# STRUCTURAL INVESTIGATION ON CONFINED MASONRY OF SOIL-CEMENT BRICKS TO INCORPORATE INTO EL SALVADOR HOUSING CODE

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**ABSTRACT**

Because of its natural formation, El Salvador is a country that has a lot of earthquakes and volcanoes. Therefore, we can find soil that comes from volcanic ashes all round the country. This kind of soil has been used for many years in El Salvador only for filling and compaction in construction, but now it is used as an alternative material to create brick. Soil-cement bricks, which are made of cement and soil that comes from the ash of volcanoes, are eco-friendly alternative. To obtain the properties of soil-cement masonry, tests in the material were performed. In addition, to know the structural performance of the masonry walls, test in confined an unconfined masonry specimens were done. The specimens were subjected to compression and shear test, from where strength and shear crack load were obtained and recorded.

**Keyword:** Confined masonry, Soil-cement bricks and El Salvador housing code.

## 1. INTRODUCTION

In the year 2001, El Salvador experienced several earthquakes that created many damages around the country. A series of seismic events accompanied with several earthquakes and several aftershocks started on January 13, 2001, causing serious damages on people, infrastructure, productive activities and the environment. The first earthquake occurred on Saturday January 13 at 11:33 a.m. with a magnitude Mw = 7.6. Exactly a month later, on Tuesday February 13 at 8:22 am a second earthquake of magnitude Mw = 6.6 was felt.

Red brick is a product widely used in confined masonry, due to it easy preparation and fabrication. Production of red bricks requires a large quantity of combustible materials; burning of these materials produces a big amount of smoke that pollutes the air. Use of wood for burning the bricks accelerates deforestation finding as a result the loss of aquifers and land erosion. Because this process of burning is harmful to the environment, research is made to create and alternative brick instead of red brick, such as soil-cement. The soil-cement brick was not invented in El Salvador, but recently it has been used as an eco-friendly alternative for construction.

The main objective of this study is to be able to acquire more information on the behavior of the soil-cement masonry, so that the study can be used as a guide for future design in house; by knowing how the behavior of these confined masonry, and how its fail will help us to learn more about the interaction during earthquakes. Another specific objective that hopefully will be accomplished is that this data can later be incorporated into and considered in an improvement of the Housing Code of El Salvador.

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## 2. INFORMATION OF ASHES IN EL SALVADOR

The caldera of Ilopango is located at a latitude of 13° 40'N and a longitude of 89° 03' W. The earliest eruption of the volcano of Ilopango occurred in 430 A.C. This volcano nowadays look like a caldera that contain a lake, covering an area of 72 $km^2$ and has a depth of 230 m. The eruption covered a big area in El Salvador, and pyroclastic flows from the eruption are mainly deposited over present metropolitan area. It is assumed that this volcano has made 4 explosive eruptions in the past 57,000 years. The volume of the last eruption is considered to be of 20-30 $km^3$, close to the border of the caldera of Ilopango in which a 60 m thickness layer of ash can be found. Due to the peculiar color of the ash the soil is called "Tierra Blanca" which means White Soil. This name was given by Hart, W. and Steen-McIntyre in 1983.

### 2.1 What Are Soil Cement Bricks?

Adobe is a natural sundry brick made of clay, sand and water and in some countries it contains organic or fibrous materials. Red bricks are made of clay, and clay needs burning or application to heat to make it stable. The soil cement brick is different from adobe and red brick in that the soil used in this bricks is not clay but soil that comes from ash which is considered as silt. They are not burn they are wind dried.

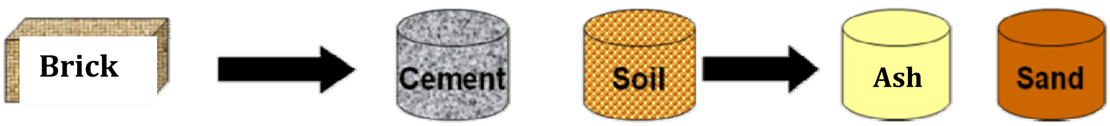


Figure 1.Content of Soil-cement bricks

An investigation was performed as a part of the TAISHIN project to establish combination of cement sand and silt which fulfills all the requirements of bricks for confined masonry in El Salvador. As result they obtained that the combination could 50% ash and 50% sand or 25% ash 75% sand and a proportion of 1 cement and 10 of soil.

## 3. EL SALVADOR STANDARDS FOR CONFINED MASONRY

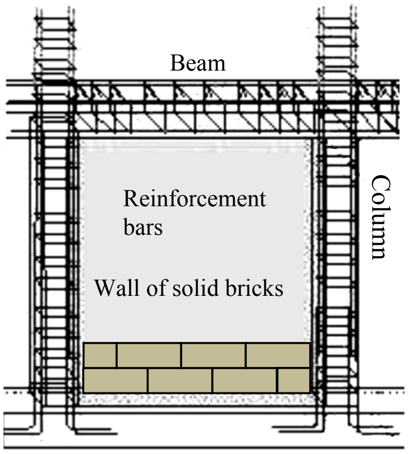


Figure 2. Typical confined masonry in El Salvador

Confined masonry in El Salvador can be explained as a wall made of masonry of solid brick, which are traditionally confined by reinforced concrete columns and beams. For the construction process the reinforcement bars are put in place first, and later the wall is created by locating the bricks joining with mortar, as shown in figure 2, leaving for last the concrete casting to create the confined wall.

In the 1997 Technical Standard for Design and Construction of Masonry Structures of El Salvador, bricks made of cooked clay or also called red bricks and concrete blocks are the only materials considered for making confined masonry. But in the 2004 Technical Standard for Design and Construction of Masonry Structures of El Salvador which is not legally approved yet but is in revision stage, soil cement bricks are considered as material for confined masonry. There is no distinction between both in the characteristics and in the construction process of confined masonry, by use of red brick and soil cement bricks.

## 4. METHODOLOGY OF THE MASONRY STRUCTURAL TESTING OF SOIL CEMENT HANDMADE BRICKS

### 4.1 Procedure of Elaborating Bricks

The combination of soil use for this study is 50 % sand and 50 % ash, with a relation of 1 cement for 10 of soil. The mixture was done by mixing the soil, cement, ash, and water. The bricks were elaborated by hand. The mixture is put in the mold and compacted by using the hand. The upper surface of the brick must be smoothening with the hand or wooden ruler. The molds must be taken immediately after the smoothening process. After 24 hours the bricks can be turn over so that the bottom part can get dry. On day 3, the bricks are ready to be pile up together.

### 4.2 Material Testing

The materials use for elaboration of the specimens such as mortar, concrete and steel bars ware tested to make sure the behavior, properties and quality.

#### *4.2.1 Mortar and Concrete*

To obtain the compression strength in mortar and concrete, cylinders were made as the Japanese Industrial Standard JIS A 1108. The compressive strength is obtained by equation (1).

$$\sigma_c = P/\pi(d/2)^2 \qquad (1)$$

where $\sigma_c$ is compression strength in mortar, P is maximum load and d is the diameter of the specimen. The mortar use for joining each brick has a relation of 1:3 (1 cement by 3 of sand). The bed join between bricks was fixed to 1 cm. The concrete use for the elaboration of the confined element was made by using 955 kg sand , 244 cement and 923 kg coarse.

Concrete cylinders were subjected to the splitting cylinder test following the Japanese Industrial Standard JIS A 1113. The tensile strength can be calculated by using the below equation.

$$\sigma_t = 2P/\pi dl \qquad (2)$$

where $\sigma_t$ is the tensile strength, P is maximum load, d is the diameter of specimen and l is the length of the specimen. The elastic modulus of concrete is defined as the slope of the stress-strain curve from laboratory test. The modulus of elasticity is obtained from the elastic deformation region of the stress-strain curve as in equation (3).

$$E = \sigma/\varepsilon \qquad (3)$$

where E is the modulus of elasticity, σ is the stress (Load/Area) and ε is the strain or unitary deformation.

#### *4.2.2 Steel Bars*

The steel bars used to make the reinforcement in the specimen are D4 (diameter: 4 mm) and D6 (diameter: 6mm). The tensile test was performed by the Japanese Industrial Standard JIS Z 2241.

#### *4.2.3. Cylinders of Soil-Cement*

There is no specific standard that covers soil-cement, therefore in this study cylinder of soil-cement were done and tested. The test performed to the soil-cement cylinders are compression strength in cylinder using equation (1), tensile strength will be calculated with equation (2) and modulus of elasticity is obtained by using equation (3)

## 4. 3 The Dimensions and Construction of Specimens

Two types of bricks were elaborated as shown in figure 3. The first brick is a full size and second is half brick.

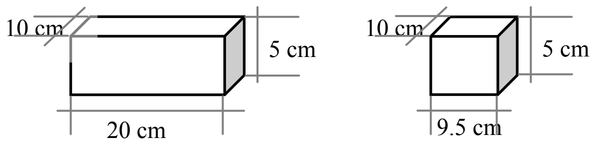



Figure 3. Dimension of bricks

### *4.3.1 Absorption*

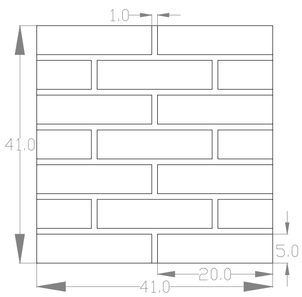
The absorption is calculated with the equation (4). Where $W_w$ is wet weight of the brick and $W_d$ is dry weight of the brick

$$\text{Absorption} = (W_w - W_d)/W_d \times 100 \qquad (4)$$

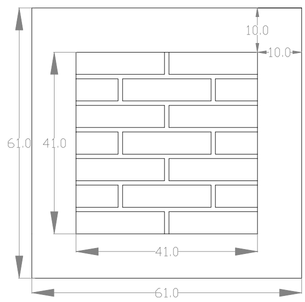
### *4.3.2 Compression in Bricks*

The compression strength is calculated by using equation (5), where $f'_u$ is compression strength in bricks unit, P is the maximum load and A is the area (obtained as: width x length)

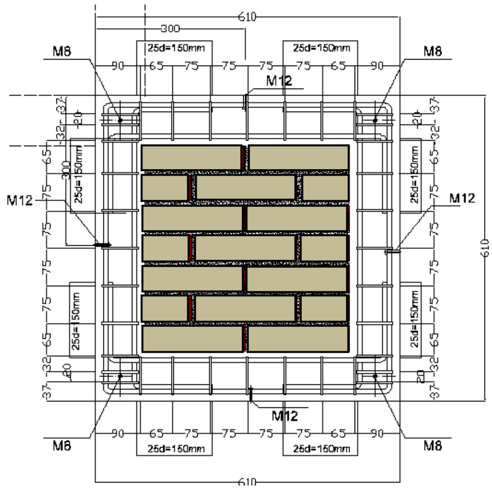
$$f'_u = P/A \qquad (5)$$



a)Unconfined masonry (URM)



b)Confined masonry with plane concrete (CP)




c) Confined masonry with reinforce bars

### *4.3.3 Compression on Piles*

The compression test of piles is done to know the compression strength of the masonry. The piles are made of 3 layer of bricks. Where $f'_m$ is compression strength in masonry calculated with equation (6).

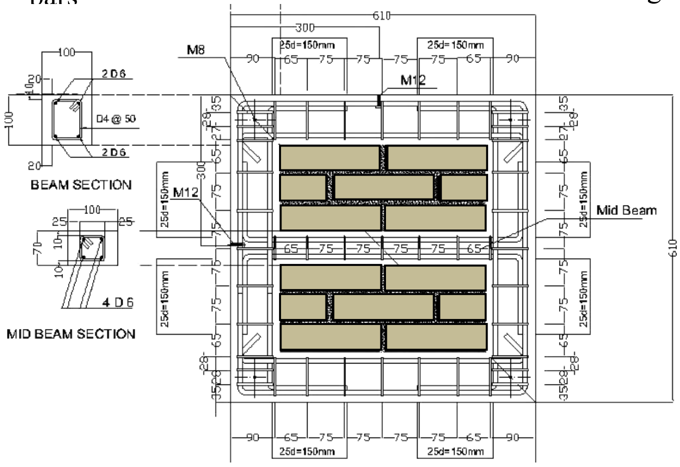
$$f'_m = P/A \qquad (6)$$

### *4.3.4 Diagonal Tension on Prisms*

For the diagonal tension test, the prisms made had several configuration, each test shows a different characteristics of the masonry. The procedure and the calculation for the test are according to the ASTM E 519. For obtaining the shear stress, the equations below are uses.

$$S_s = 0.707P/A_n \qquad (7)$$

$$A_n = ((W + h)/2)tn \qquad (8)$$




d) Confined masonry with reinforce bars and with intermediate beam (CRM)

Figure 4. Type of prisms

where $S_s$ is the shear stress on net area, P is the applied load, $A_n$ is the net area of the specimen, W is width of the specimen, h is height of specimen, t is total thickness of specimen and n is the percent of the gross area of the unit that is solid, expressed as decimal; since is a solid bricks this number is 1. The diagonal tests were performed by using a “Portable Structural Testing Equipment” (PSTE).

## 5. TEST RESULTS ANALYSIS

### 5.1 Result of concrete and mortar

Table 1. Compression strength in cylinders of mortar and

| | Mortar | | | Concrete | | |
|---|---|---|---|---|---|---|
| Nº of specimen | 1 | 2 | 3 | 1 | 2 | 3 |
| Section area, $cm^2$ | 19.7 | 19.8 | 19.7 | 78.54 | 78.54 | 78.54 |
| Maximum load, KN | 40.4 | 49 | 29 | 96 | 99.2 | 90.3 |
| Compression strength, $kN/mm^2$ | 20.49 | 24.76 | 14.71 | 12.23 | 12.63 | 11.5 |
| Average, $kN/mm^2$ | 20 | | | 12.12 | | |

Table 2.Modulus of Elasticity of concrete

| Nº of specimen | Modulus of Elasticity, $N/mm^2$ |
|---|---|
| 1 | 0.017051 |
| 2 | 0.017691 |
| 3 | 0.017191 |
| Average | 0.017311 |

Table 3. Splitting test on concrete cylinders

| Nº of specimen | 1 | 2 | 3 |
|---|---|---|---|
| Height, cm | 20 | 20 | 20 |
| Diameter, cm | 10 | 10 | 10 |
| Maximum load, kN | 37.70 | 33.30 | 32.80 |
| Tensile strength, $N/mm^2$ | 1.20 | 1.06 | 1.04 |
| Average, $N/mm^2$ | 1.10 | | |

Concrete compression strength has an average of 12.12 $kN/mm^2$. The average value of tensile strength is 1.10 $N/mm^2$. As it was expected, the tensile strength of concrete is around 10% of the compression strength.

### 5.2 Reinforce bars.

Table 4. Results of the tensile test reinforce bars

| Type | Diameter mm | Yield force KN | Yield strength $N/mm^2$ | Yield Deformation mm/mm | Maximum load KN | Maximum strength $N/mm^2$ |
|---|---|---|---|---|---|---|
| D4 | 3.9 | 4.98 | 416.9 | 2096 | 6.97 | 583.5 |
| | | 5.04 | 421.9 | 2146 | 7.26 | 607.7 |
| | | 5.08 | 425.3 | 1876 | 7.32 | 612.8 |
| D6 | 6.3 | 8.18 | 262.4 | 1766 | 16.05 | 514.9 |

### 5.3 Soil - Cement Cylinders

The soil cement is not cover in the JIS or in any other standard, the tests were carried out in order to get more knowledge of the behavior and to set a parameter for future references, see table 5, 6, and 7.

Table 5. Results of the compression test in cylinders of soilcement

| Nº of specimen | 1 | 2 | 3 |
|---|---|---|---|
| Section area, $cm^2$ | 78.54 | 78.54 | 78.54 |
| Maximum load, kN | 24.79 | 25.19 | 23.66 |
| Compression strength, $N/mm^2$ | 3.16 | 3.21 | 3.01 |
| Average, $N/mm^2$ | 3.13 | | |

Table 6. Modulus of Elasticity of soil-cement cylinders

| Nº of specimen | Modulus of Elasticity, $N/(mm^2x10^6)$ |
|---|---|
| 1 | 0.001633 |
| 2 | 0.002887 |
| 3 | 0.002626 |
| Average | 0.002382 |

Table 7. Splitting test on soil-cement

| Nº of specimen | 1 | 2 | 3 |
|---|---|---|---|
| Height, cm | 19.8 | 19.8 | 20 |
| Diameter, cm | 10 | 10 | 10 |
| Maximum load, kN | 10.40 | 6.30 | 5.85 |
| Tensile strength, $N/mm^2$ | 0.33 | 0.20 | 0.19 |
| Average, $N/mm^2$ | 0.24 | | |

### 5.4 Bricks and Masonry of Soil Cement

Table 8. Compression in half size bricks

| Identification brick | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Length, cm | 10 | 9.7 | 10 | 9.7 | 9.8 |
| Width, cm | 9.5 | 9.5 | 9.4 | 9.3 | 9.4 |
| Thickness, cm | 5.1 | 5 | 5.1 | 5.1 | 5.1 |
| Area, $cm^2$ | 95 | 92.15 | 91.18 | 90.21 | 92.12 |
| Maximum load, kN | 41 | 40.31 | 38.52 | 39.57 | 36.99 |
| Compression Strength, $N/mm^2$ | 4.316 | 4.374 | 4.098 | 4.386 | 4.015 |
| Average, $N/mm^2$ | 4.24 | | | | |

Table 9. Compression piles in half size bricks

| Identification pile | 1 | 2 | 3 |
|---|---|---|---|
| Area, $cm^2$ | 185.25 | 188.16 | 189.15 |
| Maximum load, kN | 64.40 | 69.59 | 61.85 |
| Compression Strength, $N/mm^2$ | 3.25 | 3.48 | 3.10 |
| Average, N/mm2 | 3.27 | | |

The capacity of the soil-cement bricks to absorb water is 21.4%. This value is from the average of the absorption test made in half and full size bricks. The relation between the compression strength of the masonry and the compression strength of the brick is 0.7, it can be express as $f_m' = 0.7 f'_u$. Piles with full size bricks where also done to know the difference between full and half-size strength in pile the compression strength obtained was 2.99 $N/mm^2$.

The shear crack load was read when the first visible crack appears on the specimen, this value is an approximation. The first cracks that appear on the specimens were shear crack and as the tests continue other types of cracks also appear, such as bond and crush of concrete. The crush of concrete appeared at the last stages of the tests due to the holders use for support the measurements instrument.

Table 9. Resume of the diagonal test in all type of prisms

| Identification | URM-1 | URM-2 | URM-3 | URM-4 | URM-5 | CP-1 | CP-2 | CP-3 | CR10 | CRM10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Shear crack load, KN | 41 | 41.45 | 54.7 | 50 | 50.1 | 33 | 62.2 | 54.4 | 75 | 86.4 |
| Maximum shear strength, kg/cm$^2$ | 8.02 | 8.57 | 9.44 | 8.96 | 9.78 | 5.64 | 10.45 | 9.11 | 12.65 | 16.03 |
| Maximum shear strength, N/mm$^2$ | 0.802 | 0.857 | 0.944 | 0.896 | 0.978 | 0.564 | 1.045 | 0.911 | **1.265** | **1.603** |
| Average, N/mm$^2$ | **0.895** | | | | | **0.840** | | | | |

## CONCLUSIONS

1. The bricks made for the study had a compression strength of 4.2 N/mm$^2$, El Salvador requires that the compression strength for red bricks must be 4 N/mm$^2$ (for a 1 or 2 story houses). El Salvador bricks of soil-cement had a compression strength of 7.797 N/mm$^2$. Although the strength is different, it can be taken that the compression strength of bricks that have dosage of 50% sand - 50% ash and a relation of 1:10 can be found in the interval of 4-8.N/mm$^2$.
2. The difference can lie in many aspects like the scale factor. The different in the type, together with the possibility that temperature and humidity can change the water content in the mixture.
3. As for the shear strength of unconfined masonry, the average value is 0.68 N/mm$^2$ in El Salvador and the average is 0.89 N/mm$^2$ in this study. If we consider that both values of shear strength have standard deviation, the difference between them becomes approximately of 1 N/mm$^2$. We can conclude that the interval for shear strength can be from 0.6 to 0.9 N/mm$^2$.
4. For this study, 4 different types of diagonal test were performed. A lot of new information has been gathered to impact and set background for making changes in the El Salvador Housing Code. In the case of the prisms, URM and CP show that degradation and collapse occurred after reaching maximum load. CR and CRM prisms give a clear view of why confinement is necessary and how the strength incremented by giving more confinement to the masonry.
5. It is necessary to reflect and incorporate in the Housing Code, specific parameters for calculating the compression strength so that can be used for the design of confined masonry of soil cement bricks.

It is highly recommended that furthermore experiments are needed to be done to analyze the scale factor in soil cement bricks, and more diagonal tension tests are required to be able to give generalized values of shear strength and shear crack.

## ACKNOWLEDGMENT

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