Historical Patents and the Evolution of Twentieth Century Architectural Construction with Reinforced and Pre-stressed Concrete

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Much of the history of the architecture of the twentieth century is bound up with the development and evolution of reinforced and pre-stressed concrete. Ever since 1878 when Monier patented the first reinforced concrete beam, this new material has been at the centre of world-wide technical and scientific investigation. In 1928 Freyssinet outlined the discovery of a different technique which used tensioned steel within the concrete and thereby introduced pre-stressed concrete.

The work of Maillart, Le Corbusier, Wright, Torroja, Nervi, Esquillan, Hossdorf, and Saarinen led to an interest in high rise and wide span buildings. These buildings required specialist research to develop the materials and components and new methods of calculation. In many ways these early buildings were experimental test beds to develop the associated technology and production techniques.

It must be remembered that until the year 1959, when Le Corbusier designed the Philipis Pavilion, the international association of laminar structures IASS was created that Eduardo Torroja presided over from the Technical Institute of the Construction, when great part of the most excellent laminar structures had already been constructed. Previously, in the year 1949, the AEHP had been created (Spanish Association of Pre-stressed). The International Association of pre-stressed would not be founded until 1952.

Experimentation and investigation resulted in many patents for different elements, techniques and machinery that made possible the evolution and use of different types of strucutre and construction. Freyssinet, for example, registered patents ranging from the system of opening of keystone (1907), the vibration method (1917), the folding of a laminar structure (1921), and pre-stressed concrete (1928), to the varied prefabricated pieces of Nervi, its well-known ferrocement and the direct results of its investigations on models in the I.S.M.E.S (1935), whilst Eduardo Torroja contributed to the development of architecture and civil engineering by his many patents and new techniques and systems of calculation and analysis.

REINFORCED CONCRETE PATENTS

The development of concrete armed patents at the beginning of the twentieth century went in parallel with the evolution of processes for the calculation of structures. From the theories of M.

Koenen (Koenen, 1902) 1886 for the calculation of badges system Monier, up to the studies of R.Maillart (Maillart, 1921) and of T. Turner (Turner and Jevons, 1925) with his contributions to the resolution of the problems of push-up and the delimitation of the states of distortion in the early part of the twentieth century the theoretical ones will evolve in the application of the calculations as instruments of cross-check that had to fit to the results of the essays and tests of load of the patents, towards a general theory of the Applied Mechanics.

In this period the development of systems of mechanical calculation of distribution of efforts in the pieces awarding with the different hypotheses will take placed, the proportional parts of the terminal states that will assume concrete and steel .The architects will get overturned in the search of the constructive coherence of the technical piece of news, as well as his structural elementary logic, the reticle of concrete that, on having confronted with the traditional constructive body, will show the contradictions of the relation structure - form.

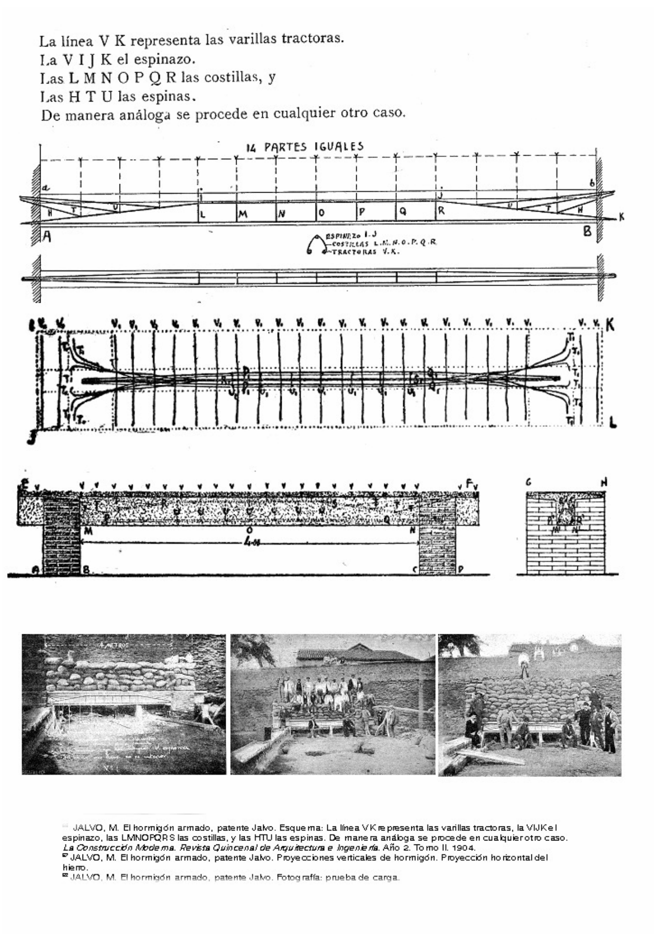


Figure 01. Beam Patent Jalvo. . Madrid 1901, M. Jalvo

The technical and scientific magazine *La Construcción Moderna*, edited by the military engineer Eduardo Gallego, was published between 1903 and 1935. The magazine spread the studies and investigations which were made in Spain with new materials and systems such as armed concrete. It was also be the frame, there being established comparative scientific, technical and economic studies, which will serve to denounce in many cases the bad orientations of some solutions, and mathematical interpretations of the authors of the patents, which will be done in expediency with the economic studies of the companies.

One of the first illustration shown in *La Construcción Moderna* magazine (García Benítez, 1903, pp.8) was of a refrigeration tower for a train Echer-Wisse in Madrid. It consists of a skeleton structure of armed concrete that Eduardo Gallego will project and construct, and that made clear the consequences to the structure derived from the processes of calculation used. The system of connected vertical solves by means of badges of armed concrete system Coignet for reinforcements of wall (Twelvetrees, 1915), whereas the horizontal planes of the structure, will be connected by a system of tensile of steel that the props will tie in the corners, and will join the competing ornaments as triangles of rigidización of knots, controlling this way the deformability of the reticle.

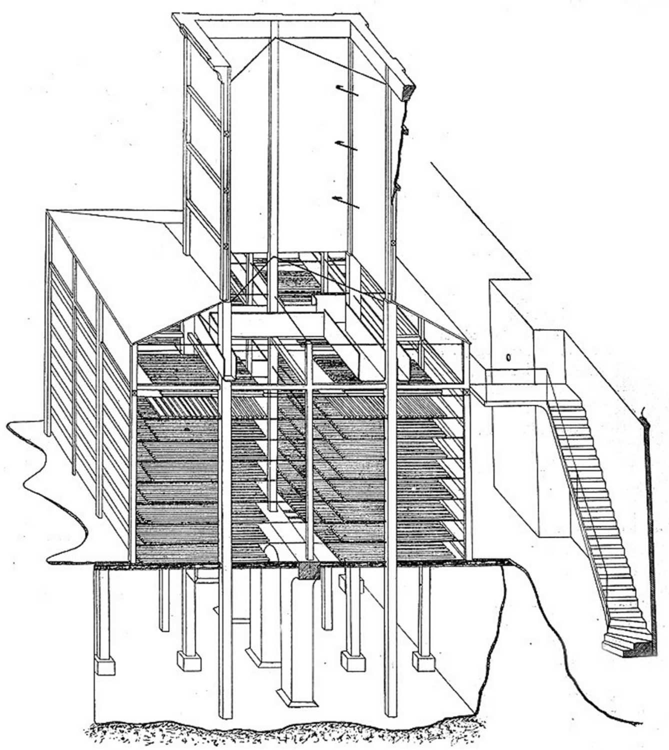


Figure 02. Tower of refrigeration Echer-Wisse Madrid, 1901. E. Gallego

The simplification used for the calculation of elements, heiress of the solution of structural design, for composition of constructive forms, will imply the development of a structural typology that will not liberate the plant in all his surface, characteristic that it will identify to the new reticulated typology, being still evident, certain contradictions between the dimensional obtained advances and the consideration of the structure in his set, what will use to the time reticles of knots.

The reticulated system will be a product of the new industrial society, whose representation and diffusion will be realized by the characteristics of a model. The solution does not become exhausted as response to a concrete problem, his value will reside in be proposing as system (Augrós, 1926), that is to say with independence of the constructive solution of the knot and of the spatial solution to resolve structurally.

The step of a linear interpretation of the system of skeleton to the employment of the reticle in all the directions of the space will take place jointly with the development of the technology of the concrete, and the solutions of continued flagstone.

A significant example of a structure of reticulated type continues that it will be the construction to beginning de1905 of the Third Deposit of Madrid (Reid, 1908, Gallego, 1903). A covering of 80.000 square metres wasr is constructed, by means of parabolic reduced vaults, of 1/10 thickness, 0,05 m. in the key and 0,10 m. in the starters, saving a light of 6,02 m. resting on a series of porches continuos linear of beams of 0,50 of singing, and 3800 props, of 8,50 m., of height and 0,25 x 0,25 m. of section.

On April 8, 1905 the first subsidence took place with a progressive collapse of the props, which was followed by the second collapse on June 6 of the same year. The accident was significant both for the magnitude of the catastrophe and for the personalities that intervene as technicians. José Eugenio Ribera will be project engineer and Juan Manuel Zafra, engineer of calculation.

Tedesco published an article in *Revue Technique* (Tedesco, 1905) in the one that estimates some of the factors that will contribute to the fatal ending. The economy of material as reason that will facilitate the securing of contracts of construction (Ribera, 1903), the absence of solutions of bundle that they will affect to the stability of the set, and fundamentally the finished solidarity of all the parts of the work that will not allow the distortions of the material.

New requirements will originate for the constructive structures, moving to the ambience of the theory the interest in the reconsideration of the hypotheses of calculation of the structure, in the base of the analysis of the behaviours of the material and with independence of the solution adopted for his construction .There will become explicit , to sum up, the origin of the problems of incompatibility of distortions with the use of the formulae of the Mechanics Applied for the calculation of the new structures (Emperger, 1909).

Juan Manuel Zafra (Zafra, 1911) civil engineer who will inaugurate the subject of Constructions of concrete armed in the “Escuela de ingenieros de Caminos” of Madrid in 1908 and who will execute works of relevancy, like the Viaduct on the Guadalquivir 1904, reviewed by H.E.Reid (Reid, 1908) as one of the excellent works in the world, will develop to the time one of the first theoretical works based on the scientific skills of the concrete armed for his calculation and measuring, text which use will spread until the first years of the second third of the century (Zafra, 1911-1915).

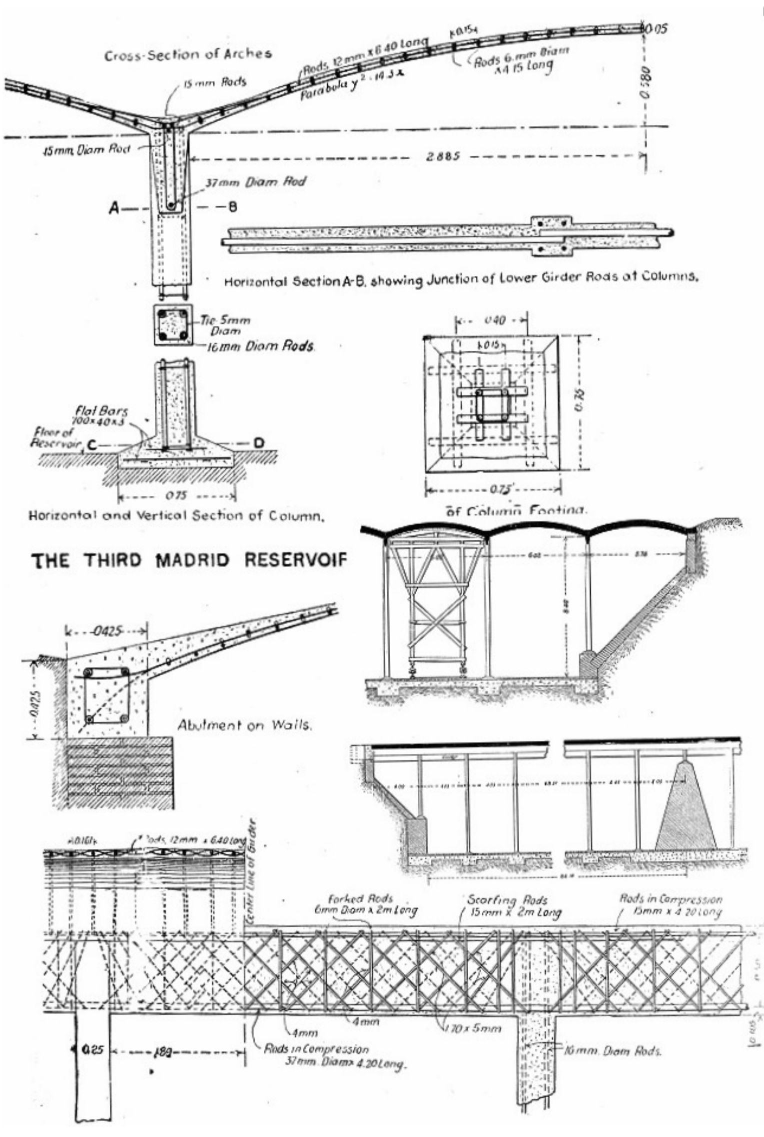
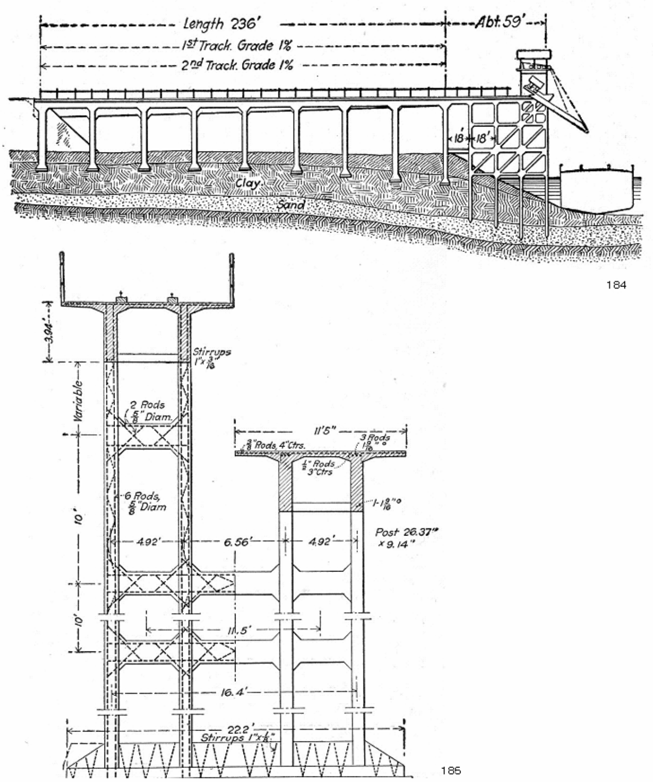


Figure 03. Third Deposit of Madrid. 1903. Ribera patent. 1901 J.E.Ribera



[184] Sección transversal. Viaducto sobre el río Guadalquivir. REID, H.A. *Concrete and Reinforced Concrete Construccion.* Myron C. Clark Publishing Co. New York, Chicago. 1908.
[185] Armado de jácena. Viaducto sobre el río Guadalquivir. Op. Cit. fig. 183.

Figure 04. Viaduct on the Guadalquivir .Seville 1903. J. M. Zafra

Zafra defineed the resistant section as an autonomous solution of the constructive used system and of his form. Awarding coefficients of work to the concrete and to the iron, not uniforms, question of importance will establish the mathematical conditions for the definition of the neutral fiber for heterogeneous sections ó for all that in Spain there did not exist instructions that were regulating it, *("Regulatory instructions for the Employment of the Reinforced concrete"* Spanish instruction approved in 1912 and written by the Laboratory of Engineers' Materials inspired by the " Prussian Circular letter " of April, 1904).

It claimed the free application and the use of the skills of the concrete armed opposite to the hereditary mastery of the patents, as well as the definition of the constructive sections which origin will place in the results of an attentive study of the distortions of every piece.

Opposite to the constructive unemployment in concrete armed after the subsidence of the Third Deposit, in the North of Spain and in Cataluña a construction activity will be supported in the ambience of the industry, practising from 1905 and for 10 years.

During this period the society “Construcciones y Pavimentos” will realize a wide work of construction in civil work, industrial constructions and building making clear, as the reticle in the space of the factories, the free functional surface, the use of big lights and the repetition of structural elements, they will accentuate the value of the free plant, turning the structure into the new formal characterization of the architecture.

The project of the Stores Damián of 1915 in Barcelona, of the architects Luís Homs, Eduardo Ferrés and Agustín Mas, will represent a synthesis of resources and of interpretations of the application of the concrete armed like new materially, with a constructive language which dimensional base will be established by the structural mechanism.

The building shows the reticulated heredity of the metallic constructions, differentiating the resistant pieces and the spatial definition. It will denote also, the indeterminations that the calculation was supporting, as the impossibility of determination of the displacements with reliability of the pieces submitted to torsion and the ignorance of the effects produced in the resistant elements, for the displacement of charges. Representing the principal directions of the structure the simplifications considered for the calculation of the building.

The cover of the building will be realized by a semi-vault, reinforced in two directions of the space defined from an orthogonal reticle of beams of straight guideline, in intersection with another family of curved beams. And establishing a resistanf form without the concourse of a flagstone, it will mean structurally the reticle for his value of form as spatial mechanism, which scientific essentials will be able to be located in the works of Föppl (Föppl 1892).

With the employment of the frameworks of steel and concrete from 1918 at the end of the First World War, and the contributions in the field of calculation of problems of push-up as that it had realized Turner (Turner and Jevons, 1925) and Maillart (Maillart, 1921), who will be translated in new formulae of application of the calculation of reactions and distortions, the use of the methods of calculation will be generalized as constructive reference.

The use of structural elements which conditions of dimension will be solved by methods of calculation up to the predeterminable limits for a material and a constructive system, it will make open the relation of the origin of dimensional references defined with resistant criteria (Maximo, 1922, Hilbersimer and Vischer, 1928), assimilating the changes of scale of the structure as typical proper piece of news of the typology, question that it will establish, a relation of new dependency between project of architecture and design of structure, recapturing solutions as those of Vierendel

(Vierendel, 1900, Moya, 1928), where the calculation will play the role of economic and formal fitter between the idea of the architecture and his constructive identification.

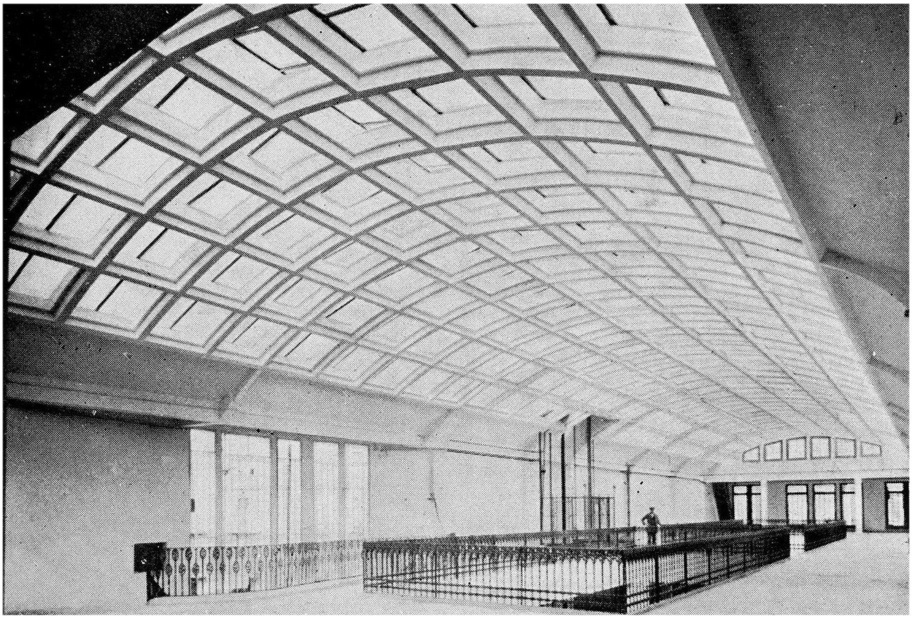


Figure 05. Stores Damians. Barcelona 1915. E. Ferrés

THE PATENTS OF SLABS (hollow brick floor) IN THE SPANISH POSTWAR PERIOD 1939-1962

The construction in Spain during the 40s and 50s was clearly characterized by three aspects:

- Abundant and cheap manpower.
- Minimal employment of steel, which usage was limited by decree in 1941.
- Predominance of the ceramic products as fundamental material of construction, being very significant that its price was constant in the period 1948-1954.

All these factors gave place to the appearance of a series of patents to solve the horizontal structures of the buildings known generically as “autarkic slabs".

Ignacio Paricio gives us a clear vision of the evolution of slabs in the years object of study:

> “The necessary limitations in the usage of metallic elements during the post-war period led to slabs to its lower moment of quality. The quantity of used steel turns into an

obsession and sharpens the ingenuity looking for solutions increasingly purified to scratch some grams of material in every square meter. In this moment the ceramic slab spreads the ones that optimise the use of the steel used exclusively where it's irreplaceable: to support the tension stress"

Without layer compression, without band or hoop, without weight, with joists produced by a few manufacturers on which picaresque about pre-stressing everything has been said , the slab has touched the bottom in its evolution (Paricio 1986)

So called "autarkic slabs", belonging to the type 2 with elements to prefabricate on site to mount without formwork , appeared on the market in the early 40s using the ceramics as basic material. The manuals of maximum diffusion continue gathering these solutions in its editions up til 1963 at least.

Others type of slabs, used a lot in those years, were incorporated special or common pieces of ceramics - hollow double brick - as lightening and formwork, being indeed lightened flat or branched slabs, belonging to the type 3. Therefore here we will speak about the slabs which were solved with made joists afoot of work, which are more typical of this "sharpening of the ingenuity" to which Paricio refers.

The Autarkic Joists

The base of all these patents was the piece or ceramic pieces that were shaping, for juxtaposition, the made joists afoot of work. The thickness of these pieces were 8, 9, 12, 15, 16 and 18 cm. The maximum span that could be saved with overcharges using 200 Kg/m2 were 6 m.(approx)

Later the description is reproduced, recommending conditions of execution and form manufacture of the joists, extracted from the manuals of usage (Ulsamer 1963)

Description

"The framework elements are formed for the juxtaposition of small pieces, some later than others, joined by cement mortar.

In a few grooves arranged to the effect, there the rods of reinforcement are placed, surrounded with cement mortar that, once plotted, joins strongly all the pieces with the rods, constituting a monolithic joist that, because of the numerous hollows with which the pieces are provided , it is of small weight and an easy assembly in work. The elements of landfill or slab are generally placed so that with a bit of mortar or concrete it joins them strongly together and with the framework, until everything forms a constant lightened slab, in which the layer compression is of concrete or of ceramics, or of both materials together, according to the system of the floor. The calculation of the reinforcement is effected like for a monolithic slab of concrete of the same thickness, having in it counts the minor weight of the hollow ceramics. The diameters of the rods must be chosen according to the section obtained in the number of available grooves per meter.

Conditions that must full-fill the Ceramic Slabs:

"The reinforcement must be distributed as uniformly as possible during the placement of the irons, not being allowed rods of iron of diameter less than 5 mm. The dosing of the concrete used will be at least of 400 Kg of cement per cubic meter.

The useful height of the slab in order to be stiff and the deflection, therefore, won't be excessive, will be, when less, 1/30 of the distance between supports or points of void moment. Treating itself of continuous slab, this distance between points of void moment can take equally to 4/5 of the span. All the irons must end in hooks, specially when the joists or the nerves go trimmed in the beams of reinforced concrete.

The re-covering of mortar of the rods must cover, at least, 0,5 cm. to the sides of the irons for the lower face and 1 cm. for the upper face, in the open air the re-covering will be like minimum of 1,5 cm.

If they place two irons in the same joint, the separation or free distance between the same ones will be equal to the diameter of the thickest iron, at least, and never less than 1 cm.

The width of the joints or of the boxes provided with reinforcements will not be lower than 1/8 of the height of the ceramic piece nor to 2 cm. If the ceramic pieces are placed themselves without re-joining and the putting in work of the concrete is by pouring the width of the joint will not be less than 1/5 of the height of the ceramic piece, nor than 3 cm.

The ceramic slabs that do not have pavement, must be protected against the wear and tear other causes with a coat of mortar of 1 cm minimum, which will not be considered in the calculation, though the slab has layer compression.

The ceramic pieces used in the slabs, must have a rough surface, fluted and sometimes also are made with eyelashes, in order for it to stick well to the mortar and the concrete."

Manufacture and assembly of the joints
(the execution is reproduced of the "Piso único P.A.U.S.A. ", that can be generalized to all the patents with small variations).

“The execution of the floor consists of two different phases: First, the manufacturing of the joist and secondly, the execution of the slab. To make the joist, the pieces join at the top, with cement mortar, with dosing of 300 Kg , for which, they will be placed in inverse position which they will take in slab (or the same one depending on the patent), and in order to make the introduction and pouring concrete of the rods easier ; for this you will need a flat surface. The grooves are refilled with Portland's mortar or concrete of “almendrina” with grain superior to 1,5 cm.; the reinforcement –rods- are fitted together that will have been totally covered by the mortar at least in 10 mm. And, beaten well the mortar, and levelled out with the mason’s trowel up to the same level of the ceramics. Before the pieces will have been saturated with water and devoid of the rib that closes the interior hollow. The mortar or concrete will be dosed with 400 to 500 kilograms per cubic meter.

For the plotted one of the piece it is needed a time not less than 20 days and, if possible, it will be left “in situ “for one month.

Once all the necessary pieces are made and some extra for if in the manipulation some of them become cracked, you place them on the supports, girders, beams, etc., in its definitive position, propping up them if the span exceeds at 3,00 meters, (in general propping up every 2 m.) to avoid the previous buckling; the most top grooves are refilled with mortar or concrete (introducing previously the auxiliary rods, in case they are necessary), and with this operation and the plotted from 25 to 30 days, the floor remains concluded.”

At the same time diverse types existed to use only in attached joists or joists and roof spaces to constitute the slab. Another important fact was the need or not of incorporating layer compression.

Next are the related patents better known indicating its peculiarities, including images of the more representative ones:

-Patents with attached joists, without layer compression. (Normally they only reach 4 m of span)

* P.A.U.S.A.: an alone type of piece
* Tauro: one type of piece.
* Piso perfecto (perfect Floor): one type of piece.

-Patents with attached joists, with layer compression

* Piso Ladrihiero: one type of piece
* Tauro: one type of piece
* Piso perfecto (perfect Floor): one type of piece
* Piso Mundial D: one type of piece

* Piso autarco I (autarkic floor I): one type of asymmetric piece, by putting the placement at 180º,to obtain a bigger "embattled" with the layer compression. (fig.6)

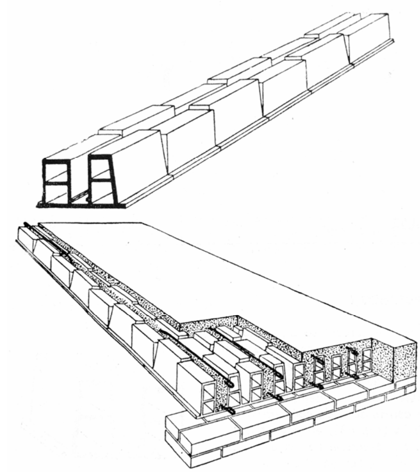


Figure 06. Autarkic Floor I

-Patents with attached joists or joists and roof space, with layer compression.

* Piso T.H.: one or two types of piece
* Piso Riera: one or two types of piece

-Patents with joists and roof space, with layer compression.

* Piso Mene: two types of piece, are mounted in its definitive position as they have sole of ceramics in the whole surface to favour the finish of the ceiling.(fig.7)

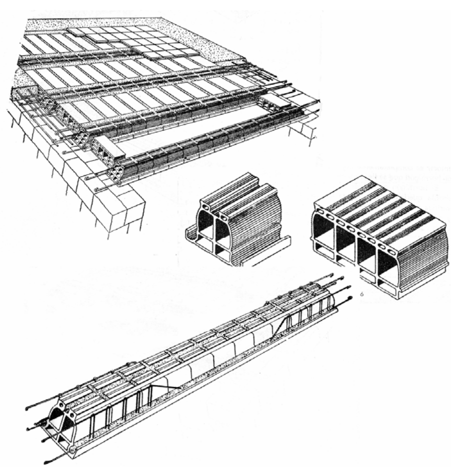


Figure 07. Piso Mene

* Piso Sita: two types of piece, they have sole of ceramics in practically the whole surface to favour the finish of the ceiling.
* Piso Ceralux: one type of piece of trapezoidal section, which placed with the major base downwards would be the joist and upside-down the roof space. The pieces of joist are inverted for pouring concrete. The system has sole of ceramics in the whole surface to favour the finish of the ceiling.

* Piso autarco II: two types of piece, the joist that would be the same as Autarco I and the roof space would be the second piece.
* Piso La I.S.A.: Three possible types of joist and piece type fine brick between joists (fig.8)

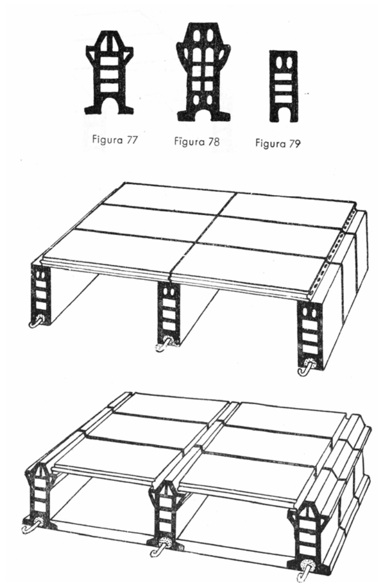


Figure 08. Piso La I.S.A.

* Piso Mundial C: Joist, formed by two pieces, and roof space.
* Piso B&M: Joist, formed in turn for two pieces in a comb form , and roof space.
* PI.CE.LI (Cellular Light Floor): two types of piece are mounted in their definitive position since they have sole of ceramics in the whole surface to favour the finish of the ceiling.

* Piso CELETYP: two types of pieces adjusted between each other, of format type “rasillón” (big fine brick), with different types of lightening and width. The so called "guitars", with triangular hollows and they are called "violins", thinner and

with square hollows. The joists were constructed with two guitars and one violin, as a sandwich, placing the pieces horizontally. Once the joists were placed, the "guitars" were mounted saving the span between joists and later the layer compression was spilt. This type of slab is the one that Coderch used in the house of Barceloneta. A chilling variant is the one that forms joists in a T with two "guitars", having the rod of tension placed asymmetric in a projection of the side of the "guitar" placed vertically (fig.9)

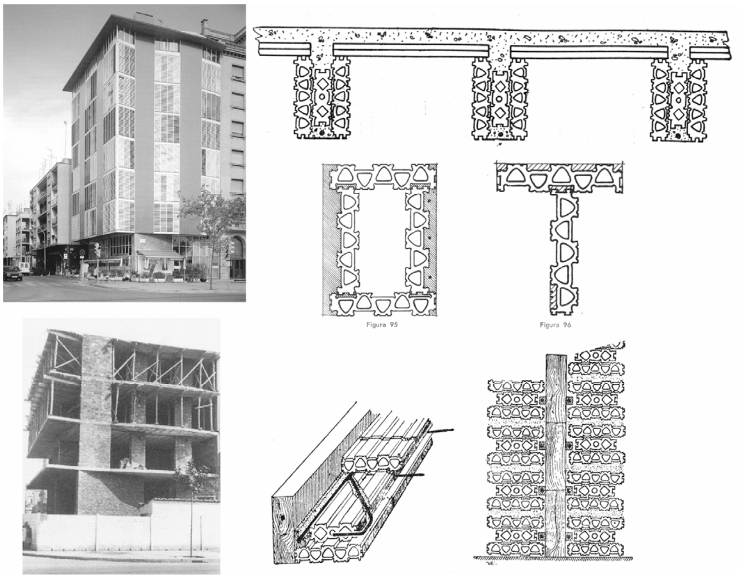


Figure 09. Piso CELETYP

* Piso Movix: the system has up to 23 different pieces that are made with extruding press to which there connects a special mouthpiece that produces several models of pieces simultaneously (fig.10)

PRE-STRESSED CONCRETE - ANCHORAGES PATENTS 1928-1967

The exact moment the idea of pre-stressed concrete was born will be for ever subject of debate. But it is a fact that the first patent of pre-stressed concrete was registered on the 2 October 1928 by Eugéne Freyssinet and Jean Séailles in France . Afterwards , in 1929 a new patent of pre-stressed concrete was registered in Germany .

Pre-stressed concrete was born as a result of the technical and scientific investigations developed from the knowledge of the limitations of reinforced concrete. There were fundamentally their own laws of deformation which demanded a new technique in order to be able to use the bar and wires to make the most of their admissible stress .

In 1908 Freyssinet built some bridges as Le Veurde connecting their abutments by pre-stressed wires of 8 mm in diameter stressed close to their limit of elasticity and anchored in pairs by wedges in pierced steel plates. In 1921 he directly involved Architecture with this new material , building the Hangar of Orly with a pre-stressed structural shell .

At the same time as Freyssinet's first patent was registered in France , Eduardo Torroja was building the Tempul Aqueduct in Spain. He suppressed the pillars which were planed on the river bed and he replaced them for two pre-stressed ties. He used high stress steel plaited wires , which were craned before , getting up on top of the pillars which wires crossed by hydraulic jack .Such us Eduardo Torroja pointed out , the anchorage systems were one of the most difficult and nonetheless one of the bigest achievements to the development of pre-stressed and postessed concrete (Torroja 1954). In 1939 Freyssinet patented a new anchorage system which consisted on a concrete anchor striated cones and a cylindrical concrete block with a conical central opening (fig.11) . This system made possible to anchor simultaneously bundles of 12 wires stressed . At this moment , pre-stressed concrete took a big step because this new anchorage would also be used against the hardened concrete and also to allow the usage of pre-stressed curved tendons from parabolic distributions of stress.

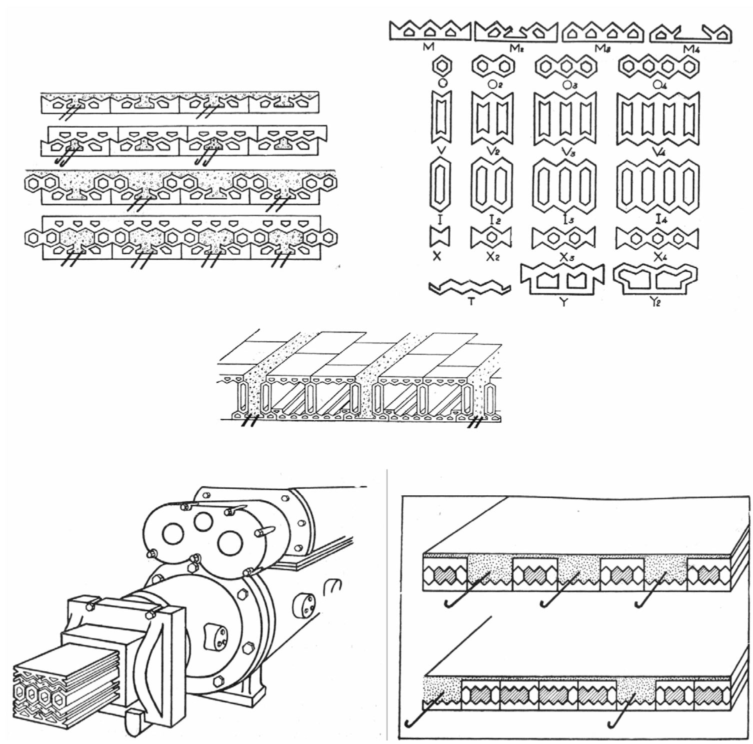


Figure 10. Piso Movix

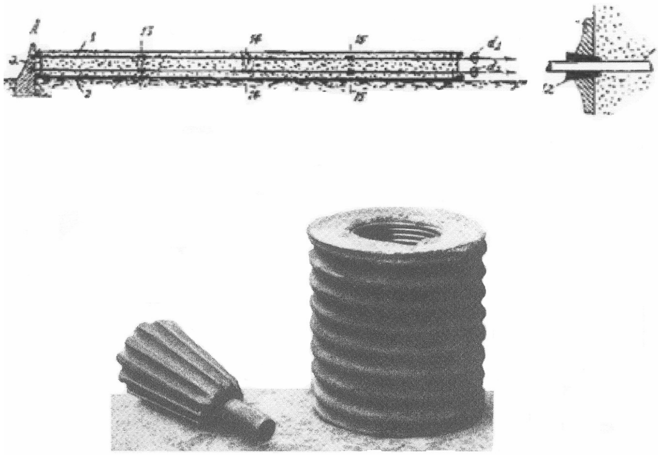


Figure 11. Pre-stressed . Concrete anchor . Freyssinet,E. 1928-1939

The idea of pretressing revolutionized Europe and since the first patent by Freyssinet new patents appeared together with the different types of constructions , fundamentally of civil engineering because the Second World War (1939-1945) did not stop the envelope of pre-stressed concrete but marked its way. In 1934 Franz Dischinger , patented a reinforced concrete beam which deformation initially appear was finally postesioned. This patent was used in the Adolf Hitler bridge in 1936. In 1937 another similar patent appeared by Ulrich Finsterwalder which consists of beams in a initial triangular form and by postesed they got a lineal position. In Belgium , Gustave Mangel built in 1944 the first pre-stressed railway bridge. He invented a new anchorage system “sandwich”, it consisted of 8 lines of pairs of wires separate by a rectangular steel plate .In 1937 Ewald Hoyer patented “Stahlsaitenbeton” in which he used thin wires directly bonding with the concrete without any anchorage system to pre-stressed.

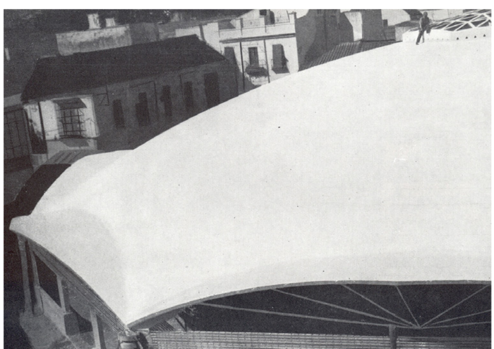


Figure 12 . Marquet of Algeciras, Torroja,E. 1933.

In 1933 Eduardo Torroja built the Marquet of Algeciras . It was a spherical structural shell 9 cm thick in which Torroja used a new postessed system in its edge ring . He used screw steel bar pre-stressed which were after bondied with the concrete getting radial stress on the unit of the pillars and shell , in this way he got to eliminate the flexural which would have appeared (fig.12). After the Spanish Civil War , in 1940 , when in Spain was impossible to get anchorages and systems patentes of pre-stressed concrete ,Torroja built the Aqueduct of Alloz using another new pre-stressed system . This consisted on two braces located between each pair of wires separated by a device in a scissors form , and with the help of a hydraulic jack the length between the braces was shortened , this way it was possible to pretress wires.(fig.13)

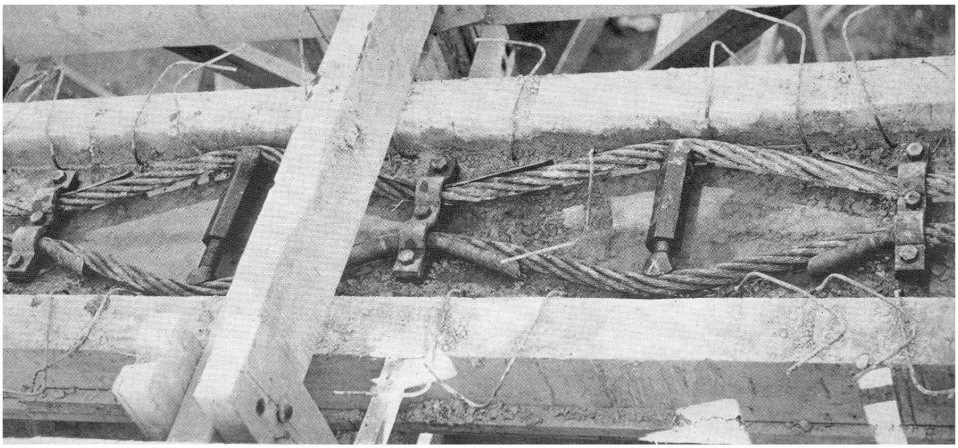


Figure 13 . Pre-stressed system . Aqueduct of Alloz . Torroja,E. 1940.

In order to understand the history of Pre-stressed Concrete it is important to remember that the Federation International of Pre-stressed (FIP) was not created until the year 1952 in Cambridge. Before that date each country enveloped their own experience without being able to count on the desired communication , exchange and technical and scientific common rules . The most important debates were carried out in the Civil Engineering Societies and in the special Investigation Centres from each country , so in this way it was in England that Paul Abeles put forward his new vision about partial pre-stressed concrete in 1940 , and as Eduardo Torroja founded the Spanish Asociation of Pre-stressed Concrete (AEHP) in 1949 when he was president of "Instituto Técnico de la Construcción (itcc)" in Spain which he had founded earlier. From this moment the pre-stressed concrete enveloped with more control about all its fundamental aspects and the diffusion of the rules and news were by F.I.P where in addition several international groups of work about pre-stressed were formed. The anchorages and systems patents proliferated appearing a lot of new patents and the old patents were developed . Some of the well known ones were: *Freyssinet System* (nut cone and male cone striated which allow the anchorage of wires with 5 or 6 mm united in cable of 8 to 32 wires in each anchorage), *Mangel System* (distribution plates , anchorage plate for pairs of wires with kite tail and space bar) ,*VSL System* (plate, screw cylinder , limit ring and wedges) , *BBVR System* (top clinched wires , several form of anchorages ; plates , trumpet and spiral), *LEOBA System* (the wires go through the axle of the conical wedge which is divided by four pieces) , *DISCHINGER System* (which was to use bars with similar diameters which used on reinforced concrete , threaded anchorage on the end , suitable to build by pieces because it was so easy to unite) , Barredo System or Spanish System.(fig.14)

Figure 14. Barredo System .Torroja,E. 1955.

In Spain the first indirect pre-stressed system was patented in 1952 by Barredo and with the advice of Eduardo Torroja and it was tested in the “Instituto Técnico de la Construcción (itcc)” in Madrid. This system consisted on wedge anchorage for 3 wires or braid cables , resulting a fixed static set and with the same stress on all wires. The anchorage cone and the wedge were made from steel . One of the advances which this system got was the variety of models for armature unit .This system was used by Torroja in great part of his pre-stressed works like “Depósito de Fedala” in Marruecos in the year 1956 or the Church of Grao de Gandía in the year 1961 which was one of his last works.

In 1954 the young Swiss engineer Heinz Hossdorf who contributed in a notable way to the development of the pre-stressed appeared on the scene. He developed anchorages and pre-stressed system in his buildings and he made many technical and scientific contributions (Cassinello 1996).

In 1958 he invented a new system called “aerial post-tensing“ when he built the Central Warehouse Wagen Consortium (fig.15) . Its structural shell formed by 1.152 prefabricated pieces of reinforced concrete of 4,5 cm thickness, with a small increase in its upper part with edges of 15 cm with the purpose of housing the anchorage of the post-tensing cables outside the mass of reinforced concrete itself. In 1960 Hossdorf founded his own laboratory. He developed a new technique of exterior burden simulation to reproduce the effect of a group of pre-tensed cables without physically having to build them in the model. This system was later used to make the checking of structural functioning of bridges and buildings easier. In 1967 he was the first person to take advantage of the appearance of computers to make the whole process of testing automatic, and he also invented the “Hybrid Rehearsals” (Hossdorf 1.972). A new way was found to develop new architectural and engineering technical for the next century. (Cassinello 2002)

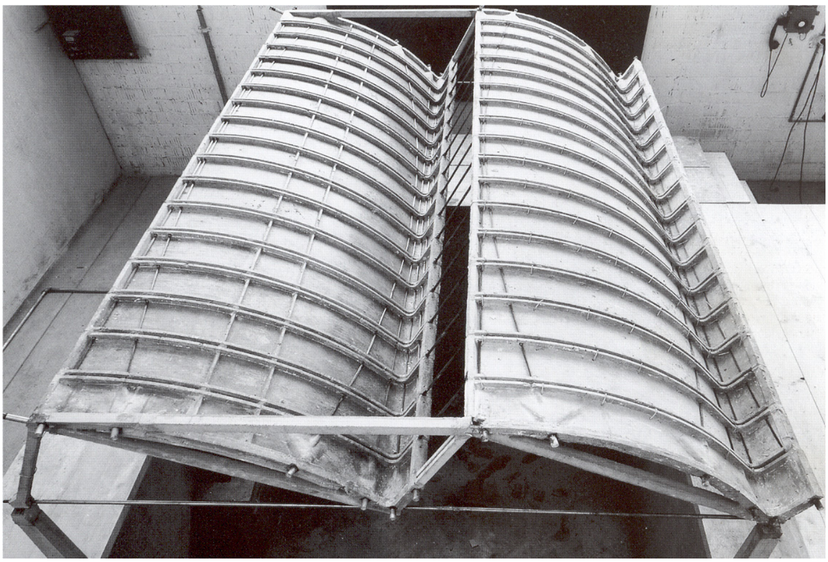


Figure 15. Aerial post-tensing. Hossdorf,H.1958.

Pre-stressed systems were not always patented by their inventors. Some of them were used in aisle constructions , and others were patented but were used for only a few years, but they were all links in a chain in which investigation , technology and science were braided with strength and wit. Pre-stressed concrete contributed Modern Architecture develops with more freedom concerning new structural types.

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