Structural Rehabilitation Studies of Masonry Building Heritage Under Near Fault Earthquake: A Case Study

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SUMMARY:
Structural rehabilitation in public buildings belonging to the heritage in a seismic zone must comply with safety requirements. This school has unreinforced ceramic masonry walls. Currently it presents structural pathologies due to various seismic events and lack of maintenance. To study the behavior of this building is performed using finite element modeling, which involves standardized testing physical and mechanical characterization of materials used and the use of nontraditional techniques such as measuring soil waves and environmental vibrations. The analysis of the improved building should consider the various alternatives available for the site. The criteria for rehabilitation have been agreed with heritage experts, finding a balance between new and existing technologies for the rehabilitation of the structure with steel and reinforced concrete. In this paper we evaluate the work done to add value to a school building from the early twentieth century in the area of greatest seismic hazard to Argentina.

Keywords: masonry - foundation – modelation – heritage - rehabilitation

1. INTRODUCTION

The renovation of existing structures is a requirement, increasing the sustainability of local communities. This problem is exacerbated in a seismic zone and in the case of restoration of historical buildings with heritage value, the emphasis of it is given in the architectural and historical value, while the use may be of secondary importance. The most important structural challenge when you have to enable them to public use as in schools, churches and museums (Maldonado et al., 2011)

School infrastructure in the province of Mendoza, Argentina, from the early twentieth century, is built with the fired ceramic masonry unassembled. The geological conditions of the region imply that the structures are at greatest risk of earthquakes in the country, under near-source earthquakes (Maldonado and Tornello, 2008). Therefore the study of the vulnerability of these buildings is justified by the social function of schools

The structural restoration techniques chosen are trying to balance heritage considerations and respect the safety requirements for public use. Also it is a great importance the local availability of technology for the execution of the work, because you must know in depth the properties of the original materials and new materials to use (Maldonado and Olivencia, 1992).

2. DESCRIPTION OF BUILDING

It is a monumental masonry building, 7m in height, designed for school use, with courtyards, surrounded by classrooms with handmade ceramic brick walls cooked 0.50 m thick, settled with lime mortar. The roof is made of cane and mud and covered with corrugated iron with the support structure of wood. As mentioned Grementieri and Schmidt (2010) in the chronicles of the time, the evolution of its construction was affected by problems of local politics, with successive arrests of work and reduced quality of budgets according to their habilitation in 1906.

The original building has had various enhancements, and some have created even more problems of pathology. The effect of earthquakes has been very important for the damage that occurred in the masonry. The first improvement, post-earthquake Lavalle, 1927, resulted in the placement of tension-level openings in one direction, not solution enough to achieve adequate structural behavior. The 1985 Mendoza`s earthquake originated cracking of the masonry from the front to 45 degrees and the eviction of the building. A major earthquake August 2006 led to the separation of the front (Fig. 1).

Figure 1: View of original front and the current temporary shoring.

Another enhancement that has come with problems, it was the replacement of wooden floating floor to tile floor, with cancellation of the air chambers, which avoided the presence of moisture in the walls.

Another problem was the inappropriate maintenance such as painting classrooms oil to a height of 1.50 m, which was displaced in height the appearance of moisture in the masonry walls, with a corresponding deterioration.

From the standpoint of structural behavior, lack of maintenance on stormwater drainage systems and sewage water generated significant losses that affected the soil bearing capacity and generated significant settlements and the consequent state of cracking in the existing masonry bearing (especially in arcs).

2.1. Experimental Studies

During the last decade there have been field and laboratory studies to characterize materials and two soil studies to assess the soil conditions and bearing capacity (Maldonado and Michelini, 2000).

Laboratory testing has been characterized physical-chemical and mechanical masonry and mortar composition applied as plaster.

Also it was performed the measurement of ambient vibrations (normal heavy traffic) in different parts of the building in order to compare the dynamic aspects after the structural rehabilitation.

The parameter values obtained are used in modeling the structural behavior of the building.

2.2. Behavioral Evaluation

To assess the commitment that presents the current building was modeled using finite element method, introducing a predefined deformation of the same order of harm presented by the displacement of the front (0.02 m) to evaluate the stress state and verify that the structure is cracked because it has exceeded over 2 times its service status (47 vs. 115 kN/m2). Fig. 2 shows the stress state which is consistent with the general state of cracking in the building (Maldonado et al, 2011).

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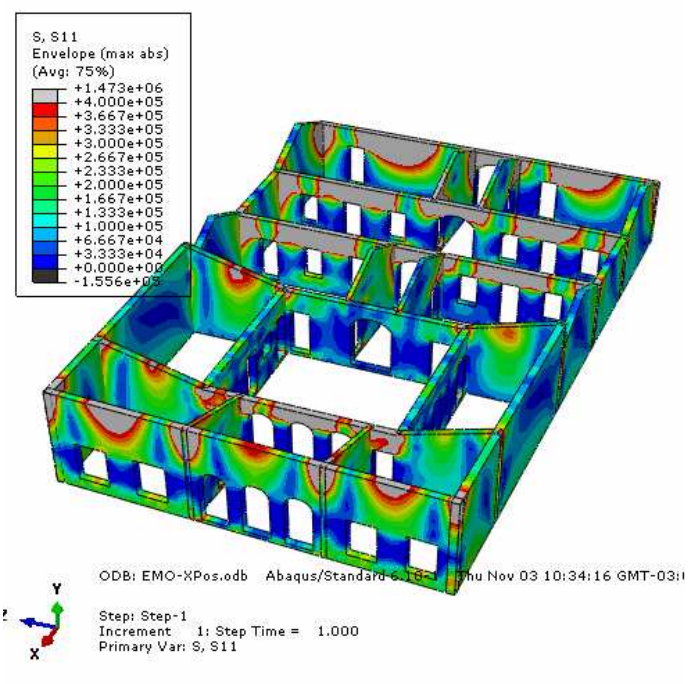

Figure 2: State of Stresses for Building from FEM analyses using Abaqus

3. CRITERIA FOR REHABILITATION

The proposed rehabilitation design should be completed two aspects:
- Recover the monolithic with the building that was designed.
- Complete the requirements to ensure that the structure in use for security against the local seismicity.

From the standpoint of heritage a reversible enhancement is required in masonry but from the point of view of the foundations, the improvement will be irreversible when using concrete to restore stability, strengthen and restore the support system.

To retrieve the monolithic masonry structure is proposed to use cementitious grout or epoxy injections, depending on the thickness of the cracks to restore the masonry and mortar adhesion. Depending on the thickness of the cracks stitching will be held on the masonry with steel nails.

To complete the structural requirements has been proposed:
1. Optimizing the existing foundation, strengthening the foundation of rubble by the inclusion of a high beam foundation similar to the height of existing foundation and building up to the Roman piles up supporting layer (-9 m). The beam foundation, partially invades existing foundation, and lashed by sector to transmit loads to the foundation piles.
2. Form a chained outside with a metal grid on top of the building, so bracing in both directions masonry walls by steel beams anchored to the walls and metal profiles, triangulating the space to cover. The metal grid is positioned so that the suspended ceiling will not let in evidence and can in turn be used to locate plumbing facilities (electricity and air conditioning).
3. Generate external reinforcements or vertical supports efforts to convey the structure to the foundations by metal columns anchored in the masonry structure and the structure foundation.
4. The exterior and vertical reinforcements form a lattice that stiffens the structure and is able to withstand seismic loads for the actual destination of construction.

5. Replace water drainage systems existing technology and best materials available today. In the case of sheet roof covering if the metal is corroded, it is necessary to replace the plate and improve the slope for water drainage.

4. DISCUSSION AND ANALYSIS

For the enhancement of the building, it can choose different methods of improvements in the foundation. The choice will be directly related to knowledge of art and the technical and economic opportunity in the region. It can have superficial procedures (reinforcement, expansion or replacement), deep procedures (emphasized by piles or micropiles) or improving procedures surrounding soil, depending on the availability of technology and environmental conditions (U.S. Dep. of Housing and Urban Planning, 1997).

In this case an important issue in terms of adjacencies, is that the building is surrounded by buildings, so do not fully apply the procedures are not superficial and has not large open space to locate equipment driven. It was considered viable place concrete piles, spread evenly, transferring loads to the granular blanket (Plaxis V.B., 2004). To ensure the replacement of the foundation beams are proposed rigid link between piles, with the inclusion of columns needed to form the flat resistant masonry walls of the building, connecting to the heads of the piles.

For checking the building's structural model is formulated nonlinear finite elements, using 8-node isoparametric elements (3D) constitutive models that simulate the nonlinear behavior of the masonry in order to verify the structure to the various actions, considering already existing damage to the structure, the various support declines it has suffered (Fig. 3).

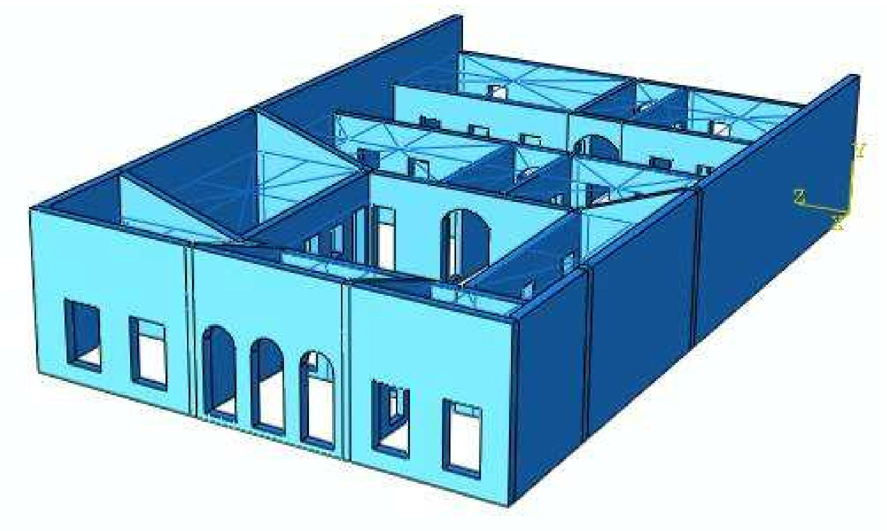

Figure 3: Structural model of the building using SAP 2000

For a practical solution, we analyze the structure in a linear pattern, using a 3D finite element software, which allows design and verification of the proposed solution that allows sizing the various structural elements (SAP 2000, 2000). The supporting structure of the building consists of thick masonry walls and masonry columns. The cover is determined by wooden trusses supporting a framework of wood and cane. Were used to represent elements of plate and bar, they would simulate adequately considered the structural aspects of interest in this study. It is important to note that the model only includes structural elements. The model boundary conditions were adopted displacement restrictions in the 3 coordinate directions in the areas of contact with the foundation, to be modeled with bar elements, which transfer their load to the piles, which are connected to ground through springs simulate ground deformation, both in the vertical direction and in the horizontal, whose constant coefficient derived from vertical and horizontal ballast obtained in the study of soils

(Maldonado et al, 2011). The walls have been modeled as membrane elements, with the elastic characteristics of masonry according to data from local trials (Fig. 4).

The physical characteristics of the masonry are: specific weight = 1653 kg/m3, porosity = 22%, moisture varying between 15 to 20% and the mechanical characteristics indicate an average compressive strength of 2.5 MPa and compression strength combined shear strength between: 0.2 MPa and 0.5 MPa to 1.1 MPa and 0.9 MPa respectively (Michelini and Maldonado, 1991).

The grid of conection has been modeled by bar elements, including in their design the effects of buckling instability. The quality of steel is considered to F24. The gravity loads were considered for permanent weight, predominant in this type of construction, snow and seismic loads equivalent, as indicated in the requirements in force in the Province of Mendoza and the corresponding combinations.

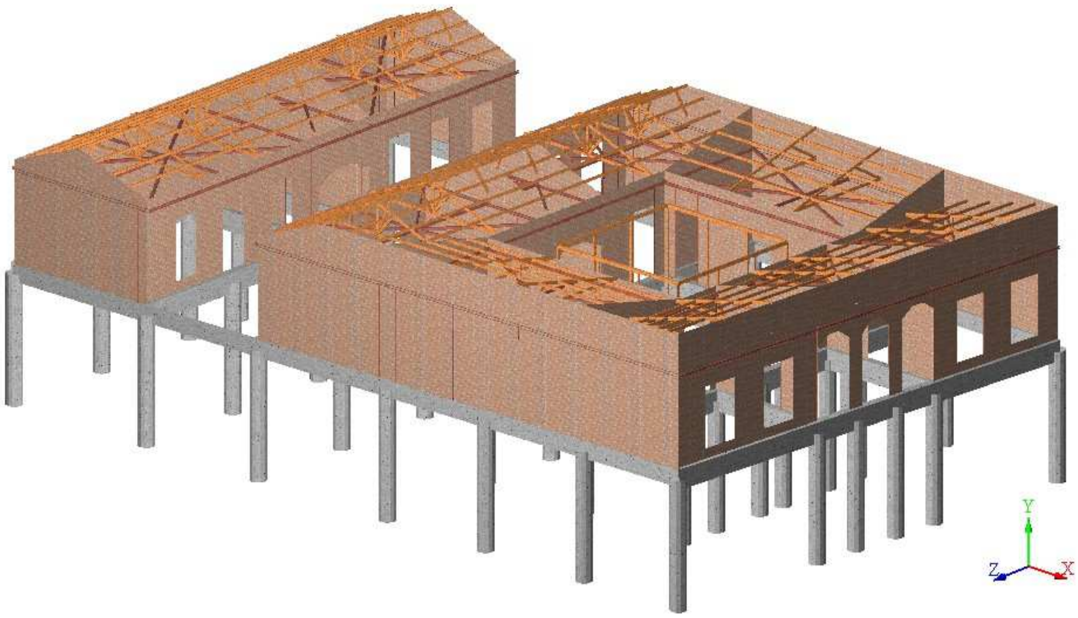

Figure 4: Complete Structural Model of the Building (SAP 2000)

For the determination of the seismic action considered the equivalent static method, since it is a construction of a single level, the application of dynamic methods, does not provide additional relevant information regarding the verification of structural safety against seismic actions. The seismic coefficient obtained is 0.625 (Gobierno de Mendoza, 1987). Given the almost orthogonal directionality of the walls that make up the structure is considered that the seismic action acts in every direction orthogonal component in a direct and one caused by an accidental torsion and dynamic according to regulations (SAP2000, 2000).

Model analysis, it appears that the stresses in the masonry does not exceed the maximum values of the tests that were performed and Fig. 5 shows the result of the envelopes of loads (dead load + seismic load). It shows the stress concentration associated with the ties of walls and load application points, points that should be reinforced locally, while the rest of the masonry is subjected to a level below normal tensional stresses. The remaining structural system, including walls, maintains a stress level below its capacity (Abaqus, 2004).

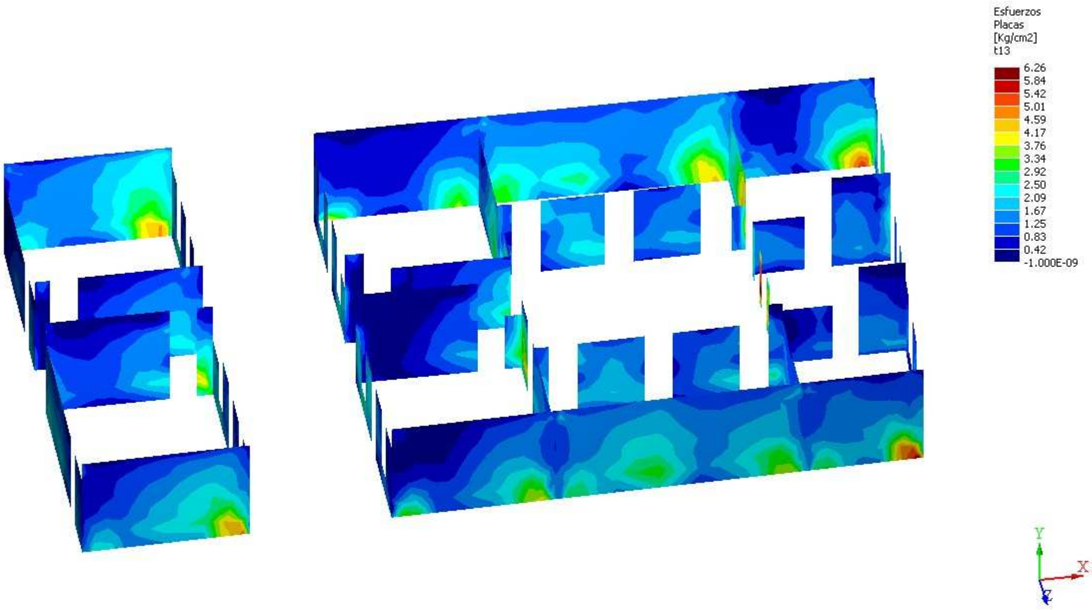

Figure 5: Maximum shear stress in plates due combined loads

The upper grid is fixed to the structure subjected to stress below its capacity, as shown in Table 1.

Table 1. Verification upper grid

Description	Section	Ratio	Status
Truss3	100x140#4.0	0.64	Ok
Truss4	140x140#6.35	0.66	Ok
Lateral beam both faces	2 UPN 140	0.29	Ok
Lateral beam one face	UPN 140	0.30	Ok
Truss1	80x140#3.2	0.61	Ok
Truss2	80x140#3.2	0.71	Ok
Column	UPN 180	0.75	Ok

UPN profiles of both beams attached to the walls and the columns are linked to the existing structure through a set of anchors. These anchors will focus on the soul of the profile with a maximum spacing of 50 cm. Adopting a chemical anchoring threaded rod high strength steel of diameter 5/8" and 30 cm in length. In cases that are elements on both sides of the wall, the threaded rod should link the two elements.

For beams of foundation and piles adopting a concrete H-20 (20 MPa) as indicated in Tables 2, 3, 4 and 5.

Table 2. Beam Foundation (VF)

ID	Size		Solicitations			Total Reinforced Steel		Longitudinal Steel Reinforcement							
	b	H	M+	M-	Q	As	As'	Below				Upper			
	m	m	t*m	t*m	t	cm2	Cm2	20	25	cm2	Description	20	25	cm2	Descr
VF	0.30	0.90	46.81	-31.50	30.08	14.57	9.38	2	2	16.10	2Ø20+2Ø25		2	9.82	2Ø25

Table 3. Shear Beam Foundation (VF)

ID			Shear Steel Reinforcement			
	V_{adop}	V_{calc}	Øarms	spacing	A_{est}	Description
		[kgf/cm2]	12	[cm]	[cm2]	
VF	13.88	12.84	2	20.0	2.26	e2rØ12c/20cm

Table 4. Verification of Foundation Pile

Pile	Pile Dimensions			Ultimate Capacity		Solicitations		Pile Verification		
	Df	Db	H	Compression	Tension	min	max	N +	Safety factor -	Safety factor +
	[m]	[m]	[m]	[t]	[t]	[t]	[t]	[t]		
P1	0.80	0.80	5.00	342.67	67.79	0.00	72.51		Cs+>2.0	4.73

Tabla 5. Verfication of Foundation Pile

Pozo	Steel Reinforcements									
	Longitudinal						Transversal			
	Abnec	Ab	Steel min			Descr.	Quantity	Ømín	Øadopt	spacing mín.
	[cm2]	[cm2]	[cm2]	12	[cm2]		[%]	[mm]	[mm]	[cm]
P1	690.60	5026.55	10.05	9	10.18	9Ø12	0.03	6.00	6.00	21.60

5. EXECUTION OF REHABILITATION WORKS

Rehabilitation is currently running. It has started sectioned to ensure the bearing capacity of foundations in the first place and advance the capacity of the superstructure. Fig. 6 and 7 present the execution states of foundations and locate assemblies for load bearing columns and the cleaning of masonry walls.

Figure 6. Details of reinforcement of pile cap (left) and foundation beams (right)

 

Figure 7. Reinforced foundation beam under wall (left) and cleaning of plaster of masonry (right)

6. SUMMARY AND CONCLUSIONS

Strengthening of historical and monumental buildings shall be justified only when is inevitable; the adopted strengthening technique shall be in compliance with the theory of restoration and local technologies and workmanship.

The stress states obtained for the adopted numerical model indicate that the proposed solution provides the necessary degree of structural safety for the destination of use of the building.

It is considered appropriate software used in the modeling of this building.

Laboratory studies, field tests and finite element structural modeling have led to develop technical specifications best suited to the construction process of rehabilitation of historic masonry building.

During the execution of the work, the building has been supported M=5.4 earthquake without damage, proving the effectiveness of rehabilitation of foundations.

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