ANALYSIS OF THE CONTACT AREA OF CONCRETE BLOCK MASONRY STRUCTURES IN RELATION TO THE TYPE OF MORTAR BEDDING AND USE OF DIMENSIONAL ADJUSTMENT PIECES

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ABSTRACT
Currently, structural masonry still has some advantages in the construction industry when compared with other conventional construction systems. This paper studies the influence of the contact area in structural concrete masonry units with respect to the compressive strength of wallettes and prisms by varying the type of mortar bedding (full and face-shell bedding) and the use of dimensional adjustment pieces, known as "*rapaduras*", to achieve the modulations in masonry walls. This analysis was carried out in order to verify whether the increase of the contact area is proportional to the increase of the compressive strength of the wallettes and prisms, thus establish a rule to be followed by the designer in this aspect. Experimental tests were carried out to characterize the materials and to assess the compressive strength of units, prisms, and wallettes. All materials complied with the current standard requirements. The experiments also showed that the compressive strength is not proportional to the contact area, although this is an important property to estimate the loss or gain of compressive capacity.

KEYWORDS: Mortar type, dimensional adjustment pieces, contact area, structural masonry

INTRODUCTION
Masonry is a construction process produced in a building site, resulting from the union of bricks or blocks called masonry units, through mortar joints, which form a hardened and cohesive set. It is designed to resist compressive strength loads or also a combination of loads, and may contain reinforced concrete or mortar in the horizontal and/or vertical plane (Machado, 2001).

In the construction process, the type of mortar bedding can be decisive in the production and performance of the construction work. The partial (or ridges) mortar bedding in horizontal joints has been widely used as it promotes a faster bonding. Furthermore, the incompatibility between the dimensions of the components and of the construction often results in higher density dimensional adjustments, which when not foreseen in the project, lead to improvisation in the construction work. One such example is the use of small massive precast members, known as "*rapaduras*", industrialized or molded at the work site, whose role is to fill the existing voids.

The main objective of this paper is to conduct an analysis of the contact area in the concrete block masonry in comparison with the compressive strength of the wallettes by changing the type of mortar bedding (full and face shell), and the use of dimensional adjustment pieces ("*rapaduras"*) in order to verify whether the increase in the contact area of the region is proportional to the increased strength of the wallettes and prisms, thus create a rule to be followed by the designer in this aspect.

EXPERIMENTAL PROGRAM

The experimental program studied the behavior of the masonry on specimens such as prisms and wallettes. The tests only included compressive strength, with uniformly distributed load, monotonic static load.

Therefore 4 types of series were built:
a) Series I– usual dimensions with full mortar bedding;
b) Series II– usual dimensions with face shell mortar bedding;
c) Series III–adjusted and with full mortar bedding;
d) Series IV– adjusted and with face shell mortar bedding.

Testing the compressive strength of the specimens

The tests performed included the compressive strength of the prisms, wallettes and cylindrical mortar specimens at 28 days after molded.

Table 1 shows the number of specimens tested per series.

Table 1 − Total prisms and wallettes to be tested

Series type	Prisms	Wallettes	Mortar cylindrical specimens
I series	12	6	6
II series	12	6	6
III series	12	6	6
IV series	12	6	6
Full test specimens	48	24	24

Figure 1 shows the nominal dimensions of the different specimens used in this study.

The prisms were not instrumented, unlike the wallettes, which had four transducers, two placed on each face.

As capping material, soft wooden ceiling in buildings were employed. This type of capping is simple and easy to use. For the capping of the mortar specimens, their surfaces were rectified with a Refining machine, achieving regular and smooth surfaces, ideal for uniform load distribution on the surfaces of the cylindrical specimens, as indicated by the standard for this test procedure.

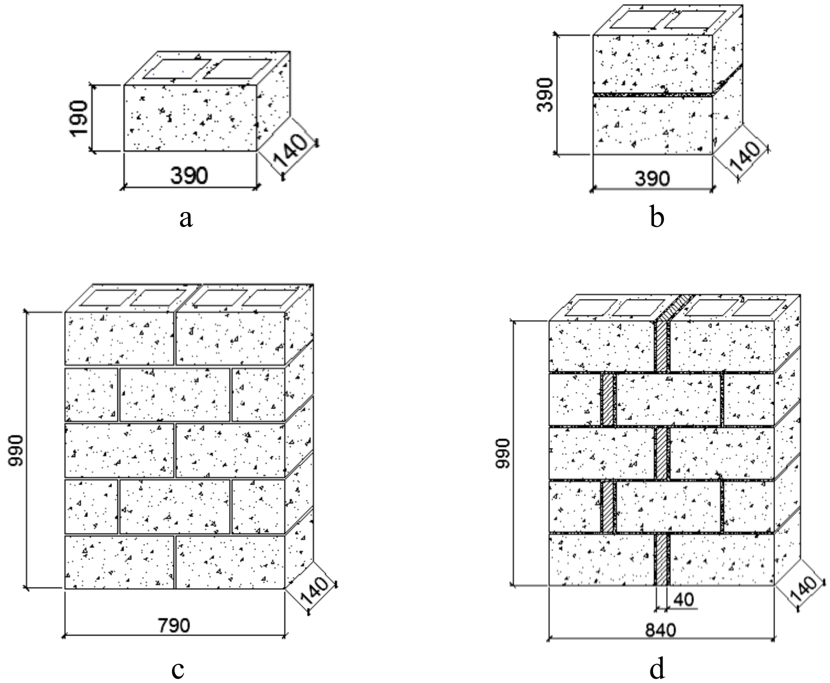


Figure 1: Nominal dimensions of: a) Blocks; b) Prisms; c) Wallettes without adjustment; and d) Wallettes with adjustment (measured in mm)

ANALYSIS OF RESULTS

The following are the mean values of the data and the results obtained in the experimental test and also their analysis.

For a better understanding of the results and the conclusions, the following statistical methods were used: the F test for the analysis of the homogeneity of variances, and next the T-test or "Student's t test", in view of the F test previously performed to compare the means of the samples.

In the analyzes performed in this study, as a null hypothesis it assumed the equality between the means or the variance between the two sets of data at a significance level of 5% (α = 0.05). These analyzes used a commonly available spreadsheet program.

Compressive strength of the bedding mortar

Table 2 shows the compressive strength results of the mortar used to prepare the prisms and the -wallettes of the four series, and also of the statistical results.

Table 2: Compressive strength results of the bedding mortar

Series	Mean strength (f_{am}) (MPa).	Standard Deviation (Sd) (MPa)	Coefficient of Variation (CV) (%)
I	7.22	1.93	7.77
II	6.12	1.82	4.44
III	7.40	2.18	11.84
IV	6.44	2.22	8.28

Analyzing the results shown in Table 2, it can be stated that the compressive strength of the mortar was expected, according to BS 5628: Part 1 (1992), the mortar type (ii), whose feature is of 1:0.5:4.5, and mean strength of 6.5 MPa in the laboratory.

Compressive strength of the blocks

The compressive strength tests of the units generally showed a cone-shaped failure, typical of the compressive load of a test-specimen confined at the ends (DRYSDALE et al, 2003).

Table 3 shows the results of the compressive strength of the blocks of each batch.

Table 3: Results of the compressive strength of the units

Batch	Series	Mean compressive strength (f_{bm}) (MPa).	Standard deviation(MPa)	Coefficient of Variation (%)	Characteristic compressive strength (f_{bk}) (MPa)
1	I e II	11.16	0.34	3.05	10.25
2	III e IV	7.48	0.16	2.16	7.10

Overall, the characteristic compressive strength of the blocks of the two batches was greater than that stated by the supplier regarding the characteristic strength: 4.5 MPa.

Compressive strength of the prisms

Table 4 shows the results of the compressive strength of the prisms. Recalling that series I and III correspond to the full mortar bedding and series II and IV to the face shell mortar bedding, and that between these pairs of series the compressive strength of the blocks differ.

Table 4: Results of the compressive strength of the prisms

	Series	Mean strength of blocks f_{bm} (MPa)	Mean strength of prisms f_{pm} (MPa)	Sd (MPa)	CV (%)
Full mortar bedding	I	11.16	7.82	0.81	10.34
Face shell mortar bedding	II		5.25	0.47	8.95
Full mortar bedding	III	7.48	5.83	0.25	4.23
Face shell mortar bedding	IV		3.55	0.58	16.29

Table 4 illustrates clear evidence that the prisms prepared with face shell mortar bedding showed less compressive strength than the prisms with full mortar bedding, with a mean difference of

36%. This difference was significant, according to statistical analysis, confirming that the type of mortar bedding influences the compressive strength of the prisms.

Compressive strength of the wallettes

Table 5 shows the compressive strength results of the wallettes, also recalling that the mean compressive strengths of the blocks, between the first two and the last two series differ.

Table 5: Compressive strength results of the wallettes

	Series	Mean strength of the blocks f_{bm} (MPa)	Mean strength of the prisms f_{pm} (MPa)	Mean strength of the wallettes f_{m-p} (MPa)	Sd (MPa)	CV (%)
Full mortar bedding without adjustments	I	11.16	7.82	4.62	0.54	11.76
Face shell mortar bedding without adjustments	II		5.25	4.20	0.26	6.11
Full mortar bedding with adjustments	III	7.48	5.83	3.83	0.60	15.73
Face shell mortar bedding with adjustments	IV		3.55	3.15	0.46	14.73

As can be seen, two factors are studied in these four series:

- The type of mortar bedding;
- The use of adjustment pieces (*rapaduras*).

<u>Effect of type of mortar bedding</u>

To study this effect series I will be compared to series II, which differ in the type of mortar bedding and do not exhibit adjustments; and series III with series IV, which do not have the same bedding but contain adjustments. Each pair of series to be compared has the same block strength and similar strength of the mortars.

Table 6 enables to compare the results, always taking as reference the wallettes with full mortar bedding.

Table 6: Comparison of the compressive strength results of the wallettes, analyzing the type of mortar bedding

	Series	Compressive strength f_{m-p} (MPa)	Comparison of compressive strength
Full mortar bedding without adjustments	I	4.62	II<I in 10%
Face shell mortar bedding without adjustments	II	4.20	
Full mortar bedding with adjustments	III	3.83	IV<III in 18%
Face shell mortar bedding with adjustments	IV	3.15	

The figures in Table 6 show that like the prisms, the type of mortar bedding influenced the wallettes. The decrease in compressive strength of the wallettes with face shell mortar bedding was 14% on average, in comparison with the wallettes with full mortar bedding. Statistical analysis showed significant differences between these values for the two pairs of series. Thus, it shows that the type of mortar bedding influences the compressive strength of masonry wallettes, with full mortar bedding being better.

<u>Effect of using adjustment pieces (*rapaduras*)</u>

For the study of this effect, series I was compared with series III, which differ in adjustment and exhibited full mortar bedding; and series II with series IV, which also differ in adjustment and have face shell mortar bedding.

The analysis of this aspect is somewhat more complex due to the fact that the wallettes with and without adjustments exhibited differences in the compressive strength of the blocks. On account of this fact, we analyzed the efficiency of the wallettes, standardizing them, in other words, removing the influence of the block and of the prism from the compressive strength values of the wallettes. Finally, we analyzed the standardized results of the wallettes in relation to the block and prism, thus comparing the series that show the compressive strength differences of the blocks.

Figure 2 (a) shows the standardized results of the wallettes with respect to the block and Figure 2 (b) with respect to the prism.

Table 7 shows the comparisons between the series, always taking as reference the wallettes without adjustments, with full or partial mortar bedding.

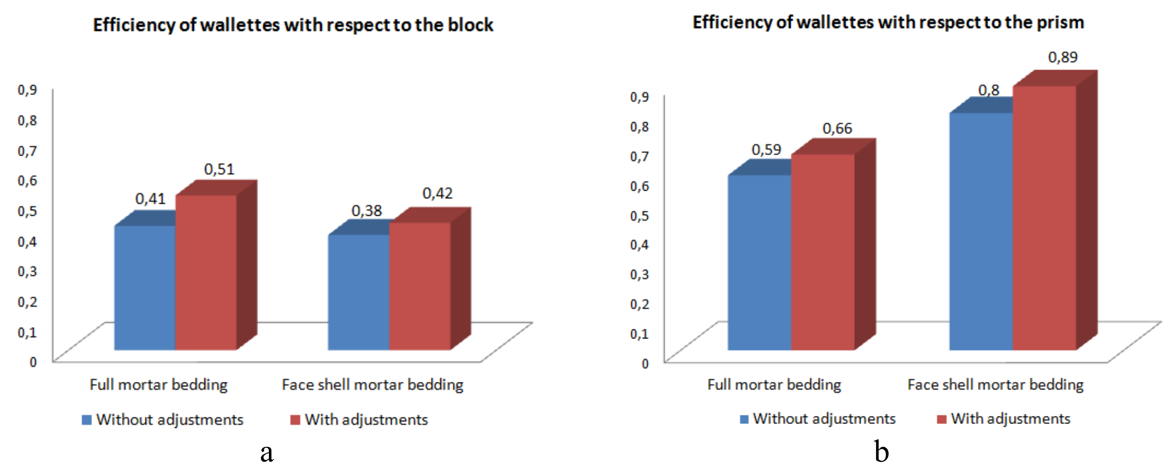


Figure 2: Efficiency of wallettes: a) With respect to the block; b) With respect to the prism

Table 7: Comparison of the efficiency of the wallettes, studying the use of adjustment pieces

	Series	Efficiency (wallette/block)	Comparison	Efficiency (wallette /prism)	Comparison
Full mortar bedding without adjustments	I	0.41	III>I in 24%	0.59	III>I in 12%
Full mortar bedding with adjustments	III	0.51		0.66	
Face shell mortar bedding without adjustments	II	0.38	IV>II in 11%	0.80	IV>II in 11%
Face shell mortar bedding with adjustments	IV	0.42		0.89	

Figure 2 clearly shows that the series with adjustments exhibited higher efficiencies than the series without adjustments. Table 7 shows how these values were higher for the standardizing of the wallettes. These values indicate that the presence of the dimensional adjustment pieces do not produce a loss of compressive strength in structural masonry wallettes. On the contrary, the adjustment has a positive influence.

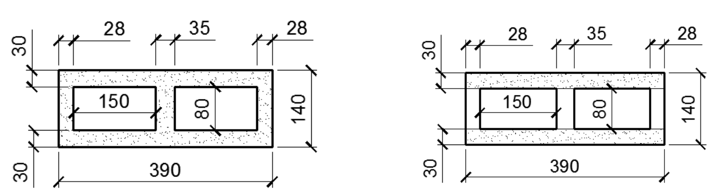
Statistically, for the two pairs of series, these differences in values were significant for a significance level of 0.05.

ANALYSIS OF THE CONTACT AREA

Up to now the compressive strength values of the prisms and wallettes were analyzed in relation to its gross area, regarding the two factors; the effect of the type of mortar bedding, with the full mortar bedding being better, and the effect of the adjustments, which produced no reduction in compressive strength of the wallettes. It is considered that these findings thus far, are due to a very important factor: “the contact area.”
In order to enrich the result analysis of this study, it was decided to demonstrate and discuss the results obtained for the contact area of the prisms and wallettes.

The contact area of the prisms

The contact area of the prisms is the region in which the mortar was placed, as illustrated in Figure 3. This area was calculated taking into account the lowest thickness of the blocks, comparing top and bottom.



a b

Figure 3: Region of the contact area of the prisms with a) Full mortar bedding; b) Face shell mortar bedding (measured in mm)

Table 8 shows the values of the contact area, the compressive strength as a function of the gross area, and a comparison of the results in the different series.

Table 8: Comparison of the contact area and compressive strength as a function of the gross area of the prisms by analyzing the type of mortar bedding

Series	Contact area (cm^2)	Comparison of the contact area	Compressive strength (MPa) (gross area)	Comparison of compressive strength
I (full)	306	II<I in 24%	7.82	II<I in 33%
II (partial)	234		5.25	
III (full)	306	IV<III in 24%	5.83	IV<III in 39%
IV (partial)	234		3.55	

According to the results in Table 8 and as expected, the region of the contact area of the prisms with face shell mortar bedding was lower than those with full mortar bedding, and also the strength. But this decrease in the contact area did not occur at the same proportion as the decrease in strength. Therefore, the contact area was not the only factor that influenced the compressive strength of the prisms, but it proved to be an important estimate for the loss or gain of strength.

Contact area of the wallettes

The contact area in the wallettes is the region where the blocks of the lower course overlap with the top course of blocks and the mortar. This area was calculated taking into account the lowest thickness of the blocks, the shape of the adjustment pieces, and then, if necessary, subtracting the spaces used by the vertical joints.

Figure 4 illustrates a representative scheme that shows the overlapping of two consecutive courses of blocks of the four series.

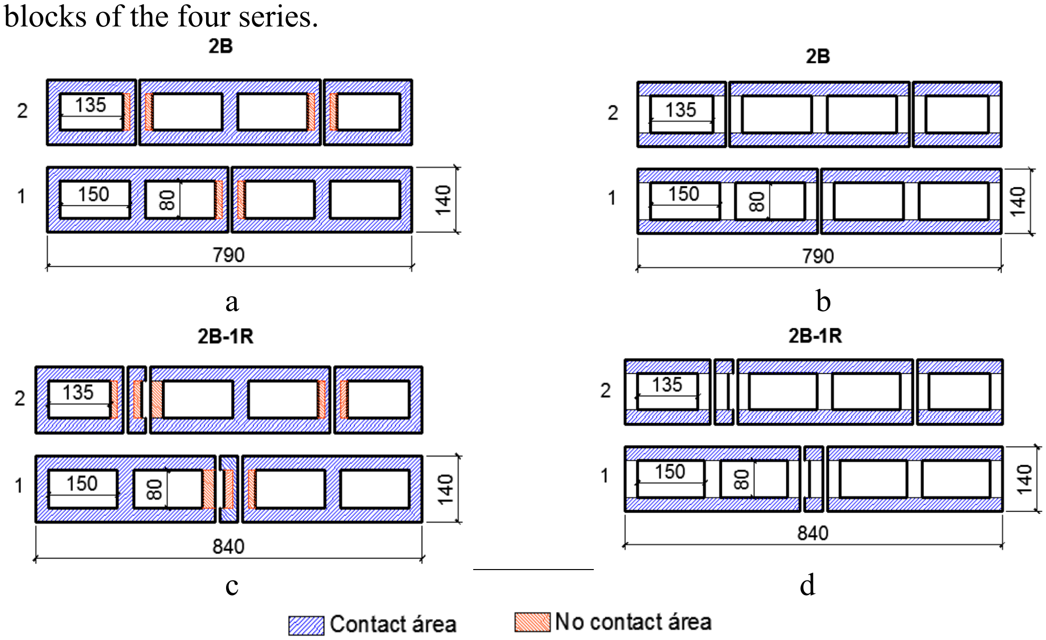


Figure 4: Contact area of walletes: a) Series I; b) Series II; c) Series III; d) Series IV (measured in mm)

Table 9 shows the values of the contact areas and the ratio to the gross areas.

Table 9: Values of contact areas of the four series

	Series	Contact area A_c (cm^2)	Contact area/Gross area A_c/A_b
Full mortar bedding without adjustments	I	560	0.51
Face shell mortar bedding without adjustments	II	440	0.40
Full mortar bedding with adjustments	III	578	0.49
Face shell mortar bedding with adjustments	IV	458	0.39

The following is the analysis, considering the two factors studied separately: type of mortar bedding and use of adjustment pieces (*rapaduras*).

Effect of the type of mortar bedding

Table 10 shows the values of the contact area and the compressive strength as a function of the gross area of the wallettes to verify whether the increase in the first one was proportional to the second one, and then create a rule for the designer to follow with regards to this aspect. The comparison was made always taking as reference the wallettes with full mortar bedding.

Table 10: Comparison of the contact area and the compressive strength of wallettes analyzing the type of mortar bedding

	Series	Contact area(cm^2)	Comparison of contact area	f_{m-p} (MPa)	Comparison of compressive strength
Full mortar bedding without adjustments	I	560	II<I in 21%	4.62	II<I in 10%
Face shell mortar bedding without adjustments	II	440		4.20	
Full mortar bedding with adjustments	III	578	IV<III in 21%	3.83	IV<III in 18%
Face shell mortar bedding with adjustments	IV	458		3.15	

According to the data in Table 10, there was no proportionality between the increased contact area and compressive strength of the wallettes with full and face shell mortar bedding. This indicates that it was not only the contact area that affected the behavior of the wallettes, although like in the prisms, it is an important estimate for the loss or gain of compressive strength.

At this level of the analysis, a definitive rule cannot yet be established for the designer to estimate the strength in the masonry wallettes with only the increase or decrease in the contact area. However, it should be noticed that this aspect has relevant influence on the behavior of the compressive strength of the brickwork. The reduction in the contact area leads to a reduction in the compressive strength. However a more in-depth study is necessary, including a detailed numerical analysis for the wallettes with regards to these matters.

Effect of the adjustment pieces (*rapaduras*)

Table 11, shows the values of the contact area/gross area ratio, calculating the changes and taking as reference the series that did not exhibit adjustment pieces. It also shows the efficiency values of the wallettes with respect to the blocks, to analyze the correlation that exists between the contact area and the increased efficiency.

Table 11: Comparison of contact area/gross area ratio and the efficiency of wallettes analyzing the use of adjustment pieces

	Series	**A_c/A_b**	**Comparison A_c/A_b**	**Efficiency (wallette/block) (gross area)**	**Comparison of efficiency**
Full mortar bedding without adjustments	I	0.51	III<I in 4%	0.41	III>I in 24%
Full mortar bedding with adjustments	III	0.49		0.51	
Face shell mortar bedding without adjustments	II	0.40	IV<II in 3%	0.38	IV>II in 11%
Face shell mortar bedding with adjustments	IV	0.39		0.42	

Table 11 clearly shows that the contact area of the wallettes with adjustment decreased very little in comparison with those without the parts, however their compressive strength increased. The opposite occurred in the analysis for the influence of mortar bedding, in which the reduction of the contact area of the wallettes with partial mortar bedding was accompanied by a drop of their compressive strength. It can be argued that it is a difficult to explain and complex phenomenon, but the most important fact is that the presence of adjustment in the wallettes did not influence negatively the compressive strength of the wallettes.

CONCLUSIONS

As for the compressive strength tests of the prisms, it can be concluded that the effect of the type of mortar bedding significantly influenced their compressive strength, with the full mortar bedding being better, since the specimens with this type of bedding showed greater strength and efficiency. As the prisms with full mortar bedding exhibit a larger contact area, the compressive strength values are higher, but are not proportional to the increase in the contact area. It is then concluded that the contact area was not the only factor that influenced the compressive strength of the prisms, however it is an important factor to estimate the loss or gain of compressive strength.

Regarding the type of mortar bedding in the wallettes, it reached the same conclusion as the prisms: the effect of the type of mortar bedding influenced the compressive strength of the wallettes, with the full mortar bedding being the best one, since the specimens with this kind of bedding showed greater resistance and efficiency. The increase in the contact area of the wallettes with full mortar bedding was not proportional to the increase in compressive strength, but this was not the only factor that influenced the compressive strength behavior, but possibly the most important one, and the one the designer must always take into account.

Regarding the use of dimensional adjustment pieces, it can be concluded that they did not adversely influence the compressive strength of the wallettes, promoting no drop in their compressive strength.

There are several factors that influence the compressive behavior of masonry, such as the effect of the contact area, the failure mode (when the partitions are not aligned), and the number of joints. All these factors are important, however this study showed that the region of the contact area is one of the most important aspects, significantly influencing the gain or loss of compressive strength in masonry, which should be taken into consideration during the project design.

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