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Geotechnical aspects on seismic retrofit

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Abstract

In the paper numerical analysis of foundation of damaged masonry structure using finite element method is presented. Retrofitting of those structures has been performed using technology DC90. By retrofit design, the foundation structure is confined with the foundation collar, connected by anchors and in which the vertical stiffening elements are anchored. Numerical quantification of benefit of seismic retrofit of building foundation in terms of future excitations was done. Additionally, the soil-structure interaction issue has been addressed

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1. Introduction

Seismic retrofit of old objects is very important is seismic prone areas. While performing massive retrofit aim is to standardize solution for most of the buildings. However, aspects of local seismic site response and geotechnical conditions need to be considered before applying retrofit solution.

In this paper is presented one case study of masonry structure- the most sensitive to seismic loading. In the present paper geotechnical analysis of damaged masonry structure using finite element method is presented. Retrofitting of structure using technology DC90. Seismic load of retrofitted structure (FEM network) is transmitted to FEM network of soil elements below the building foundation.

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2. Observed house and location

Observed building is typical two store building made from bricks and mortar is shown in Fig. 2(a), located in Kolubara region, Central Serbia. This region is one of the seismically most active in Serbia and even more in 2014 there were devastating floods in this area. Therefore, the Serbia has established National Disaster Risk Management Program (literature), and seismic strengthening and retrofit is important part of this program. The proposed case study is masonry structure because it is well known that those structures have large mass, and consequently because of very bad cohesion between bricks (stones) and mortar they crack and suffer damage due to earthquakes. DC90 is system is applied on 350 objects in Kolubara region during 2002, and valuable experience and knowledge has been gained.

In previous studies Petraskovic et al. (2005), that are basis for this paper, building structure is modeled by shell finite elements. Example of retrofitting of house are explained in detail by using seismic retrofit technology the lateral stiffness of walls is increased. Foundation structure is confined with foundation collar, which is connected by anchors and in which the vertical stiffening elements are anchored.

However, from the other site during the potential earthquake excitation the nature of the load on the foundation is changed/increased, and the aim of this paper to prove that foundation and surrounding soil can withstand the loads and deformations induced by potential earthquakes. This analysis considers following steps:

- Analysis of the house structure and maximal seismic loads (performed in Petraskovic et al. (2005))
- Verification of the seismic site response (consideration of official seismic map)
- Analysis of the house foundations (static soil-structure interaction)

On the basis of the available seismic data from the seismic hazard maps, it was detected that house is located in VIII seismic zone MSK PGA=0.18 g for T= 475 years. Fig. 1 shows the hazard maps. The value from the right figure (b) has been taken into account considering that was no seismic site response analysis on building location.

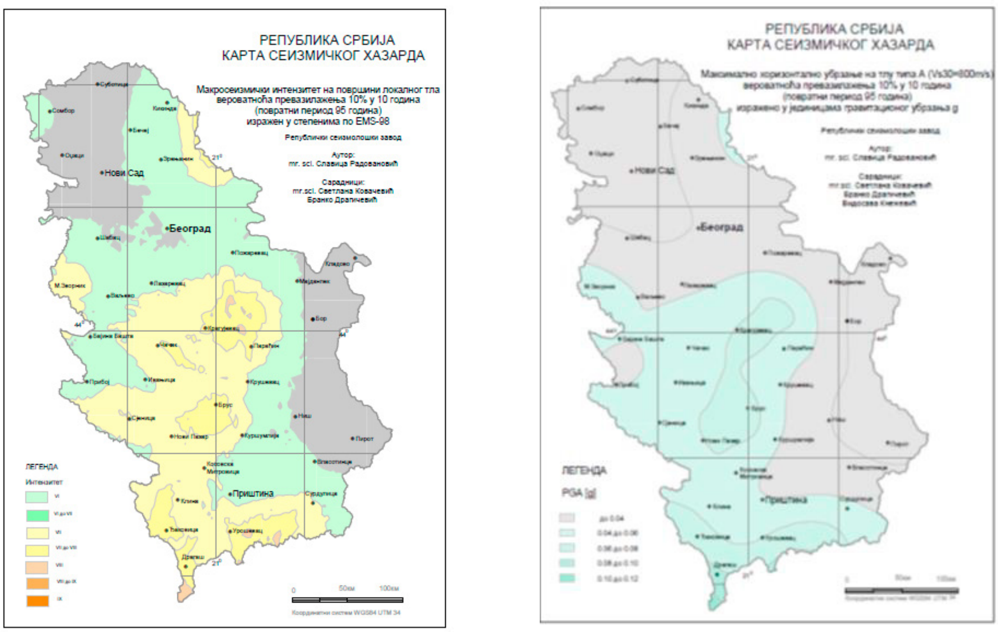

Fig. 1. (a) official seismic map base rock; (b) official seismic map local soil (Seismological survey of Serbia website)

Having in mind that there was no valuable data on seismic records for dynamic analysis, the EL Centro record been used in structural analysis seismic record has been used scaled to adequate parameters that match local soil conditions.

The more advanced approach can be to select several records selected from the set of databases of natural seismic records (Zugic et al (2015). That means that the average response spectrum computed from all the accelerograms should match a target spectrum prescribed by a seismic code Eurocode 8 within a certain tolerance, over a specified range of periods.

3. The details of the seismic retrofit

On presented case study (Fig 2.) walls of the house are strengthened by vertical stiffeners that connect all horizontal slabs and the foundation. Vertical stiffeners – trusses consist of the vertical ties, which are pre-stressed, and the other elements are diagonals with the seismic energy absorber and horizontals as a part of stiff floor slabs. Walls strengthened in this way become ductile (tough) and capable to accept the alternative horizontal dynamic displacements. However, additional loads on the foundations will be locally transmitted in case of dynamic excitation. (Fig 3.(b)).

The numerical analysis (Fig 3.) is performed with two directions of earthquake effect. Analysis shows that the largest tensile stresses, responsible for crack initiation, occur between holes (windows, doors) and cracks grow in direction of cross diagonals (Fig. 2, Fig. 3). System DC 90 comprises a number of structural elements which strengthen brittle walls and make them ductile and tough. They make floor slabs and ceilings stiff and capable to transmit the load in their own plane and connect them by foundation collars. These elements make structure stronger to accept the horizontal and vertical loads.

Fig. 2. (a) 3D House before reftrofit (; (b) House after retrofit (Petraskovic et al. (2005))

The laboratory testing was performed at the beginning of February 2004, in the Dynamic Testing Laboratory of the Institute of Earthquake Engineering and Engineering Seismology at Skopje. The testing program consists of several phases: Definition of resonant frequencies Definition of elastic response of the models (comparatively non-strengthened and strengthened).

The subject of experimental investigation was shaking table test of a reduced scale models 1/10 of masonry walls strengthened by DC 90 system. The models have been constructed in scale 1/10 having the dimensions: length: 30 cm, height: 25 cm and thickness 3.5 cm. The first type of model was made by so called giter blocks, the second one by plane burned bricks and third model by plane dried bricks. Each type of model was made in two ways: as conventional and as strengthened by DC 90 System.

The idea was to compare dynamic behavior of traditional and strengthening method of construction for the same type of bricks, as well as to compare the influence of brick type to dynamic behavior of the models.

The conditions at failure are associated with formation of a macro crack, whose direction is consistent with either Rankine’s or Mohr-Coulomb representation.

The calculated stiffness should be related to the scale factor 1/10 to obtain the actual stiffness of the real wall element. From results it can be seen clearly the contribution of the elements of System DC 90 to increasing of stiffness of walls. Initial shear stiffness was Es = 20/3.5 = 5.7 kN/mm, and later it slightly decreased, mostly due to anchorage yield of lower tie, and then it rises up again.

That leads to the conclusion that anchorage must be done properly, and that quality control (expert supervision) of performed works must be done. This will provide that house behave as similar as numerical and laboratory model. One important issue that has not been analyzed is resistance of subsoil, therefore another numerical analysis is necessary in order to prove the applicability of retrofit solution in this particular case.

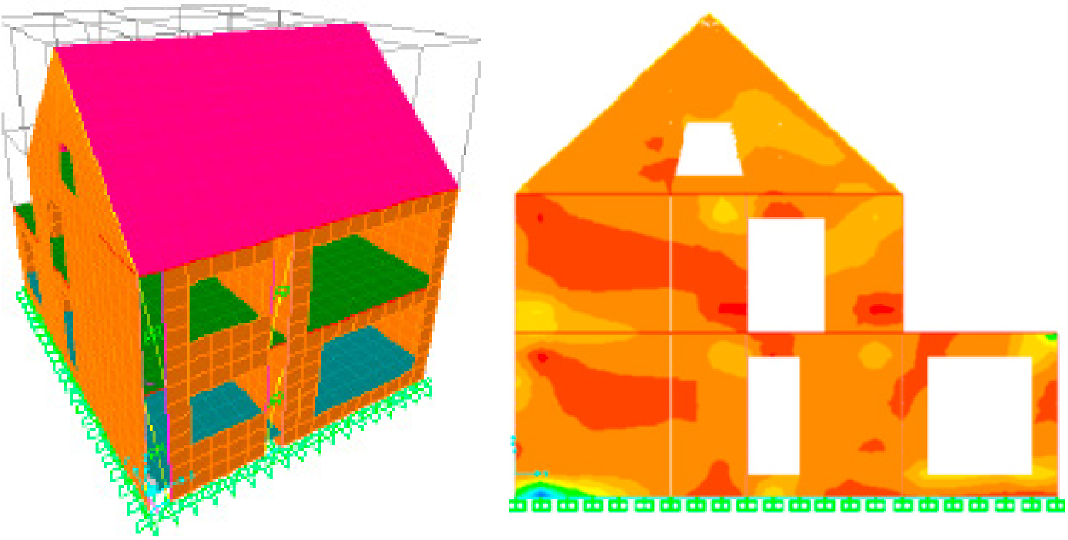

Fig. 3. (a) 3D FEM Model of house; (b) Maximal stresses from the earthquake (Petraskovic et al. (2005))

4. Numerical analysis

On basis of the findings described in previous chapter the geotechnical model has been formed. Although the seismic loads source is soil, this approach can be called "back" analysis where the loads received from the free vibration from the building are transmitted to the mesh of soil elements. Fig 3.(b). Considering that there was no geotechnical investigations from this particular object, the soil parameters has been interpolated from the neighboring building report and basic geological maps.

Table 1. Properties of conducted numerical analysis

Type of analysis	Common practice	Conducted analysis
Seismic hazard assessment	Yes(from the map)	Yes (from the map)
Seismic site response (local soil)	no	Yes (taken from the map)
Soil structure interaction analysis – static	no	yes
Soil structure interaction – dynamic	no	no

The conducted analysis basically takes into account static soil structure interaction (table 1). Coupled dynamic soil structure interaction, that is the most advanced level can be considered for the buildings of big importance. The main aspects of the dynamic soil structure interaction can be found in literature Mylonakis et al (2000).

Seismic site response is important issue even though in most cases there is no possibility to perform local soil seismic response analysis. In case of performing seismic site response analysis the adopted soil profile need to be consistent with the geotechnical model adopted in stress deformation analysis.

Numerical analysis has been conducted in commercial software Geostudio 2012 - module Sigma/W for stress deformation analysis, Fig. 4. The loads have been used from the FEM dynamic analysis conducted in (Petraskovic et al. (2005)). The size of finite element in SIGMA/W, using a simple 3-layer system. Constitutive model is linear elastic Mohr-coulomb, that is suitable enough for this level of seismic hazard and expected mesh deformations.

The maximal calculated settlement is 0.34 cm won't affect the building structure. This is very important finding in terms of the building retrofit solution durability. In case of dynamic excitation (earthquake occurrence) building structure will sustain the bigger deformations. The worst scenario is that seismic forces transmitted to the house foundations will induce soil collapse - large settlement subduction or liquefaction in some cases.

The main characteristic of DC90 system is that role is technique is to exhaust earthquake energy and, in this case, the inserted structural elements may be broken or damaged. Fortunately, these elements can be easily replaced. However, the underground soil can't be "replaced" in most cases and the main aim of this study was to prove that in this case soil brake will be avoided.

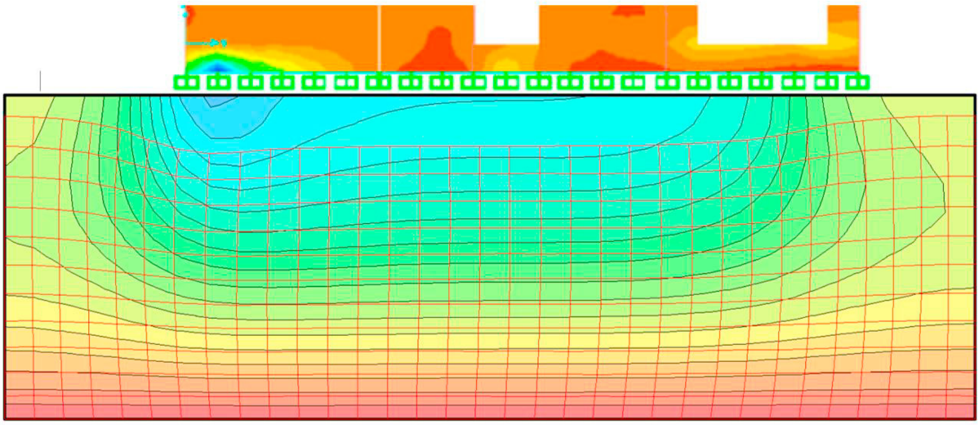

Fig. 4. Main outcome of numerical FEM geotechnical analysis – vertical deformation

5. Conclusion

Presented case demonstrates importance of taking into account geotehnical aspects while aplying the seismic retrofit tehniques. Structural retrofit of the bulding, in terms of numerical analysis and practice, can not be analysed separaterly from the foundation and soil stability analysis.

Observed example demostrate conection and corelation between numerical modeling of buidling structure and geotecnical model of local soil. The validation of retrofit solution in terms of patricural geotehnical condition is achieved by this example, and sugestion of author is that it should be comon practice for the most of sesmic retrofit calculations.

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