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Study on the Earthquake Action of Old Masonry Structures

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Abstract: In this study, the behavior of three historical buildings under earthquake was evaluated with experimental and numerical methods and numerical model was correlated with the experimental results. Many old masonry buildings are historical monuments and their preservation is a priority for every nation. Earthquakes are a serious threat to historical monuments because they were not designed with the current level of structural elements knowledge. Old structures were only designed to withstand gravitational loads and the horizontal loads weren't included in this process. In the earthquake evaluation process, according to EUROCODE 8, a behavior factor, q, is included. This behavior factor accounts for the energy dissipation capacity and its value varies according to the type of structure. Because the walls are made from masonry in this study, in theory, the behavior factors have values between 1.5 and 2.5. In practice, this is not true because existing buildings can have cracks, moisture and damage that affect the dissipation capacity of the structure. In this case, the value of q must be smaller, but the typical values cannot accommodate this fact. The aim of this study is to show how damages in existing structures affect the value of the q and establish the reference values for this important parameter.

Key words: Masonry, earthquake, safety, behavior, durability

INTRODUCTION

The significant number of buildings constructed in the world before the appearance of compulsory earthquake projecting norms, as well as the subsequent construction in the safe seismic zones, necessitates a constant re-evaluation of the strength of the structures.

Many old buildings are historical monuments and their importance is critical from a cultural standpoint. To preserve these monuments, each case must first be analyzed to establish the degradation and safety level of the structure. Because financial resources are limited, a priority list must be made according to the degree of safety and the importance of each objective. To discover the most urgent situations to be analyzed, engineering specialists can establish the objectives with specific tests and analysis and propose appropriate intervention.

The safety degree evaluation has five steps, which are shown in Fig. 1. To get a reliable result, each step must be performed carefully.

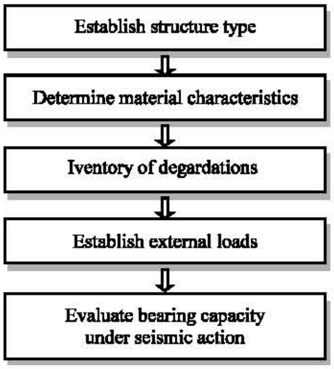

Fig. 1: Steps to establish the safety degree of old historical monuments

ESTABLISHING THE STRUCTURE TYPE

The first step in structural analysis is to establish the structure type. This step can appear simple from a technical point of view because a visual examination can easily be made. Because reinforced and pre-stressed concrete are relatively new materials, in most of cases, old historical monuments have a masonry structure.

In fact, this step is not so simple because interventions on very old buildings are usually added throughout time. In many cases, the documents (e.g., projects and plans) are lost and some supplementary tests must be performed.

The simplest method to analyze internal structure is infrared thermography (Meola, 2007). This method uses the principles of thermal energy absorption, transmission and emission to distinguish between hollow and grout-filled cells in masonry.

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In this method, an infrared camera is used to detect relative differences in thermal radiation from a masonry surface. Hollow or insulated masonry cells act as a thermal barrier in masonry construction. Solidly grouted cells act as a heat sink and transmit the majority of the thermal energy through the masonry section. Because the majority of the heat is transmitted through a grouted cell, very little thermal energy is emitted back in the direction of the heat source. In short, hollow or insulated cells emit more energy than solid grouted cells.

This method is very easy to apply to external walls where the sun warms the surface, but for internal walls, it is necessary to use some heating elements before analysis.

Because this method can only differentiate between hollow and solid masonry cells (steel cannot be detected), it is often coupled with another methods to locate and evaluate reinforcement installation.

A better method to analyze the structure is the use of surface penetrating radar. This method utilizes the principles of electromagnetic wave propagation and reflection to distinguish between different material interfaces. The main unit emits a series of discrete electromagnetic wave pulses that travel through the material of interest. When the wave passes through different materials, the propagation of the wave alters and some or all of the wave energy reflects from the interface between the two materials. Air, steel and grout within a masonry wall reflect the radar signal at their interfaces. Steel is a perfect reflector of electromagnetic waves, while masonry, grout and mortar reflect only a portion of the electromagnetic energy. Air causes rapid attenuation of the electromagnetic wave and is readily distinguishable in the reflected wave signal.

Voids in grout space and reinforcing bars or profiles embedded in grout space can be identified with this method. However, the surface penetrating radar method cannot be used to directly determine reinforcing bar diameters.

To determine the reinforcement bar diameter, a pachometer or profometer must be used. The profometer is the most recent generation of pachometer and uses the latest in microprocessor technology. Both tools use the pulse induction measuring method, but the profometer has enhanced accuracy because the instrument is virtually insensitive to external interference. In addition, a correction can be included to take into account the effect of adjacent, parallel bars on diameter determination and concrete cover measurements.

DETERMINING MATERIAL CHARACTERISTICS

The mechanical characteristics of materials change with time and are very difficult to establish after many years. For example, even the strength in compression for a brick is known initially; after one hundred years, the change can be significant. Many factors can influence the strength of materials: for example, external loads, moisture, chemicals and freeze-thaw cycles.

Thus, the mechanical characteristics of materials must be determined. This is accomplished using either destructive or non-destructive test methods. Because destructive methods are not recommended on historical monuments, non-destructive methods are usually used.

One method of establishing the strength of bricks under compression is the hardness test with a Waitzmann hammer (Brozovsky *et al.*, 2007). This method is based on measuring a dimple created in the material by thrusting a tool of defined size into the material.

Dimple diameters are detected with a foil laid on the tested material and compared to the diameter of the reference hammer. During testing, the hammer exerts a pressure force so that the dimple diameter on the reference bar is approximately 2 mm. The advantage of the Waitzmann hammer, as compared with other impact hammers, is that its thrust is automatically eliminated. Body cracks do not significantly impact compression strength.

Similarly, penetration tests can be applied on mortar. Felicetti and Gattesco (1998) propose a simple method to establish the mechanical response of mortar in old masonry buildings.

Another method used to establish the mechanical characteristics of masonry is the ultrasonic impulse method. The method consists of measuring the travel time of an ultrasonic pulse passing through the masonry block. A comparatively higher velocity is obtained when the masonry quality is good in terms of uniformity and homogeneity.

The efficiency of the ultrasonic pulse method in determining masonry characteristics is disputable, although helpful in some cases. This method becomes useless if pores, cracks and/or voids are partly or completely filled with ice, salt crystals or other solid materials.

The most effective test on masonry uses flatjacks. Flatjack testing is a non-destructive way to evaluate the stress condition of *in situ* masonry (Carpinteri *et al.*, 2009).

The flatjack is an envelope-like bladder made of two sheets of thin stainless steel. Each sheet is generally 1 to 6 mm thick. They are either rectangular or circular in shape, as shown in Fig. 2. The jack has an inlet and outlet port so it can be pressurized with hydraulic oil.

Mortar joints in a local building are cut out and preloaded. Before cutting the wall, the original dimensions are measured between gage points. Once the cuts are made, flatjacks are loaded into the cuts and readings

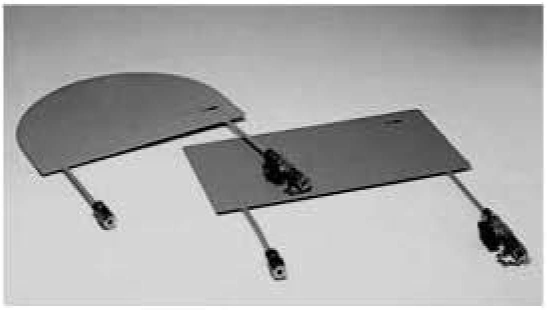

Fig. 2: Rectangular and circular flatjacks

between the gage points are taken at various pressures. From this data the stress present in the wall before the cuts were made as well as the modulus of elasticity of the masonry can be back-calculated. After data for both tests are obtained, the cuts are repaired with mortar.

Three methods of testing are used:

- Flatjacks control normal compressive stress to determine mortar joint shear strength index with normal compressive stress. The horizontal displacement of the test unit is monitored in this test
- Without flatjacks controlling the normal compressive stress to determine the mortar joint shear strength index when using an estimate of the normal compressive stress at the location of the test site, the horizontal displacement of the test unit is not monitored during this procedure
- With the flatjack applying a horizontal load to determine the mortar joint shear strength index using an estimate of the normal compressive stress at the location of the test site, the horizontal displacement of the test unit is generally not measured during this procedure

A new method based on acoustic emission was proposed by Carpinteri and Lacidogna (2006). The damage processes were monitored using this technique and an estimation of the amount of energy released during the fracture process is made. A new theory is proposed based on fractal concepts for assessing the stability of masonry structures from the data obtained with the acoustic emission technique.

INVENTORY OF DEGRADATIONS

Mechanical characteristics of masonry determined in the previous step are only representative for the good part of the structure. Cracks, voids and other degradations can diminish these characteristics and affect the bearing capacity.

It is very important to make an inventory of all degraded parts of the structure because they must be taken into consideration in the final evaluation of the structure.

This step appears to be easy because the cracks, moisture and other problems can be found with a simple visual inspection. In fact, many times these problems are fixed improperly by simple covering them with plaster. This is a very dangerous situation because, even though the cracks exist, they are not visible.

Thus, it is very important to analyze the structural walls with advanced methods, like infrared thermography, the surface penetrating radar or acoustic emission methods.

ESTABLISHING EXTERNAL LOADS

Gravitational loads are known and can be established easily according to actual prescriptions. A much more difficult problem is to evaluate the seismic action for existing buildings. The seismic load is the same for new and old building, but there is one major difference.

For example, according to EUROCODE 8, the design spectrum $S_d(T)$ for the reference return period, normalized by the acceleration of gravity g, is defined by the following expressions:

- $S_d(T) = \alpha S.\left[1+\frac{T}{T_B}.\left(\frac{\beta_0}{q}-1\right)\right]$ if $0 \le T \le T_B$
- $S_d(T) = \alpha.S.\frac{\beta_0}{q}$ if $T_B \le T \le T_C$
- $S_d(T) = \alpha S.\frac{\beta_0}{q}\left[\frac{T_C}{T}\right]^{k_{d1}}$ if $0 \le T \le T_B$
- $S_d(T) = \alpha S.\frac{\beta_0}{q}\left[\frac{T_C}{T}\right]^{k_{d1}} \ge 0,2\alpha$ if $T_C \le T \le T_D$
- $S_d(T) = \alpha.S.\frac{\beta_0}{q}\left[\frac{T_C}{T_D}\right]^{k_{d1}}.\left[\frac{T_D}{T}\right]^{k_{d2}} \ge 0,2\alpha$ if $T_C \le T \le T_D$

with the values of α, β_0, S, T, T_B, T_C, T_D, q, k_{d1}, k_{d2} as defined in EUROCODE 8.

The difference between old and new buildings is evident in two parameters: the vibration period of a linear single degree of freedom system T and the behavior factor q.

To determine the vibration period T of the existing structure, it is extremely important to know the effective mechanical characteristics of the construction materials precisely. These characteristics continuously diminish over time because of static and dynamic fatigue, as well as internal structure continuity deterioration under utilization strains.

Moreover, cracks, moisture and other degradations decrease the stiffness of the building and increase the vibration period T. Because the weaknesses are not uniformly distributed on the structure, the analytical model used in the computation presents a high degree of imprecision, which is mainly determined by insufficient knowledge of the degraded material properties and the bond between strong and weak zones of the structure.

Luciano and Sacco (1998) proposed a mathematical model to analyze the behavior of damaged masonry with finite elements. The model defines a new type of finite element with a damage variable and can evaluate the new value of vibration period T according to the damages.

Cuadra *et al.* (2008) used the microtremor measurements to estimate the dynamic characteristics of the stone structures and to calibrate the analytical model.

The results obtained with analytical analysis can be partially corrected by statistically computing the measured data, but a probabilistic interpretation requires a great volume of information which must be obtained with a significant amount of material and human effort.

The behavior factor q takes into consideration the strength of the structure seismic energy dissipation capacity. Thus, many parameters that are difficult to evaluate must be taken into account: the construction ductility, the stress re-distribution capacity, the extent to which the neglected strength reserves intervene in the calculus following an advantageous general behavior, as well as the vibration damping effect, others than those associated with the structure strength. For new masonry buildings, the values of the behavior factor are shown in Table 1. The recommended behavior factor q is justified only in the case of new constructions, which simultaneously fulfill both the ductility and strength conditions.

The behavior factor for the existing buildings is different from that of a new construction because old structures have already experienced several earthquakes. If rehabilitation measures were not applied after each seismic action, a big part on the strength reserves was consumed in previous earthquakes.

If cracks and damage are present in structural elements, ductility is significantly decreased and the behavior factor must be smaller.

Further, the re-distribution capacity of the structure depends on the stiffened-plate effect of the floors. When one vertical wall reaches it's bearing capacity and cannot take more horizontal force from the earthquake, the stiffened floor transfers this force to other vertical walls that can support supplementary stress. The stress is redistributed between vertical members and the structure can pass through the earthquake. If the floors are timber, the horizontal stiffness is weak and the redistribution of the horizontal force is only partially ensured.

Table 1: Behavior factors according with EUROCODE

Type of masonry structure	Behavior factor q for new buildings
Unreinforced masonry	1.5
Confined masonry	2.0
Reinforced masonry	2.5

When the behavior factor was established, it took into consideration some minimum constructive measures to ensure the general ductility of the structure (e.g., rigid floors and confined walls for high structures). These measures were not applied on old buildings because they were unknown at the time.

In conclusion, the behavior factor q used for new buildings cannot be applied to old constructions, because its unrealistic big value induces an over-estimated bearing capacity and a false sense of security. Unfortunately, European norms do not give any different values for existing buildings, even though they accept the difference between old and new structures.

Thus, the authors propose a new method to establish the behavior factor according to the age of the structure, seismic zone and structural degradations. This method was improved and verified on three old masonry buildings, which are presented in this study.

The age of the structure significantly influences the behavior factor, not only from a material point of view (older materials are weaker materials), but from two other viewpoints: the engineering knowledge used in the design process and previous earthquakes experienced by the structure. If a structural rehabilitation is made, the initial bearing capacity can be restored and even exceeded if some supplementary elements (e.g., reinforced concrete members or steel profiles) are embedded in the structure (Gouveia and Lourenco, 2007).

The design process is continually changing and initially, only vertical loads were used to check structural elements. Horizontal loads, like wind and earthquakes were only withstood by the structure through constructive measures. During the 20th century, when design skills greatly expanded, buildings were capable of withstanding horizontal loads because of proper measures.

Table 2 shows the influence of the construction age on the behavior factor; q is the behavior factor for new buildings according to EUROCODE 8.

Table 2: Influence of age on the behavior factor

Age of the structure or time passed from last rehabilitation (years)	Behavior factor
Under 20	q
Between 20 and 50	0.94q
Between 50 and 100	0.89q
Over 100	0.80q

Table 3: Influence of earthquakes withstood by the structure on the behavior factor

No. of earthquakes with magnitude bigger than 6 on Richter scale passed by the structure without rehabilitation	Behavior factor		
	Strong seismic zone	Medium seismic zone	Weak seismic zone
One earthquake	0.90q	0.93q	0.96q
Two earthquakes	0.78q	0.85q	0.91q
Three earthquakes	0.62q	0.75q	0.84q
Four or mode earthquakes	0.45q	0.63q	0.75q

Table 4: Influence of various degradations on the behavior factor

No. of degraded zones	Behavior factor
Few small areas under 10% of the structure	0.95q
Medium areas under 50% of the structure	0.90q
Big areas, over 50% of the structure	0.85q

Every large earthquake consumes part of the structural ductility and the bearing capacity of the structure decreases. Energy consumption depends on the seismic intensity and in this study, all considered earthquakes had a magnitude greater than 6 on the Richter scale.

Because the earthquake magnitude is measured at the epicenter and the structures can be far from this point, three seismic zones are defined according to the design ground acceleration value for the reference return period a_g:

- Strong seismic zones with a_g>0 25
- Medium seismic zones with 0, 16<a_g≤0 25
- Weak seismic zones with 0, 16 <a_g≤0, 25

Table 3 presents the influence of earthquakes with a magnitude greater than 6 on the Richter scale that the structure withstood without any structural rehabilitation. If the structure has degradations from other causes than earthquake (e.g., settlements or dynamic live loads), they affect the behavior factor according to Table 4.

If more than one criterion is present for the same structure, the reduced value of q from various criteria is cumulative.

EVALUATION OF BEARING CAPACITY ON SEISMIC ACTION

In theory, each loaded cross-section of the structure is verified analytically by comparing the designed resistance value with the external values. According to EUROCODE 8, seismic action is verified computationally according to the following relation:

$$\gamma_{Sd} \cdot E_{new,d} \leq \frac{1}{\gamma_{Rd}} R_{new,d}$$

where, γ_{Sd} and γ_{Rd} are two safety coefficients, $E_{new,d}$ is the external seismic action and $R_{new,d}$ is the design resistance value of the computed cross-section (Griffith *et al*., 2003).

This relation can be applied to new buildings, but for old buildings, this check is useless. Over time, research identifies new details about earthquakes and the prescriptions change frequently. First, seismic norms had only a few requirements, but the number of restrictions increases with every new revision.

According to the EUROCODE, after each new revision of the seismic norms (with new requirements), the old buildings are unsatisfactory according to the new requirements and must be rehabilitated. This conclusion is not a rational one and the EUROCODE check is too restrictive.

For example if the seismic norm changes every ten years, all new buildings erected in this time must be rehabilitated because they do not satisfy the new requirements. To correct this situation, EUROCODE 8 defines a global seismic resistance index to establish the intervention priority. The EUROCODE correction is only partial because no reference value is specified for the global seismic resistance index. Thus, its value is useful to identify the top priority out of more than one building, but if only one building is analyzed, the global seismic resistance index is useless from the EUROCODE 8 point of view.

Similarly, with some global seismic resistance index, some norms from European countries define a safety degree factor as the ratio between the designed resistance value and seismic action (with proper safety coefficients):

$$S_f = \frac{\frac{1}{\gamma_{Rd}} R_{new,d}}{\gamma_{Sd} E_{new,d}}$$

For a new building, the safety degree factor S_f is greater than one. For old structures, a value greater than 0.6 is satisfactory; the priority is low and no urgent rehabilitation interventions are necessarily. In other cases, a lower value of the safety degree factor increases the intervention priority (Mihai and Florea, 2005).

In conclusion, to decide if rehabilitation measures are required for an old building, a safety factor or a similar value must be evaluated. To establish this value, the bearing capacity of the structure is compared with external seismic action. The main problem occurs because of seismic force because the behavior factor q for old buildings is smaller than that of new constructions. In this case, the real seismic action is greater than the theoretical value estimated with seismic norms.

This is a very dangerous situation because underestimating of the seismic force overestimates the safety degree factor. A greater safety degree factor induces a false sense of security and delays intervention on the structure.

To illustrate this potentially dangerous situation, three cases are presented: the Palace of Culture Iasi, The Great Synagogue Iasi and the Aroneanu Church, which are all in Romania.

Study case 1: Palace of Culture Iasi: The Palace of Culture, acknowledged as an effigy of the city of Iasi, was built in the neogothic style and, as such, was one of the last expressions of Romanticism in official architecture as shown in Fig. 3A and B.

The edifice was built between 1906 and 1925 and is the most outstanding work of the Romanian architect I.D. Berindei, who was trained at the Parisian School. Decoratively, the central hall shows a figurative mosaic that includes various representations of a gothic bestiarum, concentrically arranged: two-headed eagles, dragons, griffons, lions. The hall is superposed by a glass ceiling room, where a greenhouse was initially arranged.

In spite of its archaic-looking design, the Palace was designed to integrate modern materials and technologies. Thus, the stone blocks were replaced with lighter and much cheaper materials. In addition, some rooms were decorated using a special material licensed by Henri Coandã, under the name of bois-cement and imitation oak wood. Decorative ironmongery elements are also remarkable and they can be admired, for instance, on the doors of Voivodes' Hall. The building was also equipped with high-tech facilities for the time.

Equipment includes electric lighting, pneumatic heating, ventilation system, thermostat, vacuum cleaners, which are all directed from the machinery room, at the basement level.

Taking also into account the 14 fires that affected previous buildings, Berindei treated the wooden structure of the attic with a fireproof product and for the roof, he used a special material. Because degradations appear over time and affect the structure, the building was analyzed to establish its behavior under the static and seismic actions.

According to the EUROCODE, the behavior factor was 1.5 and the safety degree of the building was 0.48. According to Romanian norms, 0.48 is an acceptable value and the priority for intervention is low.

Over time, the building suffered six large earthquakes and cracks are present throughout the structure. Further, because the building is placed on the edge of a hill,

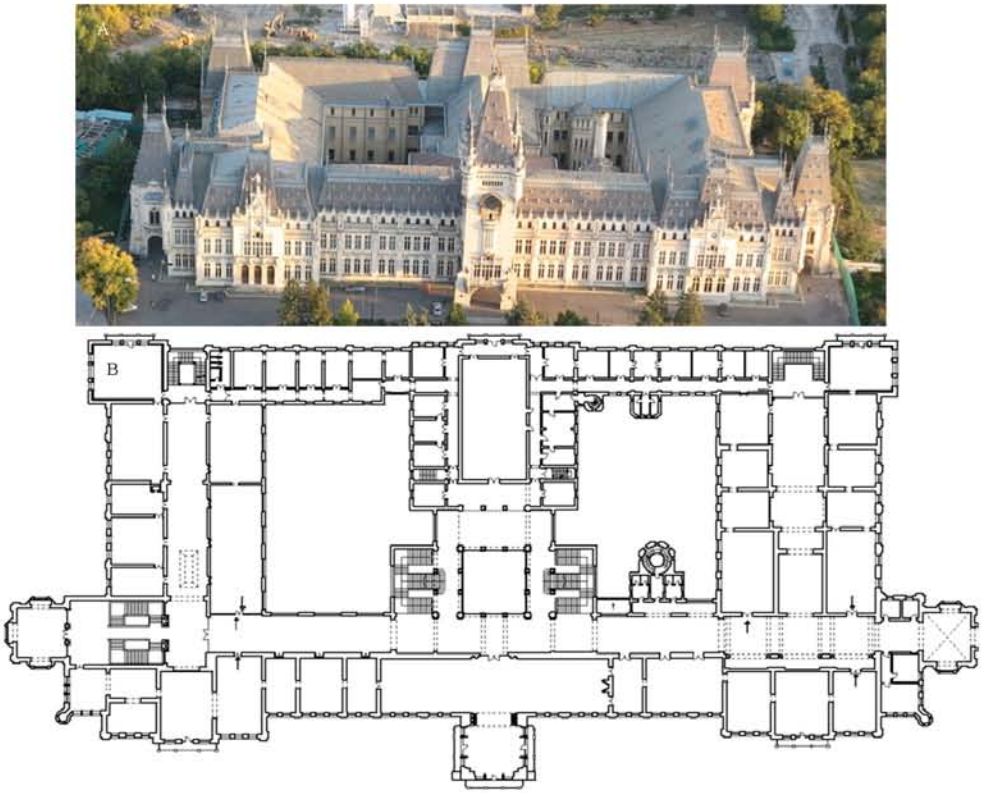

Fig. 3: The Palace of Culture, (A) top view and (B) ground floor plan

settlements appear throughout the structure. The true status of the building is worse and to establish the real intervention priority, the safety degree was established according to the proposed method. The new behavior factor was established to be 0.64 and the new safety degree was 0.20; this value corresponds to a very high intervention priority. Thus, the Palace of Culture Iasi was included in a rehabilitation program and intervention is currently in progress.

Study case 2: The Great Synagogue: The Great Synagogue was built between 1659 and 1670 and is the oldest Jewish praying houses in Romania. Its exterior is very simple, without any decorations; the interior is very sophisticated and is decorated with valuable objects.

Although, called the great, the size of the synagogue is actually very modest, with a total length of 22 m. Built in an eclectic style with strong late Baroque influences, the building has remained unchanged for the most part since the late 18th century. The edifice exterior boasts a prominent cupola over its East side, while the west end is covered by a half-barrel-shaped roof according with Fig. 4. Reminiscent of the fortress synagogues found in Poland, the Great Synagogue of Iasi has relatively small windows and doors and 1.20 m thick stone walls.

The Eastern part of the hall is covered by the 10 m diameter cupola. All walls are white-painted, with the exception of the eastern one, which is almost completely covered by the Holy Ark.

The present Holy Ark was renovated in 1866 after the biggest earthquake in Romania (in 1802): it is richly decorated with small columns, lavish decorations of carved wooden painted in black, red and green are dominated by sculptures of eagles in gilded wood and gilded wood doors that feature stylized floral motifs.

The safety degree according to EUROCODE was 0.38, which is a medium priority level. Because only earthquakes alter the structure, the new proposed behavior factor is greater than that compared with The Palace of Culture. With the 0.756 behavior factor, the new safety degree is 0.19. According to this new result, the structure was included in the rehabilitation program with a high priority level.

Study case 3: The Aroneanu Monastery: The Aroneanu Monastery was built in 1594 by the ruler Aron Voda. After several economic breakdowns, the monastery was restored in 1907 and it became the parochial orthodox church of the village Aroneanu. The originality of the exterior decorations is remarkable and unique in the history of medieval Romanian art as show as in Fig. 5A-C.

Because the monastery is very old and many earthquakes have affected its structure, eight repairs were made (the first was in 1788 and the most recent was in 1977). All interventions were local and did not affect the architecture.

The structural analysis according to the EUROCODE revealed a surprisingly good safety degree factor, 0.53 at the ground level. This value is clearly too optimistic and is in discordance with the age of the building.

The structure was analyzed again with the new proposed behavior factor and the final safety degree result is 0.23. According to this value, the structure was recently rehabilitated.

Fig. 4: The Great Synagogue (front view)

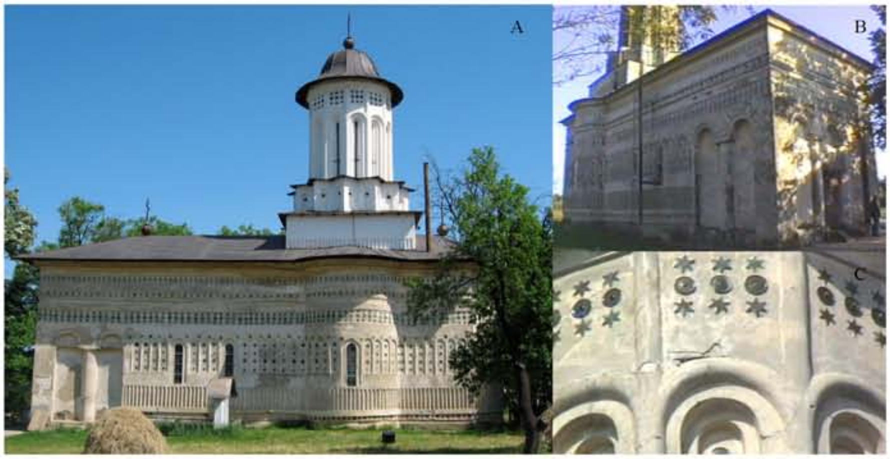

Fig. 5: The Aroneanu Monastery (A) front view (B) lateral view and (C) detail

RESULTS AND DISCUSSION

The evaluation of safety factor, according with EUROCODE 8 provided optimistic conclusions regarding the behavior of the masonry structures to seismic action.

For the structure of the Palace of Culture, the seismic analysis based on EUROCODE revealed a safety factor equal with 0.48., as is shown in Fig. 6. This value is considered a medium one and therefore, based on this value the priority of intervention was considered low.

In reality, the structure of the Palace of Culture had many damages, partly due to earthquakes and differential settlements and in situ visual evaluation indicated a critical situation concerning to the resistance of the structure. Bearing capacity evaluation for damaged walls based on FEM procedures (Milani *et al*., 2007) revealed worse results in comparison with the evaluation data provided by EUROCODE 8. Hence the priority level was considered high.

Therefore, in order to implement the EUROCODE's seismic force relation, the behavior factor was lowered with 57% according with the damages revealed on site (Table 2 -4). Thus for a new seismic analysis the value of the safety factor decreased with 57% and therefore, the priority level shifted from low to high.

For the structure of The Great Synagogue, the life time is longer in comparison with the structure of the Palace of Culture, but the soil conditions are better and the settlements are missing. Nevertheless, the safety factor according with EUROCODE 8 resulted around 0.38, as is shown in Fig. 6. This value was considered quite optimistic and based on this value the considered priority level was medium. Comparatively, an evaluation on damaged elements based on a visual inspection, the determination of deficiencies and a numerical analysis concluded that the priority level is high. In order to reach the same result based on EUROCODE the behavior factor was substantially reduced with 50% according with the Table 2 and 3.

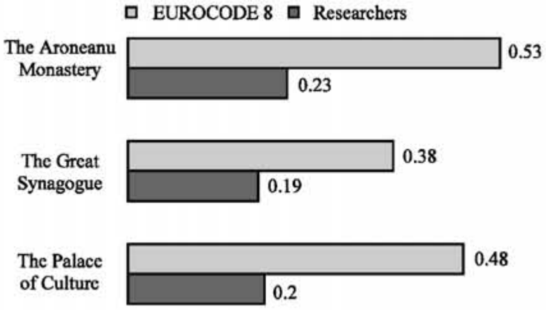

Fig. 6: Safety degree of three study cases evaluated with two methods

The seismic evaluation on the Aroneanu Monastery, which is the oldest from the studied masonry structures, revealed a safety factor of 0.53. This unexpected high value has conducted to a low priority level.

In situ visual evaluation revealed many cracks and moisture due to earthquakes, settlements and fire and indicated a critical situation concerning to the resistance of the structure. Numerical evaluation of the damaged walls model revealed a lower safety degree factor in comparison with the evaluation data provided by EUROCODE 8.

Therefore, in order to implement the EUROCODE's seismic force relation, the behavior factor was lowered according with Table 2-4 and the new safety factor (0.23 according with Fig. 6) indicated a high priority level.

CONCLUSIONS

The greatest menace for historical monuments is earthquakes because the knowledge level for structural element designed was very limited.

Unfortunately, the earthquake evaluation process according to EUROCODE 8 was not adapted for old buildings and the bearing capacity is over-estimated. In this case, the priority level can be decreased and necessarily interventions will be delayed.

The authors proposed a new method to evaluate the safety level of the structure and the results of the proposed model are more accurate than those of EUROCODE 8 as shown in Fig. 6.

This new method reduces the behavior factor q according to the age of the structure, the earthquake zone and the amount of damage in the structure. The new behavior factor offers a better approach for evaluating old historical monuments.

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