composed by a sequence of homogeneous layers. This allows the separation of the equation of motion into two independent problems that can be solved exactly: the propagation of SH (Love) waves, which have particle motion in the y -direction, and the propagation of P-SV (Rayleigh) waves, with particle motion in the xz plane. The waves are decomposed into either those propagating upward and downward in some layers, or into horizontally propagating waves, which either decay or grow exponentially with depth in the other layers. In the half-space that terminates the structural model at depth, horizontal propagation describes the wave motion and

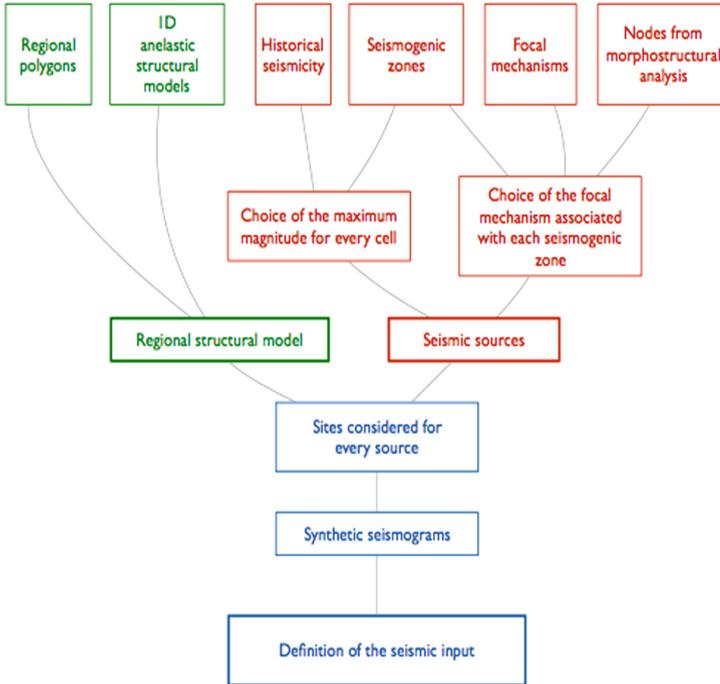


Fig. 2. Flow chart of the different steps in the Multi-Scenario Seismic Hazard Assessment approach for the regional scale analysis

the coefficient of the exponentially increasing wave must vanish. The problem is then reduced to fulfilling all boundary conditions at the interfaces which separate the layers. This leads to an eigenvalue problem in which the eigenvalues (phase velocities) and eigenfunctions (displacement-depth and stress-depth functions) are to be determined.

The seismic source is introduced by using the Ben-Menhaem and Harkrider (1964) formalism. In these expressions, the first-term approximation to cylindrical Hankel functions is used which gives the displacements in the far field. Calculation of synthetic seismograms is then accurate to at least three significant figures, as long as the distance to the source is greater than the wavelength. The seismograms computed in this way contain all the body waves whose phase velocities are smaller than the S-wave velocity of the half-space that terminates the structural model. Starting from the available knowledge about Earth's structure through which seismic waves propagate, seismic sources and seismicity of the study area, it is possible to realistically compute the synthetic seismograms from which one can quantify peak values of acceleration (PGA), velocity (PGV) and displacement (PGD) or any other ground motion parameter relevant to seismic engineering, e.g. response spectra.

4 Input Data for Hazard Computation

In order to perform seismic hazard assessment for the country and for the synthetic seismogram computation, one has to properly model the characteristics of the source generating the seismic energy, and of the structural model through which the seismic wave field propagates.

Earthquake Catalogue

Egypt is well defined as a country of moderate seismicity in a relative sense, although it has experienced strong earthquake impacts along history from regional (e.g. Hellenic arc; Dead Sea fault system) and local (e.g. Gulf of Suez; Dahshur) active earthquake sources even of moderate size (Fig. 3). The high earthquake impacts that happened due the occurrence of moderate size earthquakes can be attributed to a combination of several factors i.e. the proximity of seismic sources to urbanized areas; to the effects of unconsolidated water-saturated soils on the propagating seismic waves over which the cities were built (i.e. horizontal polarization and liquefaction potentialities), the inappropriate engineering design and construction practice of buildings that make the buildings too vulnerable to seismic loads of even modest level. Therefore, the proper inspection of the seismic action and the geotechnical properties of the sediments on which a project will be established are indispensable.

Egypt has a relatively long historical seismic record which goes back about four millennia with variable levels of reliability and detail. The historical seismicity of Egypt has been studied by several authors (e.g., Maamoun et al. 1984; Ambraseys 2009) and the last revised version of the historical catalog was introduced by NRIAG in (2010).

Upgrading a uniform and as much as can completed seismic catalog is an essential step in the seismic hazard analysis. Here, an updated historical and instrumental catalog for earthquakes in and around Egypt (far and near-source) with $M \geq 5$ compiled from different sources covering the period from 2000 BC till 2020 is used. Usually, strong motion from earthquakes with $M \geq 5$ is of much engineering interest due to the possible earthquake impacts (Panza and Suhadolc 1987).

The earthquake catalog that will be used for the computation of the ground motion requires the availability, as complete as possible, only for earthquakes with $M5+$. Earthquake catalog for Egypt is updated taking into account the available historical or instrumental earthquake catalogs from national (e.g. Abu El-Nader 2010; Abou Elenean 2009; National Research Institute of Astronomy and Geophysics (NRIAG)) and international sources (e.g. European Mediterranean Seismological Center (EMSC) <http://www.emsc-csem.org/>; International Seismological Center (ISC) bulletins http://www.isc.ac.uk/isc_bulletin/search/). All these information were used to compile a uniform and, as much as possible, complete earthquake catalog. The pre-instrumental earthquake catalog is taken from the revised and quality controlled catalog of NRIAG (2010).

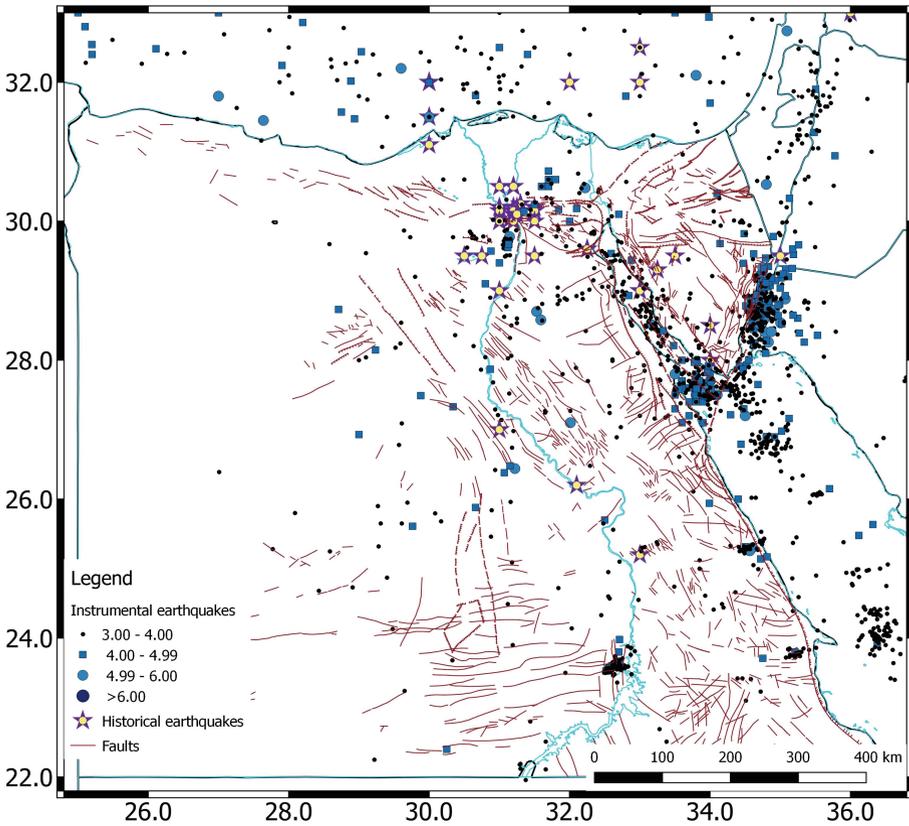


Fig. 3. Historical and instrumental seismicity (from 2000 BC till 2020) and main tectonic features of the study region.

Seismotectonic Model

The principle for seismic source zones is that they represent enclosed areas within which a uniform seismicity distribution and maximum magnitude are expected. Background sources have been avoided in the sense that all areas have been covered by seismic sources, even very low seismicity areas. The principles along which seismic source zones in the current model have been constructed are based on information from geological structures on different scales, tectonics and seismicity.

The upgrade of the seismotectonic model of Egypt was motivated due to newly released information, and it will be subject to future modification when new data are available. Figure 4 shows the seismogenic zones that have been delineated for Egypt using all the available information from different disciplines to be used in the ground motion computation. Most of the defined zones are bounded along well known and clearly defined active trends and faults, while few of them cover the areas that exhibit sporadic seismic activity. The seismotectonic zones, which are marked by strong earthquake $M5+$, are identified in this work. This condition could guarantee reliable identification of seismogenic zones not influenced by non-tectonic events (e.g., quarry blasts)

which are common in many areas in Egypt. We use magnitude between 3 and 5 to define the zones borders reliably. Then, for areas that did not show earthquake M5+ , we have used pattern recognition analysis for the identification of seismogenic nodes (earthquake prone sites), which represents a complementary step. A responsible seismic hazard assessment requires the incorporation of both results (i.e., defined seismogenic zones and nodes).

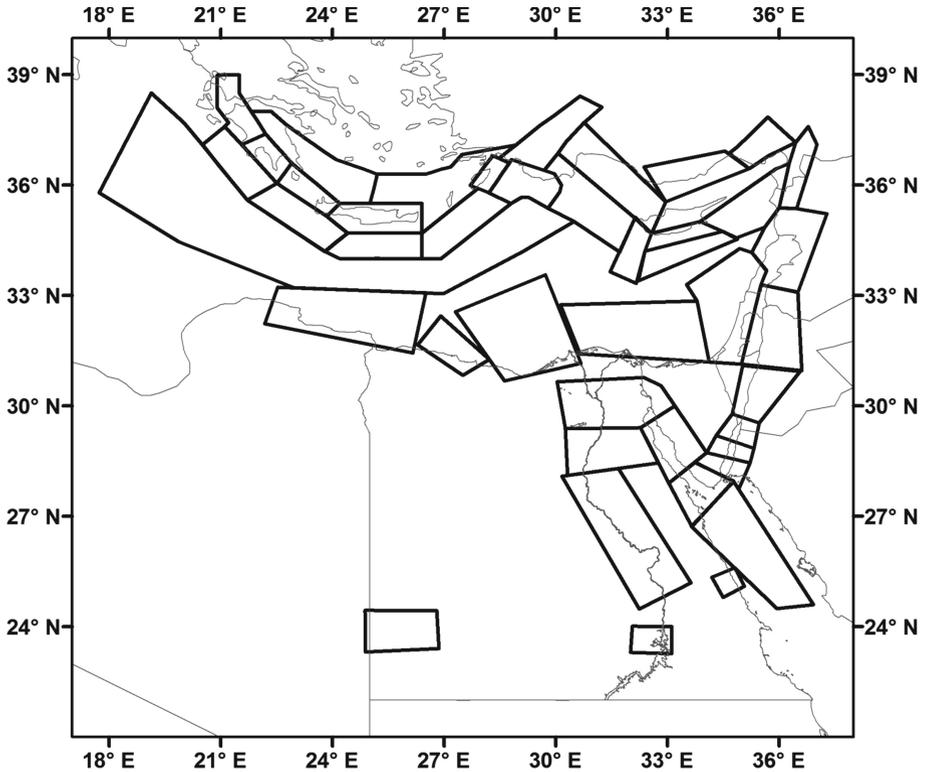


Fig. 4. An updated seismotectonic zones model for the seismic hazard computation at the Ionic Tower site.

A responsible seismic hazard assessment requires the incorporation of both results (i.e., defined seismogenic zones and nodes). Figure 5 displays the delineated nodes developed by Gorshkov et al. (2019), which we are going to be used in hazard computation. We expect that the incorporation of seismogenic nodes information in seismic hazard computation with the seismogenic zones will improve performance of the resulting maps for the studied region, especially for the sites of rare or no seismic activity so far.

Seismic sources are placed in the center of every $0.2^\circ \times 0.2^\circ$ cell that falls within seismogenic zones and seismogenic nodes. The magnitude associated with each source is obtained after a smoothing algorithm (Panza et al. 2001) is applied to the image of seismicity. The smoothing process makes Multi-scenario based seismic hazard approach

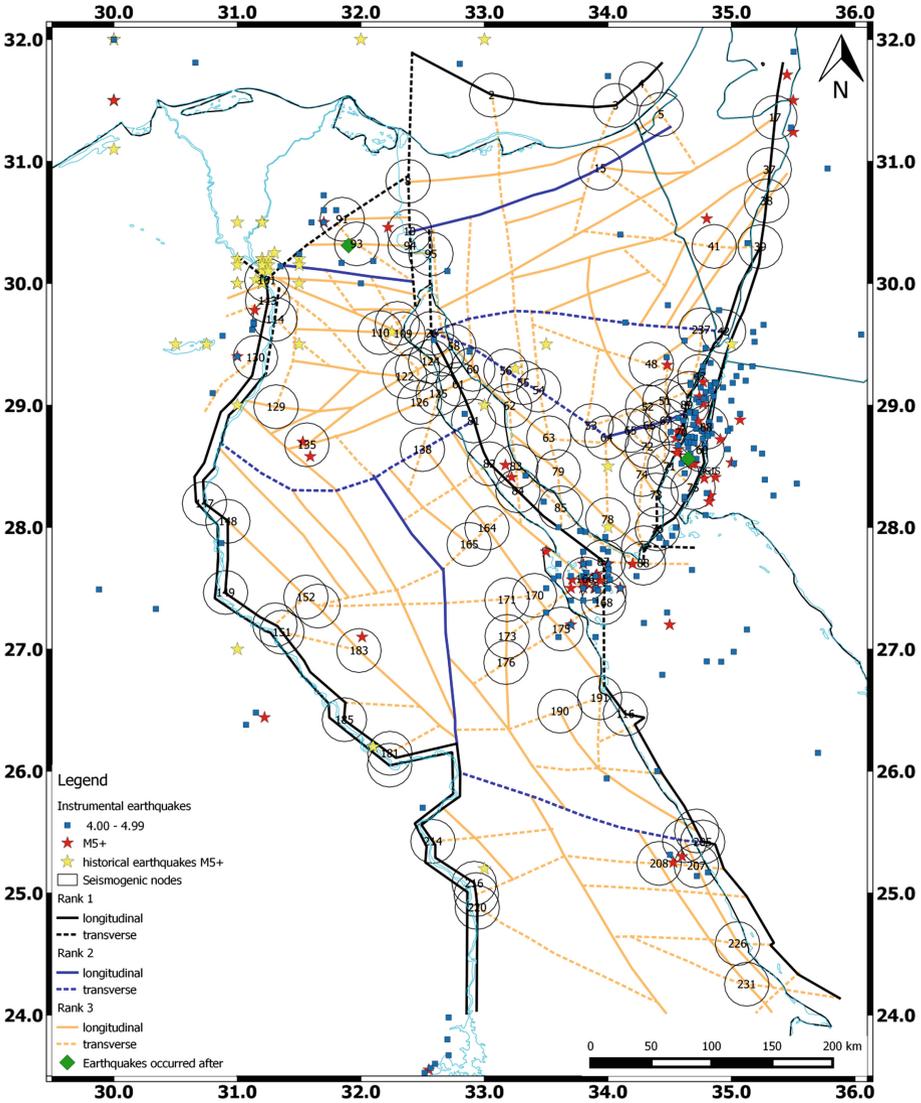


Fig. 5. Seismogenic nodes delineated for eastern side of the country by Gorshkov et al. (2019).

robust and prevents the possible uncertainties in the earthquake catalogue, which is not required to be complete for $M < 5$. This aspect is relevant for the studied area, given that the rather poor completeness of the earthquake catalogue at ($M < 5$). It also accounts for spatial uncertainties and for source finiteness.

A double-couple point source is placed at the center of each cell, with a representative focal mechanism which is consistent with the present-day dominant tectonic regime of the corresponding seismogenic zone. Source depth is taken into consideration as a function of magnitude (Fig. 6).

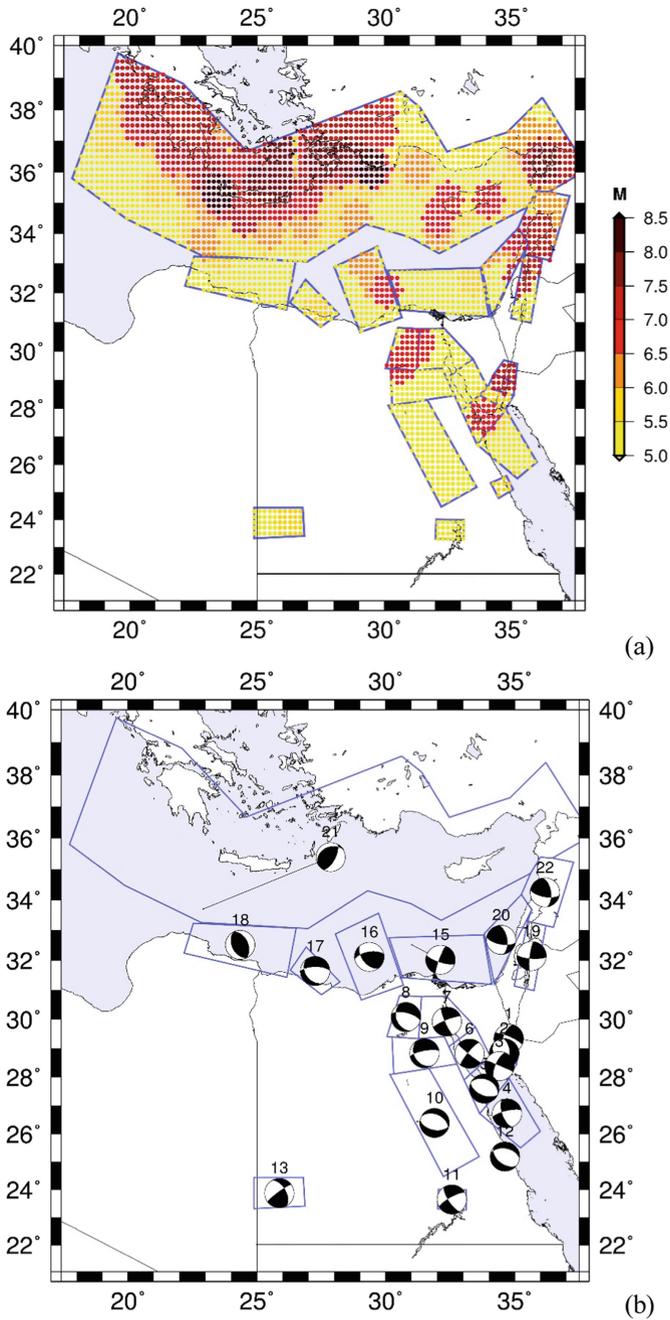


Fig. 6. a) Smoothed magnitude within the seismogenic zones developed in this computation; b) Updated seismotectonic zones and representative focal mechanisms for Egypt; d) Thickness and V_S for the uppermost layer of the updated structural model used in Variant 2.

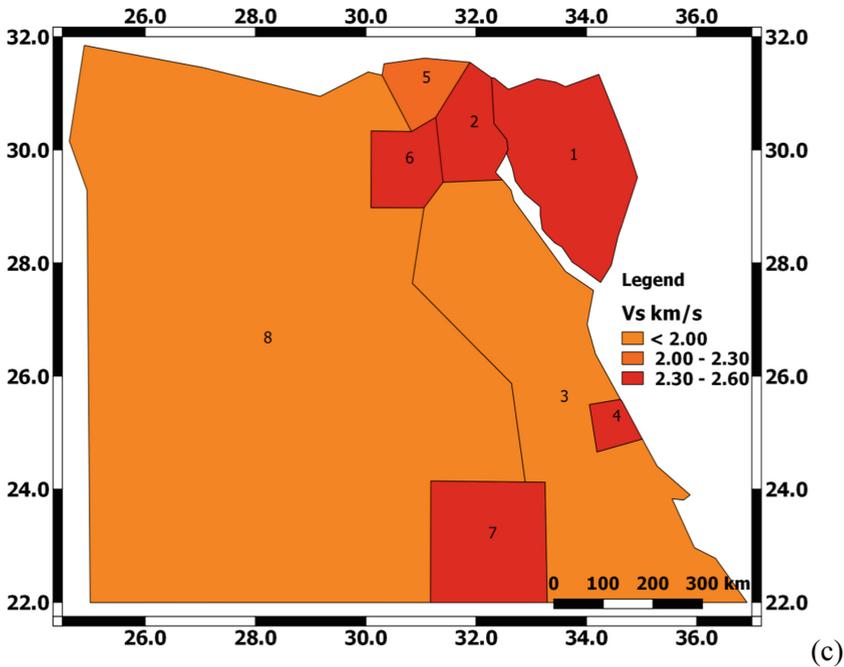


Fig. 6. (continued)

Synthetic seismograms are computed in the time and size scaled point-source approximation, using a double-couple of forces placed at the hypocenter. Besides the hypocentral depth and the magnitude, the properties of the source considered are strike, dip and rake. Depending on the above angles, we have different radiation patterns from the source. Directivity effects are also taken into account and the source time functions (STF) are generated according to the methodology proposed by Gusev (2011). Several parameters can be adjusted in generating the Source Time Function STF. We here consider unilateral and bilateral rupturing styles, with backward, neutral and forward directivity with respect to the site position. An example of slip distribution and rupture propagation is shown in Fig. 7.

4.1 Lithospheric Model

Once the source location, mechanism and magnitude have been defined, the Earth's lithosphere characteristics have to be parameterized in order to model wave propagation from each source to the sites of interest. The model is assumed to represent the average properties of the structure between the sources and the sites of interest. The regionalization applied in the area is shown in Fig. 8.

Focusing on the area where the structure is planned, a crustal model has been defined, according to the specific structural properties of the considered region (Fig. 9). The adopted structure model is modified from the 3-D model of seismic P and S velocities in

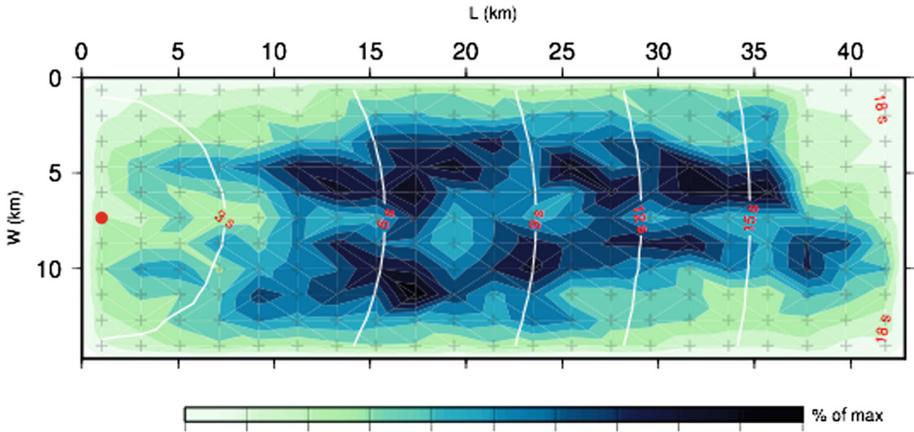


Fig. 7. Slip distribution (green contouring) and rupture velocity (white isochrones) for one realization of the rupturing process of an earthquake with $M = 6.9$, with unilateral rupture style. Red point on the left side of the figure is the nucleation point

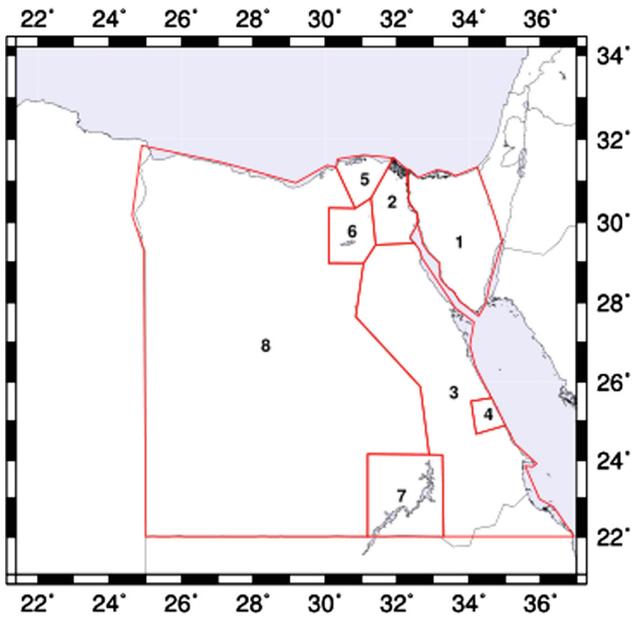


Fig. 8. Regionalization of the crustal properties of Egypt.

the crust and uppermost mantle based on the results of active seismic refraction, which is accomplished by Hassan et al. (2017b).

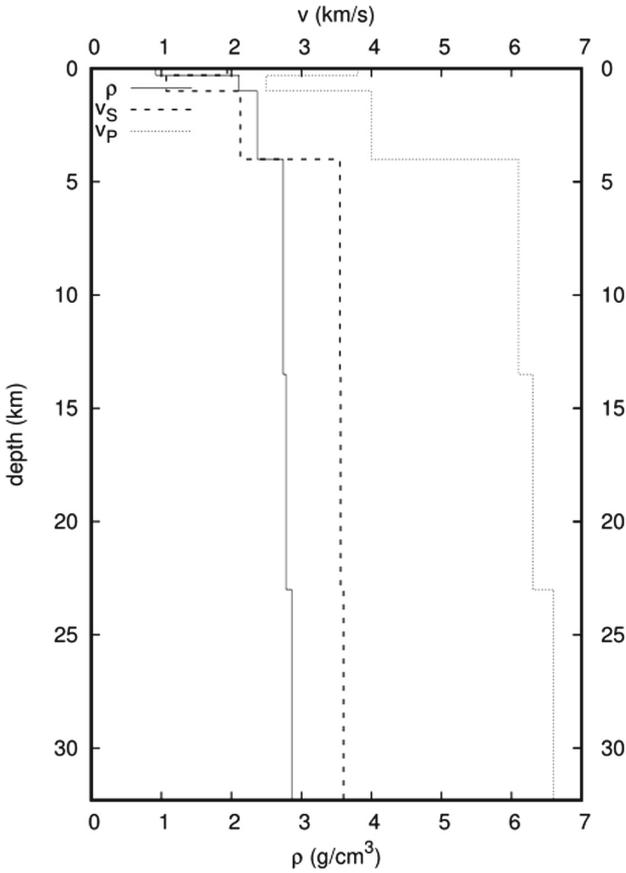


Fig. 9. Layered model associated with polygon n.2 of Fig. 8.

5 Result and Conclusion

In the framework of Multi-Scenario Seismic Hazard Assessment procedure, the study region is covered by a regular grid of sites ($0.2^\circ \times 0.2^\circ$). According to the up mentioned procedures and inputs, a huge set of synthetic seismograms is calculated at each grid point all over Egypt bringing at each grid point displacement, velocity and acceleration for every seismic source that may affect that area taking into account all possible uncertainties into the modelling process generating at the end a massive dataset which we processed to generate maps of peak displacement, velocity and acceleration are produced for the whole region of interest (Fig. 10a, b, c).

The ground motion parameters have been computed for the vertical and horizontal components then the maximum value at each site is extracted and plotted as a map of peak ground motion. The PGD, PGV and DGA value at each site are computed and mapped as shown in Fig. 10a, b, c. and present the computed ground motion

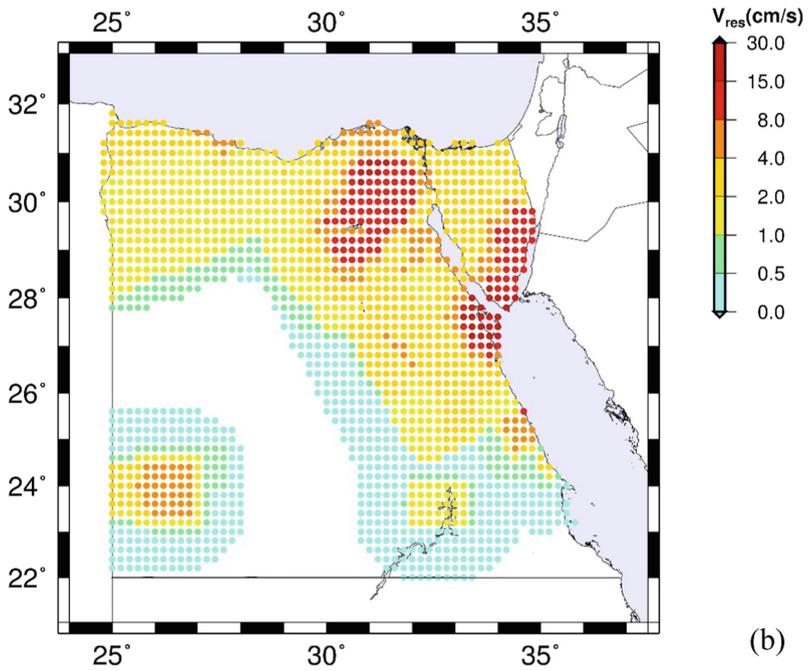
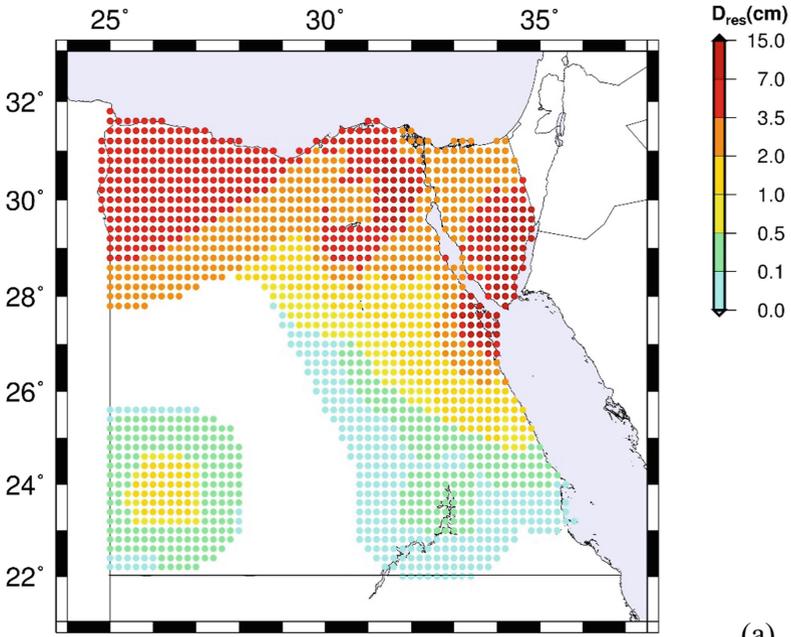


Fig. 10. Peak displacement (a), velocity (b) and acceleration (c) maps for Egypt, for a single realization of the rupturing process at the source

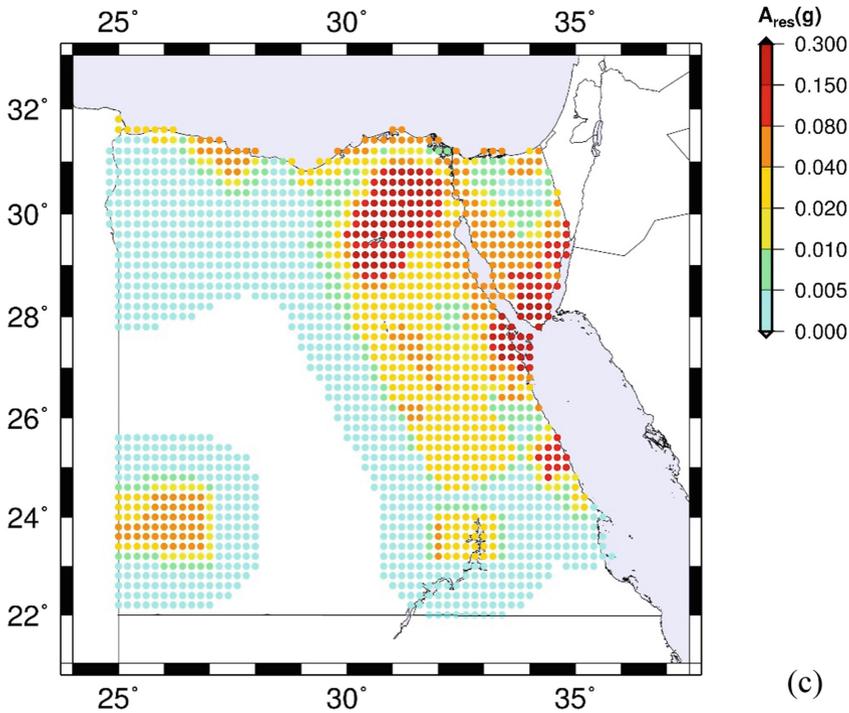


Fig. 10. (continued)

For each dot mapped in Fig. 7, the time series computed at bedrock are available and ready to be used as seismic input for the design of seismo-resistant structures or further geotechnical investigations of site response. The map of extracted peak ground motion values shows relatively high earthquake hazard along the Gulf of Aqaba, entrance of the Gulf Suez of Suez, and area around Cairo. These maps can be used directly to pick up the ground motion values instead of smoothed seismic Zonation map.

A designed response spectrum defines the normalized elastic response spectrum of the ground motion for different rock/soil types (i.e., A, B, C and D; they are assigned based on shear-wave velocity), considering a certain percentage of damping can be employed in all the executions to compute the ground motion acceleration at higher frequencies, which is defined for 5% critical damping in future work.

In the updated version of ground motion maps for Egypt, we have revised and updated all input data relative to the reference variant, i.e., earthquake catalog, seismotectonic zones with their representative focal mechanisms and structural models. The release of a new data and data quality control studies, which have been carried out during the last decade has motivated the following updates:

- A single map cannot supply useful enough answers to all the problems posed by adequate seismic risk assessment. The NDSHA approach provides a big database of synthetic seismograms for each configuration, particularly crucial for the regions that

suffer from endemic lack of strong motion time histories. The synthetic seismograms is computed with a cut-off frequency as large as 10 Hz for a set of laterally non-varying structural models, where the fault finiteness is duly taken into account by size and time scaled point source (STSPS) model (Parvez et al. 2011), computed with PULSYN06 algorithm (Gusev 2011, Magrin et al. 2016) that provides a broadband kinematic source model.

- Seismic hazard maps should have thorough evaluation of input for hazard computation, methods, and results and the associated uncertainty and validated before they are being accepted then adopted by the code.
- The results obtained represent a database toward detailed and comprehensive ground motion modeling in Egypt.
- An updated building code in order to present and future accommodate theoretical, methodological and application advances in Engineering, Seismology, and Geotechnical aspects of the code is indispensable.

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