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REHABILITATION OF MASONRY BUILDINGS USING SEISMIC ISOLATION SYSTEMS IN THE BASE – CASE STUDY

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Abstract. This paper aims to highlight the importance and efficiency of the rehabilitation of old buildings using an alternative to the classic rehabilitation, namely seismic isolation in the base. The method is efficient and will not interfer in the architecture and structure. The case study was conducted on a church that has a brick masonry structure. The structural analysis was pergormed by using SAP2000 soft, as for the study we used rubber bearings with metal inserts. The modeling was performed both for the unconsolidated structure and the proposed variant of consolidation using the rehabilitation method with isolation systems in the base (rubber bearings with metal insertions).

Key words: old buildings; rehabilitation; masonry; seismic isolation.

1. Introduction

The rehabilitation of the buildings has become a topic often studied, the main reason is the fact that many buildings have been affected by earthquakes and those with masonry structure faced the most problems (Anastasiu, 2009; Branco & Guerreiro, 2011).

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In the developed countries, 60% of the buildings have a masonry resistence structure, and most of them were not designed based on seismic loads, because they were built in the last century (Nuti & Vanzi, 2008; Shi, 2008; Eigawaday *et al.*, 2004).

2. Main Body

Along time, the rehabilitation methods for buildings were diversified because of the rise of performant materials and new technologies.

One of the consolidation methods is the seismic rehabilitation of the structures using the isolation in the base. This type of consolidation has some advantages, including the fact that it can be used for old buildings rehabilitation or the cultural heritage ones, because this method doesn't affect the building's architecture.

This technique is accomplished by introducing bearings at foundation level. Among the most used bearings there are: small damping bearings, lead core bearings, pure friction bearings, EDF bearings, big damping bearings and sliding bearings.

2.1. Case Study

In order to prove the efficiency of this technique, we performed a case study on the structure of Cathedral in Arad (Old Cathedral).

Fig. 1 shows the Cathedral's drawing.



Fig. 1 – Cathedral's drawing.

The Romanian Ortodox Cathedral in Arad was built in Baroque style, after demolishing the old cathedral in 1857. The building of the cathedral lasted for three years, till 1865. The church has two bell towers which were raised in 1905. Moreover, the Parish Cathedral Arad-Center is listed as a historical monument. Along time the church was restored several times, the most important took place in 1905-1906, 1912, 1921, 1956-1958, 1978-1980, 1991, 2002-2003 (http://www.fipindustriale.it...).

The cathedral's structure of resistance in entirely of brick masonry, its foundations are continuous from masonry, the arches and and domes are built in masonry.

With the help of the structural soft SAP2000 we performed a structural modelling as may be seen in Fig. 2.



Fig. 2 - SAP2000 modelling.

In determining the bulding efforts, we performed a modelling of the structure by using the soft SAP2000. The masonry was modelled using finit elements type SHELL-THIN, and for the arches zone, including their support, we used finit elements type FRAME. The numerical analysis carried out to catch the seismic effect was the Response Spectrum Analysis.

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The characteristics of the materials used for the building of the church were established taking into account a full brick with a resistance of 5 N/mm² (C_5) and a lime mortar with a resistance of 0.40 N/mm² ($M_{0.4}$). The materials resistances were so small also because the Cathedral was built in 1865, and the materials resistances were diminished in time.

The Cathedral has two towers (Fig. 3). The right tower has three bells with total weight of 5.5 to and the left tower has one bell with a weight of 5 to. The weights of the bells were introduced in the model as punctual force.



Fig. 3 - Old Cathedral from Arad (http://www.catedralaveche.ro/istoric.php).

The seismic load was considered according to the norm P100-1/2013 for Arad spectrum with $T_c = 0.7$ s and $a_g = 0.20$ g.

The proposed solution uses passive control systems, namely rubber bearings.

The rubber bearings which are used for seismic isolation (Fig. 4) not only have to be flexible for movement transmission but they have to be rigid for vertical actions. Because of this fact, in order to give the bearing the best stiffness, rubber bearings (natural or neoprene) with metal inserts were designed (http://aradcity.blogspot.ro/2010...).



Fig. 4 - Rubber bearing with metal inserts (Zaharia, 2004).

The bearings are made of industrial FIP (Renle *et al.*, 2012) and for the case study we chose a bearing type SI-S 500/102 with a displacement of 200 mm and features as in Table 1.

Table 1Features of Bearing SI-S 500/102 with Move of200 mm (Eigawaday et al., 2004)

Bearing SI-S 500/102 with displacement 200 mm							
<i>V</i> , [kN]	1,420	t_e , [mm]	102				
F_{zd} , [kN]	5,550	<i>h</i> , [mm]	190				
K_e , [kN/mm]	0.77	<i>H</i> , [mm]	240				
K_v , [kN/mm]	1,038	Z, [mm]	550				
D_g , [mm]	500	<i>W</i> , [kg]	270				

Where: V is the maximum vertical load at load combinations including the seismic action; F_{zd} – maximum vertical load at non-seismic load combinations, at ULS, concurrent with 0 rotation and 10 mm horizontal displacement; K_e – effective horizontal stiffness; K_v – vertical stiffness; D_g – elastomer diameter; t_e – total elastomer thickness; h – height excluding outer steel plates; H – total height including outer steel plates; Z – Side length of outer steel plates; W – isolator weight excluding anchoring elements.



Fig. 5 – Model of structure with bearings – bottom view with bearing position.

In order to determine the position of the bearings we carried out a predimension according to P100-3-2008 which resulted in a number of 30 bearings positioned as in Fig. 6.

In the numerical model (Fig. 5), these bearings were designed using elements type LINK, which have a liniar mechanical behavior and following features: stiffness to axial force of 1,038 KN/mm and stiffness to translation on both horisontal directions of 0.77 KN/mm.



Fig. 6 – Zone of comparing the efforts.

Following those two alaysis, we notice (Tables 2 and 3) that the vibration periods for the first three own modes of vibration are much bigger than the bearing model one. Moreover, the directions of these vibration modes are the same in both calculus models, this fact being highlighted by the values of the "Participating Mass Ratio".

Model Without Bearings							
Mode	Period, [s]	Participating mass ratio					
		UX	UY	RZ			
Mode 1	0.380253	0.000003526	0.46094	0.29707			
Mode 2	0.352022	0.4215	0.00001827	0.07624			
Mode 3	0.315748	0.00003858	0.00088	0.02145			
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 Table 2

 Iodel Without Bearing

Where: UX is the direction by x; UY – direction by y; RZ – rotation by z.

Model with Dearings						
Mode	Period, [s]	Participating mass ratio				
		UX	UY	RZ		
Mode 1	2.806889	0.000002304	0.99589	0.41081		
Mode 2	2.793443	0.9976	0.000002344	0.59286		
Mode 3	0.659159	0.000000629	0.00003095	0.93955		

Table 3Model with Bearings

Where: UX is the direction by x; UY – direction by y; RZ – rotation by z.

In terms of efforts, in the variant with bearings, their values decreased significantly as shown in Figs. 8 and 9. While in some areas in the variant with no bearings the efforts are -0.12 Nmm, in the variant with bearings the value of the efforts is -0.05 Nmm. The value of the efforts were taken from the check zone in Fig. 7.



Fig. 8 – Value of efforts in variant without bearings.

3. Conclusions

Every day more and more buildings suffer from earthquakes and the same time the buildings have more value especially from the architectural point of view. The technological development helps us to maintain these constructions with a historical inheritance which are functional due to the emerging technologies and new materials.

Using the technique of seismic isolation in the base is one of these technologies, and especially a very efficient one with very good results.

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REABILITAREA CLĂDIRILOR DIN ZIDĂRIE UTILIZÂND SISTEME DE IZOLARE SEISMICĂ ÎN BAZĂ – STUDIU DE CAZ

(Rezumat)

Se arată importanța și eficiența reabilitării construcțiilor vechi din zidărie utilizând o alternativă la reabilitarea clasică și anume izolarea seismică in bază. Metoda amintită este una eficientă și în plus în acest fel nu se va interveni la structură și 144 Maria Nicoleta Roman Pintican, Andrei Faur, Mihaela Dumitran and Răzvan Iernuțan

arhitectură. Studiul de caz s-a realizat pe o Biserică având structura din zidărie de cărămidă. Analiza structurală s-a realizat cu ajutorul programului SAP2000, iar pentru studiu s-au folosit reazeme de cauciuc cu inserții metalice. Modelarea s-a realizat atât pentru structura în stare neconsolidată cât și în varianta propusă de consolidare utilizând metoda de reabilitare folosind sisteme de izolare în bază (cu reazeme de cauciuc cu inserții metalice).