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Framework for the derivation of analytical fragility curves and life cycle cost analysis for non-seismically designed buildings

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ABSTRACT

The quantification of the devastating effects of earthquakes on buildings can be achieved with the use of earthquake risk assessment. The formulation of strategies to minimise this risk is a complex task which relies on data regarding mainly the hazard, vulnerability and remaining life of the building. In this paper, the case study of Limassol municipality is presented. Initially, the building inventory and categorisation is defined followed by the selection of hazard scenarios and the development of analytical vulnerability curves. In the final part, risk assessment is performed leading to the formulation of retrofitting strategies for long term use.

1. Introduction

Since the beginning of civilisation, millions of people and thousands of structures around the world have been perished by earthquakes. Unfortunately, short-term earthquake prediction is still impossible. However, there are methods available for the approximate long-term prediction of earthquake events. Earthquake Risk Assessment (ERA) is necessary to develop risk management strategies (RMS) usually used to mitigate the undesirable results of seismic actions. The mitigation is achieved through strengthening of the existing building stock to avoid undesirable damage on the buildings within a predefined time framework (remaining service life of a building). The island of Cyprus, which is located in the North Eastern Mediterranean region, lies within the second highest seismic hazard zone of the earth. Throughout its history, Cyprus has suffered significant damage due to earthquakes. Since 1995, three major earthquakes, with magnitudes $Ms > 5.7$ have hit the island, causing three fatalities, approximately 50 injuries, severe structural damage and economic losses, which add up to approximately €15 million. This has increased concern amongst the people of Cyprus and highlighted the need for improved risk assessment and management. The first basic seismic provisions in the island were introduced in 1986 followed by a formal and comprehensive seismic code in 1994 [1].

In order to examine the seismic risk of the existing building stock of the island it was decided to use the municipality of Limassol as a case study as it is situated at the southern part, which has proven to be of higher risk due to its proximity to the Cyprian Arc. In addition, most of the buildings were constructed prior to the enforcement of the aseismic code, which is the case for all the tall buildings (> 6 floors), with the use of low strength concrete and very low ductility reinforcement. The district of Limassol is shown with the red line in Fig. 1, whereas the borders of the Limassol municipality, which is the case study area, are shown with the black line. The spatial distribution of buildings in the municipality is shown in Fig. 2. It is observed that it comprises of a very dense building stock concentrated close to the coastal line.

The scope of this study is to examine the vulnerability and risk of the existing building- stock in Limassol and propose retrofitting alternatives adopting a life-cycle assessment methodology for seismic retrofitting purposes. This is the first analytical seismic-risk assessment study conducted for Limassol, and even for Cyprus, which is based on the characteristics of the existing building stock, on the provisions of modern seismic codes for the derivation of fragility curves and on results from a local microzonation study. In addition, it is the first time that a retrofit decision tool (life-cycle assessment) is used to arrive at retrofitting decisions accounting for various levels of retrofit, so as to select the most cost-effective retrofitting solution for the population of the existing structures, on a case by case basis.

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Fig. 1. Satellite image of Cyprus (the district of Limassol with red line the municipality with black line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

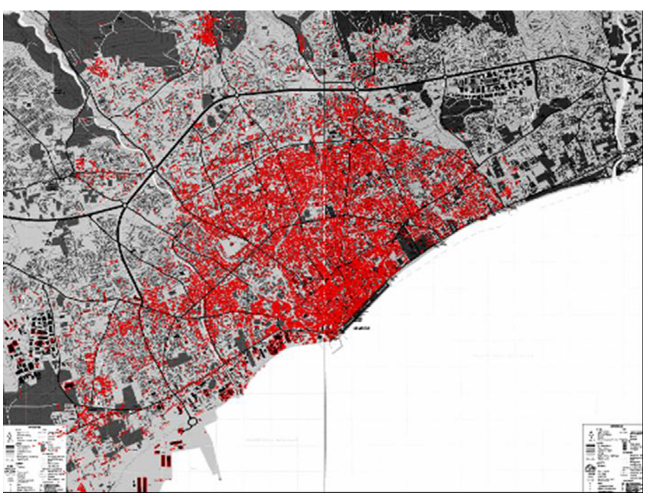

Fig. 2. Distribution of buildings in Limassol municipality.

Table 1
Number of houses and apartments in Limassol district (urban).

	1946–1960	1961–1970	1971–1980	1981–1990	1991–1995	1996–2001	2001–2011
Houses	4221	5725	9973	12345	5550	4583	14,986
Apartments	341	1057	4267	7135	2912	1683	13,674

Since a large number of data regarding the existing building stock had to be collected (height, year of construction etc.) this is why it was decided as a first step to apply the procedure to the Limassol municipality only. It is easily understood that given the availability of data, the study can be applied for the whole of the island. Since the main interest of the municipality authorities regarding their building stock is the prospect of retrofitting old buildings without seismic design provisions, this study contributes in this aspect with the use of a life cycle analysis methodology to provide the alternatives to the decision makers.

2. Compilation of the building stock

The first task for ERA is the compilation of the building inventory which should include the number of buildings and their categorisation based on parameters such as their height, year of construction, material properties etc., that affect their vulnerability. For the area under study, the data resources available were the Statistical Service Department of Cyprus and the archives of the local municipality. For the scope of this paper it was decided to choose 2 building categories for further investigation in order to determine their optimum retrofit level. These categories should resemble the most vulnerable and high risk buildings in the area under investigation.

The initial approach towards obtaining inventory data was by using the data in the most recent Census of Population that includes information on the existing building stock. The available information regarding our study was the number of houses (≤ 2 floors) and apartments per district and urban/rural areas and the number of living quarters per municipality and community and per urban/rural areas. The extracted data for the case study area are shown in Tables 1 and 2. Table 1 shows the number of houses and apartments in Limassol district per construction period and Table 2 shows the number of living quarters (houses and apartments) in urban Limassol.

It was assumed that the percentage of living quarters in Limassol municipality per construction period can be used to deduct the number of houses and apartments in Limassol municipality. Therefore, using the number of living quarters in Table 2 it was possible to calculate the corresponding percentage of Limassol municipality (case study area) per time period to the whole of Limassol district. These percentages were then used to multiply Table 1 values to estimate the number of houses and apartments in Limassol municipality per time period (Table 3).

Based on the estimated data for the municipality it was observed that nearly 70% of the existing building stock lacks any