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BEHAVIOR AND DURABILITY OF CERAMIC HERITAGE MASONRY IN NEAR SOURCE FAULT ZONE

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Abstract

The metropolitan area of Mendoza is the largest city exposed to seismic risk in Argentina. The last significant earthquake, 1861, originated in the near faulting, destroyed the city and killed half of its population. Very few construction of that time has been maintained. Subsequent earthquakes, significantly affected adobe buildings and unreinforced masonry and few buildings of historic masonry can be located. The methodology used to carry out the objectives includes the stages: detailed survey, emergency decisions, analysis of the conservation conditions of the building, diagnostic and proposal rehabilitation. Physical and mechanical features of local masonry mortars and units indicate resistant levels under standards. In addition to this, there is chemical attack of salts from the same masonry or from the presence of capillary water, leading to a decreased capacity. The site features, quaternary geological formation, in soils disposal in alluvial fan with alternate layers of silts and clays. The conditions of conservation of masonry construction are affected by environmental conditions of use and maintenance. This paper presents the results of performance and durability of four ceramic heritage masonry buildings evaluated for enhancement, the study techniques of applied materials and environmental conditions and the criteria chosen for modeling the historical masonry are evaluated.

Keywords: masonry; heritage; near fault; performance; regulations

1. Introduction

In Argentina there are very few heritage buildings prior to the arrival of the Spanish in the sixteenth century, that remain in the northwest in form of stacked flackstones (Fig. 1) or low adobe buildings. Mendoza is the oldest city in Argentina with a pre-Hispanic era and other Hispanic or colonial era. One example is the existing system of artificial irrigation through canals and ditches, built by the Huarpes Indians, taking advantage of watercourses natural slopes and geological faulting, constituting a drain-channel-path spatial unit [1].

Fig. 1 – Prehispanic Pircas (Uspallata), Stone Bridge (Luján de Cuyo), Church of Jesús Nazareno (Guaymallén)

During the subsequent Hispanic colonial period, there are constructions with a very simplistic Baroque style because Argentina was a peripheral, poor and sparsely populated territory of the Spanish Empire. The only important colonial buildings that have remained correspond to town halls and churches. The historic center of major cities was characterized by its austere civil architecture, with adobe walls, wooden ceilings, with few openings without glass and courtyards with cisterns for water supply.

From 1860 the colonial style mixed with the classic one (Italian style) prospered with the national reorganization and from 1880 architectural movements academicians, eclectic and art noveau in construction appeared (Fig. 2). So, Argentine is an ethnically and culturally unique country in all America from the heritage preservation point of view [2]. This was a surprise because of the celerity with which some buildings were built and others demolished for their progress.

Fig. 2 – Historical Heritage of Mendoza: Molina Pico Museum (Guaymallén), Provincial Museum of Fine Arts (Luján de Cuyo), Caro Wine Vault (Godoy Cruz).

A different approach to heritage building occurs when there is a seismic risk region, as in the case of Mendoza, which urban nucleus is the one with the highest seismic risk of the country [3]. Large earthquakes of Argentina are characterized by shallow earthquakes associated with the fault rupture under compression meeting of the Nazca and South American plates that cross or are very close to major cities, as in the case of Mendoza. Historical seismicity studies detect this problem of buildings´ damage due to the proximity of faults (pulses severe effects, directivity). Mendoza earthquakes of 1792, 1861, 1903, 1917, 1920, 1927 and 1985 destroyed the adobe buildings and severely damaged unreinforced masonry buildings, affecting older buildings (Fig. 3).

Fig. 3 – State of San Francisco Church after the earthquake of 1861, in 1999 and 2016.

From the point of view of heritage conservation very few buildings of natural stone masonry for the pre-colonial period can be detected in Mendoza (remains of the Inca Trail, Fig. 1).

From colonial times it only remains the ruins of fired clay masonry with lime mortar of the Church of San Francisco product of the destruction of the earthquake of 1861 (Fig. 3) and some chapels outside of Great Mendoza. Subsequent to that earthquake, heritage buildings are also rare and some of them are detected within the educational park.

Urban buildings of the late nineteenth century and early twentieth century were made in masonry of fired ceramic bricks [4]. In the transition to the use of reinforced appear concrete constructions employing hybrid metal profiles for supporting floor slabs, or as bridges and columns within the masonry to withstand earthquakes known as sidero-brick [5]. Since 1930 the use of reinforced concrete in Argentina is widespread, leaving the brick masonry walls for minors, or cladding in reinforced concrete structures or termination of facades.

1.1 Local seismicity

The way in which a structure is damaged during an earthquake is strongly influenced by its proximity to the area of fault rupture. For structures located within 15 km distance to the seismic source, the damage often occurs for one or two severe cycles of inelastic deformation, matching speed pulse of high amplitude, generally in the normal direction to the trace of the fault. In many cases the presence of characteristic pulses is due to the effect called address break forward [6] when two conditions are met: the front rupture propagates to the registration site, and the direction of sliding of the fault is aligned with it.

The rupture propagation to the site at a similar speed to the one of the shear waves traveling along the ground causes most of the energy of rupture comes with a single large pulse movement which occurs at the beginning of register. This pulse movement represents the cumulative effect of much of the seismic radiation from the source.

This radiation pattern of shear displacement on the fault causes this great pulse of movement that tends to be perpendicular oriented to the sliding of the fault. The conditions for this effect may occur in both strike-slip faults as normal or reverse type.

The presence of characteristic pulses in acceleration, velocity and displacement can generate larger shears in the base floor and distortion floors, and lateral displacements compared with records that do not have these pulses. Also the ductility demands may be much higher, while additional damping may be less effective. Nonlinear incursions are usually concentrated in very severe few pulses, so that structures are required to dissipate energy in a few cycles, in some cases in only one, it cannot make through multiple hysteretic cycles.

Under the great demands on acceleration and displacement of the events studied only the conjunction updated with new design procedures regulations, a regular good structural design, static redundancy and proper implementation will allow structures to survive strong earthquakes [7].

This problem has also been evident in the service life of the historic buildings of Mendoza, especially those of Mendoza which has a high seismotectonic risk, as were identified and studied. Quaternary faults are associated with shallow earthquakes with surface breaks where the seismic waves may suffer a significant amplification in alluvial soils, and as a result they could cause further damage to buildings near the seismic sources by approaching the critical frequencies of low-rise buildings of adobe and masonry [8].

2. Methodology

The methodology used in the study of cases first evaluates whether the historical works have heritage values or not, (Fig. 4) defining the responsibilities before specifying the procedure [9].

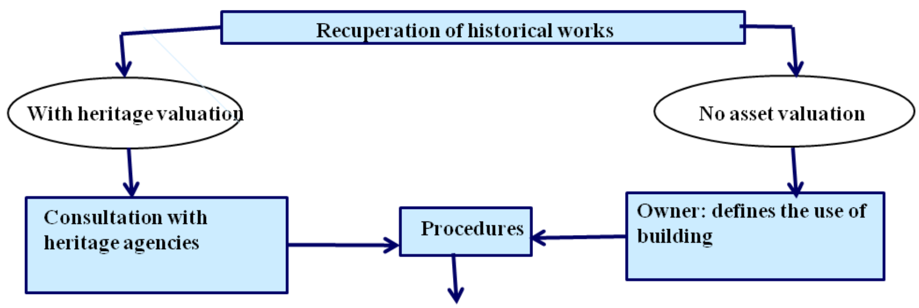

Fig. 4 – Basic criteria for recovery of historical works

Fig. 5 presents the different steps of the procedures followed for the rehabilitation of historic buildings in Mendoza, Argentina, applying safety criteria laid down in the regulations [10, 11]. The aspect of durability is not stated, because it is included in the analysis of storage conditions and evaluated on the causes of degradation. The same can be done with the habitability when building functionality is evaluated.

Table 1 shows the data of affiliation of the buildings studied and background.

Table 1 – Data of the buildings studied

Evaluated	**San Francisco Ruins. Capital[12]**	**Ex-school Mitre. Capital [13]**	**Juan Giol Chalet. Maipú [14]**	**Fader House. Luján de Cuyo [15]**
Building date	XVIII century	late nineteenth century -1906	1910	1892 House 1905-6 Paints Fader's
Date of study	1999	1999 and 2010	2012	2013
Charge heritage	National Direction Architecture Municipality of Capital	Direction of Heritage Government of Mendoza	Municipality of Maipú National Direction Architecture	Direction of Heritage National Direction Architecture
Intended use	Outdoor museum	Educational museum	Vintage museum	Fine arts museum
Archaeological and historical background	Historical and archaeological studies	With few historical and archaeological studies	With few historical studies. No archaeological studies	With few historical studies. No archaeological studies

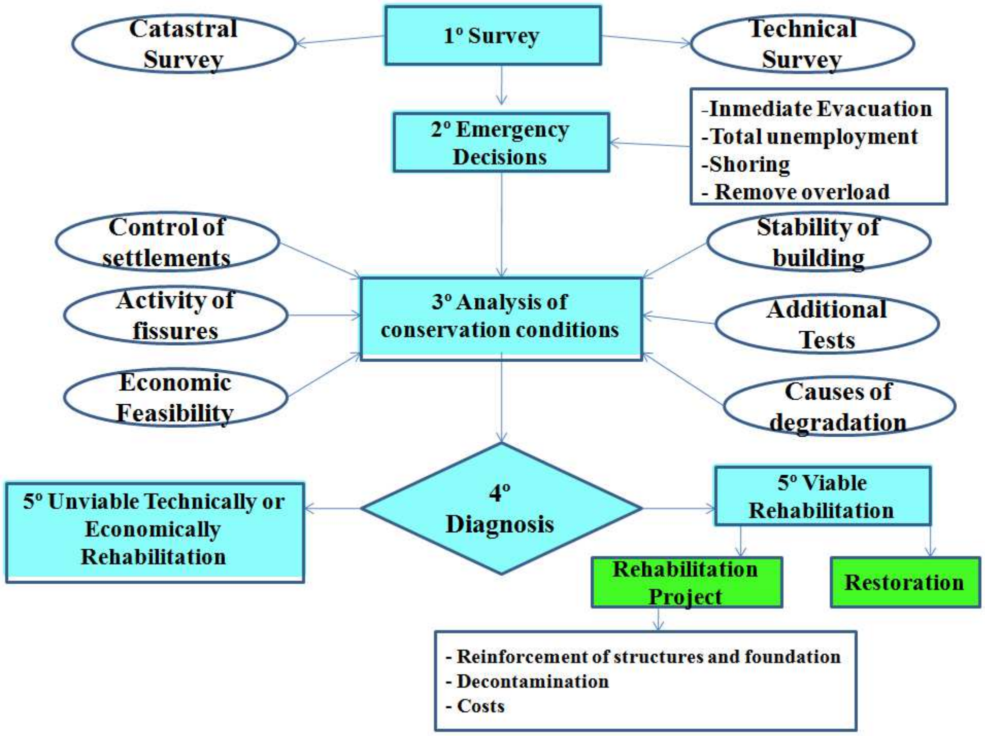

Fig. 5 – Procedures of study of heritage construction

3. Analysis and discussion

The preservation of buildings of cultural value requires knowledge to guide the technical and economic strategies to keep them [16]. Building materials degrade over time when in contact with the environment, being a natural and inevitable process. From the standpoint of utilization the main unknown behavior is the rate of deterioration, data necessary to raise the estimated service life of construction in relation to security and / or functionality.

The use of masonry has significant advantages in cost, speed of installation, aesthetics, durability, sound insulation, thermal insulation, fire resistance and accidental damage, energy consumption, maintenance and repair, availability of materials and local workmanship and potential recyclability. Among the disadvantages can be detected: the need for greater resistant area compared to reinforced concrete, better foundations, problems in the insulation, the size of the openings, in the arrangement of the joints, considerations of safety and health, durability problems by presence of water and salts and currently lack of skilled labor.

The presence of moisture causes deterioration in old buildings masonry which origin may be in the soil or rainfall, or breakage contribution plumbing services. Different measurement techniques can be applied, but they do not provide repeatable results. In other cases, new interventions with new materials have increased the problems of moisture.

Local climatic conditions are beneficial for minimal moisture: Zone IVa: cold mountain temperate [17] corresponding to a semiarid and dry climate, with temperatures that range between 14 and 18 ° C. Winter is cold and dry, with average temperatures below 10 ° C, with occasional night frosts and low rainfall. Summer is warmer and wetter by the occurrence of most rainfall and average temperatures are above 25 ° C, reaching values above 40°C a few days. Rainfall is low, with an annual average of 200 mm. The outstanding feature of the dry climates is that evaporation exceeds the annual rainfall. Due to its geographical position, it has a high exposure to solar radiation on the horizontal plane, so summer mean values are recorded between 25 to 27

MJ/m2day, with 14 hours of daily sunshine; while in the winter measurements decrease average values between 9 to 12 MJ/m2 day, with 9 hours of sunshine per day [18].

The masonry used in the study area has a wide spectrum and significant variability in physicochemical and mechanical properties. The average porosity exceeds 22% and capillary suction 1.35 kg m2 min-1. Found oxides are SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, Na_2O and CaO. Table 2 shows the results of valid contributions from different eras, the characteristics of the masonry used, the main detected faults and durability problems encountered.

Table 2 – Characteristics of previous interventions, masonry and existing pathologies

Evaluated	**San Francisco Ruins. Capital[12]**	**Ex-school Mitre. Capital [13]**	**Juan Giol Chalet. Maipú [14]**	**Fader House. Luján de Cuyo [15]**
Valid contributions from different epochs	1941: Put in value Maintenance Ruins Park and archaeological exploration	Maintenance (paint, flooring) 1955: Replacement of floating floors 1964: Reinforcing bases	Different uses over time (bank deposit, file, housing).	Summer house. 1949: put in value as a museum. Subsequent updates of aesthetic value.
Masonry type	Masonry handmade ceramic solid mortars with different types of bonding. Thicknesses variables 	Handmade ceramic solid 0.55 m (head and rope). Good constructive technique employed 	Handmade ceramic solid 0.30m (head) with metal profiles on walls (sidero-brick) 	Handmade ceramic solid 0.55 m (head and rope). Slab of masonry and metal beams Good constructive technique employed 
Main problems detected faults and durability	1861: Destruction by earthquake Deterioration by weathering (capillarity). Cracking in critical areas.	Cracking cut eardrums 1985 earthquake. Separation facade 2006 earthquake. Lack of perimeter chains. Settlement arches for lack of foundation bearing capacity. Water drainage problem and sewers. Efflorescence and soluble salts.	Expansion mortar corrosion of wires and profiles on walls. Reinforcement corrosion losses in storm drains. Contributions of soil moisture plumbing losses. Presence of soluble salts.	Cracking of supporting structures, mixtures of materials, lack of soil bearing capacity Contributions soil moisture. Problems in storm drains. Masonry deterioration by weathering (capillarity), efflorescence and presence of soluble salts.

Table 3 shows the causes of structural damage, the regional seismic risk assessment, soil characteristics and site, the period of the building and its measurement.

Table 3 – Assessment of regional seismic risk

Evaluated	**San Francisco Ruins. Capital[12]**	**Ex-scool Mitre. Capital [13]**	**Juan Giol Chalet. Maipú [14]**	**Fader House. Luján de Cuyo [15]**
Causes of structural damage	Mendoza earthquake of 1861 and later	Mendoza earthquake of 1861 and later	Lack of maintenance	Several earthquakes Interventions Lack of maintenance
Regional seismic risk	High (alluvial soil)	High (alluvial soil)	High (alluvial soil)	High (alluvial soil)
Soil profile	-2.4m filling -3.9m sand -4.3m granular -5.7m silt -8.0m gravels	-4.5m plastics CL -9.0m granular	-1.3m filling -1.85m silt -3.0m granular	-1m filling -3m silt -4m granular
Spectral type	3- SE	3- SE	2- SD	2- SD
Measured periods	Soil period 0,026s Unpropped period structure 0,07s Period buttressed structure 0.0425 s	Original period 0,070s Reinforced foundation 0,063s With full backing 0,060s	Soil period 0,20s Towers 0,23s period to 0.28s	Soil period 0,07s Period towers to 0,241s and 0,204s
Techniques used	Vibration monitoring Reticulated metal and concrete base support.	Vibration monitoring. Steel reinforcements as horizontal and vertical linkages Strengthening foundations	Vibration monitoring. In proposed intervention	Vibration monitoring. Steel reinforcements as horizontal and vertical linkages Strengthening foundations

Table 4 shows the soil criteria and masonry modeling for different buildings studied. It is taken as a criterion modeling by finite elements for walls using the type plate element of 4 or 8 nodes. Failure criteria that consider the confinement compression and simple implementation as Mohr Coulomb, Drucker Prager have been used for the simulation of material failure.

The foundation is modeled by elastic springs or the soil is modeled directly, considering its rigidity (elastic), since in this type of structure soil stiffness plays a fundamental role. The cover, which is generally flexible main resistance elements such as trusses or girders (ridges, etc.) are modeled, distributing loads to these elements.

The seismic action is determined by applying the static methods established by the regulations as proportional forces to the mass of each node of the finite element mesh. The seismic action is determined by applying the static methods established by the regulations [10, 11] as proportional forces to the mass of each node of the finite element mesh. The regulations in force consider the seismicity of the site by response spectrum, taking into account the near fault site, and the dynamic amplification. Moreover, the seismic force derived from the mass of the shell is distributed in the main modeled elements.

Tabla 4 – Modeling and type of intervention

Evaluated	San Francisco Ruins. Capital[12]	Ex-school Mitre. Capital [13]	Juan Giol Chalet. Maipú [14]	Fader House. Luján de Cuyo [15]
Modeling soil	Triangle 15 nodes Mohr-Coulomb elastic theory Plaxis Bv	Triangle 15 nodes Mohr-Coulomb elastic theory Plaxis Bv	Elastic theory	Elastic theory Interaction with Abaqus
Modeling structure	Elastic Midlin theory Plaxis Bv	8 nodes isoparametric nonlinear Abaqus SAP2000 linear rehabilitation	linear masonry plates SAP2000 linear rehabilitation	Nonlinear Model Drucker Prager masonry Abaqus SAP2000 linear rehabilitation
Estimate safety	It supports earthquake IV MM	> 80% of the original	> 80% of the original	> 80% of the original
Type of proposed intervention	Reversible (temporary propping) until the final consolidation project is defined.	Reversible (outer metal reinforcement chained) Irreversible in foundation.	Irreversible (removal of corroded profiles) Without intervention foundation.	Reversible (reinforcement chained outside). Irreversible in foundation.
Present status	Executed	Executed	Proposed	Proposed

4. Conclusions

It is emphasized that in the region most historic buildings that have been standing are comprised of ceramic solid bricks, only very few of adobe and stone have managed to survive due to the high demand for ductility of earthquakes near-fault.

The study of rehabilitation involves a team of specialists from historians, architects, structural engineers, geotechnical and chemical technicians, etc. That is, it cannot be considered only as a structural problem.

The seismicity of the site and the abandonment of the old buildings have caused the collapse of most of the old buildings, lost cultural values that have been part of the history of the province. Therefore, the rehabilitation of old buildings should be considered a state policy, in order to preserve the few buildings that remain for the future.

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5. References

[1] Ponte JR (1987): *Mendoza, aquella ciudad de barro. Historia de una ciudad andina desde el siglo XVI hasta nuestros días*. Municipalidad de la Ciudad de Mendoza, 1st edition

[2] Cirvini SA (2011): Escuelas Argentinas. Discurso técnico y tipología arquitectónicos. El caso de Mendoza 1861-1916. *Revista Historia de América*, **72** (144), 71-121.

[3] INPRES (1989): *Seismic Microzonification of Great Mendoza*. INPRES, 1st edition.

[4] Traversa LP, Di Maio AA, Iloro F, Martínez G.A. (2010): Patologías en Construcciones de fines del siglo XIX y principios del XX. *VI Congreso Internacional sobre Patología y Recuperación de Estructuras CINPAR 2010*, Córdoba, Argentina.

[5] Girini L (2004): Arquitectura, Industria y Progreso. Las bodegas vitivinícolas de Mendoza en el Centenario. *Tesis doctoral*, Universidad de Mendoza, Argentina.

[6] Somerville P G, Smith N (1996): Accounting for near-fault rupture directivity in the development of design ground motions. *11th World Conference on Earthquake on Engineering*, Acapulco, México.

[7] Frau CD (2004): Demanda sísmica incluyendo efectos de directividad en zonas near-fault de Argentina. *Tesis doctoral*, Universidad Tecnológica Nacional, Argentina

[8] Frau CD, Giolo E, Guevara M, Calderón F, Gallucci AR, Luján F, Tornello M (2015): Efectos de sitio en la localidad de Villa Marini, Mendoza, Argentina. *XI Congreso Chileno de Sismología e Ingeniería Sísmica*, Santiago, Chile.

[9] Maldonado NG, Michelini RJ (2000): Rehabilitación de un edificio de mampostería histórica en zona de elevado riesgo sísmico: un caso de estudio. *Congreso de Ingeniería 2000*, Buenos Aires, Argentina.

[10] Gobierno de Mendoza (1987): *Código de Construcciones Sismorresistentes*. 1st edition.

[11] INPRES-CIRSOC (2013): *Reglamento Argentino para Construcciones Sismorresistentes. Parte I. Construcciones en General*. INTI, 1st edition.

[12] Maldonado NG, Michelini RJ, Olivencia LA (1997): Evaluación estructural de las Ruinas de San Francisco para trabajos de recuperación en zona sísmica. *IV Congreso Iberoamericano de Patología de la Construcción y VI de Control de Calidad*, Porto Alegre, Brazil

[13] Maldonado NG, Martín PE, Maldonado IA, Panella DS, Palencia JC (2010): Ex Escuela Mitre. *Informe técnico Nº 15/2010*, CeReDeTeC, Universidad Tecnológica Nacional, Argentina.

[14] Maldonado NG, Martín PE, Maldonado IA, Palazzo GL, Affranchino G, Calderón FA, Castiglia B, Camargo M, Fantinel A (2013): Chalet Juan Giol. *Informe técnico Nº 03/2013*, CeReDeTeC, Universidad Tecnológica Nacional, Argentina.

[15] Maldonado NG, Martín PE, Maldonado IA, Palazzo GL, Affranchino G, Calderón FA, Castiglia B, Camargo M, Fantinel A (2013): Museo Provincial de Bellas Artes Emiliano Guiñazú, Casa de Fader. *Informe técnico Nº 01/2014*, CeReDeTeC, Universidad Tecnológica Nacional, Argentina.

[16] Maldonado NG, Michelini RJ (1999): Técnicas aplicadas para la restauración de construcciones antiguas de mampostería en zona de elevado riesgo sísmico". *V Congreso Iberoamericano de Patología de las Construcciones y VII Congreso de Control de Calidad. CONPAT99*, Montevideo. Uruguay.

[17] Norma Argentina IRAM 11603 (2012): *Thermal conditioning of buildings. Bioenvironmental classification of Republica Argentina*. IRAM, 3rd edition.

[18] Domizio MC, Maldonado NG, Arena AP, Fernández Luco L (2014): Hygrothermal Importance of a Historical Retrofitted Building in a High Seismic Risk Zone of Argentina. *XXXVI Jornadas Sudamericanas de Ingeniería Estructural*, Montevideo, Uruguay.