TENTH
NORTH AMERICAN MASONRY CONFERENCE
June 3-6, 2007
St. Louis, Missouri, USA

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TESTS FOR EVALUATION OF SLENDERNESS CORRECTION FACTOR FOR MASONRY PRISMS

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Abstract

A series of experimental compression tests were performed to evaluate the slenderness correction factors for masonry prisms, with typical masonry units used in Peru. The Masonry Design Code, called "Norma E.070" (SENCICO 2006), considers a nominal slenderness ratio of five, and provides correction factors for other slenderness ratios. However, these factors are different than the ones used in other Codes, as well as the ASTM C 1314, 2003 standard, in which the nominal slenderness ratio of two is used. The experimental results showed that slenderness ratios less than 3 give erratic results; therefore, the nominal slenderness of two is not adequate. The tendency curve showed better results with the Peru code factors than with other codes and standards.

Introduction

The masonry compressive strength, f'_m, is widely used in masonry design. ASTM C1314 (2003) is usually the standard used to evaluate f'_m. In developing countries, ASTM standards are very important, mainly because experimental data are nonexistent or unavailable, and local researchers rely on the experience of a prestigious institution to copy the standard. Therefore, the evaluation of a design parameter such as f'_m should be precise taking into account local materials and workmanship.

The masonry compressive strength, f'_m, is calculated by testing masonry prisms, composed of two or more units, placed one over the other with mortar. To facilitate the construction, handling, storage, and transportation from the construction site to the laboratory for the tests, total prisms height should not be too tall.

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Prisms are to be tested under axial compression until failure 28 days after they are made (Figure 1). To evaluate f'_m, the slenderness ratio "E" (height to thickness, E=h/t) is considered by setting a correction factor to the calculated strength, for given values of h/t.

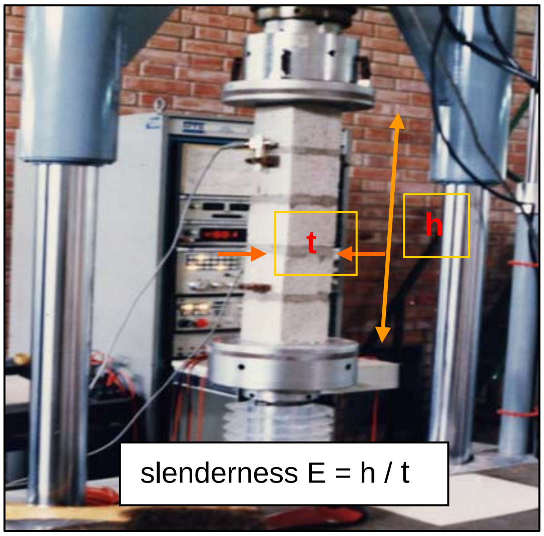

Figure 1. Axial compression test of typical masonry prisms and slenderness definition.

Type of masonry units has an important influence on the masonry compressive strength. Masonry units differ in the material (clay, concrete or other), in the size (bricks or blocks), and in the fabrication process (artisan or industrial). Therefore, prisms tests using local units need to be done, to determine correctly the values of f'_m to be used in local design codes.

The value of f'_m depends on the slenderness of the prisms. ASTM C1314 (2003) uses a nominal slenderness ratio of 2 for masonry prisms. For other slenderness ratios, a set of correction factors is given. On the other hand, a nominal slenderness ratio of 5 is used in Peruvian Masonry Code E.070 (ININVI 1982 and SENCICO 2006), with a different set of correction factors for other slenderness ratios. Due to these observed differences and because the Peruvian Code set of values had not experimental basis, an experimental research was conducted with the support of SENCICO. All the tests were performed at the Structures Laboratory of the Pontifical Catholic University of Peru. The tests included material properties and prisms axial compression tests.

Code Comparison Regarding Masonry Compressive Strength

The Peruvian Masonry Design Code has been recently changed. However, both the previous Code (ININVI 1982) and the new Code (SENCICO 2006), have the same method for the experimental evaluation of the masonry compression strength, f´m. The method indicates that for the test of masonry prisms, a set of correction factors is given for different slenderness ratios, with a value of 1.0 for a slenderness ratio of 5. Therefore, a research was conducted to evaluate the correction factors for typical masonry units used in Peru, which are clay bricks (for confined masonry) and hollow concrete blocks (for reinforced masonry).

Different masonry design codes or standards were reviewed, to compare the way the slenderness ratio is considered to determine the masonry compression strength, f'_m. The revision included documents from USA, Mexico, Chile, Colombia, and Peru.

The factors of the Colombian code NSR-98 (AIS 1998) and the Peruvian institution for materials regulations, INDECOPI 399.605 (2003) are similar to those given by ASTM C1314 (2003), which are indicated in Table 1. The Mexican Code (2004) gives the correction values given in Table 2. The Chilean Code NCh1928 (1993) only indicates that the slenderness ratio must be greater or equal to 3. Finally, the Peruvian Masonry Design Code E.070 (SENCICO 2006) gives the correction values shown in Table 3.

TABLE 1. Slenderness correction factors for f´m (ASTM, PERU-INDECOPI, COLOMBIA)

ASTM slenderness	1.3	1.5	2.0	2.5	3.0	4.0	5.0
Correction Factor	0.75	0.86	1.00	1.04	1.07	1.15	1.22

Note: The Colombian Code does not include the slenderness of 1.3.

TABLE 2. Slenderness correction factors for f´m (MEXICO)

Mexico code slenderness	2.0	3.0	4.0	5.0
Correction Factor	0.75	0.90	1.00	1.05

TABLE 3. Slenderness correction factors for f´m (PERU-SENCICO)

Peru code slenderness	2.0	2.5	3.0	4.0	4.5	5.0
Correction Factor	0.73	0.80	0.86	0.95	0.98	1.00

The values displayed in Tables 1, 2, and 3, show that the correction factors of 1.0 correspond to different slenderness ratios (normalized slenderness ratio), depending on the Code.

Another important issue is the number of layers a masonry prism should have for the compression test. ASTM C1314 indicates in article 5.7 that "…build prisms a minimum of two units high with a height-to-thickness ratio, h/t between 1.3 and 5.0." The Mexican Code (2004) indicates that prisms must have three units or more, with height-to-thickness ratio, h/t between 2.0 and 5.0. The Chilean Code NCh1928 (1993) indicates in its Appendix B that the prism height should include a minimum of three layers, and that the ratio between the height and the thickness must be greater or equal than 3.

At this point, it can be concluded that the Masonry Codes differ in the correction factors, the normalized slenderness ratio and the minimum number of layers of each prism.

Material Properties for the Masonry Prisms

The material masonry units (bricks and hollow blocks) used for the prisms specimens were clay and concrete. For the experimental research, firstly, mechanical properties of the materials used in building the masonry prisms were determined. The materials tested included four types of masonry units, two types of mortar and one type of grout.

Masonry units

Four types of masonry units were selected for this research (Figure 2). Three of the units were solid, used for confined masonry walls, differing in their manufacturing and material. The fourth one was a concrete hollow block used for reinforced masonry walls. Several tests were done on the units in order to classify them: dimension variation, concavity, axial compression, absorption and hole percentage in the bearing surface (Figure 3).

Figure 2. Masonry units used in the experimental tests, left to right: 1) AC (artisan clay); 2) IC (industrial clay); 3) ICo (Industrial concrete); 4) BIC (block industrial concrete).

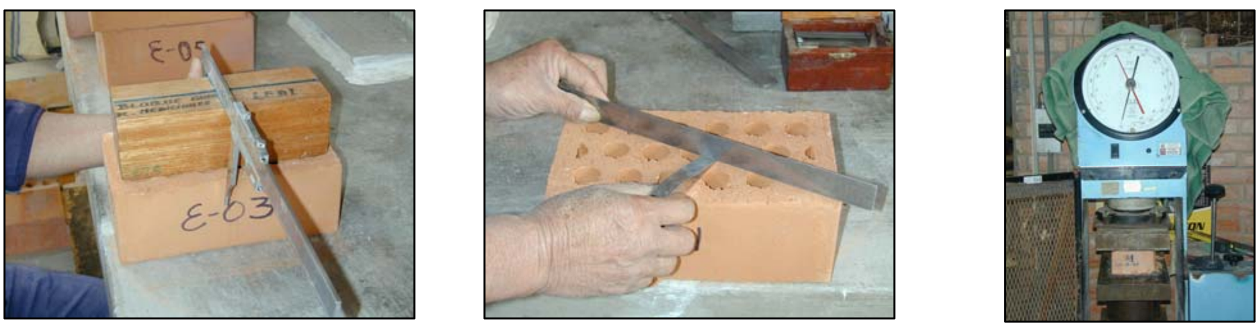

Figure 3. Tests on masonry units, left to right: dimension variation, concavity and compression.

The test results on the units are displayed in Table 4. The compressive strength was obtained by subtracting one standard deviation to the average value. All strength values were obtained using the gross area. It must be mentioned that the Peruvian Masonry Code considers units to be solid when their hole percentage in the bearing area does not exceed 30%. All brick units classified as solid, capable to be used for bearing walls.

Table 4. Properties of Masonry Units				
Unit	AC	IC	ICo	BIC
Compressive strength f'_b in MPa (*)	8.3 (21%)	21.3 (11%)	15.7 (14%)	9.7 (4%)
Absorption after 24 hour submerged	12%	15%	6%	5%
Hole percentage	0%	30%	30%	44%
Average dimensions LxBxH (mm) and dimension variation (%)	212x119x98 (-1%, 1%, 2%)	243x131x93 (-1%,-1%,-3%)	240x130x91 (0%, 0%, -1%)	390x140x190 (0%, 0%, 0%)
Concavity (mm)	1	2	0	---

(*) Number in parentheses indicates the dispersion percentage of results

Mortar

Two types of mortars were used for this research. The clay units were laid wet, therefore a mortar composed of cement and coarse sand in 1:4 proportions was used. The concrete units were laid dried; therefore, the mortar was composed of cement, lime and coarse sand in 1: ½: 4 proportions. The addition of lime is necessary to increase the mortar water retention. In all cases, the cement was Portland I, and the lime was hydrated and normalized.

For each type of mortar, a set of small cubes (50mm side) was constructed. These specimens were cured with water and tested for compression after 28 days (Figure 4). The results are indicated in Table 5.

Figure 4. Mortar preparation and cube tests, left to right: mixture of cement, lime and sand, test of the small cubes in compression, and some of the cubes already tested.

Table 5. Mortar Compressive Strength		
Mortar	Average strength (MPa)	Variation Coefficient
1: ½ : 4 (with lime)	14.4	9.08%
1 : 4 (without lime)	14.3	4.99%

Grout

The concrete block cells were filled up with grout. The grout mixture was 1: 2.5: 1.5 cement, coarse sand and small stones. It was prepared in a mixing machine and the slump measured was 250mm (Figure 5).

For compression testing, four specimens were prepared, with 100x100x190 mm dimension, using the concrete blocks for casting. Filtering papers were used to allow a natural transfer of water to the blocks. These specimens were kept in their site for 28 days, without curing. The average compressive strength reached f'_c = 20 MPa, with a dispersion of 14%.

Figure 5. Grout preparation and tests, from left to right: slump measure, casting with filtering paper, test machine and typical failure of a grout specimen.

Construction of Masonry Prisms

A total of four specimens per variable were constructed and tested. Variables were the material unit and the slenderness, which was obtained through a fixed amount of layers in each prism.

Masonry prisms made of brick units were prepared in sets of 2, 3, 4, and 5 layers. Prisms of concrete blocks were prepared in sets of 2, 3 and 4 layers. Each set had 4 specimens, making a total of 60 prisms to be tested (Figure 6).

For all specimens, the horizontal mortar layer had 10mm thickness, and all the bearing surface was filled with the mortar.

All clay bricks were watered for half an hour about 10 to 12 hours before use, in order to reduce their high absorption. The objective of this operation is that at the moment of placement, the surface has to be relatively dry, while the inside core should be saturated. This lets that cement components of the mortar be sucked by the brick surface and also, the water in the core can cure the mortar.

On the other hand, all concrete bricks and blocks were laid dry. Due to their high porosity, the mortar for these units included lime in order to elevate the mortar water retention. All the blocks prisms were filled up with grout, one day afterwards the prism was built.

Figure 6. Masonry prisms built of clay bricks (AC and IC), concrete bricks (ICo), and concrete blocks (BIC).

Compression Tests of Masonry Prisms

Previous to the tests, all prisms were tapped with a gypsum-cement capping of 3mm thick. The age for the tests in all cases was 28 days. The speed of the compression load was 40 kN/min. Figure 7 shows the whole testing equipment.

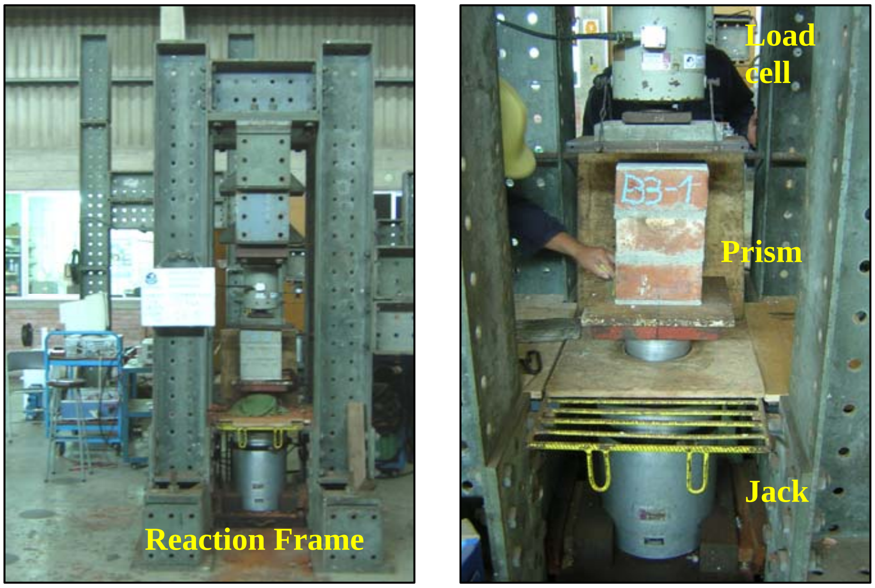

Figure 7. Equipment layout for compression tests of masonry prisms.

The type of failure in all cases was fragile, as shown in figures 8 to 11. For the industrial clay units (IC), the lateral sides tend to fell apart. In case of the concrete bricks (ICo), the vertical cracks usually followed the brick slots. For the concrete block units (BIC), a lack of bond in the grout-block interface was observed.

Table 6 indicates for the 60 tested prisms, the following data: height (h), number of layers (n), thickness (t), slenderness (E=h/t), gross section area (A), maximum compression load (P). Also, for each series, the average load (Pm) and the load percentage dispersion (D), obtained dividing the standard deviation between “Pm”, are shown.

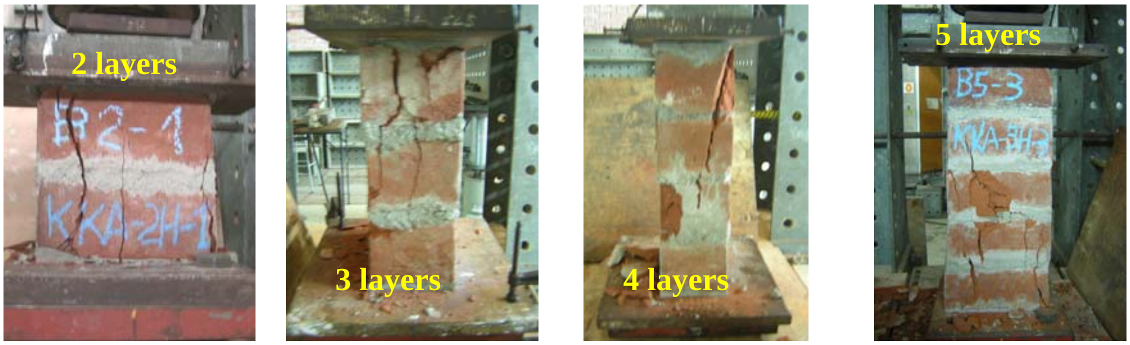

Figure 8. Tested prisms of artisan clay units (AC).

2 layers

Figure 9. Tested prisms of industrial clay units (IC).

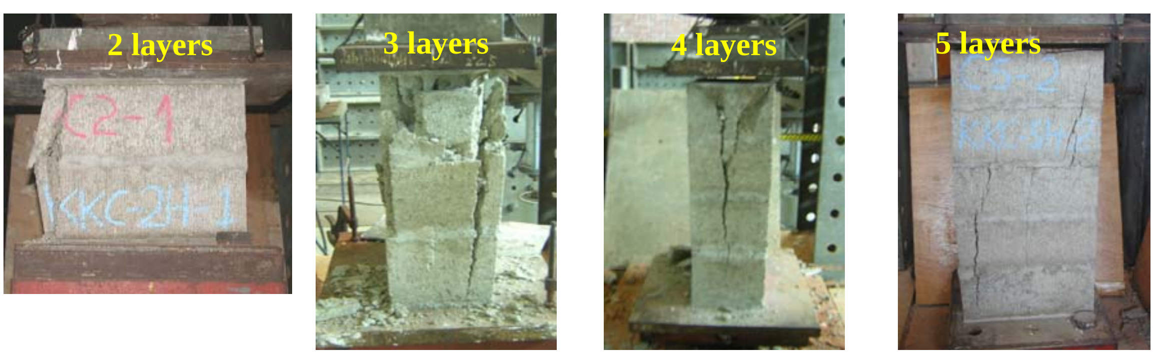

Figure 10. Tested prisms of industrial concrete brick units (ICo).

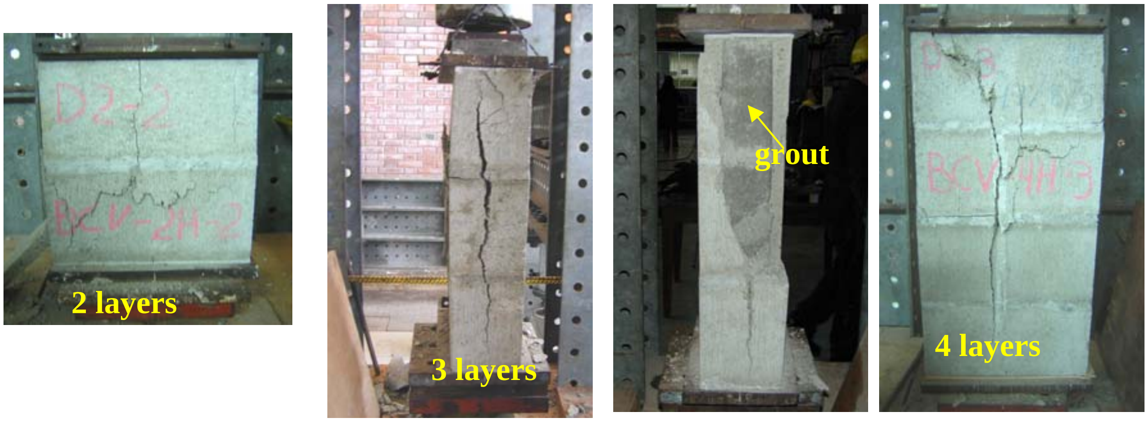

Figure 11. Tested prisms of industrial concrete block units (BIC).

Table 6. Complete tests results, P is in kN

UNIT	h (mm)	E = h/t	P1	P2	P3	P4	Pm	D (%)
AC	220 – 2n	1.85	**183.75**	**186.76**	**181.74**	**167.68**	179.98	4.7
t = 119 mm	332 – 3n	2.79	130.26	**141.01**	**158.53**	**136.54**	141.585	8.6
A=25200mm^2	438 – 4n	3.68	141.84	174.16	90.77	97.99	126.19	31.0
	546 – 5n	4.59	**123.50**	164.67	**154.63**	**124.51**	141.83	14.8
IC	210 – 2n	1.60	**415.93**	**441.08**	**480.32**	**514.54**	462.97	9.4
t = 131 mm	313 – 3n	2.39	**386.76**	380.73	**471.26**	**466.23**	426.24	11.5
A=31800mm^2	425 – 4n	3.24	**379.89**	**454.30**	**456.30**	**389.90**	420.10	9.7
	524 – 5n	4.00	**398.83**	**442.08**	**352.57**	**371.68**	391.29	9.9
ICo	203 – 2n	1.56	303.30	292.26	352.57	263.11	302.06	12.3
t = 130 mm	305 – 3n	2.35	390.74	337.58	360.47	355.77	361.14	6.1
A=31200mm^2	407 – 4n	3.13	341.70	308.54	355.77	334.66	335.17	5.9
	505 – 5n	3.89	344.53	405.87	394.81	377.71	380.73	7.0
BIC	402 – 2n	2.87	**562.86**	**578.97**	590.05	**541.72**	568.40	3.7
t = 140 mm	603 – 3n	4.30	**450.13**	**511.52**	444.10	**476.29**	470.51	6.5
A=54600mm^2	798 – 4n	5.70	**462.21**	489.38	**474.28**	**434.04**	464.98	5.0

Masonry Prism Correction Factor

To obtain the experimental prism correction factors, the following five steps were performed.

Step 1.- Refinement of Data

The inconsistent results shown in Table 6 were removed in order to have only 3 prisms in each series or none, if too many data were inconsistent. An inconsistency was defined when the maximum or minimum P value in the series did not follow the expected result. For example, all the series of industrial concrete bricks had to be discarded, because the prisms with larger slenderness resisted more load than prisms with smaller slenderness, which is not logical. A possible explanation for these erratic results is that the slots in the ICo bricks, which were not completely filled with mortar, produce a small effective width in the prisms; the perforated bricks do not exhibit this problem. Also, the AC series of 4 layers was discarded due to its high dispersion (more than 30%).

Step 2.- Calculation of f'_m

From hereafter only refined data was used. The average compressive resistance was obtained by dividing the average of maximum loads of a series, Pm (see Table 7), into the gross prism section area A. The prisms compressive resistance f'_m was evaluated as the average value minus one standard deviation.

Step 3.- Calculation of f'_m normalized to a slenderness ratio of 5

The Peruvian Masonry Code establishes a normalized slenderness ratio of 5 for a masonry prism. Actual prisms had different ratios, so a linear interpolation was performed using the refined data in order to obtain the value of f'_m (E = 5).

Step 4.- Calculation of correction factor (CF) for f'_m

For each series, the correction factor CF (see Table 7) was obtained by dividing the value of f'_m for the normalized Peruvian Masonry Code slenderness of 5, into the value of f'_m for the actual slenderness (Equation [1]).

$$CF = \frac{f'm(E=5)}{f'm(E)} \qquad \textbf{[1]}$$

Table 7. Evaluation of Slenderness Correction Factor (CF).

UNIT	E = h/t	Pm (kN)	Dispersion	f'_m (MPa)	CF (Eq. [1])
AC A=25200mm^2	1.85	179.98	4.7 %	6.80	0.657
	2.79	145.36	8.0 %	5.30	0.842
	4.59	134.21	13.2 %	4.62	0.966
	5.00	---	---	4.46	1.000
IC A=31800mm^2	1.60	462.97	9.4 %	13.2	0.756
	2.39	441.42	10.7 %	12.4	0.805
	3.24	420.10	9.7 %	11.9	0.837
	4.00	391.29	9.9 %	11.1	0.900
	5.00	---	---	9.97	1.000
BIC A=54600mm^2	2.87	561.18	3.3 %	9.94	0.815
	4.30	479.31	6.4 %	8.21	0.986
	5.00	---	---	8.10	1.000
	5.70	456.84	4.5 %	7.99	1.014

Step 5.- Regression Curve for correction factor (CF)

Experimental correction factors and corresponding slenderness were fit into a regression polynomial curve (Figure 12). Table 8 displays the adjusted correction factors obtained using this curve, whose expression is given in equation [2].

$$CF = -0.0053E^3 + 0.051E^2 - 0.0631E + 0.7074 \qquad \textbf{[2]}$$

Comparison of Masonry Prisms Correction Factor (CF)

The correction factors used in ASTM C1314 are normalized to a slenderness ratio of 2.0; therefore, for comparison to the values of the Peruvian Masonry Code E.070, those values had to be normalized to a slenderness of 5.0. The CF values of ASTM, Peruvian Code, and equation [2], are presented in figure 12 as well as in Table 8. Also, the percentage difference between the predicting equation [2] vs. ASTM values and vs. Peruvian Code values is presented in Table 8. It may be seen that the Peruvian Code values are closer to the regression curve values (equation [2]), than the ASTM values. Also, the differences increase for slenderness "E" below 3.

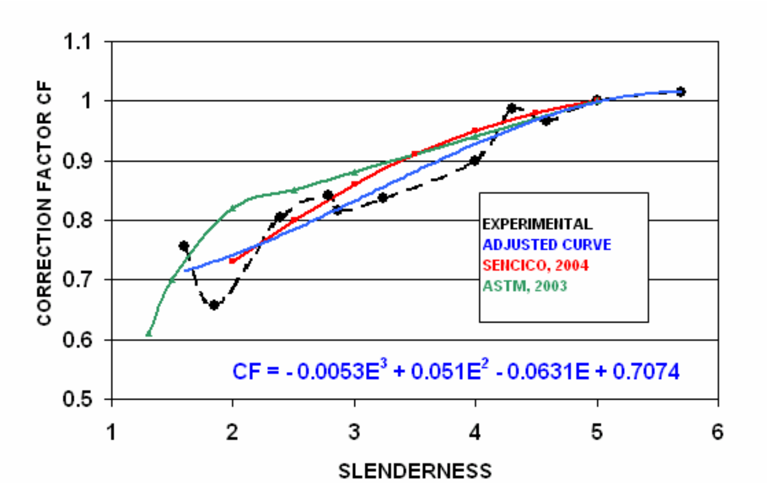

Figure 12. Comparison of slenderness correction factors for a normalized slenderness of 5.

Table 8. Comparison of the correction factors CF.								
E = h/t	1.3	1.5	2.0	2.5	3.0	4.0	4.5	5.0
ASTM (original)	0.75	0.86	1.00	1.04	1.07	1.15	---	1.22
ASTM (E = 5)	0.61	0.70	0.82	0.85	0.88	0.94	---	1.00
Peru Code	---	---	0.73	0.80	0.86	0.95	0.98	1.00
Equation [2]	0.70	0.71	0.74	0.79	0.84	0.93	0.97	1.00
Peru Code vs. Equation [2]	---	---	-1%	+1%	+2%	+2%	+1%	0%
ASTM (E=5) vs. Equation [2]	-13%	-1%	+11%	+8%	+5%	+1%	---	0%

Conclusions

The experimental slenderness prisms correction factors for three different Peruvian masonry units of this research, were closer to the Peruvian Masonry Code values than the ASTM values. So, it appears adequate that each country should have its own correction factor taking into account its local materials and workmanship.

The experimental results demonstrate that data is very sensitive to slenderness ratios below 3. Therefore, for the normalized slenderness, it is suggested to use a ratio larger than 2 used by ASTM. Also, the prisms should be composed by at least 3 layers to avoid test problems in smaller specimens (bearing plates restrictions, failure by crushing of prism or others).

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