DEVELOPMENT OF A NEW TEST FOR DETERMINATION OF TENSILE STRENGTH OF CONCRETE BLOCKS

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ABSTRACT

An accurate experimental, numerical and analytical analysis of masonry structures is only possible if detailed information on the mechanical properties of masonry materials is known. In general, tensile strength of fragile brittle materials is a property difficult to measure in direct tensile tests. In this paper a new indirect tensile test method is proposed for determination of tensile strength of concrete blocks based on compression tests of blocks in the direction parallel to bed joints. Results of the proposed test are compared with direct tensile tests of small specimens cut from the concrete blocks. The compression test seems to be an alternative method of measuring the tensile strength of the units since it is easier to carry out and avoids problems like rotation of the specimen and debonding of the specimens from the plates.

KEYWORDS: concrete block, tensile strength, characterization test

INTRODUCTION

Masonry walls in a building are mainly subjected to compressive stresses due to gravity loads. However, this compression leads to masonry units that may also be subjected to tensile stresses due to the lower stiffness of mortar, which tends to be more deformable than the masonry units, see Figure 1a.
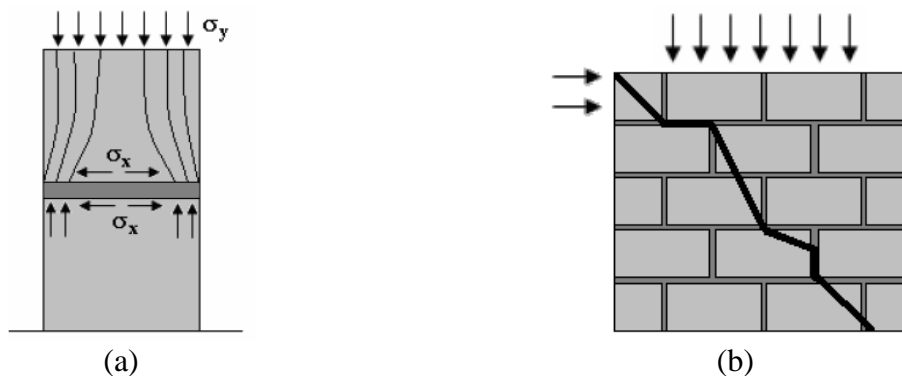
Figure 1: Tensile stresses in masonry units: (a) masonry under compression and (b) masonry subjected to lateral loading.

Masonry walls have play an important role in improving seismic resistance and global stability of masonry buildings. Due to their role in buildings, walls must withstand significant horizontal loads induced by earthquakes. When a masonry wall is subjected to in-plane lateral loading a diagonal crack may open, producing severe deterioration in wall strength, see Figure 1b. This diagonal crack depends on the properties of the unit-mortar interface and on the tensile strength of the unit.

Tensile strength of brittle materials is a property difficult to measure in direct tensile tests. So, indirect tests such as splitting tests or flexural tests have been used to measure this property. ASTM C1006-07 covers the test method for determination of the splitting tensile strength of masonry units. This test method produces a line load along the bed surface of the masonry unit, see Figure 2a. The compressive load (F) applied to the unit, imposed by means of bearing rods, results in a tensile stress distributed over the height (h) of the unit for the split length (l) of the unit. The splitting tensile strength (f_{bt}) of the specimens is calculated using equation (1). ASTM C67-12 covers procedures for the sampling and testing of brick and structural clay tile. In this standard a test method to measure the modulus of rupture (S) of clay units is described, see Figure 2b. This is a flexure test which produces compressive and tensile stresses at the top and bottom of the specimens, respectively. The modulus of rupture is calculated using equation (2).

(a)   (b)
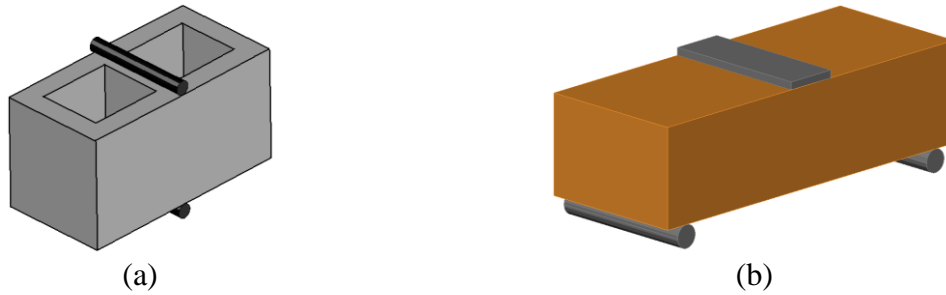
Figure 2: Indirect tensile tests of masonry units: (a) splitting test and (b) flexure test.

$$f_{bt} = \frac{2F}{\pi ht} \qquad\qquad (1)$$

$$S = \frac{3F\left(\frac{l}{2} - x\right)}{bd^2} \qquad\qquad (2)$$

Where, l is the distance between the supports, b is the net width (face to face distance minus voids) of the specimen at the plane of failure, d is the depth (bed surface to bed surface distance) of the specimen at the plane of failure, and x is the average distance from the mid-span of the specimen to the plane of failure measured in the direction of the span along the centre-line of the bed surface subjected to tension.

This work proposes a new test for determination of the tensile strength of concrete blocks based on compression tests of blocks in the direction parallel to bed joints, and compares these results with direct tensile tests.

EXPERIMENTAL PROGRAM
The concrete blocks were produced in reduced scale (1:2) in order to comply with technical limitations at the structural laboratory of University of Minho, Portugal, to perform real scale tests on masonry walls. Two (2C-units) and three cell (3C-units) concrete blocks were defined with the shape and geometry indicated in Figure 3. The idea of using frogged ends in 3C-units is to allow placement of vertical reinforcement in a continuous vertical joint in order to simplify the construction technology. The 2C-units has a geometry very similar to non-structural concrete blocks existing in the Portuguese market and is a very common geometry used for load-bearing masonry in Brazil.
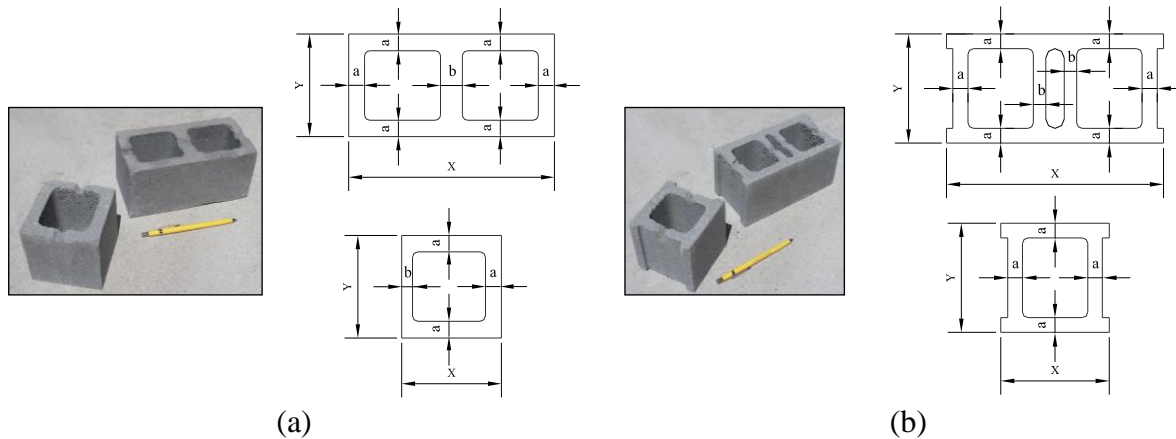
(a)   (b)
**Figure 3: Concrete blocks: (a) two cells and (b) three cells.**

Physical properties such as dimensions and dimensional variability, percentage of vertical perforation and water absorption due to capillarity action were obtained for the concrete units according to EN 772-16 (2000), EN 772-2 (1998) and EN 772-11 (2000) respectively, see Table 1. In all tests, six concrete units were used. In Eurocode 6 (2005), units are classified in four groups according to geometrical requirements such as percentage of voids and thickness of webs and shells. According to the classification proposed in Eurocode 6 (2005) both units belong to group 2.

Table 1 – Physical properties of blocks.

	X (mm)	Y (mm)	Z (mm)	a (mm)	b (mm)	Net area of blocks (cm^2)	Area of voids (cm^2)	Percentage of voids (%)	Coefficient of water absorption (g/(mm^{2}s^{0,5}))
Block (2C-units)	196	94	94	16	21	98.0	87.5	47	171.8
Half block (2C-units)	96	94	94	17	12	47.8	41.8	47	246.7
Block (3C-units)	201	100	93	16	14	110.1	93.9	46	228.3
Half Block (3C-units)	101	100	93	16	-	57.2	46.1	45	226.7

The normalized compressive strength perpendicular to bed joints of the concrete blocks calculated to gross area was obtained according to EN772-1 (2000) which provided an average value of 12.1 MPa and 9.38 MPa for 3C-units and 2C-units, respectively. The Young's modulus of the concrete blocks was derived from the compressive stress-strain diagrams, being on average 9.6 GPa and 8.8 GPa for 3C-units and 2C-units, respectively.

The tensile strength of units was measured following the test setup used by Vasconcelos (2005) and Mohamad (2007). The tests were performed on specimens cut from the shells of blocks, see Figure 4. According to Vasconcelos (2005), the adoption of a constant cross section for the specimens leads to uncertainty about the localization of the micro-cracks, voids and other defects, which represents the usual supplementary difficulty for the control method of this type of test. Thus, it was decided to introduce two lateral notches with a depth of 6 mm at mid height of the specimen in order to localize the fracture surface. Twelve specimens of each type of block were prepared.
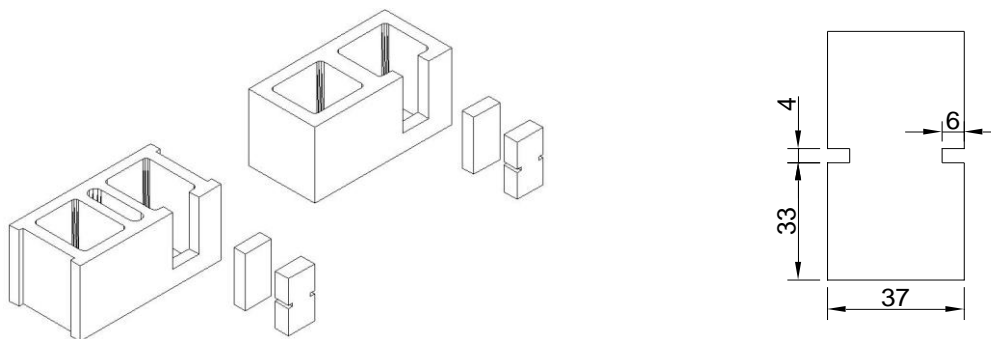
Figure 4: Specimens used in direct tensile tests of units.

The direct tensile tests were performed by using a CS7400S servo-controlled universal testing machine with fixed end plates. This equipment has a load cell connected to the vertical actuator with a maximum capacity of 22 kN, and is particularly suitable to small specimens. Specimens were glued to the steel plates of the equipment and two LVDTs were used to measure the crack opening.

Blocks were also tested under compression in the direction parallel to the bed joint. This test was carried out given that in case of the masonry beams, the compressive stresses in masonry develop in the direction parallel to the bed joints. Compressive tests in the direction parallel to bed joints were carried out in six specimens. Vertical deformations of the specimens were measured using two LVDTs to evaluate elastic modulus, see Figure 5.

Tests were conducted under displacement control at a rate of 5 μm/s by means of a vertical LVDT connected to the actuator. Two steel plates supported by transversal bars were added to the test for safety reasons, given the fragile behaviour of the blocks.

**Figure 5: Test setup of the compressive tests in direction parallel to bed joints.**

RESULTS

There was practically no difference in the results of the direct tensile tests for 2C-units and 3C-units, which was expected since both blocks were produced in a modern plant at same time, with the same concrete and were cured under the same environmental conditions, see Table 2.

Table 2 – Results of the direct tensile tests.

	Mean Stress (MPa)	Standard Deviation (MPa)	C.V. (%)
2C-units	3.13	0.74	23.58
3C-units	3.19	0.68	21.43

In most specimens the crack appeared in the notched section, see Figure 6a. However, in a few specimens the crack appeared in the region with larger cross section close to the fixed ends, see Figure 6b. This behaviour can be explained by the fact that the localization of the smaller cross section zone may be not compatible with the weakest zone of the material (Wittman et al., 1994). The LVDTs presented distinct behaviour due to rotation of the specimen despite the large stiffness of the testing machine. This can be seen in Figure 7..
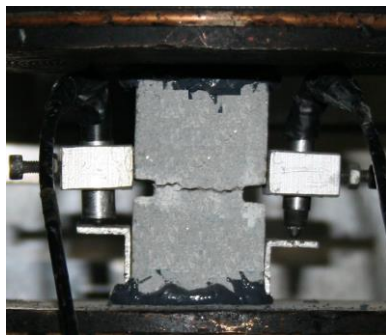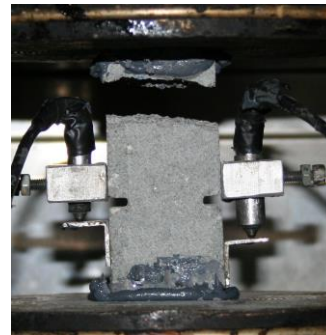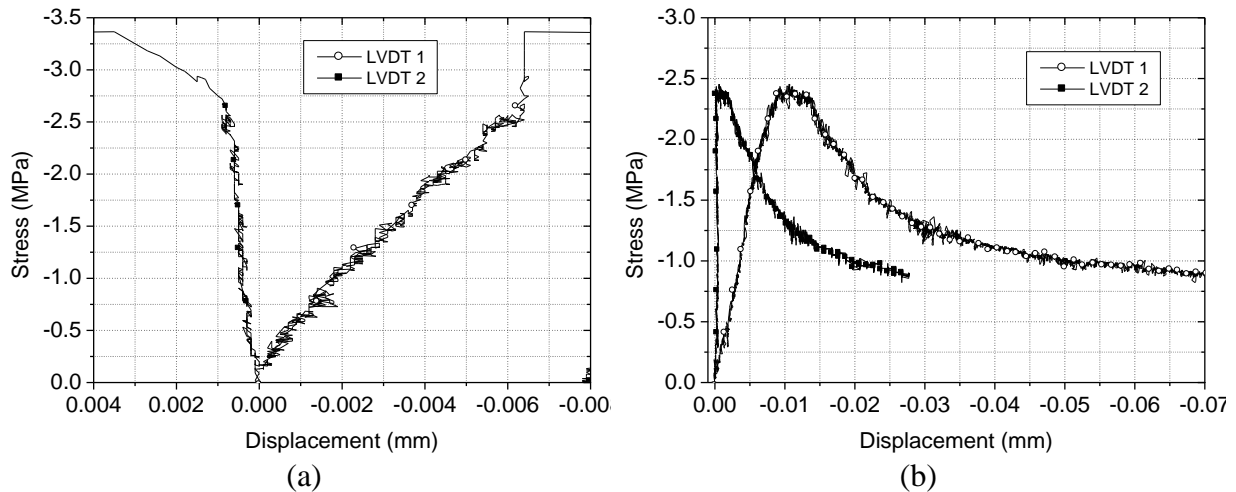

(a)   (b)

Figure 6: Fracture of the specimens in direct tensile test: (a) typical fracture and (b) fracture in the zone with larger cross section.

Figure 7: Stress-displacement diagrams of the specimens in tensile tests: (a) common behaviour and (b) specimen with post-peak.

It was very difficult to avoid the rotation of the specimens because of their small size. In addition, the heterogeneity of the material is enough to cause the rotation of the specimens during the test, since one region of the specimen has different stiffness from other regions. So, in spite of the low velocity used in load application (0.08 µm/s),it was not possible to obtain the post-peak behaviour. In fact, post-peak behaviour was only obtained in three of the twentyfour specimens tested..

In the case of compressive tests parallel to the bed joint, 2C-units and 3C-units presented distinct behaviour, as the geometry of unit had significant influence. The behaviour of blocks of 2C-units can be divided in two phases. Firstly, the blocks exhibited compressive deformations due to the increasing of vertical loading. However, the distributed vertical load at the top and at the base of the unit created flexural efforts. The flexure in shells of blocks was prevented by the presence of the web, leading to tensile stresses developing in the webs. When tensile stresses in the webs reached the tensile strength of the concrete, a crack appeared in this element. After this point, the LVDTs began to register tensile strains in the faceshells since there was no resistance of the web and flexure was predominant, see Figure 8.
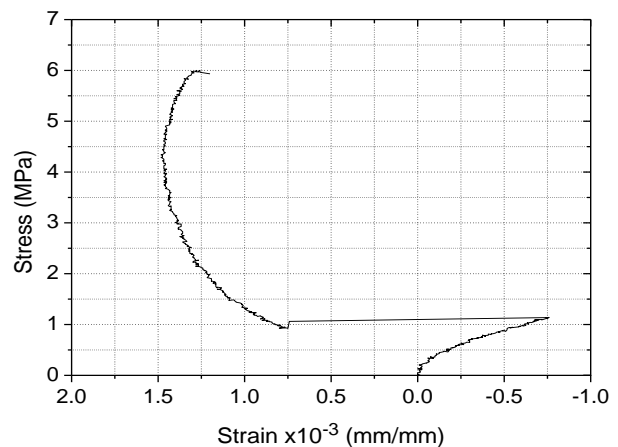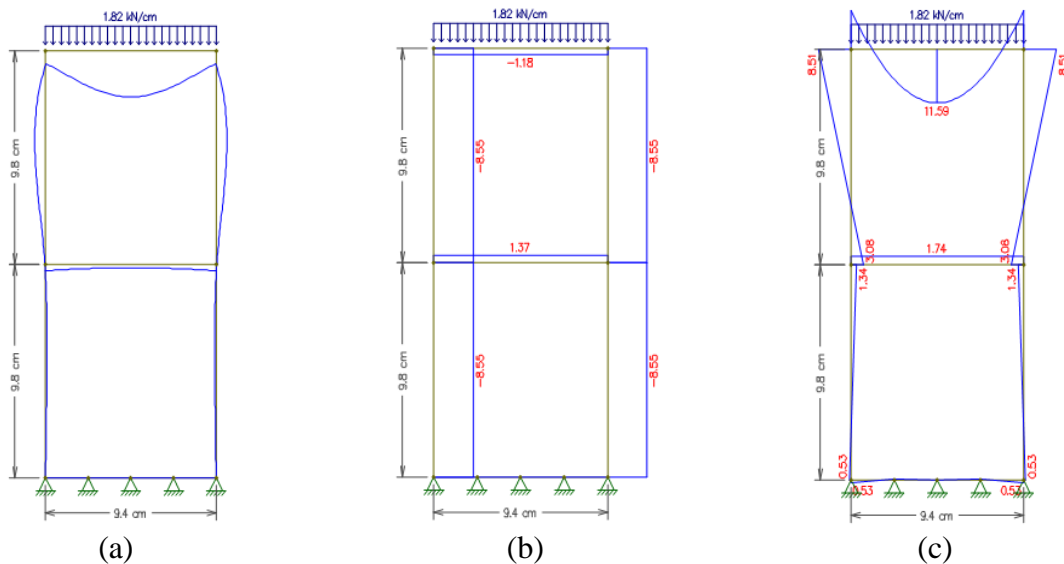

Figure 8: Behaviour of 2C-units under compression parallel to bed joints.

The onset of the cracking of the web is clear, and identified by the discontinuity in the stress vs. strain diagram. This test can be seen as an indirect tensile test of the units if the tensile strength of the units is the tensile strength of the web of the units.

2C-units can be represented in a simplified manner as a frame with a distributed load, as shown in Figure 9. Normal forces and moments can be evaluated from the frame and the tensile stress at the moment of the failure of the web can be calculated. With this assumption, the tensile strength of the units can be calculated by using Eq. (3):

$$f_{bt//} = \frac{N t_{web} + 6M}{h_b t_{web}^2}$$ (3)

Where, $f_{bt//}$ is the tensile strength of unit through the compressive test in the direction parallel to the bed joints, h_b is the height of the unit, t_{web} is the thickness of the web and N and M are the normal force and bending moment acting in the web, respectively.
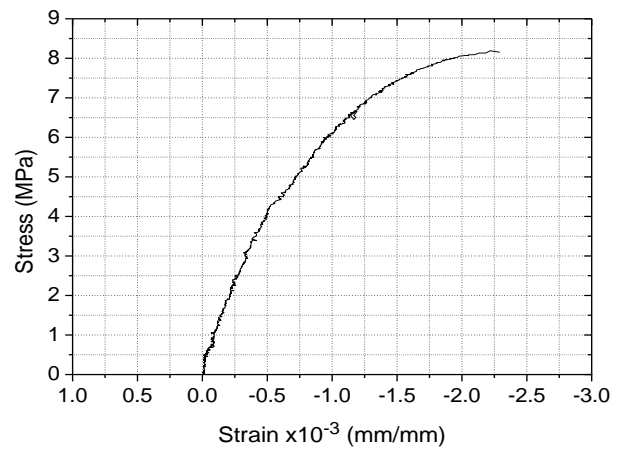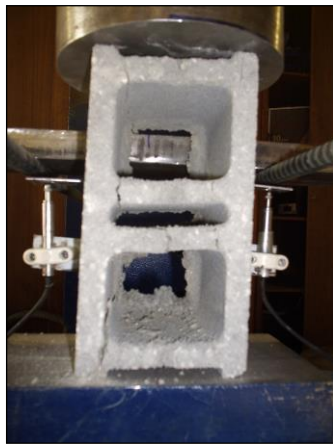

(a)   (b)   (c)

Figure 9: Behaviour of 2C-units tested under compression parallel to the bed joint before cracking of the web: (a) deformed state, (b) diagram of normal forces and (c) diagram of bending moments.

The value of $f_{bt//}$ measured in the tested specimens was 3.21 MPa with a coefficient of variation equal to 35%. Tensile strength evaluated through the compressive test in the direction parallel to bed joints was only 2% higher than the value found in direct tensile test. Thus, the compressive test seems to be an alternative method of measuring the tensile strength of the unit. It is easier to carry out and avoid problems such as rotation of the specimen and debonding of the specimen and the plates.

In case of 3C-units, two samples were prepared for the test: blocks with capping and without capping. Firstly, the use of capping had the objective to avoid the rupture of the frogged ends of the blocks due to the concentration of stresses. However, it was decided to test blocks without capping since the concentration of stresses in bands of units also happens in a masonry wall built

with this block. Both specimens had a similar failure mode, although specimens with capping reached lower forces probably because the different velocity of distribution of stresses. Blocks of 3C-units also showed cracks in the webs as in case of 2C-units, see Figure 10. However, these cracks appeared only at the end of the test. Figure 11 shows moments and normal forces in shells and webs of the 3C-units. A very small flexure in webs or shells can be observed in specimens of 3C-units. The presence of two webs in the middle of 3C-unitsincreased the stiffness of the block considerably, see Figure 12. Shells of 3C-units reached high stresses before the failure of webs and these stresses reduced the stiffness of shells changing the configuration of moments and normal forces in block. Shells of 3C-units reached a compressive stress equal to 24.60 MPa at the moment of failure. Considering the compressive strength perpendicular to bed joints on the net area (22.83 MPa) as a reasonable value to evaluate the compressive strength of the concrete block material, shells did not presented sufficient capacity to resist the loading after the failure of webs and failed as well.
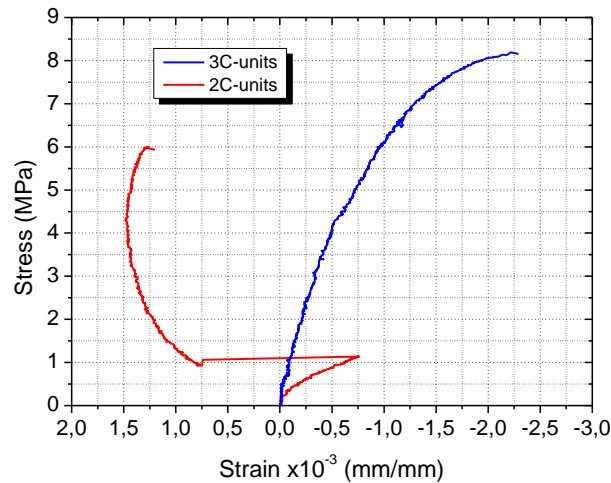

Figure 10: Behaviour of 3C-units under compression parallel to bed joints.

(a)   (b)   (c)
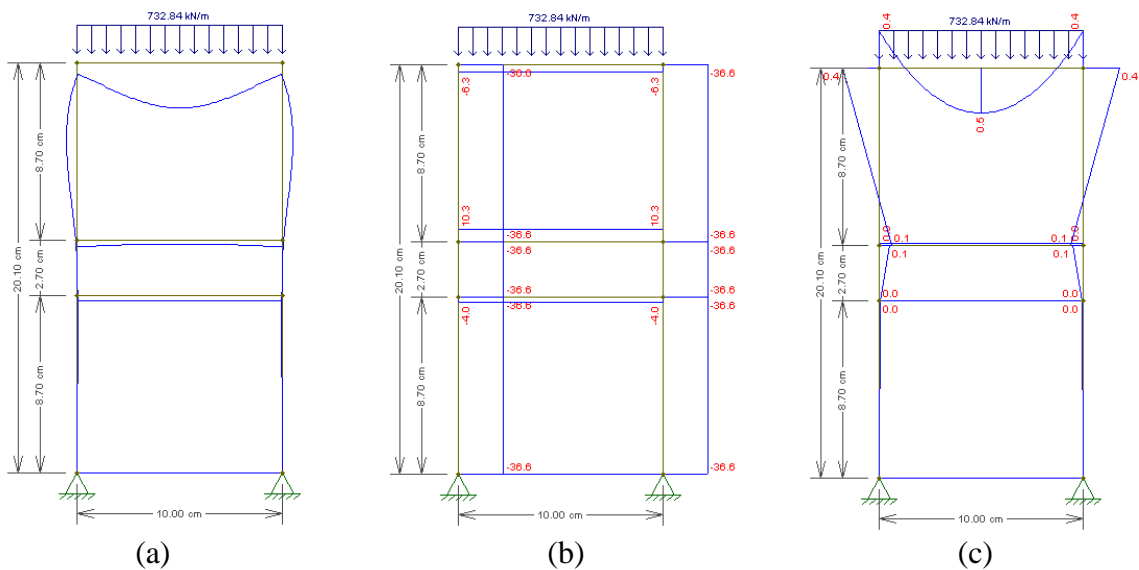
Figure 11: Behaviour of 3C-units tested under compression parallel to bed joint before cracking of the web: (a) deformed state, (b) diagram of normal forces and (c) diagram of bending moments.

Figure 12: Comparison between the behaviour of 3C-units and 2C-units.

In the case of the three-cell geometry, this behaviour made it difficult to perform the correlation between the results of the test and the value of tensile strength of block,. In this way, a limitation of the compressive stresses in the shells at the moment of failure of the webs should be considered in order to ensure the feasibility of using the compressive test parallel to bed joints to evaluate the tensile strength of concrete masonry blocks. Thus, the compressive stresses in shells at the moment of failure of webs should be lower than ⅓ of the compressive strength of the concrete block material in order to ensure the elastic behaviour of the shells and the validity of equation (3).

CONCLUSION

This paper proposed a new experimental test based on the compression parallel to bed joints for determination of tensile strength of concrete masonry blocks. Two different geometries were used in the tests and the results were compared with direct tensile tests carried out in specimens cut from the blocks. From the experimental results, the following preliminary conclusions can be drawn:

a) Compressive tests parallel to bed joints are easier to perform than direct tensile tests and may be an alternative method to evaluate the tensile strength of concrete masonry blocks;
b) Geometry of the block has a large influence on the feasibility of using compressive tests parallel to bed joints in the evaluation of tensile strength of concrete masonry blocks. For two-cell blocks without frogged ends good results were obtained;

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