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THE EXISTENT BUILDINGS STOCK VULNERABILITIES AND THE POSSIBLE RETROFITTING STRATEGIES

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Abstract: *Being in countries with high seismic risks and vulnerability or mining subsidence we have the legacy of an existing buildings stock (with masonry and gravitational frame structures) which must became safety from all the viewpoints. Depending of the computational tools of each period, after about 20 years of work and about several hundred case studies of different building types (from different typological groups) the author attend to find some general considerations about the behavior of the buildings with gravitational frame structures and their optimal possible retrofitting solution. In this trend several idealized study cases were used.*
Keywords: *vulnerabilities, retrofitting, strategies, subsidence, hazard*

1. INTRODUCTION

There are quite a lot of existing buildings (erected in different historical periods) with different design methods (sometimes without any design rules, just life experience of the masters) and representing a huge cultural heritage.
On the same hand there is a big provocation for the new architects and civil engineers to preserve these and to put in safe from different points of view (structural and architectural).
These existing buildings highlight a lot of vulnerabilities: gravitational, wind/snow, seismic, differential settlements, mining subsidence, temperature and others. The gravitational safety, the brittle failure mechanisms must be resolved for majority of the existing structures.
There are a lot of retrofitting solutions; the problem is to find the better one for each study case. The majority “classic” solutions are based on RC solutions, but are invasive. Sometimes the solutions with RC jacketing present some inconvenient architectural aspects so is absolute necessarily to carry out real or computational tests and new methods of other retrofitting solutions.
From the seismic and mining subsidence point of view there are two aspects which must be resolved: the stiffness capacity and the strength capacity prob. RC retrofitting solutions offer both of these characteristics during the FRP solution of retrofitting may give sufficient strength capacity but from the stiffness point of view other solutions may offer better responses.
Different type of analisys must be carring out including elastic and elastoplastic analysis, 2D or 3D computational models may help to reach a final better result. To improve all the analitical skils and numerical tests instate of phisical tests
On the other hand, the existing buildings are made from different types of materials such as: timber, masonry (diferent type of bricks and mortars), RC and others so the problems of materials complementarity must be resolve. Only few of them were elected for this ample study. [2]

2. PRINCIPAL VULNERABILITIES OF THE BUILDING STRUCTURES

The translation and integration of hazard, vulnerability and inventory data in the assessment of earthquake risk requires the development and refinement of each ingredient of the loss model. Concerted efforts worldwide have focused on the refinement of *hazard* through the development of models that more accurately represent the earthquake source, path effects, site response and topographical influence. This has led to better estimates of strong ground motion and the description of hazard in terms of spectral ordinates, as opposed to ground parameters, to account for the response periods of the systems exposed to earthquakes. Efforts have furthermore been dedicated to the improvement of the fragility or *vulnerability* representation of exposed systems in terms of their sub-division into classes according to the characteristics that most influence their response. Limit states have been better defined in terms of deformations rather than load exceedence, and multiple limit state satisfaction has become a realistic target [1]

5. STATE OF THE ART CONCERNING BUILDINGS WITH MASONRY STRUCTURES VULNERABILITIES AND DESIGN

Several relatively simple evaluation methods based on engineering knowledge has been developed with the goal to design new masonry buildings and to assess the vulnerability of existing masonry buildings within the scope of the earthquake scenario project for countries in seismic zones.

Comparisons with experimental results have shown that the results from the evaluation methods lie within the accuracy required for earthquake scenarios.

However, many assumptions had to be made in order to use this methods in practice as the behavior of unreinforced masonry buildings under earthquake action is not yet very well understood.

Further research could help to reduce the lack of knowledge and to improve the reliability of the evaluation methods.

Taking into consideration the period of the design and erection for these masonry walls, we may accept that:

If the building is an existing building, made without design codes or with incipient rules it happened that the masonry walls to be the first resistance line against the earthquakes, before the RC frame systems.

If the building is designed under the actual design codes, the connection between frames and infill panels must be very wise considered to assure that the first resistance is represented by frames. It happens that the piers or masonry structural walls to remain one of the first resistance line in a building structural system.

To consider the infill panels contribution at the entire system stiffness and strength capacities it is necessarily to identify the failure mechanism of these and the shear forces according with the fissure stage. [4] [5]

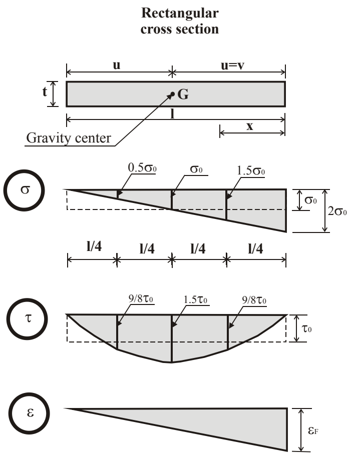

Figure 1 – Fissure stage

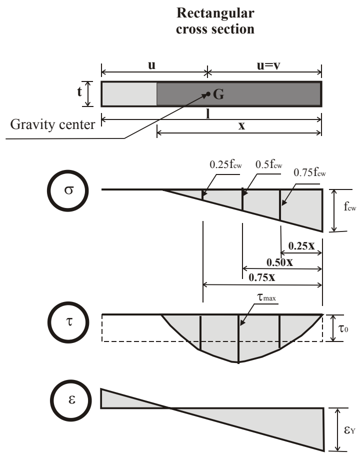

Figure 2 – Yielding stage

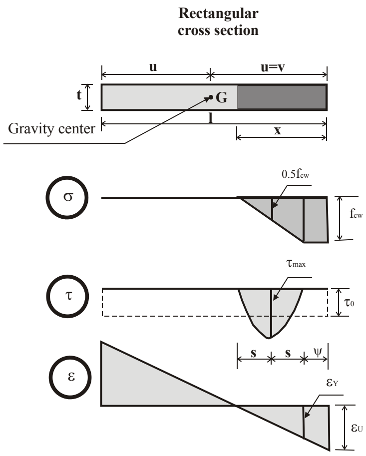

Figure 3 – Ultimate stage

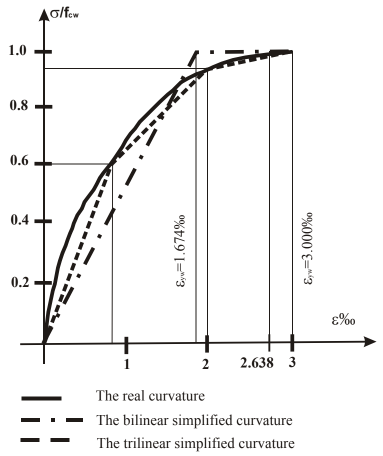

Figure 4 - Constitutive law – (Masonry characteristic curvature)

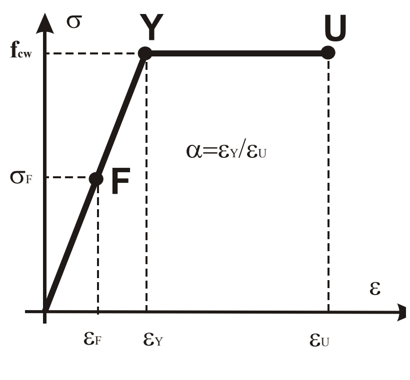

Figure 5 – Simplified bilinear curvature

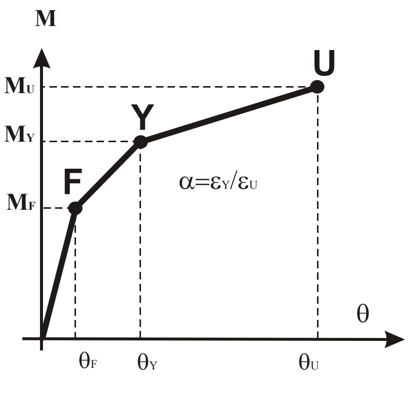

Figure 6 – Simplified trilinear curvature

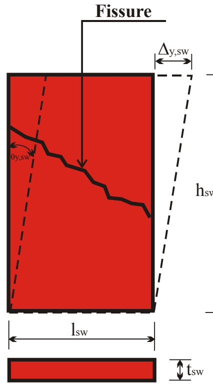

Figure 7

Short wall

$$\frac{l_{sw}}{h_{sw}} < 0.6$$

$$\theta_{y,sw} = 6‰$$

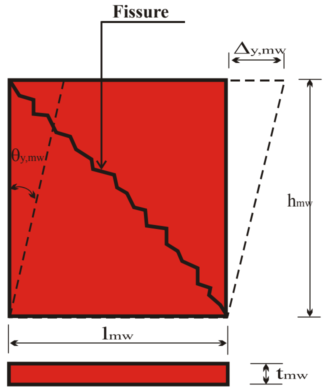

Figure 8

Middle wall

$$0.6 \le \frac{l_{mw}}{h_{mw}} \le 1.5$$

$$\theta_{y,mw} = 4‰$$

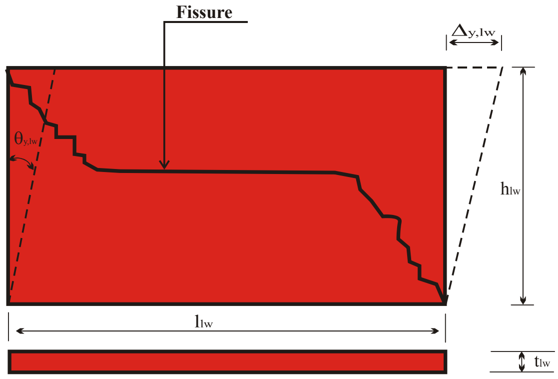

Figure 9

Long wall

$$\frac{l_{lw}}{h_{lw}} > 1.5$$

$$\theta_{y,lw} = 2‰$$

6. STATE OF THE ART CONCERNING BUILDINGS WITH RC GRAVITATIONAL FRAMES STRUCTURES VULNERABILITIES AND DESIGN

In order to obtain the vulnerability function of a RC building, i.e. the damage as a function of the spectral displacement, the displacement at the top of the building D is associated with the damage grades according to the European Macroseismic Scale. For each damage grade, indicators are defined that allow the identification of the points at which the building enters the next damage grade on the capacity curve of the building.
A simple evaluation method for existing reinforced concrete buildings has been proposed in analogy to the evaluation method for unreinforced masonry buildings. A comparison with a thoroughly checked deformation orientated method has shown that the results lie within the accuracy required for earthquake scenarios.
The evaluation of reinforced concrete buildings and the evaluation of unreinforced masonry buildings are based on the same principle. They only differ in the capacity curves which are calculated depending on the material. It is therefore possible to consider mixed structures, i.e. buildings with reinforced concrete gravitational frames, structural walls and unreinforced masonry walls. Like for "pure" buildings the capacity curve of the building is obtained by superposition of the capacity curves of all the structural elements. [4] [6]

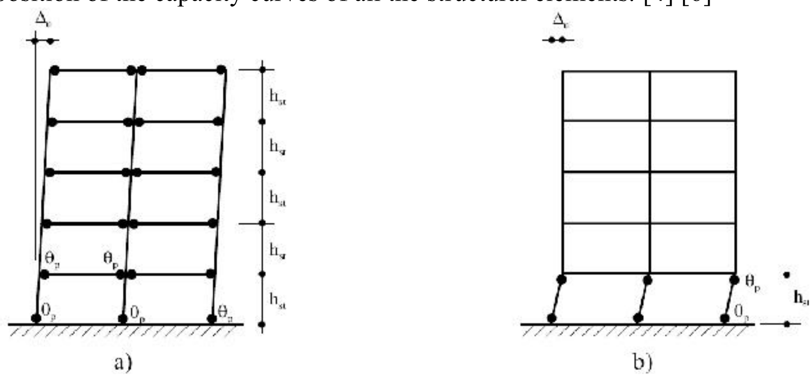

Figure 10: Plastic hinges occurrence

a) The accepted mechanism

b) Unaccepted level mechanism (soft and weak level)

7. GENERAL CONSIDERATIONS ABOUT THE BEHAVIOUR AND RETROFITTING SOLUTIONS FOR THE EXISTING BUILDINGS WITH MASONRY STRUCTURES. IDEALISED STUDY CASES VS REAL STUDY CASES.

These buildings present a lot of irregularities including architectural and structural ones, in the plan or in the elevations;

The masonry structures, in parallel with the gravitational frame structures are probably the most irregular cases. From the general considerations the masonry structures may be:

- Unitary – meaning practically one building, made from the beginning and kept in this shape;
- Attached – meaning that in time the owners (different or not) attached in plane (other bodies of the building) or on the vertical (other levels);

From the structural point of view the masonry structures may be:

- Optimum developed in plane and space – with similar stiffness characteristics on each principal direction and on the vertical;
- „In lane or wagon type" buildings – where usually there is a huge difference between the stiffness characteristics on principal directions.

Without any specific design tools, masonry structures were more or less the architects appendage. The masonry walls thickness were generally in accordance with the solid brick dimensions (7x14x28 cm) made from a good class of bricks (about C50-C100) and a worse class of mortar (between M4-M10). There were not any computations for these kinds of structures, excepting the centric compression stresses. Usually there are not any small columns or ties in these masonry structures meaning that we may consider a URM solution. The coupling beams (lintels) are from masonry and timber or steel at the bottom.
The considered slabs thickness was about l/40 (where l=minimum dimension of the slab, from both directions). Always the foundation soil was considered with a conventional pressure between 200-300 KPa. [3] [4]

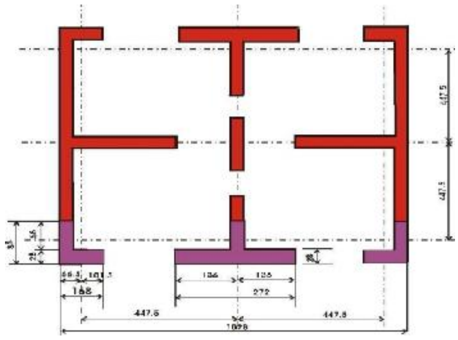

Figure 11 – Idealised study case

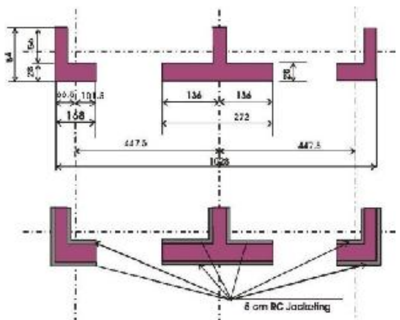

Figure 12 – Existent vs retrofitted masonry piers

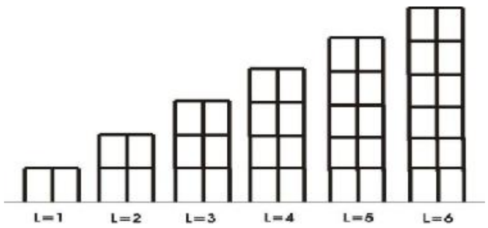

Figure 13 – Number of levels

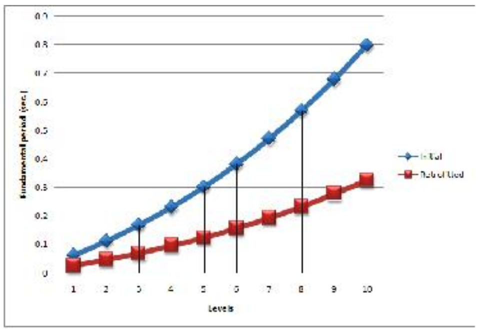

Figure 14 – Initial vs retrofitted vibration periods

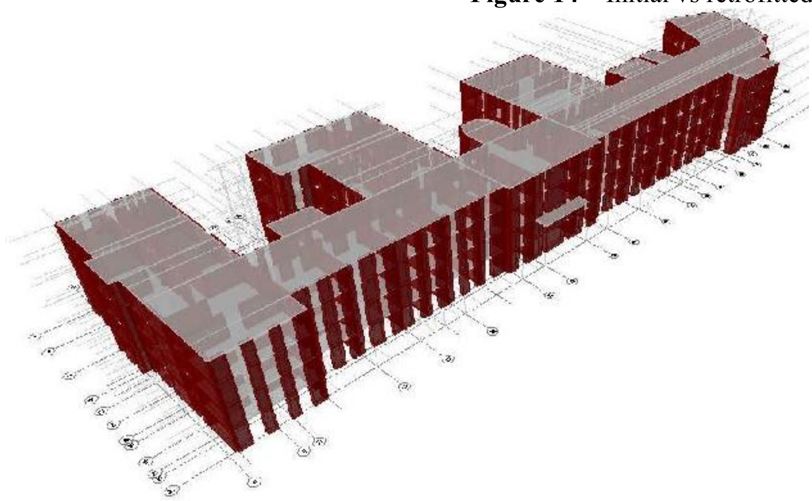

Figure 15 – Real existent vuilding study case

8. GENERAL CONSIDERATIONS ABOUT THE BEHAVIOUR AND RETROFITTING SOLUTIONS FOR THE EXISTING BUILDINGS WITH GRAVITATIONAL FRAME STRUCTURES. IDEALISED STUDY CASES VS REAL STUDY CASES.

This ample study is just at the very beginning, but even after the things presented above, we shall say that the buildings with **existing gravitational frame structures** are very flexible structures. If normally in a simplified manner we appreciate the fundamental period of vibration for a frame structure at **T=0.1n**, for these existing structures we found an average period of **T=0.200+0.15n** (where **n** is the storeys number) but whish actually is very sensitive to the considered model:

- For poor frame structures – T=0.156n+0.278 (sec);
- For soft&weak structures – T=0.151n+0.245 (sec.);
- For infill frame structures – T=0.128n+0.115 (sec).

Usually the cross section areas of the columns both from the eccentrically compression or shear force point of view are smaller than the actual codes demands and must be increase. Two retrofitting solutions are viable to increase the stiffness, the cross section areas and the strength capacities of the structure: RC jacketing of the columns and/or RC structural walls implementation.
It appear a very good behaviour for both type of retrofitting solutions for the buildings with the height beyond 5 levels and the RC structural walls retrofitting solutions seems to have a better behaviour for the building above 5 levels.
When a designer must expertise and retrofit this type of structures, from the beginning he will know the structural responses and expectations of them in comparison with all the demands. Having these ideas will be more comfortable and easy to have discussions with the architects involved in the same project and of course with the owner of the building, in the idea to choose the better way to put in safe the existing building structure. Sometime other problems may occur such are the soil characteristics, the neighbourhood buildings. [3] [4]

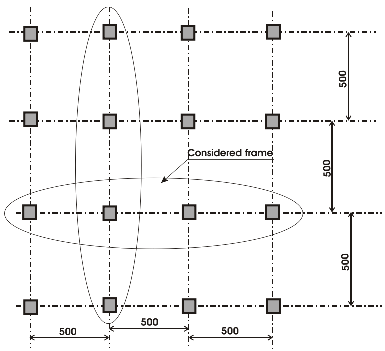

Figure 16 – Idealised study case

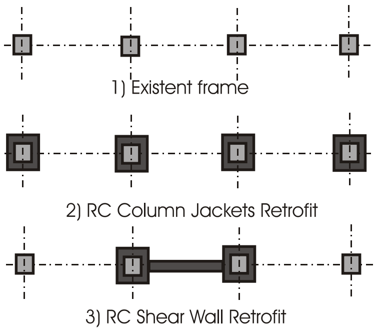

Figure 17 – Idealised study case lines

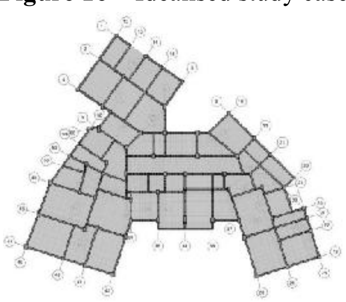

Figure 18 – Existent building layout

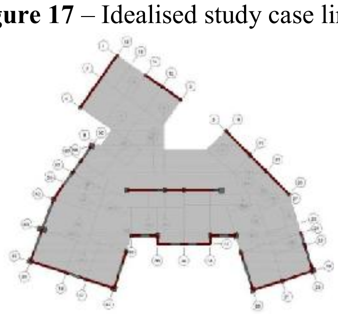

Figure 19 – Rettrofiting solution for building layout

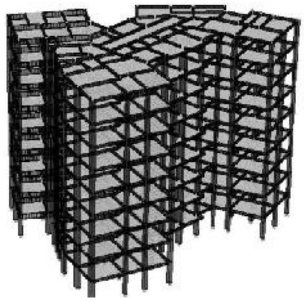

Figure 20 – Existent building 3D view

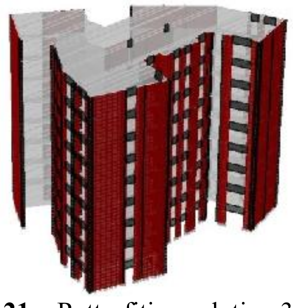

Figure 21 – Rettrofiting solution 3D view

9. CONCLUSIONS AND RECOMMENDATIONS

In almost of the European countries we may find the same problems because until the WW2 the design and the erection were more or less the same;
There are several types of usually structures we may find:

- Timber structures
- Masonry structures
- RC frame structures
- Precast structures
- Steel frame structures

In this work we attend just two of them and this was actually just because of the necessarily time, to find ideal models, for the structural modelling and for the data analyses and process;
The mainly retrofitting solutions we may chose are:

- RC jacketing;
- The implant of new RC structural subsystems;
- Steel structural elements and or dampers;
- FRP solutions including: aramid, glass, carbon fibbers or polymeric grids.

The most important characteristics of a structural system which are the stiffness and the strength capacities show which of the previous retrofitting solutions are recommendable from the safety and economical point of view.
Usually the gravitational frame structures are very flexible and have less strength capacity. To increase both of these the FRP are excluded from the beginning (because this solution offer just strength not stiff). In this idea we may use FRP retrofitting solutions only for buildings with masonry structures or for the frame structures with enough stiffness.
We cannot use steel or dampers solution for retrofitting because the structural joints were not designed for lateral loads. So introducing this kind of retrofitting solution we shall obtain other vulnerabilities for the structures.
If the different settlement is poor is enough to consider the lateral displacements produced by the pseudo-earthquakes or earthquakes, but if the different settlement is heavy, mean that the building structure suffer a lot of damages which cannot be solve with simple solutions of retrofitting and which request very invasive and expansive solutions. However is impossible to retrofit these buildings with the inhabitant's presence or during the production, for the factories. In this situations the demolition and re-erection seems to be the better option.
The aim of all these articles is to start the developing of the new generations design codes, separately for each country and globally for the entire Europe.

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