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A new proposal for the design of confined masonry buildings

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ABSTRACT:
Confined masonry has been efficiently used for buildings in Latin-America, Northern-Africa and Asia, even in seismic areas. However, despite all the research on the seismic behaviour of this structural typology, mainly in Latin-America, the lack of clear criteria for confined masonry design limits its application in Europe. In this work, a semi-empirical strength criterion for confined masonry, based on the diagonal shear failure of confined walls, is proposed. For this purpose, data mining is applied to a database of confined walls under cyclic loading tests, in order to clarify the variables that influence the shear strength. This study showed that the shear strength can be acceptably predicted by a multiple regression of the normal stress, diagonal shear strength, slenderness and masonry cross-section ratio of the walls. The relevance of longitudinal reinforcement of the confinement columns is low, with a significant contribution only in the post-cracking stage.

Keywords: *Confined masonry, seismic design, shear behaviour, data mining, sensitivity analysis, modelling*

NOTATION

f_{v0} masonry initial shear strength determined by a test with brick-triplets;
τ_{m0} masonry shear strength determined by a diagonal compression test;
N axial load on the confined wall;
Cor Pearson correlation coefficient.

1 INTRODUCTION

Sustainability of building construction requires that several requirements, namely functional, structural, societal, economical and environmental all be satisfied. Unreinforced masonry was historically, and is actually, the structural solution that best addresses these requirements [1]. However, in seismic areas, unreinforced masonry buildings present limitations to behaviour with respect to severe earthquakes, and the masonry structural system needs to be improved, for example by using confined masonry whose performance is demonstrated in Figure 1. This figure shows confined masonry buildings that survived severe earthquakes, whereas nearby unreinforced masonry buildings collapsed.

Confined masonry is a typical construction technique of buildings in countries of Latin America, Northern Africa and Asia, which in the past were mainly designed with non-engineered criteria and using poor quality materials. Earthquakes demonstrated a deficient seismic performance of these buildings and the need to study the seismic behaviour of this structural typology became evident. Since the late 1960s several experimental studies were carried out, particularly in Mexico [2], Peru [3], Argentina [4], Slovenia [5] and Japan [6], which mainly consisted of experimental programmes of lateral cyclic tests on confined masonry panels. These studies were based on local practices and materials, with different behaviour observed and distinct theories introduced. In each country, the design codes have been based on the behaviour observed in local tests, resulting in different criteria.

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This disparity does not allow universal rules for confined masonry design, particularly in Europe, where the knowledge on confined masonry is limited. In this context, recently, a global program [7] was signed to define worldwide guidelines for the development of design codes for confined masonry.

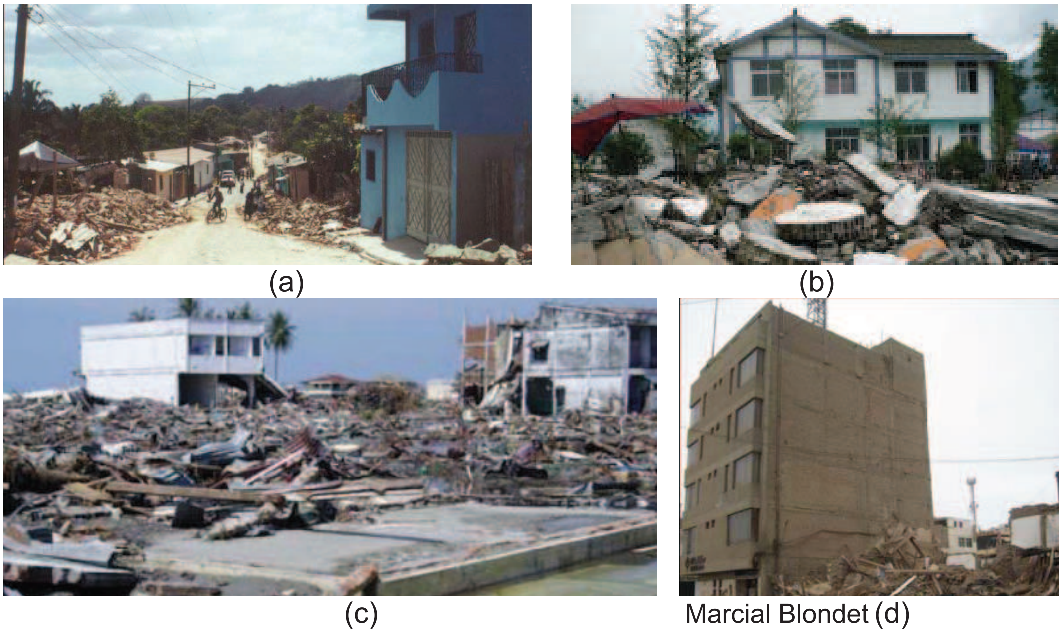


Figure 1. Performance of confined vs. unreinforced masonry buildings subjected to earthquakes in: (a) El Salvador, 2001 [8]; (b) Sichuan, 2008 [7]; (c) Sumatra, 2004 [9]; (d) Pisco, 2007

In Europe, reinforced concrete frames with infill masonry is the main structural typology, where it is assumed that only the reinforced concrete elements provide strength. However, studies have demonstrated that the infill masonry significantly contributes to the in-plane stiffness and shear strength [5]. Additionally, the cost of the masonry in the construction of buildings and the actual quality of masonry units justify a more effective participation of the masonry system in the structural, particularly seismic, performance of buildings.

The confined masonry technique, which is based on the construction of the masonry panels prior to the casting of the surrounding reinforced concrete elements, uses the assumption that the confined wall responds as a whole, where the masonry is the main structural element. In practice, this technique allows reducing the amount of concrete and steel reinforcement for the confinement elements, which leads to economical advantages. The use of confined masonry in small-to-medium height buildings is assumed sustainable in modern society, since these buildings represent an important percentage of the building stock.

In this work, a review of hypothesis and models for the seismic behaviour of confined walls is made. Afterwards, a robust proposal is presented as a guideline to seismic design of confined masonry buildings, based on conceptual and numerical models extracted from experimental evidence. This work intends, finally, to evolve from the wall response to the global building seismic response.

2 WALL RESPONSE

The experimental evaluation of the behaviour of confined masonry panels under lateral cyclic loading has received significant attention. In fact, a confined wall is considered the single structural member of confined masonry buildings, meaning that its individual response contributes to the global response of the whole building. In the following, the conceptual aspects of the wall response under lateral cyclic loading are explained, and a data mining process is applied to an experimental database in order to investigate the shear strength of confined walls.

2.1 Experimental research

The experimental investigation on the lateral cyclic behaviour of confined masonry panels started in Mexico [2], where the confined masonry typology was particularly widespread in the construction of buildings. One of the more extensive experimental programs on confined masonry panels under lateral loading was carried out at Pontifical Catholic University of Peru, evaluating several features of the confined walls, particularly the strapping of confinement columns, slenderness of panels, column-masonry connection, number of leafs, reinforcement and vertical load [3].

According to San Bartolomé [3] a confined wall behaves monolithically and elastically until the first visible crack in the wall, which may be by tension in the concrete elements. Then, the first diagonal cracking occurs, due to diagonal tension in the masonry panel. After the diagonal cracking the masonry panel behaves as two triangular pieces confined by the columns, when the top triangle rotates and slides around the compressed column. This process is corroborated from Aguilar and Alcocer [10], as can be observed in Figure 2, where a plastic hinge is identified at the base of the compressed column.

On the other hand, if a wall is subjected to a higher vertical load, *N*, the masonry panel mainly slides, and consequently the reinforcement bars of the tensioned column do not yield and the ultimate strength is mainly associated with the dowel action of the reinforcement bars of the compressed column [3, 5]. From Figure 3, which illustrates results of lateral cyclic tests on solid clay brick walls, a drop on the load-displacement envelope is identified concurrently with diagonal cracking, after which the tie-columns play the main role in the response of confined walls. According to Zepeda el al. [11] the reinforced concrete tie-columns have a very important effect on the reserve strength, ductility and stability of walls after diagonal cracking.

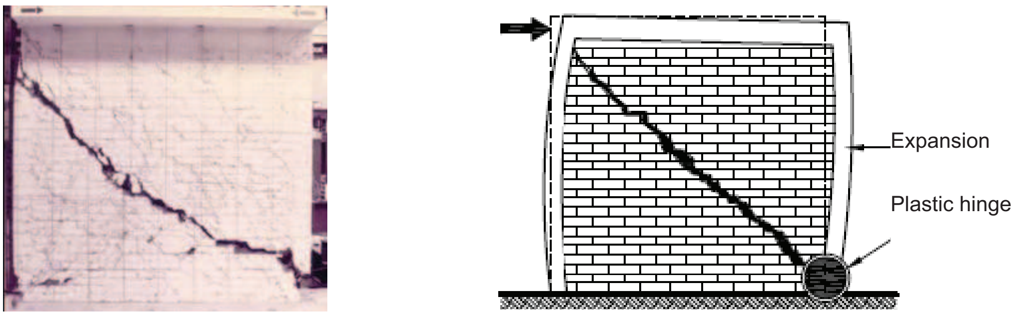
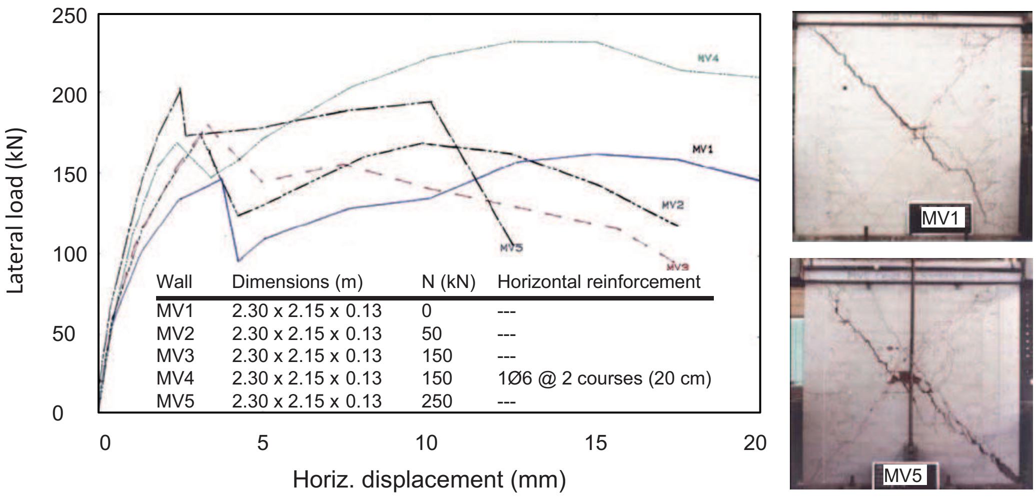


Figure 2. Plastic hinge developed in a confined wall [10]



(a) (b)

Figure 3. Experimental response of confined walls under lateral cyclic loading [3]: (a) lateral load-displacement envelope and (b) final crack patterns of walls MV1 and MV5

The drop on the load-displacement envelopes observed in [3] is not evident in tests performed by other researchers. This fact can be related with the way that the diagonal crack progresses to the tie-column ends. From Figure 3, it can be observed that for Wall MV5 the diagonal crack entirely crosses the compressed column, with a load drop lower than observed for Wall MV1 where the diagonal crack partially crosses the tie-column ends. This drop can also be due to the brittleness of the masonry units. When robust units are used a mixed pattern with steeped and horizontal cracks can be expected, because the tie-column is stressed along the full height.

Other mechanisms that can occur in confined walls include the flexural one, which is characterized by horizontal cracking along the mortar bed joints on the tensioned side of the wall, and in some cases separation of the tie-columns from the masonry panel, due to the use of poor reinforced tie-columns and/or weak connection to the masonry panel sides (Figure 4(a-b)). This mechanism is similar to the sliding shear, which is a typical failure mode in masonry infilled frames, as illustrated in Figure 4(c). Then, to optimize the masonry panel contribution to the wall shear capacity, the confinement columns must be sufficiently reinforced and a good connection between masonry and tie-columns is required. According to San Bartolomé and Quiun [12], if the sliding is avoided the cracked walls inside the confinements provide lateral load resistance.

(a) (b) (c)

Figure 4. Flexural failure of a confined wall with (a) horizontal cracking and (b) separation of tie-column [13] similarly to (c) a typical masonry infilled frame mechanism [5]

The diagonal tensile strength of masonry panels plays a major role in the shear response of confined walls. In the codes of Latin America and the United States a diagonal tensile test is specified, e.g. [14]. On the other hand, in Europe this test is not usual and reference values do not exist. Based on results which compare expressions for shear strength of Latin America codes and Eurocode 6, Magenes et al. [15] propose a ratio between the initial shear strength f_{v0} and the diagonal shear strength τ_{m0} of 0.6. The influence of the masonry diagonal shear strength on the response of confined walls will be further analyzed in Section 2.3.

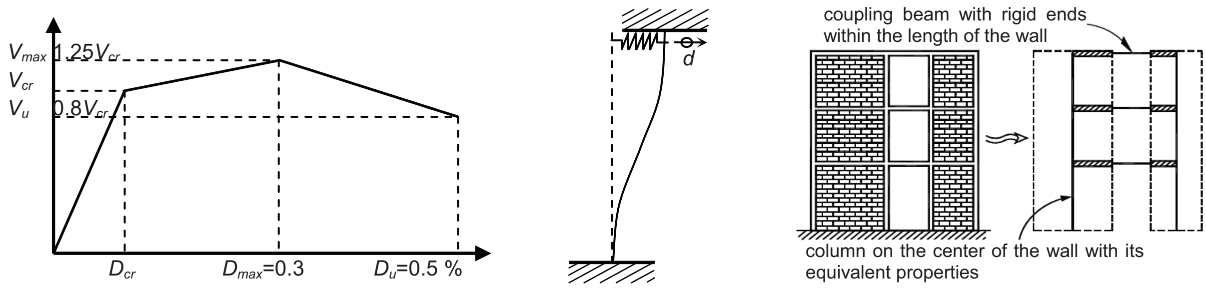
2.2 Development of analytical models for seismic analysis and design

The experimental response of confined walls under lateral cyclic loading was explained above, and its understanding is essential to any analytical modelling. Recent tendencies of performance-based design require the consideration of a shear-displacement response.

Based on ample experimental evidence, Flores and Alcocer [16] proposed a tri-linear envelope for the lateral cycle shear (*V*)-drift (*D*) response of confined walls, which is presented in Figure 5(a). Note that the subscript "*cr*" in Figure 5(a) corresponds to the point at which the first significant cracking occurs, which experimentally is associated with about 40% reduction in the panel stiffness.

The behaviour of confined masonry panels under lateral cyclic loading is complex, but even more complex is the global behaviour of a confined masonry building, since it is an assemblage of confined walls, some of these with openings. Research on the seismic behaviour of unreinforced masonry buildings lead to the use of macro-modelling in seismic assessment and design, by performing a nonlinear static (pushover) analysis [1] in which the masonry walls are discretized as panels defined between openings. In the case of confined masonry buildings, the walls can also be divided into macro-elements, namely by considering these as equivalent columns (Figure 5(b)).

Existing design proposals are mainly based on the use of linear elastic analysis, but codes have introduced approaches, as the modified wide-column model [17] exemplified in Figure 5(c), which has been used in displacement-based seismic assessment of low-height confined masonry buildings [18].



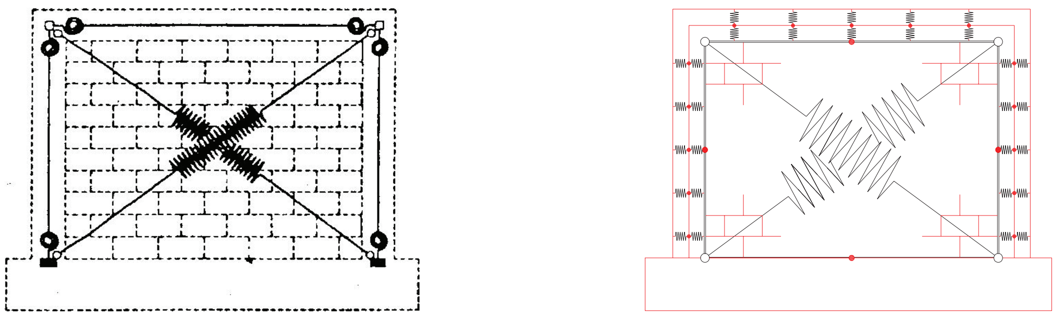
(a) (b) (c)

Figure 5. Wall modelling through equivalent columns: (a) confined wall backbone response [16]; (b) equivalent column macro-element; (c) modified wide-column model [17]

The confined wall initially behaves as a monolithic element for which an equivalent section can be defined, but as the masonry panel starts to crack and the connection between the panel and the confinement elements is affected, the wall is converted into a multi-element system, where a complex mechanism occurs involving interactively the masonry panel and the confinement elements.

For this reason, for a more global simulation of possible mechanisms, a discrete macro-element can be used, which should include modelling of the masonry panel, confinement elements and their interaction. Žarnić [19] proposed a discrete macro-element for simulation of the response of infilled frames under dynamic loading, where the frame columns and beams are modelled as flexural springs and the masonry infills are modelled as longitudinal springs that simulate equivalent bracing (Figure 6(a)), which does not allow, however, simulating the interaction between masonry and frames. Càlio et al. [20] developed a macro-model which simulates the shear behaviour of the masonry panel by using diagonal springs connected to the corners of a pinned quadrilateral made with four rigid edges, and in this case also the interaction between masonry and frames. For this purpose, normal springs to the sides of the macro-element are included, which interact with the confining elements modelled as subdivided frame elements, as shown in Figure 6(b).

Future development of macro-elements can be expected, which need however to be validated with experimental results. For this purpose, experimental tests of confined masonry buildings subjected to lateral loading have been identified in the literature, even if many tests have been made under dynamic testing. Comparison of results from dynamic and quasi-static tests is therefore another relevant aspect of research.



(a) (b)

Figure 6. Macro-element for (a) infilled [19] and (b) confined (adapted from [20]) walls

Analytical models have been developed to simulate wall behaviour under lateral loading, so that they can be assembled for a global "building" analysis. The performance of these models is dependent on the assumed shear-displacement response for the confined wall. Despite the significant number of experimental studies on confined walls under lateral loading, as a consequence of the great dispersion of used materials and constructive practices, a consensual numerical model for their response remains unavailable.

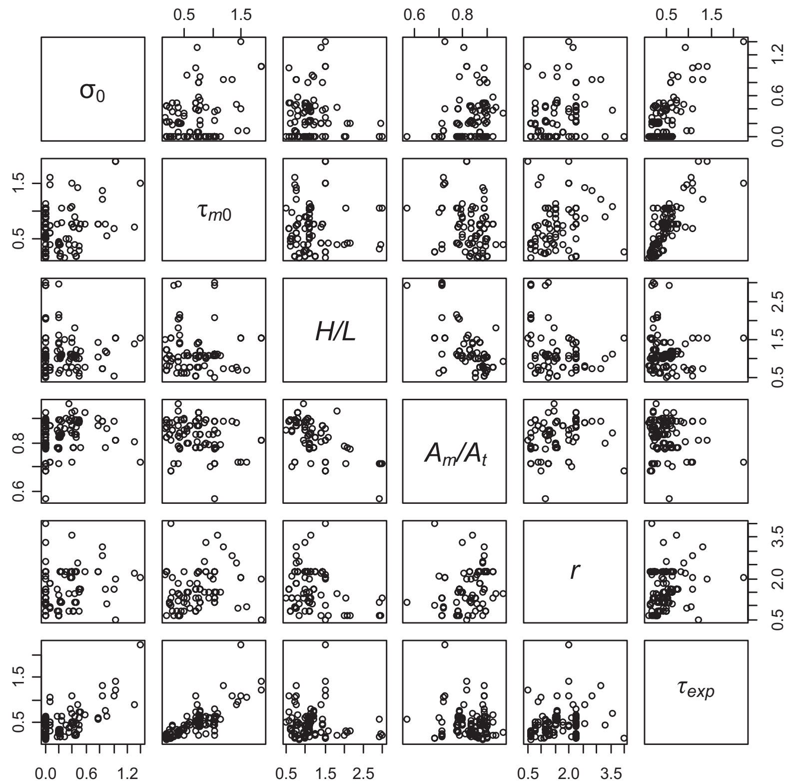
Recently, Riahi et al. [21] proposed a backbone model for the lateral cyclic response of confined walls, based on lateral tests gathered from an extensive database and derived through a linear regression analysis, which intends to be a “universal” model. However, the database used was subjected to a pre-validation process, eliminating outliers, meaning that particular cases of behaviour of confined walls were discarded.

In this work a similar procedure to that used in [21] was carried out, using a data mining process on an experimental database of results collected from the literature. A larger database and the absence of any filtering allow a general approach, aiming at the prediction of the shear strength of confined walls.

2.3 Data mining

Data mining (DM) is a process developed in the area of Artificial Intelligence, which aims at the extraction of high-level knowledge from raw data [22]. The use of DM has been disseminated in different areas, from medicine to business, including also Structural Engineering. This process consists of an extensive analysis of databases, by applying methods developed from the analogy with natural learning processes, such as artificial neural networks and decision trees. Then, based on an idealised analytical structure, different models can be fitted to predict the value of an output variable, as a function of the assumed input variables.

In this study, a database with results from 105 tests of confined masonry panels under lateral cyclic loading has been created from a literature review. Figure 7 shows a matrix that represents graphically, through points, the associations of values between variables from the entire database. This figure denotes significant dispersion, where a linear trend between the masonry diagonal shear strength and the experimental shear strength can be noted.



Legend:

σ_0 – normal stress on the wall (MPa)

τ_{m0} – masonry diagonal shear strength (MPa)

H/L – wall slenderness

A_m/A_t – masonry panel cross-section area ratio

r – column longitudinal reinforcement ratio (%)

τ_{exp} – experimental maximum overall shear strength (MPa)

Figure 7. Relationship matrix between the database variables

Here, beyond the typical multiple regression, different DM techniques were tested, namely the regression trees, artificial neural networks, support vector machines and k-nearest neighbours, by using a library created by Cortez [23]. In this study, the technique evaluation scheme is based on ten executions (runs) of a five-fold cross validation, where the data is divided into five partitions of equal size. Sequentially, each different subset is tested and the remaining data is used for fitting the model. The overall performance is given by the average of the Pearson correlation (Cor) coefficient on all ten executions, and its confidence interval under a *t*-student test with a 95% confidence level.

According to a model that predicts the experimental shear strength as a function of all remaining variables in the database, the multiple regression and the support vector machine are the techniques that provide the best performances, which are presented in Figure 8(a-b).

Whereas the multiple regression is a simple model widely known, the support vector machine is a complex model. For the latter, the input data is transformed into a high *m*-dimensional feature space by using nonlinear mapping, and then the support vector machine finds the best linear separating hyperplane related to a set of support vectors, in the feature space [23]. This model uses a complex formulation, but the predictions are basically founded on the weighing under a set of support vectors located in the transformed space. Then, these two techniques can be understood as referential for linear models (the multiple regression) and for nonlinear models (the support vector machine).

To better understand the studied problem, a sensitivity analysis was performed to measure the input relevance, by computing the variance produced in the output when an input attribute varies through its full range. This analysis provided the relative importance shown in Figure 8(c), where the masonry diagonal shear strength (τ_{m0}) is preponderant. If a multiple regression model is assumed, the column longitudinal reinforcement ratio (*r*) presents non-significant importance. On the other hand, by fitting the support vector machine, a lower but significant importance is attributed to this variable. This fact can denote a nonlinear dependency from the column longitudinal reinforcement ratio.

Additionally, the high value of the independent coefficient in the multiple regression model stresses the need to consider other input variables, such as the unit percentage of holes and a measure of the masonry-to-column connection.

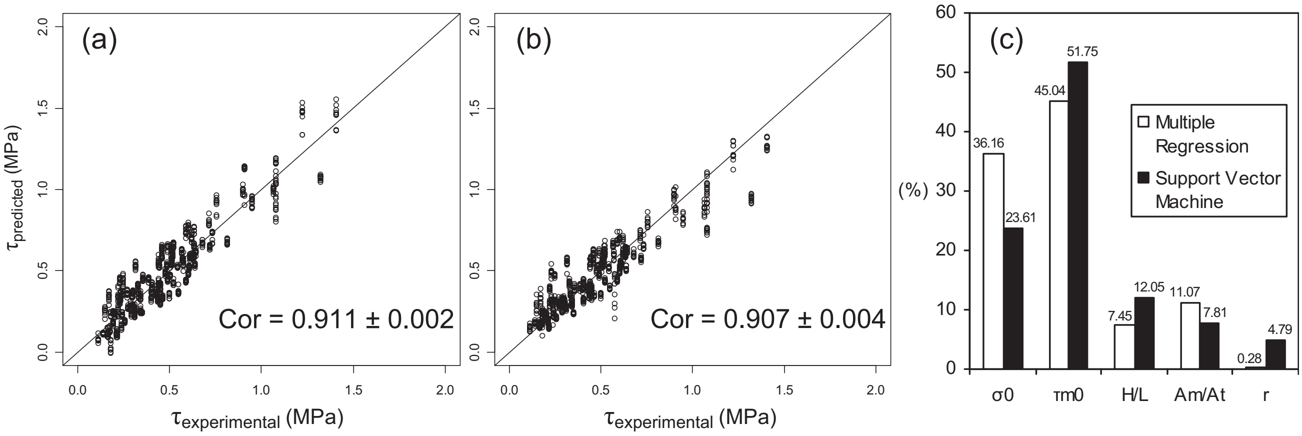


Figure 8. Experimental versus predicted shear strength values according to: (a) multiple regression and (b) support vector machine fittings; (c) importance of variables in the prediction

2.4 Comparison of shear strength prediction models

Until today, several models have been proposed to predict the shear strength of confined masonry panels, which are presented below. A fitted multiple regression is also introduced, which is independent of the column longitudinal reinforcement ratio, because its influence is rather small according to the linear model.

Figure 9 presents scatter plots of the experimental versus the predicted shear strength values according to different models. The support vector machine and the proposed multiple regression are the models that, in general, best predict the collected data. The proposed multiple regression is simple and its use is recommended. On the other hand, the support vector machine involves a complex computation (not shown here).

1. Argentinean code Inpres-Cirsoc 103 [24]:

$$\tau = 0.6\tau_{m0} + 0.3\sigma_0 \tag{1}$$

2. D'Amore and Decanini [25]:

$$\tau = (0.6\tau_{m0} + 0.3\sigma_0) \cdot K_t \text{, where } K_t = min(1.2 - 0.2H/L, 1) \tag{2}$$

3. Moroni et al. [26]:

$$\tau = 0.45\tau_{m0} + 0.3\sigma_0 \tag{3}$$

4. Turnšek and Čačovič [27]:

$$\tau = \frac{0.7336\tau_{m0}}{b}\sqrt{\frac{\sigma_0}{0.7336\tau_{m0}} + 1} \text{, where } b = min(H/L, 1.5) \geq 1 \tag{4}$$

5. Tomaževič [5]:

$$\tau = \frac{0.7336\tau_{m0}}{b} \cdot \left(\frac{H/L}{2 \cdot \alpha \cdot b} + \sqrt{\left(\frac{H/L}{2 \cdot \alpha \cdot b}\right)^2 + 1 + \frac{\sigma_0}{0.7336\tau_{m0}}} \right), \tag{5}$$

where $b = min(H/L, 1.5) \geq 1$ and $\alpha = 5/4$

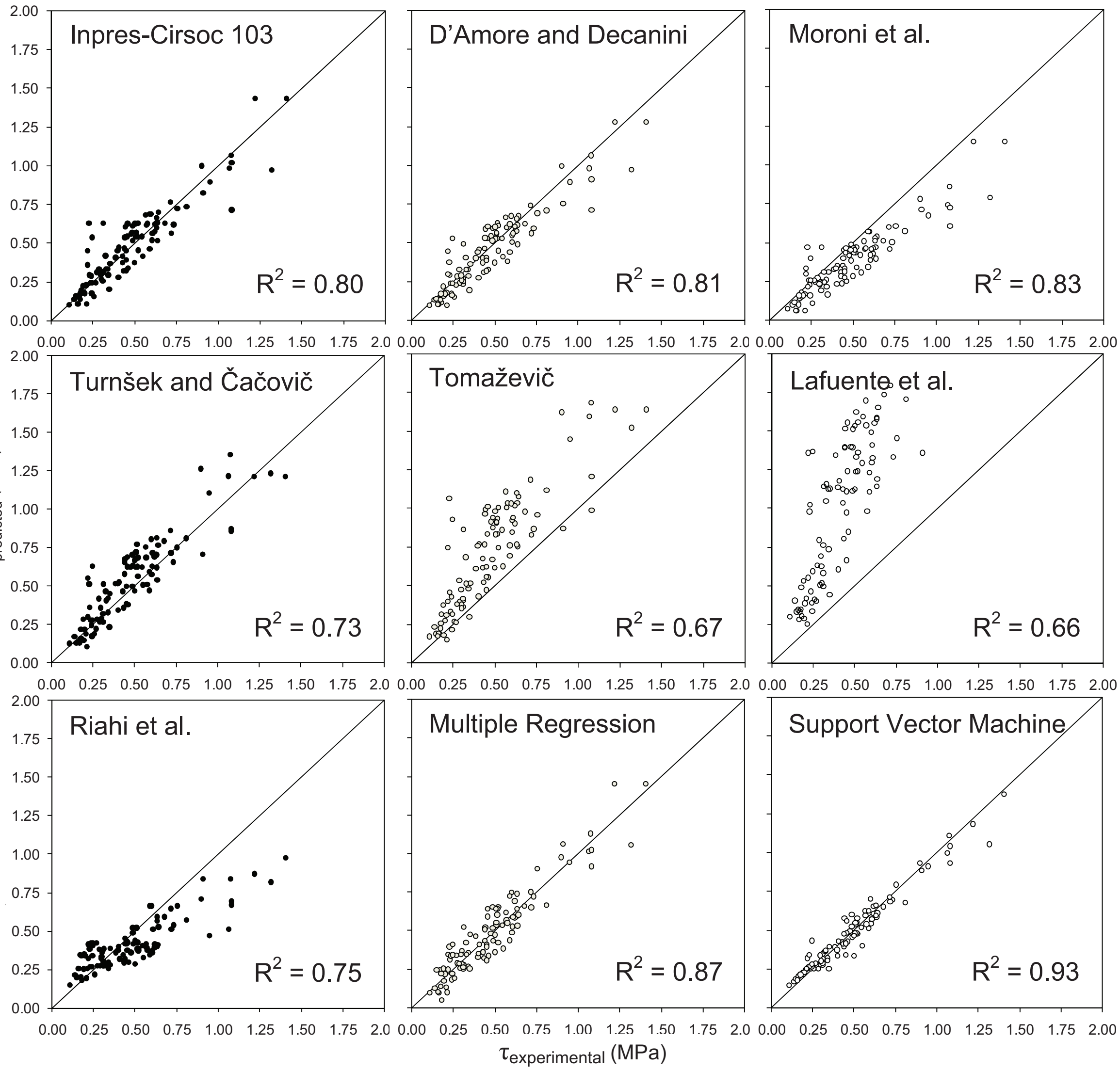


Figure 9. Experimental versus predicted shear strength values from different models

6. Lafuente et al. [28]:

$$\tau = 0.7336\tau_{m0} \cdot \frac{a}{L} \cdot \left(H/L + \sqrt{H/L + 4 + 4 \cdot \frac{\sigma_0}{0.7336\tau_{m0}}} \right), \tag{6}$$

where $a/L = 0.56, 0.65$ and 0.85 respectively to $H/L = 1.21, 1.01$ and 0.76 by interpolating

7. Riahi et al. [21]:

$$\tau = 0.21\tau_{m0} + 0.363\sigma_0 + 0.0141\sqrt{r \cdot f_y \cdot f_c} \tag{7}$$

where f_y is the steel yelding strength and f_c the concrete compressive strength

8. Proposed Multiple Regression:

$$\tau = 1.0072 + 0.4897\tau_{m0} + 0.5341\sigma_0 - 0.137H/L - 0.9966A_m/A_t \text{ [MPa]} \tag{8}$$

3 CONCLUSIONS

This study aimed to review conceptual aspects and to propose and compare analytical models for the response of confined walls under lateral cyclic loading, based on experimental evidence. The objective is to allow seismic assessment and design of confined masonry buildings.

The review of the experimental lateral cyclic behaviour of confined walls, particularly its damage evolution, stresses the need to consider the masonry-column interaction.

The applied data mining process allowed one to obtain prediction models for the shear strength of confined walls more accurately than the existing formulas, according to linear (multiple regression) and nonlinear (support vector machine) models.

The sensitivity analysis indicates that the masonry diagonal shear strength is crucial in the prediction of the shear strength of confined walls, whereas the column longitudinal reinforcement ratio is less relevant. Additionally, the need to consider additional variables in the prediction was identified, such as the unit percentage of holes and a measure of the masonry-to-column connection.

Aiming at the seismic design of confined masonry buildings, the proposed formula can be used to define a backbone shear response of confined walls for pushover analysis of buildings modelled by simplified frame methods, as the modified wide-column, or more complex methods using discrete macro-elements.

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REFERENCES

[1] Marques, R. & Lourenço, P.B.: Potentialities of construction and design of unreinforced masonry buildings. *Construção Magazine*, submitted January 2009 (in Portuguese).

[2] Meli, R.: *Seismic behaviour of masonry walls*. Report No. 352, Instituto de Ingeniería, Universidad Nacional Autónoma de México: Mexico City 1975 (in Spanish).

[3] San Bartolomé, A.: *Masonry Construction. Seismic Behaviour and Structural Design*. Editorial Fund, Catholic University of Peru: Lima 1994 (in Spanish).

[4] Decanini, L.; Payer, A.; Serrano, C. & Terzarioll, R.: Experimental Research on the Behaviour of Real Scale Prototypes of Confined Masonry Walls. In: *Proc. Colloquia 85*, Buenos Aires, 1985, 1541-1572 (in Spanish).

[5] Tomaževič, M.: *Earthquake-Resistant Design of Masonry Buildings*. Series on Innovation in Structures and Construction – Vol.1. Imperial College Press: London 1999.

[6] Matsumura, A.: Shear Strength of Reinforced Masonry Walls. In: *Proc. 9th World Conference on Earthquake Engineering*, Tokyo-Kyoto, 1988, 121-126.

[7] CMN: www.confinedmasonry.org, website of the Confined Masonry Network, 2010.

[8] EERI: *Preliminary Reports and Annotated Images from the El Salvador Earthquakes of Jan. 13 and Feb. 13, 2001*. CD, Earthquake Engineering Research Institute: California 2001.

[9] Boen, T.: Sumatra Earthquake 26 Dec. 2004. www.eeri.org, Earthquake Engineering Research Institute, Oakland: California 2005.

[10] Aguilar, G. & Alcocer, S.M.: *Effect of Horizontal Reinforcement on the Behaviour of Confined Masonry Walls under Lateral Loads*. CENAPRED: Mexico City 2001 (in Spanish).

[11] Zepeda J.; Alcocer, S.M. & Flores, L.: Earthquake-Resistant Construction with Multi-Perforated Clay Brick Walls. In: *Proc. 12th World Conf. Earthquake Engineering*, Auckland, No. 1541, 2000.

[12] San Bartolomé, A. & Quiun, D.: Design Proposal of Confined Masonry Buildings. In: *Proc. 10th North American Masonry Conference*. The Masonry Society: St. Louis 2007, 366-377.

[13] Yoshimura, K.; Kikuchi, K.; Kuroki, M.; Nonaka, H.; Kim, K.; Wangdi, R. & Oshikata, A.: Experimental study for developing higher seismic performance of brick masonry walls. In: *Proc. of the 13th World Conference on Earthquake Engineering*, Vancouver, No. 1597, 2004.

[14] ASTM E 519-02: Standard test method for diagonal tension (shear) in masonry assemblages. CD, American Society for Testing and Materials: Philadelphia 2002.

[15] Magenes, G.; Calvi, G.M. & Gaia, F.: *Shear tests on reinforced masonry walls*. Serie Rapporti Scientifici. Report RS-03/96, University of Pavia, 1996.

[16] Flores, L. & Alcocer, S.M.: Calculated response of confined masonry structures. In: *Proc. 11th World Conf. on Earthquake Engineering*, Acapulco, No. 1830, 1996.

[17] NTCM: *Mexican Code for Design and Construction of Masonry Structures*. Gaceta Oficial del Gobierno del Distrito Federal: Mexico City 2004 (in Spanish).

[18] Terán-Gilmore, A.; Zúñiga-Cuevas, O. & Ruiz-García, J.: Displacement-based seismic assessment of low-height confined masonry buildings. *Earthq. Spectra*, 25 (2009) 2, 439-464.

[19] Žarnić, R.: Inelastic model of R/C frame with masonry infill - analytical approach. *Engineering Modelling*, 7 (1994) 1-2, 47-54.

[20] Caliò, I.; Cannizzaro, F.; Marletta, M. & Pantò, B.: *Theoretical manual of the 3Dmacro computer code*, Version Beta. Gruppo Sismica: Catania 2009 (in Italian).

[21] Riahi, Z.; Elwood, K. & Alcocer, S.: Backbone Model for Confined Masonry Walls for Performance-Based Seismic Design. *Journal of Structural Engineering*, 135 (2009) 6, 644-654.

[22] Witten, I.H. & Frank, E.: *Data Mining. Practical Machine Learning Tools and Techniques*, 2nd Edition. Morgan Kaufmann: San Francisco 2005.

[23] Cortez, P.: Data Mining with Neural Networks and Support Vector Machines using the R/rminer Tool. In: *Proc. of the 10th Industrial Conference on Data Mining*. Springer: Berlin 2010.

[24] Inpres-Cirsoc 103: *Argentinean code for earthquake-resistant constructions, Part III: Masonry constructions.* INPRES: San Juan 1983 (in Spanish).

[25] D'Amore, E. & Decanini, L.: Shear strength analysis of confined masonry panels under cyclic loads: Comparison between proposed expressions and experimental data. In: *Proc. of the 9th International Seminar on Earthquake Prognostics*. Costa Rica: San José 1994.

[26] Moroni, M.; Astroza M. & Mesias, P.: Displacement capacity and required story drift in confined masonry buildings. In: *Proc. 11th World Conf. Earthq. Engineering*, Acapulco, No. 1059, 1996.

[27] Turnšek, V. & Čačovič, F.: Some experimental results on the strength of brick masonry walls. In: *Proc. of the 2nd Internat. Brick & Block Masonry Conference*. England: Stoke-on-Trent, 1970.

[28] Lafuente, M.; Castilla, E. & Genatios, C.: Experimantal and Analytical Evaluation of the Seismic Resistant Behaviour of Masonry Walls. *Masonry International*, 11 (1998) 3, 80-88.