Paper:

Implementation of Database of Masonry Walls Test – Review of Existing Test Data in Peru

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Confined masonry walls represent one of the most widely used construction systems for dwellings in Peru and other Latin countries. This study describes the procedure for implementing a database with a web interface of results collected from the experiments conducted over the years by the Japan Center for Earthquake Engineering and Disaster Mitigation. This paper attempts to contribute to the seismic design procedure of this type of structure, and parameters such as stiffness ratios and the deformation (drift) for the characteristic stages of confined masonry walls under different limit states or performance levels are proposed. Also, a semi-empirical equation for estimating the shear capacity using the database is proposed.

Keywords: confined masonry walls, limit states, data test, shear capacity

1. Introduction

Masonry dwellings are commonly used around the world, and Peru is no exception. In Peru, the construction evolution started with adobe, quincha (cane with mud), adobe with quincha and masonry walls using clay bricks. Confined masonry buildings have been widely used in Peru since the middle of the last century, especially because of good earthquake performance of confined masonry houses having one and two stories. For example, San Juan de Dios Hospital stood up well in the 2007 Pisco Earthquake. Other advantages are that the materials used in the construction of confined masonry buildings are relatively inexpensive and their execution does not require specialized inspections, although the buildings do need to be well designed.

The main feature of this type of construction is that the structural system is formed by a reinforced concrete (RC) frame filled in with masonry walls (confined masonry walls). This type of construction is thought to resist the actions of axial loads (gravity) and lateral loads (earthquakes), but it is the lateral loads that dominate their design (seismic resistant design).

To achieve proper designs that ensure good earthquake performance while taking into account the needs generated by the criteria incorporated in the modern seismic design standard in which different levels of performance are recognized (limit stages), it is necessary to know the deformation capacity of confined masonry walls to define the limit stages. Therefore, the main objective of this work is to determine the levels of deformation of confined masonry walls for a given limit state and their corresponding designs. To these ends, the information provided by some experimental studies conducted over the past 25 years in the laboratory of structures of CISMID, which belongs to the National University of Engineering, are used.

2. Background

As masonry walls have a low capacity to resist tension due to their brittle behavior after cracking occurs, they have important limitations in their ability to resist seismic actions. It is therefore necessary to strengthen them, and one such way is through reinforced concrete elements (columns and beams). These confine the masonry walls, but they must comply with the requirements of the standards design and calculation of masonry structures [1]. Confinement is achieved to the extent that the column and beam frames completely the masonry, providing the lateral deformation capacity and energy dissipation once cracking of the masonry wall occurs. The design of confined masonry must follow some specifications.

- The masonry wall must be built in two phases. The first phase is at half of the height (1.2 m, approximately) to avoid the excessive compression of the mortar in the joints between the masonry units. The second phase is continued building until the full height is reached; on both lateral edges of the wall it is necessary to leave mesh conformed for clay bricks units, after that is joined with concrete elements. Furthermore, it is recommended that the masonry units fill the space in completely or, if a perforated pattern is used, that the space reduction of the perforations be less than 30% of the total.

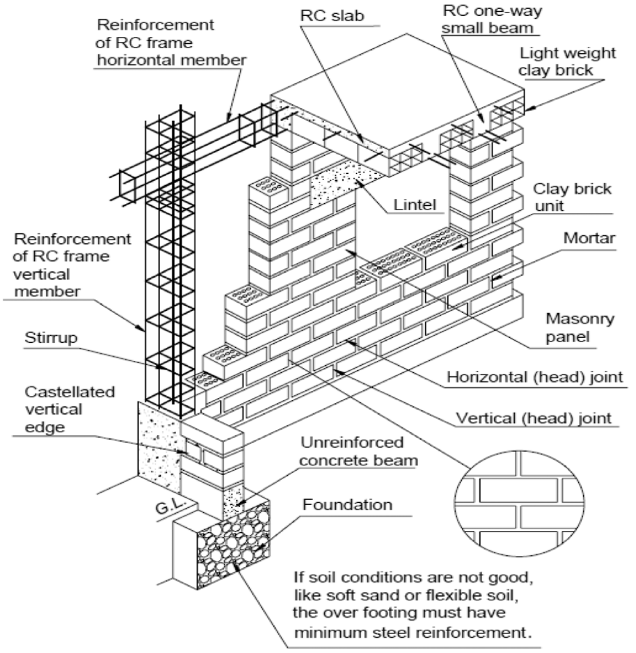

Fig. 1. Construction process of confined masonry wall in Peru.

- For the vertical concrete elements (columns), the construction process must be uninterrupted, and columns must be vibrated so that honeycombs are not generated. Then, the construction of the beam may proceed.

The behavior of a confined masonry wall depends on the quality of the masonry, dimensions, and number of reinforcement elements of confinement (RC frames). The horizontal and vertical reinforcement of RC frame must resist the tensile stresses produced by the bending moments due to loads acting in the plane of the wall, such as bending and shear forces. Everything together makes the confined wall perform well under seismic loading and stresses. Still, it is necessary to have a bigger concentration of stirrups in areas where the cracking may occur in the masonry wall. To avoid these cracks, stirrups are located around the joints of the RC frame.

3. Database Collection on Masonry Walls

Masonry takes on many forms around the world. In Peru, the materials most commonly used are adobe, quincha and masonry bricks.

3.1. Results of Masonry Compression Tests

Some tests were conducted to obtain compression strength values for adobe and masonry. The following values were obtained for the average compression strength. **Table 1** presents the mechanical properties of masonry, both those from the database and those prescribed in the standard.

3.2. Masonry Walls Collection

Nowadays, red clay brick is the material most commonly used to build masonry walls, and they have many configurations and set ups. **Fig. 2** shows the masonry arrangements and configurations tested in CISMID-UNI.

This collection provided 30 typical walls, two composite walls, two reinforced walls, eight two-story walls, two walls + one opening, two walls + two openings, and three H walls for a total of 49 walls [2–8].

It must be noted that 80% of the total of hysteresis curves used in this study were digitalized from former studies due to their digital data is not available. Thus, some errors may be have been introduced, related to scales, distortion of plots, or determination of cracking and yielding points.

Table 1. Characteristics resistances of masonry.

Material	Compression Strength f' m (kgf/cm^2) (pile test)	Adobe Standard: NTE 080 (1999) Masonry Standard: NTE 070 (1997)
Adobe	8.6	8.0
Masonry Factory	188.9	65
Masonry Handmade	54.9	35

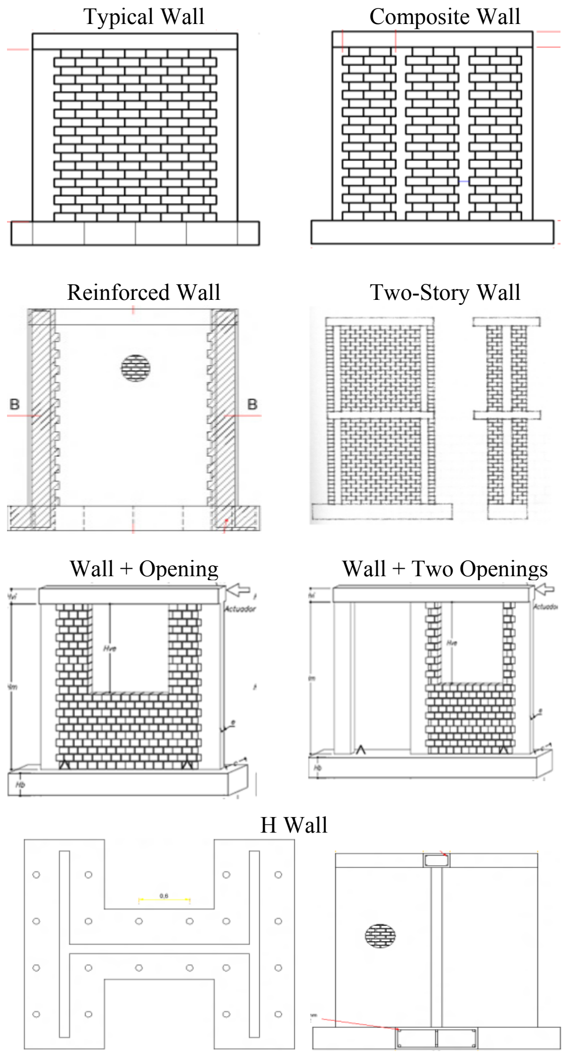

Fig. 2. Masonry configurations.

Table 2. Characteristics of typical wall.

N°	Author	ID	Type of Unit	Brick Dimension (cm)	f' m (kg/cm^2)	Beam/Slab $(b \times h)^*$	Column $(b \times h)^*$	Horiz. Bars	Vert. Bars
01	P. Gibu, C. Serida	MCST1	Factory	9.5 × 12 × 25	97.91	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
02	P. Gibu, C. Serida	MCST2	Factory	9.5 × 12 × 25	97.91	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
03	P. Gibu, C. Serida	MLCC1	Factory	9.5 × 12 × 25	97.91	200 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
04	J. Delgadillo	MC1-1	Factory	9.0 × 12 × 24	251	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
05	J. Delgadillo	MC1-2	Factory	9.0 × 12 × 24	251	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
06	J. Delgadillo	MCR-1	Factory	9.0 × 12 × 24	251	30 × 20	25 × 15	4 ϕ 1/2″	4 ϕ 1/2″
07	J. Delgadillo	MCH-1	Factory	9.0 × 12 × 24	251	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
08	J. Delgadillo	MCH-2	Factory	9.0 × 12 × 24	251	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
09	J. Delgadillo	EML-1	Factory	9.0 × 12 × 24	251	200 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
10	J. Delgadillo	EML-2	Factory	9.0 × 12 × 24	251	200 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
11	Salinas, Lazares	M-ART	Handmade	10.0 × 11.5 × 23	33.2	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 1/2″
12	Salinas, Lazares	M-IND	Factory	11.0 × 11.5 × 23	22.1	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 1/2″
13	M, Ramirez	M-1-A	Factory	9.0 × 13 × 24	108	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
14	M, Ramirez	M-2-A	Factory	9.0 × 13 × 24	108	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
15	M, Ramirez	M-3-A	Factory	9.0 × 13 × 24	108	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
16	M, Ramirez	M-4-A	Factory	9.0 × 13 × 24	108	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
17	M, Ramirez	M-3-B	Factory	9.5 × 12 × 25	91	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
18	M, Ramirez	M-4-B	Factory	9.5 × 12 × 25	91	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 3/8″
19	Zavala, Kaminosono	WALL A1-3	Handmade	9.0 × 14 × 24	59.26	30 × 20	30 × 25	4 ϕ 3/8″	4 ϕ 1/2″
20	Zavala, Kaminosono	WALL A1-4	Handmade	9.0 × 14 × 24	59.26	30 × 20	30 × 25	4 ϕ 1/2″	4 ϕ 1/2″
21	Zavala, Kaminosono	WALL A2-3	Handmade	9.0 × 14 × 24	59.26	30 × 20	30 × 25	4 ϕ 3/8″	4 ϕ 3/8″
22	Zavala, Kaminosono	WALL A2-4	Handmade	9.0 × 14 × 24	59.26	30 × 20	30 × 25	4 ϕ 3/8″	4 ϕ 1/2″
23	Zavala, Kaminosono	WALL C2-HM	Handmade	9.0 × 14 × 24	59.26	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 1/2″
24	Zavala, Kaminosono	WALL C2-FM	Factory	9.0 × 14 × 24	70.24	30 × 20	25 × 15	4 ϕ 3/8″	4 ϕ 1/2″
25	O. Ramirez	MEL-1	Factory	9.0 × 12 × 25	304	30 × 20	25 × 12	4 ϕ 3/8″	4 ϕ 3/8″
26	O. Ramirez	MEL-2	Factory	9.0 × 12 × 25	304	30 × 20	25 × 12	4 ϕ 3/8″	4 ϕ 3/8″
27	O. Ramirez	MC1	Factory	9.0 × 12 × 25	304	30 × 20	25 × 12	4 ϕ 3/8″	4 ϕ 3/8″
28	O. Ramirez	MC2	Factory	9.0 × 12 × 25	304	30 × 20	25 × 12	4 ϕ 3/8″	4 ϕ 3/8″
29	O. Ramirez	MEC 1	Factory	9.0 × 12 × 25	304	30 × 20	25 × 12	4 ϕ 3/8″	4 ϕ 3/8″
30	O. Ramirez	MEC 2	Factory	9.0 × 12 × 25	304	30 × 20	25 × 12	4 ϕ 3/8″	4 ϕ 3/8″

*Units in centimeters.

On the other hand, some parameters are shown in **Table 2**, such as author, id, type of unit, brick, beam and column dimension, and reinforcement amount (horizontal and vertical bars).

3.3. Media Store and Web Application

The database was collected from experiments conducted on structural walls in the structure laboratory of CISMID over the past 25 years. The collected database is meant to be disseminated, so a web application has been developed using freeware in order to store new data as experiments are conducted. This technology consists of a web application that allows remote users with regular computer, independent of the operating systems used, to access this information for any academic purpose.

The database[1], MySQL, uses PHP/JavaScript as programming languages, which are hosted on a Linux server located at CISMID. It is important to note that as the freeware applications used are open-source, there are no annual licenses to be paid. This is desirable for academic purposes (**Fig. 3**).

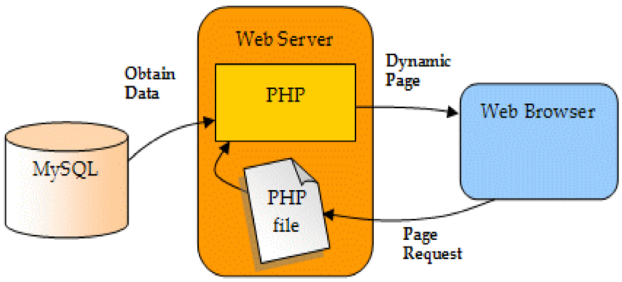

Fig. 3. Media storage and web application flow.

4. Characteristics of Database

4.1. Limit States on Confined Masonry Walls

Before the collected data is evaluated, the evolution of structural damage (cracks) on confined masonry walls will be studied. Damage is defined according to the fol-

1. To get access to the database, just sign up on the following website: http://www.cismid-uni.org/wallx/

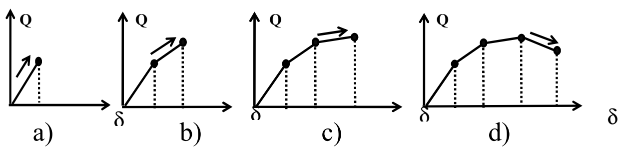

Fig. 4. Process of limit states on confined masonry walls.

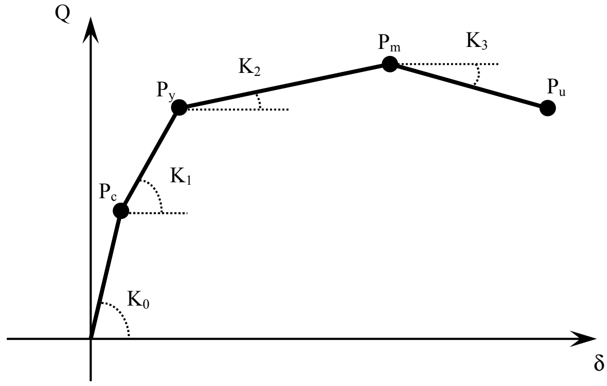

Fig. 5. Limit states and levels of stiffness degradation.

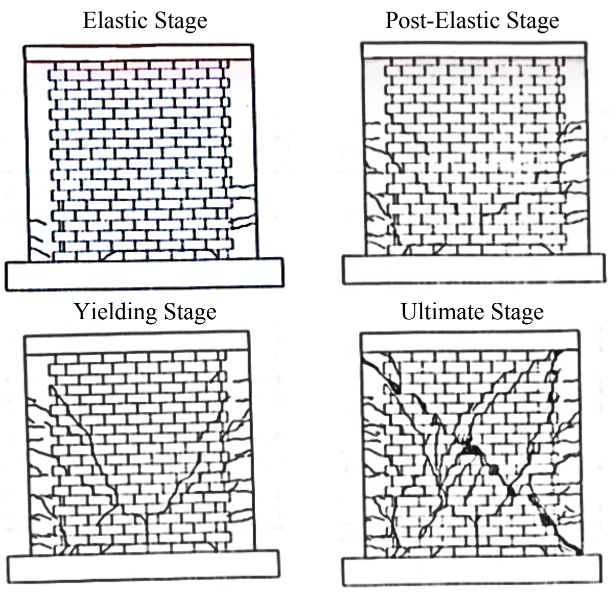

Fig. 6. Cracking pattern of the limit states.

lowing stages (**Fig. 4**).

a) ***Elastic Stage:*** This occurs when the wall has elastic behavior with an initial stiffness (K_0) until the first cracks are found on confined masonry walls. This is called the cracking point (P_c). When the small displacements and strength are given by the cyclic lateral loading test, the horizontal cracks appear in columns.

b) ***Post-Elastic Stage:*** After the first cracks, there is incremental cracking until the initial diagonal cracks appear. This is called the yielding point (P_y). Then the confined masonry wall shows a post–elastic stiffness slope (K_1). This stiffness has a value lower than the initial one.

c) ***Yielding Stage:*** During this stage, characterized by a large level of deformation with a slight strength increment, exhibits a huge reduction in stiffness (K_2) until the point of maximum resistance (P_m) is reached, until the stiffness and resistance go down. At the same time, the diagonal cracks increase incrementally.

d) ***Ultimate Stage:*** The stiffness decreases with a negative slope (K_3), and there is a drastic reduction in resistance until the wall fails. In this research, the point of failure, called the ultimate point (P_u), is considered reached when there is a 20% reduction in strength. In some walls, the envelope curve does not reach a level of strength reduction lower than 20% of its resistance. In this case, the ultimate point was considered to be the ultimate drift reached during the test.

Figure 5 shows the proposed theoretical envelope curve following the limits states and stiffness degradation stages for confined masonry wall defined above.

4.2. Database on Confined Masonry Walls

In order to investigate the results of experiments on confined masonry walls and their variation, results were collected from experiments done on 30 typical masonry walls subjected to axial loads (simulating the weight of upper floors) and lateral loads (simulating seismic loads). These specimens were subjected to reversal lateral loading (cyclic). The predominant behavior of these walls was flexural-shear failure because the initial cracks appeared in the columns (flexural cracking). This corresponds to the elastic stage. Then, as lateral displacement increased, stiffness degradation was observed during the tests. Cracks expanded onto the wall, and this state corresponds to the post-elastic stage until the initial diagonal cracking appears (shear cracking). After that, the lateral displacement increase until the maximum shear capacity of the wall was reached during the yielding stage, in which the shear crack opened to form a full diagonal crack. Finally, as lateral displacement increased after the maximum shear strength was reached, shear wall failure, with a drastic reduction in resistance, occurred. The cracking pattern of the limit states is shown in the **Fig. 6**.

The wall database comes from theses and corresponding tests conducted in CISMID. For these walls, it is noted that the stiffness ratio for the elastic stage present similar values in most of the specimens. However, there are several discrepancies, for example the maximum resistance.

It can be observed in **Fig. 7**, the maximum resistance of walls MEC-1 and MEC-2 are significantly different from the others because MCE-1 and MCE-2 are longer (360 cm) than the other specimens (240 cm).

In **Fig. 7**, the difference in the initial behaviors of walls A2-3 and A2-4 can be observed. Both of them have the same geometrical dimensions, but there is a difference be-

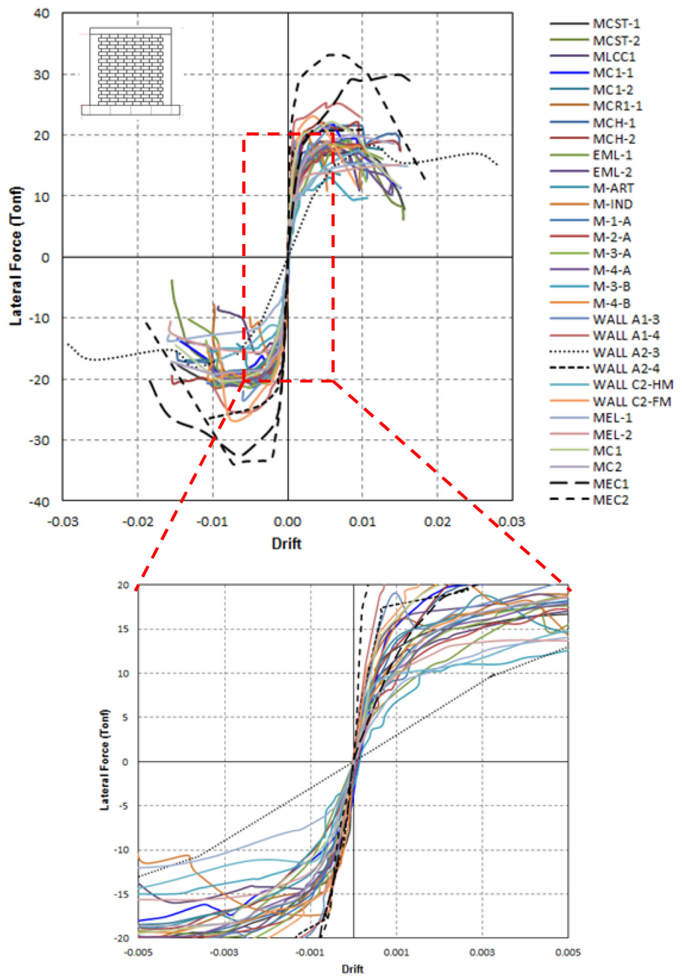

Fig. 7. Envelopes of thirty typical masonry walls.

tween the reinforcement of columns. Also, the cracking pattern on wall A2-3 starts with a sliding crack in the masonry bricks and the base foundation. This pattern is different from the usual initial cracking pattern (flexural cracking in columns).

The database also includes details such as geometrical properties, the horizontal and longitudinal reinforcement of columns and beams, mechanical properties of the materials, and vertical load and wall configurations. After all envelopes of the thirty walls were investigated and collected, an analysis of the parameters was carried out. First, all stages were identified, and then the initial stiffness (K_0), corresponding to the initial cracking on columns of confined masonry wall, was determined by P_c which corresponds to the initial cracking on columns on confined masonry walls. To determine the secondary stiffness (K_1) was considered using a linear regression from P_c over the envelope curve until P_y with a correlation coefficient above 95%. For other parameters, such as (K_2) and (K_3), the slope corresponds to from P_y to P_m and from P_m to P_u, respectively. Stiffness ratios K_1/K_0, K_2/K_0, and K_3/K_0 are shown in **Fig. 8**.

Some tendencies of the K_2/K_0 and K_3/K_0 ratios can be observed while the K_1/K_0 ratio presents a high dispersion. In the case of K_2/K_0 ratio, values are greater than

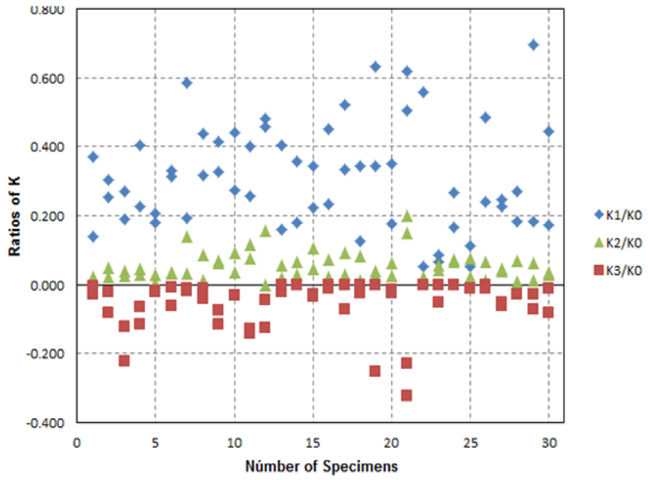

Fig. 8. Stiffness ratios.

Table 3. Ratios of stiffness parameters of masonry.

Ratios	K_0 (tonf/cm)	K_1/K_0	K_2/K_0	K_3/K_0
Minimum	12.745	0.052	0.000	−0.322
Maximum	265.344	0.696	0.200	0.000
Average	94.757	0.314	0.051	−0.051
Stand. Dev.	49.789	0.149	0.040	0.068

0.000 and less than 0.200 while in the case of K_2/K_0 ratio, values are greater than −0.322 and less than 0.000.

Table 3 lists some statistical parameters, such as the minimum and maximum values, averages, and standard deviations. Values of the initial stiffness indicate high dispersion because specimens have different geometrical and mechanical properties, etc.

Table 3 shows variation and a larger difference on K_0 due to the minimum value (12.745 tonf/cm) from wall A2-3. This is because the sliding crack appears during the first steps of the test. The maximum value (265.344 tonf/cm), corresponding to wall MEC-2, has the highest slope because it has different geometrical dimensions than do others. On the other hand, wall A2-3 and A2-4 have the same geometrical dimensions and mechanical properties. In **Fig. 7,** differences on the positive side (pulling) can be observed, but on the negative side (pushing), the elastic stage is similar. For other parameters, note that the minimum value of K_2/K_0 in **Table 3** is zero when the point of maximum resistance is the same as the yielding point. For K_3/K_0, the maximum value is zero because the ultimate point is taken as the maximum point. As a result of this research, it is recommended that the average values of K_0, K_1/K_0, K_2/K_0, and K_3/K_0, which correspond to 94.757 tonf/cm, 0.314, 0.051 and −0.051, respectively, be taken.

The drift at important points when the loading is pushing and pulling during the cyclic lateral test on a confined masonry wall, such as the cracking point (δ_c/h), yielding point (δ_y/h), maximum resistance point (δ_m/h), and ultimate point (δ_u/h), are plotted in **Fig. 9**.

In the same way **Table 3**, **Table 4** shows some statistical parameters, such as minimum and maximum values,

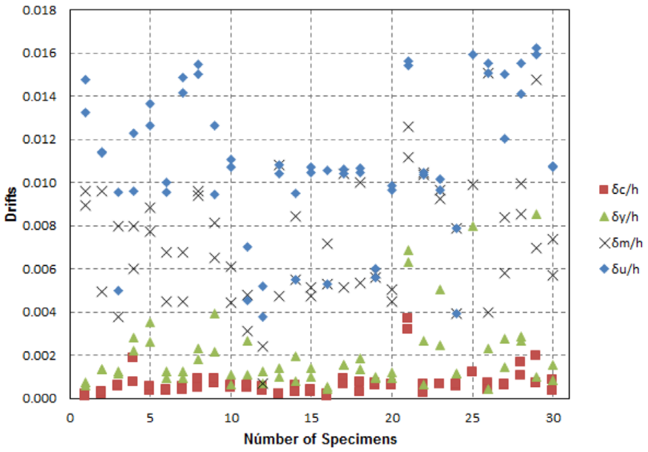

Fig. 9. Drift ratios.

Table 4. Ratios of the drifts of typical masonry walls.

Ratios	δ_c/h	δ_y/h	δ_m/h	δ_u/h
Minimum	0.0001	0.0001	0.001	0.004
Maximum	0.004	0.009	0.015	0.016
Average	0.0007	0.002	0.007	0.011
Stand. Dev.	0.001	0.002	0.003	0.003

average, and standard deviation. Drift values indicate a high dispersion because specimens have different geometrical and mechanical properties. This condition occurs mainly at the maximum resistance and ultimate stage.

In **Fig. 9** and **Table 4**, the tendency for δ_c/h to show an average of 0.007 can be observed. Specimen 21 (wall A2-3) has a high value for the reason mentioned before. Also, the drift δ_y/h, corresponding to the yielding point, has a low accuracy or tendency. This variability comes from the method used to obtain this point. Based on the results of this research, it is recommended that strain gauges be used at the reinforcement points in columns to get the yielding point accurately. Unfortunately, strain gauge data has not been collected for all walls.

For δ_m/h and δ_u/h, two criteria used to decide the ultimate point of the specimen were adopted. First, when the state of stability of the specimen was compromised and the capacity of the wall did not decrease by 20%, we considered the last point over the envelope point as the ultimate stage. A second criterion was adopted when the ultimate point decreased more than 20% on the envelope curve; in this case, we considered 20% of the capacity as the ultimate stage.

According to the Peruvian Standard for masonry NTE 0.70 [1], the maximum drift allowed in repairing a wall damaged due to severe earthquake is 1/200 (0.005). **Fig. 9** shows that some walls reach their maximum drift (δ_m/h) under the drift limit. Walls 11 (M-ART) and 12 (M-IND) shows the weakest behavior because they were made of hollow bricks called "pandereta."

5. Multi-Linear Regression and Shear Capacity Estimation

Using the experimental database from masonry walls, a multi-linear regression was performed to get a semi-empirical equation in order to estimate the shear capacity of masonry walls, as shown in **Fig. 10**.

Based on the multi-linear regression analysis, the following semi-empirical equation has been determined.

$$\frac{\tau_u}{f'_m} = 0.050 - 0.026\frac{h}{L} + 0.010\frac{P_t\sigma_y}{f'_m} + 0.008\frac{\sigma_0}{f'_m}$$

where:

- τ_u : Shear stress of the masonry wall (kgf/cm^2)
- f'_m : Compressive strength of masonry prism (kgf/cm^2)
- h : Height of the wall (cm)
- L : Length of the wall (cm)
- P_t : Lateral reinforcement ratio (%)
- σ_y : Yielding strength of tensile reinforcement (kgf/cm^2)
- σ_0 : Average axial stress of wall (kgf/cm^2)

The equation shows parameters used for multi-linear regressions for those behavior curves on pulling and pushing during the cyclic lateral test on confined masonry walls. The parameters used are explained as follows and shown in **Table 5**.

- h/L: Geometrical ratio of the wall. Depending on the geometry, there will be some influence on the strength of the wall.
- $P_t\sigma_y/f'_m$: Resistance ratio of reinforcing steel over the resistance (f' m) of a pile of bricks. The strength of the wall depends on the amount of steel reinforcement bars.
- σ_0/f'_m: Ratio of load bearing capacity of the wall because the axial load on the wall has influence its resistance.

Table 5 shows relevant values of $P_t\sigma_y/f'_m$ and σ_0/f'_m, such as those for wall 11 (M-ART) and 12 (M-IND), with higher values than those for the other walls. This is because of the lower compressive strength of masonry prism ($f'm$), 33.2 kgf/cm^2 for wall 11 and 22.1 kgf/cm^2 for wall 12.

Some statistical parameters are shown below:

Multiple correlation coefficient:	0.976
Standard deviation:	0.074
Variance:	0.005
Determination coefficient:	0.952

Those parameters correspond to the multi-linear regression analysis shown in **Fig. 10**. The analysis it was conducted in order to estimate the shear capacity of masonry walls, for this purpose the semi-empirical equation was developed in terms of the ratio of masonry shear stress over the compressive strength of masonry prism (τ_u/f'_m).

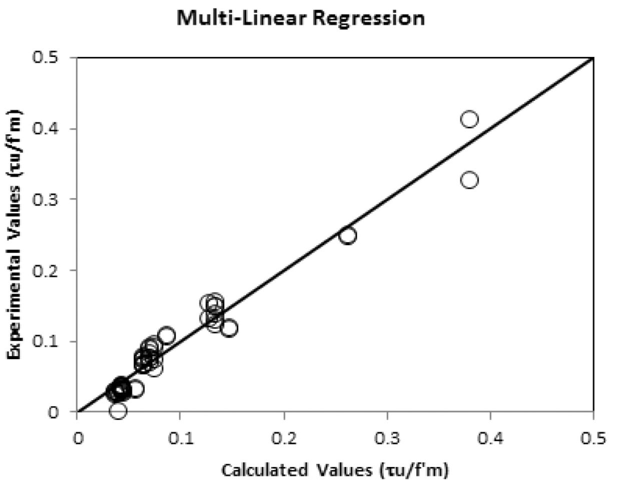

Fig. 10. Multi-linear regression of 30 typical masonry walls.

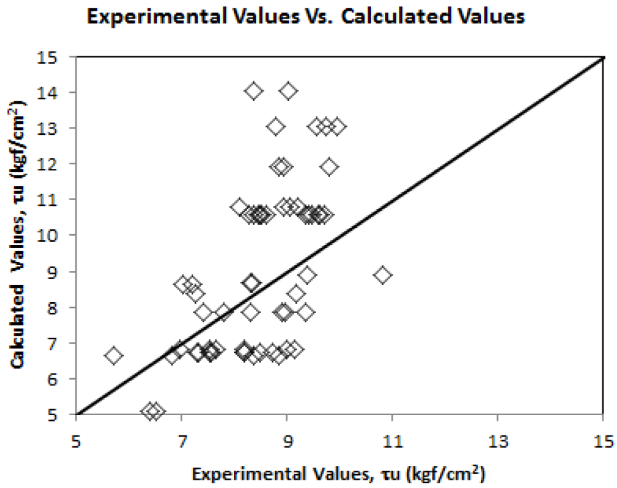

Fig. 11. Experimental values vs. calculated values for 30 typical masonry walls.

Table 5. Parameters for multi-linear regression.

Wall	Pull			Push		
	h/L	$P_t\sigma_y/f'm$	$\sigma_0/f'm$	h/L	$P_t\sigma_y/f'm$	$\sigma_0/f'm$
1	1.00	4.72	0.04	1.00	4.72	0.04
2	1.00	4.72	0.04	1.00	4.72	0.04
3	1.00	4.72	0.04	1.00	4.72	0.04
4	1.00	1.84	0.02	1.00	1.84	0.02
5	1.00	1.84	0.02	1.00	1.84	0.02
6	1.00	3.27	0.02	1.00	3.27	0.02
7	1.00	1.84	0.02	1.00	1.84	0.02
8	1.00	1.84	0.02	1.00	1.84	0.02
9	1.00	1.84	0.02	1.00	1.84	0.02
10	1.00	1.84	0.02	1.00	1.84	0.02
11	0.96	24.77	0.12	0.96	24.77	0.12
12	0.96	37.22	0.19	0.96	37.22	0.19
13	1.00	3.95	0.04	1.00	3.95	0.04
14	1.00	3.95	0.04	1.00	3.95	0.04
15	1.00	3.95	0.04	1.00	3.95	0.04
16	1.00	3.95	0.04	1.00	3.95	0.04
17	1.00	5.08	0.05	1.00	5.08	0.05
18	1.00	5.08	0.05	1.00	5.08	0.05
19	0.94	11.13	0.04	0.94	11.13	0.04
20	0.94	11.13	0.04	0.94	11.13	0.04
21	0.94	6.26	0.04	0.94	6.26	0.04
22	0.94	11.13	0.04	0.94	11.13	0.04
23	1.09	12.96	0.05	1.09	12.96	0.05
24	1.09	10.93	0.04	1.09	10.93	0.04
25	1.33	2.03	0.02	1.33	2.03	0.02
26	1.33	2.03	0.02	1.33	2.03	0.02
27	1.00	1.52	0.02	1.00	1.52	0.02
28	1.00	1.52	0.02	1.00	1.52	0.02
29	0.67	1.01	0.02	0.67	1.01	0.02
30	0.67	1.01	0.02	0.67	1.01	0.02

The masonry shear stress (τ_u) was calculated using the proposed equation, by multiplying corresponding compressive strength of masonry prism (f'_m). The experimental results were compared with the calculated results; both results are plotted in **Fig. 11**. The difference between **Fig. 10** and **Fig. 11** can be observed because the compressive strength of masonry prism of the data wall has a high dispersion, with an average of 163.69 kgf/cm^2 and a standard deviation 103.02 kgf/cm^2.

In order to safely estimate the shear stress of masonry walls, values estimated using the proposed equation will be equal to or greater than the resulting experimental values. Therefore, results are safely estimated when marks in **Fig. 11** are above the line. 57% of the results from a total of 60 behavior curves (30 pushing and 30 pulling) from 30 specimens are safely estimated.

6. Conclusion

Data from 25 years of experiments conducted in CISMID have been collected and the results of experiments have been analyzed. In processing the data, some parameters have been determined, such as stiffness ratios and drift ratios, for characteristic stages of confined masonry walls.

Comparisons of the test results from 30 envelopes have revealed that there are some differences among them, mainly in terms of maximum resistance (MEC-1 and MEC-2) and initial stiffness (Wall A2-3).

From the thirty envelopes curves, after data of walls were collected and investigated, the parameters were analyzed. First, all stages were identified, and then the initial stiffness (K_0) was determined by the P_c, which corresponds to the initial cracking of the columns of a confined masonry wall. To determine the secondary stiffness (K_1), from P_c with a slope variation of less than 5% until P_y was considered. For other parameters, such as (K_2) and (K_3), the slopes corresponded to from P_y to P_m and from P_m to P_u, respectively.

One equation to estimate the shear resistance of masonry walls was proposed after a multi-linear regression analysis was done on the database.

A total of 60 behavior-curve results (30 pushing and 30 pulling) were analyzed from 30 masonry wall tests, some of them digitalized from former studies. This number is quite limited in terms of its use to produce accurate ratios or equations. Further studies are needed to obtain results that are more accurate and to be able to identify the behaviors of confined masonry walls according to their characteristics.

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