USING GIS IN ESTIMATING SEIMIC HAZARD STATISTICS IN CRETE ISLAND, SOUTHERN GREECE

Dimitrakis Vasileios, Tsouchlaraki Androniki

Department of Environmental Engineering, Technical University of Crete
Technical University of Crete; Kounoupidiana 73100; Chania; Crete; Greece

vasileiosdimitrakis@gmail.com
niki.tsouchlaraki@enveng.tuc.gr

Abstract
Nowadays, Several seismic safety regulations across the globe, such as IBC, NEHRP, EC-8 etc. has adopted seismic hazard as basic parameter for engineering design of buildings and other structures. Hence, a reliable seismic hazard assessment is imperative towards an effective anti-seismic policy. In this study a probabilistic approach is followed, that intends to estimate seismic hazard in a GIS environment for the area of interest that is Crete Island. The key in this effort is to attain the experienced PGA, over a control period, for the entire region in question, utilizing seismic data that derive from a respective homogenous earthquake catalogue. In this effort, various geospatial analysis tools are put to use, in order to project the aforementioned calculations and to apply the necessary statistical analysis. The outcome is then presented in thematic maps and further more is set against the Greek seismic Code provisions.

Keywords: *Seismic Hazard, PGA, Geo-spatial Analysis, GIS, Data Mining*

INTRODUCTION

Southern Greece is located on the convergent boundaries of the Eurasian and African tectonic plates, which form a subduction zone of grave seismic activity, where many destructive earthquakes have taken place over the centuries (Becker & Meier 2010). The island of Crete constitutes the central section of the subduction margin, where converge rate reaches up to ca. 40 mm/yr (Reilinger et al. 2010). Seismicity in Crete is closely connected to the subduction geodynamics and characterized by earthquake events of shallow and intermediate depths (Hollenstein et al. 2008) showing historically maximum magnitudes up to 7.0 (Papazachos & Papazachou 1997; Papanastassiou et al. 2001; Kiratzi & Louvari 2003; Meier et al. 2004).

As such, the region of Crete is widely considered as an area that poses great seismic threat to the built environment. This threat is commonly described in terms of seismic hazard and/or seismic risk, although their exact definition includes some controversial understanding issues within the scientific community (Wang 2006). Seismic hazard has been adopted by many seismic safety regulations across the globe, such as IBC, NEHRP, EC-8 for engineering purposes of buildings and structures and the method that has been widely used to assess seismic hazard is Probabilistic Seismic Hazard Analysis (PSHA) that was firstly introduced by Cornell (1968). In general, it is considered that seismic hazard describes the potential of ground motion occurring, due to earthquake activity in a certain area, over a given time-period. The intensity of this ground motion is most commonly presented by Peak Ground Acceleration (PGA) that can be derived from various empirical attenuation relationships. For the region of Greece alone, several attenuation relationships have been proposed, the most recent of which include Margaris et al. (2002), Skarlatoudis et al. (2003) and Danciu & Tselentis (2007).

In this framework, the above approach of seismic hazard is followed, as it is consistent with the Greek Seismic Code (GSC) that constitutes the current seismic safety regulation for buildings in Greece. According to GSC provisions there are three seismic hazard zones in Greece, each representing the potential seismic related ground motion expected, in terms of PGA (I:0.16g, II:0.24g and III:0.36g). The entire region of Crete falls into zone II of “0.24g”, which reflects to 10% probability that PGA will exceed at least once the value of 0.24g (g=gravitational acceleration) over the next 50 years. This practically means that a seismic event of at least 0,24g in PGA has an average return period of 500 years in the area. A seismic hazard is thus imposed to the entire area of interest (AOI) that lacks geographical orientation and so it is implied that the whole region of Crete is expected to present the same seismic behavior regarding the ground vibration and its potential consequences.

However, it has been concluded by Dimitrakis & Tsouchlaraki (2014) that for the western part of Crete in the last century seismic activity is much differentiated among the individual parts of the area. In specific, areas located south and west are of very high seismic activity, where as those located north and centrally are of quite low seismic activity. This fact could suggest that there is an expected deviation in the potential consequences of seismic activity along the areas, that is to be estimated by assessing the associated seismic hazard.

Following this assumption it is intended to estimate the actual seismic hazard expected in the region of Crete by utilizing a vast number of occurred earthquake events followed by a probabilistic analysis. This is achieved in a GIS environment, which offers tremendous advantages, not only in mapping simple geographic distribution of information, but mainly in processing and comparative combination of a multitude of thematic data. The followed methodology and the respective results are presented in the sections below. Thematic maps are provided accordingly using ESRI's GIS software ArcGis 10.1 and at the end conclusions are reached. It is advised that the reader bear a basic GIS knowledge, in order to fully understand the process of spatial analysis presented in this paper.

As regards effective anti-seismic protection, it is essential that seismic hazard assessment be reliable and up to the contemporary needs of society, in order to mitigate any potential consequences of an earthquake of great magnitude occurring in the area. It is important that the established seismic safety regulations incorporate the current scientific knowledge and approach to the matter in conjunction with the available technological advancements and tools of analysis. It is worth mentioning that this venture is a part of a larger project that is aiming to shed further light in the seismic activity of the above region and its associated aspects in the natural and built environment.

METHODOLOGY

GIS Data

The AOI as mentioned above is the region of Crete and it is presented in figure 1. In addition, an extended version of this area (approximately 100 km around Crete' shoreline) has been formed in order to encompass earthquakes of great magnitude that occurred in a long distance away of Crete. The extended AOI is set to provide a preliminary four level decrease in the macroseismic intensity scale, in accordance with the attenuation effect equation (1) provided by Papazachos (2005) for the Greek region:

$$I_0 - I_i = -5.36 + 4.5 * \log(R_i + 17) \quad (1)$$

Where, I_0 is the epicentral intensity and I_i and R_i the intensity and epicentral distance in point "i" respectively.

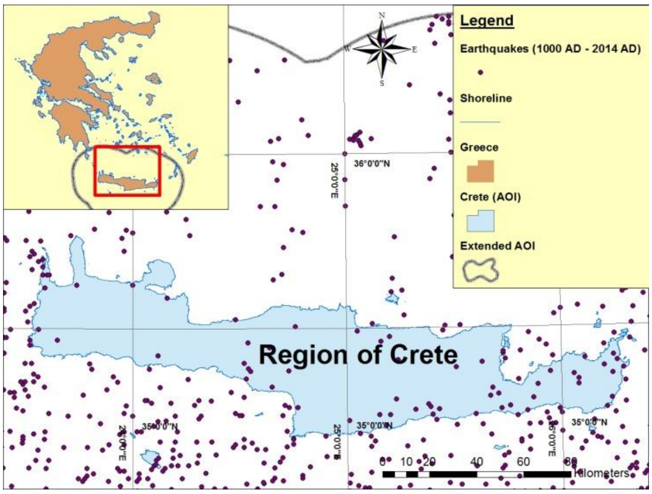

Figure 1. Area of Interest (AOI) and extended AOI

Regarding the earthquake events, the main concern was the homogeneity of the data and the time span coverage in order for the subsequent statistical analysis to be reliable and valid. Taking that into account, it was deemed that the selected earthquake data can yield sufficient results on the characteristics under investigation. Thus, the earthquake data used in this study consists of the following individual catalogues:

- The SHARE European Earthquake Catalogue (SHEEC) 1000-1899 (Stucchi et al. 2012) that has been compiled in the frame of the EC project SHARE (Seismic Hazard Harmonization in Europe).
- The catalogue of Makropoulos et al. (2012) that covers the time period from 1900 to 2009 and is provided by the Institute of Geodynamics (IG) of the National Observatory of Athens (NOA) in collaboration with the national and Kapodistrian University of Athens (UOA).
- The seismic events from 2010 to 2014 that were derived from the IG - NOA moment tensors database available online (Institute of Geodynamics /Seismicity: Moment Tensors, Catalogues and Database).

The aforementioned catalogues record among other things date, coordinates, moment magnitude (Mw) and depth in km, while the combined time period of the whole dataset is referred to roughly one millennium. The catalogues were converted initially to ".dbf files" and then to shapefiles by the "display xy" data tool. Afterwards, they were merged and cut to fit the aforementioned extended AOI. The final dataset comprises of more than 1500 recordings that include major earthquakes of moment magnitude Mw > 4.

Apart from the earthquake events, another essential data towards PGA estimation is the site classification or soil conditions. Site classification measures the seismic site response and this is achieved by estimating the average shear velocity down to 30m or V_s^{30}. Allen and Wald (2007; 2009) suggest using V_s^{30} measurements, which is conducted via Shuttle Radar Topography Mission (SRTM) 30 arcsec DEM, as an alternative in case of absence of data for the exact geological and geotechnical composition of the soil. V_s^{30} is provided by the U.S. Geological Survey (USGS) web page in ASCII, JPG, GMT format and for any given location. For the purposes of this study, an ASCII (American Standard Code for Information Interchange) file was obtained for the AOI that was converted to Raster with resolution 50x50 m^2 and therefore utilized in the analysis. It is worth noting that V_s^{30} for the AOI varies from 760 m/s to 180m/s meaning that AOI consists of sites with very dense soil - soft rock (type C) and stiff soil profile (type D), according to the National Earthquake Hazards Reduction Program (NEHRP) classification provisions.

Needless to mention that all the above data and associated features were projected to Greek Geodetic Reference System 1987 (GGRS87 – Greek Grid), as it offers better accuracy for the Greek region and it is used by all GIS users in Greece.

Attenuation Relation

In order to take into account the attenuation effect for every seismic event that occurred within the extended AOI, a suitable empirical peak ground motion predictive relation should be used. As mentioned above, many such relations are documented for the Greek region that can provide PGA estimates in space. In this study the empirical attenuation relation of Skarlatoudis et al. (2003) was selected, which for shallow earthquakes is formed as follows:

$$\log PGA = 1.07 + 0.45Mw - 1.35\log(R+6) + 0.09F + 0.06S \qquad (2)$$

Where, PGA is in cm/s^2, Mw is the Moment magnitude, R is the epicentral distance in km, F is referring to the effect of the faulting mechanism and S is the variable accounting for the local site conditions (site classification).

In the above equation the effective depth (6 km) assumption is adopted as in the case of Margaris et al. (2002). For intermediate to deep earthquakes, an alternative version of the above equation is used that incorporates also the parameter of the focal depth of the seismic event.

The S variable in the above equation follows the NEHRP site classification and so for category C and D it takes the value of 1 and 2 respectively. As regards the faulting mechanism variable, it is well documented (Caputo et al. 2010; Mountrakis et al. 2013) that normal faulting is dominating in the AOI and adjacent areas. That can also be supported by the European Database for Seismogenic Faults or EDSF (Basili et al. 2013), which is provided by the Instituto Nazioale di Geofisicae Vulcanologia (INGV), where all the major active faults within or in the vicinity of the extended AOI are of normal faulting nature. Therefore, according to Skarlatoudis et al. (2003) the variable F was set to 0.

Geospatial Analysis

The geospatial analysis performed in this study consists of following certain steps to acquire the objective calculations and in the same time maintain flexibility for any further desirable research. For this reason the AOI is standardised to a specific set of cells using as baseline the site classification data. All the subsequent rasters that are produced throughout the analysis are snapped to this baseline. By this procedure the outcome of the analysis is geographically standardised, cell based and subject to further enrichment of additional relevant data.

With all the seismic data, as well as the site classification, available, the attenuation relation is put to use and PGA is calculated for every single earthquake event in the catalogue and for every single cell that belongs to the AOI. To achieve this, appropriate "selection" combined with "Euclidean distance" tool and "raster calculator" is applied accordingly. Over 5000 rasters are produced that practically constitute the basis of the subsequent statistical process.

Following the probabilistic approach of the Poison distribution, as described in Wang (2006; 2008; 2010) and Love (2012), the probability (probability of exceedance – PE), that a specific phenomena with an average recurrence interval T (in years) will exceed a certain value / magnitude at least on time in the next t years (exposure time), is given by the following equation:

$$PE = 1 - e^{-\frac{t}{T}} \qquad (3)$$

Under the Poisson approach, it is assumed that all the events are independent, which is also adopted in the present study. The PE of the above equation represents practically, by definition, the seismic hazard of a given area due to seismic activity in the broader region.

Taking all the above into consideration, it is examined in a cell by cell basis whether the experienced PGA has exceeded a certain threshold value and if so how many times in the time period of the analysis. In doing so, the "greater than frequency" tool and "cell statistics" are used appropriately. After the frequency for the set threshold (e.g. PGA: 0.24g) is acquired over the time period in question, the next step is to estimate the average recurrence interval T that will then lead to the calculation of the PE for every single cell of the AOI, applying equation (3) in raster calculator, for the desired threshold and exposure time. The data is processed mainly in raster format, where in some cases and due to presentation requirements the rasters are converted to feature class files accordingly.

The threshold values for PGA are set initially to meet the corresponding provisions of the GSC seismic hazard zones (0.16g, 0.24g, 0.36g). In addition, three more values were added 0.025g, 0.045g and 0.093g that correspond to lower ground vibration in the Modified Mercalli Intensity (MMI) scale (IV, V, VI respectively) in accordance with the work of Tselentis (2008). These threshold values serve as checkpoints indicative of the severity of the potential ground vibration expected in the area.

Furthermore and in order to examine the potential hazard of more recent seismicity, an alternative method to the above is applied. The maximum experienced PGA is estimated in every part of the AOI for every year since 1950. Then, following the same steps, as described above, the frequency of PGA exceeding the threshold values is calculated in every cell for the time period in question. Under the Binomial approach and having in mind that the row of events is fixed in time assuming total independency, it is inferred that the probability (PE) that the maximum PGA will exceed a specific threshold value in the next year is given by the MLE (Maximum Likelihood Estimation) of the Binomial model that is:

$$PE_{MLE} = \frac{y}{N} \qquad (4)$$

Where, y equals the frequency of occurrence and N is the time period in question in years. The calculations are performed in "raster calculator" accordingly. It is believed that this method can be utilized supplementary to the one described above (Poisson) for completeness reasons regarding the more recent and lower in scale events.

All the aforementioned steps in every procedure are conducted within the GIS environment making it simple and easy to project the results, to compare the individual outcomes and to proceed if need be with further study over the whole AOI.

The above procedure describes the basic steps in order to complete the necessary analysis of the available data. It is acknowledged though that the present outcome should be assumed as dynamic, since future earthquake events will most likely produce large scale ground movements that will affect the estimated seismic hazard of the individual areas. This future seismic activity can easily be incorporated in the present results by following the same steps as above in order to apply the respective PGA in the AOI, then populate the existing frequency files and then recalculate the Poisson probabilities.

RESULTS

Upon the selection of threshold value and exposure time, it is evident that the above methodology can lead to various maps depending on the desired goal of the study. Due to obvious limitations, the thematic maps presented in this paper intend to summarize the outcome and support the goals and of the current venture highlighting the capabilities of the used methodology.

According to the seismic hazard zones included in the GSC provisions, it is assumed that the PE for PGA 0.24g is 10% in the entire AOI in the next 50 years. Following the Poisson approach in the manner presented above, the PE is calculated for PGA threshold equal to 0,24g in the next 50 years (exposure time) over the entire AOI and for the recurrence interval estimated in the time period of the available data (1000 - 2014 AD). The results are presented in figure 2, where it is shown that the above PE varies from 0% to 18% as opposed to the fixed 10% provision of the GSC. In addition, the area covered by the individual PE intervals, in relation to the total area of the AOI, is estimated and shown in the relevant chart.

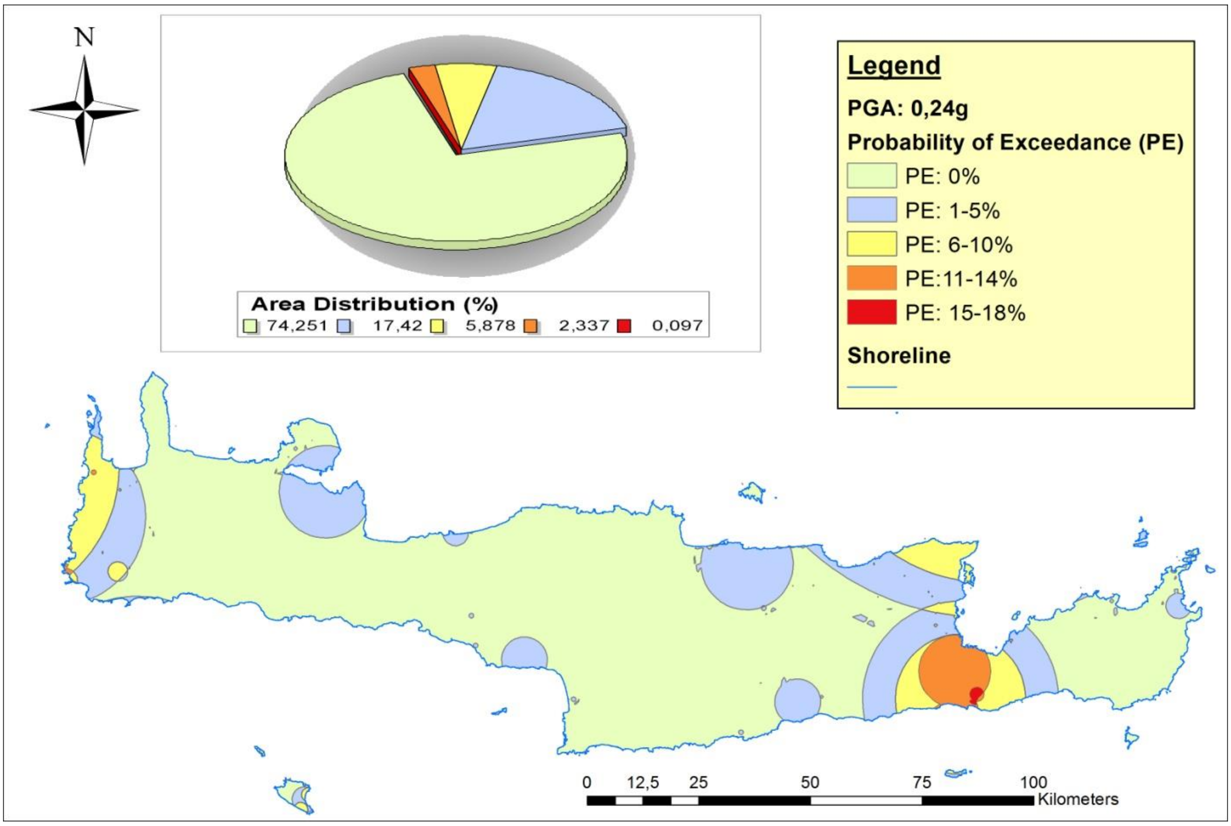

Figure 2. Probability of Exceedance (PE) for PGA value 0.24g in the next 50 years

According to the map above, the majority (about 74%) of the AOI exhibits zero PE for PGA 0,24g, consequence to the fact that these areas have never experienced ground motion due to earthquake activity of up to 0,24g in PGA in last millennium. It is evident that the estimated PE is depending on how many times the PGA value has exceeded the selected threshold for the time period in question. According to the above results, for PE between 1% and 10% the area covered in relation to the whole AOI reaches to percentage of 23,3%, while the respective percentage of areas with PE more than 10% is about 2,4%.

Given this fact, it can be inferred that seismic hazard, as described in the GSC provisions, is overestimated mainly for the majority of the AOI, where on the other hand there are areas where the same provision is underestimated despite the fact that these areas compose a small but important fraction of the whole AOI. Among other things, the estimated area distribution of the PE indicates the profound questions about the validity and reliability of GSC provisions. It is believed though that it can be utilized accordingly in order to adequately render AOI in seismic hazard zones.

Furthermore following the same approach, PE is examined for all the threshold values of PGA mentioned above (seismic hazard zones provisions and lower ground motion) over the same exposure time in relation to the available data for the AOI. The summary of the results regarding the area covered as percentage of the AOI for the individual PE intervals as well as the minimum and maximum PE estimated, with regard to the PGA thresholds, are presented in table 1.

Table 1. PGA thresholds and the respective min, max PE and PE interval's area coverage

PGA	Min PE (%)	Max PE (%)	PE intervals						
			0%	1-5%	6-10%	11-14%	15-18%	19-22%	>22%
			Area coverage as percentage of the AOI (%)						
0,36g	0	13,75	91,01	6,84	1,51	0,61	-	-	-
0,24g	0	17,9	74,23	17,42	5,87	2,33	0,097	-	-
0,16g	0	29,18	41,68	20,71	19,14	10,35	5,6	2,43	0,05
0.093g	0	44,66	1,48	19,01	13,44	13,71	14,69	22,33	15,34
0,045g	17,9	73,58	-	-	-	-	0,01	0,16	99,83
0,025g	52,27	95,06	-	-	-	-	-	-	100

Since GSC is focusing on the 10% PE for the PGA values used in the corresponding seismic hazard zoning, it is considered that 10% in PE denotes the critical point in characterizing the seismic hazard of the area. According to this and in order to give a further spatial aspect to the above results, figure 3 is presented, where for every part of the AOI the maximum PGA threshold value is attributed that is estimated to exceed 10% in PE. This map also depicts the vast difference in the potential ground motion expected along the AOI and it is thought that it is able to form a basis in achieving reliable seismic hazard zoning in the AOI.

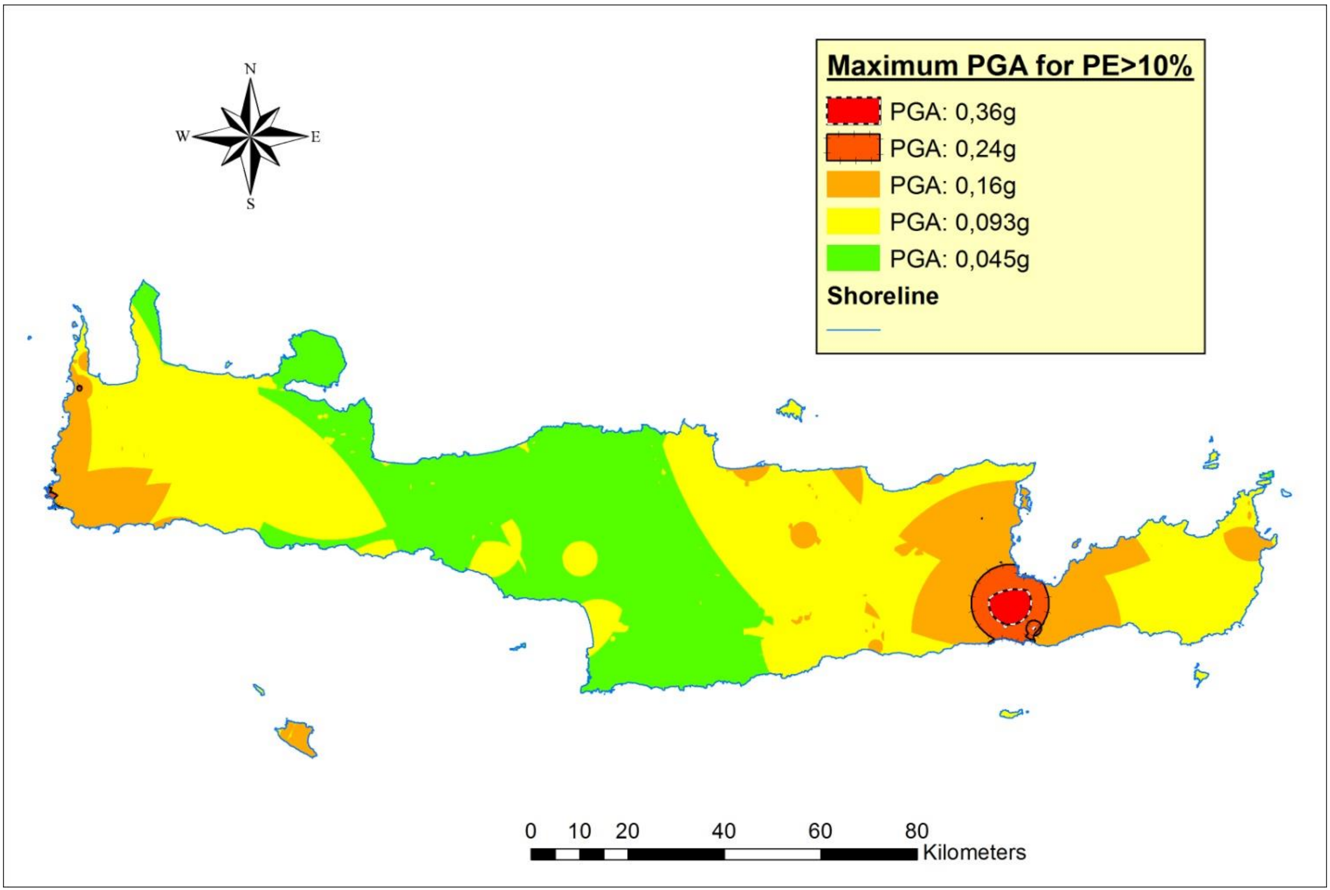

Figure 3. The maximum PGA value estimated to exceed 10% in PE

Apart from the long term analysis presented above, it is also intended to examine the seismic hazard level of the area due to relatively recent seismic activity. Alternate to the Poisson model the Binomial distribution is used estimating the MLE as described above. Due to the framework of the problem and the data applied, it is deemed that this method can equally provide reliable results. In this geospatial process the yearly maximum experienced PGA is estimated due to earthquake occurrence since 1950. From this dataset the respective frequencies are calculated in relation to the times the selected PGA value is exceeded. The MLE is then estimated as described above. The results for the lower scale PGA thresholds are presented in figure 4. The PE estimated is referring to the probability that the selected PGA will be at least once exceeded in the next year.

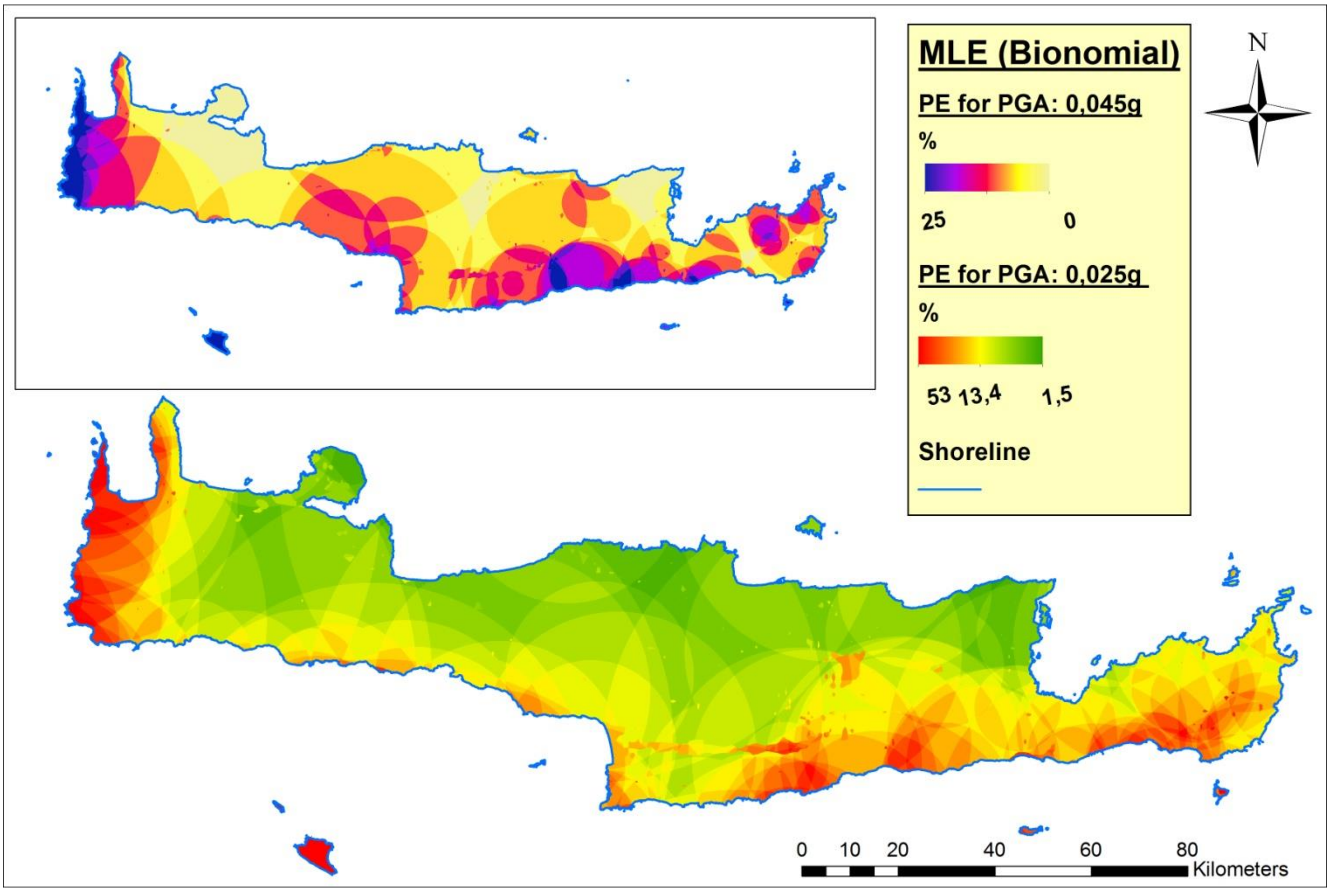

Figure 4. Probability of Exceedance (PE) for PGA using binomial approach in the next year

It is apparent, that the probability of significant ground motion occurring in the west, south and southeast areas of the AOI is much more intense than the one in the northern areas of the island. The outcome is also indicative of the difference of lower seismic hazard level expected in the AOI. These findings can be attributed to the current geophysical dynamics of the fault and crustal system as well to the on-going subduction process in the area. Nevertheless, it is considered that the above results can aid in the effort to extract short term estimates about the potential effects of seismic activity in the region, as well as provide useful data to relevant scopes of research and shed further light to the seismic phenomena at all.

CONCLUSIONS

To this day the engineering design of buildings and structures in Greece, concerning the anti-seismic aspect, relies strongly on the provisions of the GCG and the respective seismic hazard zones, in which Crete is considered a uniform zone of certain seismic hazard level. By this study it is intended not only to show the difference in the seismic hazard expected in the region, but also to realistically estimate the relevant probabilities of seismic hazard in every part of the AOI by using a powerful tool like GIS in analysing the respective seismic data available. In this effort a methodology is provided that can lead to effective results pertaining flexibility in the desired outcome and the capability to adapt to further purposes of the analysis.

The present venture has shown that the seismic behaviour, in terms of PGA, expected in the region is far from identical for the individual areas comprising the AOI. The seismic hazard estimated, in relation to the respective one suggested in the GSC, varies geographically indicating that GSC provision is rather strict in the main part of the region (central and northern areas), whereas in some areas (west and southeast) appears to be relatively conservative.

Furthermore, the area distribution for the individual PE intervals of the selected PGA threshold, can present a competent parameter in order to assert reliable conclusions about the general seismic hazard expected in the area. The current outcome is of course subject to change, as more seismic events and consequently ground vibrations are yet to come in the AOI.

In light of the above, having in mind the need for a reliable anti-seismic policy as well as the economic implications that a strict seismic code can impose to the manufacturing services, it is deemed that the GSC be revised accordingly to cover all the possible aspects of seismic hazard in the AOI. It is within the states responsibilities to assess the relevant data and to take any necessary proactive measures towards an effective anti-seismic framework and appropriate public awareness.

REFERENCES

Allen, T.I. & Wald, D.J., 2009. On the Use of High-Resolution Topographic Data as a Proxy for Seismic Site Conditions (VS30), Bull. Seism. Soc. Am., Vol. 99, No. 2A, 935-943.

Basili, R., Kastelic, V., Demircioglu, M.B., Garcia Moreno, D., Nemser, E.S., Petricca, P., Sboras, S.P., Besana-Ostman, G.M., Cabral, J., Camelbeeck, T., Caputo, R., Danciu, L., Domac, H., Fonseca, J., García-Mayordomo, J., Giardini, D., Glavatovic, B., Gulen, L., Ince, Y., Pavlides, S., Sesetyan, K., Tarabusi, G., Tiberti, M.M., Utkucu, M., Valensise, G., Vanneste, K., Vilanova, S. & Wössner, J., 2013. The European Database of Seismogenic Faults (EDSF) compiled in the framework of the Project SHARE. Available at: http://diss.rm.ingv.it/share-edsf/, doi: 10.6092/INGV.IT-SHARE-EDSF.

Becker, D. & Meier, T., 2010. Seismic Slip Deficit in the Southwestern Forearc of the Hellenic Subduction Zone, Bull. Seismol. Soc. Amer. 100, 1, 325.

Cornell, C. A. (1968), Engineering seismic risk analysis, Bull Seismol Soc Am, 58, 1583–1606.

Caputo, R., Catalano, S., Monaco, C., Romagnoli, G., Tortorici, G., & Tortorici, L., 2010. Active faulting on the island of Crete (Greece), Geophys. J. Int.,183, 111–126, doi: 10.1111/j.1365-246X.2010.04749.x.

Danciu, L. & Tselentis G.-A., 2007. Engineering Ground-Motion Parameters Attenuation Relationships for Greece, Bulletin of the Seismological Society of America, Vol. 97, No. 1B, pp. 162–183, doi: 10.1785/0120040087.

Dimitrakis, V, Tsouchlaraki, A., 2014. Seismic Activity Analysis Using GIS in the Western Part of Crete Island, Southern Greece, FG, Vol. 2(3), 41-52.

Hollenstein, Ch., Muller, M. D., Geiger, A. & Kahle, H. G., 2008. Crustal motion and deformation in Greece from a decade of GPS measurements, 1993–2003, Tectonophysics, 449, 17–40.

Institute of Geodynamics - IG, 2016. Seismicity: Moment Tensors, Catalogues and Database, National Observatory of Athens (NOA), Available at http://bbnet.gein.noa.gr/HL/seismicity/mts/revised-moment-tensors [Accessed 15 Jan 2016].

Kiratzi, A. & Louvari, E., 2003. Focal mechanisms of shallow earthquakes in the Aegean Sea and the sourrounding lands determined by waveform modeling: a new database, J. Geodyn., 36, 251–274.

Love, J., 2012. Credible occurrence probabilities for extreme geophysical events: Earthquakes, volcanic eruptions, magnetic storms Geophysical Research Letters, 39, L10301, doi:10.1029/2012GL051431.

Makropoulos, K., Kaviris, G. & Kouskouna, V., 2012. An updated and extended earthquake catalogue for Greece and adjacent areas since 1900, Nat. Hazards Earth Syst. Sci., 12, 1425–1430.

Margaris, B., Papazachos C., Papaioannou C., Theodulidis N., Kalogeras I. & Skarlatoudis, A., 2002. Ground motion attenuation relations for shallow earthquakes in Greece, in Proc. of Twelfth European Conference on Earthquake Engineering, paper ref. 385.

Meier, T., Rische, M., Endrun, B., Vafidis, A. & Harjes, H.P., 2004. Seismicity of the Hellenic subduction zone in the area of western and central Crete observed by temporary local seismic networks, Tectonophysics, 383, 149–169.

Mountrakis, D., Kilias, A., Pavlaki, A., Fassoulas, C., Thomaidou, E., Papazachos, C., Papaioannou, C., Roumelioti, Z., Benetatos, C., Vamvakaris, D., 2013. Neotectonic Analysis, Active Stress Field and Active Faults Seismic Hazard Assessment in Western Crete, Bulletin of the Geological Society of Greece, vol. XLVII, Proceedings of the 13th International Congress, Chania, Sept. 2013.

Papanastassiou, D., Lataoussakis, J. & Stavrakakis, G., 2001. A revised catalogue of earthquakes in the broader area of Greece for the period 1950–2000, Bull. Soc. Geol. Greece, 34, 1563–1566.

Papazachos, B. C, Karakaisis, G. F. & Xatzidimitriou, P. M. 2005. Introduction to Seismology, 306-308, ISBN 960-431-979-5, Edition Zhth.

Papazachos, B. & Papazachou, C., 1997. The Earthquakes of Greece, p. 304, Editions ZITI, Thessaloniki.

Reilinger, R., McClusky, S., Paradissis, D., Ergintav, S. & Vernant, P., 2010. Geodeticconstraints on the tectonic evolution of the Aegean region and strain accumulation along the Hellenic subduction zone, Tectonophysics, 488, 22-30.

Skarlatoudis, A., Papazachos, B. C., Margaris, B. N., Theodulidis, N., Papaioannou, C., Kalogeras, I., Scordilis, E. M., & Karakostas, V. 2003. Empirical peak ground-motion predictive relations for shallow earthquakes in Greece, Bull. Seism. Soc. Am., 93, 2591–2603.

Stucchi, M., Rovida, A., Gomez Capera, A., Alexandre, P., Camelbeeck, T., Demircioglu, M. B., Gasperini, P., Kouskouna, V., Musson, R. M. W., Radulian, M., Sesetyan, K., Vilanova, S., Baumont, D., Bungum, H., Fäh, D., Lenhardt, W., Makropoulos, K., Martinez Solares, J. M., Scotti, O., Živčić, M., Albini, P., Batllo, J., Papaioannou, C., Tatevossian, R., Locati, M., Meletti, C., Viganò, D. & Giardini D., 2012. The SHARE European Earthquake Catalogue (SHEEC) 1000–1899. Journal of Seismology,17, 523-544, doi: 10.1007/s10950-012-9335-2.

Tselentis, G.A. & Danciu, L., 2008. Empirical Relationships between Modified Mercalli Intensity and Engineering Ground-Motion Parameters in Greece, Bulletin of the Seismological Society of America, Vol. 98, No. 4, pp. 1863–1875, doi: 10.1785/0120070172

Wald, D.J. & Allen, T.I., 2007. Topographic slope as a proxy for seismic site conditions and amplification, Bull., Seism. Soc. Am, Vol 97, No5, 1379-1395.

Wang, Z, 2006. Understanding seismic hazard and risk assessments: An example in the New Madrid Seismic Zone of the central United States. In Proceedings of the 8th National Conference on Earthquake Engineering, April 18–22, 2006, San Francisco, Calif., paper 416

Wang, Z., 2008. Understanding seismic hazard and risk: A gap between engineers and seismologists, in 14th World Conference on Earthquake Engineering, October 12–17, Beijing, China, Paper S27-001, 11 pp.

Wang, Z., 2010. Seismic Hazard Assessment: Issues and Alternatives, Pure Appl. Geophys, Springer Basel AG DOI 10.1007/s00024-010-0148-3.

BIOGRAPHY

Vasileios Dimitrakis is an Aircraft engineer in the Hellenic Airforce (HAF) working at HAF/General Staff in operational requirements and force structure Division. Vasileios is currently a Phd candidate in the Environmental Engineering School at Technical University of Crete (TUC), where he also got his master (MSc) in Environmental Engineering. His research is focused on the consequences of earthquake activity in built and natural environment.