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A Case Study on a Historical Monument and Methodological Implications

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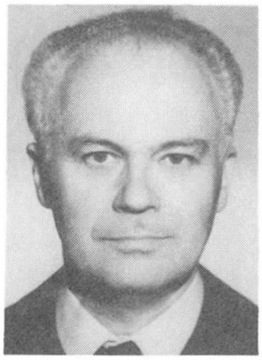

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Summary

References are made to a French - Romanian project on the rehabilitation of a XVII - th century monastery, representing a historical monument. The analysis presented in the paper was concerned with the belltower of the monastery referred to. Basic data on seismic hazard and on the dynamic characteristics of the structure are presented. The engineering analysis was performed for the elastic stage, as well as for the stage corresponding to the observed, severe, damage. The way in which damage occurred is explained. The strengthening solution is referred to and some results on its ability to resist future strong earthquakes are discussed.

Keywords: historical monument, earthquake protection, restoration, earthquake resistance, dynamic analysis, damage pattern.

1. Introduction

A French - Romanian project was initiated in 1991 in relation to the rehabilitation of the Apostolache Monastery (a historical monument, built in mid-seventeenth century). The project was intended to represent a pilot study, in the frame of which know-how of both parts was to be mobilized. Besides the French participation, coordinated for the architectural part by B. Mouton and for the structural part by V. Davidovici, Romanian specialists from several institutions, coordinated by the Direction of Historical Monuments (DMASI) were active in the project. The cooperative effort started with the belltower (about 14 m. tall) of the monastery.

2. Summary of some reference data

The reference data used were related to the seismic conditions at the monastery site and to the outcome of monitoring of ambient vibration. The site is located in a zone that, according to the provisions of the earthquake resistant design code of Romania, are the most severe of the country. According to hazard estimates performed by the authors, the basic design factor is in the range of 0.16 g for 20 years, and of 0.55 g for 200 years return period. The full-scale monitoring of ambient vibration put to evidence fundamental natural periods of 0.27 s. across the wall and 0.19 along the wall of the monastery.

3. Objectives of the engineering analyses

Analyses were related to the pre-intervention and to the post-intervention stages. The objectives for the pre-intervention stage were to explain the kind of damage observed, to explain the implications of damage upon structural performance, to estimate lower bounds of material strength, to conclude on the intervention need. The objectives for the post-intervention stage were to predict the features of performance during future earthquakes and to predict the eventual damage pattern.

4. Linear dynamic analysis

The linear dynamic analysis of the structure was aimed to help in identifying some belltower characteristics and to help also in detecting the places and nature of damage to first occur in case of a strong earthquake acting upon the undamaged structure. The adoption of a stick-type modelling was considered suitable. A parametric analysis showed what natural periods would correspond to various alternative elasticity moduli of masonry and soil. It turned out that the elasticity moduli should be very low.

5. Resistance analysis

The resistance analysis made it possible to estimate the ultimate ground accelerations , corresponding to foundation uplifting, under alternative hypotheses: for the two main directions of motion and for two limiting assumptions on the structure: integrity preserved and upper part disintegrated (as observed) respectively. The accelerations ranged from about 0.3 g to 0.6 g.

6. Expected implications of the rehabilitation and strengthening solution

The solution adopted included: reconstructing of the disintegrated masonry, introduction of horizontal and vertical (weakly prestressed) mild steel tendons and intervention at foundation level, to improve ground-structure contact. According to verifications performed, the horizontal tendons adopted are sufficient to prevent future disintegration of masonry as in fig. 2. The resistance of masonry to compressive foresee is sufficient to provide capacity of resisting up to foundation uplifting. The resistance to shear forces in horizontal sections appears to be sufficient too. Under these conditions, in case of very strong ground motions, the non-linear performance should correspond essentially to transient foundation uplifting, without significant structural damage and, also, without any practical risk of overturning.

7. Additional methodological considerations

The alternative stick models used may be considered to be quite rough. The authors believe nevertheless that this way was rather well suited in this case, given the general circumstances encountered. Something like a finite element model could not have been justified under conditions of this non-homogeneity, of lack of data about the constitutive laws and of lack of programs appropriate for non-linear analyses under these circumstances. On the other hand, the fact that ground deformability was accounted for in some way, be it simplistic, was important. It would be most suitable to repeat after the restoration work the monitoring of ambient vibration, which could provide most valuable information on the effectiveness of work undertaken.

8. Final considerations

The experience of this case showed again how important it is to try to develop models to account for the behaviour of structures on the brink of collapse. Even in case of quite rough modelling, there is a chance to obtain more realistic results than by using sophisticated linear models.