

## **6m SPAN LINTELS TESTS ON A NEW WALL PI-BRACKETS TYPE**

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### **SUMMARY**

Reinforced masonry has been subject to research and investigation in Spain for over 20 years now. This paper presents a new contribution within the AllWall System, referred to as the Halfen-Allwall support (Pi-Bracket). This support being regularly spaced every 6m to form a “braced arch” effect and provide reinforced masonry. This line of investigation has been made possible through the industrial development of a new patented invention under the trade name Halfen-AllWall Pi-Brackets in combination with Murfor brickwork reinforcement.

This combination provides a new way of supporting external walls at fixed points coinciding with the verticals of the structural supports. The system prevents the loading of slabs which, in addition to providing great economy in construction, inhibits cracking due to structural deformation at the support base of the wall and also allows the continuation of insulation and ventilation throughout the cavity.

Three tests of the Pi-Brackets have been made in Germany and other three 6m span walls on the Pi-Brackets, have been tested in Instituto Eduardo Torroja (Madrid).

The results of this research opens a new solutions for the enclosure masonry walls, that is wide use in the spanish building for its economy and easy construction.

**KEYWORDS:** Masonry; brick; bed joint reinforcement; Pi-Bracket; Braced arch.

## INTRODUCTION

When comparing 19<sup>th</sup> century brick architecture [Adell 1987] with that of the 20<sup>th</sup> century, far more defects or faults may be observed in more recent exposed brickwork than in that of earlier construction. The first step towards preventing the large-scale cracking of brickwork apparent in Spain in the latter part of last century was taken in 1992 [Adell 1992] which established the criteria, subsequently considered in the Eurocode 6: “Masonry Structures”, of recommending a reinforcement cross section over 0.03% of the wall cross section and vertical spacing between bed joint reinforcement of no greater than 600 mm.

The main difference between the Spanish Murfor Manual [Adell, 1992] and those of other countries lies in the fact that in addition to controlling cracking, the manual offers the possibility of making the steel work to deformation limits equivalent to those of reinforced concrete. This then allows a considerable increase in the span length of reinforced masonry lintels which may reach up to double the length for the same load. This important breakthrough in brick lintels with Murfor reinforced masonry was subject to multiple testing in Spanish laboratories using 3m long lintels, the results of which were published in the 4<sup>th</sup> International Masonry conference in London in 1995 [Adell, 1995]. Testimony to the technical advance seen by the use of “blind braced arches” in the block of flats in the Plaza de la Remonta was provided by the illustration carried on the cover of the book “Maçonnerie Portante” [Pfeffermann, 1999].

Professor Adell subsequently published books on masonry defects [Adell, 2000] and the possibilities of reinforced masonry to control cracking and increase the possibilities of brick and blockwork [Adell, 2000]. Following on from these scientific and research activities, he then chaired and organized the 12<sup>th</sup> IBMAC, International Brick/Block Masonry Conference in Madrid in 2000. In order to herald this scientific gathering, the “Millennium Arch” [Adell, 2000] was built in front of the Madrid Conference Centre using “flowerbricks” which allowed the internal housing of vertical reinforcement to withstand vertical bending as well as the torsion generated by its vertical form outside the vertical. This arch was widely reported both at home and abroad.

This paper takes up the possibilities of increasing the performance of reinforced masonry using “large span blind braced arches”, established for the first time in the Spanish manual, and which allows 6m spans with just two 5mm diameter Murfor reinforcements in the lower part of the lintels.

In 2002, a new invention was patented for a new support which took advantage of the bracing of reinforced masonry and developed a new Distanced Support System for masonry walls of up to 6m to coincide with the loading of the wall in the vertical of the supports in a framed structure [Adell, 2002].

In 2005, the Halfen Group took an interest in the commercial development of this patent and on this basis developed a new improved patent which now goes under the name of “Halfen-AllWall” Pi-Brackets [Halfen+Adell, 2005].

This paper describes the design of the new bracket and all the laboratory tests on both the bracket and the reinforced brick walls supported by it which serve to validate this new construction system in Spain.

## THE NEW SYSTEM APPLIED TO BRICK/BLOCK ENCLOSURE WALLS

Throughout Europe walls tend to be built with two leaves of masonry connected by wall or cavity ties. However, these ties are not employed in Spain as the inner leaf employed is not sufficiently strong: these walls tend to be built as facings in framed structures and not as load-bearing walls.

In 115mm wide brick walls (using the Castilian 240x115x50 mm brick), horizontal wind action takes priority over the vertical deadweight load of the brick panels. As the outer leaf of the enclosure wall cannot be tied to the inner leaf in Spain, it is necessary to anchor these to the columns of the structure which tend to be spaced every 6 or 7m (Figure 1). In order to allow complete freedom of movement between the brickwork panels and the framed structure holding the wall, anchors have been developed which allow double movement in the wall plane (vertical-Z and horizontal-X), while withstanding the wind action (perpendicular-Y).



Figure.1. Traditional Spanish enclosure wall over-hanging on the edge of the floor slab.

When the distance between structural columns exceeds 3m (these columns tends to be spaced between 5-7m), it is necessary to place one or two intermediate steel posts between the columns

In order to ensure sufficient moisture and temperature effectiveness of the masonry wall, the support to the wall has to be set separately ahead of the floor slabs to allow spacing for continuous insulation and a cavity. In Central Europe, the support solution consists of brackets attached at one metre intervals to a rail set on the face of the floor slab during concreting (Figure 2). This European system, while of undoubted quality and efficiency, is very expensive to install and requires a certain amount of time for the incorporation of the support brackets prior to the construction of the enclosing brickwork. However, this type of forward planning cannot usually be considered in Spanish construction.

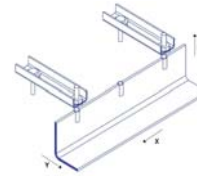
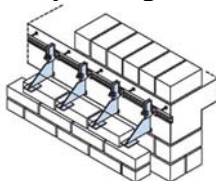


Figure 2. Standard European brackets anchored to a rail, embedded in the face of the slab.

Figure 3 a) Halfen-AllWall bracket to be anchored on the slab; b) Tolerances “X”, “Y”, “Z”

The new support presented here reduces the cost of the support system substantially by extending the bracket spacing to 6m, while at the same time offering a more resistant form and eliminating the need to place support rails during the concreting of the slabs.

The new bracket may be adjusted in three directions (X, Y and Z) to guarantee the perfectly plumb construction of the wall and provide correct support without requiring additional

plates, regardless of the customary adjustment tolerances between the concrete structure and the masonry (Figures 3a and b).

With this new support, the load of masonry panels in any type of brick or blockwork, may be transferred to the wall supports by means of the braced arch effect provided by reinforced masonry, in accordance with Spanish Murfor Manual calculations and as a result of this new type of patented support (Figures 4a, b and c).



Figure 4 a) Side view of Halfen-AllWall Pi-Bracket with its vertical (Z) and horizontal (Y) adjustments; b) Frontal view; c) View of bracket supporting the first brick in the lintel course.

## THE NEW SUPPORT FOR REINFORCED MASONRY

The new system allows the supports of walls to be spaced at 6 metre intervals when employing reinforced masonry and where the bed-joint reinforcement acts as arch bracing within the interior of the supported masonry.

The reinforcement between spaced supports is the same regardless of the height of the arch supported, as the thrust provided by the arch at its base depends on the span and not on the height when considering the load as that of its deadweight: the same bracing is then valid for both reduced linteled arches or raised wall lintels (Figure 5.a). When walls are supported at regular intervals coinciding with the vertical supports, the enclosure assembly no longer loads the slabs and, instead, transfers loads through the vertical supports and prevents defects associated with the deformation of the slabs and their ensuing transfer to the facing wall (Figure 5.b).



Figure 5 a) Braced arches of different heights all fitted with the same section of steel bracing; b) Braced masonry facing wall set on a framed structure and using the arch effect.

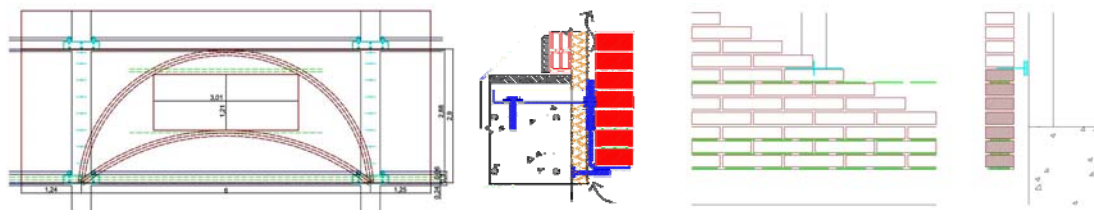


Figure 6. Possible reduced or circular arches for the same bracing set between 2 supports  
Figure 7. Vertical section of the Pi-Bracket, showing continuous, insulated+ventilated cavity.  
Figure 8. Vertical section through the centre of the brick panel at the same level of support.

This has the advantage that in facing walls with openings, the arch formed within the masonry may pass both above and below the opening in a panel of standard floor height and only requires 2 or 3 reinforcements of 5 or 4mm diameter for distances between supports of 6 to 7 m respectively (Figure 6).

The section of the wall support for this type of facing wall has all the necessary adjustment components to provide suitable cavity width and continuous insulation in front of the slab and incorporates reinforcement between the 6m spaced supports (Figure 7). Furthermore, the section of this same wall in the centre of the panel clearly reveals that it is not necessary to support the masonry on account of the “braced arch” effect (Figure 8).

## TESTS CARRIED OUT

There follows a description of the tests carried out to experimentally guarantee the validity of this new construction system previously endorsed by calculation.

The tests supporting this research work were carried out in 2 laboratories in Germany and Spain. In Germany, tests were made on 3 bracket prototypes. In Spain 3 tests were made on 6m brick walls set on these brackets.

### Tests carried out in Germany of the Pi-Bracket

The tests were carried out at the Hegger & Partner laboratory in Aachen. All components were in galvanized steel, meeting all durability specifications for external use, except the threaded stud bolts and sockets which were made of stainless steel given the stress levels.

The test consisted of vertically loading the brackets by a jack set on an “I” beam profile which uniformly distributed the load on the bracket until reaching the maximum working values and, at the same time, verifying whether support strains were within admissible limits (Figure 9).

Three wall brackets were tested in their normal working position with the brackets fixed on the top of a slab and reacting against the face of the slab. The deformation (strain) recording method is shown in the figures where the values “d0”, “d1”, “d2” and “d3” (Figure 10a) refer to the vertical deformations and values “d4” and “d5” refer to horizontal deformations produced by the moment generated on the application of the load (Figure 10b).

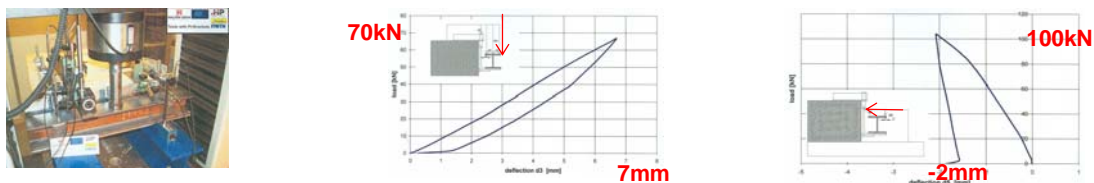


Figure. 9. Testing of one of the three Halfen-AllWall Pi-Bracket prototypes in Germany.  
Figure. 10. a) Graph of vertical deformation “d3”; b) Graph of horizontal deformation “d5”.

The first two tests reached loads of 66kN, without plastic deformation, and revealed the horizontal reaction of the bolts in the concrete. On reaching maximum deformation load there was evident rotation of the bracket. The third test reached a maximum load of 104kN and caused cracking in the concrete around the supports of the “U” angles and around the horizontal reaction bolts.

## Tests carried out in Spain of 6m Reinforced Masonry Lintels

The tests on perforated brick wall panels set on the new brackets (manufactured and tested in Germany) were supplemented with tests on full scale walls employing reinforced masonry. Tests were carried out at the Instituto Eduardo Torroja in Madrid. In order to characterise the masonry material employed, tests were carried out on 600 x 600 x 115 mm masonry specimens composed of standard perforated brick (240 x 115 x 50 mm) with a minimum standard strength of 10N/mm<sup>2</sup> laid in a 1:3 cement mortar.

Using these specimens, tests were carried out to establish the compressive strength perpendicular to the bed joints, the compressive strength parallel to the bed joints and shear strength. The tests were carried out on standard perforated bricks with 12 equal perforations and gave the following masonry strength values: normal compressive strength = 11.73N/mm<sup>2</sup>; compressive strength parallel to the bed joints = 9.53N/mm<sup>2</sup>; shear strength = 0.81N/mm<sup>2</sup>.

In order to test vertical bending, 3 walls were built on the new wall brackets, set with a 6m spacing between centre lines and leaving a “clear span” of 5.25m between supports. All the walls were fitted with two Murfor RND 5/S-80mm reinforcements set on the first and second course at the base of the lintel over the support (Figure 11 a and b). Suspended hooks were not employed to hold the bricks in the bottom course as it was considered that the perforations offered a suitable bond with the reinforcement and mortar.

The stress strain diagrams corresponding to the extensometric gauges set on bed joint reinforcement (B1, B2, B3, B4) show that these work almost in unity until the loss of mortar bond, and do not indicate potential reinforcement failure (Figure 12).

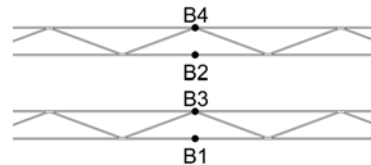


Figure 11. a) Continuous bed joint reinforcement; b) Murfor.5/S-80mm. 5.85m (inox. B800)

Figure 12: Arrangement of extensometric gauges in 2 Murfor centre (B1, B2, B3, B4).

The 3 different walls specimens had the following variations in order to optimize the AllWall System with the Halfen-AllWall Pi Bracket and the Murfor bed joint reinforcement.

The 1<sup>st</sup> lintel was built with perforated brick of standard quality (M-10) with M8 mortar, reinforced solely with 2 bed-joint reinforcement: “A” (on the 1<sup>st</sup> course) and “B” (on the 2<sup>nd</sup> course) of Murfor RND.5/S-80 stainless steel (B-800), with the left support set on a neoprene seal between the masonry and the wall brackets and right support facing the brick directly to the metal profile (Figure 13) (Figure 14 a and b) (Figure 15).



Figure 13. Left support of the lintel with neoprene layer between brick and steel.

Figure 14: a) 1<sup>st</sup> bed joint reinforced course (inox. B800); b) 2<sup>nd</sup> bed joint reinforced course.

Figure 15. Brickwork at the right support set directly on the steel Pi Bracket.



The walls were tested for vertical bending using 2 hydraulic jacks with the same load, set at one third span distances from the edge of the wall, in order to simulate the effect of uniform load equivalent to its deadweight. Vertical strain gauges were set on the wall in addition to two extensometric gauges in the centre of each Murfor “A” and “B” truss-type bed joint reinforcement forming the bracing to the brick panel (Figure 16 a y b).

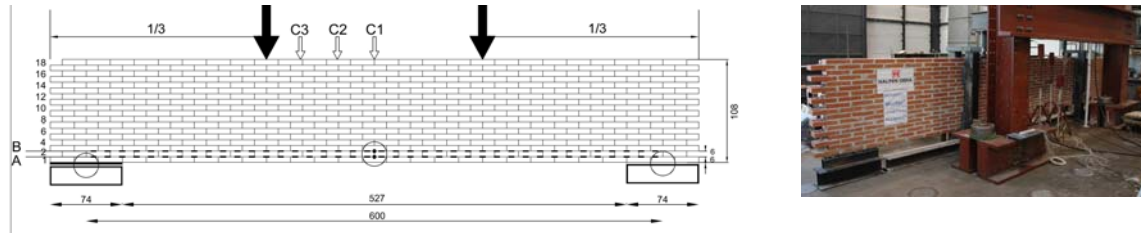


Figure 16: a) 1<sup>st</sup> brick 6m span lintel, simply braced, with A and B Murfor (inox. B800)  
b) 1<sup>st</sup> brick lintel of 6.75x1.08x0.115m, set on Pi Brackets, ready for testing.

The 2<sup>nd</sup> lintel was built with perforated brick of standard quality (M-10) with M8 mortar, reinforced with bed-joint reinforcement (“A” and “B”) and additional uniform reinforcement (“C” and “D”) of Murfor RND.5/S-80 stainless steel (B-800), with brickwork set directly on wall brackets at both sides (Figure 17 a and b).

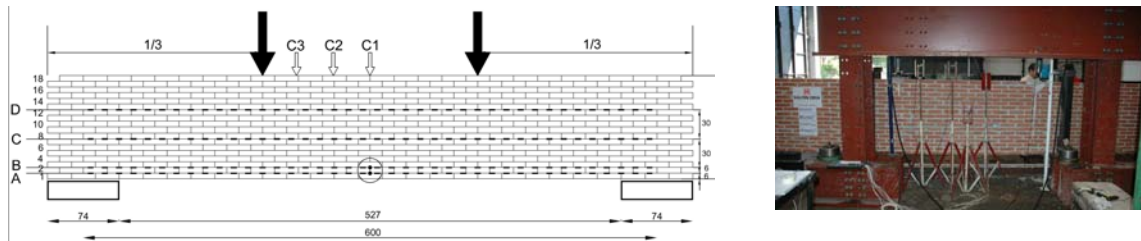


Figure 17: a) 2<sup>nd</sup> brick 6m span lintel, simply braced, with A, B, C and D Murfor (inox. B800)  
b) 2<sup>nd</sup> brick lintel of 6.75x1.08x0.115m, set on Pi Brackets, ready for testing.

The 3<sup>rd</sup> lintel was built with perforated brick wall of standard quality (M-10) with M8 mortar, reinforced with bed-joint reinforcement (“A” and “B”) and additional uniform reinforcement (“C”, “D” and “E”) of Murfor RND.5/Z-80 standard galvanized steel (B-500), with brickwork set directly on wall brackets at both sides (Figure 18 a and b).

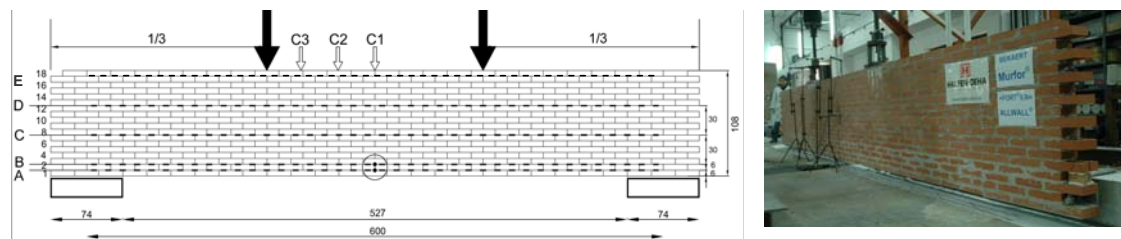


Figure 18: a) 3<sup>rd</sup> brick 6m span lintel, simply braced, with A, B, C, D and E Murfor (galva. B 500)  
b) 3<sup>rd</sup> brick lintel of 6.75x1.08x0.115m, set on Pi Brackets, ready for testing.

The test on the 1<sup>st</sup> wall (with only 2 stainless steel bed joint reinforcement as a brace) (inox. B800) was satisfactory in accordance with the safety margins established for the materials. The first lintel to be tested failed by compression in the direction of the bed joints in the upper central third close to the jacks, without reaching the breaking stress of the reinforcement of the lower brace (Figure 19). The crack in the centre of lintel in the tensile area barely exceeded 1 mm and the overall cohesion of the wall was retained (Figure 20 a and b).

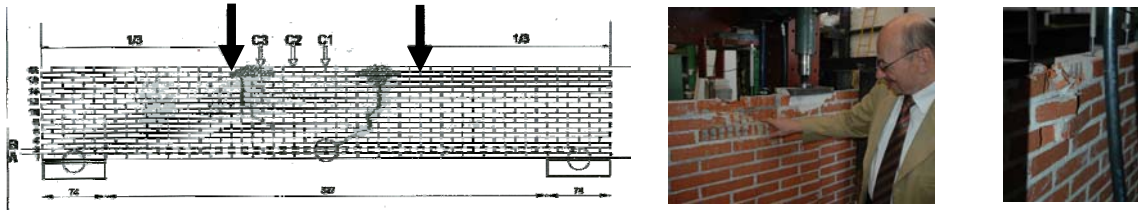


Figure 19. Failure due to horizontal compression of the 1<sup>st</sup> tested brick lintel (2 inox. B 800).  
Figure 20. View of collapsed brickwork after testing: a) At the left jack; b) At the right jack.

The stress strain diagrams corresponding to the extensometric gauges set on bed joint reinforcement (B1, B2, B3, B4, B5) of the 1<sup>st</sup> test, show that these work almost in unity until the loss of mortar bond, and do not indicate potential reinforcement failure (Figure 21.a). The LVDTs placed to record vertical strain (C1, C2, C3) deformed together until reaching the cracking stress of the brickwork, at around 40kN loading on each of the two jacks (Figure 21.b).



Figure 21: 1<sup>st</sup> Test: a) Stress-strain diagram of extensometric gauges (B1, B2, B3, B4) set on reinforcement; b) Readings of the vertical displacement load recorded by LVDTs (C1, C2, C3).

The test on the 2<sup>nd</sup> wall (with 4 stainless steel bed joint reinforcement) (inox. B800) was totally satisfactory in accordance with the safety margins established for the materials. The 2<sup>nd</sup> lintel tested failed by shear in 45° direction from the laterals supports, without reaching the breaking stress of the reinforcement of the lower brace (Figure 22). The crack in the centre of lintel in the tensile area barely exceeded 1 mm and the overall cohesion of the wall was retained (Figure 23 a and b)

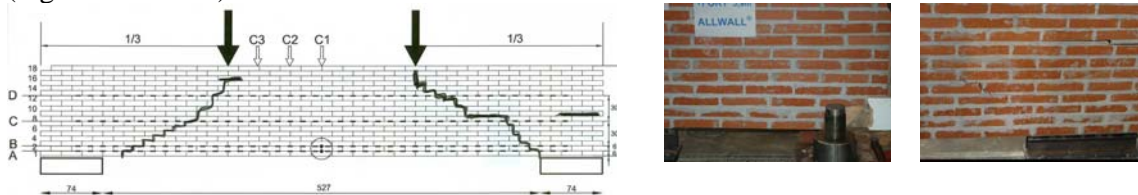


Figure 22. Type of shear failure of the 2<sup>nd</sup> tested brick lintel (4 Inox. B 800).  
Figure 23. View of collapsed lintel after testing: a) left shear crack; b) right shear crack.

The test on the 3<sup>rd</sup> wall (with 5 stainless steel bed joint reinforcement) (galva. B500) was totally satisfactory in accordance with the safety margins established for the materials. The 3<sup>rd</sup> lintel tested failed by traction in the bottom in the centre of the lintel, reaching the breaking stress of the reinforcement of the lower brace (Figure 24) (Figure 25 a and b).

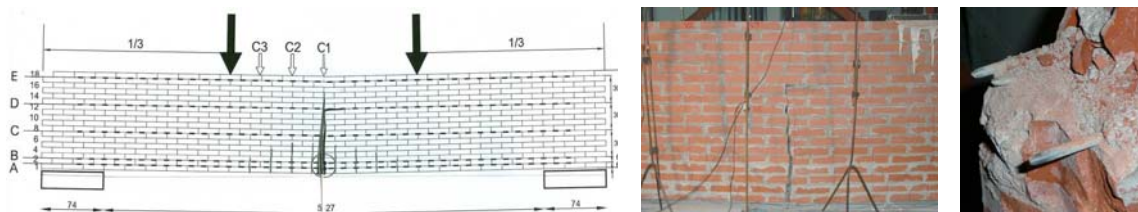


Figure 24. Shear failure of the 3<sup>rd</sup> tested brick lintel (5 galva. B 500).  
Figure 25. View of collapsed lintel after testing: a) central crack; b) reinforcement detail.



The stress strain diagrams corresponding to the extensometric gauges set on bed joint reinforcement (B1, B2, B3, B4, B5) of the 3<sup>rd</sup> test show that these work almost in unity until the loss of mortar bond, and do not indicate potential reinforcement failure (Figure 26.a). The LVDTs placed to record vertical strain (C1, C2, C3) deformed together until reaching the cracking stress of the brickwork, at around 140kN loading on each of the 2 jacks (Figure 26.b).

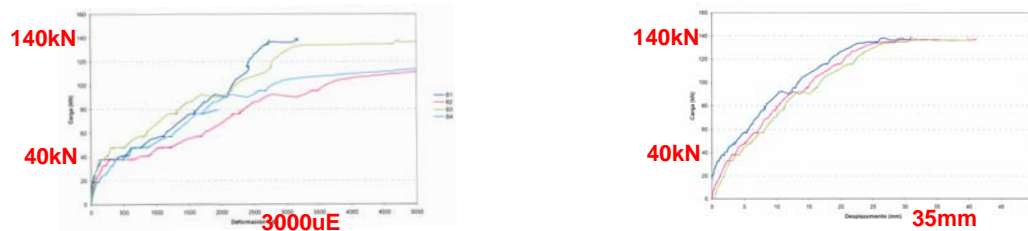


Figure 26: 3<sup>rd</sup> Test: a) Stress-strain diagram of extensometric gauges (B1, B2, B3, B4) set on reinforcement; b) Readings of the vertical displacement load recorded by LVDTs (C1, C2, C3).

## RESULTS AND DISCUSSION

### Tests carried out in Germany (Pi-Bracket)

The tests carried out in Germany on the wall bracket gave values of between 66 and 104kN. In the case of the maximum load test of 66kN, the stress-strain diagram showed a deflection of some 4mm at the outer edge of the profile on reaching 40kN.

### Tests carried out in Spain (Lintels on Pi-Brackets)

- No difference in reaction was seen when using two different supports in the 1<sup>st</sup> test: the left support using neoprene between brick and steel and the right support with the brick set directly on the wall bracket. Due to this results, the 2<sup>nd</sup> y 3<sup>rd</sup> test have been built without neoprene resting the brick directly on the metal of the Pi Bracket.
- No bricks in the 1<sup>st</sup> course were seen to move/spall in the 3 tests. This supports the theory that it is not necessary to hang perforated bricks on the upper reinforcement by steel hooks.
- In the 1<sup>st</sup> test the total cracking load approaches 90kN, which implies 45kN in each Pi-Bracket. This load distributed over the 85,000mm<sup>2</sup> of each Bracket, implies a 0.53N/mm<sup>2</sup> load which is a very conservative value for M-10 type masonry. The cracking load approaches the safety coefficient of the masonry of 2.4 times the load of 3m high wall. The cracking at the centre of the panel, around the Murfor reinforcement, did not exceed 1mm during the test until the end with horizontal compression crack.
- In the 2<sup>nd</sup> test the total cracking load approaches 160kN, which implies 80kN in each Pi-Bracket. This load distributed on the Pi Bracket implies a 0.94N/mm<sup>2</sup> load which is nearly double of the value of the 1<sup>st</sup> test value. The cracking load approaches the safety coefficient of the masonry of 4.0 times the load of 3m high wall. The cracking at the centre of the panel, around the Murfor reinforcement, did not exceed 1mm during the test until the end with shear crack.
- In order to achieve the bed joint reinforcement break in the 3<sup>rd</sup> test (that could not get in the first and second test), the construction of the 3<sup>rd</sup> lintel, was built changing the B-800 inox. wire for the B-500 galva. wire with less stress-strain capacity.
- In the 3<sup>rd</sup> test the total cracking load approaches 140kN, which implies 70kN in each Pi-Bracket. This load distributed on the Pi Bracket implies a 0.82N/mm<sup>2</sup> load which is also conservative for the M-10 type masonry. The cracking load approaches the safety

coefficient of the masonry of 3.6. The cracking at the centre of the panel, around the Murfor reinforcement, did not exceed 1mm until getting the crack load of the reinforcement.

## CONCLUSIONS

In the three tests carried out in Germany on the Halfen-AllWall Pi-Bracket, failure occurred in the slab concrete at the support of the two “U” Halfen-AllWall anchors after easily exceeding the stipulated loading on masonry panels established through testing at the Torroja Institute and in the region of 40kN.

The 2<sup>nd</sup> and 3<sup>rd</sup> lintel tests carried out at the Torroja Institute had a far more uniform response in terms of the cracking of masonry with higher vertical loads, which doubled the safety coefficient of masonry obtained in the 1<sup>st</sup> test.

By way of conclusion, the fact that the brackets tested in Germany and the walls tested in Spain on these brackets, readily surpass the corresponding working loads and safety margins without cracking, demonstrates the viability of the new system.

This new technology makes the construction of quality masonry facing walls more economical while guaranteeing their thermal and moisture efficiency and controlling potential cracking in brickwork at a significantly lower cost than other systems available today.

The loads applied on the spanish lintels, exceed the values of the loads of the Pi Brackets obtained in Germany, giving more fiability to the coordinated components of the AllWall System and making possible the use of Pi-Brackets every two levels in brick façades.

Test Number	Nº Reinforcement	Steel Quality	Craking Type	Load (kN)	Safety Coefficient (*)
1º	2	B-800	Horizontal Crack	90	2.4
2º	4	B-800	Shear Crack	160	4.0
3º	5	B-500	Wire Break	140	3.6

(\*) Being “1”, the load of 3m high brick wall.

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