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Numerical analysis of a masonry residential building using AmQuake software

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Abstract: Many masonry structures are located in seismically active areas where the action of seismic forces has revealed their vulnerability. Since such structures are built of composite materials, attention should be paid to all the structural elements that make it up. The objective of this paper is to present the procedure and analysis results for a masonry building in order to determine its seismic resistance. The AmQuake software, which facilitates the design and calculation of masonry buildings according to European standards and norms, was used for the analysis. By using the pushover method, the system response to an increasing horizontal force with a constant vertical load is monitored through the calculation. Based on the calculation results, a conclusion on the conducted analysis is given.

Key words: masonry structures, earthquake, pushover method, numerical analysis

Numerička analiza zidane stambene zgrade primjenom AmQuake software-a

Sažetak: Mnoge zidane konstrukcije nalaze se u potresno-aktivnim područjima u kojima je djelovanje potresnih sila razotkrilo njihovu povredljivost na iste. Iz razloga što su ovakvi objekti izgrađeni od kompozitnih materijala potrebno je obratiti pozornost na sve elemente konstrukcije koji ju čine. Cilj ovoga rada jeste prikazati postupak i rezultate proračuna zidane stambene zgrade kako bi se odredila njena potresna otpornost. Za analizu je korišten AmQuake software koji omogućuje dizajniranje i proračun zidanih objekata prema Europskim standardima i normama. Kroz proračun se korištenjem metode naguravanja prati odgovor sustava za rastuću horizontalnu sliku uz konstantno vertikalno opterećenje. Na osnovu rezultata proračuna dat je zaključak o provedenoj analizi.

Ključne riječi: zidane konstrukcije, potres, metoda naguravanja, numerički proračun

1. INTRODUCTION

Masonry, or laying stone or clay blocks on top of one another while binding them together with mortar if necessary, is the oldest construction technique that has been preserved to this day. The long tradition and worldwide spread of masonry are attributed to its simplicity and to the longevity of masonry structures, which is evident in many such buildings that are hundreds and even thousands of years old. The pyramids in Egypt dating from the period between 2800-2000 BC, the Parthenon in Greece from the fifth century BC, the Great Wall of China whose construction began in the fifth century BC, and the Colosseum in Rome from the first century AD are just some of the examples of such buildings that have also become symbols of some cultures.

Despite the simplicity that is manifested during construction of masonry structures, understanding and describing the mechanical behavior of such structures, especially under seismic loading conditions, is still a true challenge due to the nature of masonry, which shows complex and markedly nonlinear behavior caused by the presence of joints between blocks, which may or may not be filled with mortar. Many masonry structures are located in seismically active areas where earthquakes have revealed all their vulnerability. These earthquakes often damage masonry structures and monuments categorized as cultural heritage as well as modern masonry structures.

Modern masonry structures are widely popular due to their reasonable price, thermal insulation, fire protection, durability, ease of construction, and low maintenance costs. This type of structures behaves well under vertical loading due to its good compressive strength, however their resistance to horizontal actions is reduced.

2. AMQUAKE SOFTWARE FEATURES

AmQuake software is intended for the design of masonry structures according to Eurocode 6 and 8. It was developed as a result of close cooperation between the companies Červenka Consulting and Wienerberger, the largest European manufacturer of bricks and building systems. When calculating masonry structures, AmQuake uses the pushover analysis and equivalent frame method to verify the seismic safety of masonry structures.

The program has a database of products and national standards of 11 European countries. When creating a new project, the desired national standard can be selected and the parameters of the selected standard can be selected separately. Seismic zone, soil category, reference ground acceleration can be selected in the basic seismic load settings, while spectrum limits and other seismic parameters can be changed in the advanced settings. The program includes an extensive database of Wienerberger brick products with all technical characteristics of products. It is possible to define the type of masonry, reinforced, non-reinforced, confined and reinforced-concrete masonry. When entering walls and other structural elements (ring beams, lintels, ceilings), it is necessary to define the type of material of the individual element.

The model of the structure is entered in DXF format from a CAD program. The topology of the model is set in the CAD program, where the main geometric elements are walls, windows and ceilings.

Each ceiling comprises a defined load, along with the corresponding safety factor that is automatically filled based on the national standard annex, but can be changed as necessary. After the model and corresponding loads are entered, a finite element mesh is automatically generated, and appropriate parameters can be manually set in the advanced options. After the model is calculated, the masonry structure is checked according to Eurocode 6, and the reinforced concrete structure according to Eurocode 2. Seismic evaluation of the model is made according to Eurocode 8, and all results can be shown in RTF format.

3. PUSHOVER METHOD

3.1 General

The pushover method is a nonlinear static method for calculating existing or new structures. The basic principle of the method is to monitor the system response for an increasing horizontal force with a constant vertical load. The seismic resistance of the system can be determined from the obtained relationship between the horizontal force and the reference displacement.

The seismic load is gradually applied to the system that has previously been fully subjected to the action of vertical loads. The inertial forces that occur in the system during an earthquake load are simulated in this way. Increasing the load leads to failure of individual elements of the structure, which causes a decrease in the rigidity of the system. The method is based on the procedures for design and repair of damaged buildings, which comprise engineering concepts based on structural behavior.

It was realized that more attention should be devoted to damage control during design. This can be achieved only by introducing nonlinear calculation into the seismic calculation methodology. One of the most suitable approaches is to combine the nonlinear static pushover method with the spectral response methodology. The assessment of earthquake resistance is given on the basis of monitoring one characteristic node - the control node. The control node is usually the center of masses of the highest floor. The load-bearing curve, from which the seismic resistance of the system can be estimated, is constructed based on trajectory of the control node.

3.2 Assumptions for pushover method

Some assumptions according to EN 1998-1: 2004: are used for pushover method.

- ✓ Zero post-yield stiffness can be assumed;
- ✓ Longitudinal forces due to gravitational loading should be taken into account when calculating EN 1998-1;
- ✓ Mean values should be used for material properties;
- ✓ The value of transverse and bending stiffness of masonry and reinforced concrete is assumed as ½ of the actual one in order to simulate cracking of cross section;
- ✓ As a minimum bi-linear force-deformation relationship should be used at the element level;
- ✓ Spatial model should be made for irregular structures, and two analyses are necessary for two different directions. where it is not necessary to consider horizontal actions from two directions in a single calculation;
- ✓ Transverse forces should be set at the center of masses, or at the center of floors with eccentricity set according to EN 1998-1

$$e_{ai} = \pm 0.05 L_i$$

  Li – floor dimension perpendicular to earthquake action
- ✓ Horizontal forces for the case of modal distribution are determined according to the expression:

$$F_i = F_b \frac{z_i\, m_i}{\Sigma z_j\, m_j}$$

F_b – total transverse force,
z_i – floor height,
m_i – floor mass according to EN 1998-1:2004.

3.3 The pushover method implementation procedure

The pushover method is carried out in the following steps:

- ✓ Determining spectral acceleration from elastic response spectrum of a single-degree system;
- ✓ Determining pseudoforce from spectral acceleration, and determining the relationship between spectral acceleration and spectral displacement;
- ✓ Determining the target displacement of a single-degree system;
- ✓ Transformation of a multi-degree system into an idealized single-degree system;
- ✓ Making an idealized elastoplastic diagram;
- ✓ Determining the period of the idealized system;
- ✓ Determining the target displacement of the idealized system;
- ✓ Determining the target displacement of the system.

According to the calculation needs, the systems can be divided into single-degree and multi-degree systems.

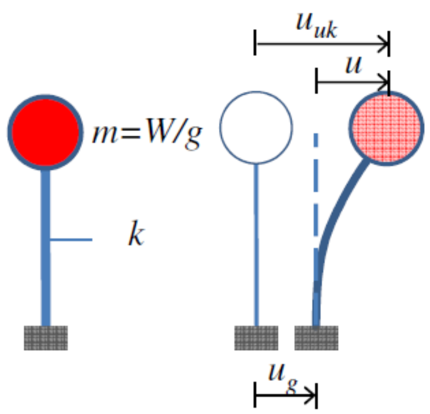

Figure 1. Single-degree system

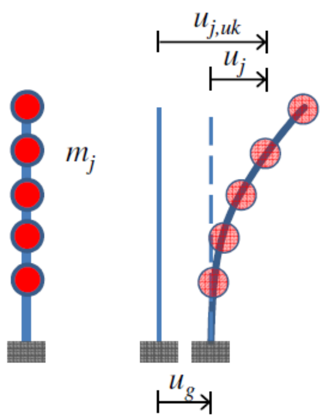

Figure 2. Multi-degree system

u_g – ground displacements during seismic action
u_j – relative displacements
$u_{j,uk}$ – total displacements

4. AN EXAMPLE OF CALCULATION OF A MASONRY RESIDENTIAL BUILDING

4.1 Technical description

The residential building taken as the calculation example consists of four floors, a ground floor and three floors. The height of the building from ground level to the top of the roof slab is 11.48 m. The floor height is 2.87 m, while the clear height is 2.60 m. The gross plan area of the ground floor is 362 m², while the gross area of floors is 390 m². On each floor there are 4 apartments with approximately equal area. The vertical communication in the building consists of an elevator and a two-flight staircase that extends to the top floor. The roof is made as a flat impassable roof with 80 cm high parapets.

The building is founded on category B soil and is located in a seismically active area with expected design ground acceleration of 0.28 g for a return period of 475 years, and 0.14 g for a return period of 95 years.

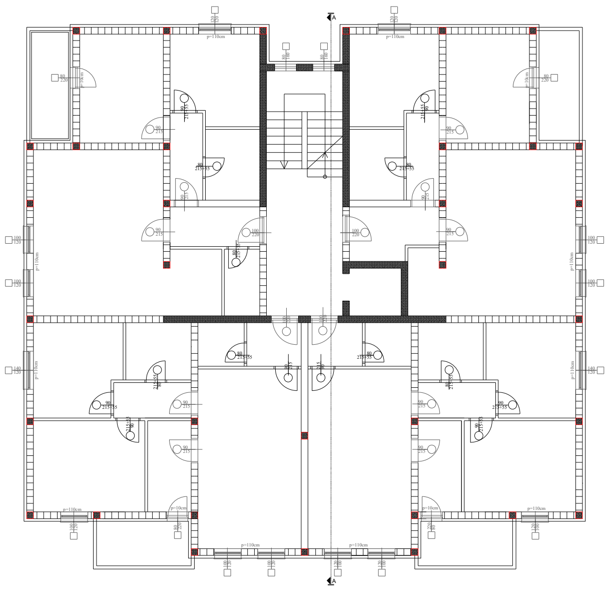

Figure 3. Plan view

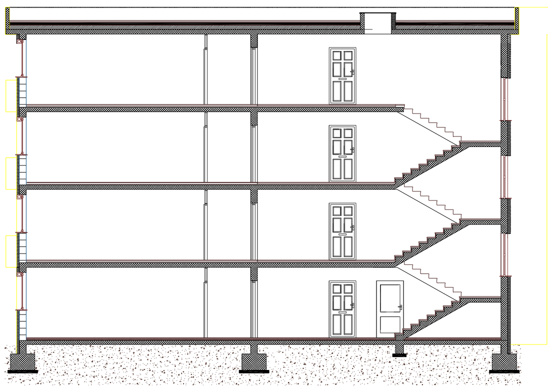

Figure 4. Cross section

The foundation structure of the building consists of 0.90 m wide and 0.60 m thick foundation strips, at an elevation of -1.10 m, and the elevator foundation slab with dimensions 2.65 x 2.80 m and thickness 0.30 m, located at an elevation of -1.70 m. The vertical system consists of masonry walls made of 25 cm thick porotherm bricks, and 25 cm thick reinforced concrete walls, concrete class C25/30, which extend regularly through all floors. The horizontal system consists of monolithic reinforced concrete slabs with a thickness of 17 cm and a floor slab with a thickness of 15 cm. The staircase is planned as a reinforced concrete element, the slab thickness of which is 15 cm.

4.2 Analysis of loads

The basic loads acting on the structure are permanent, variable and accidental actions.

4.2.1 Permanent action

Permanent action on the structure includes dead weight of the structure itself, and the additional permanent load. Additional permanent load for:

- floor slab (POZ 100, 200, 300):

Finishing coat: 0.54 kN /m²
Insulations, installations, plaster: 0.21 kN/m²
Cement screed: 0.96 kN/m²

Total: 1.71 kN/m²

- roof slab (POZ 400)
    Finishing coat: 0.72 kN/m²
    Insulations, installations, plaster: 0.68 kN/m²
    Cement screed: 2.16 kN/m²
    Total: 3.56 kN/m²

4.2.2 Variable actions

Variable actions on the structure are service load, wind load, and snow load. The rooms are classified into 5 basic categories for which the characteristic values of loads on floor structures, balconies and staircases are determined. Values for category A building (residential areas and households, rooms in residential buildings and houses)
    Floor structures: 1.50 kN/m²
    Balconies: 3.00 kN/m²
    Staircases: 3.00 kN/m²
    Partition walls: 0.80 kN/m²
The total service load on floor structures is 2.30 kN/m².

4.2.3 Accidental action

For the relevant ground acceleration, the value was read from seismological maps for a return period of 475 years, and the load was finally set in two plan-view, mutually perpendicular directions (X and Y).
Computational ground acceleration: a_g = 0.28 g (T=475); g=9.81 m/s²
Soil category: B
Spectrum type: 1
Importance factor: II (common buildings, residential, without special importance)
The behavior factor of the structure for confined masonry is q = 2.0 - 3.0, and q= 2.5 was selected for the subject structure.

4.3 Calculation by the pushover method

The calculation using the pushover method was performed in the AmQuake program, which performs proof of seismic resistance by combining the equivalent frame method and the pushover method. Calculation results are affected by the settings related to finite element mesh, so it is necessary to choose individual options in the program with special attention. The basic idea is to model all load-bearing elements with 1D beam elements. This is related to vertical and horizontal elements such as walls, tie columns, ring beams, lintels above doors. The next assumption is concerned with floor structure, which is infinitely stiff in its plane, while out of that plane its stiffness is negligible.

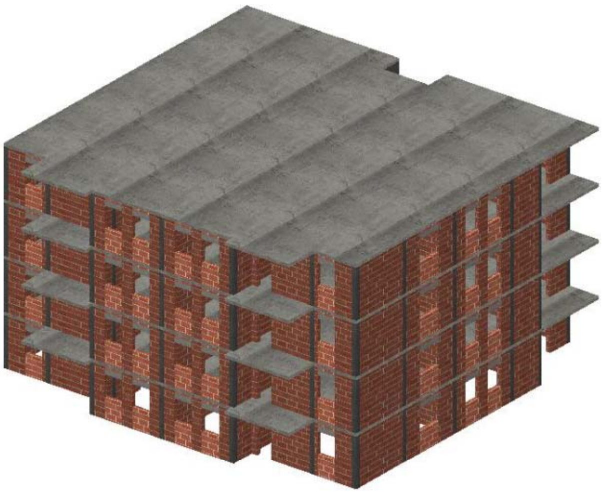

Figure 5. 3D model of the building – AmQuake

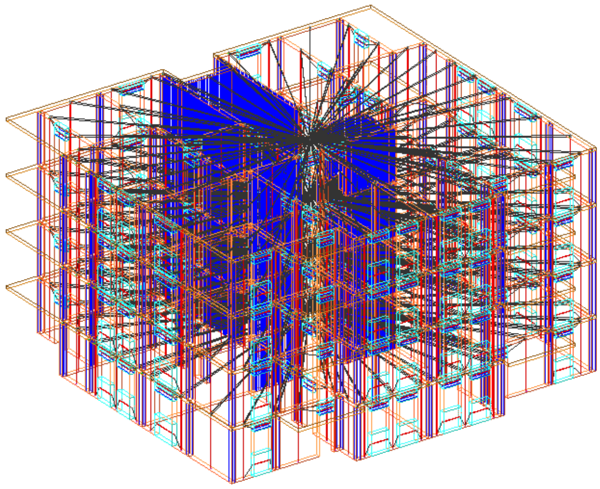

Figure 6. Finite element mesh

4.3.1 Calculation results - uniform loading in X direction

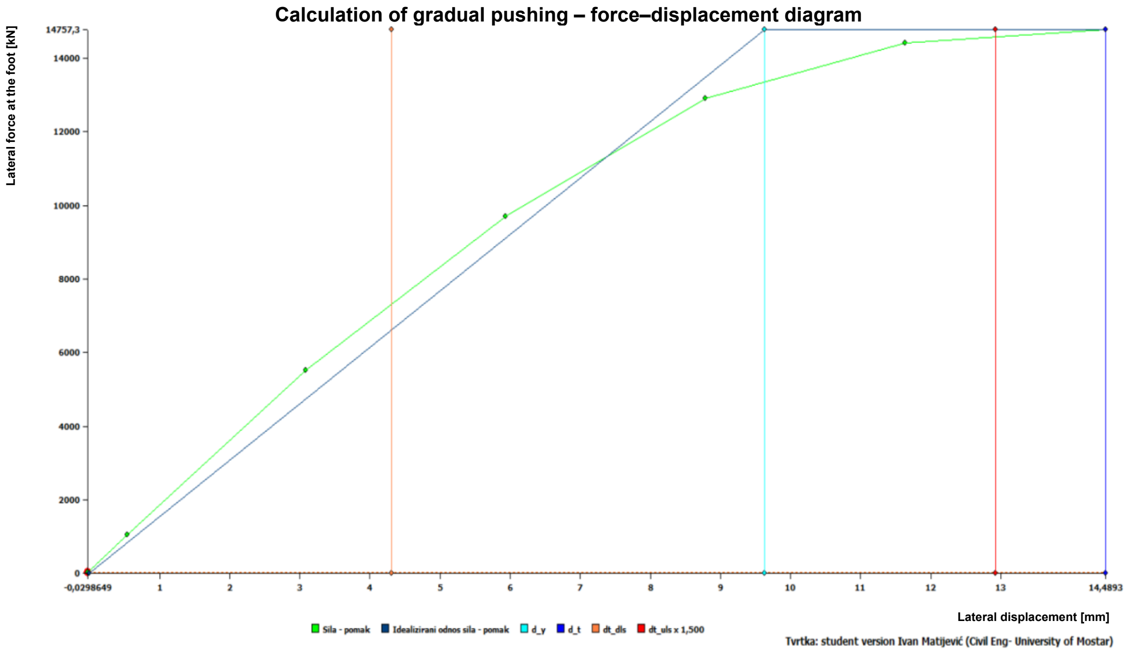

Figure 7. Force-displacement diagram for loading in X direction

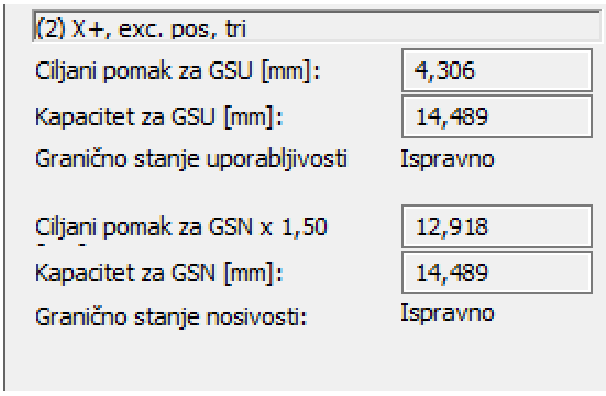

Figure 8. Results for SLS and ULS in X direction

The results show that the target displacement for the serviceability limit state (SLS) is 4.306 mm, while the capacity for SLS is 14.489 mm, which means that the design structure satisfies the serviceability limit state. The target displacement multiplied by factor 1.50 for the ultimate limit state (ULS) is 12.918 mm, while the capacity for ULS is 14.489 mm, which means that the design structure also satisfies the ultimate limit state.

4.3.2 Calculation results - uniform loading in Y direction

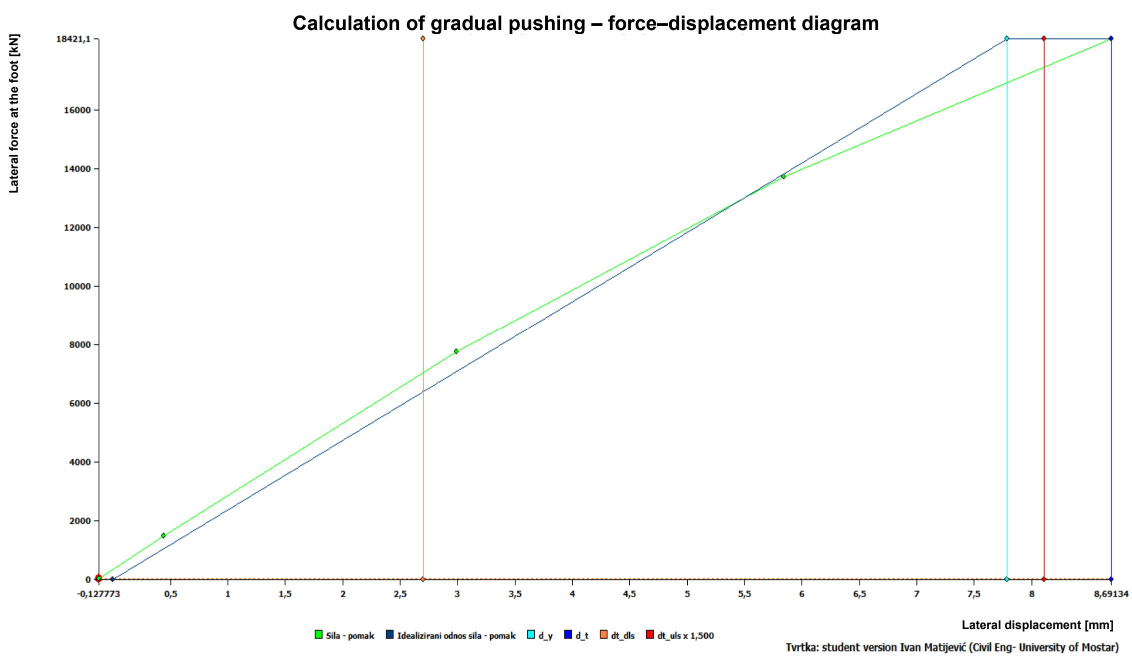

Figure 9. Force-displacement diagram for loading in Y direction

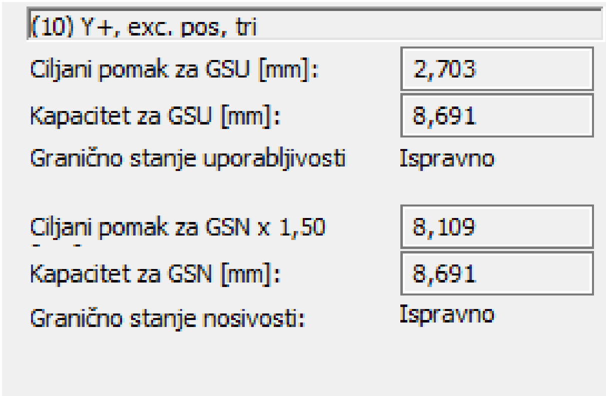

Figure 10 - Results for SLS and ULS in Y direction

In Y direction, it can be observed that the target displacement for the serviceability limit state (SLS) is 2.703 mm, while the capacity for SLS is 8.691 mm, which means that the design structure satisfies the serviceability limit state. The target displacement multiplied by factor 1.50 for the ultimate limit state (ULS) is 8.109 mm, while the capacity for ULS is 8.691 mm and the design structure also satisfies the ultimate limit state.

5. CONCLUSION

The paper presents the calculation of a masonry residential building. Analysis of seismic resistance was performed using the pushover method implemented in AmQuake software. Based on the obtained results, we can conclude that the pushover method is an effective procedure for analyzing the seismic resistance of masonry buildings, which determines the load-bearing capacity and deformation of the structure due to the action of seismic forces. Assessment of seismic resistance for masonry buildings in seismic areas is greatly influenced by the regularity of the building in the plan view and in height, what the example of building presented in this paper is like.

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