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## SPATIAL STRUCTURES IN SPAIN 1950-1970. FIRST EXPERIENCES BEFORE THE STANDARDIZED SYSTEMS

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History, construction, projects, building techniques, spatial structures, spatial grids, spatial trusses, Spain

### Abstract

The first steel spatial structure for a roof dated in Spain was erected in 1952. From this pioneer experience authored by Eduardo Torroja and Florencio del Pozo, a series of other interesting realizations were followed by different architects and engineers. A special characteristic of all these early experiences was the limited availability of bars and manufactured elements specific for the special complexity of this kind of structures. For example, it was not until 1962 that steel tubes could be used in a spatial truss in Spain. Before that, ingenious solutions with standard rolling profile elements were employed.

In spite of these difficulties, from the beginning of the 60s, simple ways of union between bars were developed and the first important structures of this type were assembled in Spain. After several previous experiences, at the end of the decade, engineers Bueno y Calavera designed and constructed a roof for a sport arena in Madrid covering a rectangle of 70 x 50 m. The joints of the structural elements were always welded and an extensive use of skilful labor was needed. Only some years later but already in the early 70s, the engineers Calavera and González Valle built the most important spatial truss of this early period: the roof for the National Cattle Market in Torrelavega (Cantabria). The solution there was a low rise vault measuring 250 x 60 m.

The aim of this paper is to describe and analyze the particular systems used in Spain these first years, a period leading to the outbreak of international patents later widely used as Mero and others. The Spanish experiences shall be exemplified by their most outstanding achievements, but also by other minor but interesting examples of a more peculiar character. Among them deserves mention the removable system developed by the designer Carrillo Figueras and used for the Spanish Pavilion of the Teheran 1969 exhibition. For all of them it was not only important the structural design but also the methods of on site assembly.

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## INTRODUCTION

According to José Calavera (1999, 41), engineer Florencio del Pozo Frutos was the first who “assimilated vaulted triangular trusses to continuous shells, system that was used in the workshops of the Institute [Eduardo Torroja] of the Construction”.<sup>2</sup> These steel triangulated vaults of 9,75 m wide, rising 2 m and covering spans of 15 m were indeed the first steel spatial structures erected in Spain. The roof of the workshops was formed by a series of eight transversal vaults and besides Del Pozo, the project was authored by Eduardo Torroja in 1952. Without hollow bars available at this moment, the structure was composed by 80 mm I rolled profiles.

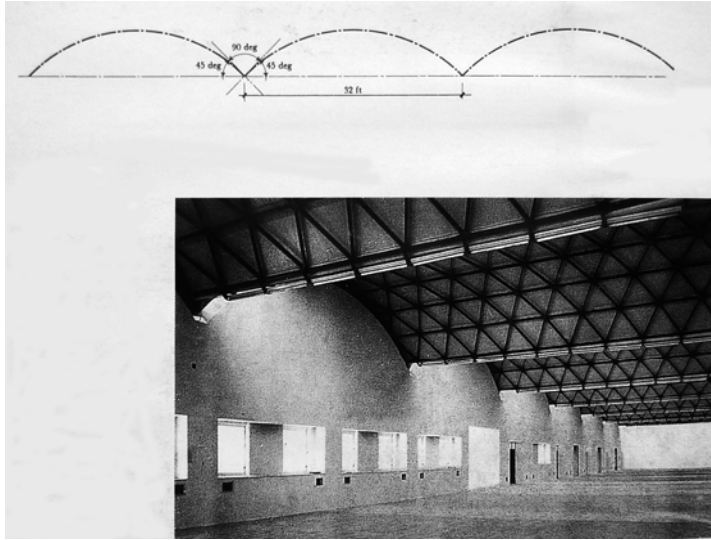


Figure 1. Institute of the Construction Eduardo Torroja. Workshops. 1952 (Fernández Ordóñez 1999)

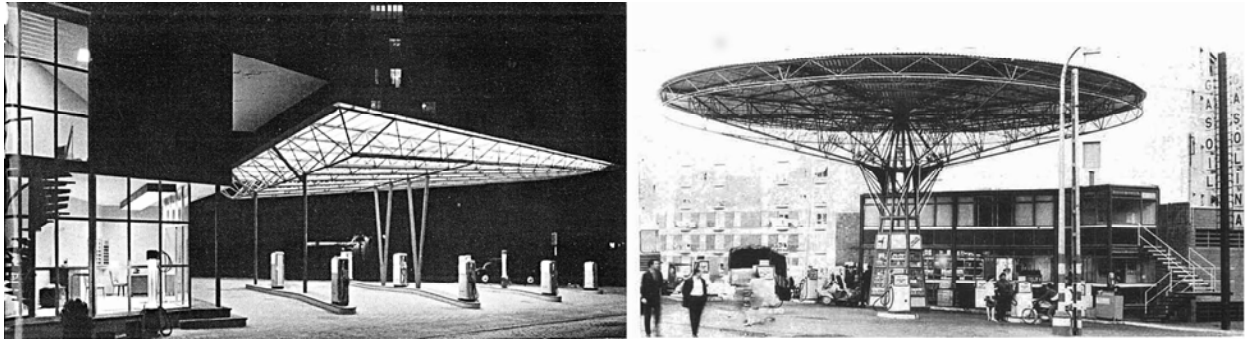
After this pioneer example different kinds of spatial structures were constructed, a group of which can be characterized by their singular solutions.<sup>3</sup> They correspond mainly to experimental projects devised as attempts to test these types of new structures even with limited resources. Among this group is noticeable the service station in Madrid, 21 María de Molina street, with a spatial truss on a trapezoidal plan and cantilevered 11 m. Designed by architects Capote and Serrano-Suñer (1963), it was another example of rolled profile construction, in this case with L and T sections. Also without nodes or intermediate connection elements between the bars it can be mentioned the gas station in calle Pi y Molins of Barcelona (Puig 1967). Built about four years later than the first one, it is however an example already made with circular tubes. Its highlight is the 20 m diameter circular plan and it is also worth mentioning the continuity of the main tubes of the truss to form the 8 elements central support.

In this introductory section a last example is the spatial structure of a factory in Rubí, near Barcelona by architect Francisco Rius in 1969. In this case spheres were included in the nodes but the general arrangement was a quite ingenious net of squares and diamonds connected by diagonals (Margarit 1972, 58).

<sup>2</sup> The analysis was published by Del Pozo in an Eduardo Torroja Institute monograph (Del Pozo 1958).

<sup>3</sup> In this paper the previous structures composed by spatial beams which are antecedents of the true spatial trusses will not be considered. We dealt with them in the paper “Entramados de la Autarquía y el Desarrollo” (García 2013). Regarding the spatial trussed structures, most of the main examples showed in this paper are here presented or discussed in detail for the first time by us yet some of them appeared in the mentioned paper in a summarized way.

As opposed to these examples other structures planned with a more systematic development were also soon built.



Figures 2 and 3. Gas Stations in Madrid (Capote, Serrano Súñer 1963, 23). and Barcelona (Puig 1967, 44).

### NEW LIGHTNESS TROUGH SPATIAL SLABS

The most important and quick advances in the development of spatial trusses are found in the trussed slabs or flat types. Within them is to be found the more clear progression in sizes and spans. In most cases they could be erected because they were competitive solutions to alternative and more traditional structures, as conventional trusses or web beams. Typically, the solution of all of them was two layers of flat nets of bars connected by diagonal elements in different arrangements.

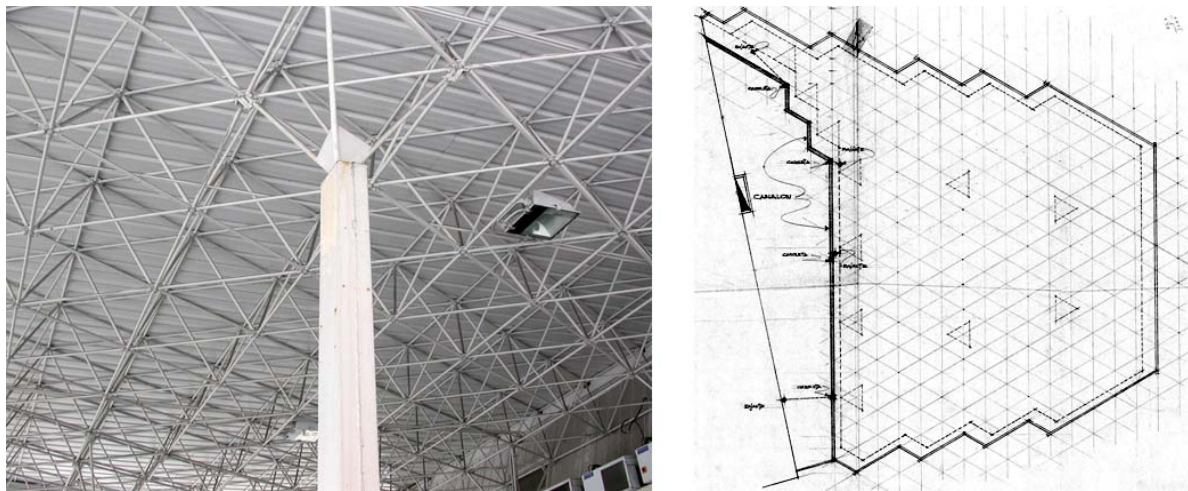


Figure 4. The Tenderilla service station, Oviedo, 1958-59 (Landrove 2011, 80).

Curiously the first example of a trussed slab documented in Spain was built with circular hollow bars even before the availability of structural tubes in Spain. The initiative came from a plumber who decided to use unemployed stocks of galvanized pipes for the construction of a new service station in Oviedo, Asturias, inaugurated in 1959. The architect Álvarez Castelao who designed the station in 1958, found an original solution for the structure with the “Castelao node” of his own invention (Landrove 2011, 80). It consisted of a flat ring and a manufactured tripod to fix the diagonal bars which connected the parallel layers. All the connections were bolted and the horizontal bars had cuttings in their extremes to introduce them in the flat ring. Of

moderate spans, the roof rests in four central supports and in a line of supports in one side. The three free sides are cantilevered about five meters. The importance of this peculiar structure lies indeed not only in the ingenious arrangement of unusual material and elements but also in the year of construction, anticipating to all the structures of this kind later assembled in Spain.

A few years later engineers Bueno y Calavera started the construction of the most important group of flat trusses erected in Spain in the early period we deem in this contribution. Because of the acquired experience they should be considered the most prominent practitioners of this type of structures.<sup>4</sup> Besides, as all the following examples covered rectangular plans and bars were in all the cases steel circular tubes, easy comparisons can be made between their main parameters.

In the first of them, built at the latest in 1962 and designed for the chapel roof of the Brocense secondary school in Cáceres, the surface covered was 24 x 17 m (Bueno, Calavera 1962). The spatial arrangement was the same as in all the other structures of the authors: two layers of triangles which form part of a compact clustering of octahedral and tetrahedral cells. In this first structure the length of the bars forming the triangles in the two layers was 1,113 m and the slab depth 0,964 m. All the bars were equal in diameter of 33 mm and 3 mm thick.<sup>5</sup> A peculiar characteristic of this structure was the embedment of the perimeter in a surrounding concrete beam; other was the type of node: as steel spheres were not yet available the nodes were constituted by vertical cylindrical bushings. For them tubes of 75.5 mm diameter and 3.75 mm thick were selected, but the consequence was that the fitting of bars in the node became intensive in labor. To prevent flattening, the cylindrical bushings were filled in with mortar.

Regarding the construction process, the structure was assembled in the floor, then raised to an intermediate level to complete weldings in the lower side, and finally fixed in the definitive level. The final weight of the structure without roof covering was of 20 kg/m<sup>2</sup>.

In 1963 the same engineers built two twin spatial trusses of the same type for the new factory of the Mahou brewery company in Madrid. Already with spherical nodes, they covered plans of 27 x 25 m and served as a preliminary experience for a third slab for the same factory. Published in 1965 (Buzón, Bueno, Calavera 1965), this last structure built over a rectangular plan of 57 x 46 m, deserves some additional commentaries. The choice of this solution was mainly for economical reasons since it was proved to be 20 percent cheaper than beams and girders. But also esthetic and experimental values were taken in account by the property.

Following the same arrangement as the previous one, the side of the horizontal triangles was in this case 1.87 m, with a depth of slab of 2.20 m and diagonals of 2.45 m.<sup>6</sup> The steel spheres were 23 cm diameter and 7 mm thick and also were filled in with mortar. As special characteristic of this structure, which differed significantly from the first of the series, was the supporting condition realized with simple support of the spheres in the whole perimeter. They just rested on steel plates embodied in the concrete edge beam. However, so simple support had to prevent the rising of the corners and a very special solution was implemented for that purpose. Groups of 4 or 5 spheres in each corner (in total 18) were anchored to the concrete beam by the connection of these spheres with other smaller spheres of 60 mm diameter effectively embodied in the concrete. These second spheres could however rotate freely into the concrete because they were

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<sup>4</sup> Later Calavera worked with González del Valle in the last spatial truss that shall be commented in this contribution.

<sup>5</sup> The calculations resulted in some bars of 21 mm diameter but the whole structure was uniformed with 33 mm tubes. With the indicated length and depth, the octahedra are not completely regular but the internal diagonal bars are always equal to each other and slight different than the reference of 1,113m.

<sup>6</sup> With the mentioned dimensions of bars, the two layers of the structure were even more proportionally separated than in the previous commented example. Obviously neither the octahedra nor the tetrahedra were regular.

coated by a thin layer of plaster and bathed in oil. The structural spheres, connected with tubes to the small ones, formed a sort of pendulums that allowed the free dilatation of the structure.

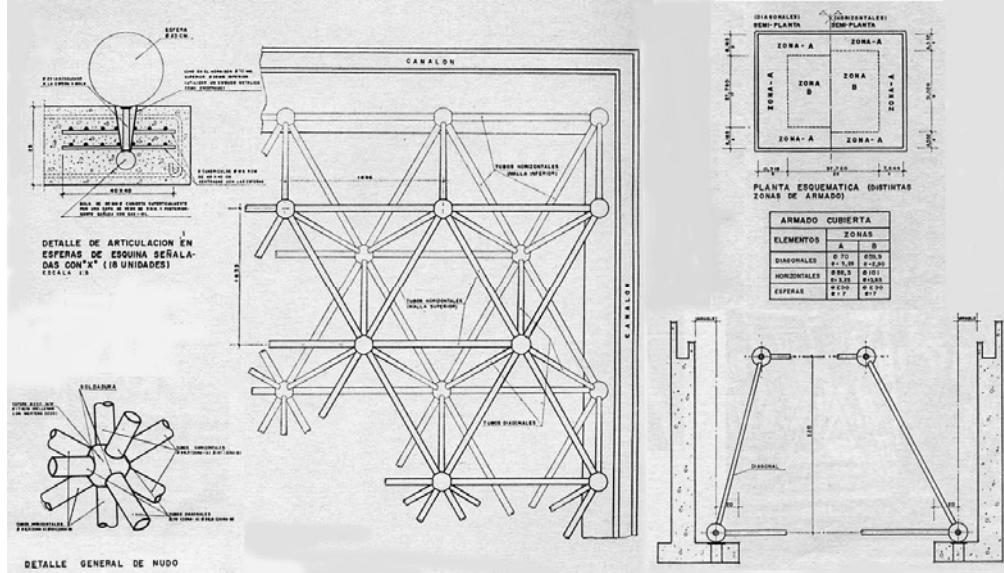


Figure 5. Trussed slab in Mahou factory, Madrid. Details of dilatation anchor, node, truss corner, bars pattern and truss supporting. (Buzón, Bueno, Calavera 1965, 104).

In a different way than the first commented structure, a scaffold in the definitive position of the truss was built for the assembly, and sections of four triangles pre-assembled in shop were welded in site. Also the section of tubes was different here with four varying diameters ranging from 101 mm diameter to 59,9 mm, and thicknesses from 3,65 mm to 2,90 mm. They were distributed over the slab following a simple pattern distinguishing between horizontal and diagonal bars and two different areas A (interior) and B (edge) in each layer. For the calculations the structure was assimilated to an anisotropic solid slab using the double series development of Fourier (Bueno, Calavera 1967). The structural weight was 40 kg/m<sup>2</sup>.

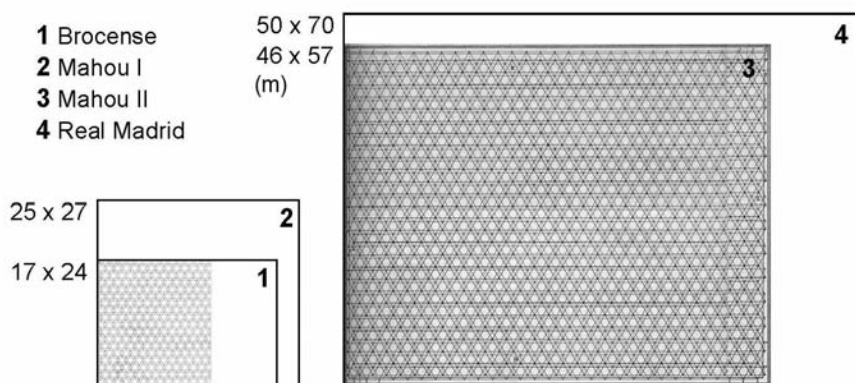


Figure 6. Sizes and proportions of the trussed slabs.

This important group of flat spatial structures had its end in the roof for the Raimundo Saporta Real Madrid sport pavilion inaugurated in 1966. Also authored by Bueno and Calavera, the covered plan was 70 x 50 m and was for a short time, world record among this kind of structures (Calavera 2012).

## BEYOND THE FLAT SPATIAL TRUSSES

The short history of the first spatial structures in Spain has also two interesting accomplishments that explored the possibilities of other arrangements different from the flat patterns above commented. The first of them was the Spanish pavilion in the II Asian Fair in Teheran in 1969 projected by the industrial designer Antonio Carrillo. Its main singularity was that in this case its global geometry was truly spatial and not flat as in most of the realizations made until this time (Carrillo 1970).<sup>7</sup> The roof, that covered a square plan with chamfered corners, adopted the form of a sort of trough constituted by a flat central section, four inclined rectangles in the sides and four chamfered planes in the corners. In this way the structure had three types of resistant behaviors: the more typical as a trussed slab in its central section, the at least partial beam-like behavior of the side rectangles and the special concentrated support behavior of the sloped corners. The lower part of this chamfered corners simply rested on brick walls of thickness 0.80 m.

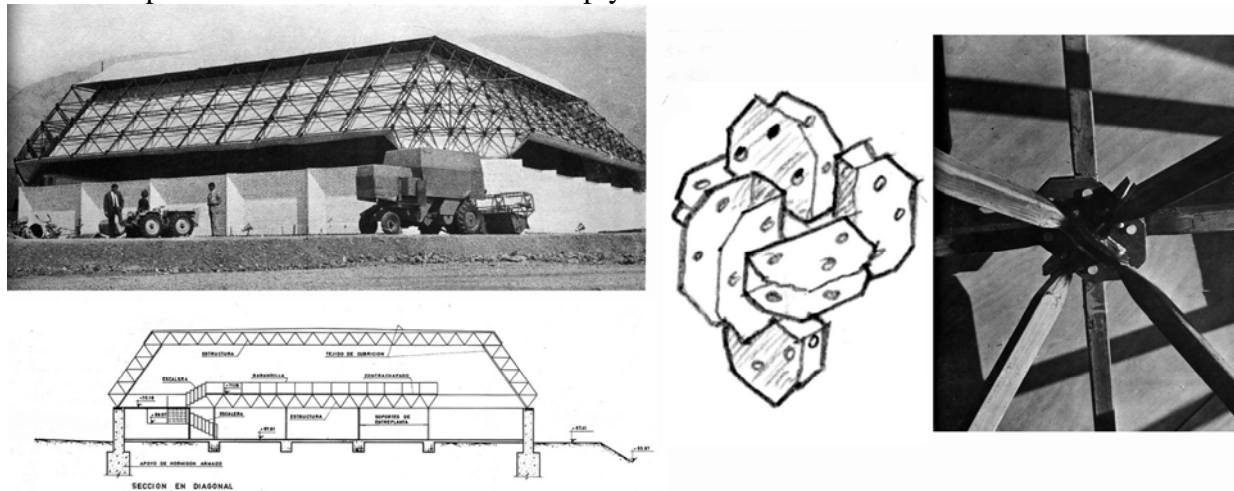


Figure 7. Spanish Pavilion, 2<sup>nd</sup> Asian Fair, Teheran 1969. (Carrillo 1970). Node sketch (author).

The spatial net chosen was based in two layers of displaced squares connected by diagonals. According to this, the inner cells were pyramids and tetrahedra and the whole net was easily adapted to the slop of the sides and corners. This arrangement generated a wider variety of angles and connections in the nodes and was solved by the special node designed and patented by Carrillo. It was formed by 6 equal U elements welded each other and admitting up to 18 bars in all the required directions (3 bars by element).<sup>8</sup> Every bar was simply pinned to the node by a bolt. The advantage of this system is that every single bar could be assembled or disassembled regardless its position in the net even with the whole structure assembled. This peculiarity enabled the use of the same nodes and bars as scaffold for the structure. After a section of the structure was in position and self-stable, the scaffold bars could be retired easily and reused even for the next section of structure.

All the bars were square section tubes of 40 x 40 mm and thickness 2.9 mm except the special bars reinforced for compression of 45 x 45 mm. There were two lengths of bars,  $L = 1.828$  m and  $L' = 1.272$  m measured between the extreme pinning holes ( $L/L' \approx \sqrt{2}$ ). The ends were spe-

<sup>7</sup> In the referenced article (Carrillo 1970, 48) is also mentioned the architect Aguilar and the constructor Tecglen without further comments.

<sup>8</sup> The essays showed that the nodes and bolts were more resistant than the bars. Consequently the calculations only paid attention to the linear elements.

cially manufactured by flattening the extremes and including flat bars with the pinning holes. The side of the covered square was 26 m but the real span (diagonal) between supports was 28.3 m. The structural thickness was 1 m.

Noteworthy was the accuracy of execution. The holes were 13 mm diameter and the bolts 12.7 mm diameter. That means a tolerance of only 0.6 mm for every single bar. Also interesting it was the supporting device intended for the simple support of the structure and its free dilatation. Fixed metallic guides, welded to anchor plates embedded in the supporting brick wall, permitted the diagonal free slide of every supporting node of the structure.<sup>9</sup> The possible differential settlements were also taken in account and the support device included a threaded thick disc that via hand-operated coupling levers made the rise or fall of the node possible.

The solution for the pavilion was the winner of an architectural competition published on March 8, 1969. On August 18 of the same year the structure was completely assembled in Teheran. Meanwhile, just over 5 months, the project was draft, the electronic calculations were carried out, the manufacturing of the elements was performed, the nodes and bars were tested, a previous assemblage of the whole structure was realized and disassembled in the grounds of the Institute Eduardo Torroja in Madrid and the complete pavilion was sent in trucks to Teheran.<sup>10</sup> After the closure of the Asian Fair on October 24, 1969 the pavilion was newly dismantled and its elements came back to Spain and were stored in a warehouse. Although the original idea was to reuse the structure for another exhibition, this never happened.

In 1968 the Spanish Ministry of Agriculture and the Council of Torrelavega, Cantabria, decided the construction of a new cattle market in this town with the architect Federico Cabrillo as responsible of the project. The program of requirements established that 7,000 cattle should be sheltered simultaneously in the same place and 90 trucks could be parked at the same time in a loading dock. Many other services as reception halls, spaces for conferences, livestock associations, veterinary, assurance companies, police station, feedstuffs, tools and machinery stores, restaurants and others should be as well housed in the complex. An important requirement was also to prevent animal odors as far as possible (Cabrillo, Calavera, González Valle 1979; Calavera 2012).

This program determined a building with a 250 x 60 m main hall, a secondary hall of 115 x 27.4 m, a roofed dock of 111 x 27 m, two storey galleries surrounding the big halls and a more conventional section for the spaces without special requirements. Because of the special characteristics of the main hall a competition for its roof was held among five teams of architects and engineers. The engineers team of Enrique González del Valle and José Calavera won the competition with the solution of a trussed vault (Calavera 2012). This spatial truss can be considered the last and most important structure of this type within the initial period previous to the coming of international patented systems as Mero and others. The vaulted truss structure was chosen after discussing and rejecting four previous possible solutions:

- a. Arcs and girders; b. Sheds; c. Hanging structure; d. Flat spatial truss

Solution a was considered clearly more expensive, b was rejected by esthetics reasons, c because of the excessive height of the suspension piles and d for the null slab effect of the truss with the given dimensions. A vaulted truss instead could benefit of the previous experience of Calavera in trussed structures since the constructions proceedings were relative simple and known. Besides, the high hyperstaticity made unimportant possible local fails and above all, the budget was very competitive and the solution was undeniably very elegant and esthetic.

<sup>9</sup> The sliding was eased by means of a 6 mm thick teflon layer fitted between the in contact steel plates.

<sup>10</sup> The mezzanine floor was also assembled with the same structural elements.

The truss arrangement was formed by two layers of squares displaced each other and connected by diagonal bars. The truss net was therefore of the same type as the Teheran pavilion except for the curved directrix of the vault. For ease of construction the directrix line was a segment of circle which reduced to only four the number of different length of bars.

The span was 60 m and the rise 10 m. Of course, this produced an important thrust but was easily supported by the concrete gallery surrounding the hall. This suggested a supporting solution of the vault with concrete plastic hinges. The length of bars of the upper layer was 1.50 x 1.64 m and the thickness of the truss (distance between layers) 1.50 m.<sup>11</sup> The nodes were also spheres as in previous examples, in this case of diameter 13 cm and 4 mm thick. All the bars were circular tubes welded to the spheres and with two different diameters, 70 and 42.2 mm. The respective bar thickness were 2.6 and 2.3 mm. A dilatation joint was set every 40 m. The structural weight was only 17.14 kg/m<sup>2</sup>.

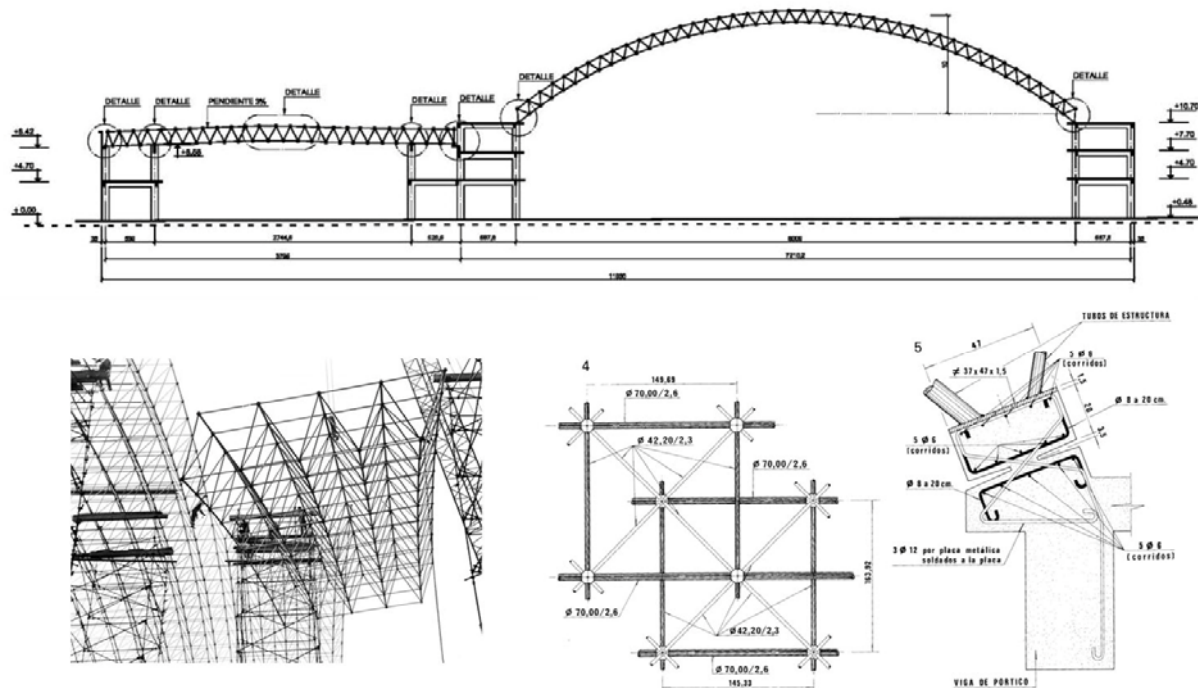


Figure 8. Torrelavega cattle market. General section, raising, grid and plastic hinge (Calavera 2012, 18, 27; Cabrillo, Calavera, González Valle 1979, 72).

When the trussed vault solution was selected, the convenience to apply also similar structures in the second hall and in the dock roof was considered. For both, flat trussed slabs were constructed with the same arrangement and length of bars as in the vault. The structural depth in the second hall (with a central span of 28 m) was also the same as in the main hall (1.50 m) but for the dock was only 1.0 m. A corrugated galvanized sheet was fixed over all the trusses. This showed to be an appreciable benefit for the structural behavior. Measures when the load test of the vault demonstrated a collaboration of up to 15 percent.

Finally, also the mounting process deserves some comments. Sections of 6 x 6 m were assembled on the floor. Then every two sections were connected to each other and these new sections connected in pairs. These new sections finally obtained (every one of 1.4 ton), were raised with a crane and left resting on three scaffold towers. The process ended with the welding of the

<sup>11</sup> In the lower layer one side of the squares net was slightly shorter than the correspondent in the upper layer.



sections and the placing of the edge bars welded to the plates in the hinges. The market was inaugurated in 1973 by the then Spanish royal princes couple.<sup>12</sup>

No later that 1972 the first Spanish spatial structure with the Mero system was erected in a pavilion for the Agricultural Fair in Madrid. In 1975 architects Margarit and Buxadé built the dome of the Victoria market in Vitoria with a diameter of 84.4 m. These were new steps of an uninterrupted tradition of spatial trussed construction in Spain that continues until today.

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<sup>12</sup> The structure was presented in the 2nd Conference on Space Structures, London (Calavera, González Valle and Cabrillo, 1975).