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Seismic safety assessment of an unreinforced masonry building in Albania

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Abstract. In Albania, hundreds of masonry buildings were constructed during the communist period which covers 45 years until 1990s. Most of these buildings were designed without any seismic criterion. To mitigate seismic risk in Albania, structural performance of masonry buildings have to be correctly evaluated. In this paper, the efficiency of nonlinear-static procedures with a particular reference to the FEMA 440 method, for estimating the seismic vulnerability of masonry buildings has been studied at local and global levels. For this purpose, one template design most widely used in Albania has been selected. Selection of the material properties and plan features of the case study structure has been based on archive study. By means of pushover analysis, capacity curves of the investigated building were determined and quantitative estimate of earthquake damage is performed for various earthquake levels. This evaluation has been carried out in compliance with Eurocode 8 requirements and safety assessment was carried out FEMA 440 guidelines.

Keywords: Unreinforced masonry buildings; Pushover analysis; Performance assessment

1 INTRODUCTION

Traditional and historical masonry buildings constitute the majority of the current building stock in Albania like in many other countries. Recent devastating earthquakes (1999 Kocaeli, Turkey; 2001 Gujarat, India; 2009 L'Aquila, Italy; 2010 Haiti) clearly showed that such buildings, mainly designed under gravity loads, experience severe damages under earthquake shakings. From this point of view, seismic safety assessment and evaluation of such existing buildings' vulnerabilities under different earthquake scenarios is one of the most important issues among the earthquake engineering community [Bilgin and Korini, 2012].

In Albania, template designs developed by the governmental authorities are used for many of the buildings intended for residential purposes as common practice to save on architectural fees and ensure quality control during the communist period [Korini, 2012]. The representative typology of the country is unreinforced masonry (URM) buildings. The majority of these existing buildings in Albania, were designed to resist only to vertical loads [KTP-9, 1978] until the seismic code became in force in 1989 [KTP-N2, 1989]. Even though Albanian seismic code [KTP-N2-89] is expected to undergo a revision in a near future after the implementation of the adoption to Eurocode norms, this normative is still in use for the design of building structures [Frangu and Bilgin, 2012].

Hence to really mitigate seismic risk in Albania, structural performance of masonry buildings have to be evaluated. The objective of this study is to assess the seismic performance of an existing 5-storey typical URM building designed according to old Albanian Code [KTP-9, 1978] considering the nonlinear behavior of structural components. Mechanical properties of the case study building was taken from the blueprints of the building and adopted for analysis. The performance of the structure is assessed using the results of the pushover analysis and the inter-story drift ratios. Seismic safety assessment has been done in accordance with FEMA 440 (FEMA 440, 2004)

2 DESCRIPTION OF CASE STUDY BUILDING

Until the end of communist period in 1990s, URM buildings continued to be built using template designs. Today, these buildings are in use and their main functions are for residential purposes. A considerable number of buildings have the similar template design in different parts of Albania (Korini, 2012).

An archive study was carried out in National archive of Albania. According to the survey results, there were about 30 types of URM template designs. As the case of this study, TD-72/1 was selected for seismic safety assessment (Fig. 1). Since there is not sufficient experimental results to achieve a complete mechanical characterization of the whole masonry, mechanical properties of the masonry have been assessed based on national code indications provided as a function of the masonry. According to the Albanian code (KTP-89), selected building was built with clay bricks of M75 with a resistance of 7.5 MPa and mortar of M25 with a resistance of 2.5 MPa. The load bearing wall thickness is 380 mm on first two storeys and 250 mm on the remaining three storeys.

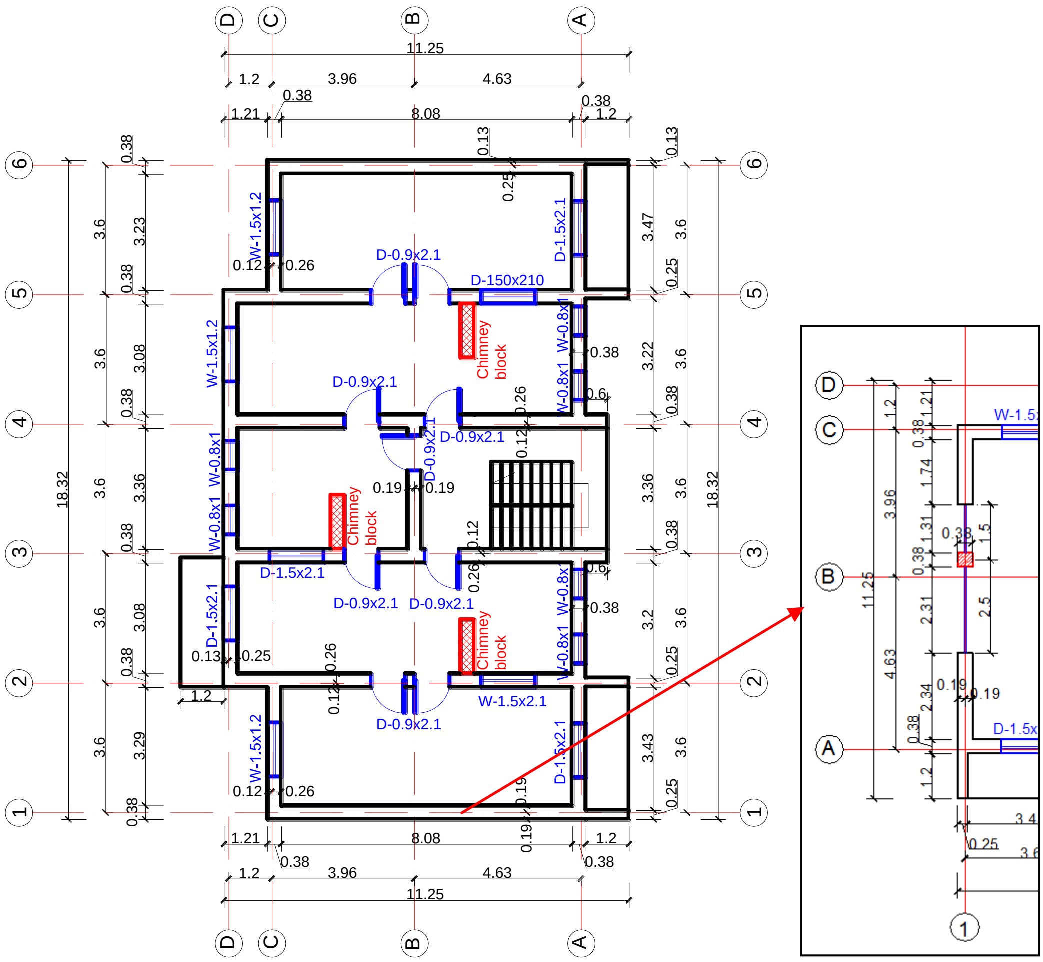

Figure 1. Typical plan view of the case study building and modification (units m.).

3 NUMERICAL MODEL

Based on the geometry of the building, a model with bi-dimensional finite elements type “nonlinear layered shell” has been executed using the commercial software SAP2000 CSI (release 15). The shells are divided to consider the effect of openings and in order to distribute the stresses as good as possible

(Fig. 2). The thickness is the real one of the walls. The floors are modeled by introducing the rigid diaphragm constraint at each storey level. Concrete ring beams are modeled on the walls in order to apply the loads of the floors and distribute them uniformly on the walls.

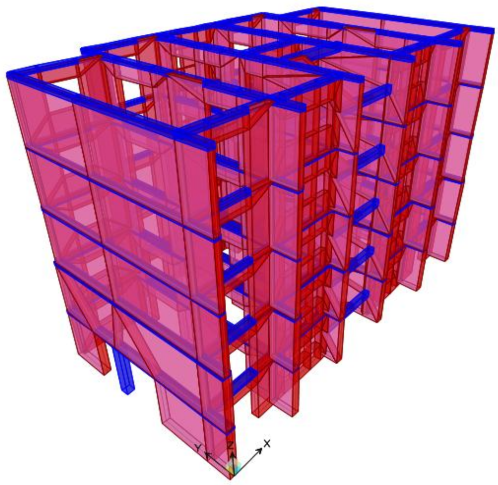

Figure 2. 3-D analyses model in Sap2000 software

In this paper the masonry elements are modeled using the nonlinear layered shell element. The layered shell allows any number of layers to be defined in the thickness direction, each with different thickness, behavior, and material. Material behavior is considered nonlinear. Out-of-plane displacements are quadratic and are consistent with the in-plane displacements. The masonry wall behaves like anisotropic material. For this reason masonry is modeled by 2 different stress strain curves. Each of them represents respectively vertical and horizontal stress S22 and S11, and shear stress S12 (Fig. 3). The accuracy of this approach depends on the prediction of the stress strain curves for each direction. Here the S11 and S22 curves have the same behavior. The validity of these assumptions has been checked and validated (Galasco et al., 2006).

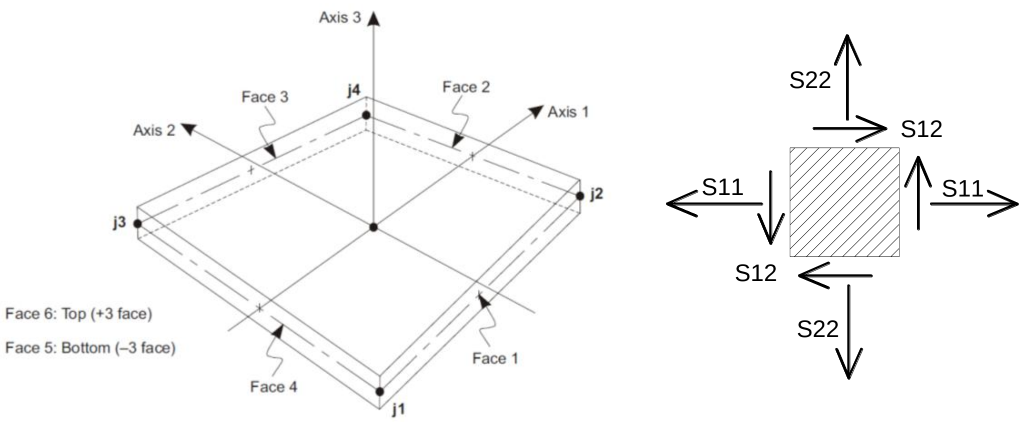

Figure 3. A four node shell element and in plane stresses.

To execute earthquake analysis of URM buildings, particular attention is needed to model the non-linearity. Performance based earthquake engineering requires predicting accurately nonlinear response at different seismic intensity levels. The use of convenient force-deformation relationships influences the global seismic performance of the building. Even though spread plasticity elements lead usually higher computational cost than the lumped plasticity models, they provide for good estimations in the full range of structural response.

Seismic capacity of URM buildings is simulated by means of pushover analyses. The capacity curve is a representative indicator of inelastic response of the building. Displacement-based procedures require the plot of this curve under increasing horizontal displacement demand. Control displacement represents earthquake demand whereas base is a measure of intensity measure. Nonlinear static analysis enables to control seismic performance of a masonry building by plotting different demand parameters versus several intensity measures at global and local levels. Accordingly, structure's seismic performance can be assessed whether they meet required performance objectives or not at a given hazard level.

For nonlinear analysis of the selected URM building, material properties determined from the blueprints of the designs were taken into account. Nonlinear static analyses have been performed. Member sizes in the template design were used to model the selected building. No simplifications are made for the members. The anisotropy of masonry is modeled by two stress-strain curves (Figure 4). Each of them represents respectively vertical stresses and shear stress. Vertical stress-strain curves are determined using the relation suggested by Kaushik et al. (2007). Shear resistance is represented by a material nonlinear curve (cohesion) and friction is neglected. Annex C of EN EC8 (2004) provides drift limits for in-plane behavior of URM buildings. For shear stress-strain curves, an approach which was used by researchers (Lagomarsino et al., 2007) adopted for the analysis.

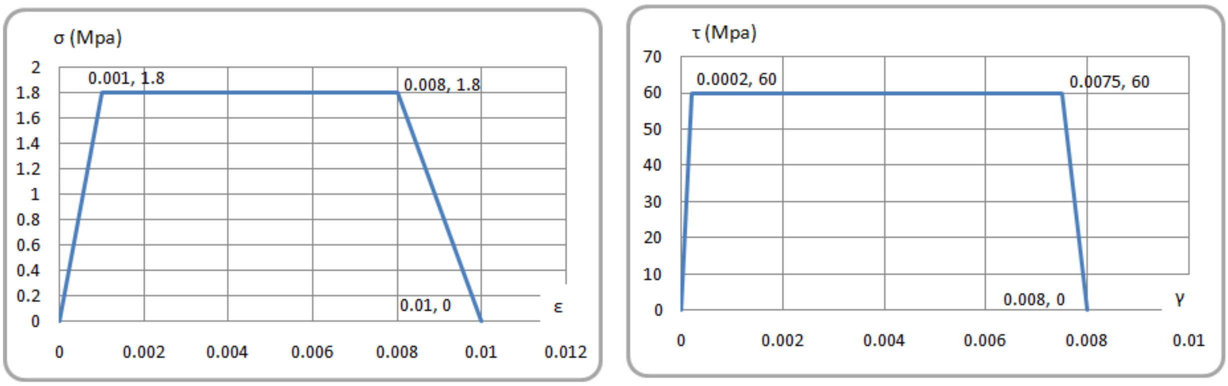

Figure 4. Idealize material nonlinear curves compression (left) and shear (right).

4 SEISMIC DEMAND

Earthquake loads are commonly represented by response spectrum functions. In this study Eurocode 8 and KTP-N2-89 spectrums are used to make a comparison and question the adequacy of current design spectrum (Fig 5). In this study, the demand calculations for the seismic assessment of the considered buildings are performed considering the soil Type C with a moderate seismicity (0.2g) according to Eurocode 8 [2004] and its corresponding spectra considering Soil category II and medium seismicity in KTP-N2-89.

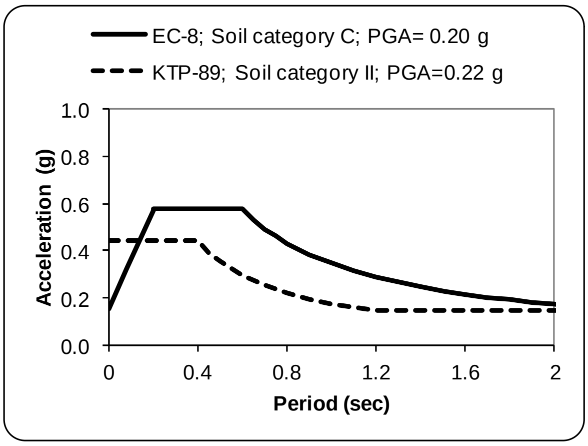

Figure 5. Elastic Spectrums.

5 ANALYSIS RESULTS

5.1 Global Performance Limit States

A performance level is a limit stage on the pushover curve that is used to classify the damage. There are different approaches to damage limit states classification for masonry. Researchers like Calvi (1999) have introduced an inter-storey drift method with three limit states. The inter-storey drift is one of the most recent and is closely related to lateral bearing capacity of individual members and global response. Calvi (1999) proposed three damage limit states for masonry structures as stated below (Fig 6):

- LS2 - Minor structural damage and/or moderate non-structural damage; the building can be utilized after the earthquake, without any need for significant strengthening and repair to structural elements. The suggested drift limit is 0.1%.
- LS3 - Significant structural damage and extensive non-structural damage. The building cannot be used after the earthquake without significant repair. Still, repair and strengthening is feasible. The suggested drift limit is 0.3%.
- LS4 - Collapse; repairing the building is neither possible nor economically reasonable. The structure will have to be demolished after the earthquake. Beyond this LS global collapse with danger for human life has to be expected. The suggested drift limit is 0.5%.

Below is shown a schematic capacity spectrum with damage limit states.

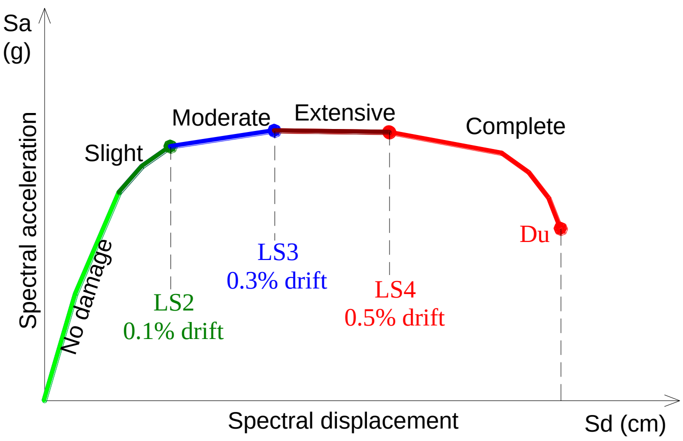

Figure 6. Performance levels on pushover curve.

5.2 Seismic safety assessment of the building

Pushover analysis data and criteria of Fig. 6 criteria were used to determine interstorey drift ratios of the building in both directions. Identification of damage limit states and its representations on capacity curves for each building is given Fig. 7. Small displacement capacity at different performance levels is remarkable for *x*- direction due to the openings in this direction.

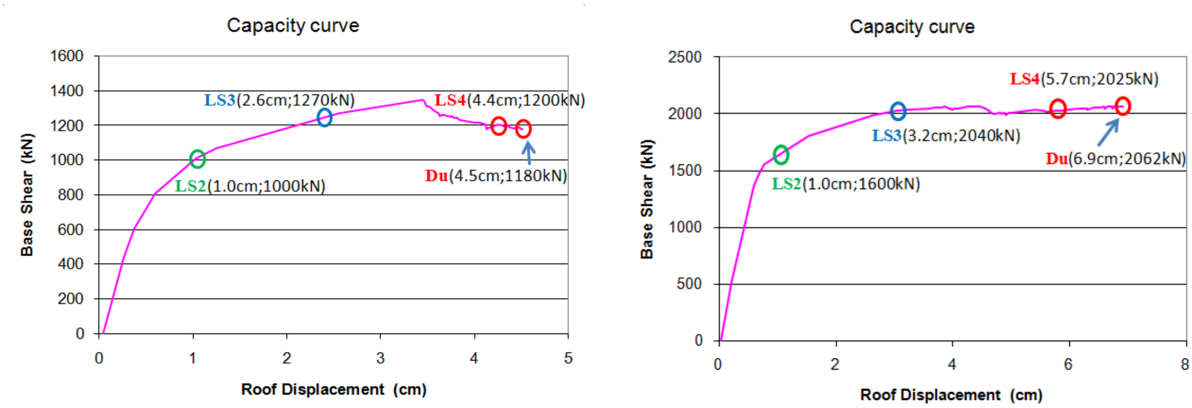

Figure 7. Pushover curves for *x*- direction (left) and *y*- direction (right).

This structure shows ductile behavior in both orthogonal directions. In comparison with *y*- direction, the lateral load capacity is not very high in *x*- and this makes the structure prone to damages under EC8 spectrum. The regularity in plan and elevation makes a good distribution of stresses and increases ductility. LS3 damage limit state is guaranteed. Performance point is reached only for EC8 spectrum with high ductility and it is close to LS3. Regarding KTP spectrum, performance point is not reached due to the shape of KTP demand spectrum. The *y*- direction behavior has higher capacity and resistance. Stresses are uniformly distributed and global response is satisfactory.

Performance points of the structure were obtained as described in FEMA-440 (Table 1). For KTP and EC8 spectrum is guaranteed LS3 damage level. Moderate damage is caused by both of them, which is higher for EC8 seismic load. Also it is obvious the big distance between the performance point and ultimate LS4 damage level. This means that this structure is safe under both spectrums in Y direction.

Table 1. Nonlinear analysis results for TD-72/1

Design spectrum	Direction	Ductility	Performance point	
			Shear	Displacement
Eurocode 8	X	3.9	1230 kN	2.3 cm
	Y	2.7	1900 kN	2.1 cm
KTP -89	X	NA	NA	NA
	Y	1.5	1650 kN	1.1 cm

Another aspect of damage assessment is the accurate prediction of interstorey drift ratios. The correct prediction of inter-storey drift ratio and its distribution along the height of the structures is critical for the seismic performance evaluation purposes since the structural damage is directly related to this parameter. The inter-storey drift ratios and their corresponding profiles along the height of the template building are illustrated in Fig. 8. As this is the case, the inter-storey drift ratio over the height of the structures become non-uniform as wall thickness changes.

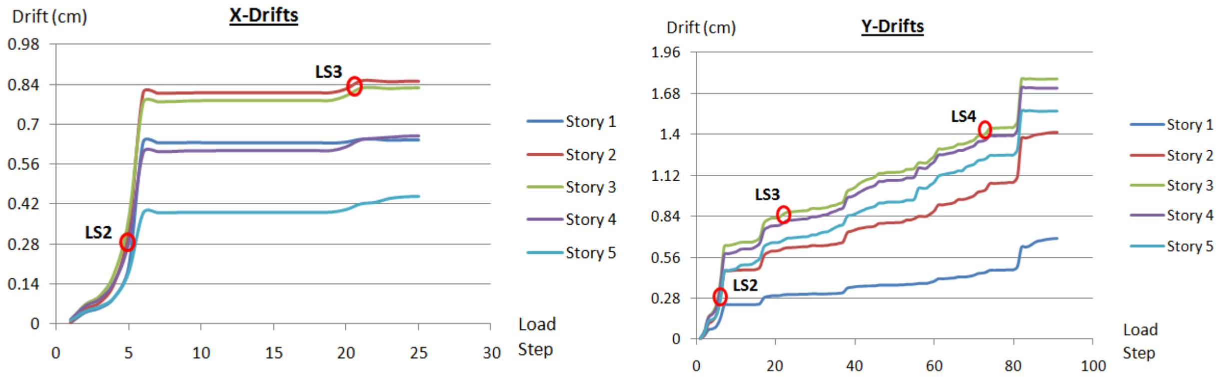

Figure 8. Inter-storey drift curves for the case study building.

The seismic performance assessment is made for the template design and the results are summarized in Table 2.

Table 2. Analysis results for the template design

Building	Direction	KTP-N2-89 Albanian	EC 8	Comment
TD-72/1	*x*	Safe LS3	Safe LS3	Low stiffness according to KTP but safe for EC 8
	y	Safe LS3	Safe LS3	Moderate damage is expected under both spectrums

6 CONCLUSIONS

The seismic performance of a typical 5-storey URM building of the Albanian masonry stock has been analyzed. The capacity of the building was calculated by a structural model that uses macro elements for masonry panels. The expected demand has been defined by two response spectra proposed by the EC8 and KTP-89. The mechanical properties of the materials used have been taken from the blueprints of the project.

TD-72/1 shows ductile response in both orthogonal directions. The regularity in plan and elevation makes a good distribution of stresses and increases energy dissipation capacity. LS3 damage limit state is assured. Due to the low lateral load capacity, extensive damage is expected under EC8 spectrum. Performance point is reached only for EC8 spectrum and it is close to LS3. This building has a higher capacity and resistance in *y-* direction. Stresses are uniformly distributed and global response is satisfactory. Performance is found for both spectrums with a medium to high ductility. LS3 damage level is satisfied for both spectrums. Moderate damage is caused by both of them, which is higher under EC8 demand spectrum. It can be said that this structure seems to remain safe under both spectrums in *y*- direction.

REFERENCES

Bilgin, H., and Korini, O. (2012). Seismic capacity evaluation of unreinforced masonry residential buildings in Albania. *Nat. Hazards Earth Syst. Sci*., **12**/3753-3764/ 2012, doi:10.5194/nhess-12-3753-2012.

Calvi, G. M., (1999). A displacement-based approach for vulnerability evaluation of classes of buildings. *J Earthquake Eng* **3**(3):411–438.

CSI, SAP2000 V-15 (2011). Integrated finite element analysis and design of structures basic analysis reference manual; Berkeley, California (USA); Computers and Structures Inc.

EN 1998-1. European seismic design code. (2004). Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings".

Federal Emergency Management Agency, Fema-440, (2005). Improvement of Nonlinear Static Seismic Analysis Procedures, Applied Technology Council

Frangu, I., Bilgin H. (2012). Evaluation of seismic analysis procedures for seismic actions: A Comparative study between Eurocode 8 and KTP-89. *International Students' Conference of Civil Engineering, ISCCE 2012, ISBN: 978-9928-135-02-5*; Paper no: 17, 10-11 May 2012Epoka University, Tirana, Albania

Kaushik, H. B., Rai D., C., Jain, S., K., (2007). Stress-Strain characteristics of clay brick masonry under uniaxial compression. *Journal of Materials in Civil Engineering*, ASCE, **19**:9 (728).

Korini, O. (2012). "Seismic Assessment of Albanian Masonry Buildings Using Nonlinear Procedures", MSc thesis, 150 pages, Epoka University, Tirana, Albania.

Lagomarsino, S., Penna, A., and Galasco, A., (2006), TREMURI program: seismic analysis program for 3D masonry buildings, University of Geneoa, Genoa.

Lagomarsino, S., Galasco, A., and Penna, A., (2007), Nonlinear macro element dynamic analysis of masonry buildings. *In: Proceedings of the ECCOMAS thematic conference on computational methods in structural dynamics and earthquake engineering*, Rethymno, Crete.

KTP-9-78, Albanian masonry design code. (1978).

KTP-N2-89, Albanian seismic design code. (1989).