



## **Mechanical behavior of concrete block masonry - Influence of vertical joint**

Gihad Mohamad<sup>1</sup>, Paulo Brandão Lourenço<sup>2</sup> and Humberto Ramos Roman<sup>3</sup>

### **Abstract**

The main objective of this study is to verify, through compression tests on different prisms, the vertical and horizontal deformability and the failure modes of the components of concrete blocks under compression. In this study two mortar mixes were tested, according to the recommendations of BS-5628 1992, along with two types of prism, with and without the presence of a vertical joint. The conclusions were: the appearance of non-linearities of the masonry corresponds to an increase in the lateral strain due to extensive cracking of the material and a progressive increase in the Poisson ratio; the cracks in the three-block prisms built with the mortar type I were vertical, occurring symmetrically on both sides; the prisms built with mortar type II had, as a consequence of localized crushing, an association with vertical cracks due to the concentrations of stresses at some points; the presence of a vertical joint led to the appearance of separation cracks between the middle block and the vertical mortar joint, when the stress reached approximately 30% of the compressive strength of the set; the prisms with two whole blocks and one vertical joint (B) built with the mortars of mixes I and II had a compressive strength of the order of 42% and 66% of the prisms with three whole blocks (A), respectively.

### **Introduction**

Unreinforced structural masonry can be considered as a system formed of distinct materials which interact to respond to vertical and horizontal loads produced by self-weight, wind and seismic activity during its useful life, with a low tensile strength, as stated by Vermeltfoort 2004.

---

<sup>1</sup> Universidade Federal do Pampa. Departamento de Engenharia Civil, 97542-620, Alegrete, RS, Brasil. gihad.civil@gmail.com

<sup>2</sup> Universidade do Minho, Departamento de Engenharia Civil, 4800-058 Guimarães, Portugal. pbl@civil.uminho.pt

<sup>3</sup> Universidade Federal de Santa Catarina, Departamento de Engenharia Civil. 88040-900, Florianópolis, SC, Brasil. humberto@ecv.ufsc.br.

It is worth noting that the behavior of the set is dependent not only on the quality of each material employed, but also on the physico-chemical interactions between the materials. Thus, a structural masonry wall must be treated not as a function of the characteristics of its individual materials but as a composite material resulting from the interaction of the unit, of the mortar and also, when used, the grout. It is therefore important to understand completely the behavior of 'masonry material', which can vary from unit to unit and with the different types of mortar and grout. For this reason, the structural performance of masonry walls cannot be estimated without carrying out tests on the walls or prisms of the materials to be used.

The main mechanical properties which masonry walls must offer are the compression, tensile, flexural and shear strength. Of these properties, the most important is the compression strength since, in general, masonry walls are submitted to more intense vertical loads than horizontal loads produced by wind or seismic activity. Previous studies on blockwork masonry indicate that the failure mode of masonry occurs under a biaxial state of tension-compression stress and the nonlinearity of the stress-strain correspond to large increasing in the Poisson's ratio which are associated with microcracking of the concrete and to evaluate the carrying capacity of the wall and to improve the knowledge about the compressive strength is important to understand the mechanisms involved in deformation and failure (Hamid 1979, Cheema 1986, Dhanasekar 1985, Hendry 1981, Khoo 1972, Page 1978 and Shrive 1985).

This study aims to analyze the mechanical results for prisms relating to the failure mode as a function of the ratio between the strength of the materials (block and mortar), as well as to initiate a discussion on the linear and non linear deformability characteristics of the set. This paper addresses different relevant issues for the discussion of the mechanics of hollow concrete block masonry under compression.

### Compressive strength of masonry, blocks and mortars

It is important to highlight that the compressive strength and failure mode of masonry components are important for the specification of appropriate materials for the construction of a building. Thus, for the different types of units and mortars, the behavior of the 'structural masonry' has variations, whether in the failure mode or in its strength compared with the

Figure 1 shows a diagram of the distribution of stresses in the materials.

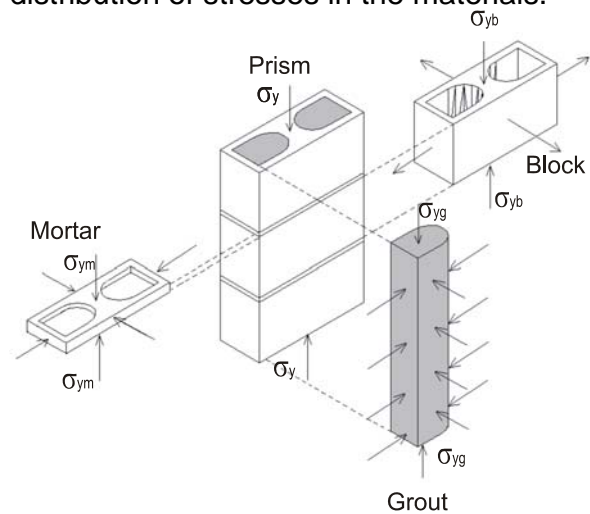


Figure 1. Vertical and horizontal stresses in materials.

materials strength of which it is composed (unit, mortar and grout) by Mohamad 2007. A commonly used concept to define this relation is called the efficiency factor. This factor is obtained by dividing the compressive strength of the masonry prism by the compressive strength of the unit. Generally, this value is lower than one and decreases as a function of the increase in the resistance of the unit.

## Objectives of the study

This study aims to evaluate the mechanical behavior of two types of concrete block prisms produced with two mortar mixes, through the parameters of compressive strength, axial deformability, lateral deformability and failure mode.

## Experimental methodology and program

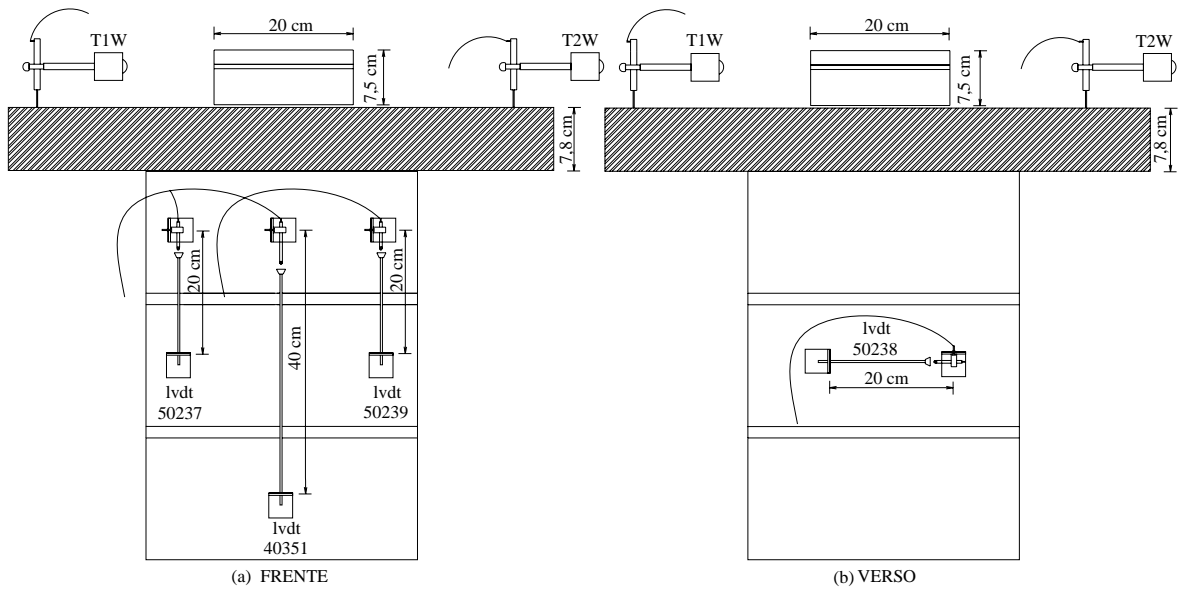
For the experimental studies two types of prism were tested, the first named 'A' containing three whole concrete blocks joined by two horizontal mortar joints. In this type of prism there are only two bed joints. The second type of prism, named 'B', is three blocks high, the middle block being composed of two half blocks with one vertical and two horizontal mortar joints. The main objective of the tests was to determine the influence of the vertical joint on the deformability characteristics and failure mode of the set. The total number of prisms of type A was eight, that is, four for mortar mix I and four for mortar mix II, with the volume compositions shown

in Table 1. For type B the number of prisms built with mixes I and II were 4 and 6, respectively. A larger number of prisms were built with mix II due to the possibility that mortars with a lower strength may have higher scattering in the values.

**Table 1.** Proportion of cement, limestone and sand in the mortar mixes (by volume).

Series	Mix – Proportion of materials used (by volume)		
	Cement	Limestone	Sand
I	1	0.25	3
II	1	0.5	4.5

The axial strain measurement devices for one and two bed joints are shown in Figs. 2 and 3. A total of six LVDTs with different displacement fields were used. The LVDTs were numbered as follows: numbers: 50237, 50238 and 50239, with a maximum displacement field of  $\pm 1$  mm (measurement base of 20 cm); and LVDT number 40351 had a maximum displacement field of  $\pm 5$  mm (measurement base of 40 cm). The LVDTs T1W and T2W accompany the steel plate and allow to observe whether the load transfer causes flexion.



**Figure 2.** Positioning of the LVDTs in the tests with prisms made of three blocks (type A).



**LVDTs:  
50237, 40351 and 50239**



**LVDT number 50238**

**Figure 3.** Positioning of the LVDTs in the tests with prisms made of two whole blocks (type B).

## Experimental program

### Experimental results for the type A prisms

The individual ( $f_{prism}$ ) and average ( $f_{p\ average}$ ) results for compressive strength for the three-block prisms (type A) are given in Table 2, with the respective standard deviations and coefficient of variance (cv). The values for the compressive strength of the prisms are given in net area. Table 3 shows the average results for the block, mortar, and prism strength together with the  $f_{prism}/f_{block}$  (efficiency factor) and  $f_{mortar}/f_{block}$  ratios.

**Table 2.** Average results for compressive strength of the prisms.

Series	I	II
$f_{prism}$ (MPa)	15.9	15.1
	15.1	16.0
	16.1	15.0
	13.7	11.1
$f_{p\ average}$ (MPa)	15.2	14.3
Standard deviation (MPa)	1.09	2.18
cv (%)	7.2	15.2

**Table 3.** Compressive strength of blocks, mortars, prisms and their ratios.

Series	$f_{block}$ (MPa)	$f_{mortar}$ (MPa)	$f_{p\ average}$ (MPa)	$f_{p\ average}/f_{block}$	$f_{mortar}/f_{block}$
I	23.1	19.8	15.2	0.66	0.86
II	23.1	7.2	14.3	0.62	0.31

The potential equation, using the average values for the prisms, establishes a correspondence between the  $f_{p\ average}/f_{block}$  and  $f_{mortar}/f_{block}$  values, allowing a comparison between the influence of the mortar and that of the block, in the way given in the EUROCODE 6 2005, Equation [1].

$$f_{pm\acute{e}dio} = 0,6929 \cdot f_{mortar}^{0,0597} \cdot f_{block}^{0,9403} \quad [1]$$

From the coefficient obtained in Equation 1, it can be noted that the compressive strength of the mortar has little influence on the compressive strength of the prism. From the experimental results it was not possible to estimate the increase in the stiffness of the mortar joint due to the confinement. Table 4 gives the average results for the deformability, the stress/strength ratio and the secant elasticity modulus of the prisms with a bed joint, obtained for the LVDTs designated as 50237 and 50239. It was verified that there is an increase in the average compression strain of the prisms, due to the decrease in

the compressive strength of the mortar. The secant elasticity modulus values calculated for the stress/strength ratio ( $\sigma/f_c$ ) of 30% for prisms I and II were close.

**Table 4.** Average experimental results for the strain of the prisms.

Prism	n*	Average strain (50237 and 50239)	$\sigma/f_c$	Elasticity Modulus (MPa)
I	4	0.0002266	0.31	20989
II	4	0.0002447	0.33	19405

\* n is the numbers of the specimens;

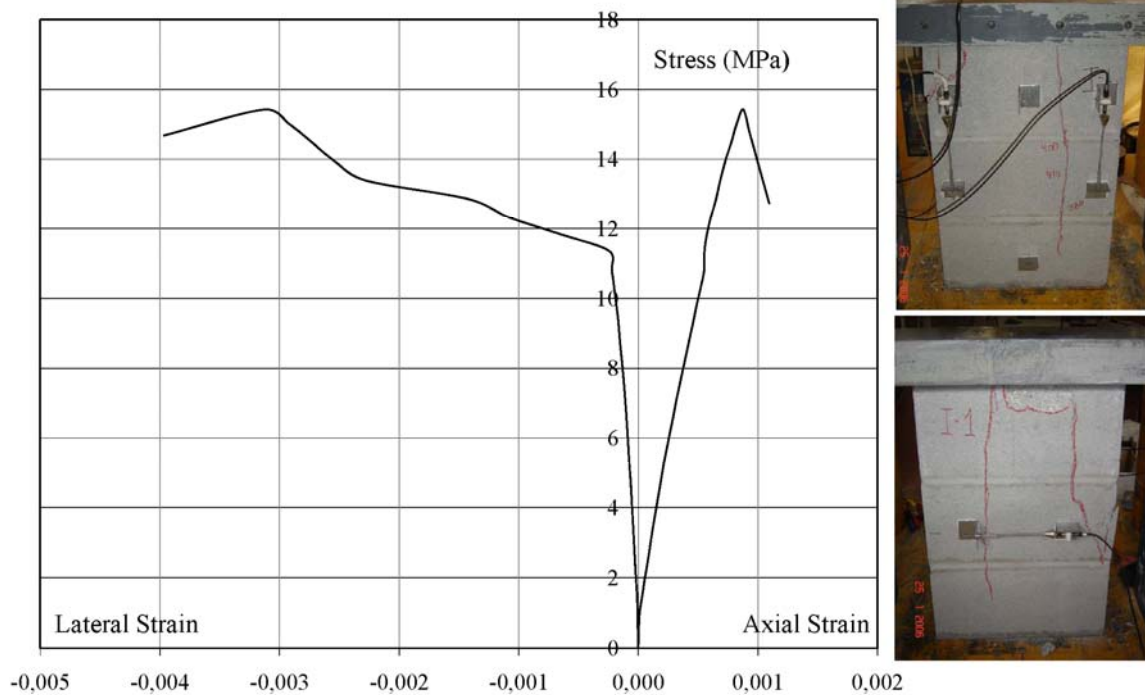
Table 5 shows the average results for the prism strain, the stress/strength ratio, the Poisson ratio and the secant elasticity modulus of the prisms. In this case the strain of the two bed joints was considered. In the same way, the horizontal strain of the set at half the prism height was verified, allowing the determination of the Poisson ratio of the prism.

**Table 5.** Average experimental results for the strain of the prisms.

Prism	n	Strain 40351	Strain 50238	$\sigma/f_c$	Poisson	Elasticity Modulus (MPa)
I	4	0.0002962	0.0000670	0.31	0.22	16056
II	4	0.0003098	0.0000866	0.33	0.28	15326

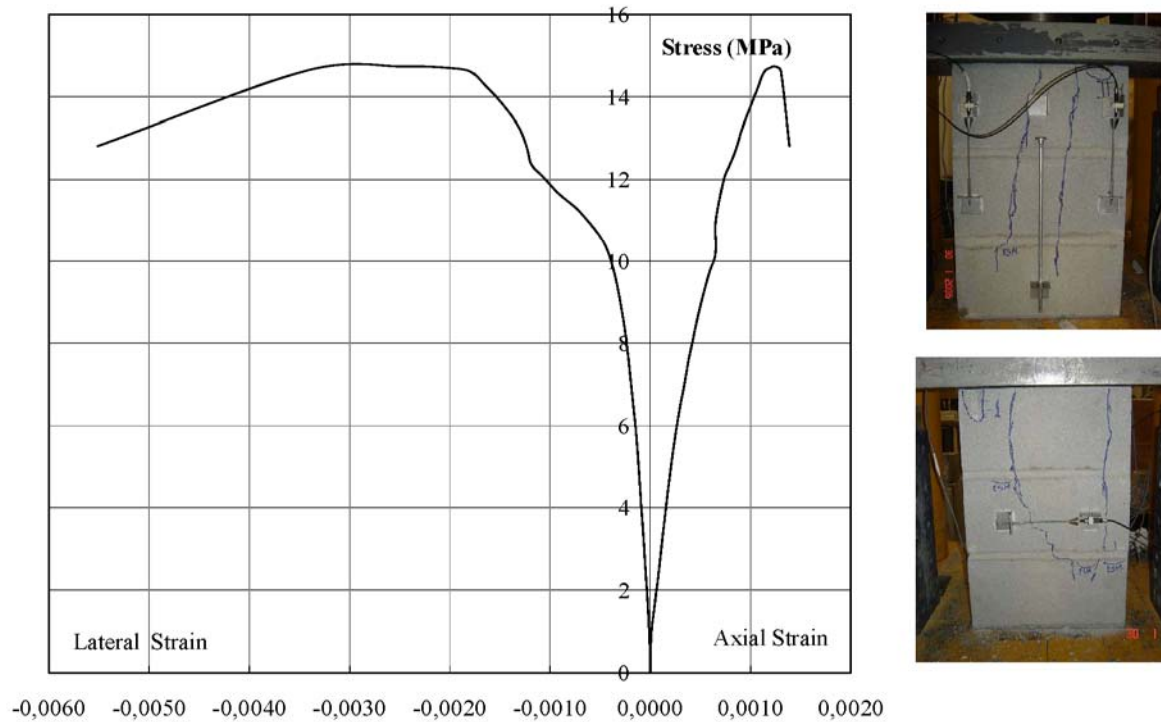
\* n is the numbers of the specimens;

Figures 4 and 5 show the axial and lateral stress-strain diagrams for the prisms built with mortar mixes I and II.



**Figure 4.** Stress-Strain diagram for prism A and mortar mix I.

For prism A of mix I an increase in the lateral strain can be observed until the stress reaches 0.80 of compressive strength, as shown in Fig. 4. For the prisms with mix II localized crushing and crumbling of the prisms was observed. There was no instantaneous increase in the lateral strain. The areas of crushing were located in the upper mortar joint of the prism for a stress level close to 50% of the compressive strength, after which the crumbling of the block surface began and the propagation of vertical cracks.



**Figure 5.** Stress-deformation diagram for prism A and mortar mix II..

### Experimental results for type B prisms

The individual results for the compressive strength of the prisms are given in Table 6, with the respective values for the average, standard deviation and coefficient of variation (cv). The cvs of the results were 11.1% and 16.9%, respectively, for the mortar mixes I and II. The standard deviations of the samples of mixes I and II were 1.19 and 1.45 MPa, respectively. It can be observed that, for this type of prism, the vertical joint can introduce an increase in the cv of the results. This probably occurs due to the fact that the failure process begins at the vertical joint. The average results for the compressive strength of the prisms with a vertical joint were lower than those for the prisms without a vertical joint (A). This decrease was 42% and 66% for the mortar mixes I and II, respectively. Table 7 shows the average results for the compressive

strength of the block, mortar and prism, together with the  $f_{prism}/f_{block}$  (efficiency factor) and  $f_{mortar}/f_{block}$  ratios.

**Table 6.** Average results for the compressive strength of prisms (type B).

Series	I	II	
$f_{prism}$ (MPa)	10.2	7.0	9.9
	10.9	9.2	6.5
	12.3	9.3	-
	9.5	9.6	-
$f_p$ average (MPa)	10.7	8.6	
Standard deviation (MPa)	1.19	1.45	
cv (%)	11.1	16.9	

\* n is the numbers of the specimens;

**Table 7.** Compressive strength of blocks, mortars, and prisms and their ratios (type B).

Series	$f_{block}$ (MPa)	$f_{mortar}$ (MPa)	$f_{p\ average}$ (MPa)	$f_{p\ average}/f_{block}$	$f_{mortar}/f_{block}$
I	23.1	18.2	10.7	0.46	0.79
II	23.1	8.5	8.6	0.37	0.37

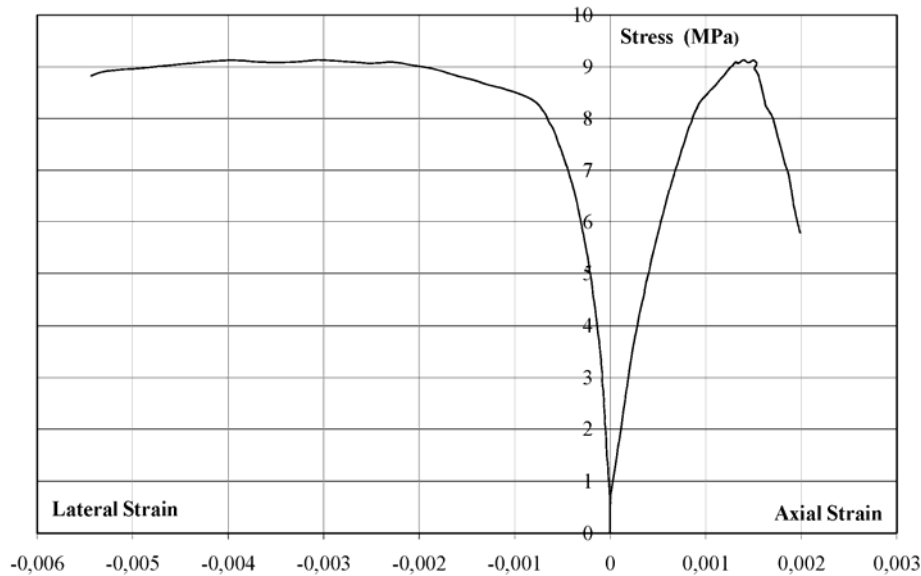
The potential equation establishes a correspondence between the  $f_{p\ average}/f_{block}$  and  $f_{mortar}/f_{block}$  values, allowing a comparison with those provided in the EUROCODE 6 2005, as shown in Equation (2).

$$f_{p\ average} = 0.4972 \cdot f_{MORTAR}^{0.30} \cdot f_{BLOCK}^{0.70} \quad [2]$$

The results show a greater influence of the block strength in the prism strength, where the exponents of Equation (2) are 0.30 and 0.70 for the mortar and block, respectively. Table 8 gives the average results for the secant elasticity modulus for the stress/strength ratio ( $\sigma/f_c$ ) of 30%, considering one and two bed joints, with the Poisson ratio measured between the block and the vertical joint. For the prisms built with a vertical joint there was a progressive increase in the Poisson ratio, with values significantly higher than those of conventional three-block prisms. Also, a decrease in the value for the secant elasticity modulus of one and two bed joints for the prisms with a vertical joint was verified. The reduction in the secant elasticity modulus of the prism with a vertical joint was 18% in relation to the prism without a vertical joint. On considering one vertical joints the average reduction was approximately 8% in relation to the cases without a vertical joint. Figures 6 and 7 show the axial and lateral stress-strain diagrams for the prisms made with mortar mixes I and II, respectively.

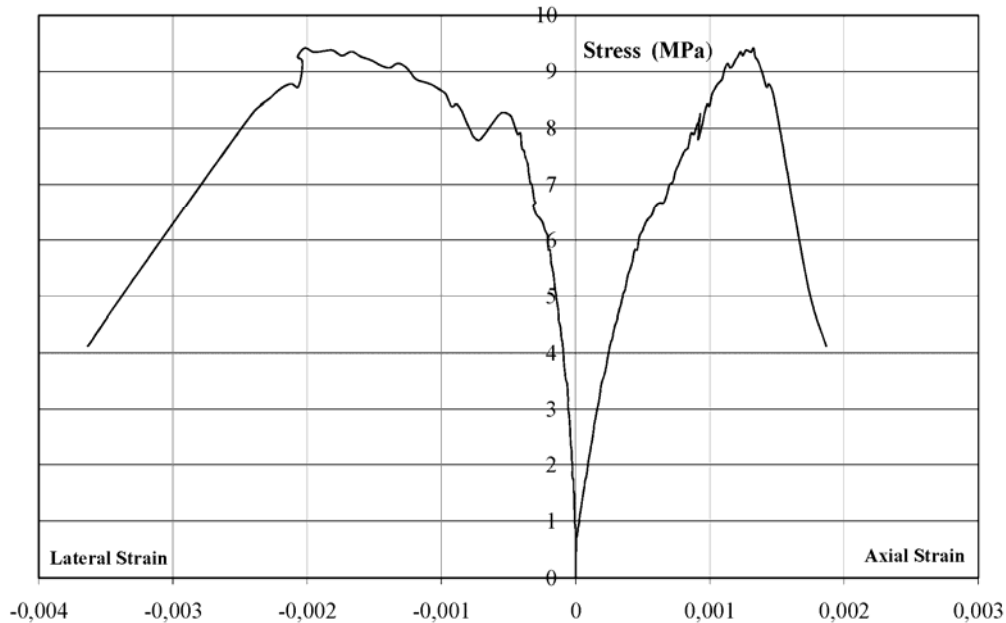
**Table 8.** Elasticity modulus and Poisson ratio for the prisms with vertical joints (type B).

PRISM	n*	$\sigma/f_c$	Elasticity modulus - one Joint	Poisson
I	4	0.34	17620	0.44
II	6	0.32	16480	0.50



**Figure 6.** Stress-strain diagram for prism B and mortar mix I.





**Figure 7.** Stress-strain diagram for prism B and mortar mix I.

## Conclusions

The appearance of non-linearities in masonry corresponds to an increase in the lateral strain due to the extensive cracking of the material and to a progressive increase in the Poisson ratio. The cracks in the three-block prisms built with mortar mix I were vertical, occurring in a symmetrical way on both sides. None of the samples had crushing points on the bed joint. It could be observed visually that the prism began to behave as a single material. The cracks were symmetrical, vertical and dispersed for this type of prism.

The prisms built with mortar type II had, as a consequence some localized crushing with vertical cracks due to the stress concentration at some points. In the failure process, the beginning of a loss of cohesion of the mortar, the crushing of the mortar joint and the crumbling of the upper and lower surfaces of the block, were verified.

For the prisms built with a vertical joint there was a progressive increase in the Poisson ratio, the values being higher than those of conventional prisms with three whole blocks. The presence of a vertical bed joint resulted in the appearance of separation cracks between the middle block and the vertical joint of the mortar. The crack was observed when the stress reached approximately the 30% of the specimen. The prisms built with mortar mix type I had the following failure modes: localized crushing of the bed mortar, crumbling of the block surface and vertical cracks in the block. It was verified that there was a significant reduction in the prism strength generated by the presence of a vertical joint.

The prisms with two whole blocks and a vertical joint, built with mortar mixes I and II, had a compressive strength of the order of 42% and 66% of the prisms with three whole blocks, respectively. The prisms with three whole blocks had average efficiency factors of the order

of 0.63. For the prisms with two whole blocks and a vertical joint the walls had average efficiency factors of 0.42 and 0.45 for mixes I and II, respectively.

## References

- BS 5628 1992: British standard institution - Code of practice for use of masonry – Part 1: Structural use of unreinforced masonry. London.
- Cheema 1986: Cheema, T. S. and Klingner, R. E, “Compressive Strength of Concrete Masonry Prism” American Concrete Institute- ACI Structural Journal , January, vol. 83(n° 1):88-97.
- Dhanasekar 1985: Dhanasekar, M, “Performance of brick masonry under biaxial loading”, Dissertation submitted to the University of Newcastle in partial fulfillment of requirements for degree of doctor of philosophy, Australia, 1985.
- Eurocode 6 2005: European standard, “Design of masonry structures – Part 1-1: General rules for reinforced and unreinforced masonry structures”.
- Hamid 1979: Hamid, A. A. and Drysdale, R. G, “Behavior of concrete block masonry under axial compression”, American Concrete Institute Journal, 76, n° 6, pp. 707-721.
- Hendry 1981: Hendry, A. W, “Structural brickwork”, Edited by Halsted Press book, John Wiley & Sons, New York,USA, ISBN 0-470-27109-4.
- Khoo 1972: Khoo, C. L, “A failure criterion for brickwork in axial compression”, Thesis presented to University of Edinburgh, University of Edinburgh, Scotland.
- Mohamad 2007: Mohamad. G, “Mecanismo de ruptura de alvenarias de blocos a compressão”, Universidade do Minho, Departamento de Engenharia Civil, 312 p. Tese de Doutorado.
- Page 1978: Page, A. W, “Finite element model for masonry”, Journal Structural Division ASCE, Vol. 104(8), 1267-1285.
- Shrive 1985: Shrive, N. G, “Compressive strength and strength testing of masonry”. Proc. 7 IBMAC, Eds. T. McNeilly and J. C. Scrivener, Melbourne, BDRI, 699-710.
- Shrive 1985: Shrive, N. G and El-Rahman, “Understanding the cause of cracking in concrete: A diagnostic aid”, Journal Concrete International, Volume 7, Issue 5, May.
- Vermeltoort 2004: Vermeltoort. A.T, “Brick-mortar Interaction in masonry under pressure”, PhD thesis, Technical University of Eindhoven.