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VULNERABILITY OF EXISTING MASONRY BUILDINGS IN FUNCTION OF THEIR HEIGHTS

Pristina, the Capital of Kosovo, is known by historical monographs as an old town evolving from ancient Ulpiana, built mainly of small dense dwellings. The materials used for construction were mainly stone, wood and clay bricks. Today, Pristina is known as a modern-built city, though there are still blocks of housing and other buildings built in the early 20th century with massive stone wall or clay brick system with lime mortar bricks.

The possibility of earthquakes in our country, more precisely in Pristina, that theoretically, according to available data (from the Kosovo Seismological Report), can be of great intensity. Also, the number of residents in these buildings is not small, so the human loss and economic consequences can be significant. From the above it can be roughly estimated that this existing category of buildings is more vulnerable to possible earthquake shocks, so the need to assess seismic vulnerability for these buildings is necessary.

Keywords: vulnerability, human and economic loss, assessment

1. INTRODUCTION

The existing methods for assessing the vulnerability of buildings based on result assignments are quite detailed and therefore time consuming. The more sophisticated methods, which imply a more detailed analysis and refined models, take even more time and therefore serve only for the evaluation of individual buildings, perhaps as a further step after a quick examination of the hazardous buildings, possible in a multiphase procedure.

The basic criteria for selecting 15 representative buildings out of a total of 50 stock buildings, which are further analyzed include the consideration of mainly the number of stories, are described in this paper.

In order to provide the best results on the seismic susceptibility of selected buildings, as the seismic movement of the selected entrance are three typical earthquake records:

Ulcinj - Albatros, El-Centro and, Prishtina Synthetic Earthquake Record. To implement a dynamic analysis to increase earthquake intensity, 11 Acceleration of Different Peak Ground Acceleration levels (PGA) from 0.025g to 0.50g have been adopted.

The estimated large number of 990 nonlinear seismic response analysis results for all 15 buildings analyzed are systematically evaluated.

1.1 EVALUATION METHODOLOGY FOR EXISTING VULNERABILITY OF MASONRY BUILDINGS

Detailed sophisticated methods for assessing vulnerability include detailed analysis ranging from recording real building conditions, (building inventory, geomechanics investigation, mechanical properties of material, seismic determination hazards or micro zone earthquake maps, etc.) until detailed static or dynamic structural analysis procedures (linear or nonlinear).

For the earthquake scenario project for this paper, the city of Prishtina, Kosovo, was therefore to use an analytical approach with simple building models based on nonlinear dynamic procedures. The method, which is presented in the following, is simple enough to allow the evaluation of a large number of buildings; still, the use of engineering models of the structure allow an understanding of the important parameters.

The key is to determine the vulnerability function (as shown in Figure 1) where it is the relationships which determine the expected damage to a building or a building class as a function of ground motion The capacity curve of building and seismic demand are key elements to define the vulnerability analysis.

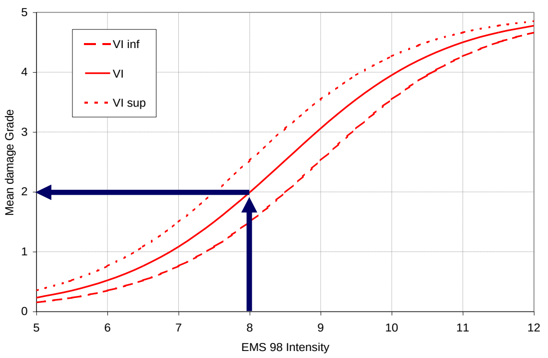

Figure 1. Vulnerability function of the building

In earthquake engineering the capacity of a building to resist seismic action is presented by a capacity curve which is defined as the base shear V_b acting on the building as a function of the horizontal displacement at the top of the building Δ, also often referred to as a pushover curve. The shear capacity of the building refers to the maximum base shear the building can sustain V_{bm} and the displacement capacity refers to the ultimate displacement at the top of the building Δ_{bu}.

Using a bilinear approximation of the capacity curve of the fictitious example building, the stiffness of the linear elastic part k corresponds to the sum of the effective stiffnesses of the walls:

$$k = \frac{V_{bm}}{\Delta_{bv}} = \sum_j k_{effj} \qquad (1)$$

To express the seismic demand, until very recently, the “intensity” was used nearly exclusively. However, information on the real ground movement is lost and empirical relationships between intensity and peak ground acceleration vary a lot. Some methods use the peak ground acceleration as the parameter defining the earthquake. The demand spectrum, respectively the elastic response spectrum (S_{ae}) is an extremely useful toll characterizing ground motions demand. It also provides convenient means to summarize the peak responses of all possible linear SDOF or MDOF systems to a particular component of ground motion.

The use of a displacement response spectrum seems therefore more appropriate. Except for very small frequencies (f < 0.2Hz) the following simple formula is used:

$$S_a \approx \omega^2 \cdot S_d \qquad (2)$$

S_a and S_d are the spectral acceleration and the spectral displacement and ω is the corresponding circular frequency, $\omega = 2\pi f$.

This vulnerability representative function should describe the overall behavior of the building and hence should be some sort of ‘mean’ of the two vulnerability functions in the two principal directions.

1.1.1 Building structure Identification

In each existing building a distinction must be made between structural and non-structural elements. The mezzanine typologies it has to identify their support direction. The masonry structural system contains the bearing capacity walls and shear walls, and their combination.

Structural elements are those elements of the building that help to support the horizontal and vertical forces acting on a building.

Every wall plane (as it is shown in figure 2) can be considered as a system of coupled walls, the case of interacting cantilever walls being a "limit case" where the stiffness of the spandrels becomes negligible with respect to the stiffness of the walls and hence the coupling effect reduces to zero [1].

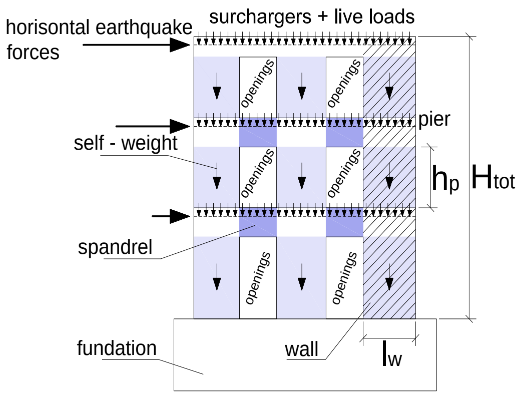

Figure 2. Masonry panel with bearing and shear walls

2. CONCEPT FOR SEISMIC RISK ASSESSMENT BASED VULNERABILITY FUNCTIONS

In many seismically active areas of the world, this type of structure accounts for only a small fraction of the building stock while a large proportion of buildings are older structures made of unreinforced masonry that pose a significant risk during an earthquake.

The integral procedure presently suggested for assessments of the expected vulnerability and seismic risk of the considered region, sub region, city, etc. should involve the following basic steps [3]:

1. identification of the present elements at risk and their distribution;
2. evaluation of the seismic hazard and its distribution;
3. derivation of the appropriate vulnerability functions applicable to the existing elements at risk (classes/level of buildings), describing the interrelation between the specific loss and seismic hazard intensity;
4. evaluation of the specific seismic risk per element at risk and the factor of participation in the existing volume of properties; and
5. evaluation of the total and/or cumulative seismic risk for the region under consideration.

2.1. ANALYSIS OF BUILDING INELASTIC EARTHQUAKE RESPONSE

In general studies, the building response in earthquake is analyzed by applying the dynamic formed inelastic model separately for the longitudinal and transverse direction of the building. The reinstatement of force in building floors the analytical model must be represented by appropriate hysterical relationships. However, the realistic values of the element model parameters are of crucial importance and should be determined based on the available experimental data and the detailed capacity analysis of the respective structural and non-structural components.

To analyze the various aspects of building dynamic behavior under earthquake excitation, in the range of the yielding begin up to the total failure, the intensity of input earthquake ground excitation must be varied in a wide range, starting form very low peak ground accelerations (i.e., PGA = 0.05 g) and then magnifying it in the case of subsequent analysis cases up to defined maximum expected level.

Considering the available statistical data from multiple analyzes of nonlinear earthquake response parameters, which basically relate the respective earthquake input intensity parameters (PGA) and computed structural response parameters (response inter-story drifts ISD), it is possible to obtain the corresponding relationships that represent structural dynamic responses in relation to the increasing intensity of earthquake land excitation in a statistical sense.

2.2. DAMAGE CRITERIA OF STRUCTURAL ELEMENTS BASED LOAD BEARING AND DEFORMABILITY CAPACITY

To establish the applicable practical element, the damage criteria which will properly reflect the most important element of the damage characteristics. The following characteristics of phenomenological failure, which characterize its hysterical behavior to the complete collapse of the elements, have been evaluated and considered.

The Figure 3 and 4 shows the range of displacement in force response and specific loss.

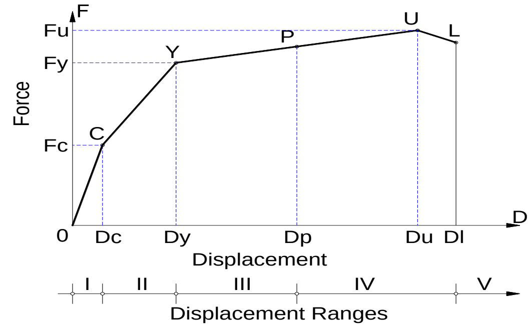

Figure 3. Envelope Curve, Force-Displacement with five ranges

The specific loss function referring to the five ranges.

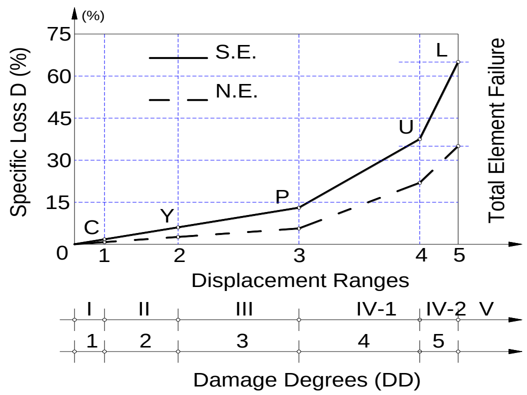

Figure 4. Specific loss functions in Structural and nonstructural elements

3. NONLINEAR ANALYTICAL MODELING FOR DYNAMIC RESPONSE

Often creation of the analytical model for the design of buildings resistant to earthquake seismic impacts considers only stiffness and deformation characteristics of structural elements of the building. This adaptation of the analytical model in many cases does not correspond to reality, where participation of non-structural elements in the overall stiffness and response can be substantial. [5].

All real physical structures, subjected to loads or displacements, behave dynamically. The additional inertia forces, from ***Newton's second law***, are equal to the mass times the acceleration. If the loads or displacements are applied very slowly then the inertia forces can be neglected and a static load analysis can be justified [4].

The force equilibrium of a multi-degree-of-freedom lumped mass system as a function of time can be expressed by the following relationship:

$$\{F\}_I^t + \{F\}_D^t + \{F\}_S^t = \{R\}^t \tag{3}$$

From there, the equation of dynamic equilibrium can be written as:

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = -\{M\}\{\ddot{U}_g\} \tag{4}$$

Equation (3) is based on physical laws and is valid for both linear and nonlinear systems, if equilibrium is formulated with respect to the deformed geometry of the structure.

4. SELECTED REPRESENTATIVE BUILDINGS

The development of the city, over time, is embryonic, forming the core towards the periphery. Old historic buildings are mainly concentrated in the City Center, including religious cult buildings, museums, public schools, and many residential buildings that are largely of a small footprint and with limited levels [1]. Figure 5 shows the existing typical masonry structure.

In the City Center there are blocks of dwelling areas, mainly built with structural masonry walls. In addition to these blocks, there are insulated buildings built in the same system, with masonry walls. Among the large number of existing buildings in the city, we have listed 55 buildings for analysis. The basic criteria for selecting buildings were the representation of a large number of buildings that can be grouped into a typical structure, the variety of the number of stories.

Figure 5. Residential Buildings in Pristina

5. SEISMIC VULNERABILITY OF ANALYZED MASONRY BUILDINGS

From the calculated results for each building in particular, comparative analysis of results is presented for different cases of building stories. Table 1. shows the analyzed building specification referring to their stories.

Table 1. Number and percentage of analyzed buildings

Number of story	No analyzed buildings	Total no of selected Buildings	Percentage of analyzed Buildings
5	2	16	29.10
4	3	14	25.45
3	7	22	40.00
2	3	4	7.30

a. Five storey/floor buildings

Displacements of separate structural elements at various levels are different and depend on the overall building stiffness for the respective directions. As building consists of five levels, displacements are not very different along orthogonal directions and are under the Ulcinj-Albatros earthquake impact at the collapse peak, displacements along the transversal direction y is 1.044cm and along the x direction is 1.732cm for PGA = 0.25g. This can be the reason of total building collapse for small PGA differences along orthogonal directions x and y.

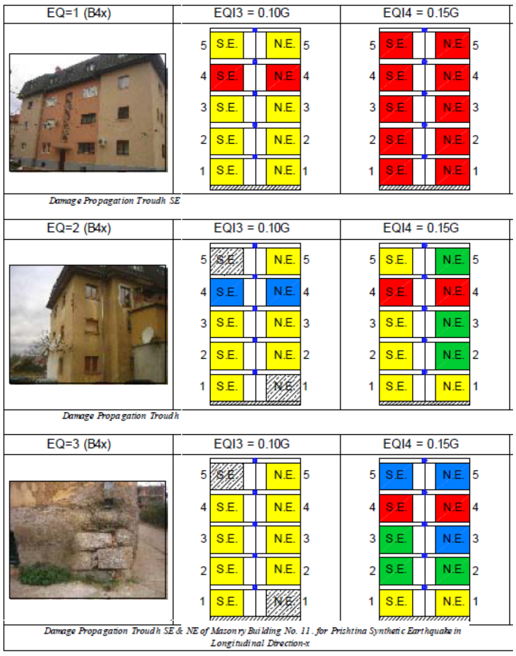

Figure 6. Damage propagation in five storey/floor buildings

Total loss is 3.45% from the total building cost in the collapse moment in case of Ulcinj Albatros earthquake acting in referent longitudinal direction-x, meanwhile structural elements take part in this loss with 2.25% and non-structural elements with 3.45%. Collapse takes place for low values of damage propagation. Figure 6 shows the damage propagation for different PGA values.

b. Fourth story/floor buildings

Maximum building displacements correspond to PGA producing collapse for the corresponding direction. Table 2 shows that values of displacements the building collapse state are not high, having in mind height of buildings.

Table 2. Maximum computed relative displacement for PGA producing collapse

No Build	Max displace (cm)		PGA (g)	Earth quake	Direct colla
	X	Y			
3	**4.149**	2.123	**0.20**	Synt.	X
7	2.073	**2.237**	**0.15**	U-A	Y
15	2.493	**2.345**	**0.30**	U-A	Y

In the stoke of buildings with four floors the horizontal displacements are bigger than five floor buildings, but collapse is happened for almost the same value of PGA.

c. Three and two storey/floor buildings

Referring to actual storey capacity diagrams we can group three storey buildings to the ones with higher capacity (buildings No. 14, 4, 12, 9, 8, 2) and building No.10, which has a lower **storey** capacity respective direction, see table 3.

Table 3. Maximum computed relative displacement for PGA producing collapse

No Build	Max displace (cm)		PGA (g)	Eart h qua ke	Direct colla
	X	Y			
2	**2.161**	**2.082**	0.25	U-A	X & Y
4	1.239	**3.474**	0.20	U-A	Y
8	**1.945**	1.099	0.25	U-A	X
9	1.201	**2.064**	0.25	U-A	Y
10	**1.732**	1.044	0.25	U-A	X
12	**3.385**	0.825	0.30	U-A	X
14	**2.228**	0.715	0.15	U-A	X

Even though collapse takes place, the computed values of relative displacements are considerably low. The results prove that collapse takes place in the first and in the second storey, and always under the impact of considered Ulcin Albatros earthquake record.

For the class of two-storey buildings it is also evident that relative displacements in the collapse stage are relatively low.

6. CONCLUSIONS

Finally, it can be concluded from the theoretical analysis carried out above and the results presented that all the buildings analyzed collapse under relatively low intensities of earthquake impacts. This observation is a direct confirmation of the expected level of intolerable vulnerability for this type of buildings that were built in the past essentially as non-seismic buildings.

Table 4. Damage propagation and collapse PGA for buildings classified by the number of storey

PGA	0.10 g	0.15 g				0.20 g	0.25 g	0.30 g		0.45 g
Number of storey Building										
Building Range	11	6	3 and 7	14	1 and 5	4	2, 8, 9, 10	12	15	13
no	14	1	6+1 = 7	6	2	1	1+6+2+5 =14	1	7	2
Percent	25.45	1.80	12.73	10.91	3.60	1.80	25.45	1.80	12.73	3.60

Table 4, figure 7, 8 and 9, leads us to conclude that buildings with larger number of storey's collapse under small PGA values, and lower buildings are more resistant to dynamic impacts. This however cannot be accepted as a general rule in evaluation of collapse based on the number of storey's, since the building response depends on many other factors that can be leading to developed different damage level.

For the small PGA value, it can be observed that SE and NE of buildings with more storey/floors receive initial cracks, as opposed to the buildings with small number of storey/floors which in the case of this small earthquake intensity level.

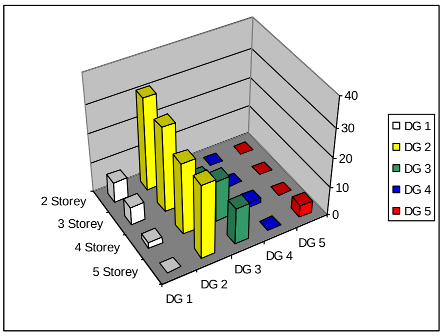

Figure 7. Damage distribution for the classes based on number of the story's under Ulcin Albatros earthquake, PGA = 0.10g, longitudinal x-direction

Multi-storey masonry buildings with load bearing and shear walls, are more vulnerable to earthquakes compared to buildings with low levels. This is also due to the fact that these structures are massive and consist of composite materials that have poor tension capability. Structural elements of masonry buildings that are exposed to earthquake impacts of varying magnitude behave as rigid elements with very low ductility.

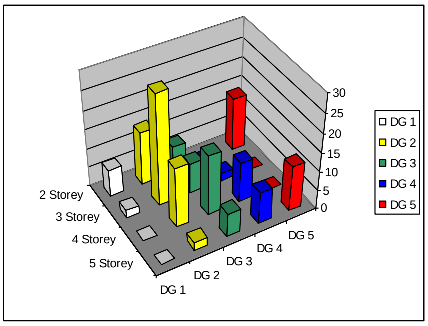

Figure 8. Damage distribution for the classes based on number of story's under Ulcin Albatros earthquake, PGA = 0.15 g, longitudinal x-direction

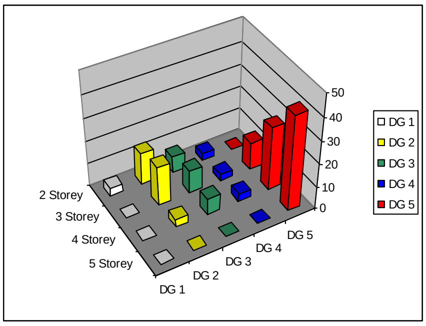

Figure 9. Damage distribution for the classes based on number of story's under Ulcin Albatros earthquake, PGA = 0.25 g, longitudinal x-direction

REFERENCES

[1] Grajcevci Florim. "Seismic Behaviour And Vulnerability of Existing Buildings In Prishtina – Kosova", PhD Skopje, 2010.

[2] E. Dumova-Jovanoska, L. Denkovska, *"Classification of Unreinforced Masonry Buildings' Concerning their Seismic Vulnerability"*, UK, August,1995.

[3] E. Dumova, P. Stojanovski, *"Knowledge Base for Evaluation of Seismic Vulnerability of Unreiforced Masonry Buildings – UMDAS"*, Italy, June, 1994.

[4] E. Dumova-Jovanoska, *"Synthesizing Artificial Earthquakes time histories which reveal the seismity of a certain region"*, September, 2004.

[5] Ristic, D., *"Building Damage Classification and Development of Empirical Vulnerability Functions",* Project IRA/90/004, Tehran 1992.