Earthquake Performance Assessment of a Low-rise URM Building

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ABSTRACT

In the present paper, seismic performance assessment of a typical low-rise unreinforced masonry (URM) building, which has been built in accordance with template designs in Albania, has been performed. For this purpose, one of the most widely used template designed URM building typology has been selected as a good representatives of residential building stock. This type shows some particular features, typical of the traditional construction techniques at that time which could be identified as the additional potential damage sources. The building was designed and constructed in 1960 and contains details which are typical of that construction period of the region. Material properties are assessed based upon experimental test results. Then, the buildings is modeled and analyzed as 3-D assembly of finite elements. The earthquake ground motion to be used in performance assessment is determined through probabilistic seismic hazard assessment. The seismic response of the buildings has been evaluated for various earthquake levels based on Eurocode 8 and FEMA 440 guidelines. Upon the evaluation of the obtained results here for the earthquake performance of this type of buildings, useful conclusions are drawn on the strength and nonlinear behavior of masonry subjected to earthquake actions.

Keywords: *Unreinforced masonry walls, earthquake performance assessment, pushover analysis, template projects.*

INTRODUCTION

Unreinforced masonry is one of the most common structural types for low-rise construction in the Albania. Particularly, Bilgin and Korini 2012, [1] have showed that the most representative typology of essential facilities (i.e., schools, hospitals, residential buildings, police stations, .etc.) of the country corresponds to URM, which are distributed throughout the region. The construction of these buildings took place during the communist period (1944-1990). Most of these existing URM have been designed considering only gravity loads without any consideration of seismic criteria [2]. Moreover, past studies [3-6] and earthquake reconnaissance team reports have suggested that URM structures are highly prone to seismic actions. Therefore, this type of structures has high seismic vulnerability over the region. This implies that a moderate or over size earthquake might cause a disastrous result associated with the URM buildings in the country.

Recently, a group of researchers have carried out the seismic hazard of Albania, approaching the problem from both deterministic and probabilistic point of views [7]. For the scope of the study, two types of response spectra are used: Eurocode 8 [8] and Albanian seismic code [9]. Mechanical properties of the case study building have been determined experimentally and adopted for the nonlinear analysis. Seismic performance evaluation of the building has been performed by N2 method proposed by Fajfar [10]. Then, using the obtained spectral displacement and damage states suggested by Calvi [11] for URM structures, damage grades and thus the performance of the building is determined.

DESCRIPTION of the REPRESENTATIVE URM STRUCTURE

Typical URM essential facilities in Albania are template designs of low and mid-rise buildings. The structure is mainly composed of two components, namely the URM bearing walls and floor and roof diagrams. The walls are stiff with many openings and the diaphragms are usually constructed of reinforced concrete slabs. For the scope of the study, a benchmark building is selected as a representative of existing URM low-rise buildings in the region. The typical URM building, which has been studied, has three stories, brick walls of 250 mm for the load bearing walls and 120 mm for other partition walls. It has 21,85 m x 10,70 m dimensions in plan with a storey height of 2,8 m (Figure 1). Solid bricks with (250 mm x 125 mm x 60 mm) dimensions connected with cement mortar are used to build the masonry walls. The slabs are in-situ concrete ones with a height of 150 mm and a flat roof. In order to ensure a better distribution of vertical and horizontal loads, ring beams are built to create a better connection between slabs and load bearing walls.

In order to truly represent the strength and structural integrity of the case building, mechanical properties of the masonry material are obtained from the experimental tests conducted on the case study building [12]. The experimental tests are performed according to ASTM C67-09 guidelines [13]. According to the test results, clay bricks and the mortar have the 4.35 MPa and 3.88 MPa resistances, respectively and the E = 4350 MPa. The load bearing walls thickness is kept constant as 250 mm over the height of the structure.

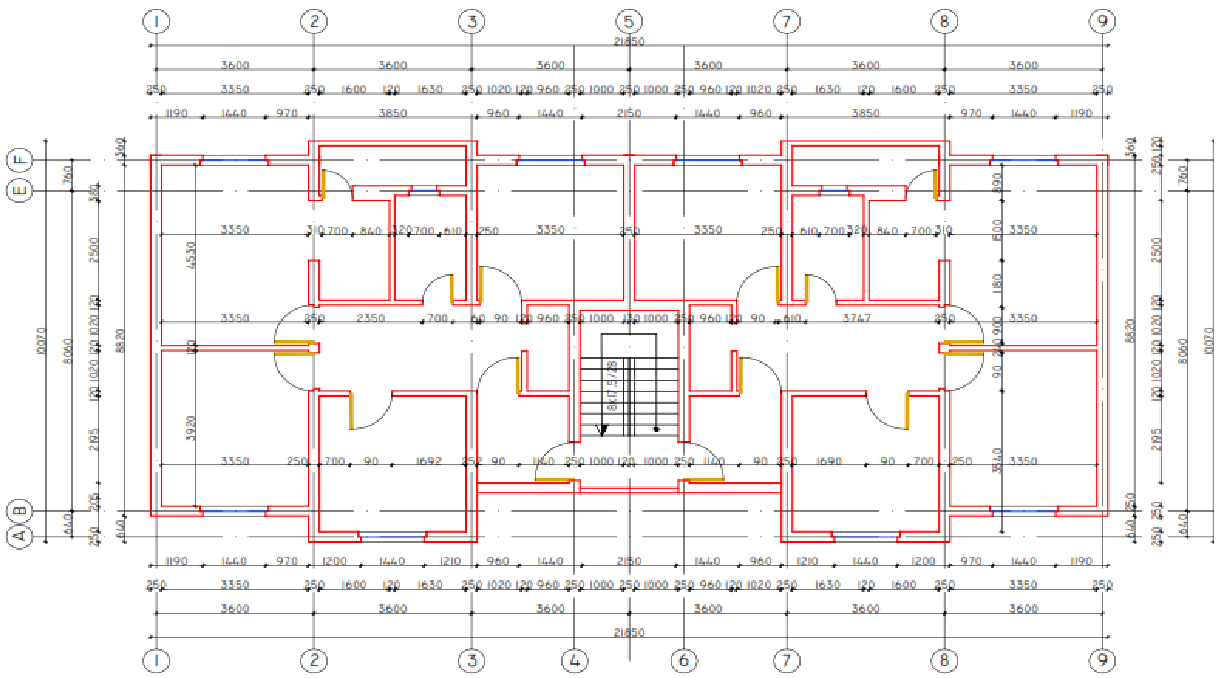

Figure 13 Typical plan view of the URM building

SEISMIC DEMAND

Albania, known with its high seismic activity, is situated on the tectonic rift that starts in South Italy, near the city of Napoli, continues with the Channel of Otranto, the cities of Vlore, Himar, Sarande, then in Thessaloniki and extends to Northern Turkey.

Earthquake loads are commonly represented by response spectrum functions. In this study, the result of a seismic hazard assessment for Lapraka area, where the building is located, is used [14]. The PGA is calculated for stiff soil conditions for two levels of probability: 10% probability of exceedance in 10 years and 10% in 50 years that correspond to two periods of 95 and 475 years repeating earthquakes. Thus, the PGA values are estimated 0.25 g for stiff soil conditions and the probability of exceeedance 10%/50 years [7]. The results are summarized in Table 1.

Table 3 PGA and Spectral Acceleration [14]

PGA	S_a (0.2s)	S_a (0.5s)	S_a (1.0s)	S_a (2.0s)
0.248 g	0.595 g	0.341 g	0.173 g	0.077 g

In this study, the demand calculations for the seismic assessment of the considered buiding are performed consideреing the soil Type B with a moderate sesimicty (0.248 g) according to Eurocode 8 [8].

STRUCTURAL CAPACITY

Modeling the URM Building

Masonry is a heterogonous material composed of two components: the masonry bricks and the mortar. Its mechanical characteristics depend upon the inherent properties of its constituents. Masonry response can be very complex under simple static loadings. In order to simulate the response of URM structure, several assumptions are made and numerical models are proposed in the literature [15].

Due to the complexity on the case study, several assumptions on the material properties and the necessity of having advanced performance computers to process the analysis, macromodeling technique is considered in this study (Figure 2). DIANA v 9.6 [16] software is deployed to conduct the numerical analysis.

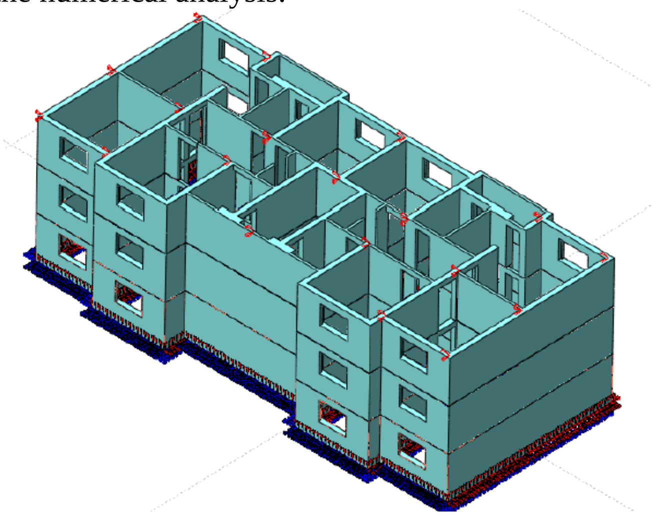

Figure 14 3D view of three storey unreinforced masonry building (DIANA v.9.6)

According to the previous experience and suggestions from the software, curved shell elements are used for modeling (Figure 3).

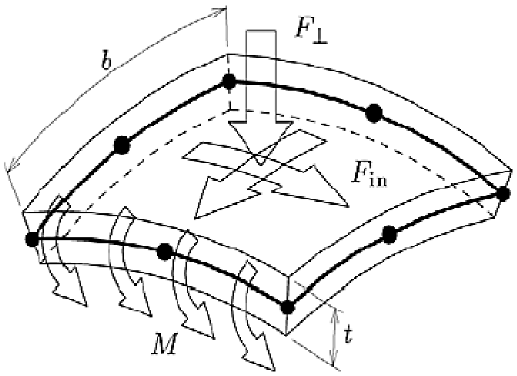

Figure 15 Curved shell element used for modeling (DIANA v.9.6)

Earthquake capacity of the URM building is obtained by pushover analysis. For nonlinear analysis, material properties are determined from experimental tests. Member sizes are used to model the selected building without making any simplifications.

ANALYSIS RESULTS

Damage Limit States

A performance level is a limit stage on the capacity curve that is used to quantify the damage. There are different approaches to damage limit states classification for masonry. Researchers like Calvi (1999) have introduced inter-storey drift ratios with three limit states. Calvi (1999) proposed three damage limit states for masonry structures as follows (Figure 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 the corresponding damage limit states.

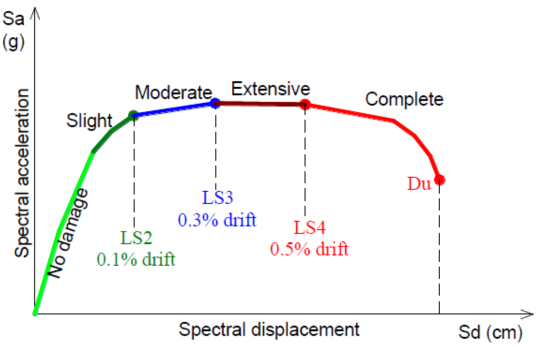

Figure 16 Damage limit states according to Calvi (1999)

Capacity Evaluation

The pushover analysis is a performance based analysis procedure which allows defining the structural response under the horizontal seismic loads and vertical gravity ones acting on the structure. The response of the structure is presented through the capacity curve which usually gives the relation between the base shear and roof displacement. It can be also plotted in ADRS format together with the demand curve and determine the top displacement under the design earthquake (performance point). The amplitudes of the seismic loads are increased in a stepwise fashion in order to observe the yielding sequences and the progress of the overall capacity curve of the structure. A non-linear static analysis is performed at each step until the structure becomes unstable.

The extended N2 method and CSM represent an assessment tool for the non-linear static analysis. However, these methods do not provide any criteria to classify the damage according to the performance point. There are various approaches to damage limit states classification for the masonry [2]. In this study are used the damage thresholds provided Lagomarsino and Penna [17] and Calvi [11]. According to Lagomarsino and Penna [17], yield point and ultimate displacement are firstly identified. After that the capacity curve is split into 5 parts (*Fig. 4*). Classification of damage state according to spectral displacement is provided in *Table 2.*

Table 2. Performance levels and criteria provided by Lagomarsino and Penna [17]

Damage state	Spectral displacement, Sd
No damage	Sd < 0.7 Dy
Slight	0.7 Dy < Sd < Dy
Moderate	Dy < Sd < Dy + 0.25(Du - Dy)
Extensive	Dy + 0.25(Du - Dy) < Sd < Du
Complete	Sd > Du

Two types of load distributions are applied for the pushover analysis, namely a linear distribution pattern and a modal distribution pattern. Capacity curves of the building with the corresponding damage limits states under both load patterns are given below (Figure. 5)

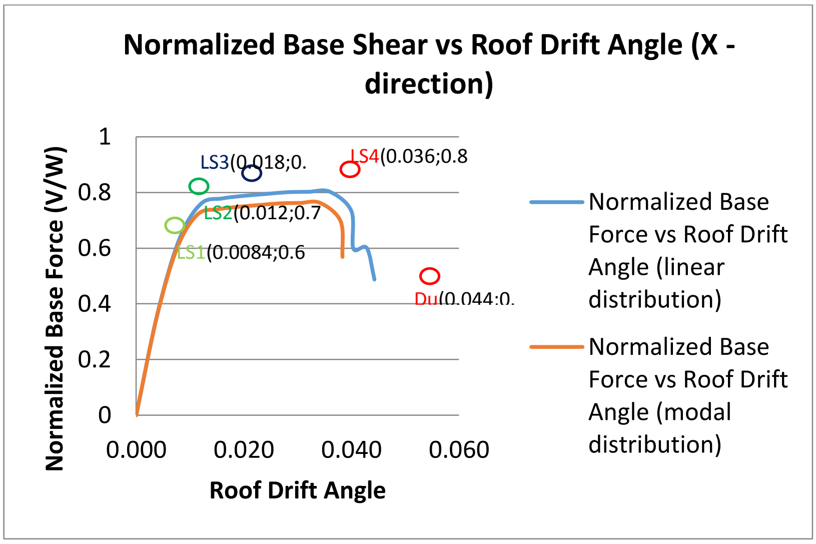

Figure 17 Capacity curve with the corresponding limit states (*x*- direction)

The linear distribution shows a more ductile behaviour of the structure than the modal one. Although the results state a ductile behaviour of the structure, the appearance of LS4 indicates an extensive damage state.

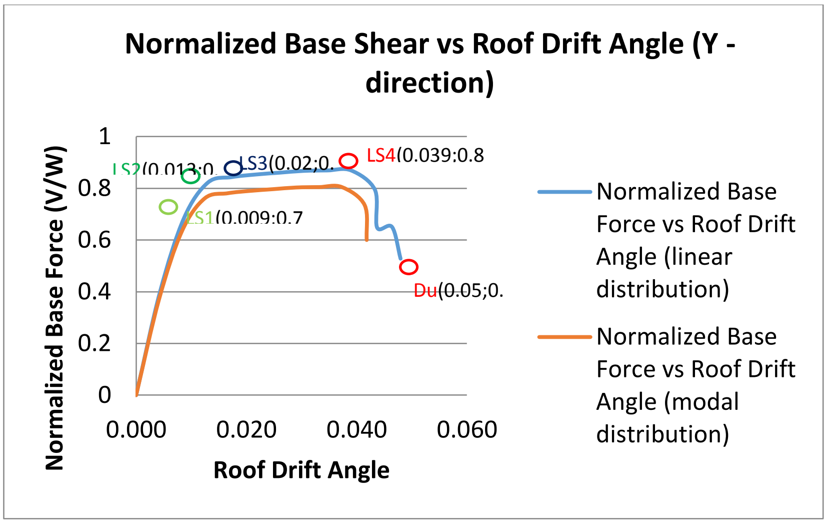

Figure 18 Capacity curve with the corresponding limit states (*y*- direction)

As in the *x*-direction, the linear distribution shows a more ductile behaviour of the structure than the modal one. Even in this direction the appearance of LS4 indicates an extensive damage state. A reason for this similarity is the distribution of the load bearing walls. They are distributed symmetrically in the two directions.

SEISMIC PERFORMANCE ASSESSMENT

As described previously, the performance point of the structure in *x*-direction is obtained through the extended N2 [10] and FEMA440 guidelines [18]. Capacity curves obtained by these two methodologies are plotted below for both directions (Figure 7-8).

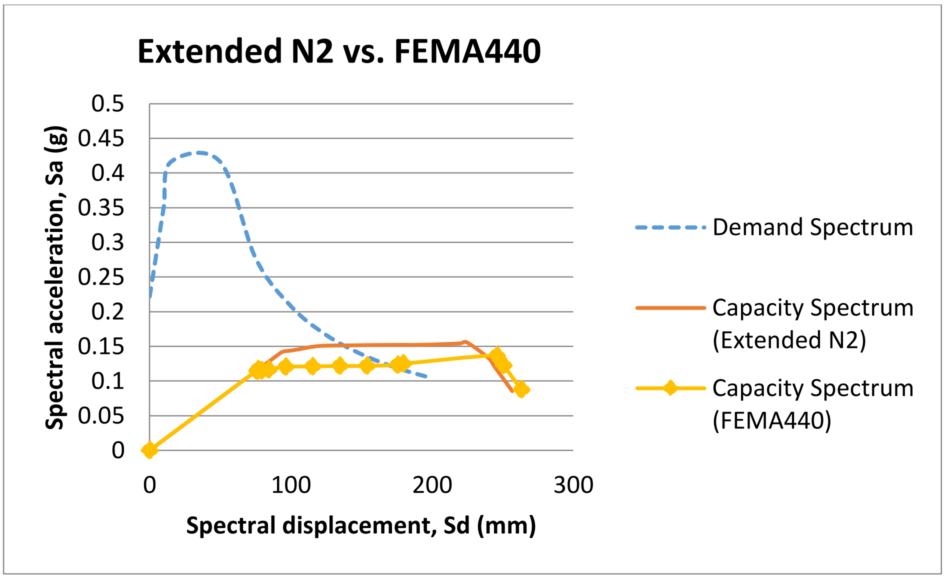

Figure 19 Performance point of URM building: Comparison of the two methodologies (*x* – direction)

FEMA440 tends to indicate a more ductile behaviour of the structure but the performance point obtained with this method is lower than the one obtained with the extended N2 method. However, both methods indicate a poor structure performance from seismic loads. This is justified by the position of the performance point: It stands between LS3 and LS4 for both spectrums.

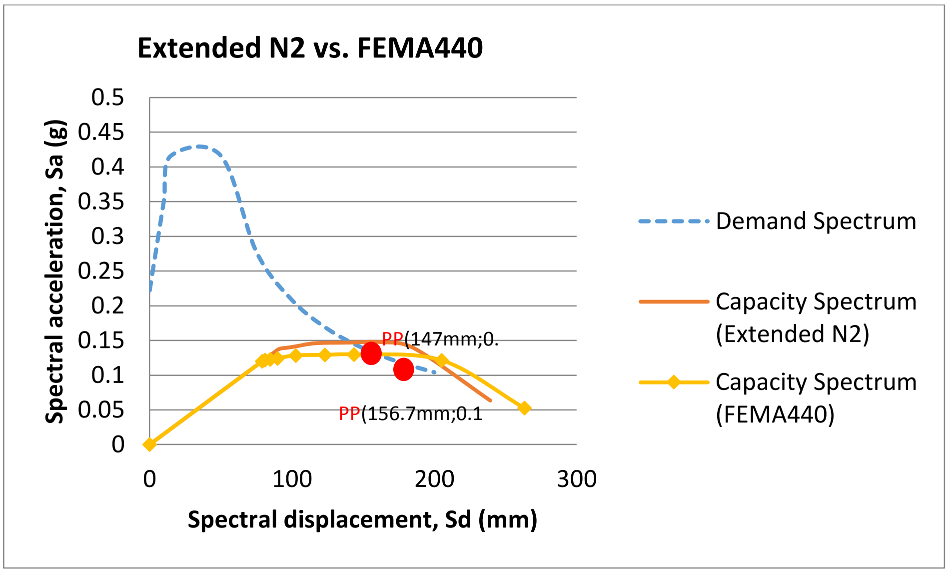

Figure 20 Performance point of URM building: Comparison of the two methodologies (*y* – direction)

Both codes indicate low stiffness in *y*-direction with a high risk of collapse. Intervention to improve the seismic capacity of the building is not economically reasonable.

CONCLUSIONS

The seismic performance of a typical 3-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 [8]. The mechanical properties of the materials used are obtained from experimental tests. DIANA v.9.6 software (TNO DIANA) [10] was employed to perform the numerical analysis phase.

Damage thresholds were determined by Lagomarsino and Penna recommendations [17], while drift limits were provided by Calvi suggestions [11]. The performance points were obtained by the extended N2 methodology [10], adopted by Eurocode 8 [8] and Capacity Spectrum Method (CSM) presented in FEMA440 [18]. According to the analysis results; capacity curves obtained by non-linear static analysis demonstrate that URM building poorly performs under earthquake loads. The presence of Limit State 4 (LS4) performance stage indicates an extensive damage state according to Lagomarsino and Penna damage thresholds.

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