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IZIIS' integrated approach in seismic retrofitting of historic buildings and monuments

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Abstract

Presently, there is a diverse list of existing code references which could be interpreted to require seismic upgrades of existing structures, but without a clear path toward addressing the hazards, evaluation and retrofitting of existing buildings. When this comes to existing historic buildings and monuments, the topic becomes much more complex and challenging, since the problem of their earthquake protection is radically different from that of other existing structures, due to the priority given to preservation of aesthetic, architectonic and historic values instead of keeping the structure operational.

Key words: seismic retrofitting, historic buildings, monuments, analytical and experimental investigation

Presently, there is a diverse list of existing code references which could be interpreted to require seismic upgrades of existing structures, but without a clear path toward addressing the hazards, evaluation and retrofitting of existing buildings. When this comes to existing historic buildings and monuments, the topic becomes much more complex and challenging, since the problem of their earthquake protection is radically different from that of other existing structures, due to the priority given to preservation of aesthetic, architectonic and historic values instead of keeping the structure operational. In providing the protection of these structures in a manner that requires the least intervention and the greatest care to preserve authenticity, the experts are permanently challenged by the fast development and the improved performance of new materials and techniques. However, the implementation of particular retrofitting methodology depends on the extent it has been investigated.

During realization of important scientific research projects involving analytical and unique experimental investigation, extensive research activities have been performed at UKIM-IZIIS for the purpose of developing of a procedure for seismic retrofitting of valuable historic monuments, which complies with the restoration and conservation requirements and encompass the following:

- Definition of seismic potential of the site through detailed geophysical surveys for definition of geotechnical and geodynamic models of the site including also the local soil effects through nonlinear dynamic analysis of a representative geotechnical model;
- Determination of structural characteristics and bearing and deformation capacity of existing structure including investigation of the built-in materials, definition of structural dynamic characteristic through ambient vibration method, developing the corresponding mathematical model and determination of dynamic response for defined seismic parameters;
- Definition of criteria and selection of concept for seismic retrofitting respecting the country regulative as well as guidelines in the ICCOMOS and ISHARCH documents;
- Definition of structural methods, techniques, materials in accordance with defined criteria and positive national and international construction and conservation practise;
- Analysis of dynamic response of retrofitted structure and verification of its seismic safety;
- Definition and documentation of field works, and their execution with constant supervision by professionals from different fields.

An integral part of IZIIS' methodology is the experimental investigation of models on a seismic shaking table as the most corresponding way of investigation from the aspect of dynamic structural behaviour during real earthquakes. The referent shaking table testing of monumental buildings performed in the IZIIS' Dynamic testing laboratory are the testing of 1:2.75 scaled model of St. Nikita church in the village of Banjani as well as 1:6

scaled model of Mustafa Pasha mosque in Skopje, (Fig. 1) in its original and strengthened state. The strengthening system applied to the church model was using stainless steel ties and injection, [1], while that for the mosque model was applying CFRP bars and wrap, [2]. The results of the investigation have shown that the applied strengthening system in both cases is efficient especially in providing the integrity of the structure under severe earthquake. The strengthened structure was able to resist seismic accelerations quite 2-3 times the one corresponding to the original capacity. This was crucial and starting point in making the decision about the concept of strengthening of the real monuments in the country and beyond.

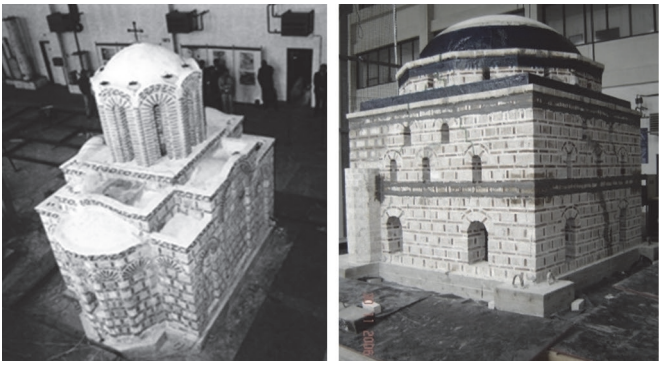

Figure 1. Scaled models of St. Nikita church and Mustafa Pasha mosque

The most characteristic examples of application of the developed methodology in the process of reconstruction and seismic upgrading of churches were (i) reconstruction of blown-up St. Athanasius Church in Leshok, (ii) consolidation and reconstruction of the church St. Panteleymon in Ohrid, and (iii) reconstruction of the blown-up church of the Holy Trinity in Mostar, [3], (Fig. 2).

Figure 2. Implementation of the developed methodology in the reconstruction of three churches, [3]

In addition, following the successful seismic upgrading of Mustafa Pasha Mosque, the same or slightly modified retrofitting methodology by using CFRP has been so far implemented in several other mosques on the territory of North Macedonia and Kosovo, all of them from the Ottoman period, [3].

The delicate problem and challenge in the long-term protection of monuments is the selection of methodology and materials for retrofitting. Proving the effectiveness of the selected consolidation system can be successfully overcome by using the methodology of "design assisted by testing", which represents a very powerful tool especially in a case of such complex structures, which are difficult to be analysed by using traditional methods.

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