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Damage assessment after the Zagreb earthquake – the case study of the educational building

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Abstract

2020 was a tough year for Croatia, which experienced two significant earthquakes during an ongoing global pandemic. Damage from those earthquakes was extensive and mostly concentrated in the old masonry buildings. Many of the mentioned buildings exceeded the usual service life span, with some existing for over a century. Earthquakes exposed Croatian building stock's vulnerability that should be mitigated as efficiently as possible in the coming years. Novel approaches in assessment procedures should be applied together with state-of-the-art repair and reconstruction of the damaged buildings.

Key words: masonry, earthquake, assessment, on-site testing, numerical modeling

The Case Study

2020 was a tough year for Croatia, which experienced two significant earthquakes [1] during an ongoing global pandemic. Damage from those earthquakes was extensive and mostly concentrated in the old masonry buildings, as shown in Fig.1. Many of the mentioned buildings exceeded the usual service life span, with some existing for over a century. Earthquakes exposed Croatian building stock's vulnerability that should be mitigated as efficiently as possible in the coming years. Novel approaches in assessment procedures should be applied together with state-of-the-art repair and reconstruction of the damaged buildings [2].

Figure 1. Masonry building damaged in the Zagreb earthquake

Masonry buildings account for a big part of housing in Croatia [3]. Hence, initial assessments are essential to inform the tenants about their damaged homes' usability and safety. The rapid assessments began only a few hours after the main earthquake. Damage classification in rapid assessments was made in accordance with the modified EMS-98 scale [4].
The educational building shown in Fig.2 and Fig.3 is an old unreinforced masonry building located in the old town of Zagreb. Its floor heights range from 3.2 to 4 m, and wall thicknesses range from 28 to 70 cm. It was one of the structures assessed by the ARES project team. In the initial assessment, it was classified as temporary unusable due to observed damage. A detailed inspection was required - the building has moderate damage without likely collapse. The load-bearing capacity is partially impaired, and it was not recommended to stay in the building. After some time, a more detailed evaluation was done, and the building's damage and possible behavior were analyzed.

Figure 2. Educational building and damage by the earthquake

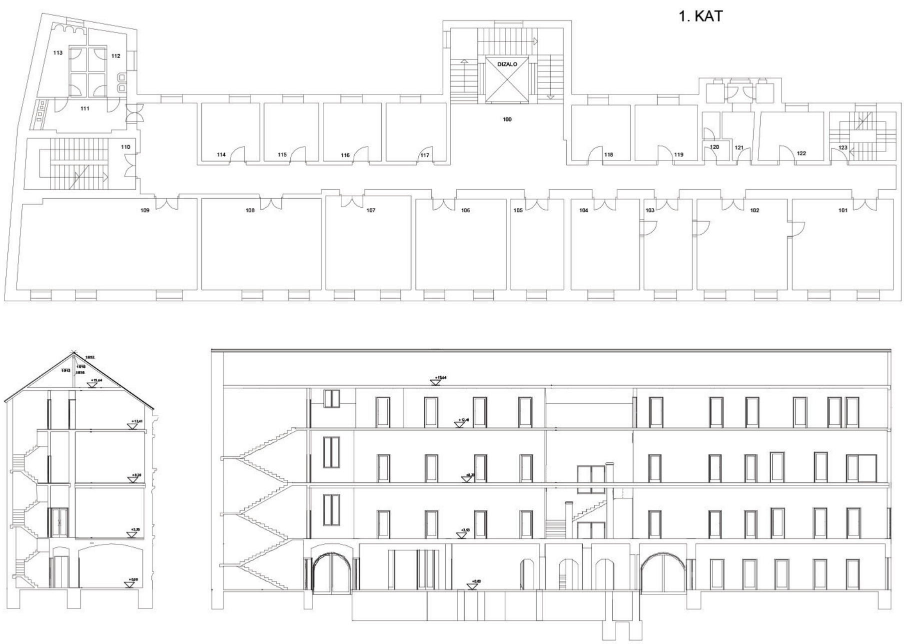

Figure 3. Building's floor plan and cross-sections

As shown in Fig.4, the numerical model was made in software 3muri, which uses the equivalent frame method and non-linear static (pushover) analysis to characterize the building's seismic response through a capacity curve. Non-linear static (pushover) analysis combines constant gravity loads with monotonically increasing horizontal loads. Two different horizontal load distribution patterns along the height of the building are used. Modal distribution follows the first mode shape for each direction obtained from elastic analysis and uniform distribution, which is proportional to the building's mass. The equivalent frame method divides masonry walls into macroelements. In piers and spandrels, all deformations and non-linear responses are concentrated. Rigid nodes connect those piers and spandrels. The numerical model's material characteristics are obtained as a combination of the literature review [5, 6] and on-site testing.

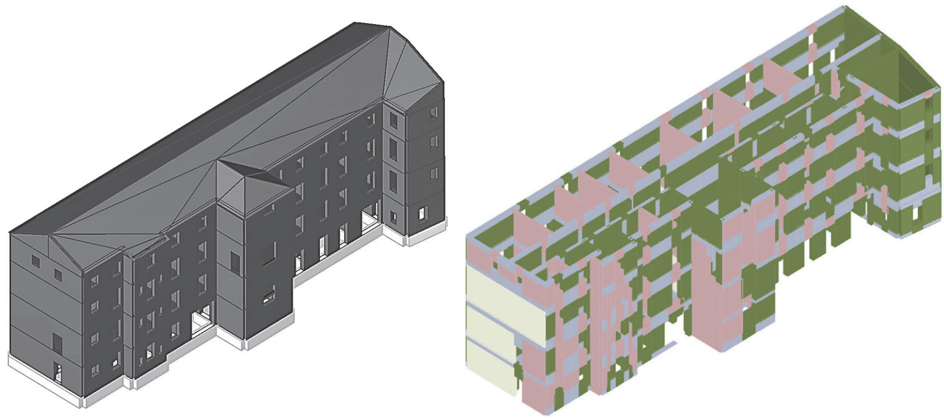

Figure 4. Numerical model and the basic results from the 3muri software

The results are as expected, where the building's behavior is in accordance with wall distribution. The obtained capacity curves can be seen in Fig.5, and target displacement determination is graphically explained in Fig.6.

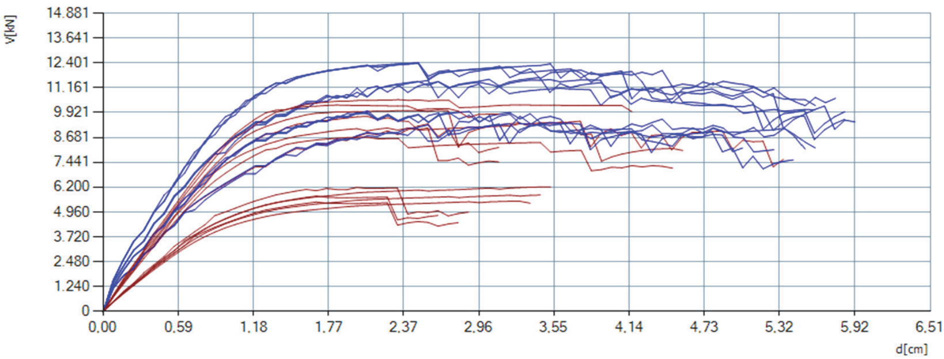

Figure 5. Capacity curves for x-direction (blue) and y-direction (red)

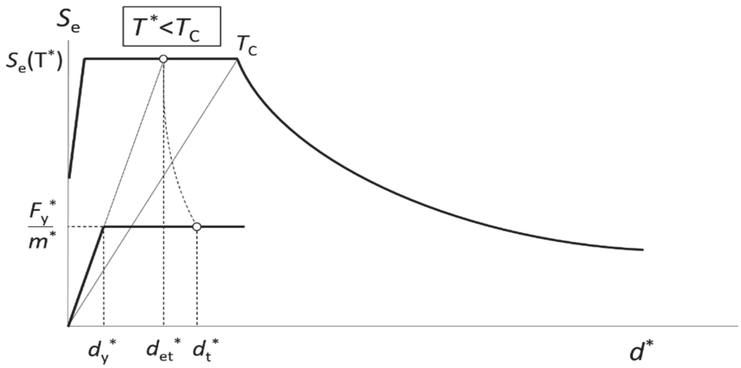

Figure 6. Target displacement determination for short periods

Real damage also corresponds with the damage distribution previewed in 3muri. Comparison between displacement capacity and the displacement demand shows us that modern, more demanding regulations (i.e. Eurocode 8 standard) are not satisfied. Hence, the next logical step after assessing the building's behavior in an earthquake is its strengthening. In repairing and rebuilding this building and the city itself, principles of build back better should be adopted, e.g. using sustainable materials and innovative concepts [7, 8, 9] or ensuring energy efficiency [10].

Contemporary materials such as FRP and TRM are among the most compatible strengthening options for masonry and cultural heritage, which is advised not to be strengthened with irreversible and invasive methods such as concrete jacketing. An insightful comparison between different design codes for masonry strengthening with FRP and TRM is discussed and showed in an example in [11].

Acknowledgments

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