

12TH INTERNATIONAL BRICK/BLOCK Masonry CONFERENCE



Ade

MILLENNIUM ARCH

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ABSTRACT

Throughout history the masonry arch has been considered as the most characteristic construction component of Architecture and Engineering ever since it was first conceived in Roman times and predating Hellenistic culture.

Ever since these times the arch has been employed as an efficient construction solution to span openings with materials which cannot withstand tension. The technical originality of the arch has led to its use in monumental architecture and its symbolisation of military feats, as was the case of the triumphal arch.

With the change of century and millennium there has been a fundamental technical advancement, which is revealed in this conference, under the name of the Integral Masonry System and which broadens the field of application of masonry by means of the incorporation of steel within perforated units which allow the three-dimensional reinforcement of any type of masonry wall. The Millennium Arch commemorates this 12th IBMAC in Madrid and reveals the technical advances provided by the Integral Masonry System, as the arch is inclined and is built in header bond using the Ladriflor or Flower Brick and reinforced with bars and hoops.

The Millennium Arch has been designed on the basis of a 14m diameter cylinder angled 30° to the ground and built in one brick thick masonry, alternating one course of yellow brick with six of red. The arch has a clearance of 10 m wide by 5.5 m high and the masonry is regularly reinforced with truss type bed joint reinforcement every 6 courses. The area of the arch (structurally speaking an angled curved beam) is reinforced with longitudinal bars and hoops of 10mm which pass through perforations set in a universal clay brick.

The Millennium arch shall remain in the gardens and form the main access to the Palacio de Congresos from the principal artery of the Paseo de la Castellana.

Key words: Arch; Universal Unit; Bed Joint Reinforcement; Bars; Integral Masonry System

Figure 1. Roman triumphal arch.
Figure 3. Alcántara Bridge,

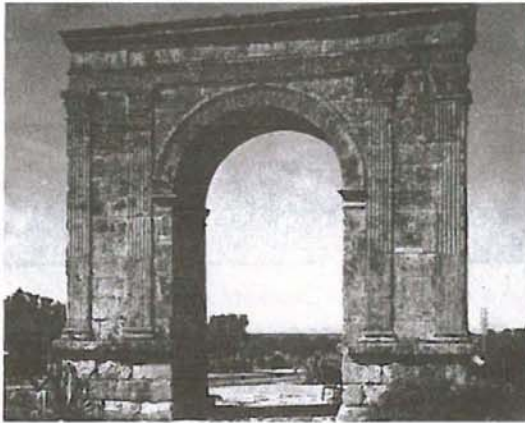
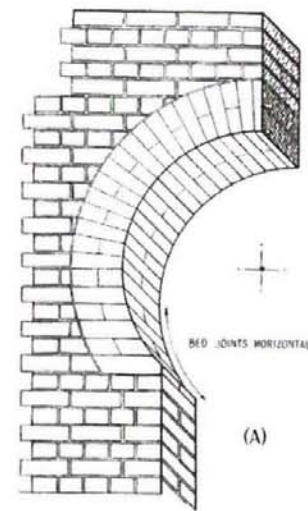


Figure 2. Aqueduct of Segovia.
Figure 4. Moorish Arch.



MOORISH ARCH

SHOWING ALTERNATIVE METHODS OF STRIKING THE
VOUSSOIRS FOR THE LOWER PORTION OF THE ARCH.

BACKGROUND

Ever since ancient Roman times the arch has been the most characteristic symbol of homage to the great feats of man. From a symbolic point of view the Roman arches existing in many countries only served to commemorate a specific military exploit of the emperor of the time. These arches having remained to the present time as Triumphal Arches (Fig.1)

The Romans were also the first great engineers to discover how to organize successive levels of arches in order to span the different heights between viaducts or aqueducts and the valleys which had to be crossed (Fig. 2 and 3).

The architecture of the arch has employed its formal aspect to characterise the style of different cultures throughout history (Fig. 4).

From the time of its first construction the arch has a significant technical function which makes it essential for the crossing of large spans such as valleys and rivers.

In more recent times the arch has continued to be used as a monumental feature in many cities and countries throughout the world. Today, and while the arch has lost a large part of its applications to architecture as a result of framed structures, it continues to be employed to mark significant feats or events.

ORGANIZATION OF THE TRADITIONAL ARCH

In architecture or engineering we began with traditional materials such as stone, block, brick and adobe, which all have good compressive strength but little or no tensile strength.

When it was necessary to span an opening, man with all his ingenuity invented the arch. The arch is a building device which manages to transfer compressive loads along a curved directrix which compresses the different blocks or voussoirs forming the same and prevents the bending and tension of the same.

The arch is, therefore, a bowed curve set in a vertical plane in which the component parts, aided by the action of gravity, are forced together in order to span a specific opening of distance, by means of certain deflection and the generation of thrust (Fig. 5).

In order to ensure that the arch is stable it is necessary to consider the support which will withstand the thrust or diagonal force exerted by the arch and which not carry vertically downwards to the ground but will, instead, follow the curved directrix of the same to the adjacent masonry on both sides of the springer or start of the arch.

Normally the masonry supports or buttresses on both sides of the arch absorb the thrust of the arch by means of their own weight.

Another method of bearing the thrust of the arch is to employ steel ties through the span which withstand the tensile stress and balance out the horizontal thrust of the arch.

The form of the arch is established by the centring which has to support the same during the construction process, so that by placing the voussoirs from the

springer or bottom of both sides of the arch upwards and then placing the central voussoir or keystone, this will then close the curved directrix and allow the masonry blocks to compress when the centring is removed (Fig. 6)

The specific form of the arch may vary though different thrust will be conducted in accordance with the form of the curve. As such, a segmental arch carries greater thrust than semicircular arches but less than a stilted arch (Fig. 7). Certain forms of arch require a specific load positioning which sometimes have to be supplemented in order to maintain their form. As such pointed arches required loading on the key stone while semicircular arches had to be loaded at the haunches or flanks (Fig. 8).

REINFORCED MASONRY AND THE BLIND TIED ARCH

If we wish to avoid the thrust of the arch it is possible to tie the same. An example of this technical solution was considered by Kahn in his buildings in Bangladesh and which combined brick arches with reinforced concrete tie beams (Fig. 9).

Reinforced masonry, that is to say, a masonry wall which is reinforced with bed joint reinforcement distributed regularly throughout its height, has steel set at different levels which provide the masonry with sufficient tensile strength in the horizontal direction of the wall. As such, a reinforced masonry wall may act in the same manner as one with successive arch ties set at regular levels.

Therefore, if a reinforced masonry panel weakens in the central area as a result of the flexural bending of the slab at the support, the lower bed joint reinforcement will then come into play and act as a hidden tie or tension member, which will create a flat or discharging masonry arch within the wall (Fig. 10). The reinforced masonry then acts in the manner of a succession of superimposed blind arches which as well as preventing the cracking of the masonry, also brace large spans over openings without the need to formally construct the arch within the wall.

In reinforced masonry lintels, the wall acts as an arch in the manner designed by calculation, that is to say, with upper elements of compressed masonry balanced out by lower levels of stretched or tensioned masonry, as there is sufficient reinforcement to absorb the stresses and balance out the stress and strain (Fig. 11).

THE INTEGRAL MASONRY SYSTEM WITH THE UNIVERSAL CLAY BRICK

The Integral Masonry System allow three-dimensional reinforcement when this be so required for reasons of design or calculation.

The Integral Masonry System supplements the bed joint reinforcement with universal masonry units and reinforcing ribs.

Universal units such as the Flower Brick, these being units which contain removable pieces which may be extracted to create large inner voids to house the reinforcement, allow the vertical reinforcement of the masonry which, subsequently, provides it with vertical tensile strength while at the same time maintaining the appearance of the desired bond.

The three-dimensional reinforcement provided by the Integral Masonry System allows masonry to be applied to areas which were previously the sole domain of reinforced concrete, as is the case of prefabricated work or in particular application such as the Millennium Arch.

While the traditional arch needs downward pressure in order to stabilise the same, with the Integral Masonry System which is reinforced through a lateral channel opened in the Flower Brick, it is possible to construct an arch which defies this downward pressure and, therefore, the shape and organization of the same surpasses the traditional parameters on which arches have been based throughout history, as a result of this new building system which allows the incorporation of steel.

DESIGN OF THE MILLENNIUM ARCH

Towards the end of the 20th century a technique was developed in Spain which is capable of changing the course of history with regards to the employment of masonry in this new millennium.

The Integral Masonry System, when suitably applied, allows the construction of leaning masonry arches which on their own would be unstable, that is to say that they would collapse as a result of downward pressure as soon as the centring was struck, but which as a result of a careful construction combining masonry units with reinforcement and mortar, allow them to bear the stresses and strains so that they become stable in spite of their apparently precarious form.

In fact this curved angled form which springs and projects from the same axis is not, structurally speaking, an arch and is more correctly a corbel. A corbel which is curved is subject to very high tensile stress, bending and torsion, which means that it can only span wide openings if it is suitably fitted with steel. This means that it can be made in reinforced concrete, or steel profiles and also with the latest masonry forms as a result of the new Integral Masonry System.

URBAN LOCATION OF THE ARCH

A formal proposal was made to the Director of the Palacio de Congresos de Madrid, the Madrid Conference Centre, to construct a temporary arch to commemorate the 12th IBMAC, and given the enthusiastic response with which the proposal was met, the Board of the Conference Centre proposed that a permanent site be found for the arch within the gardens leading on to the Centre.

Figure 5. Technical arrangement of the arch

Figure 7. Different arch forms

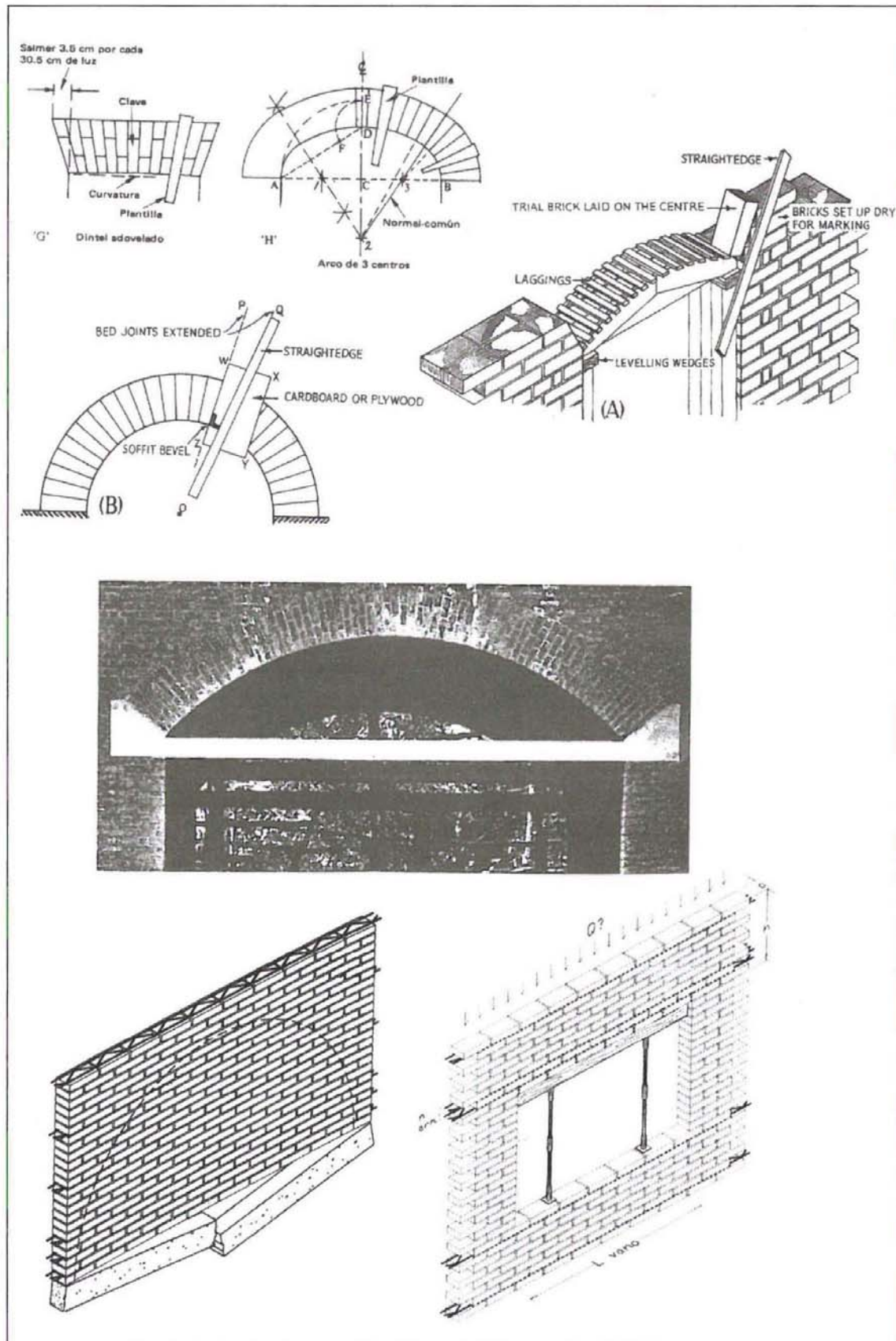
Figure 9. Kahn Arch in Bangladesh: Segmental arch tied with reinforced concrete Blind arches of tied reinforced masonry

Figure 10. Straight arch

Figure 6. Construction process of the arch

Figure 8. Loads on arches

Figure 11. Arch lintel



Under this premiss the Board selected the pedestrian approach which connects the main thoroughfare of the Paseo de la Castellana to the esplanade facing the General Perón street, as this access lack a suitable indication of entrance for such an important building.

The arch is set between the gardens bordering the pedestrian access and creates an attractive feature which emphasises the access to the main street of the two which lead on to the Conference Centre.

In this location the arch marks the access and frames the Centre in the distance with its surrounding gardens.

The Millennium Arch brings to mind a ruin which with the passage of time has become partially buried within the city. It is configured in the form of a large and slightly angled cylinder which is seen to emerge from the soil. On the face of the cylinder there is a large circular opening of oblong proportions which appears in the form of an arch and which has been created by a culture capable of three-dimensionally reinforcing masonry and which has only just been made possible in this third millennium.

CONSTRUCTION OF THE MILLENNIUM ARCH

***Construction details of the arch**

The arch is formed by a cylinder with a 14m internal diameter and constructed in one brick thick masonry in header bond, which makes a total external diameter of 14.6m (Fig. 12).

In plan form the cylinder is divided into 4 parts in relation to the four quadrants of the same. The 2 side quadrants are built in curved brick, while the front quadrant forms a corbel arch over a 10m opening of 5m high, and the rear quadrant is totally submerged and does not require construction (Fig. 13, a, b, c).

The three sectors or quadrants of the cylinder, the two supporting quadrants and the arch, are formed in lengths of 40 bricks which are bonded in one brick thick header bond.

The successive courses are spaced 1.2 cm in order to house the 1cm diameter horizontal reinforcing bars in the area of the arch.

The M-80 mortar covering employed was deemed to be sufficient as the mortar paste fills the perforations opened in the masonry units and cover the petals which have not been removed.

The 7m radius curve allows the construction of the cylinder with slender joints on the intrados of the same, and joints of normal thickness (1.2cm) on the external face (Fig, 14).

Figure 12. Millennium arch of the 12th IBMAC.

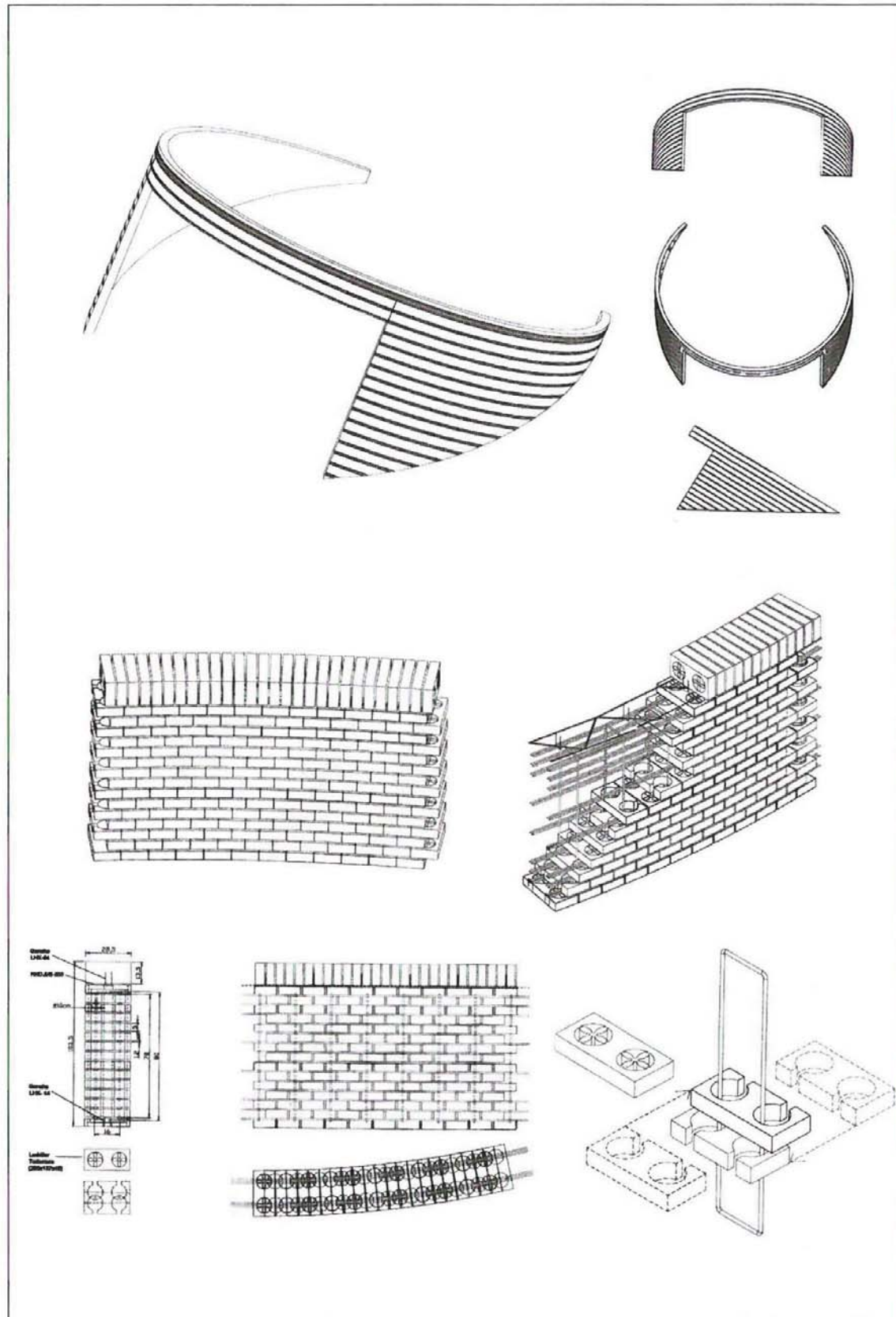
Figure 13. a) Plan; b) Front elevation; c) Side elevation.

Figure 14. Header bond with thin joints in the intrados.

Figure 15. Flower brick reinforced with vertical hoops.

Figure 16. Murfor truss type bed joint reinforcement.

Figure 17. Arch reinforced with longitudinal bars and hoops.



The curved cylindrical wall is built with one course of coloured brickwork every 6 courses, which enormously enhances the curvature and the leaning configuration.

The header bonded brickwork was made in brick supplied by INCECOSA of Barcelona (Grupo Almar) in the Catalan format (DIN) of 285x137x49mm in clinker quality and in two colours of red "Oregon flashing" and yellow "Nevada flat", and was regularly placed in 5 courses of red brickwork to one of yellow.

The brick employed was the Ladriflor or Flower brick universal clay brick which is capable of being vertically reinforced when and where required, this particularly being the case of the curved beam which formed the arch (Fig. 15).

The wall is regularly reinforced with Murfor RND 5/S-200mm bed joint reinforcement provided by Bekaert and placed every three courses.

In the arch area longitudinal rebars have been placed to withstand the tensions, using non-rusting 10mm diameter twisted bars supplied by Roldán of ACERINOX, and in order to absorb the torsion generated by the horizontal/angled arrangement of the masonry, hoops of 10mm diameter stainless steel twisted bars were embedded on the perforations opened up in the Ladriflor, in the area of the arch (Fig. 17).

In order to offset the counterweight of the arch with the mass of the cylindrical masonry, vertical tie reinforcement was placed which balances the weight of the cantilevered arch beam. As such 10mm diameter stainless steel twisted bars were embedded on the perforations opened up in the Ladriflor, in the most stressed areas of the arch supports.

In order to avoid the optical effect of the sagging of the arch on striking, the centring of the same was slightly stilted.

The coping of the cylinder employed more regular courses of coloured brickwork which was topped by a soldier course.

An inscription which reads "ARCO DEL MILENIO" is set on the coping of the arch, in commemoration of the 12th IBMAC.

***Construction process of the arch**

The construction procedure employed is the result of a broad technical analysis which has passed through three clearly different stages:

- The first option was to prefabricate the arch in a different area in three parts, the two lateral quadrants and the central arch itself, so that they could then be transported to site and then connecting together by tying the previously fitted

vertical reinforcement to the arch supports once this had been rested on the two lateral curves. This option was discarded when we were offered the possibility to construct the arch in-situ and to leave it permanently in place (Fig. 18).

- The second option, which arose from the possibility of building in-situ, considered the construction of the arch in a horizontal position. This seemed to be the simplest option from a bricklayer's point of view as it was simply a cylinder which had to be raised. However, this solution had the disadvantage that it would be necessary to then lean the arch/cylinder 30° once it had been constructed. As such a turning support platform was designed which would allow the movement of the cylinder. However, in the light of the fact that this was that it would be difficult to ensure that the arch did not crack during the turning process (Fig. 19a, b).
- The third option consisted of constructing the arch in its 30° leaning angle which would substantially complicate the bricklaying process and would prolong the building process, but which would guarantee that the arch would not crack as it would not be necessary to turn the same.

The manual construction of the masonry when bearing in mind the downward pressure, requires the construction of successive horizontal courses without losing verticality. As in this case the courses were angled at 30° the successive courses could be laid but the correct execution of the same was severely handicapped and, as such, it was necessary to employ circular guides which were angled at the said 30° and which served as a reference for the regularly placed coloured courses of brickwork.

In order to ensure that the curvature was as continuous as possible, and given that the traditional chalk lines employed to mark the level of each course would follow a straight line as soon as they were stretched between the reference points, meant that it was necessary to design templates in chipboard in order to adjust the brickwork to the desired circle between the reference points.

The arched corbel was logically propped before construction and was retained in this propped position for the necessary time to ensure the correct setting, curing and hardening of the reinforced masonry composite.

In order to visually appreciate the advantages provided by the new technique in association with the Ladriflor universal clay brick, the flat bed side of the units have been left exposed at the lower part of the arch (Fig. 20).

In the construction process it is necessary to underline the added difficulty of placing 3m long bed joint reinforcement within a curve of 7m radius and this made it necessary to cut the Murfor longitudinal reinforcement in three areas in order to establish a polygonal form in accordance with the curved layout. This meant that it was necessary to double up the bed joint reinforcement and place the successive cuts in alternating courses to form the respective concavity or convexity and ensure the continuation of the bed joint reinforcement.

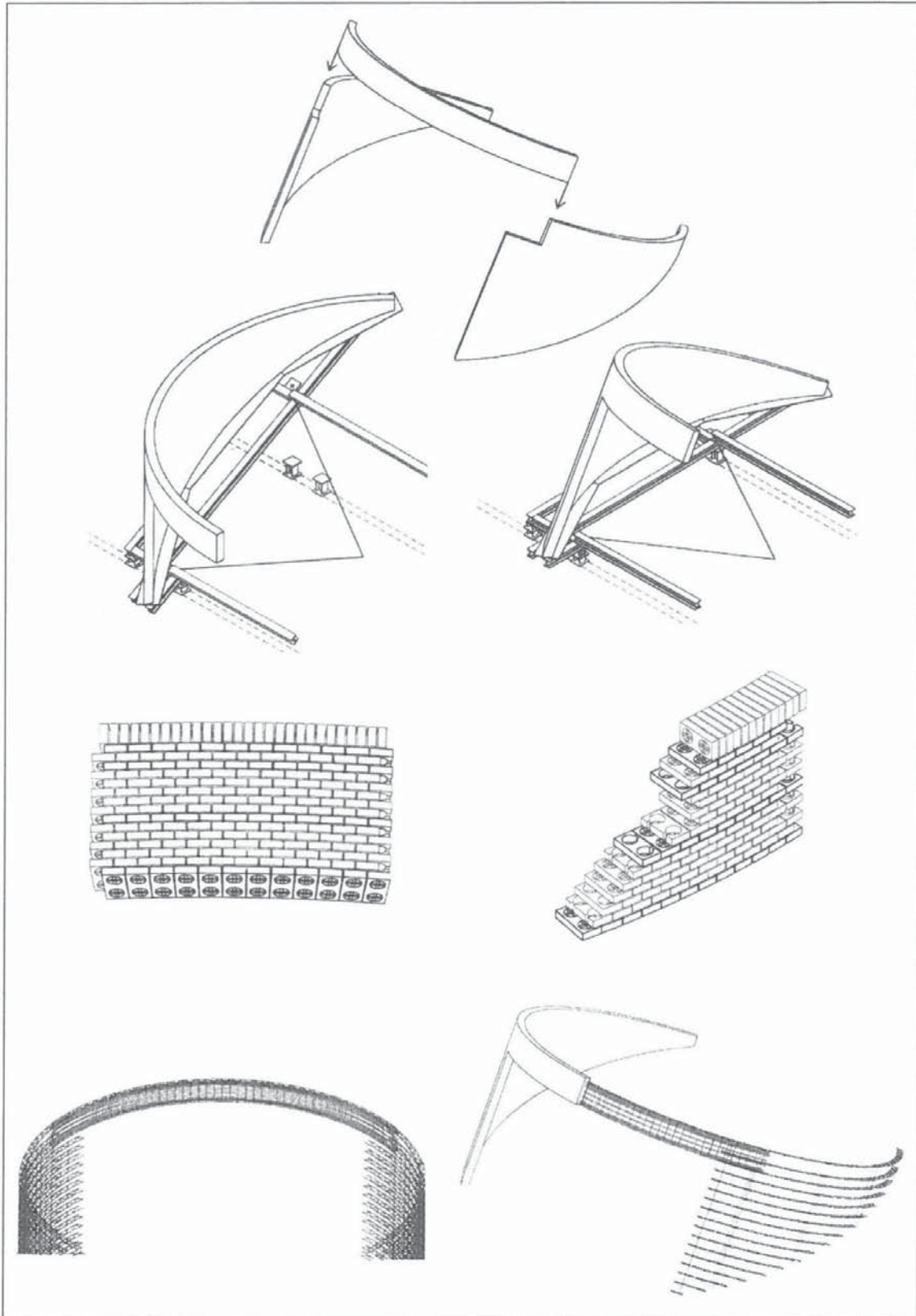
Figure 18. 1st prefabricated option. Assembly in 3 parts.

Figure 19. 2nd option of horizontal construction in-situ: a) Construction position b) Final position turned 30°.

Figure 20. Millennium arch with exposed base of Ladriflor Fig. 23. Laterally opened Ladriflor to house hoops.

Figure 21. Reinforcement of the Millennium arch.

Figure 22. Volumetry of Millennium arch: brick and reinforcement.



The vertical reinforcement necessary to brace the arch was placed through the perforations in the Ladriflor Flower Brick, and where possible coinciding with the overlaps of the bed joint reinforcement (Fig. 21).

The execution of the arch with abundant horizontal bed joint reinforcement, which was slightly curved and placed by hand by the bricklayers in the necessary courses, was progressively combined with the previous placed hoops which had been inserted through the perforations of the bricks in the first lower course of the arch (Fig. 22).

The Ladriflor units in the area of the arch have been laterally opened from the same side in order to house the hoops which pass to the left and right of the same and in order to suit the header bond arrangement of the brickwork (fig. 23)

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