Seismic assessment of historical masonry structures: The former Italian Embassy

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Abstract

Preservation of architectural heritage placed in seismic regions is an important issue. This has emerged also from the requirements of the Eurocodes that are going to replace the current design code KTP-89. This paper investigates the structural behaviour of an existing masonry building (former Italian embassy; nowadays a monument of the second category) built in the 1930s in Tirana by means of finite element analysis.

Preservation and rehabilitation of the building can be successfully achieved after a proper analysis of the structure. The static analysis of historical masonry building does not show problems to withstand vertical loads, thus attention is given to the seismic analysis. This is performed by static nonlinear procedure (pushover analysis).

Building a reliable three-dimensional finite element model of the building is essential for the accuracy of the analysis results. The model assumes that the masonry structure is homogeneous and the material behaviour is nonlinear. The masonry material strength is based in laboratory tests performed on specimens extracted from the building. The geometry of the building was based on a 2007 architectural survey and on the original plans of the 1930s.

The results of the finite element model will help to predict the local and global collapse mechanisms and assess the security based on the map of seismic risk in order to help in the identification of a proper retrofitting strategy.

Introduction

The former Italian Embassy in Tirana, today The Institute of former Political Persecuted, is a monument of the second category. It is an interesting building and with special architectonic values.

This building is part of the Albanian Built Heritage because of its architectural values and thus set under the protection of the state. The building needs continue monitoring in various fields. Problems in masonry monumental structures are usually due to seismic events, geological problems and materials decay. This paper will assess the current state of the building and its seismic behaviour during a future earthquake. Assessing the structural behaviour of an existing masonry building is a difficult task. This is due to the large number of uncertainties in the geometry of the building, connections between the structural elements, crack pattern, material properties, etc. It is widely known that masonry constructions are able to bear vertical loads and do have problems to sustain horizontal loads. To investigate this behaviour is chosen the nonlinear static analysis. The capacity curve computed from the FE model will be post processed to find the target displacement [13] and to verity the level of security of the building.

The study aims at offering a comprehension of the building behaviour under seismic loading, moreover define a possible retrofitting strategy.

Historical notes

The building is located in the center of Tirana city, next to the Albanian Parliament. It was built in two phases. The first phase comprises the central building, built in the 20”, whereas the second one was an addition in the left and back side of the building in the 30”.

Figure 1 The former Italian Embassy

After its construction it was used as the Italian Embassy (legacione Italiana) and today is used by the Institute of the former Politically Persecuted and by some retail units (basement floor). The building architecture represents the Fascism architecture of the time. It has artistic values and thus it is a monument of the second category and protected by the state. When the works started the terrain was plain in different to what we can see today. Later during the communistic regime was built the road next to the building (on the east side). During these 80 years of its history it was subject to several interventions mostly in the first floor that intended to transform its function as a basement to retail units. The most frequent intervention is switching the windows to doors. In the second and third floor the building was not subject to any structural change.

Geometrical and structural survey

The geometrical data and structural survey are based in the original Italian plans of 1930s and a 2007 survey. All these materials from different sources are confronted together and double checked with site measurements. The plan dimensions of the building ground floor are 42 m x 22m. It is a three story building. The general high is 10 m. The ground floor walls are made of stone and the two other floors walls are made of brick masonry. First floor is made of concrete whereas the other floor is made of wood. The cover of the building is made of wooden roof. The stairs from the first to the second floor are made of wood. A careful visual inspection do not show cracks in the structure, but reveals some problematic connection of the wooden floors and roof with the walls.

Figure 2 Building Main Façade (a) Today survey (b) Original Plan

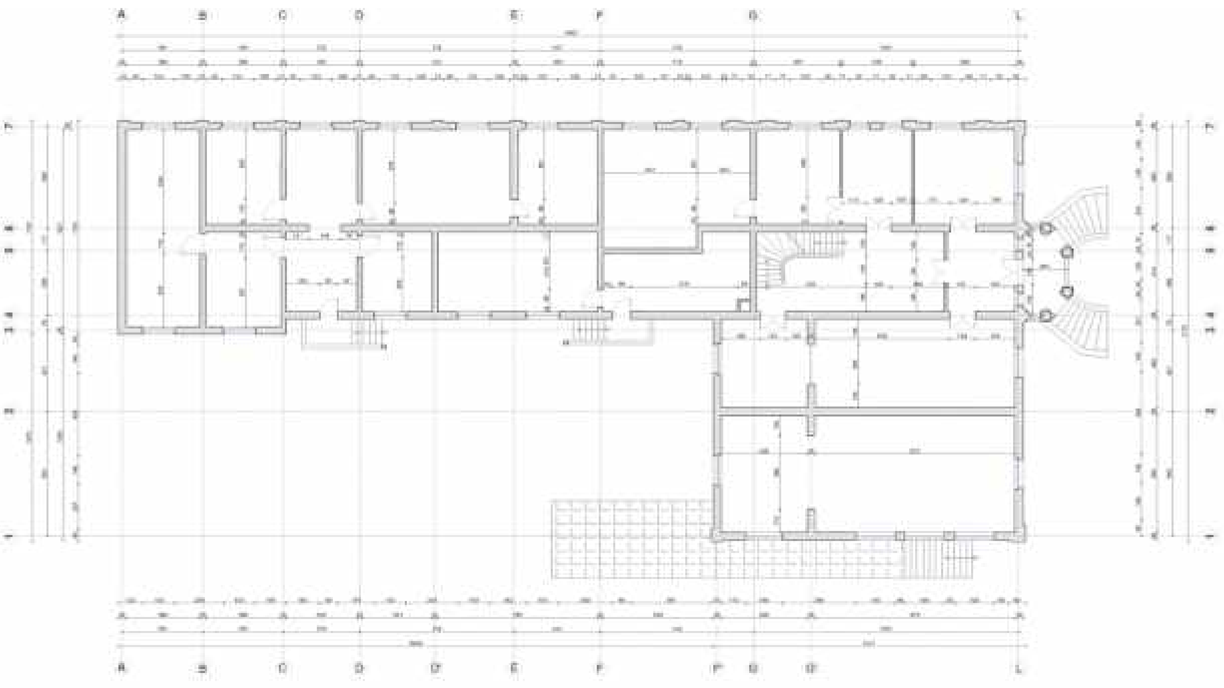

Figure 3 Plan layout of the first floor

Materials data

Tests were carried on brick masonry wall specimens extracted from the wall to evaluate its strength. For stone masonry the strength and deformability characteristics were evaluated considering the Technical recommendations and results from literature [1, 5, 8, 11].

Figure 4 Masonry wall specimens

Table 1 Material Parameters

Parameter	Brick Wall	Stone wall
Specific Weight γ (kN/m^3)	18	20
Poisson coefficient ν	0.2	0.2
Compressive Strength f_m (N/mm^2)	3	2.5
Tensile Strength f_t (N/mm^2)	0.12	0.1
Shear Strength f_{vk} (N/mm^2)	0.2	0.2
Modulus of Elasticity (N/mm^2)	1500	1250
Shear Modulus (N/mm^2)	300	270

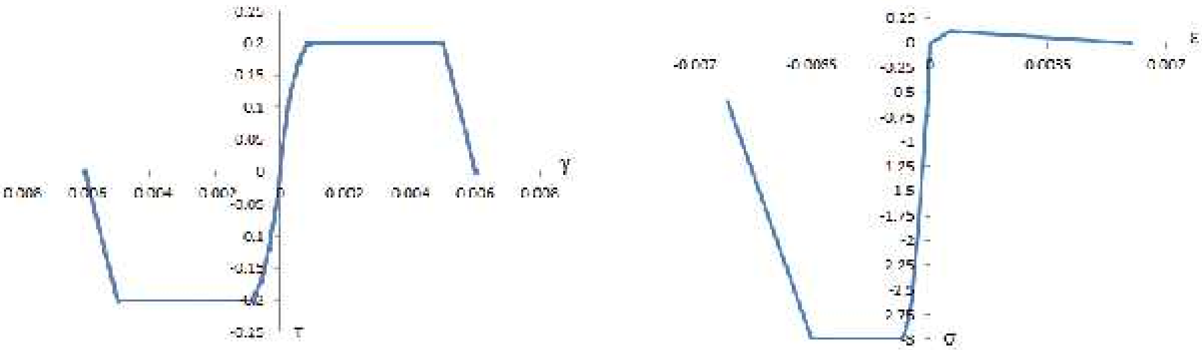

Figure 5 Constitutive law of masonry material in shear, compression and tension

Regarding the constitutive laws of masonry material, the same elastic modulus was considered in the linear part of the compression and tension curve. For the compression a linear behaviour is assumed until reaching 50% of the strength, and then the stiffness is reduced, firstly by a parabolic law, continuing after by two linear parts (simplified). The shape of the constitutive law in compression was simplified because it is expected that for masonry structure under horizontal loads the damage is expected in shear and tension, thus the post compressive behaviour would not be attained (as shown later).

Static analysis

The static analysis was carried out to assess the current state of the structure under vertical loads. The SAP2000 finite element software was used to model the structure. The model consists of nearly 5000 elements (shells and frames). This model comprises all the structural elements of the building. The material properties are described in the table 1. The load of the staircase and roof are applied in the walls. The wood floor is not taken in consideration because of its low stiffness. The loads from the floor are applied directly to the walls. The base of building is restrained.

The static analysis shows that the maximum compressive stress is 1.2 N/mm^2 reached at the basement, whereas the maximum tensile stress is 0.05 N/mm^2 reached at the upper level, due to local effects. The average stress is 0.25 N/mm^2 (compression).

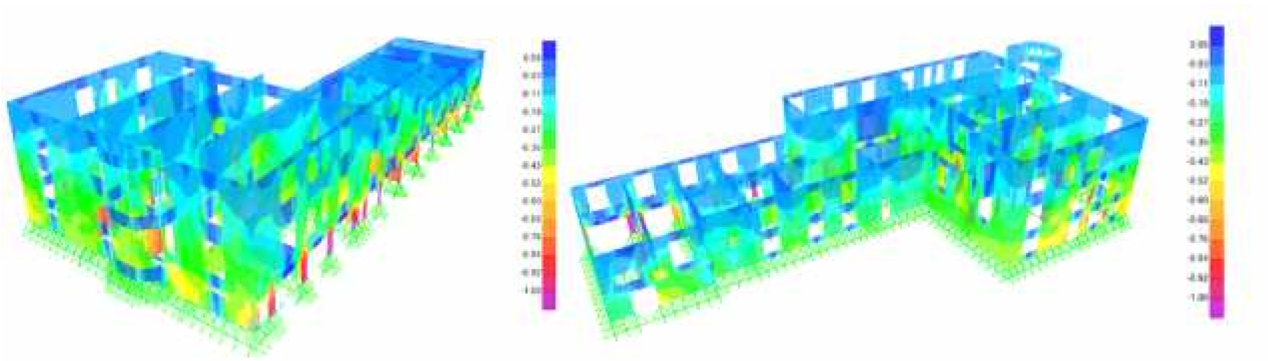

Figure 6 Stresses in masonry from static analysis

Seismic analysis

The seismic behaviour of the building was investigated by a nonlinear static procedure. The finite element model first was subject to Dead loads, after that to monotonically increasing horizontal load (push over analysis) proportional to mass. The horizontal forces are applied in two different directions independently.

Results of the pushover analysis in terms of deformed shape are presented below.

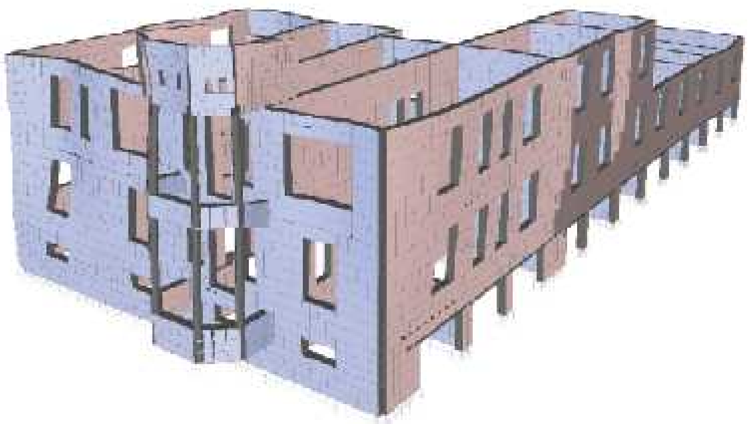

Figure 7 Deformed shape from pushover analysis in X-direction (out-of-plane failure)

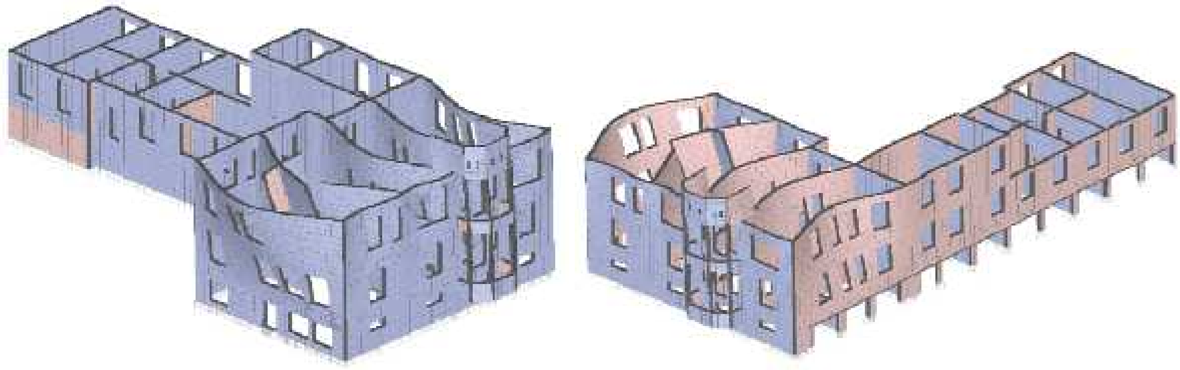

Figure 8 Deformed shape from pushover analysis in Y-direction (out-of-plane failure)

In both cases of the pushover analysis the out-of-plane behaviour is critical. Most of the walls in the central part of the building are very sensitive to the out-of-plane behaviour. This depends very much on the type of floor and on the floor-wall connection. For masonry buildings which do have the proper connection this behaviour is not critical and the capacity depends on the in-plane behaviour.

Let suppose that by ring beams, concrete floor, better anchorage or other systems we do fix the out-of-plane behaviour, so in absence of the out-of-plane failure the in-plane failure will dominate. Will this be enough to so that the building can sustain the expected peak ground acceleration predefined by the seismic risk map?

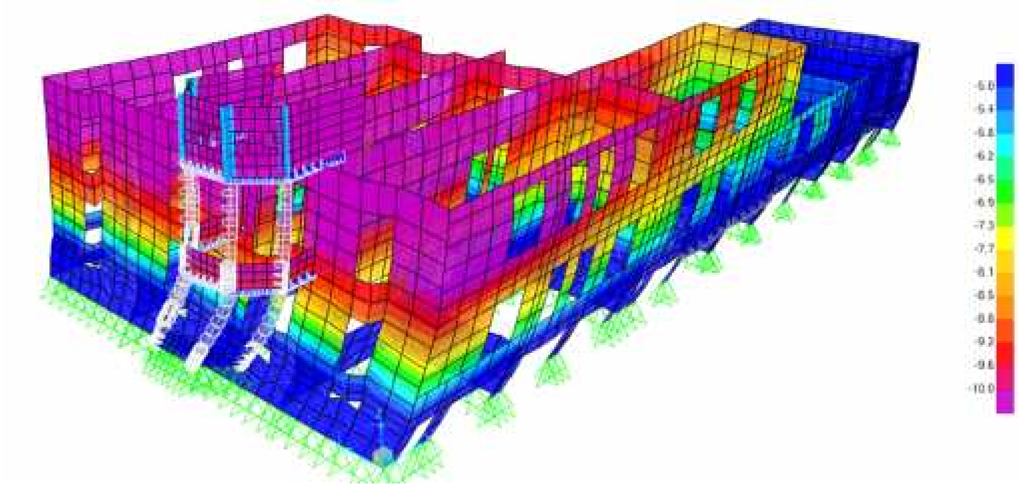

Figure 9 Deformed shape from pushover analysis in Y-direction (in-plane failure)

Now after the new improvements in the FE model the non-linear behaviour of the structure behaviour can be given by the relation of the base shear force and the roof displacement. The capacity curves for both orthogonal directions have been computed from the 3D finite element model and by superimposing the capacity curves [7] of all walls acting in the same direction.

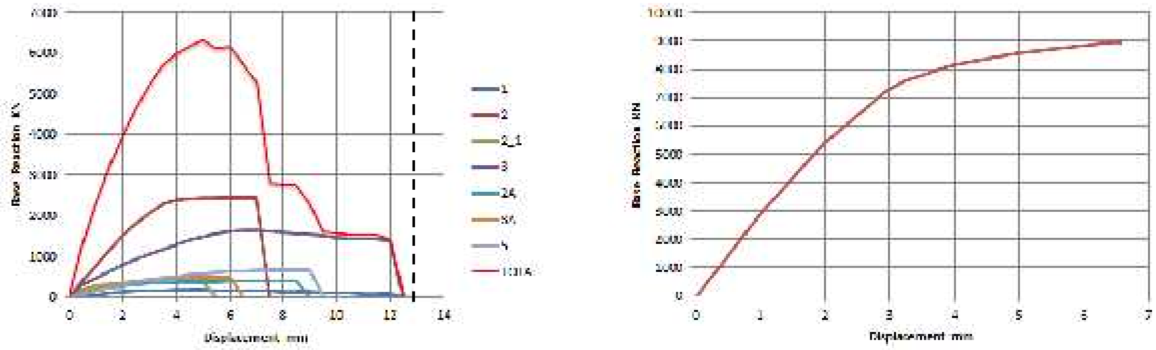

Figure 10 Capacity curves X-direction (a) Superimposing (b) 3D Model

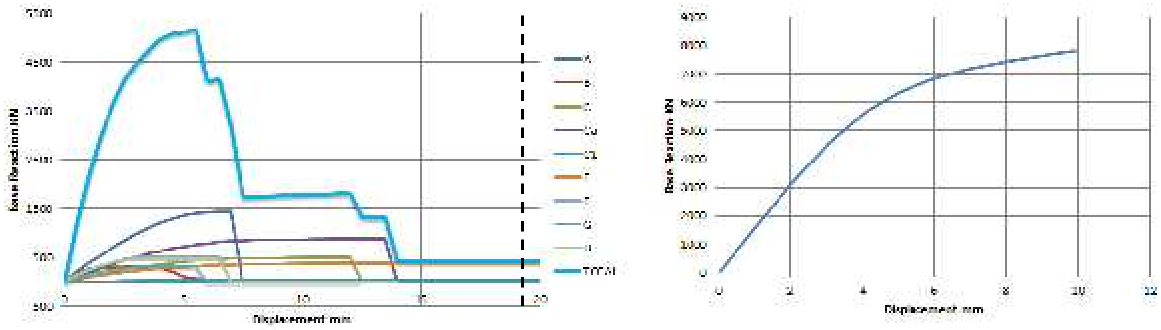

Figure 11 Capacity curves Y-direction (a) Superimposing (b) 3D Model

The capacity curves attained from the 3D model shows higher values in both directions. This is due to the collaboration of the walls in the two perpendicular directions. These curves are processed and shown later in S_a-S_d format [9].

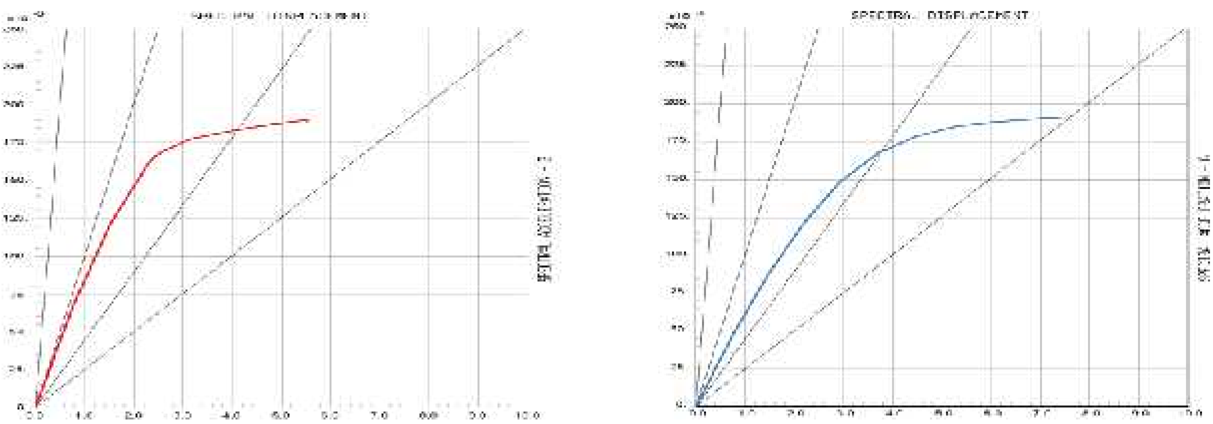

Figure 12 Capacity curves Sa-Sd (a) X-direction (b) Y-direction

The target displacement in X-direction is 13.2 mm and in the Y-direction is 19.8 mm (fig 10, 11). These results show that the structure will not sustain the peak ground acceleration $a_{g,475}$=0.248g assuming a return period of 475 years (probability of exccedance of 10% in 50 years). These results confirm once more that fixing the out-of-plane failure mode is not enough for the building to meet the code criteria [3, 12]. This analysis shows that the damage caused to the structure by removing parts of its walls (nearly 50% in the main façade) has to be repaired.

Conclusion

The building of the former Italian Embassy has been numerically analysed in order to assess its structural response under horizontal loading. The structural analysis of historical masonry buildings is particularly a complex issue since the engineer has to deal with many unknowns (geometry, material properties, structure condition, elements connection, stiffness of horizontal diaphragms, building history, etc.). The numerical study of the structure leads to the following conclusions. The static analysis shows that the structure is able to withstand vertical loads, which is confirmed by the actual state of the structure. The static incremental pushover analysis confirms that the north part as well as the west facade of the building is the most vulnerable to horizontal loads. The north part especially is very sensitive to out-of-plane failure. The retrofitting strategy should take care to prevent out-of-plane failure by improving connections between structural elements, rebuilding the removed walls, and adding steel nets to improve ductility of the whole structure.

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