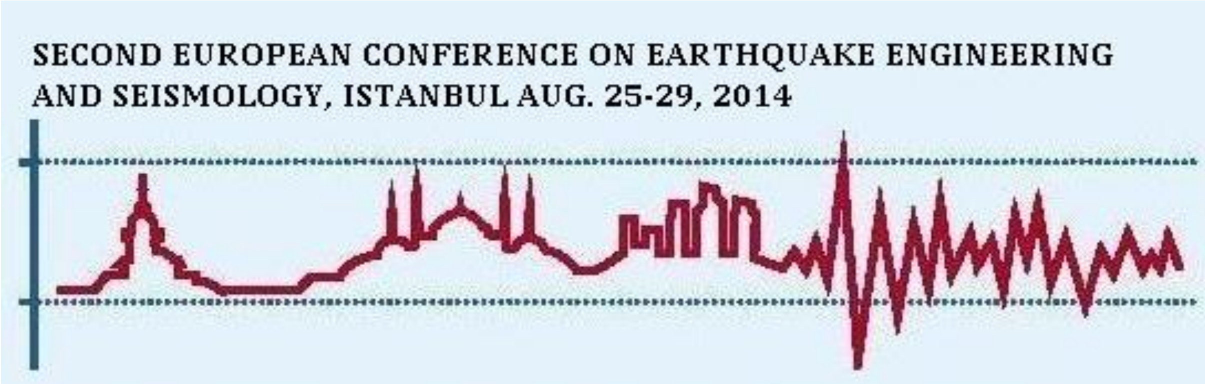

SCENARIO-BASED SEISMIC RISK ASSESSMENT FOR THE CYPRUS REGION

Christis Z. CHRYSOSTOMOU[1], Nicholas KYRIAKIDES[2], Zehra ÇAĞNAN[3]

ABSTRACT

The development of a risk assessment tool as part of the EMME project provided the opportunity for the first time to assess the risk of the existing building stock in Cyprus and in the Middle East Region, for different seismic scenarios. This was a unique opportunity to obtain risk assessment estimates for strong earthquakes for which no historical data are available.

In order to do so, a wide variety of data were collected concerning both the existing building stock but also the population. Regarding the existing building stock, a GIS based database was provided from the Department of Lands and Surveys and was enhanced using data from the 2011 Census of Population. In addition, data in the same form were provided for the northern part of the island by Zehra Çağnan of TED University. Based on the processing of the building data, it was concluded that the majority of the existing buildings is regarded as sub-standard when compared to modern seismic code provisions. Further to the building stock database, a similar database was created for the population distribution based on the recordings of the 2011 Census of Population and data provided by our associate at TED University.

In order to assess the vulnerability of the existing building stock, empirical vulnerability curves were derived for the typical building classes in Cyprus using the Lagomarsino and Giovinazzi (2006) model. The building classes used were low-rise and high-rise reinforced concrete (RC) buildings with or without significant seismic code provisions and masonry buildings. Intensity based vulnerability curves were derived for the five damage grades proposed.

Finally, the seismic hazard scenarios were determined and the corresponding expected intensity maps were derived. Two scenarios were used; the first corresponding to the design earthquake of the modern seismic hazard map and the second corresponding to the maximum credible earthquake in the Cyprus region based on the seismo-tectonic characteristics of the regional seismic faults. The resulting distribution of damaged buildings and the calculated fatalities/injuries for each scenario are presented herein.

INTRODUCTION

The quantification of the unwanted consequences from earthquakes can be achieved through seismic risk assessment. The seismic risk in a region defines, monetarily, the amount of prospective damage inflicted on structures and the population by an earthquake. Seismic risk assessment is used as a tool for the prevention, preparedness and mitigation of the consequences from seismic events and is

[1] Associate Professor, Cyprus University of Technology, Limassol, c.chrysostomou@cut.ac.cy
[2] Post-Doctoral Researcher, Cyprus University of Technology, Limassol, nicholas.kyriakides@cut.ac.cy
[3] Associate Professor, TED University, Ankara, zehra.cagnan@tedu.edu.tr

based on the assumption that losses depend on the quality of the building stock (zero seismic risk in deserts).

The quantification of the seismic risk allows for proper budgetary planning, raising public awareness, assessment and allocation of the necessary manpower for mitigation and disaster management operations, educating the public and professionals on preparedness and mitigation, and prioritization of retrofit applications. In addition, it can be used by insurance companies for premium rates calculations. It can be applied to regional or global (national) level differing in the level of detail. Empirical data can be used for global assessment whereas in the case of a small region, simplified analytical data can be used to increase the accuracy of the predictions. In the case of critical facilities such as hospitals, airports, nuclear plans, military facilities etc., the assessment may utilize very detailed data regarding the particular facility. The results from seismic risk assessment can be a very useful tool for local (municipalities) and governmental authorities and along these lines most big cities worldwide have produced seismic risk assessment studies. Re-insurance companies have moved a step forward in producing seismic risk assessment in a world-wide scale based on various global models.

RISK ASSESSMENT CALCULATION TOOL

A seismic risk tool was developed in EMME (Earthquake Model of Middle East), which was a regional program of GEM (Global Earthquake Model), to encompass the assessment of seismic risk in terms of structural damages, casualties and economic losses and also to evaluate the effects of relevant mitigation measures. As the major component of EMME, the seismic risk module includes regional loss-estimation calculations based on intensity-based vulnerability approach. The result of loss estimation is obtained in terms of building damage distribution and resulting casualties.

The objective of earthquake risk-assessment and loss-estimation studies within EMME was to prepare a quantitative basis for the prioritization of the risk mitigation. The probabilistic risk assessment methodology used includes prediction of damage, for a given probability of recurrence, based on a probabilistic seismic hazard model, population distribution, building inventory and vulnerability of the built environment. All the calculations are performed by the ELER software, which has been developed by KOERI university. The compiled data is provided in such a format that it conforms with the input standards of ELER software.

COMPONENTS OF SEISMIC RISK

The components of seismic risk assessment for a specific area under consideration are the seismic hazard assessment, which describes the expected frequency of future seismic events, and the structural vulnerability assessment of the exposure building stock (damage potential).

Seismic hazard asssesment describes the probability of a seismic shaking reaching or exceeding a certain magnitude during a reference period for a particular area. It can be expressed either through recurrence relationships (rate of occurrence) or using seismic scenarios. The most frequently used seismic scenarios are the one with 10% probability of exceedance (POE) in 50 years (corresponding to 475 years return period) and the maximum credible earthquake in an area with 2% POE in 50 years (corresponding to 2475 years return period).

For the purpose of this study and in order to derive the two scenarios for Cyprus the maximum intensities and accelerations for each seismic scenario were derived based on the recurrence rate of earthquakes in all credible sources that may affect the area and thus the probabilistic results are not based on a single scenario. They are the aggregation of all probabilities resulting from the recurrence of earthquakes in all sources. This was the philosophy behind all risk calculations performed as part of the EMME project in country level. The governing scenarios can be obtained by disaggregation, which is still under way.

For the case of Cyprus, the intensity distribution for the two above mentioned scenarios are shown in Figure 1. The first one, which corresponds to the design earthquake for new buildings in Cyprus based on Eurocode 8-Part 1 (CEN 2004) predicted an Intensity 8 in the Modified Mercalli

Intensity (MMI) scale, whereas the second scenario that corresponds to the maximum credible earthquake in Cyprus estimated an Intensity 10 in the MMI scale.

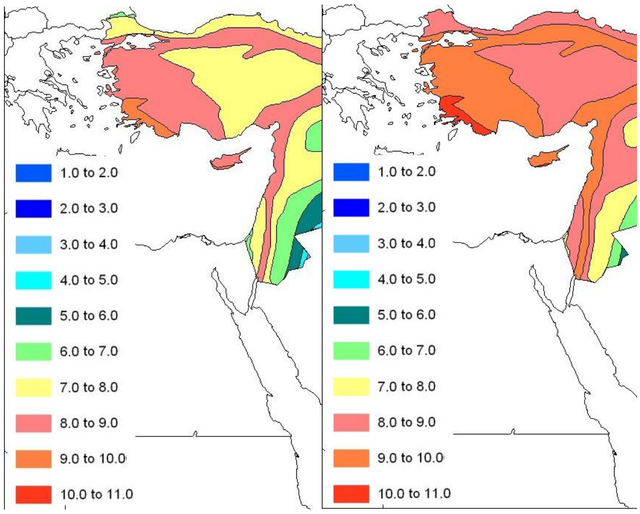

Figure 1. Expected Intensities for the two seismic hazard scenarios

Seismic vulnerability assessment refers to the expected levels of damage for each building class in the area for specific seismic hazard. It can be expressed either through the probability of reaching or exceeding a certain damage state or as the ratio of the expected damage cost to the replacement cost for a particular seismic hazard parameter.

As far as the vulnerability models in ELER are concerned, these are expressed in the form of curves (vulnerability curves). In order to perform risk assessment calculations, a combination of empirical and analytical ones were derived and are available for the above-mentioned building categories in Cyprus. The empirical ones are based on the EMS-98 (Grünthal, 1998) scale, whereas the analytical ones were derived using the EC8 Part-3 (CEN 2005) damage levels. The empirical ones are used for Level 1 country level risk assessment analysis in ELER, whereas the analytical ones are used for more detailed (Level 2) assessment. For the purpose of this paper only Level 1 analysis was performed since the assessment covered the whole of Cyprus and provided country level damage results.

The empirical curves derived based on EMS-98 scale were then used to obtain the V (vulnerability damage index) and Q (ductility based intex) values required to calibrate the vulnerability relationships proposed by Lagomarsino and Giovinazzi (2005) and calculate the mean damage grade (μ_{Δ}). The mean relationships were then disaggregated into 5 damage grades ranging from low damage to collapse. The proposed V and Q values for the specific building classes in Cyprus are shown in Table 1, for reinforced concrete (RC) buildings of category 1 (concrete moment frames), with low or medium ductility class (DCL and DCM) design and of low (L) or medium (M) height. The last building category (M2) corresponds to traditional masonry buildings. The corresponding vulnerability curves for mid-rise (M) RC buildings of low ductility class (DCL) design are given in Figure 2.

Table 1. V,Q values for selected building classes in Cyprus

	V (Vulnerability Index)	Q (Ductility-based Index)
RC1DCLL	0.64	2.3
RC1DCLM	0.66	2.3
RC1DCML	0.38	2.5
RC1DCMM	0.4	2.8
M2	0.84	2.3

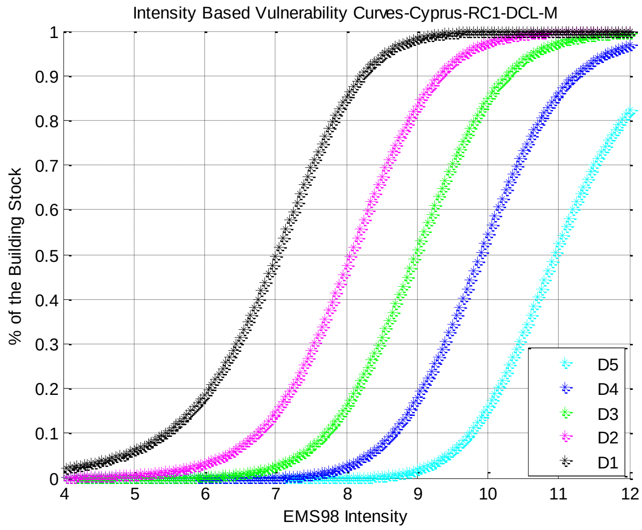

Figure 2. Vulnerability curves for mid-rise RC buildings with limited seismic design in Cyprus

BUILDING STOCK AND POPULATION DATABASES

The authors of this paper participated as local representatives from Cyprus to the EMME project and were responsible for providing the required data discussed above in order to obtain risk assessment calculations. To do so, the authors collected data from numerous sources and eventually compiled a GIS grid based database for both the existing building stock and the spatial distribution of the populaltion.

Regarding the building stock database, the main source was the GIS based building database provided by the Department of Lands and Surveys (DLS). This database includes the existing building stock with final building permits and provide the geospatial coordinates and area of each building. It also provides in a coded form the construction material and an indication of the height of each building. In addition information regarding the existing building stock in the North of the island were obtained from the corresponding 2006 Census of population recordings, which were provided by our associate in TED University. The recordings were available in tabular form showing the distribution of population per village/neighborhood and the number of households per village/neighborhood. The buildings were classified based on their structural material (RC, masonry, adobe, prefabricated buildings) and the period of construction per district.

The observations from both databases showed that the majority of buildings in the island are of RC and were build with low seismic resistance. Regarding the design practice, it was observed that two main construction and design practice periods existed before and after the enforcement of seismic design codes, which took place in 1992 for the majority of the island and 1999 for the northern part. It was also noticed that masonry and adobe type buildings were all constructed before 1975.

A 1x1 km^2 grid was generated for the whole of the island and the number of buildings per building category were calculated from the above-mentioned databases per grid cell. Five building categories were chosen in line with the European Building Taxonomy Classification. The four categories include the RC frames low-rise and mid-rise, with and with-low earthquake resistance design (ERD), whereas the fifth one includes all the traditional buildings with adobe and masonry since it is impossible to distinguish between them based on the available data. In addition, the building database provided in the 2011 Census of Population of Cyprus which includes the number of houses and apartments per municipality/community was used to update the DLS database and include a large number of buildings with no final building permit.

In the case of the population database, the process was much simpler since recent Census of Population were available and provided the population per municipality/community. This database was then processed and distributed into the grid cells in order to become compatible to the ELER format of risk calculations.

The two figures below show the final grid-based distribution of buildings and the population used in ELER for risk assessment calculations.

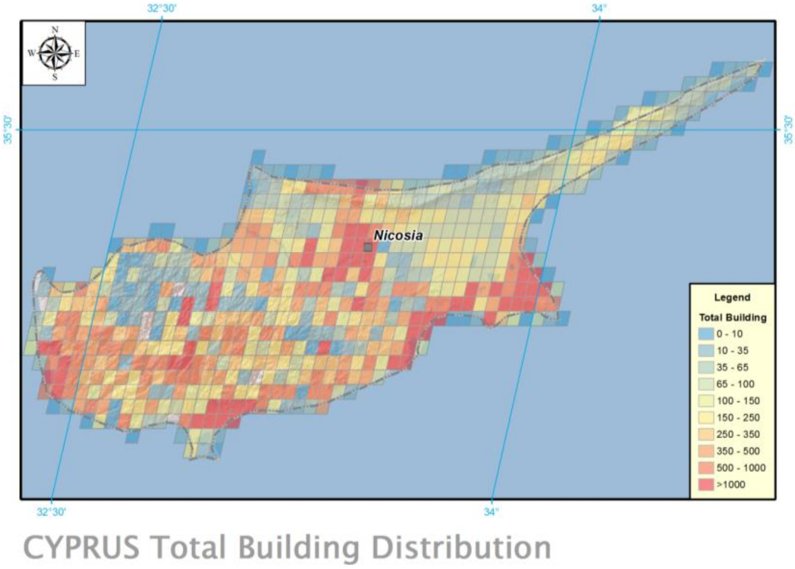

Figure 3. Grid-based spatial distribution of the building database for Cyprus in ELER

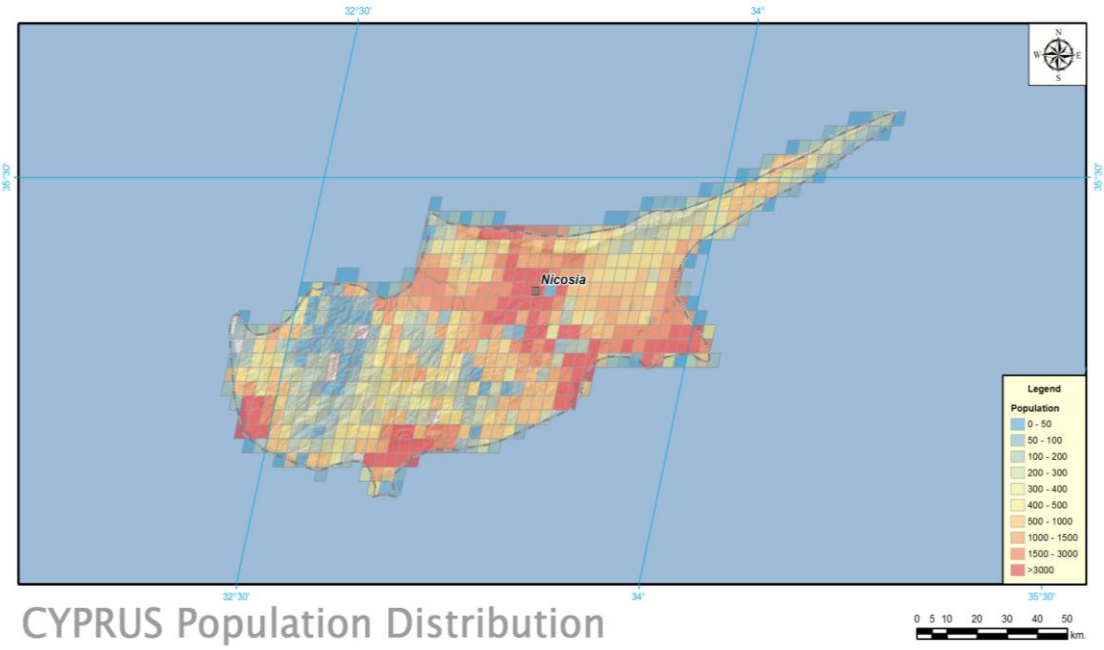

Figure 4. Grid-based spatial distribution of the population database for Cyprus in ELER

RISK ASSESSMENT CALCULATION RESULS

The derived databases for the building stock and the population along with the vulnerability models for buildings in Cyprus were inputed in ELER. Risk assessment calculations were performed for the derived Intensities from the two scenarios and the expected damage in buildings, fatalities and injuries were computed.

As far as the first scenario is concerned, it was estimated that around 16.500 buildings are expected to suffer severe structural damage, which refers to damage that can be repairable but residents have to be relocated for a certain amount of time. The majority of these buildings are located in Limassol and Paphos. The spatial distribution of severly damaged buildings is shown in Figure 5. It was also estimated that around 11.000 people will suffer minor to severe injuries (a small amount refers to fatalities).

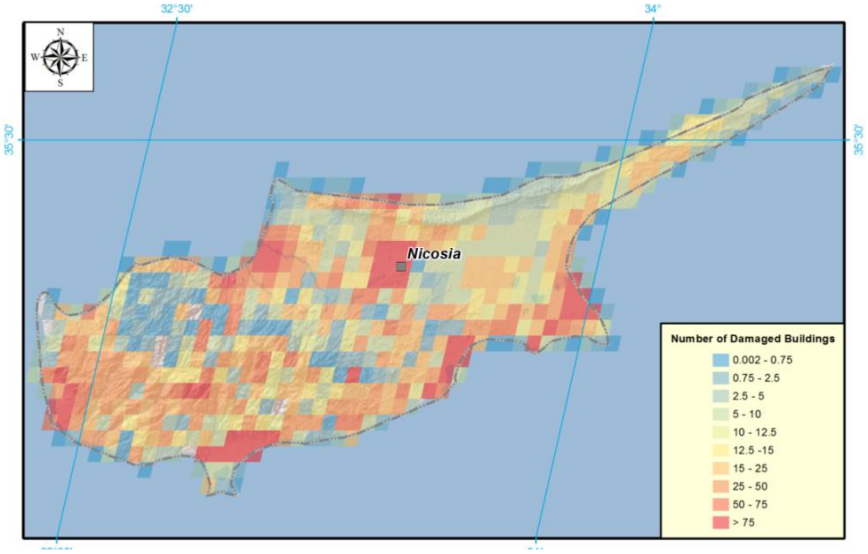

Figure 5. Spatial distribution of damaged buildings in Cyprus from scenario 1

As far as the second scenario is concerned, which refers to the maximum credible earthquake in Cyprus, it was estimated that over 55.000 buildings would suffer severe structural damage whereas over 60.000 people will be injured.

In order to obtain a comparative assessment with the neighboring countries influenced by similar seismic sources the above mentioned study was applied for all countries in the Middle-East region, as part of EMME. The resulting percentage of heavy and moderate damaged buildings per seismic hazard scenario for each country are shown in Table 2. Based on the expected damage results, it was observed that Cyprus possesses a lower seismic risk compared to countries such as Armenia, Iran and Pakistan but considerably higher compared to Turkey and Lebanon. This can be attributed to the fact that Cyprus lies in a lower seismicity region than Iran and Pakistan and the majority of the building stock has lower vulnerability compared to these countries. It is clear though that the building stock in the regions of Turkey affected by earthquakes has lower vulnerability.

Table 2. Expected damage percentage of the existing building stock in countries in the Middle East region

RISK ESTIMATION SUMMARY				
	475 YEARS		2475 YEARS	
COUNTRY	DAMAGE BEYOND REPAIR (D4+D5)	MODERATE DAMAGE (D3)	DAMAGE BEYOND REPAIR (D4+D5)	MODERATE DAMAGE (D3)
ARMENIA	5%-19%	18%-34%	22.5%-50.5%	36%-40%
CYPRUS	5% - 12%	12%-19%	16% - 31%	21%-24%
GEORGIA	0.7% - 3.2%	4%-12%	4.5%-14%	14%-26%
IRAN	6% - 18%	13% - 19%	23% - 42%	21% - 23%
JORDAN	0.2%-1.4%	2%-7%	3%-11%	11%-22%
LEBANON	1.7%-6.2%	8%-15%	11%-24%	20%-25%
PAKISTAN	24% - 27%	12% - 27%	39% - 55%	23% - 25%
TURKEY	1.3% - 4.1%	4.5% - 9%	6% -13.5	11% - 14%

CONCLUSIONS

A study was conducted using a scenario based risk assessment tool to evaluate the seismic risk for Cyprus. Both the population and building stock databases were assembled in GIS format for the whole of the island. Two seismic hazard scenarios were determined based on earthquakes of 475 and 2475 years return period and intensity-based vulnerability relationships were derived for the most common building classes in Cyprus.

The results of the risk assessment showed that for both scenarios the amount of heavily damaged buildings and injuries cannot be handled by any local authorities acting on their own. The government needs to produce a contingency plan for prevention and preparedness involving a number of authorities in order to accommodate these consequences. In this plan, the capacity of the existing rescue teams and medical services needs to be defined in order to identify shortcomings. It should also be noted that due to the large amount of building damage, the assistance of neighbouring countries will be required and this should be agreed a priori.

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