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IMPROVEMENT OF THE SEISMIC RESPONSE OF ADOBE HOUSES

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Abstract

Key words: strengthening, mud-bricks, earthquake, dynamic testing

The present work is taking place in the city of San Juan, Argentina, an area of high seismic hazard. In the region, the seismic resistance factor constitutes a factor with a strong incidence in the habitability of the housing. Added to this, within the levels of social exclusion of the referred sectors manifest themselves physically in the materialization of self-built housing neighborhoods with considerably low rates of habitability.

The present work shows reinforcement techniques that allow retarding the collapse of self-built mud-bricks buildings. The methodology applied, experimental, consists of technical verification of the seismic response of different strengthening of mud-bricks walls through the use of different types of mesh and plaster.

It begins with the determination of the mechanical strength of the masonry of mud-bricks, as part of the whole walls-ceilings, which occurs with a higher degree of recurrence in the mentioned field. It was determined the physical and mechanical properties of the materials resistant to lateral loads in its current state (mud-bricks walls) and the proposed improvements (reinforced walls).

They were trials of individual elements of the construction system (mud-bricks, meshes), subsequently pile and low walls. Obtained these models to a scale 1:2, were built in vibrating table, with the purpose of the global assessment of the behavior of the same and subsequently its numerical modeling

As a conclusion, work demonstrates techniques of reinforcement that allow you to slow the collapse of buildings that is susceptible to be implemented by means of self-construction methods. The strengthening modifies the failure mechanism of the original model by another with greater capacity of dissipation of energy.

From the results obtained it’s was developed an activity of transferring to a sector of the population of the province of San Juan, (Argentina), detected with a high seismic and social vulnerability.

1. Introduction

The Great San Juan is an urban area with a population of over half a million people in the Tulum Valley, San Juan, Argentina. This region belongs to the area of greatest seismic hazard of Argentina, Zones 3 and 4 as set by the INPRES (National Institute for Seismic Prevention).

While the rules generated by the INPRES establish guidelines for seismic design of conventional houses, there are still urban and suburban areas with different degrees of seismic vulnerability.

The habitat of the sectors of the population with unsatisfied basic needs has the highest levels of seismic vulnerability. The inclusion of these sectors in the formal social set has been hampered in recent decades due to difficult access to government plans for social housing, lack of specific professional help and the cost of traditional building materials. As a result of this situation, the most vulnerable social sectors self-constructed their homes using adobes.

Therefore, it is an important challenge proposes innovative solutions suitable for the reinforcement of adobe houses built by social sectors with unsatisfied basic needs.

2. Methodology

The proposed methodology includes the realization of numerous static and dynamic tests on bricks and adobe walls reinforced with different types of mesh and plastering.

1. Mesh tensile test
2. Compression test on adobe bricks.
3. Compression test on adobe walls
4. Diagonal tensile test on adobe walls
5. Dynamic testing in adobe houses in scale 1:2 reinforced with steel mesh and cement plastering.

3. Testing of Meshes

The economic sustainability of the constructive solutions supposes, inside the possible thing, the use of easily obtainable materials in local context. Geogrids[1] are a proven solution in several countries, with good results in strengthening adobe houses, nevertheless they are not produced by the domestic industry and import brings with additional costs. It is a question then to find alternative materials that contribute to the economic sustainability of the solutions proposed.

Local industry provides various types of plastic mesh and steel, this induces to seek in these materials an alternative to the geogrids and evaluate its efficiency as an element of strengthening.

The laboratory tests allow affirming:

The plastic mesh with better performance has presented a module of rigidity and a tensile strength lower than that provided for in the specifications of the geogrid. The graph: "load vs. deformation" is continuous, what induces a ductile behavior without brittle breakdown.

Steel meshes have a tensile strength exceeding that obtained in the plastic mesh This fact alone does not guarantee a better overall performance by working together with the adobe wall.

The obtained results allow us to advance with the proposed studies, and find the way of developing a system with better answer opposite to the seismic actions.

[1]Rules for the use of geogrid at Adobe. Management of Research and Standardization SENCICO.

4. Compressive strength test of bricks

The INPRES-CIRSOC 103 (Vol. III) standards, establish the necessary procedures for compression testing of bricks commonly used in traditional construction and also are permitted by this regulation. The characteristic resistance of the brick is determined by the following expression:

$$\sigma'_{PK} = \sigma'_{PKm}(1 - 1{,}7\ \delta) \tag{1}$$

$\sigma`_{PK}$= Characteristic brick strength.
$\sigma`_{PKm}$= Average resistance in tests.
δ= Coefficient of variation.

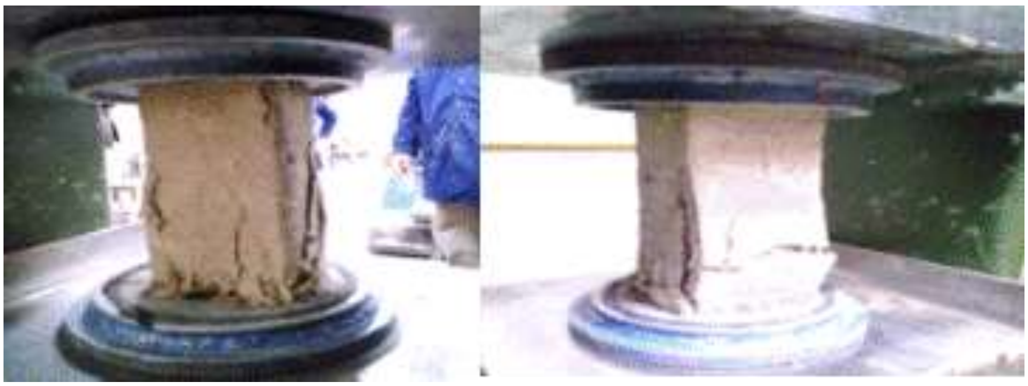

Fig.1- Failure mechanism in compression test.

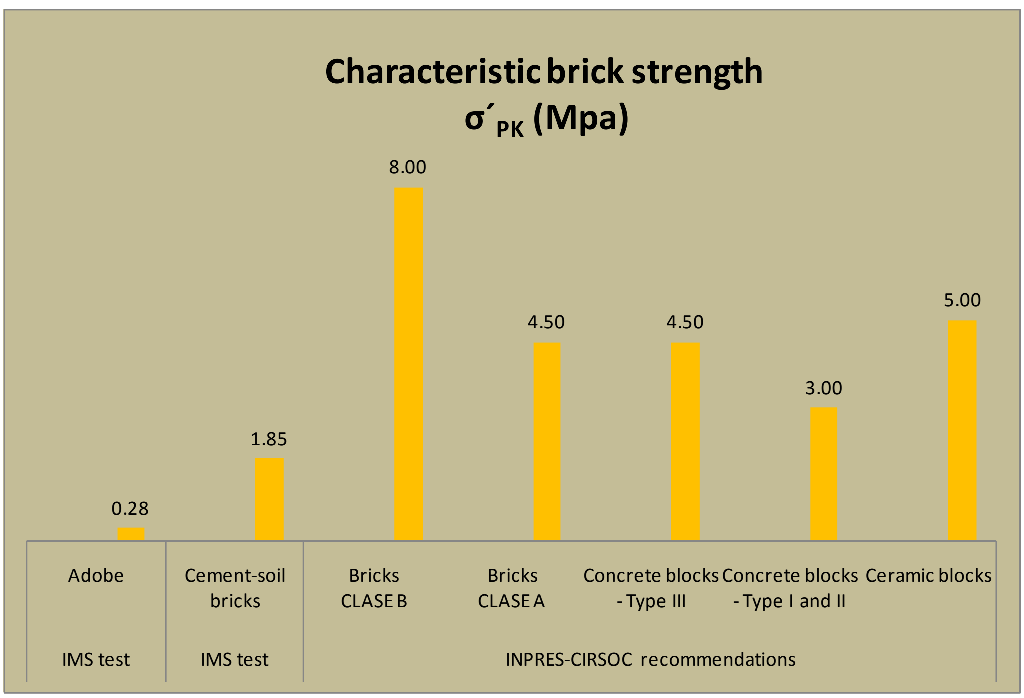

Fig.2-Compressive strength of different bricks[2]

[2]Saldivar, M; Albarracín, O. (2004). Experimental verification of soil-cement construction system in seismic areas. *IV SIACOT*. Portugal.

5. Strengths of Masonry

The resistance of the walls is characterized by two parameters:

- Basic compressive strength (σ'_{mo})
- Basic shear strength(τ_{mo})

To determine the basic compressive strength of walls can be used any of the following procedures[3]:

- Compressive strength of masonry prisms
- From the results of compression tests brick

5.1 Compressive Strengths of Masonry Prisms

If this procedure is used, the value of the basic compressive strength (σ'mo) may be taken as the characteristic strength (σ'mk) determined by the following equation:

$$\sigma'_{mk} = \sigma'_{mm} \ (1 - 1{,}8 \ \delta) \quad (2)$$

σ'_{mk}= Characteristicstrength of wall.
σ'_{mm}= Average resistance in tests
δ= Coefficient of variation (> 0,12)

The prism was built with adobe bricks in scale 1: 2 following the technique required by the regulations. After 30 days of drying proceeded to perform a compression test.

Four bricks were used in each prism, so that the total height was 30 to 35cm. Average slenderness ratio of the prisms was 3.3; value that meets the requirements of the current regulations (not less than 2.5 and not more than 5).The values obtained from testing listed in Table 1, besides the basic values of the determined resistance masonry through Equation 2 are shown.

Fig.3- Compressive test on masonry prisms.

[3] INPRES; INTI; CIRSOC.(Julio, 2005).Argentine regulations for seismic-resistant construction.Argentina, San Juan.

Table1-Compressive strength of masonry of mud-bricks

Type	Test	Dimensions			Load [Kg]	Stress [kg/cm²]	σ_{mm} [kg/cm²]	δ	$\sigma'_{mk}=\sigma_{mo}$ [kg/cm²]
		long [cm]	high [cm]	width [cm]					
Pilas en Esc 1:2	1	19.00	33.00	9.80	2660	8.23	8.00	0.12	6.27
	2	18.80	31.00	9.80	2360	7.77			

5.2 Compression tests brick

Where it is not possible execution of tests prisms, basic compressive strength of masonry can be determined based on the characteristic resistance of the bricks used through the following expression:

$$\sigma'_{mo} = f_m \cdot \sigma'_{PK} \tag{3}$$

σ'_{mo}= Basic compressive strength.
σ'_{PK}= Characteristic brick strength.
f_m= Correlation factor.

The values obtained by applying Equation 3 are listed in Table 2.

Table2.Compressive strength of masonry of mud-bricks

Adobe type	f (correction factor)	σ`bk [kg/cm²]	σmo [kg/cm²]
Brick (1:2 escale)	0,50	9.91	4.95
Brick (1:1 escale)	0.50	2.81	1.40

To evaluate the quality of adobe masonry, the values obtained with the characteristic strength of different types of masonry are compared. Such resistance for masonry bricks and concrete blocks, shown in Fig.4, were taken from the Standards INPRES-CIRSOC 103 Vol. III, corresponding to the masonry cement floor value, it was obtained in a previous research work of the same team[4].

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The value corresponding to strength of the masonry of cement-soil blocks was obtained by this research group in a previous project.

The characteristic strength of adobe masonry is of the order of 10% of the resistance of the walls of concrete blocks, the order of 5% of the value of the bricks of baked clay and of 25% of the resistance of the masonry of cement-soil blocks.

[4] M. Saldivar, A. Pereyra, O. Albarracin. Experimental verification of soil-cement construction system in seismic areas.

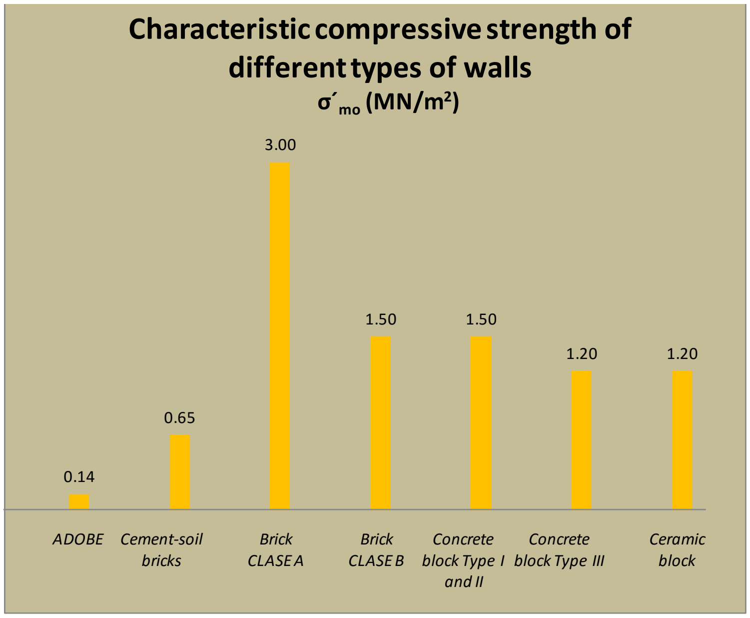

Fig.4- Characteristic compressive strength of different types of masonry[5]

6. Diagonal Compression Tests

To determine the shear strength of the masonry of adobes the compression diagonal test was used. Through this process the value of the Basic shear strength (**τ_{mo}**) resistance is taken equal to the value of the Resistance Feature average (**τ_{mk}**), obtained in the test.
Fig. 5 shows different steps in the walls construction and the tests performed on unreinforced walls and walls reinforced with plastic mesh and steel mesh.

Fig.5- Elaboration of adobe walls, and compression diagonal test.

The Table 3, it describes the characteristics of every small wall, its dimensions, load of break and the values of the resistance of reached court applying the formulae indicated previously.

[5]Saldivar M, Albarracín O, GarinoLibardi L. (2013). Decrease of the seismic vulnerability of the spontaneous constructions of mud-bricks. XIII SIACOT, Valparaíso, Chile.

Table 3.Diagonal compression tests results

Wall types		Dimensions long [cm]	Dimensions high [cm]	Dimensions width [cm]	Load [Kg]	Stress [kg/cm²]	τ_{mm} [kg/cm²]	τ_{mk} [kg/cm²]	Observaciones
Adobe Bricks Esc 1:2	Steel mesh	42.50	42.00	13.00	1997	2.59	2.59	2.59	-
	Unreinforced	40.00	40.00	10.00	799	1.41	1.41	1.41	-
Adobe Bricks Esc 1:1	Plastic mesh	78.00	88.00	23.50	4314	1.48	1.31	1.31	-
		83.00	87.00	24.00	3379.3	1.14			-
Adobe Bricks Esc 1:1	Geogrid mesh	83.00	85.00	28.00	9000	2.67	2.67	2.67	-
		85.00	82.00	28.50	3700	1.12			failure of the metal support in the wall corners
Adobe Bricks Esc 1:1	Steel mesh	82.00	78.00	28.00	8700	2.82	3.09	3.09	-
		82.00	84.00	27.00	10800	3.37			-
Adobe Bricks Esc 1:1	Unreinforced	86.00	81.00	21.00	2100	0.87	0.76	0.76	-
		84.50	77.00	21.50	1500	0.64			

The analysis of the results can be inferred that:

- The shear strength of unreinforced adobe walls is much lower if compared with the values obtained for the reinforced walls.
- The reinforcement allows the wall will not disintegrate even when walls collapsed, important property for an area with high seismic hazard.
- The values obtained for walls reinforced with metal mesh and geogrid are comparable.
- The values reached by the walls reinforced with steel mesh are comparable with those possessing the brick masonry class B. See Fig. 6.

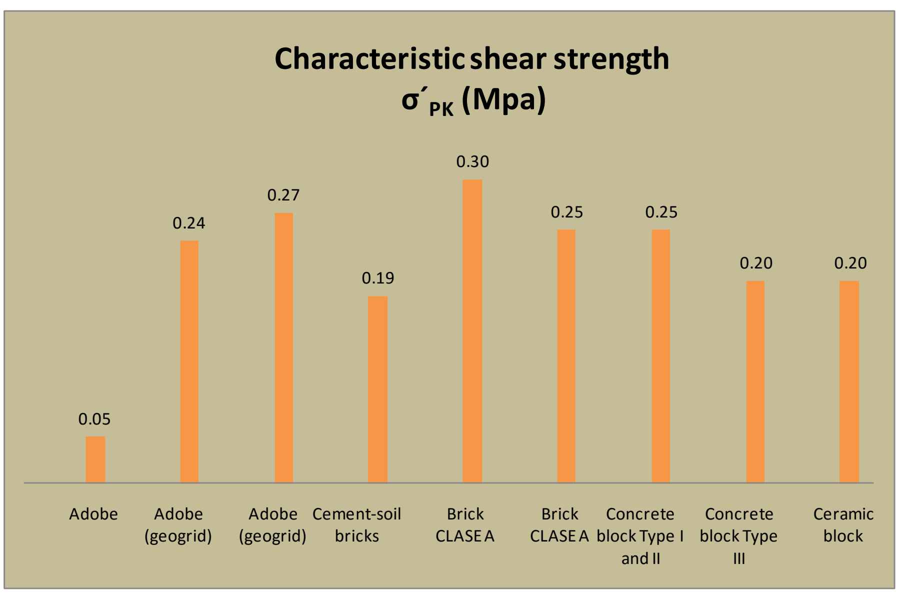

Fig.6-Characteristic shearstrength of different types of masonry.

7. Dynamic test

Test results show the ability provided by the reinforcement with steel mesh, even if the wall has reached the breaking bricks.

To study the actual behavior of physical models to seismic actions and evaluate the improvement involves the use of metal reinforcing mesh, a plan of tests was carried out on vibrating table, in the IDIA (Earthquake Research Institute of the San Juan National University)[6].

Each test consists of applying the selected module housing a movement at its base and record the response to that movement visually and by sensors installed in the housing structure.

Two models in small scale (1: 2) were tested. The first was built with adobe, unreinforced, trying to emulate the usual techniques of construction of this type. The second it consisted of a model, just like the first, but reinforced with a steel mesh and coated with cement plaster[7]. The metal mesh used is formed by galvanized steel rods 3mm in diameter and spaced 100mm, which is equivalent to a steel mesh ADN42 / 50 of 4.2mm in diameter and spaced a distance of 200 mm that would be adopted for strengthening existing homes.

7.1. Models Construction.

The model was built on a rigid concrete base, which allows lifting from the construction site to the vibrating table, without damage occurring in this operation

In the Fig. 7, show the different stages of building the model. Was used a mortar formed for clayed soil, vegetal fibers and water. This mixture was prepared 48 hours before use to ensure the league with adobes.

To support the weight of the wall over openings, lintels were formed by wooden braces 10cm of side, a technique that is conventional in existing buildings.

The roof is formed by a layer of 10 cm of mud over a wooden plate nailed to wooden braces circular section (0.04 m diameter). The weight transmitted by this roof to the walls comes from the analysis of similarity between the prototype and model.

Once the dynamic test completed we proceeded to demolish and rebuild the damaged parts, in this case the construction was done directly on the vibrating table.

Fig. 7-Construction process.

[6] Saldivar M., Bustos J.L., Albarracín O. (2006) Test under horizontal loads of walls built with soil cement bricks. V SIACOT. Mendoza, Argentina

[7] Blondet Saavedra J., Tarque Ruiz S. y Velazques Vargas J. (2006) Análisis sísmicos de adobes reforzados con mallas de polímeros. Proyecto DAI2987.Pontificia Universidad Católica del Peru. Departamento de Ingenieria.

Fig. 8- Transport model and location on vibrating table.

In the second model and before positioning the steel mesh, was generated a roughened surface by the application of mortar (cement, sand and water). Accomplished this rough surface, meshes are supported on both sides of the wall. The steel mesh used is formed by steel rods of 3mm diameter, welded together, creating a grid of 10cm opening.

Fig. 9- Positioning of the steel mesh and plaster covering application.

Both meshes were connected by pins made of galvanized wire, following a pattern quincunx distribution.

The steel mesh was not linked to the structure of the foundation and the roof structure, because the application of the technique under study pursues the strengthening of existing homes, seeking minimal interference with the occupants of the property. This linkage on the one hand would be beneficial, providing greater rigidity to the assembly, but would require further intervention.

Finally, the meshes were covered with plaster whose ratio is 1 part cement and 6 parts sand.

The models are instrumented with the following sensors:

• Four accelerometers: each located in a corner of the ceiling height model.
•Two magnetic rules: located on the walls (parallel to the direction of motion), so to record the movement of the walls independently.
•Two LVDT: placed in the walls (parallel to the direction of motion), measuring the diagonal deformation of the walls, Fig. 10.

Fig. 10- Model without reinforcement. Resonance curve.

7.2. Dynamic test results

In the first model no damage was observed up to an acceleration at the base of 0.30g. From that moment they began to appreciate cracks on the lintel of the window and door. Diagonal cracks were opened to form loose blocks. The greatest damage was observed after the rupture of the wall located behind the window occur. The model did not collapse, because the trial was stopped to avoid risks in the equipment, Fig. 11.


Fig. 11- Model without reinforcement collapsed.

The model reinforced with steel mesh was built directly on the vibrating table, on the basis of the previous model.

The model behaves properly for accelerations imposed. When the accelerations applied exceeded those imposed on Model unreinforced, separation occurred in the contact between the bricks and reinforced concrete base.

From that moment the model began to slide on the base as a rigid block, and no damage occurred. Damage was minor and concentrated around the door where some cracks and spalling of plaster are appreciated, Fig. 12.

Fig. 12- Damage to the model reinforced after the test.

8. Conclusion

Adobe strength is 200% less than the Class B brick (INPRES-CIRSOC), and this brick is the most widespread in the construction of homes in San Juan.

The strength of the adobe walls is of the order of 25% of walls built with bricks of soil-cement, 10% of the walls of concrete blocks and 5% of the value indicated for brick Class A walls (INPRES-CIRSOC). These values reflect the weakness of adobe walls with respect to the other types, in terms of compressive strength.

The shear strength of unreinforced adobe walls is much lower (5 times) compared with the values obtained for adobe walls reinforced (geogrids and metallic mesh). The values reached by the reinforced walls are of the same order a brick (class B) and mortar of intermediate resistance (CIRSOC-103, Volume 3).

The shear stress values obtained for walls, reinforced with metal mesh and geogrid are of the same order.

In addition to the resistance provided, the reinforcement allows the wall will not disintegrate even when it is collapsed, important property for an area of high seismic hazard. This prevents the detachment of blocks, being one of the major causes of deaths in homes built with this type of masonry against destructive earthquakes.

The unreinforced model behavior under dynamic action was not adequate. The cracking pattern responds expected. The first cracks (at 45 ° to a horizontal plane) were developed in the wall with openings and then on the walls without openings. Lintel beam slows the progress of the cracks.

The model reinforced with metal mesh, had a good response to the acceleration applied to the base. It developed progressively a cutting plane at the base. After completely separated from the base, the model began to slide on the base, as a rigid block, and no damage occurred. Only were observed some minor cracks and peeling of the plastering on the side of the door.

The reinforcement steel mesh produced excellent results in the dynamic tests, where the model has greater rigidity which has prevented the premature collapse. To levels greater accelerations to which caused the collapse unreinforced model, only minor damage and concentrates were observed.

The tests performed allowed the study of strengthening solutions to slow the collapse of adobe houses. Such solutions are likely to be implemented by methods of self-construction assisted technical and financially.

The proposed solutions are difficult to apply following the existing regulatory framework. Its implementation for effective mitigation of seismic risk of large sectors of the population is subject to determinations of political nature that transcend the technological field.

9. Bibliography

[1] Reglamentación para el uso de laGeomalla en el Adobe. Gerencia de Investigación y Normalización de SENCICO.

[2] Saldivar, M; Albarracin, O. (2004). Verificaciones Experimentales del Sistema Constructivo en suelo-cemento para zona sísmica. *IV SIACOT*. Portugal.

[3] INPRES; INTI; CIRSOC. (Julio, 2005). Reglamento argentino para Construcciones Sismorresistentes. Argentina, San Juan.

[4] Verificaciones Experimentales de Sistema Constructivo en Suelo-Cemento para Zona Sísmica. M. Saldivar, A.Pereyra, O. Albarracin.

[5] Saldivar M, Albarracín O, GarinoLibardi L. (2013). Disminución de la vulnerabilidad sísmica de las construcciones espontaneas de adobes. XIII SIACOT, Valparaíso, Chile.

[6] Saldivar, M, Bustos J.L, Albarracin,O. (2006). Ensayo bajo cargas Horizontales de Muro Construido con Mampuestos de Suelo Cemento. *V SIACOT.* Mendoza, Argentina.

[7] Blondet, Saavedra, J. M., Tarque Ruíz, S. N. & Velásquez Vargas, J. M., (2006). Análisis sísmico de módulos de adobe reforzado con malla de polímero. Proyecto DAI-2987. Pontificia Universidad Católica del Perú, Departamento de Ingeniería, Sección Ingeniería Civil.