Paper:

Current State of Masonry Properties Material on Emerging Zones in Lima City

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Masonry is one of the most common structural materials used to build houses in the city of Lima, Peru. The structural features of this material and its components vary widely, however, due to the manufacturing process, which uses bricks and aggregates and different levels of labor. This paper presents experimental results realized using bricks, prism and wallettes to determine the mechanical properties of masonry.

Keywords: masonry, hand-made bricks, industrial bricks, tests

1. Introduction

Masonry units or bricks are structural elements used in construction for the last 11,000 years. Pre-ceramic Neolithic farmers were the first to do so in BC9500 in the Levant, where they built circular homes and semi-excavated footings with stone and walls made of adobe.

Several archaeological sites in the city of Lima, Peru, were built using adobe. These include Huallamarca, which was probably a religious temple of traditional culture Pinazo (BC100 to AD200) and Huaca Pucllana, which belongs to the Lima culture (AD200-700).

Buildings worldwide are built using masonry because it is cheap, has good acoustic and thermal insulation, is easily available and labor is easy to obtain.

Mathematical models of structures using masonry walls require material properties and constitutive relations of the masonry and the elements that comprise it, i.e., bricks and mortar. This information is, however, difficult to obtain.

This paper, tests clay bricks and masonry specimens to determine basic mechanical properties and to define the behavior of masonry used in Lima.

Since 2010, surveys were conducted in Lima to build a database of structural systems and structural materials used in building. It showed that tubular bricks, called pandereta are also often used in constructing masonry housing walls, even if this is not permitted by the Peruvian Standard. Panderetas are recommended only for secondary elements and partition walls. Panderetas are cheap, light-weight, and commonly used in the construction of masonry houses, which is why we have included panderetas in this study.

2. Background

Studies at universities and research centers in Peru have developed to determine the characteristics of masonry. Japan–Peru Center for earthquake for Engineering Research and Disaster Mitigation (CISMID) has performed full-scale tests using masonry specimens since 1988. Studies on hand-made and industrially produced clay bricks specimens were conducted in 1995 [1].

Several districts in Lima have been assessed for seismic risk since 2010. These studies were conducted by CISMID after being requested by national government entities [2–6], with 25% to 30% of all blocks of district used as representative samples. **Table 1** shows the percentage of blocks built using masonry, beside the types of bricks used in walls and **Fig. 1** shows masonry houses in Lima.

3. Objectives

- The objective of this study is to determine mechanical properties for defining the behavior of masonry used in Lima.
- Experiments include the testing of masonry bricks and mortar. Masonry samples were tested under axial compression and wallettes were subjected to diagonal compression to induce shear failure. We thus, analyzed the effects of parameters determining the compressive strength of masonry walls. Parameters provided by the Peruvian Standard we also compared with experimental results.

4. Test Program

Mechanical properties of bricks, mortar, and masonry were tested based on the Peruvian Standard [7]. Eight types of clay bricks from six manufacturers (three hand-made and five industrially produced) and two mortar grade were tested to determine mechanical properties. **Fig. 2** shows hand-made bricks and **Fig. 3** shows industrially produced bricks while **Table 2** shows type and location of clay brick used in this study. Eighty prisms for testing axial compression resistance and thirty six wallettes tested for diagonal tension tests.

Table 1. Representative samples from Lima, Peru, districts.

District	Sample	Masonry houses (%)	Hand-made bricks (%)	Industrial bricks (%)	Tubular bricks (%)
La Molina	438	95%	9%	65%	49%
Chorrillos	554	90%	26%	66%	45%
Villa El Salvador	957	89%	45%	41%	27%
Comas	825	91%	60%	37%	22%
Puente Piedra	732	80%	47%	36%	20%
San Juan de Lurigancho	1271	95%	44%	54%	41%
Cercado de Lima	403	75%	40%	39%	21%
Ventanilla	1080	50%	13%	41%	4%
Breña	126	68%	60%	15%	13%
Carabayllo	751	92%	56%	38%	24%
El Agustino	297	93%	25%	74%	0%
Independencia	415	93%	69%	21%	17%
Lurín	350	86%	35%	44%	19%

Fig. 1. Masonry houses in Lima.

4.1. Properties of Bricks

Based on standard the Peruvian Standard, masonry bricks did not have foreign matter, such as pebbles, small shells, or calcareous nodules on the surface or inside. Individual bricks were thoroughly cooked clay, of a uniform color and not exhibit vitrification. Those hit with a hammer or similar object produces a pinging. Masonry units should have no cracks, fractures, fissures, or similar defects to degrade durability or resistance.

It was noted that some hand-made masonry units did not meet all indications in the Peruvian standard. For this

Table 2. Clay brick manufacture.

ID	Manufacturing – Location
IND-01	Industrial
IND-02	Industrial
IND-03	Industrial
ART-01	Hand-made – Lurigancho
ART-02	Hand-made – Puente Piedra, Carabayllo
ART-03	Hand-made – Puente Piedra, Carabayllo
PND-1	Industrial hollow brick
PND-1	Industrial hollow brick

Fig. 2. Hand-made bricks.

Fig. 3. Industrial bricks.

Table 3. Sizes of masonry units.

	Dimension (cm)		
Unit	Length	Width	Height
Industrial brick	23.09	12.48	9.13
Hand-made brick	19.97	11.74	9.00
Tubular brick	22.00	11.11	9.18

reason, units selected, thus contained no deterioration that might distort results.

Table 3 lists average sizes of types of masonry units.

4.2. Physical Properties of Bricks

Suction and absortion tests are conducted to test the physical properties tests of bricks.

4.2.1. Suction

Suction is related to the adhesion of bricks and mortar, because excessive suction does not achieve a proper junction. This is because brick absorbs water from mortar so fast producing, instead, junctions having low resistance. The Peruvian standard specifies that, based on weather conditions under which work is done, bricks should be watered for half an hour, between 10 and 15 hours before seating them. It is also recommended that suction have to be between 10 to 20 g/200 cm^2-min. In this study, results showed that bricks have high suction values, so it is necessary to soak bricks before bedding them and to prevent mortar from becoming dehydrated.

4.2.2. Absorption

The absorption of masonry units is directly related to its resistance. While the unit is more porous it will be more absorbent; making it more vulnerable to moisture from weathering. Units that are tested must meet absorption requirements in the Peruvian standard. In other words, based on the standard, the absorption of clay and silico-calcareous units must not exceed 22%.

Table 4 lists test results for physical properties of bricks.

4.3. Mechanicals Properties of Bricks

4.3.1. Compressive Strength of Masonry Units

For each type of bricks, compression tests were performed on 10 units to determine compression strength $f'b$ and **Fig. 4** shows compression test of bricks. Calculating resistance must consider the gross area of brick. Values between 12.6 and 1.9 MPa were obtained. **Table 5** lists test results for the compression strength of bricks.

4.4. Properties of Mortar

Two types of mortar were used in this study. The grain size of sand curve does not fit between upper limit curve and lower limit curve given by Peruvian Standard (See

Table 4. Test of physical properties of brick.

ID	Suction ($g/200cm^2$)	Absorption (%)
IND-01	40.56	13.41
IND-02	46.75	13.20
IND-03	42.69	12.10
ART-01	80.70	15.48
ART-02	36.76	13.71
ART-03	99.39	15.27
PND-1	22.72	12.50
PND-2	23.40	14.00

Fig. 4. Compression test of bricks.

Table 5. Compression test results of bricks.

ID	$f'b$ (Mpa)
IND-01	12.6
IND-02	10.4
IND-03	12.3
ART-01	5.9
ART-02	8.7
ART-03	11.0
PND-1	2.5
PND-2	1.9

Fig. 5). No corrections were made, however, to represent actual construction conditions.

Parallel to the construction of prisms and wallettes, samples were obtained for each type of mortar. These samples were cured in water, aged for 28 days, then tested for axial compression. **Table 6** lists compression test results for mortar and **Fig. 6** shows compression test of mortar.

4.5. Compressive Strength

Samples for determining the compressive strength of masonry consist of prisms made of 5 bricks. Four prisms were prepared for each of 8 types of bricks using mortar with a ratio of cement to sand of 1 : 3 and 4 prisms using mortar with a ratio of cement to sand of 1 : 5. **Fig. 7** shows construction of prisms.

Horizontal mortar joints had a nominal thickness of

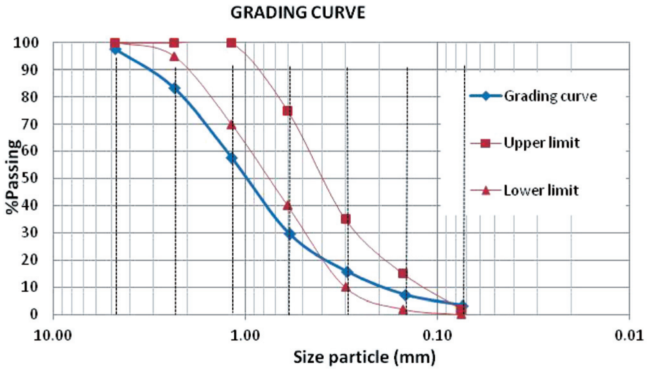


Fig. 5. Grain size of sand.

Table 6. Compression test result for mortar.

Type of mortar	Compressive strength (MPa)	E (MPa)
Mortar 1:3	22.80	18603.7
Mortar 1:5	9.30	13736.0

Fig. 6. Compression test of mortar.

1 cm. The slenderness of specimens varied between 4 and 4.7, so we made appropriate corrections.

Before testing, prism was capped using a mixture of cement and gypsum, applied on the bottom and top to correct any surface irregularity.

Tests started on specimen at the age of 28 days and compression testing was done following NTP 399.605. Test equipment consisted of a 300 ton compression machine and a data acquisition system. LVDT sensors were used to measure deformation. **Fig. 8** shows compressive strength tests of specimen.

Inconsistent values were discarded previously for data processing. The compressive strength of masonry, $f'm$, was calculated for each set of prisms as calculated by the average values minus the standard deviation, based on the Peruvian Standard. The average compressive strength of each prism was calculated as peak load divided by the gross area of the prism.

As shown in **Table 7**, $f'm$ for tubular brick is less than a minimum value of 3.4 MPa for compressive strength indicated in the Peruvian Standard for hand-made bricks.

The relationship between elasticity modulus E and compressive strength $f'm$ of prisms was developed based on regression analysis of data obtained from an experimental program. The correlation coefficient values fit between 0.6 and 0.75. This correlation has not, however, given good results for pandereta bricks prisms.

Fig. 7. Prism construction.

Fig. 8. Compressive strength tests.

Table 7. Compressive strength of masonry, $f'm$.

ID	$f'm$ (Mpa)
ART1-15	5.77
ART2-15	6.02
ART3-15	9.57
ART1-13	6.15
ART2-13	6.57
ART3-13	9.98
IND1-15	8.42
IND2-15	6.83
IND3-15	8.28
IND1-13	9.56
IND2-13	8.08
IND3-13	8.31
PND1-15	1.89
PND2-15	1.22
PND1-13	2.58
PND2-13	2.80

Figure 9 shows this relationship for industrial brick prisms, **Fig. 10** that for hand-made brick prisms, and **Fig. 11** that for both types of prisms. **Fig. 12** shows results for tubular brick prisms. **Fig. 13** shows types of failures

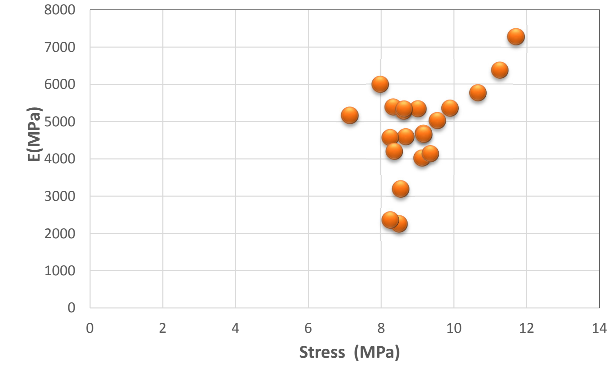


Fig. 9. Variations in modulus of elasticity of masonry with corresponding compressive strengths for industrial bricks prism sets.

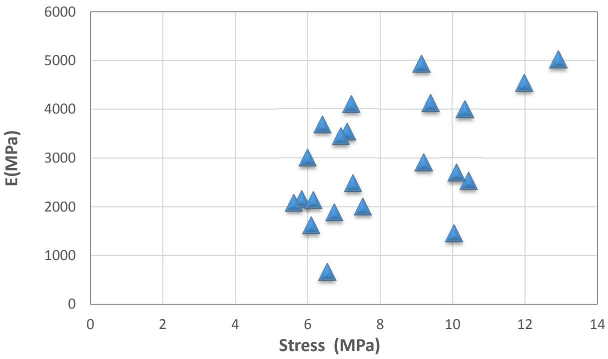


Fig. 10. Variations in modulus of elasticity of masonry with corresponding compressive strength for hand-made bricks prism sets.

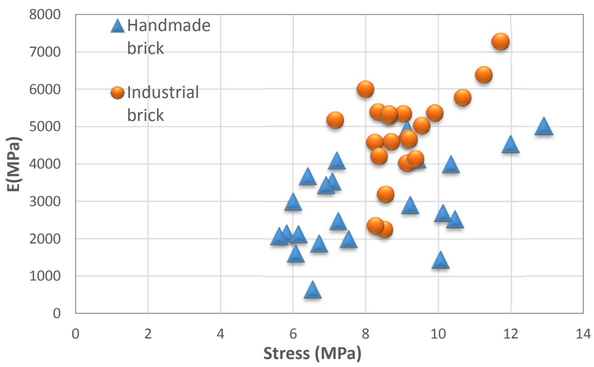


Fig. 11. Variations in modulus of elasticity of masonry with corresponding compressive strengths for all prism sets.

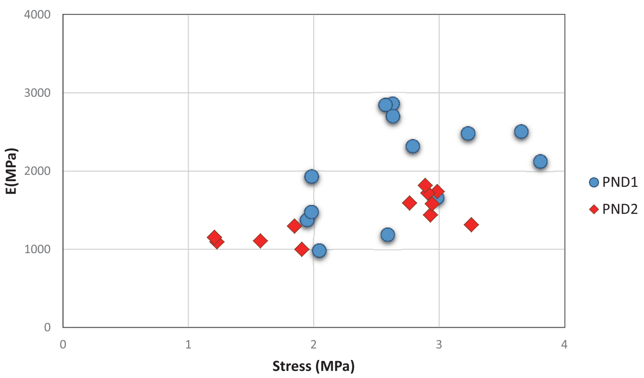
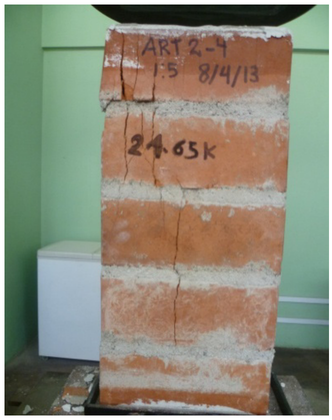


Fig. 12. Variations in modulus of elasticity of masonry with corresponding compressive strengths for tubular brick prism sets.

(a)



(b)

Fig. 13. Types of failures in prisms. (a) Vertical cracking, (b) vertical cracking and crushing.

in prisms due to compressive strength test.

For prisms made of hand-made bricks, the relationship between the modulus of elasticity and compressive strength is as follows:

$$E = 377 f'm$$

For prisms made of industrial bricks, the relationship is as follows:

$$E = 532 f'm$$

The relationship for all sets of prisms, is as follows:

$$E = 439 f'm$$

4.6. Diagonal Tension Test

Diagonal tension tests were developed to measure diagonal tension as precisely as possible. Walletes were loaded in compression along one diagonal causing diagonal tension failure if the specimen split apart parallel to the load direction. **Fig. 14** shows diagonal tension tests. Wallettes consisted of six rows of 2.5 bricks each.

Inconsistent values for processing data were previously discarded. Shear stress $V'm$ for each set was calculated by using the average values minus standard deviation. The average shear stress for each specimen was calculated as peak load divided by the gross area of the specimen.

Fig. 14. Diagonal tension tests.

Table 8. Shear stress $V'm$.

ID	$V'm$ (MPa)
ART 1 15	0.52
ART 2 15	0.80
ART 3 15	—
ART 1 13	1.11
ART 2 13	0.82
ART 3 13	2.18
IND 1 15	1.07
IND 2 15	1.01
IND 3 15	0.92
IND 1 13	0.95
IND 2 13	1.80
IND 3 13	0.83

Table 8 lists shear stress values for the test data process. These values exceed those in the Peruvian Standard. According to this Standard, the minimum value is 0.5 MPa for hand-made bricks and 0.8 MPa of industrially produced bricks.

The ART3-15 specimen could not be tested, because it was damaged in handling before testing.

5. Conclusions

- Hand-made bricks presents a high level of suction, that must be considered during the seating of bricks at constructions sites.
- For prisms consisting of hand-made bricks, the relationship between the modulus of elasticity and compressive strength was as follows:

$$E = 377f'm$$

- For prisms consisting of industrial bricks, the relationship was as follows:

$$E = 532f'm$$

- Experimental results in diagonal tension tests showed that values of shear stress ($V'm$) were greater than those prescribed in the Peruvian Standard.
- Results for tubular bricks indicated a potential damage risk during seismic events in houses built using this type of brick.
- Experimental results must be used to calibrate models of elements that are able to simulate shear behavior in masonry. These studies will be enlarged with numerical analysis.
- The compressive strength average of prisms made of tubular bricks (or pandereta) for mortar 1 : 5 was 1.55 MPa and that for mortar 1 : 3 was 2.69 MPa. These results are lower than those prescribed in the section on hand-made bricks in the E070 Peruvian Standard. Behavior during compressive tests was brittle. Based on our experimental results, tubular bricks should not be used in structural walls.

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References:

[1] T. Izquierdo, "Correlación para determinar las propiedades físicas y mecánicas de unidades o especímenes de albañilería," 1995.
[2] C. Zavala, M. Estrada, Z. Aguilar, and F. Lázares, "Estudio De Microzonificación Sísmica y Vulnerabilidad en la Ciudad De Lima," Ministry of Housing, Construction and Sanitation, 2010.
[3] C. Zavala, M. Estrada, Z. Aguilar, and F. Lázares, "Estudio de Microzonificación Sísmica, Mapas de Peligros Múltiples y Análisis de Riesgo de los Distritos del Cercado De Lima, Ventanilla y de las Ciudades de Chincha y Contumazá," Ministry of Housing, Construction and Sanitation, 2012.
[4] C. Zavala, M. Estrada, Z. Aguilar, and F. Lázares, "Evaluación del Riesgo Sismico del Distrito de Breña," CENEPRED, 2012.
[5] C. Zavala, M. Estrada, Z. Aguilar, and F. Lázares, "Estudios de Microzonificación Geotécnica Sísmica y Evaluación del Riesgo en Zonas Ubicadas en los Distritos de Carabayllo y El Agustino (Provincia Y Departamento De Lima); Distrito del Cusco (Provincia y Departamento del Cusco); y Distrito de Alto Selva Alegre (Provincia y Departamento de Arequipa)," Ministry of Housing, Construction and Sanitation, 2013.
[6] C. Zavala, M. Estrada, Z. Aguilar, and F. Lázares, "Reducción de Vulnerabilidad y Atención de Emergencia por Desastres," Ministry of Economy and Finance, 2013.
[7] Peruvian Standard NTE:070 Masonry, 2006.

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