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Consolidation Methods of Romanian Historical Building with Composite Materials

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Abstract. Timisoara is a growing city in the western part of Romania, in a seismic area, with a lot of masonry buildings with historical and cultural value, with interesting structural elements such as vaults, arches, slabs, walls, that were affected by earthquakes, subsidence of foundations, negative human actions or lack of interventions. Masonry historical structures in Banat seismic area present particular failure mechanisms, so there is a need for new, modern, fast, easy-to-apply and reversible consolidation methods. With this type of methods is possible to assure the local and global resistance, ductility, stability and rigidity for historical buildings. This article shows the consolidation methods that were applied on the buildings Sf. Gheorghe 3 and 4, in the historical centre of Timisoara, on masonry structures with historical value. The solutions that were applied are using new, innovative fibre-reinforced composite materials, in order to repair the existing damages and prevent further ones. The consolidation solutions with these new composite materials reduce the buildings vulnerability and present the advantage of being fast and easy to be executed.

Introduction

Romania is characterized by 2 major seismic zones, namely Vrancea and Banat. The first one developed intermediate deep earthquakes (150 km), with large number of cycles and long duration, while the second one is characterized by shallow earthquakes, with a peak ground acceleration of 0.20g and pulse action and short period of vibrations [1]. That is why earthquakes from Vrancea seismic area create significant inelastic deformations, while earthquakes from Banat seismic area generate powerful first cycle and horizontal and vertical components of same size [2].

Timisoara city is located in the Banat seismic area, with a lot of buildings having historical and cultural value. All of them are built in burnt clay brick [3], but the failure mechanism may differ according to their shape in plan, construction system and connection among structural elements [4].

The present article will analyse two historical buildings located in Timisoara, will identity the damages and will present several intervention solutions by using fibre reinforced composite materials, for increasing the bearing capacity of structures, while keeping the original stiffness and being reversible and easy to be applied. All these solutions are based on the Chart of Venice principles. The case study buildings are Sf. Gheorghe 2 and Sf. Gheorghe 3, from Sf. Gheorghe square, in the historical centre of Timisoara.

The case studies

Description of buildings

As it was said earlier, Sf. Gheorghe Square is one of the oldest city squares in Timisoara, dating from 18th century. The shape of the square is a U-shape. The buildings that are making the subject of the case studies were built at the end of the 19th century, with an interior yard, specific for that period. As we can see in Fig.1 and Fig.2, both buildings are presenting similar structural systems, with basement, ground level and two stories, having cellular brick wall system. Over the basement and the ground floor, the ceiling is made of vaults and arches, in masonry, while the 1st and 2nd floors ceilings are made of timber beams, with no significant stiffness in the horizontal plane [3, 5].

Fig.1 Front view of the 1st studied buildings

Fig.2 Front view of the 2nd studied buildings

State of degradation

Most of the degradation factors are because of the external factors due to climate change and exposure to wind, rain and snow and also due to lack of constant maintenance interventions. The ground settlements and past earthquakes have let a few signs of degradation, while the unauthorized interventions on the bearing structure had accentuated the degraded state of the buildings. The brick masonries are made with clay and lime mortar of poor quality, being eroded in the areas where the plaster is not anymore. Despite of that, the bricks are in good shape, without any significant damages [5].

As we can see in Fig.3, on one transversal wall, the cracks are very pronounced at the 1st and 2nd floor, because of the factors revealed earlier, such as different settlements and past earthquakes, very pronounced at the windows sill area [3].

Fig.3 Cracks at the first floor

The most dangerous crack was identified on the longitudinal central wall. It starts from the superior area of the wall and continues till the basement, as we can see in Fig.4.

Fig.4 Cracks on the longitudinal central wall

At the basement level, there were identified damages on arches ant vaults, because of irregular settlements of the foundations, which are very little recessed in the foundation ground. Despite of the general observation, only a few areas of the vaults are in bad condition. The rest are in good state, ensuring an effective bond between the walls.

Because of the humidity and improper maintenance performed by the former owner, the bearing capacity and the stiffness of the timber beams have been progressively reduced with time, showing damages at the ceilings at the 1st and 2nd floors. The roof instead is in a good state, showing only some insignificant damages, mainly at the joints.

The existing timber ceilings, being incapable to ensure the rigid ceiling behaviour, are responsible of the actual condition of the building. In fact, due to the existing floors, in case of important seismic movements, the building can suffer serious damages, leading to local or global collapse of the ceilings or walls [3, 5]. If there were at least some connectors with belts or anchors in the masonry for the wood beams, maybe the situation would not be too much dangerous. Instead, due to the lack of good connections, the vertical components of seismic movements can produce collapses of the timber beams, arches, vaults and masonry walls from the 1st and 2nd levels [3, 5].

Consolidation project

Wall consolidation

The simplified analysis of the building together with the visual observation of detected damages, has shown that the buildings have an average vulnerability degree [5, 6].

Previous similar case studies have revealed that the presence of fibres prevent the typical collapse that occurs normally on a plain arch or vault. Depending on the position and amount of reinforcement, three mechanisms are possible: masonry of the vault crushing, detachment of the fibres or sliding along joint due to the shear stresses [7].

The walls were consolidated by setting some stainless steel helical joists for sewing the fissures (AISI 304). Then, a vertical and horizontal glass fibre wired mesh (Rinforzo ARV100) was mounted on top of Geocalce mortar (without cement addition). At last, some vertical metallic profiles will be set, for the stiffening of the wall [8], as we can see in Figures 5-7.

The main advantages of using this material are: high durability and a high resistance, tested by strict environment durability tests saline and alkaline, freeze-thaw and high humidity, high shear, impact and abrasion and excellent mechanical performance provided by special treatment with water-based resin [9].

Fig.5 Consolidation of the ground floor corners

Fig.6 Consolidation of the corners

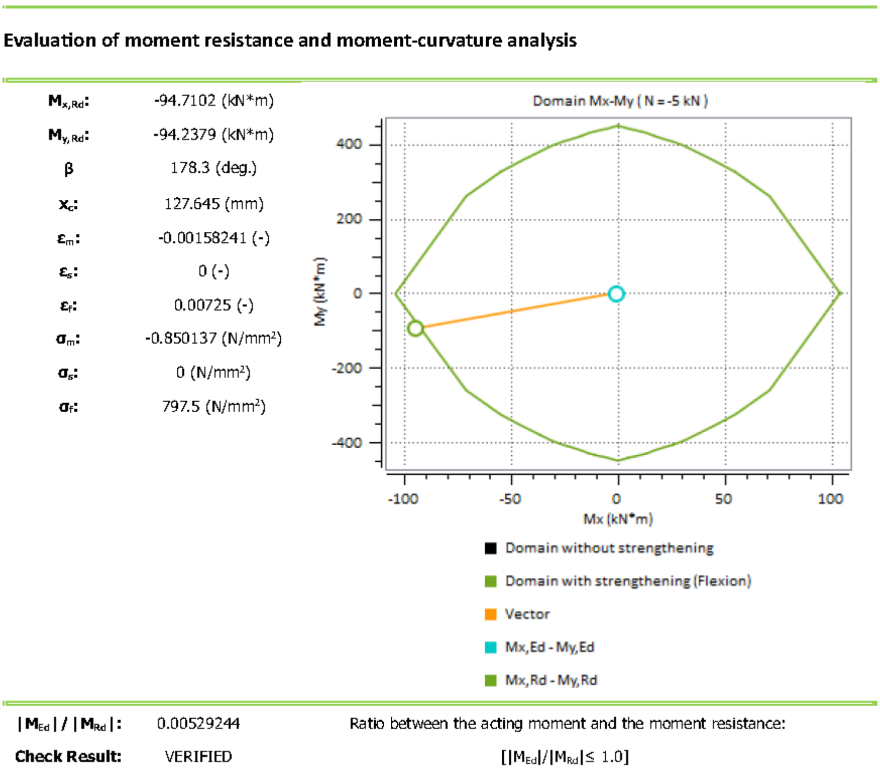
Fig.7 Consolidation of the exterior walls

Consolidation analysis

Using GeoForce One V1.10 design software, there was possible to identify the differences of behaviour between one wall similar to the masonry walls existing on site and masonry walls consolidated.

The mechanical characteristics of the masonry were considered as the characteristics of the weakest masonry in Romania.

As we can see in Fig.8, the ratio between the acting moment and the resistant moment is not verified for the unconsolidated masonry wall, but it is verified for the consolidated one.



Evaluation of moment resistance and moment-curvature analysis

$M_{x,Rd}$:	-94.7102 (kN*m)
$M_{y,Rd}$:	-94.2379 (kN*m)
β	178.3 (deg.)
x_c:	127.645 (mm)
ε_m:	-0.00158241 (-)
ε_s:	0 (-)
ε_f:	0.00725 (-)
σ_m:	-0.850137 (N/mm²)
σ_s:	0 (N/mm²)
σ_f:	797.5 (N/mm²)

$\lvert M_{Ed}\rvert / \lvert M_{Rd}\rvert$:	0.00529244	Ratio between the acting moment and the moment resistance:
Check Result:	VERIFIED	$[\lvert M_{Ed}\rvert/\lvert M_{Rd}\rvert \leq 1.0]$

Fig.8 Ratio between the acting moment and the resistant one

For the moment-curvature analyses, we can see a big difference between the original wall and that with strengthening interventions, as we can see in Fig.9. The ratio between shear action and shear resistance is also verified, as we can see in Fig.10.

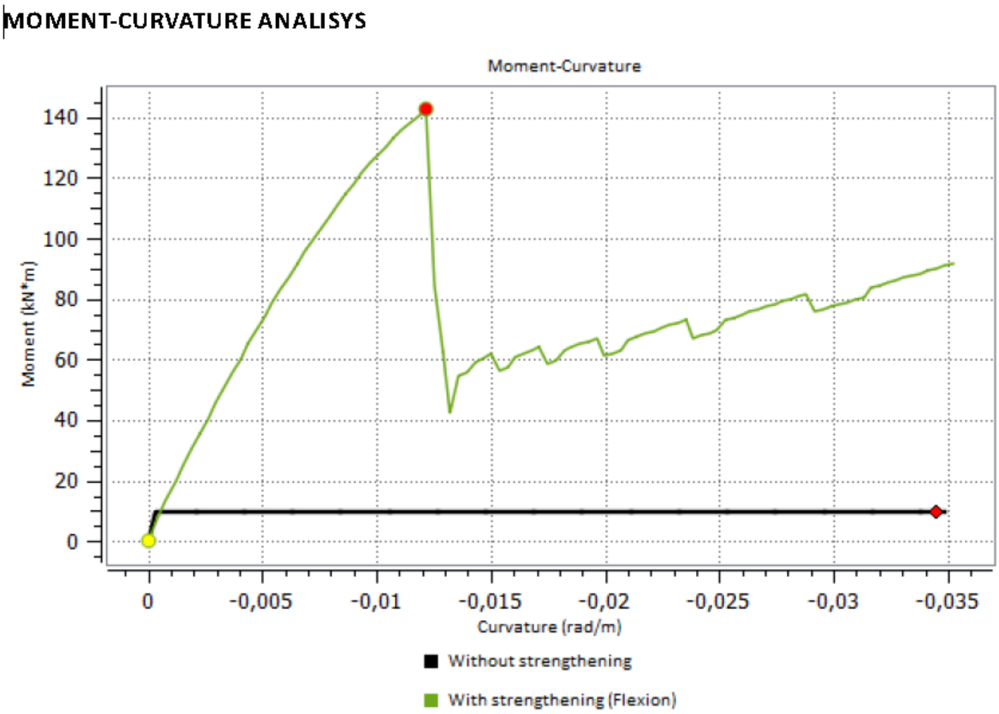
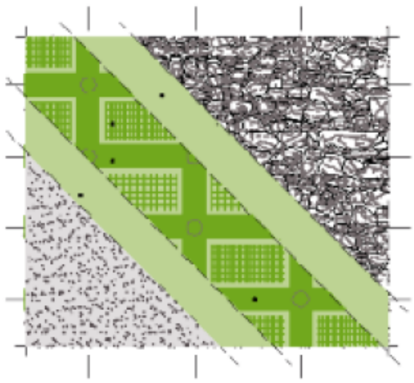


Fig.9 Moment-curvature behaviours of original wall and consolidated one

Evaluation of shear resistance



Resistance given by masonry

x	$V_{Rm,d}$	$V_{R,max}$
600 (mm)	54.0741 (kN)	320 (kN)

Resistance given by the strengthening

$V_{Rd,f}$

23.4465 (kN)

Shear resistance of the strengthened cross section

V_{Rd}

77.5206 (kN)

The resistance V_{Rd} corresponding to the sum of the resistance given by the Geosteel[$V_{RdGeosteel}$0(kN)] and the resistance given by the grid [V_{RdGrid}23.4465(kN)]

$\|V_{Ed}\| / \|V_{Rd}\|$:	0.0064499	Ratio between shear action and shear resistance:
Check Result:	VERIFIED	$[\|V_{Ed}\|/\|V_{Rd}\| \leq 1.0]$

Fig.10 Ratio between shear action and shear resistance for the strengthened wall

Vault consolidation

The consolidation system, composed of the Geocalce mortar, basaltic and stainless steel wired mesh, has been used for the consolidation of vaults. In particular, a special protective treatment with water-based resin and basalt fibre reinforced mortar (a mix between basalt fibre wired mesh and mineral mortar, based on pure hydraulic natural lime) was set, laying the mesh uniformly over the entire surface of the vault [3, 10], as we can see in Figs. 11 and 12.

Fig.11 Reinforcement of the vault intrados

Fig.12 Reinforcement of the vault extrados

Conclusions

The effects of retrofitting in many cases were not advantageous for historical buildings, because of the fact that consolidation was performed by using heavy materials, such as reinforced concrete instead of wooden beams, mixed steel-hollow tiles floors and heavy jacketing's, leading to the change of stiffness of the buildings [11]. That is why it is very important to use in consolidation designs new composite materials that do not change the stiffness and weight of the retrofitted building, but increase it bearing capacity and are reversible and easy to be applied. Also, those materials may solve the humidity problems and are reversible, in harmony with The Chart of Venice principles [12].

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