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THE MASONRY IN AREAS OF MODERATE SEISMICITY

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SUMMARY

The paper deals with the analysis of near field earthquakes that can appear in countries of moderate seismicity. The especial attention is devoted to the impacts of last moderate earthquake event in Eastern Slovakia in May 2003. The field observations are compared to the results of international research related to the effects of near field earthquakes. The response of masonry structures is analysed in relation to used materials and structural system composition. The works concentrated on the possible use of strengthening and retrofitting technique taking into account the latest progress in material technologies. The cases of use of polymer grids and fibre mortars are analysed in deep details. Necessary verifications of the strengthening technique reliability and safety interfere with reasonable initial and service costs.

INTRODUCTION

The construction of new structures, strengthening and repair of existing ones are based on the decision what will be the full or remaining life time. What degree of resistance capacity should be provided to meet combination of dead and imposed loads and future accidental impacts of seismic or other origin? When, where and how strong will be the next earthquake? What is the risk we accomplish with the structure design and execution? What are the uncertainties resulting from the estimates of loading, structure materials and systems, analysis and human errors? Which simplified methods are sufficiently reasonable to replace more sophisticated calculations? What is the answer from observations and experimental measurements either on full scale structures or on large scale models? Such and similar questions appear in the case of design of structures in seismic but also in non-seismic regions.

The environmental conditions shall be identified at the design stage so that significance can be assessed in relation to durability, and adequate provisions can be made for protection of the materials used in the structure. The environmental effects can influence the structure safety both in view of action changes and the deterioration of material properties as well. Possible sources of frequent or permanent vibrations that should be considered include walking, synchronised movement of people, machinery, ground born vibrations from traffic, and wind actions. Accidental vibrations are those from blasts, earthquakes, impacts, subsidence and explosions. A special attention should be devoted to the effects of near source

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earthquakes. These earthquakes exhibit features that deviate from those of far or middle far sources. The properties of near field earthquakes are characterised by short duration, large initial amplitude of acceleration and higher vertical component that is equal or higher than horizontal ones. Also contribution of rotation seismic motion components exceeds several times those from far or middle far sources. On the other hand, it is foreseen that also moderate earthquakes in near field exhibit the undesirable seismic actions that could be dangerous to some types of civil engineering structures.

TIME HISTORIES AND RESPONSE SPECTRA OF CHOSEN NFE RECORDS

For this purpose two records were chosen. The first one represents Japanese Ito-Oki earthquake from 9 July 1989, record at Shiofukizaki, with max accelerations NS – 0.193 g; EW – 0.193 g; DU – 0.254 g. Magnitude MW=5.3, hypocentre depth 5 km, epicentral distance 3 km. Record was obtained at the surface, soil conditions – rock (basalt), Kitada et al. [1]. Time histories and response spectra for horizontal components of this record are in Figure 1.

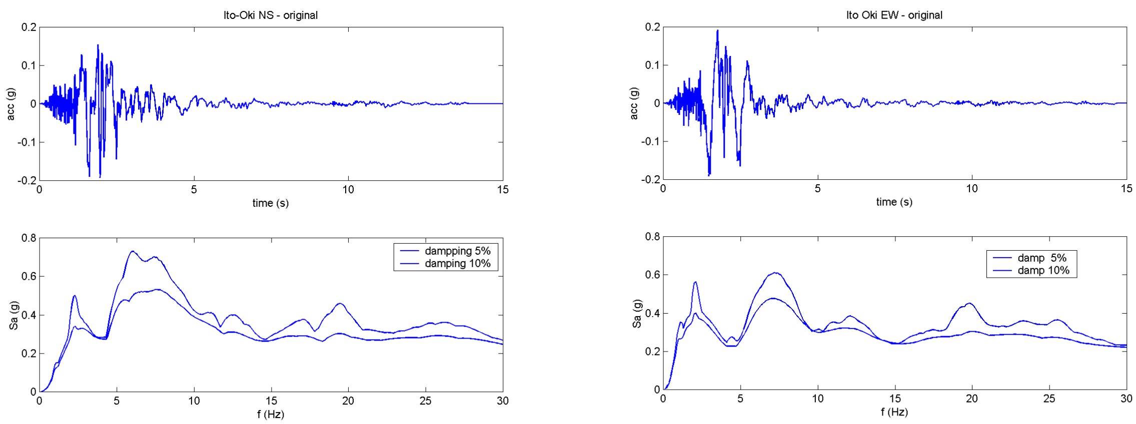


Figure 1. Time histories and response spectra of horizontal components of Ito-Oki 1989 earthquake

Second record represents Central Italy Umbria 26 September 1997 earthquake recorded at Nocera with max accelerations NS – 0.562 g; WE – 0.510 g; DU – 0.461 g. Magnitude ML=5.8, Mw=6.0, hypocentre depth app. 10 km, epicentral distance 10.7 km. Record was obtained at the surface, soil conditions – metamorphic rock, weathered - disturbed at the surface. Time histories and response spectra for horizontal components of this record are in Figure 2, Juhásová et al. [2].

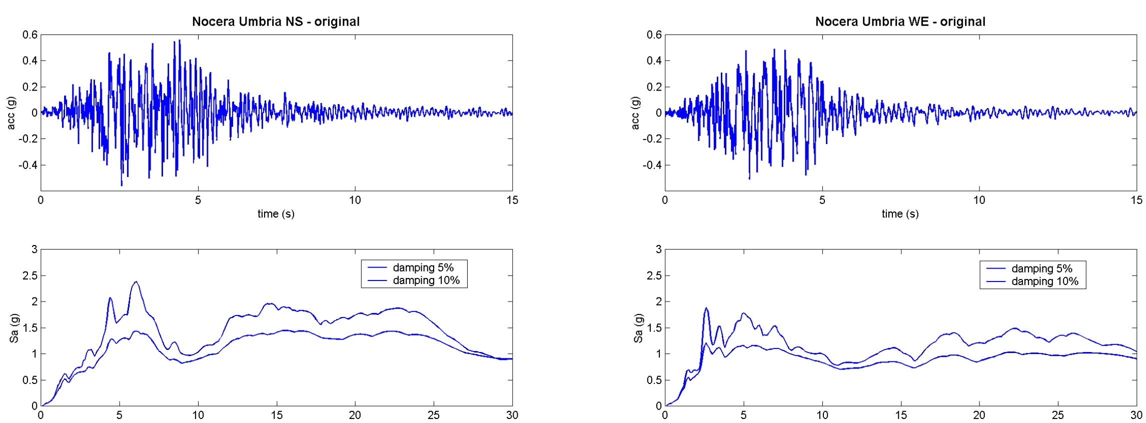


Figure 2. Time histories and response spectra of horizontal components of Umbria 1997 earthquake

EASTERN SLOVAKIA MAY 2003 EARTHQUAKE

Territory of Slovakia belongs to regions of moderate seismicity. However, more than 70 years ago the seismological observations were transferred into database for the estimate of seismic hazard and seismic loading of structures. Seismic loading has been taken into account from early sixtieths of previous century, Dvořák [3], Hruban [4]. Respective valid Slovak national seismic standard STN 73 0036 [5] was revised and edited in 1997. It is compatible with Eurocode 8.

The observations and knowledge from 2003 Eastern Slovakia earthquake have given the opportunity to analyse the resistance of and traditional masonry dwelling houses under near field earthquake actions.

The main shock of this earthquake was on 20th May 2003 with estimated local magnitude ML = 4.2–4.4. Figure 3 gives the view of concerned region and the neighbourhoods Jasenov and Paškovce where the largest impacts to buildings appeared. The distance of building sites from the epicentre was app. 12 km. The hypocentre depth was determined to be app. 10 to 12 km. According to the geological information, the active fault exists nearby these neighbourhoods (see Figures 4 and 5).

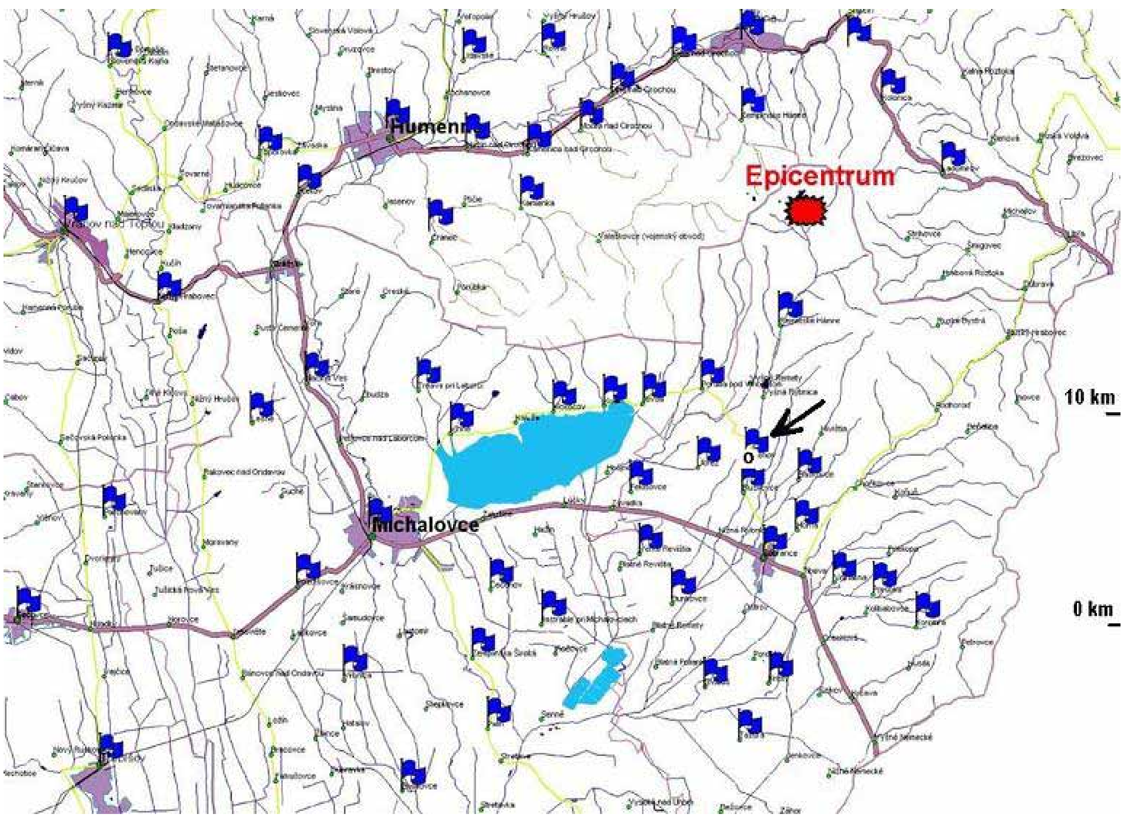


Figure 3. Eastern Slovakia, 20 May 2003 earthquake – points of macroseismic observations. The arrow shows the position of Jasenov village, see also Labák [6]

Jasenov is row village built along the stream and firstly mentioned in thirteenth century. The local traditional story says that six centuries ago the nearby village (app. 1 km) suffered the settlement, it had slumped and disappeared including its ancient church. Present orthodox church was built in 1820, its larger repair was in 1954, lately was renovated in 1995. Typical one nave masonry structure has the façade with the intrinsic tower and Prussian brick masonry vaults above the nave.

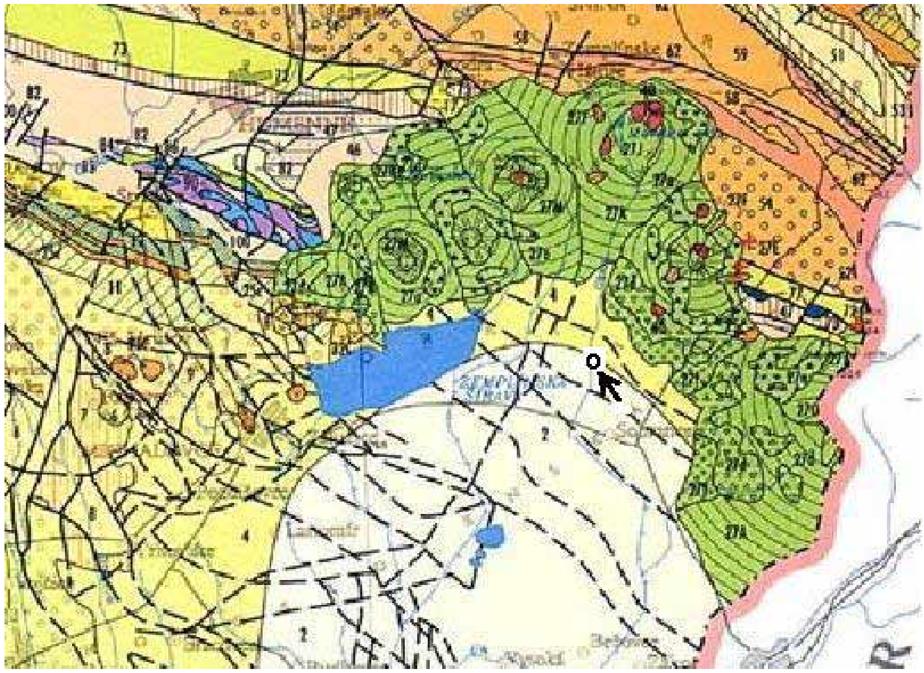


Figure 4. Geological map of Eastern Slovakia. Dashed lines correspond to assumed faults, solid lines to proved faults, thin solid lines to proved geological boundaries

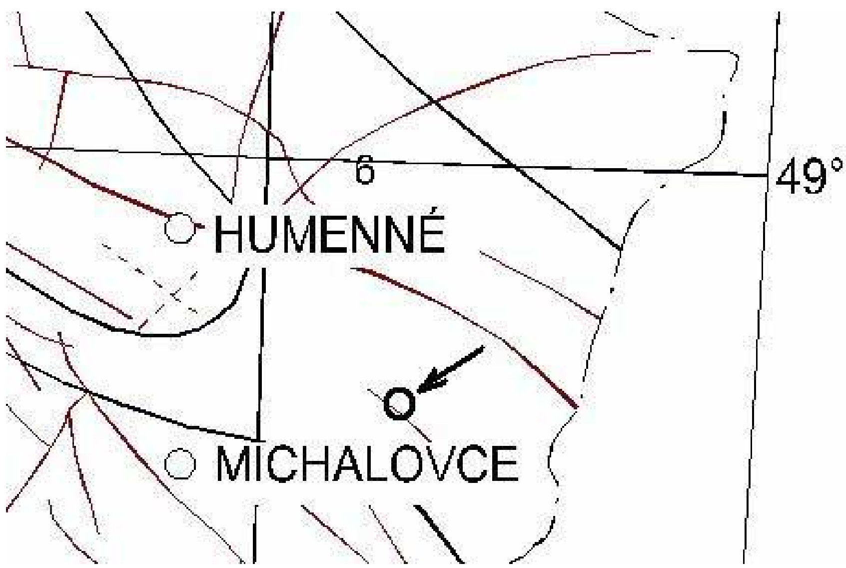


Figure 5. Major deep active tectonic faults at Easter Slovakia (Hrašna [7]). The arrow shows the position of Jasenov village

The subsoil beneath the village is weathered rock. Nearly 90 % of family houses in Jasenov recorded the damage from 2003 earthquake. The largest damage was registered in arches and vaults of the orthodox church with evident separation in vault masonry and extensive deep cracks in window arches and walls, see Figure 6.

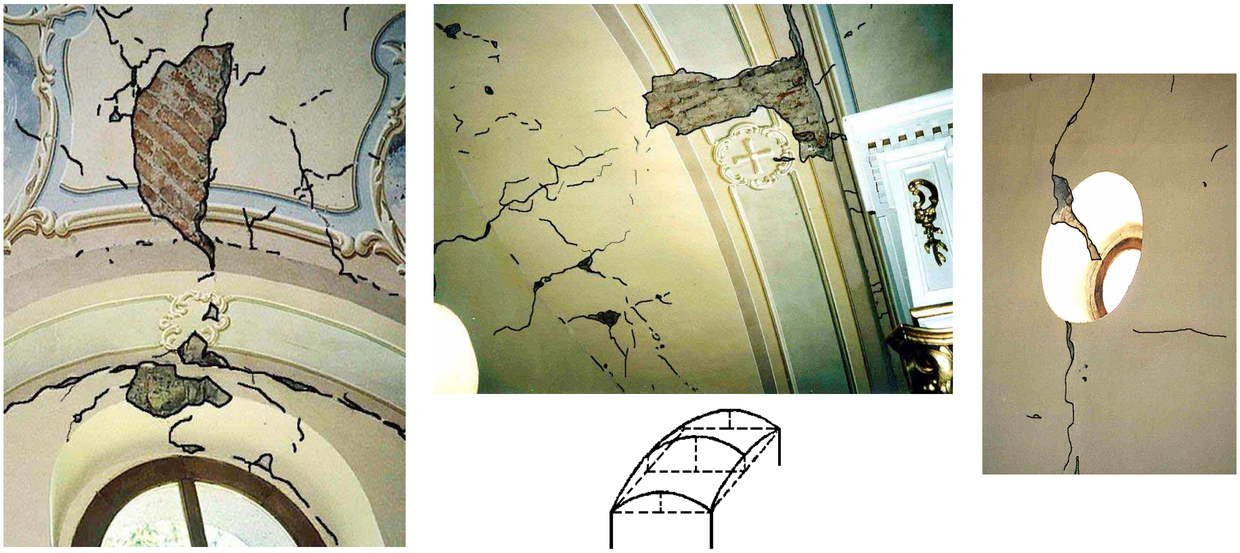


Figure 6. Damage to Jasenov ortodox church Prussian vault

Large number of family houses was built in last decades using traditional materials like solid or perforated bricks or light concrete block masonry. Floor slabs were either reinforced concrete or wooden systems. As the subsoil is rock, the majority of family houses have no underground. Houses have prevailingly strip concrete foundations, older ones have strip stone masonry foundations.

Typical damage to houses from outside view appeared in diagonal cracks following the masonry cladding but without creation of X cracks. This confirms the short duration and impact character of the main shock. Interiors of family houses suggested the considerable contribution of both horizontal and vertical impacts. The separation of perpendicular walls and partitions and spalling of the plaster from ceilings and walls appeared in many new houses. The mostly unpleasant failure was in those parts of houses where insufficient integrity predetermined vulnerable places, which were unable to resist the higher effects of near field earthquakes. Examples of typical cracks in family houses are in Figure 7.

Figure 7. Typical cracks in solid brick masonry of family house in Jasenov

POSSIBLE UPGRADING MEASURES TO SIMPLE MASONRY

The prescribed conditions exist for the use of plain masonry in seismic areas. Peak ground acceleration is limited and bricks should have sufficient robustness to avoid brittle failure, prEN 1998-1 [8]. Compression strength of bricks in the wall plane parallel to the bed face should be not less than 2 MPa. While solid bricks have more or less uniform compression strength in any direction, the perforated and cored brick units do not fulfil such condition. If the brick unit compression strength in any direction is lower than that of mortar, the cracks can appear either in mortar or in brick units. Table 1 gives indicative values of compression strength of different brick units considering the usual vertical direction of holes.

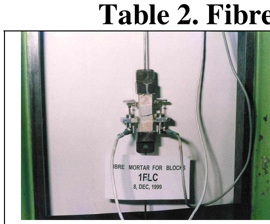
Table 1. Compression strength of different brick units

Type of brick unit	Vertical strength (MPa)	Out of plane strength (MPa)	In plane strength (MPa)
Solid bricks 290x140x65 mm	10 - 15	10 - 15	10 - 15
Perforated bricks 240x110x115 mm	10.6	3.4	2.4
Cored Thermobricks 290x115x230 mm	10.6	2.2	1.3
Light concrete blocks 397x240x298 mm	2 - 4	2 - 4	2 - 4

There exist many recommendations and practical applications of different nature for the increase of dynamic resistance capacity of masonry structures, e.g. Abrams [9], Aničić et al. [10]. Instead of discussing their advantages and disadvantages direct attention is devoted to the optimisation of fibre mortars and the advantage of use appropriate plastic grids or other materials for the reinforcement of masonry either in bed layers or inside of covering plaster. Parallel explanation of individual and combined behaviour of used materials is presented further.

The idea of improving mortar properties is in the use of isotactic polypropylene fibres of type Dimapos as the additive into mortars and plasters. The result is an increase of ductility and tension strength. Supplementary studies and experiments confirm the reasonable stiffness and strength of fibre mortars both in compression and in tension Juhásová et al. [11]. The values given in Table 2 were obtained from direct tension tests and completed the data obtained from tension-in-bending tests.

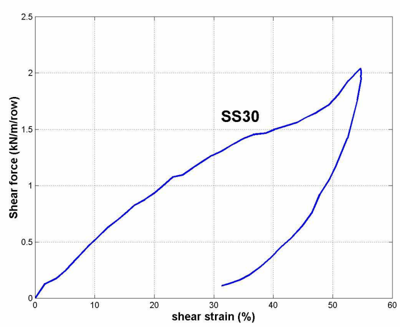
Table 2. Fibre lime-cement mortar properties obtained from tension tests



	$E_{t,max}$ (MPa)	$E_{t,sec}$ (MPa)	Tension strength (MPa)
	1800	1155	1.526
	1600	1168	1.952
	1300	1053	1.602
	1567	**1125**	**1.693**

Compression strength of fibre lime cement mortar is near the compression strength of brick units and depends on the age and the moisture degree. Mean value obtained from compression tests varied from 10 to 14 MPa. Sufficient ductility allows development of reasonable deformations under repeating and dynamic loading. The other mortars used in experiments were the lime mortar with the compression strength of app. 2 MPa; and lime-cement mortar with compression strength of app. 6 MPa. The compression-shear stress state and redistribution of stresses was controlled by tension strength of mortars Juhásová et al. [11]. Thus, simplified compression-shear normalised interaction scheme can be used, Severn et al. [12], Sofronie et al. [13].

Alternative practical solution consists in reinforcing masonry with polymer grids. Theoretically, the method is based on Prandtl's approach using theory of plasticity. It is assumed that under compressive and shear forces, when the ductile mortar reaches its ultimate limit state, bricks suddenly expel it. The polymer grids, with slender ribs and solid integrated joints, inserted in the bed layers are uniformly distributing the tensile stresses and by the "sandwich effect" any stress concentrations are prevented. If further the masonry, either plain or reinforced, is wrapped with polymer grids and plastered, then it becomes a composite with higher integrity and better behaviour under seismic or another dynamic actions, Juhásová [14].



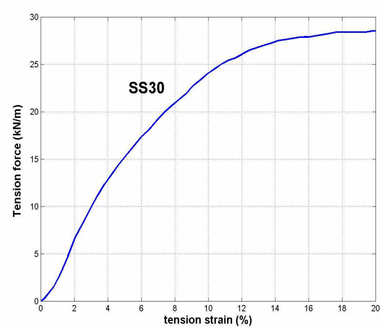


Figure 8. Behaviour of polymer grids in shear and tension obtained on small samples

Laboratory tests and numerical analyses validated this innovative method. The results of static, pseudo-dynamic and seismic tests are now available and indicate the basic features of static strength and dynamic response. Behaviour of the plastic grids like Tensar ones is effective prevailingly in tension and to some degree in shear, see Figure 8.

OBSERVATIONS FROM SHAKING TABLE AND PSEUDODYNAMIC TESTS

The response of a structure is a product of global and local stress-strain states resulting from the interference of natural modes/frequencies development and seismic input properties in time, and space Juhásová [15], Juhásová et al. [16]. Sometimes there can appear that unidirectional response is higher than multi-component one and/or one mode response can overrun multi-modal response. The extreme response variation suggests the needs of analysis spreading to those cases, which are suspicious to initiate the local or global damage.

Example of masonry behaviour in dynamic conditions is given further. The two storied masonry asymmetrical model was designed with two rooms in the first storey and one room in the second one. The floor above the first storey comprises a brick vault above one room and the wooden floor (one beam and boards) above the other room. Two doors and one window were finished with brick arches. The wooden floor of the second storey was similar like that in the first storey, but it was supported by two beams. The windows of the second storey were constructed with wooden lintels. Used materials were solid bricks and lime mortar of compression strength 0.8 – 1.0 MPa.

Results of seismic tests of original model gave information about successive cracks development with increasing intensity of loading. When the model was seriously damaged, but still possible to repair, the seismic tests of original model were stopped.

After the retrofitting procedure with the use of plastic grids Tensar SS 30 and special fibre mortar, the repaired model has been again subjected to tests. The development of new cracks showed the behaviour with considerably higher seismic resistance comparing to behaviour of original model. It should be pointed out that creation of cracks was shifted to those parts of walls where no retrofitting procedure was applied, see Fig 9. The promising result was that the seismic resistance of retrofitted model remarkable increased in comparison with the original model, e.g. Juhásová et al. [17], Colombo et al. [18]. Fig 9c gives extreme response accelerations recorded at the top ring of the model related to max input acceleration for both original and repaired stages.

Figure 9. Two storey brick masonry model after seismic tests: original and repaired

Figure 10. Cracks in the vault after the tests of two storey masonry model: original – on the left; repaired with fibre plaster – on the right

Figure 11. Cracks in the masonry wall after pseudodynamic tests of wall with openings: original – on the left; repaired with polymer grids in plaster – on the right

Taking into consideration the results obtained from large scale models seismic tests and pseudodynamic tests, the balancing ultimate strength, pseudodynamic carrying capacity and dynamic resistance exhibit influences of mortars, grids and bricks, including integrity phenomena. Any discontinuity in the added material starts local cracks initiation and their increasing. Ultimate strengths can be the same but cracks position varies. Typical vertical and horizontal cracks in case of enveloping grids replaced the diagonal cracks that represent the behaviour of unreinforced masonry. Double increase of dynamic resistance is supported by quality of mortar and effective action of used polymer grids. If the crack in masonry follows the straight line, e.g. in direction of bed joint, the one or few rows shear deformation in grid takes place. For engineering application mostly the use of SS20 or SS30 appears to be sufficient.

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CONCLUSIONS

In this paper few aspects of seismic excitation, material properties and the response estimate were depicted. It is pointed out to moderate earthquake effects in conditions of near field earthquake. A local and/or total failure can appear as the results of extensive vibrations. These vibrations and damage could be decreased by proper choice of material combination. The tools, which are used in response analysis, should be reasonable applied to improve the structure resistance capabilities. If ductility is supposed to be beneficial, the cracks can be accepted, provided that neither loss of structure integrity nor instability can appear. New materials like fibre mortars, polymer grids and other similar techniques evidently contribute to the structure integrity. Naturally, the proper detailing and the appropriate measures for increasing the total resistance capacity are key design and execution activities in the construction industry. This concerns not only earthquake effects but also transport and other dynamic effects and long term effects from soil settlements

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