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Failure Mechanisms of Interlocked Bricks of Soil-Cement and Wood Fibers

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***Abstract*— *The goal is to determine the mechanisms of soil-cement interlocked brick plus wood fibers under compressive loading. For this we used experimental stress analysis techniques. Horizontal deformations (εx) and vertical (εy) of bricks were obtained with extensometers, in the configuration of five rosettes. From the values of these deformations and using the equations of the theory of elasticity, Poisson coefficients were determined and elasticity modules, and calculated the corresponding voltages each escutcheon according to the equations of the State of plane stress. To determine the trajectory of the rupture voltage-loading graphics were made of each rosette. Knowing this trajectory determined the tensions related to the modification of the brick break mechanism. The appearance of a premature cracking or excessive is parameter used to determine the State limit of use of bricks.*

Keywords*— *Soil-cement bricks, wood fibers, limit states Stress analysis, elasticity modules.

I. INTRODUCTION

The inclusion of elements in soil reinforcement for improvement of its properties was already known to peoples of antiquity. This can be confirmed by some buildings, still exist today, such as the walls of Ziggurat of Agar Quf in Mesopotamia (1,400 BC), built using interleaved layers of soil and blankets of roots. The Incas used llama wool mixed with soil in road construction resistant to time. Are also known applications of layers of leaves and twigs on layers of soft soils, prior to the construction of landfills in these soils, in the interior of Brazil and other countries, [1, 2].

One of the advantages in the use of soil-cement can cite: soil available on-site or nearby, simple fixes on their particle size and without the need for specialized labor and good thermal and acoustic comfort. The soil-cement buildings are very comfortable because the "raw land" is a bad conductor of heat. Soil-cement buildings are fire resistant also has great durability and reduced maintenance. The main drawback, however, is the wide variety of existing soils which implies in performing assays for the characterization of land used. Such tests can be performed in any laboratory for dealing with simple and routine tests.

The inclusion of fibers in the soil-cement (fragile array) is a newer technique, however using ancient concepts. The advantages are several. One can cite: good thermo-acoustic insulation, [3], improved mechanical properties (tensile strength, bending and impact) and behavior changed after cracking, because rather than sudden rupture of the material occurs after the onset of cracking of the array, plastic deformation, more suitable for construction, [4]. According to [5, 6], the cement-based composite of eucalyptus wood has excellent thermal and acoustic insulating properties, in addition to the easy workability also features excellent resistance to fungus and good adherence to different substrates. The percentage of wood in the mix influences directly on these features. In general, the fibers inhibit the amplitude of the cracks associated with ruptured, resulting in a composite material with greater tenacity. According to [2], the fibers do not prevent the formation of cracks, however, control the spread of the same along the cement mass, benefiting the mechanical properties in the post-cracking state. The main disadvantage shown by [7, 8] is the incompatibility between the chemical plant biomass and the cement. The chemical Constitution of the biomass due to the presence of sugars, phenols, resins and starch, can adversely affect the hydration of cement. These disadvantages, however, do not render the use of particular residue. It is possible to minimize or even avoid the effects of the physical mismatch by physical-chemical treatments applied to the vegetable particles.

The interlocked bricks are designed to not use any mortar of settlement is vertical or horizontal. Stability and resistance to horizontal efforts are controlled by vertical and horizontal fittings. The misuse of this technology can result in inadequate conditions constructions such as cracks and fissures, where rodents and insects are home, endangering the health of its residents. However, when technology is well applied, buildings with quality and satisfactory resistance.

One of the first to study the stress-strain properties of soil-cement walls was [10]. The reference [11], presents stress-strain relations and elastic properties of soil-cement blocks. The results indicate that there is 2.5 times increase in resistance to the cement content duplication. The modulus of elasticity of soil-cement block ranged between 2,000 and 6,000 MPa and increases 2.5 times when the cement content is increased from 6 to 8%. [12, 13, 14, 15] feature constitutive laws of soil-cement blocks varying composition (clay, silt and cement). [16, 17, 18] use various techniques to determine the stress-strain relations of ceramic bricks, prisms and small walls.

The use of electrical extensometers (SG) along with an experimental analysis of stresses to determine the behavior of masonry structural elements, was little used. [19], presents a study about the use of the technique of "center hole" in masonry walls. Use 8 electric extensometers forming rosettes.

This work aimed to study the way the rupture, as well as get a call of a threshold from which the modification of the rupture mechanism of bricks, used electric extensometers and experimental stress analysis techniques.

II. MATERIALS AND METHODS

For the composition of the soils studied have been used, the soils of two quarries in the region of Belo Horizonte, Minas Gerais, Brazil, mixed with small portions of fine sand and thick, with the purpose of getting a soil particle size that allows you to stay within the limits recommended by [6], for the manufacture of bricks of soil-cement. The Portland blast furnace cement for general use. For the study of the waste were collected leftover wood pieces, called sawdust, of Eucalyptus grandis and Eucalyptus cloeziana. This was sifted sawdust so that only use the waste contained between the screens # 4 (4.8 mm) and # 10 (2.0 mm). Aimed at "sealing" of waste, a solution of aluminium sulphate [$Al_2(SO_4)_3$] and water (1% of water used). The residue was placed in this solution for 20 minutes. Then he was taken to the greenhouse (60° C) until their total drying. This "Proofing" or fiber protection with aluminum sulfate, according to [3] assists in the control of the degradation of the same.

2.1 Manufacture of bricks

For the manufacture of bricks of soil-cement-wood waste, was constructed a hydraulic press in such a way that it was possible to control pressure during the pressing. For this, it was instrumented with a manometer, which was calibrated with a ring dynamometer, thus enabling the conversion of the measure provided by the instrument for the measurement of compression pressure (2.0 MPa), Fig. 1. After molding, the bricks were ferried to the humid chamber where they remained for seven days at a temperature of 23 ± 0.2 ºC and relative humidity around 100%.

Were made three bricks, a first of soil-cement to soil Homogenized 1, a second of soil-cement to soil Homogenized 3 and a third of soil-cement and 0.5% of fiber to the soil Homogenized 1. The purpose was to verify the influence of the type of soil and wood fiber in the State last brick boundary.

The brick manufacturing process consists in homogenizing, pressing and hardening of the raw materials described above, previously determined quantitatively. For this use, soils considered ideals are the sandy-silt, the sandy-clay soils, silt-sandy and silt-clay soils, being the amount of sand must be greater than or equal to the amount of fines (silt and clay). Known popularly as clay soils red and yellow land are of good quality, and, for the most part, be used. The soil should be free of organic matter, and thus avoid the use of black or dark gray soils because they are detrimental to the properties of the final product, the bricks. Lumps, boulders and roots should be removed from the soil since it reduces the quality of the brick. The screening then becomes essential for such a condition is fulfilled. To obtain a perfect brick where the resistance is optimized, it is homogenized that it be produced in conformity with predetermined parameters for the compression test in soil and soil-cement. It's worth noting, then, that the performance of the brick is made based on the equivalence between the pressing Proctor Normal and the compaction of the bricks.

(a) (b)

Fig. 1: a) Brick molding press, b) Extraction of brick

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For simple compression tests in bricks, used the universal machine, model DL 30000 EMIC brand, with a capacity of 300 kN. This machine has automatic charging control and displacement. For the instrumentation of the bricks were used for each of these five rosettes from two strain gages Kyowa brand, model KFG-10-120-D16-11.

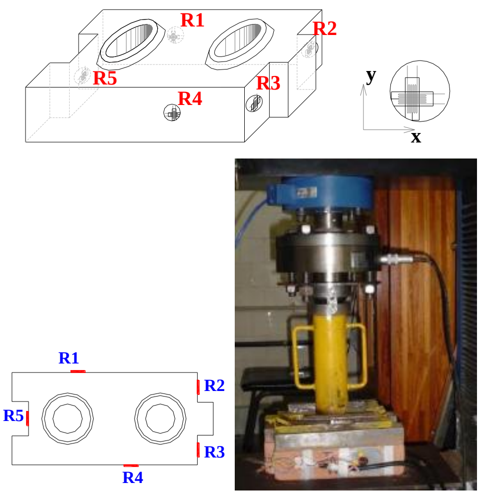
Was used a load cell, coupled to the universal machine with a capacity of 200 kN. Data provided by strain gages and by the load cell was collected by a data acquisition system.

2.2 Instrumentation of the bricks s

To catch the horizontal deformations (εx) and vertical (εy), the bricks were instrumented, each with five rosettes, formed by two strain gages (one vertical and one horizontal), at locations shown in Fig. 2a.

2.3 Test

The instrumented bricks were tested with compressive loading applied and monitored by means of a load cell, Fig. 2b.



(a) (b)

Fig. 2: a) Position and numbering of the rosettes on the brick Interlocked, b) Compression test

III. RESULTS AND CONSIDERATIONS

From the data captured in each strain gauge, and using the equations of resistance of materials, Poisson coefficients were determined in each one of the points shown and the modules of elasticity. The modulus of elasticity was determined from the constitutive law of materials (stress-strain graph), and the coefficient of Poisson (ν) from the list of horizontal deformations (εx) and vertical (εy) of each strain gages. Table 1 shows the values for the coefficient of Poisson found in three instrumented bricks. The rosettes R1, R2, R3 and R4 exhibit a similar behavior which does not occur with the rosette R5. It is observed that in every brick, for each escutcheon was found a different value for the coefficient of Poisson. The geometry of the brick collaborates for such a situation to occur. Poisson coefficient determined by the R5 was shown to be different from other due probably to the disturbances caused by the geometric configuration of the brick. For the brick manufactured with soil Homogenized 3 variation was observed between the values of Poisson's coefficient. However, the similarity between the positions was kept, which may indicate an influence of soil type used in this determination. Considering a State plan and using the Poisson coefficient values found for each point, the deformations and the modulus of elasticity, corresponding tensions were calculated in each escutcheon using the Equation. 1.

Table 1 – Values of Poisson's coefficient in bricks

Rossetes	1	4	2	3	Average	5
SC1-0% waste	0.23	0.25	0.23	0.23	0.22	0.16
SC1-0.5% waste	0.18	0.23	0.22	0.17	0.20	0.16
SC3-0% waste	0.32	0.33	0.34	0.30	0.32	0.12

$$\sigma_x = \frac{E}{(1-\nu^2)} \times (\varepsilon_x + \nu \times \varepsilon_y),$$

$$\sigma_y = \frac{E}{(1-\nu^2)} \times (\varepsilon_y + \nu \times \varepsilon_x), \quad \sigma_z = 0 \qquad (1)$$

Being: E the modulus of elasticity in MPa, ν the Poisson coefficient, σx and σy normal stress in the plan in MPa.

For the analysis of the trajectory of the failure was necessary to make individual charts of each rosette, where are tensions σx and σy operating in each of them. At every turn it was responsible for the loss of load resistant capacity, indicated by the change of the level of stress. The larger of the two was crucial in assessing the trajectory. To determine the sequence of the failure, the biggest loads obtained from each point were ordered to form crescent. Table 2 shows the path of the failure,

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showing the sequence of the rosettes. Observe the occurrence of similar behavior in bricks with Homogenized 1 soil and 0.5% of waste and with Homogenized 3 soil without waste. Both feature ductility more than the Homogenized 1 soil brick and 0% of waste. The soil Homogenized 3, naturally more plastic due to greater presence of clay fraction, presents a greater ductility. Already the Homogenized 1 soil with the addition of 0.5% of waste increases their ductility. It is observed that the comparison between the bricks more or less ductile showed that the failure began to form. This failure trajectory provides evidence that the ductility affects the way the rupture.

Knowing the trajectory of the failure, the stress related to the modification of the brick failure mechanism. It is known that the limit state is characterized by the impossibility of the job structure, in whole or in part, as Homogenized conditions of comfort and durability, even though she has not exhausted its capacity bearing. The appearance of excessive deformations or a premature cracking or excessive, etc. are parameters used for this determination. In this way, we studied bricks from the stress x charging curves, was responsible for the first charging indication of change in the failure mechanism, even if not apparent, as there is a possibility that is reaching its limit. One of the characteristics of the studied bricks is not use plaster, by this, any apparent rift could compromise their aesthetic features. Knowing the trajectory of the failure, the lowest loading of all five points of brick, admitted as being responsible for the stress. The values of stress for use of bricks studied vary: between 0.33 and 0.56 MPa when manufactured with Homogenized 1 soil and 0% of waste; between 0.28 and 0.86 MPa when manufactured with Homogenized 1 soil and 0.5% of wastes; and between 0.35 and 1.26 MPa when manufactured with Homogenized 3 soil and 0% of waste.

Fig. 3a the observed lines of vertical failure near the ends of the brick. The existence of holes in bricks might have caused points of fragility next to this region. Existing interlock on the brick show failures. In the grooves of the bricks are observed some lines of horizontal cracks. Close to the bosses have a slanted rupture line Fig. 3b and c.

Table 2- Failure path in bricks

Horizontal failure sequence.	
SC1-0% waste	3 ⇒ 4 ⇒ 2 ⇒ 1 ⇒ 5
SC1-0,5% wastes	5 ⇒ 4 ⇒ 1 ⇒ 2 ⇒ 3
SC3-0% waste	5 ⇒ 1 ⇒ 4 ⇒ 2 ⇒ 3

Fig. 4 shows the improvement achieved with the inclusion of waste. The bricks made of soil without residues tend to have fragile behavior. With the inclusion of vegetable waste, tends to be more ductile. Note the opening of cracks in bricks without residues and cracks lines presented in bricks with waste.

(a) (b) (c)

Fig. 3: Brick failure, a) longitudinal face, b) in the female fitting, c) into the male

(a) (b) (c) (d)

Fig. 4: Brick Failure with soil Homogenized 3, a) 0% waste and b) 0.5% waste, and Soil Homogeneous 1 with c) 0% waste and d) 1% waste

IV. CONCLUSION

The geometry of the brick allowed determining distinct values of stress, modulus of elasticity and Poisson's coefficient in each point coincident with the rosettes.

The determination of the way showed behaviors similar to failure the bricks that presented greater ductility (natural plasticity of the soil Homogenized 3 – more clay- or increased ductility achieved by the inclusion of vegetable residues in the soil Homogenized 1-more gritty). The brick less ductile (soil Homogenized 1 without waste) presented a way of reverse breakdown. Knowing the time of beginning of failure was possible the determination of a probable limit of stress (possibly first sign of change of behavior of brick and also first fissure point). The tests only give evidence of its occurrence, was evaluated experimentally a brick of each type.

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