



# LESE

LABORATORY FOR EARTHQUAKE AND STRUCTURAL ENGINEERING

## An empirical correction factor for the rectification of experimental out-of-plane tests results with airbag testing

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# ABSTRACT

On airbag testing, the relative displacement between the wall and the reaction structure is a key factor to estimating force values. Throughout the test, the displacement caused by the gradual inflating of the airbag is responsible for a non-negligible modification of the contact area between the wall's surface and the airbags. Thus, in order to calibrate this contact area, a laboratory full-scale test was performed, through which an empirical correction factor applicable on airbag tests was possible to estimate.

According to the exposed, the main results obtained from this experimental campaign as well as the several premises and possible approaches considered on the formulation of the correction factor obtained are presented and discussed herein.

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## 1 INTRODUCTION

The analysis of the out-of-plane behaviour of masonry walls resorting to airbags has been steadily gaining popularity over the last years (see for instance Griffith et al (2004; 2007)). However, as will be further reported herein, the values of surface pressure obtained in these tests are, in some cases, affected by a non-negligible error which arises from a gradual variation on the contact area between the airbag and the specimen. In fact, the displacement of the wall relatively to the reaction structure is a key factor to estimating values of surface pressure and force during the airbag tests, once that, with the gradual inflating of the airbag, this displacement is responsible for the modification of the contact area between the wall and the airbag. Thus, in order to calibrate the contact area between the wall and the reaction structure, a laboratory full-scale test was performed, through which an empirical correction factor was possible to estimate.

In this context, this LESE report aims at presenting a study wherein a new correction factor usable to correct experimental data obtained from the out-of-plane test of masonry elements resorting to airbags is proposed and experimentally calibrated. Moreover, in order to study such correction factor, it was applied in three different formulations which were then used to correct experimental data obtained from the test of six masonry piers under three distinct pre-compression conditions. It should be referred that these correction factors are valid for the present type of airbags.

## 2 PRESENTATION AND CALIBRATION OF THE CORRECTION FACTOR, CF

As is presented in Figure 1, two different test setups were used on the analyses of the correction factor both with only one row of airbags. The reaction structure consists of a concrete wall and steel elements.

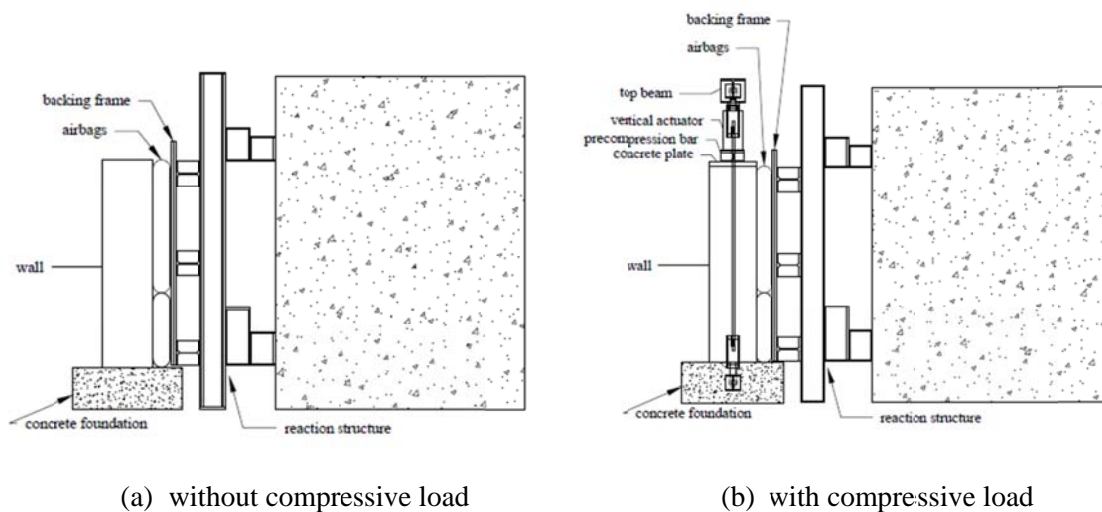
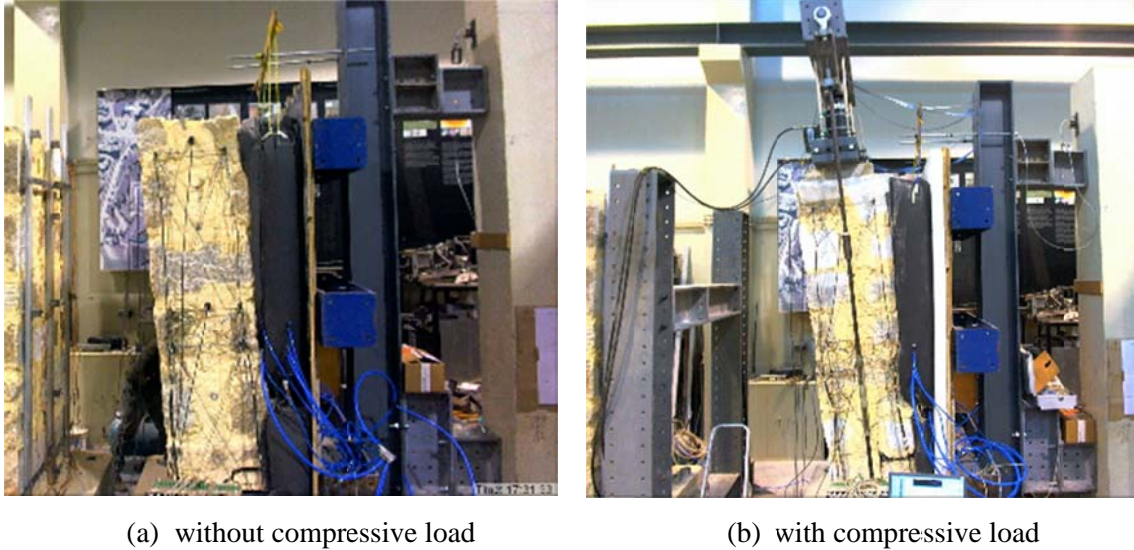


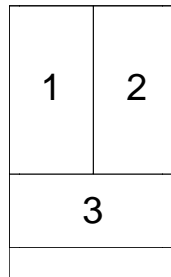
Figure 1 – Test setup used in LESE (a) with and (b) without compressive load

Additionally, as illustrated in Figure 2, several displacement transducers were placed for adequately monitoring the out-of-plane response of the piers.



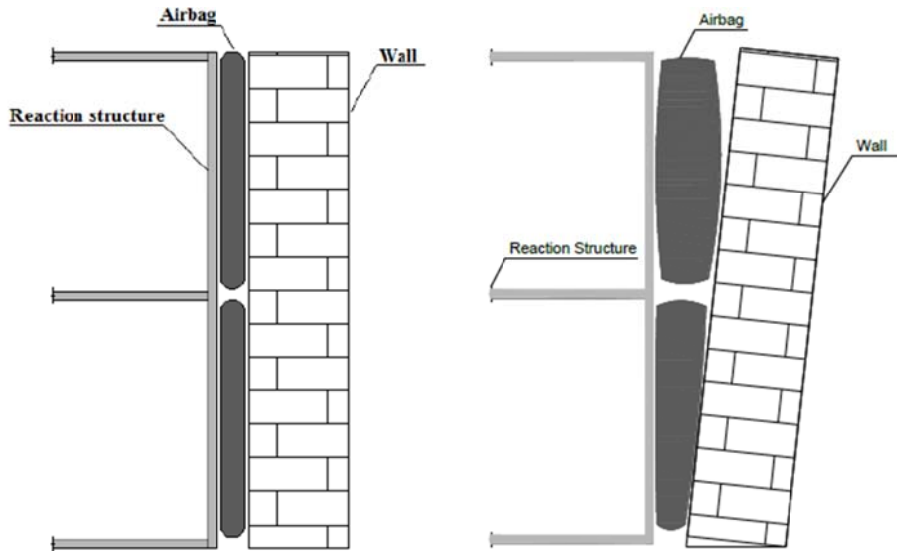
**Figure 2 – Monitoring system**

The tests were carried out resorting to three airbags with  $1.60 \times 0.70\text{m}^2$  each, disposed according to the depicted in Figure 3.



**Figure 3 – Airbags order**

As already stated, the phenomenon of the contact area between the airbags and the wall occurs because the inflated airbag does not assume a perfect rectangular parallelepiped shape (presenting curved faces) which leads to the variation of the contact area near the boundaries of the airbag body during the test (see Figure 4).



**Figure 4 – Contact area of the airbag depending on the distance between the wall and the reaction structure**

Thus, in order to calibrate the contact area between the airbag and the wall, a laboratory full-scale test was performed (Figure 5), through which it was possible to estimate the correction factor, CF. The test was performed using a nylon airbag, the strong wall of the laboratory and a steel structure composed by two fixed steel frames in order to be used as reaction structure for the airbag, and finally, 4 load cells used to measure the force exerted by the airbag and the pressure inside it through a pressure cell.

Thus, for certain displacement value representing the distance between the reaction structure and the strong wall, the correction factor is given by the ratio between the value measured by the load cells and the value measured by the pressure cell.

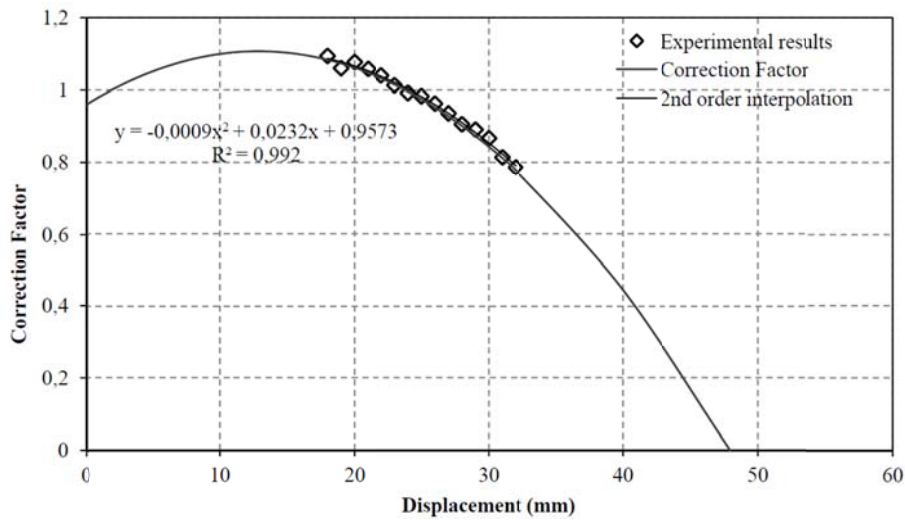


**Figure 5 – Setup of the laboratory full-scale test**

On the basis of the numerical interpolation of the experimental data obtained, it was possible to derive the following equation,

$$CF = -0.0009 \times |d|^2 + 0.0232 \times |d| + 0.9573 \quad (1)$$

which describes the relation between the correction factor,  $CF$ , and the relative displacement,  $d$ , between the wall and the reaction structure (see Figure 6). It is worth noting that the experimental correction factor is limited to values of  $d$  ranging between 18 and 47 cm of which the latter defines the limit of the contact between the airbag and the wall.



**Figure 6 – Study of the correction factor, CF**

For a certain value of displacement, the correction factor is given by the ratio between the value measured by the load cells and the value measured by the pressure cell, and that is the reason why some values are higher than 1.0.

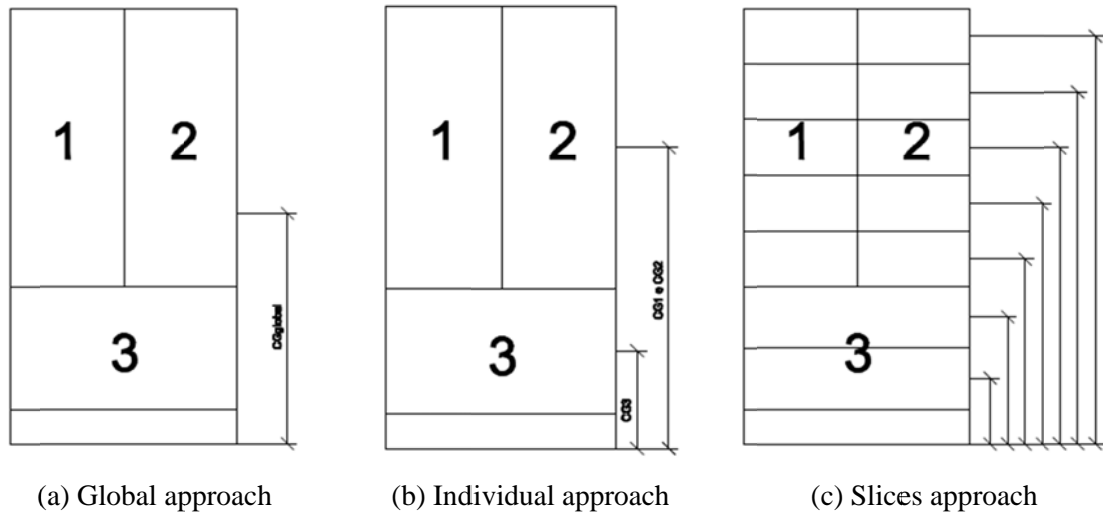
### 3 DESCRIPTION OF THREE POSSIBLE CORRECTION METHODS

Three methods were used in order to correct values of the surface pressure obtained experimentally (see Figure 7):

- The first method which involves the determination of the global centre of gravity of the airbags system (Figure 7(a)) – global approach;
- The second method which involves the determination of the centre of gravity of each airbag (Figure 7(b)) – individual approach;



- The third method which involves the determination of the individual centre of gravity of a series of seven horizontal slices (Figure 7(c)) – slices approach.



**Figure 7 – Methods scheme**

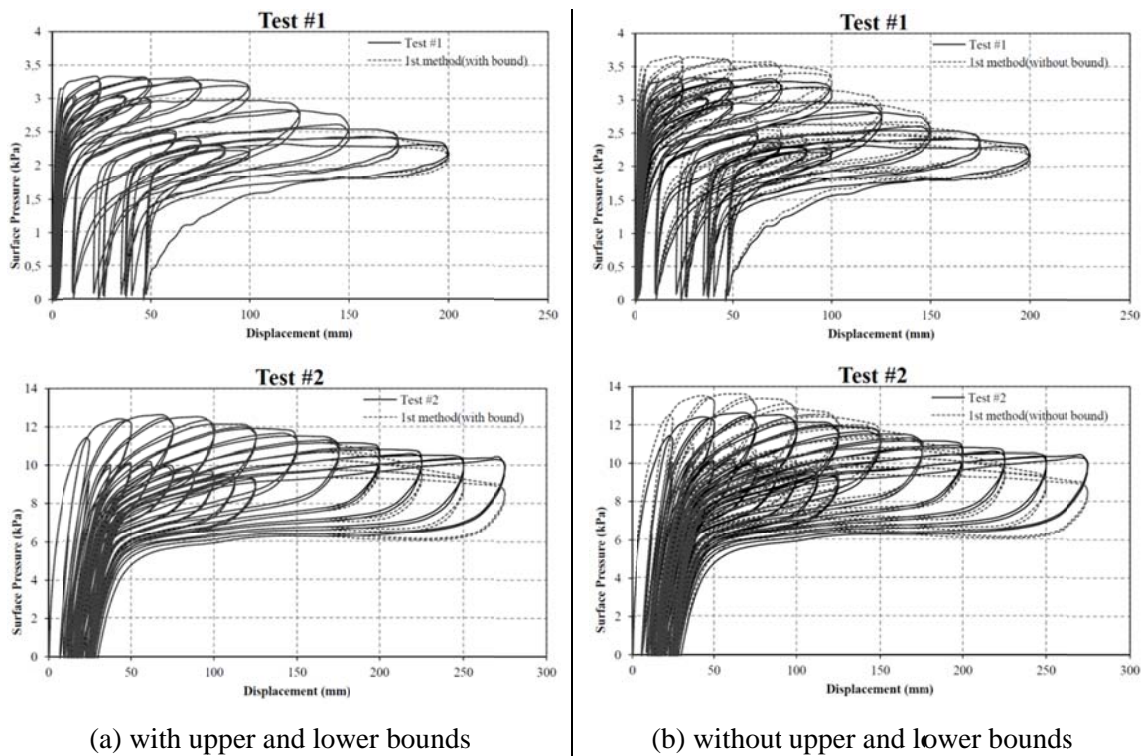
Additionally, the application of a lower and an upper bound for the correction factor,  $CF = 1.0$  and  $0$  respectively, is also proposed. The aim of this boundaries were, in one hand, to limit the minimum theoretical CF factor ( $0$ , where the airbag or the slice of the airbag is no longer in contact with the wall) and the theoretical maximum value ( $1$ , representing a full straight and perfect contact of the wall). However, and as exhibited by the experimental tests, for small displacements the contact area is higher than the theoretical area due to deformed sides of the airbags.

### 3.1 Global approach

The correction made by the first method complies the following steps:

- calculation of the global centre of gravity of the three airbags;
- determination of the displacement corresponding to the global centre of gravity;
- sum of the initial displacement (distance between the wall and the reaction structure) and the computed displacement;
- determination of the correction factor value by means of Eqn. (1);
- correction of the surface pressure experimental values with the correction factor, CF.

Figure 8 presents the surface pressure vs. displacement curves obtained with the global approach method, considering or neglecting the upper and lower bounds, respectively, Figure 8 a) and b).



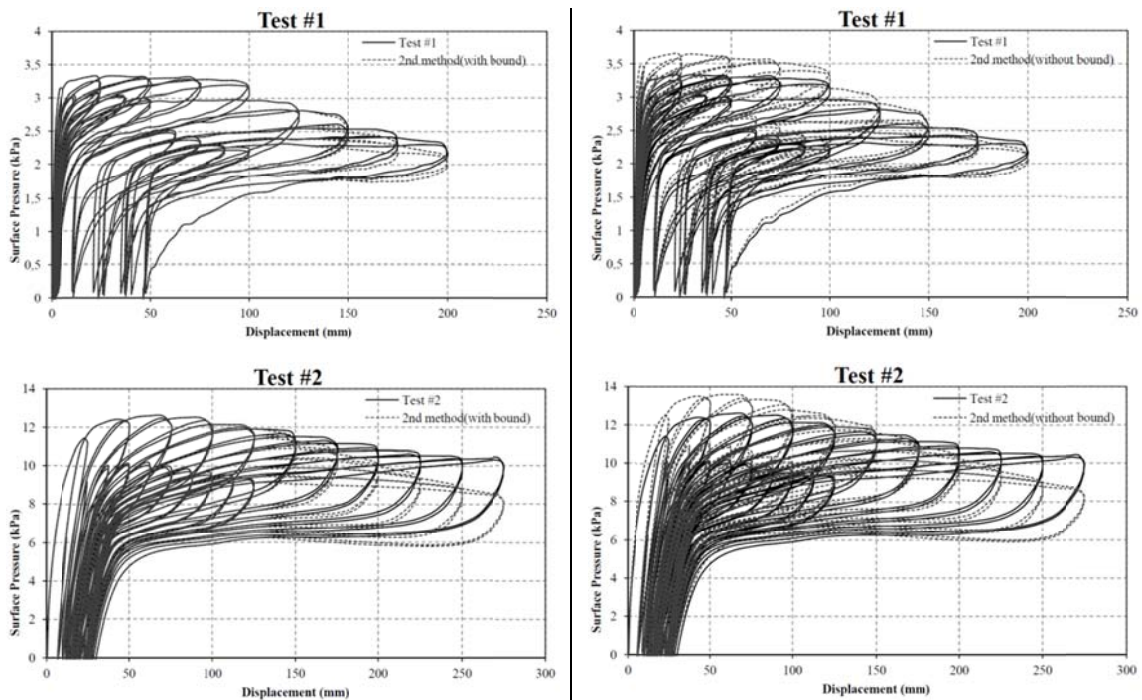
**Figure 8 – Global approach method: Surface pressure vs. displacement results (a) with and (b) without the consideration of the upper and lower bounds**

### 3.2 Individual approach

The correction made by the second method complies the following steps:

- calculation of the centre of gravity of each airbag;
- determination of the displacement corresponding to the position of each airbag;
- sum of the initial displacement (distance between the wall and the reaction structure) and the computed displacement for each airbag;
- determination of the correction factor value by means of Eqn. (1), for each airbag;
- correction of the experimental values of surface pressure, for each airbag, by multiplying the force of each airbag for the corresponding correction factors, CF;
- calculation of the force of each airbag by multiplying the surface pressure by the area of each airbag;
- sum of the forces to obtain the corrected values of the surface pressure by dividing the area of the three airbags.

Figure 9 shows the surface pressure vs. displacement curves obtained with the individual approach method, considering or neglecting the upper and lower bounds, respectively, Figure 9 a) and b).



(a) with upper and lower bounds

(b) without upper and lower bounds

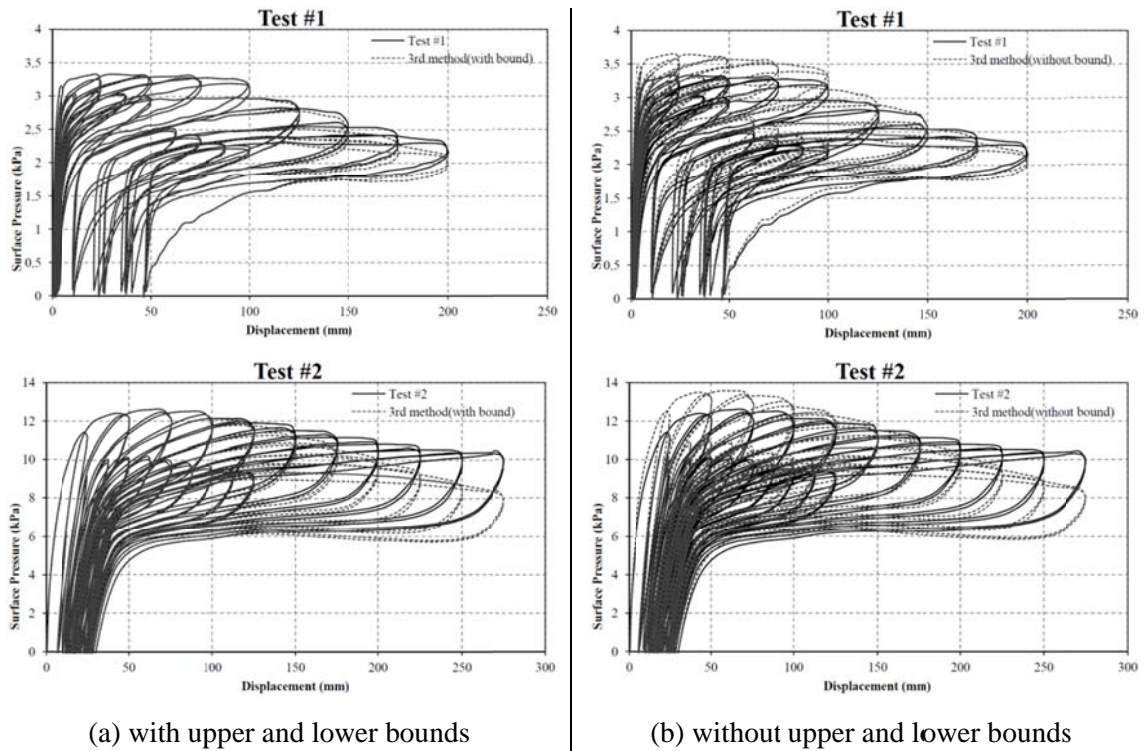
**Figure 9 – Second method: Surface pressure vs. displacement results (a) with and (b) without the consideration of the upper and lower bounds**

### 3.3 Slices approach

The correction performed with resort to the third method complies the following steps:

- calculation of the centre of gravity of each airbag slice;
- determination of the displacement corresponding to the position of each airbag;
- sum of the initial displacement (distance between the wall and the reaction structure) and the computed displacement for each slice;
- determination of the value of the correction factor by means of Eqn. (1) for each slice;
- correction of the experimental values of surface pressure, for each slice, by multiplying the force of each slice for the corresponding correction factors, CF;
- calculation of the force of each slice by multiplying the surface pressure by the area of each slice;
- sum of the forces to obtain the corrected values of the surface pressure by dividing the area of the different slices.

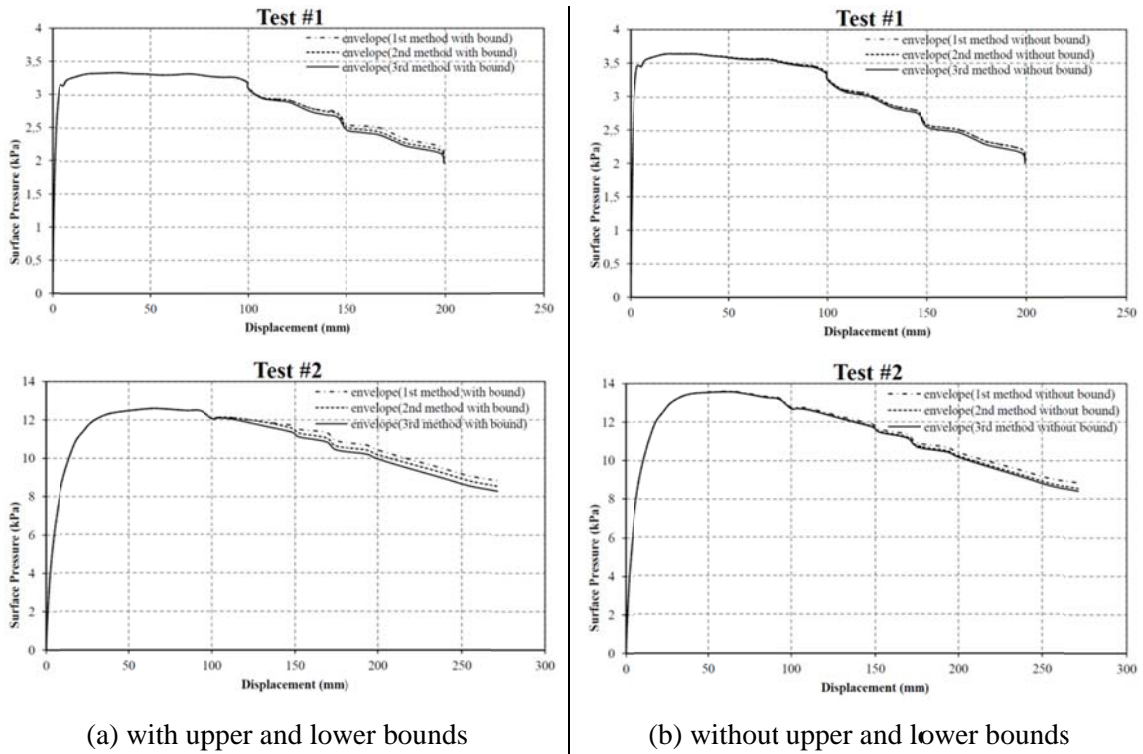
Figure 10 shows the surface pressure vs. displacement curves obtained with the individual approach method, considering or neglecting the upper and lower bounds, respectively, Figure 10 a) and b).



**Figure 10 – Third method: Surface pressure vs. displacement results (a) with and (b) without the consideration of the upper and lower bounds**

#### **4 COMPARISON AND INTERPRETATION OF THE OBTAINED RESULTS**

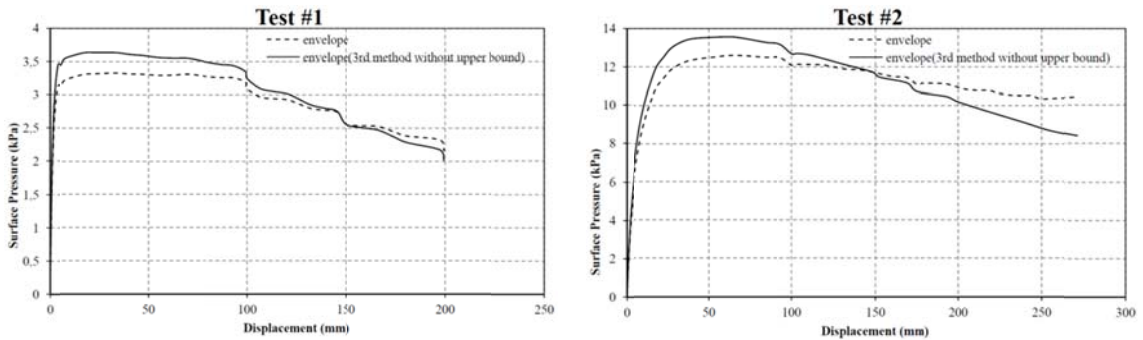
The comparison between the three methods presented above shows that third method drives to a decrease of the surface pressure value with the increase of the displacements. As can be seen in Figure 11, this fact is particularly notable in the range of large displacements.



**Figure 11 – Comparison between surface pressure vs. displacement envelopes obtained for each one of the three methods presented in this study**

The third method (slices approach) was adopted with no upper bound, that is, without limiting the correction factor to 1.0, for parameters calculation to analyze the walls behaviour to the test with airbags. The mismatch of the load cell and the cell pressure of airbags indicate that the upper bound will not be considered.

Figure 12 presents the comparison between the non-corrected experimental envelopes and the envelopes obtained through the application of the slices approach method.



**Figure 12 – Comparison between the non-corrected and the corrected surface pressure vs. displacement envelopes**

## 5 FINAL REMARKS

This LESE report includes a general overview of a study carried out in order to obtain a correction factor usable to correct experimental values obtained through airbag testing on masonry piers. Three correction methods were presented and tested, being the different obtained results presented and discussed. Taking into account that the third method, called as “slices approach” where the global contact area is discretized in different slices, is more detailed than the second method (individual approach). Therefore, the slices approach was adopted without upper bound limit, for the treatment of the experimental data obtained from airbag tests. It should be referred that the correction factor obtained within these experiments reports only to the tested airbags, but similar studies should be made for other type of airbags.

## ACKNOWLEDGEMENT

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