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ARCHITECTURE AND RESEARCH WITH REINFORCED MASONRY

J. M. Adell[1], Prof. Dr. Architect

1. ABSTRACT

By using a combination of prefabricated bed joint reinforcement with traditional masonry, a new type of composite material can be created which can provide the opportunity for Architects to achieve new levels of technical and design excellence.

This composite is obtained by placing a truss type bed joint reinforcement (Murfor wire) embeded in the horizontal masonry bed joints. The tensile strength of the masonry can be improved by the reinforcement either throughout the structure or just in localised areas dependant upon the size, quantity and positioning of this reinforcement.

Professor Adell is the first Architect in Spain to fully exploit the opportunities which this composite material can bring. The AutoSupporting Cavity Wall overcomes many of the problems normally associated with the connections between the two leaves of a cavity wall.

Professor Adell's work in Madrid is seen as breaking new ground in the use of reinforced masonry. Two Local Authority housing schemes provide two very different examples of the spectacular results this concept can bring using fair faced brickwork.

Keywords: Architecture Clay Brickwork; Bed Joint Reinforcement; Reinforced Masonry; Composite Material; ACW-AutoSupporting Cavity Wall; Tetrapilonis

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1 Professor, Member of the Spanish Eurocode Committee 140/SC6:
Departamento de Construcción y Tecnología Arquitectónicas. Escuela T.S. de Arquitectura
Universidad Politécnica de Madrid. Avda. Juan de Herrera 4, 28040 Madrid, Spain.
Telephone/Telefax: 34 1 4582983.

2. INTRODUCTION: REINFORCED MASONRY - A COMPOSITE MATERIAL.

Modern masonry products come in many different shapes, sizes and materials. Common forms include clay bricks, concrete and calcium silicate bricks and blocks, and aerated concrete blocks.

All of these materials have adequate compressive strength but suffer from a common problem in their lack of tensile strength. This shortcoming is usually seen when cracking appears in the masonry.

To help overcome this problem, Murfor prefabricated wire reinforcement, with its unique shape and material properties, can be embedded into the masonry bed joints. The use of this reinforcement will control the tensile stresses within the masonry and so substantially reduce the risk of cracking.

This traditional view of the use of bed joint reinforcement can be extended further by considering the use of different widths and spacing of Murfor within masonry to create a new composited material for designer.

When using this material, structures can be subjected to both lateral and vertical loads at the same time if need be - whilst the spacing between movement joints can be extended.

By using these properties, the Architect can achieve new levels of design and technical excellence. (See figures 1) (A + B + C)

(A) Increased Spacing Between Movement Joints

If a wall of width 'a' and height of 'h' is reinforced with uniformly distributed Murfor throughout its height, the distance 'l' between the movement joints can be considerably increased without any cracking problems due to expansion and contraction in the masonry being encountered. The minimum area of reinforcement used should not be less than 0.05% spread throughout the masonry. The wall thickness will determine whether two or three layers of Murfor should be used per metre height.

(B) Reinforced Masonry Subject to a Vertical Deflection

When an area of wall is unsupported as in the case of a lintel or supported by a slab or beam which can deflect, cracking will occur unless it is reinforced.

A wall of width 'a' and height 'h' which is supported by two points at distance 'l' and subjected to a vertical load will deflect.

To prevent deflection and increase the effective height of the wall 'he', that is the distance between the reinforcement area and the top of the wall, the masonry reinforcement must be concentrated at the bottom of the wall.

To increase the concentration of reinforcement within a single bed joint it is possible to lay a number of small width strips of Murfor in the bed joint side by side. An example of this may be with a 200mm block to place two 50mm widths of reinforcement in the bed joint as opposed to the conventional one width of 150mm.

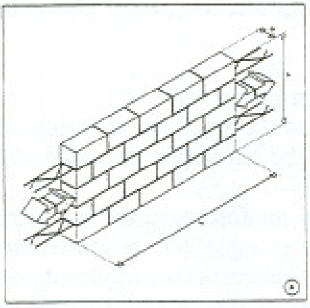
(C) Reinforced Masonry Subjected to lateral Deflection

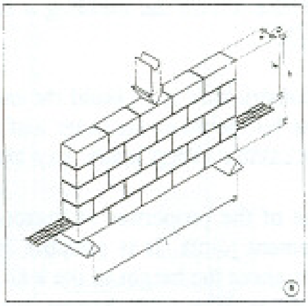
Walls subject to lateral wind loads can be exposed to considerable stresses. Similar stresses are found in the retaining walls of cellars.

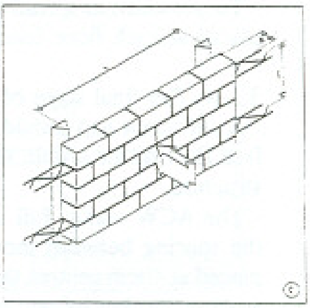
In the case of a wall of effective width 'd' subjected to a lateral load, it is possible to increase the distance between lateral restraints by the use of Murfor reinforcement uniformly distributed trhoughout the wall spaced at vertical distance 't'.

In all cases it must be remembered that the higher the compressive strength of the masonry material used, the more effective the use of masonry reinforcement will be.

By taking these properties of reinforced masonry as a composite material into account when designing structures, the Architect, through specifying prefabricated reinforcement in appropriate quantities and locations, is able to extend previous architectural boundaries.







3. AUTOSUPPORTING CAVITY WALL

The AutoSupporting Cavity Wall (ACW) is a means of construction designed to overcome many of the problems normally associated with the connection between two leaves of a cavity wall.
With the ACW system the two leaves of the cavity wall are constructed so that they are structurally independent and do not react with each other.
This structural independence between the two leaves is made possible by using the composite material features of reinforced masonry, that is: (A + B + C)

The ACW is built in four stages starting with the inner leaf construction.
The structural frame of the building may be constructed from either concrete or steel. The example we shall use to illustrate this method of construction was built in concrete in El Espinillo, Madrid.

3.1. The Construction Process of the Adell Cavity Wall (See figures 2 and 3)

3.1.1. At the first stage of construction particular attention must be paid to ensuring that the outer face of the building is completely flush (1A). Steel profiles to enable the later anchoring of the outer leaf wall to the frame should be fixed at this time (1B).
- Provision should also be made for supporting the base of the outer leaf of the wall (4A). Because of the vertical deflection properties of reinforced masonry previously described, this support need not be continuos.

3.1.2. The second stage of construction is to build the inner leaf of the cavity wall. Of major importance here is to ensure that the outer face of this wall is completely flush with the outer face of the building frame.
- To prevent cracking in this inner leaf due to deflections in the supporting floor slabs, appropriate quantities of masonry reinforcement should be placed in this structure (2A).
- In Spain provision is also made at this time for placing the prefabricated cage to house the shutter system (2B).

3.1.3. Having completed the inner cavity leaf, insulation can be applied to its outer face (3A). This may be applied in either spray or panel form. As the face of the building is completely flush the insulation can be applied to both the building frame and masonry structure at the same time.

- To prevent the spread of fire within the building a fire protection barrier should be placed at each floor level (3B).

3.1.4. The final stage of construction is to build the outer cavity wall.
- A sufficient gap should be left between the outer leaf and the insulation to ensure the free flow of air within the cavity. Weep holes may also be left within the outer wall structure.
- The ACW makes full use of the properties of masonry reinforcement by increasing the spacing between movement joints. It is possible for example with reinforcement placed at 40cm centres throughout the height of the wall, to increase the movement joint spacing in clay bricks to every 30m (4F). Movement joints should still however be placed at every change of direction irrespective of spacing.
- In the example shown the base of this free standing outer wall (4A) is resting on concrete plinths. The area at the base of the wall between these plinths can be considered as a lintel. The vertical deflection likely at this 'lintel' is dependent upon the mass of masonry found directly above this point. As such the amount of masonry reinforcement required in this area will vary from the resultant loading.
- A damp proof course should be located in the appropiate position below all of the weep holes.
- When constructing masonry lintels for the windows (4B) the masonry reinforcement must extend 500mm beyond each side of the opening. Lintel hangers should be fixed into every other perpend joint in the bottom layer of masonry. As the bottom face of the masonry is exposed directly above the opening care should be taken to select appropriately solid masonry material for this area.
- With the outer leaf of the wall being reinforced throughout its structure it is not necessary to tie it to the inner leaf as a means of withstanding lateral deflection. Instead the properties of the composite material will adequately prevent deflection between the lateral supports (4C).
- For example in the case of an average wind load acting upon a half brick wall thickness it is possible for lateral restraints to be positioned every 4 to 6m by using masonry reinforcement at 40 to 50cm centres throughout the wall height. (Spanish clay bricks are usually 240 x 115mm or 290 x 140mm).
- Even with the reinforcement in place there is still controllled movement within the outer masonry leaf. Lateral movement is controlled by the bed joint reinforcement. In the case of vertical movement sufficient flexibility at the predetermined anchoring points (4D) should be allowed by the fixing system (1A).

For the ACW system to operate at its best, the two leaves must function separately throughout the entire area of the wall. Covers fixed to the top of the wall should be designed to allow independent movement of the two leaves (4G). Any other elements which relate to both leaves must similarly only be fixed to one of the leaves. The window frames for example should be fixed to the inner leaf. Care needs to be taken around the still area to ensure the throating prevents the passage of water to the inner cavity whilst maintaining structural independence. Similarly the shutter rail should be fixed only to the inner wall (4E).

Before using the ACW system the designer needs to asses his specific requirements. If a building of more than three or four storey's is to be constructed, specific calculations must be made.

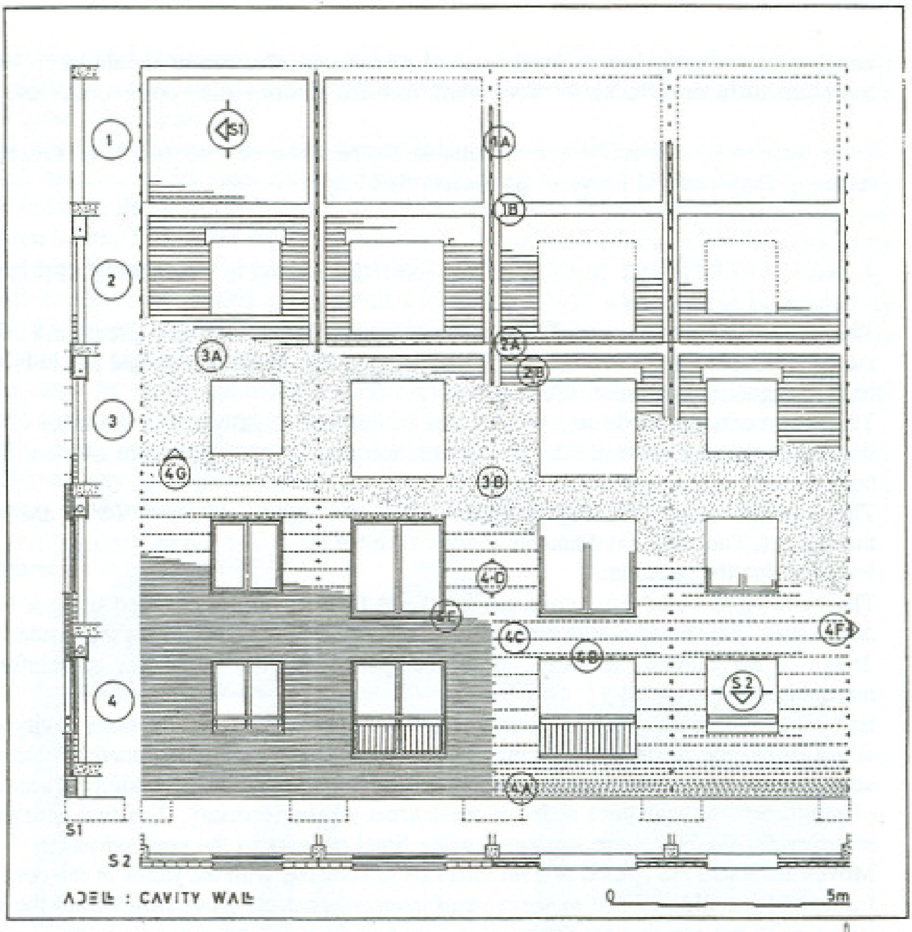


Figure 2:
The construction process of the ACW, using an outer leaf of bed joint reinforced autosupporting masonry.

1. Structural Frame for the Building
   1A - Profile for the outer leaf anchoring system
   1B - All faces of the frame to be completely flush
2. Construction of the Inner Leaf of the Cavity Wall
   2A - Reinforcement in the inner leaf
   2B - Prefabricated cage for the shutter system
3. Fixing of Insulation
   3A - Continuously applied over building face
   3B - Fire prevention barrier at each floor
4. Construction of the Reinforced Masonry Outer Leaf
   4A - Base of the self standing wall
   4B - Masonry lintel reinforcement
   4C - Outer leaf reinforcement throughout its structure
   4D - Anchors for fixing the outer leaf to 1A profile
   4E - Connection for window frames, sill, shutter rail,
   4F - Increased spacing of movement joints
   4G - Cavity wall topping

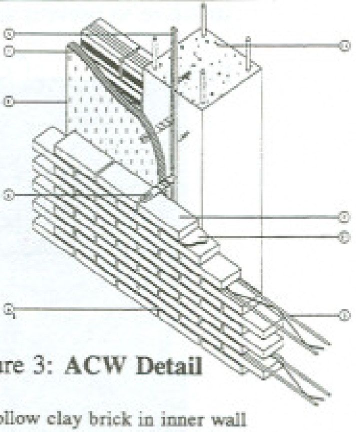


Figure 3: **ACW Detail**

1. Hollow clay brick in inner wall
2. Murfor reinforcem. RND5/E-80
5. Track outer leaf anchor. HMS 25/15-D
6. Halfeneisen lug ML 120/3 (6 cours. h.)
7. Palau fair-faced clay brick 240x115x50
8. Cavity wall outer leaf
9. Continuous applied insulation 40mm
21 Joint mortar 8 N/mm²

In all cases correct practices for the use of masonry reinforcement should be followed to ensure sufficient overlap between reinforcement sections and good mortar cover.

Other version of this ACW can be suitable for rebuilt a new architectural wrapping, covering the structural frame of an ancient building.

4. NEW APARTMENT BLOCK IN EL ESPINILLO WITH TWO TETRAPILONIS

This project relates to a new 76 dwelling apartment block built on a greenfield site in the El Espinillo district of Madrid. The building is five storey's high and has only four basic designs of apartment. (See figures 4)

The apartments are set in two blocks, one behind and slightly above the other due to the sloping ground. Between the blocks there are areas of open courtyard and four brick built towers wich house the staircases.

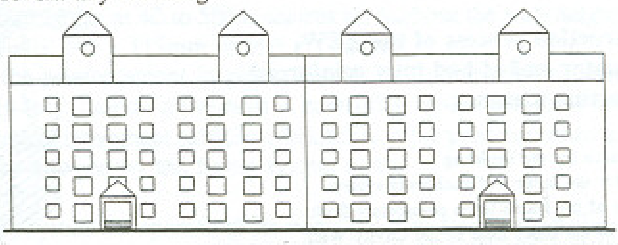
The frontage of the building is dominated by the square windows which are used throughout. The large 2m diameter windows are for the dining rooms, the smaller 1.5m windows for the bedrooms.

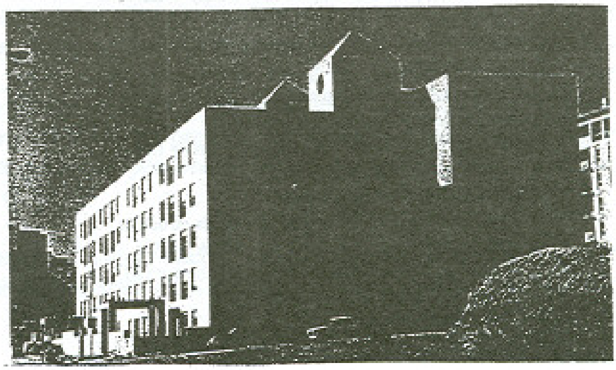
The building is based on a concrete structural frame which is finished using a brick cavity wall. Fair faced bricks are used on the outside, hollow bricks on the inside. The design of the building is based on the composite material properties of reinforced masonry.

Bed joint reinforcement has been uniformly distributed throughout the outer cavity wall at six brick course centres (36cm). The windows have been positioned to take full advantage of this reinforcement in forming solid brick lintels. Small additional amounts of reinforcement have been added in these areas where necessary. The first courses of masonry for the lintels are supported using lintel hangers in the perpend joints.

Movement joints are spaced at 33m intervals to coincide with the joints in the concrete frame of the building. The masonry reinforcement controls movement within the wall structure to prevent any cracking.

Figures 4:





The two main entrances to the blocks in El Espinillo each feature a brick built tetrapilonis topped with a four sided reinforced brick cover. The tetrapilonis forms a 4m cube. (See figures 5)

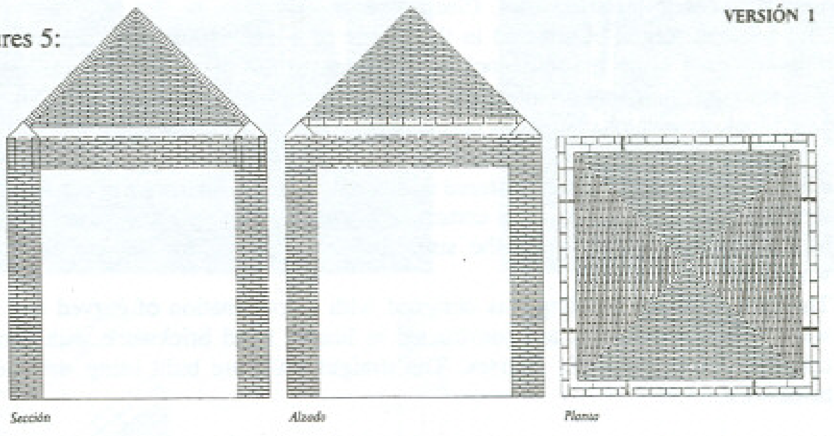
The cover for the tetrapilonis is supported upon four reinforced brick double lintels. Each lintel has a 3m span and has a section 500mm high x 115mm wide. To achieve the required depth of the lintel, that is the same width as the tetrapilonis pillars, two 30mm widths of Murfor reinforcement were used in the bottom bed joint followed by a further 50mm width in the second.

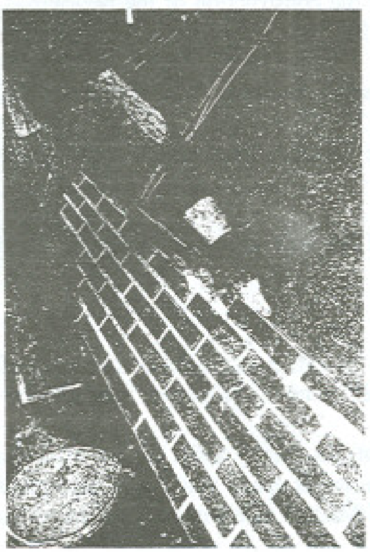
Each double lintel needed to withstand a load of 5 KN/m which would be exerted by the roof cover. In tests the lintel sections were seen to withstand loads of 35 KN/m without any sign of cracking.

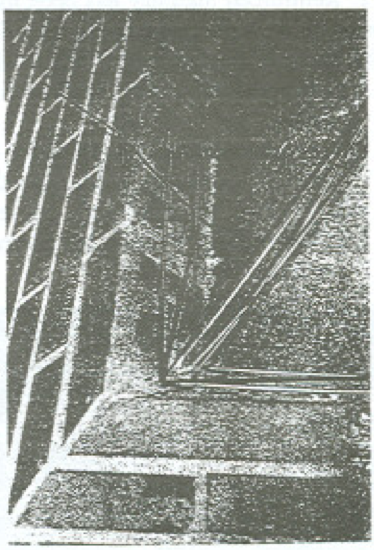
The cover for the tetrapilonis involved the novel use of reinforced masonry. It is a half brick thick with fair faced sides being visible from top and bottom.

Both covers were prefabricated in an off-site factory. Each cover was constructed in a different way to present a different personality for each door whilst also allowing further experimentation to take place into the potential for reinforced masonry.

Figures 5:







On one cover the bricks have been laid horizontally, on the other, vertically. For the horizontal brick cover the bed joint reinforcement was laid in the normal way. For the vertical bricks the reinforcement was placed horizontally through the holes in the Palau bricks. In both cases reinforcement is provided at the edges of the cover.
After fabrication the covers were transported to site where they were set to rest on top of triangular metal supports which lay on top of the masonry lintels. This method of support gives the illusion of the cover resting on air. (See figures 6)

5. NEW APARTMENT BLOCK IN PLAZA DE LA REMONTA

This project is a new 57 apartment building situated in the residential district of Tetuan, Madrid. The area has a strong traction of clay brick construction which dates back to its use of '19th Century Brick Architecture' well known for its ornamental brickwork.

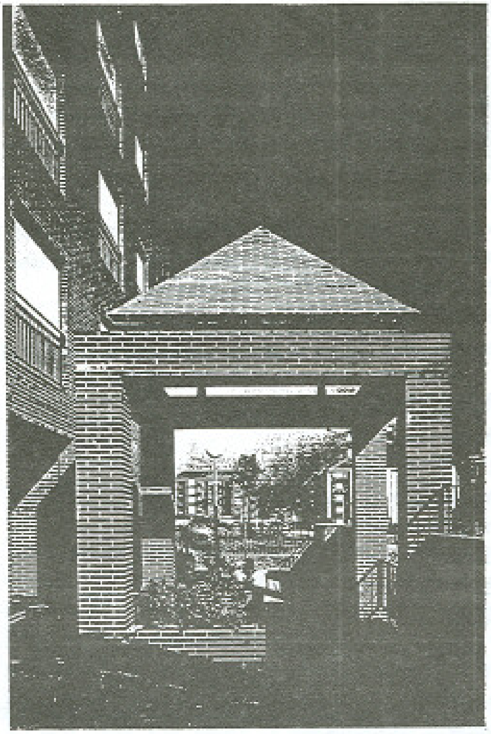
Due to the complexities of the site a total of twenty three different designs of apartment were required to meet the brief. (See figure 7)
The building was to be situated in the corner of a large 100m wide square. Existing buildings onto which the new block was to be joined featured a covered walkway which was amongst the many architectural features which had to be continued. To give the new block its own character, its corner was to feature a cylindrical tower at the top.
Architecturally the design required the combination of two opposite criteria. Many existing buildings in the area featured traditional header bond brickwork structural walls with vertical windows. Modern construction methods with the separation of the outer leaf of the cavity wall from the structural frame called for the use of horizontal windows.
The outside of the building was designed with a combination of curved and straight walls. The curved walls are constructed in header bond brickwork with contrasting coloured bricks every six courses. The straight walls are built using stretcher bond brickwork.

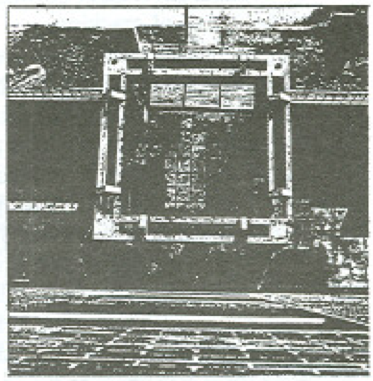
5.1. Reinforced masonry has been used in the construction of the two wings flank the tower at the buildings corner. (See figure 8)
The masonry reinforcement was used to:

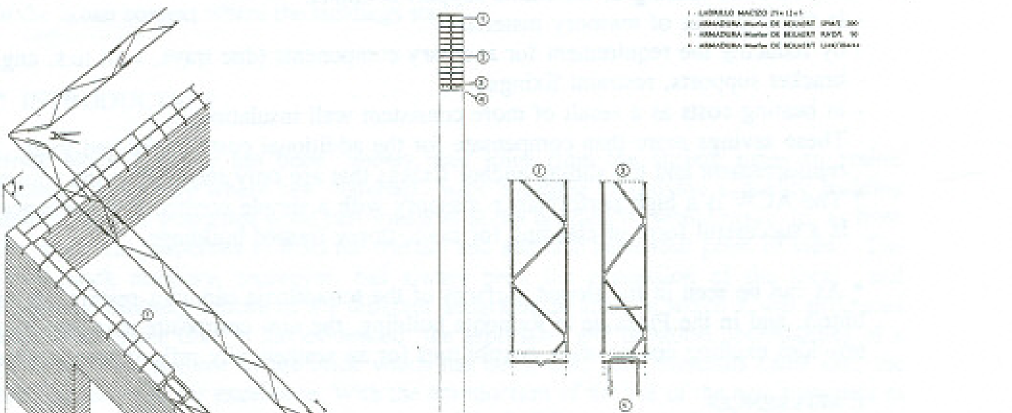
5.1.1. Support the vertical load of the masonry resulting from the construction of the lintel.
5.1.2. Overcome cracking problems in the masonry lintel which could be caused through expansion and contraction.
5.1.3. Tie together acute angle corners.
5.1.4. Tie together the two brick leaves of the wall so presenting a fair faced exterior on each side.
5.1.5. Resist lateral wind loads.

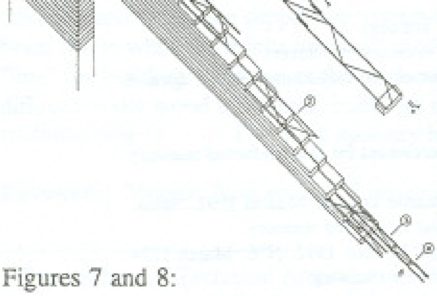
All of this has been achieved by the use of different combinations of prefabricated reinforcement in masonry which provides a new composite material for creative architecture.
In the final analysis, masonry reinforcement can greatly assist the Architect but as with all things it is his imagination and creative use of space which will be remembered as with this window which frames the sky of Madrid (see Figure 8 tower).

Figures 6:

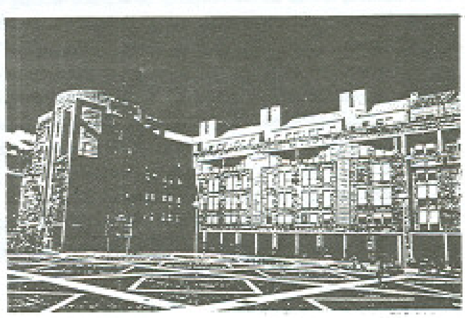








Figures 7 and 8:



6. CONCLUSIONS:

* The Adell work introduces an architectural COMPOSITE MASONRY MATERIAL NEW that uses different combinations of prefabricated steel bed joint reinforcement.
* This new composite masonry material achieves imporved performance characteristics with any type of masonry. It provides crack control and allows more economical and creative architecture.

* The ACW, autossuporting cavity wall, with an outer leaf of bed joint reinforced new composite masonry material, is a new type of an "off-the-frame cladding" for use with steel or reinforced concrete structural frames.
* The advantages of the ACW are:
- differential movement between masonry and frame is accommodated simply and without risk of cracking.
- support angles or brackets are not required for the masonry.
- movement joint spacing can be greatly increased.
- the need for compressible joints at supports and floors is avoided.
- conventional lintels are used and no additional lintels are necessary.
- a continuous cavity is maintained within the wall which:
    - avoids risks of water penetration.
    - requires dpc only at the base of the wall.
    - provides good cavity ventilation.
    - allows simple continuity of insulation for better control of heat loss
* The ACW is an economical form of construction that can show savings:
- in the frame due to reduced dead loads from the cladding and making it possible to increase the spacing of the frame support columns.
- in the thickness of masonry material.
- by reducing the requirement for ancillary components (dpc trays, wall ties, angle or bracket supports, restraint fixings).
- in heating costs as a result of more consistent wall insulation.

These savings more than compensate for the additional costs of the bed joint reinforcement and the sliding anchor fixings that are only required at the columns.
* The ACW is a high performance masonry with a simple construction sequence and is a successful form of cladding for multi-storey framed buildings.

* As can be seen in the sloped surfaces of the tetrapilonis canopics resting on double lintels, and in the Plaza de la Remonta building, the new composite masonry material provides exciting construction possibilities for an aesthetically refined architecture.

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