EDUARDO TORROJA MUSEUM

It is the idea, above and beyond any manner of engineering, that moulds material into the structural form that fulfils its purpose.

This book hinges on that premise.

Eduardo Torroja 1957
Razón y Ser de los Tipos Estructurales

FUNDACIÓN EDUARDO TORROJA
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EDUARDO TORROJA MUSEUM

Una Idea en Movimiento
Carmen Pinart 2016

CONTENTS

One of the primary aims pursued by Fundación Eduardo Torroja is the identification, study, conservation and dissemination of documentary information on the multi-faceted activity conducted by its namesake. E.Torroja, co-author with architects C. Arniches and M. Domínguez of the design for La Zarzuela Racecourse, the museum's headquarters, was one of the early twentieth century's most highly reputed structural engineers. The foundation has always sought a suitable space in which to exhibit the most significant elements of his activity, both for experts in the field and the public at large. The aspiration, in a nutshell, was to have premises in which to install the Eduardo Torroja Museum.

And that Museum exists today, thanks to the support and sponsorship of a number of public and private entities. Firstly, the company itself, Hipódromo de la Zarzuela, S.A., under the leadership of its President, Faina Zurita, struggled to overcome the many difficulties that arose along the way. To Ms Zurita's efforts and belief in the museum project we owe its materialisation. Instrumental support was likewise provided by the Ministry of Public Works' Directorate General of Architecture and Centre for Public Works Studies and Experimentation (Spanish initials, CEDEX), Fundación ACS and Fundación Rafael del Pino. The project has likewise benefited from the sponsorship of the Technical University of Madrid, the Madrid Schools of Architecture and Civil Engineering, the National Research Council's Eduardo Torroja Institute for Construction Science and Fundación Juanelo Turriano.

The museum custodies documents on much of Eduardo Torroja's activity, which could hardly have been more diverse. His first job was as construction engineer with a general contractor. A very few years later he founded his own engineering studio, producing designs that by 1936 had earned him enormous international repute. Beginning in 1934 he focused his efforts on research in what is now the Eduardo Torroja Institute for Construction Science. He also engaged intensely in teaching at the Special School of Civil Engineering, where he lectured in second, third and fourth years.

The museum exhibits a significant portion of Eduardo Torroja's oeuvre in the form of photographs, documents and scale models of works selected by Torroja himself for his book *The Structures of Eduardo Torroja; an Autobiography of an Engineering Accomplishment* (1958). The aim is to convey the author's own message:

'Many of my works are not mentioned here, but I feel that the few which are included best exemplify what I was searching for, and what I finally achieved.'
Eduardo Torroja, 1958

Hopefully this museum, like Torroja's book, will succeed in disseminating his oeuvre and his thinking and ultimately in keeping his legacy alive.

José Antonio Torroja Cavanillas
President, Fundación Eduardo Torroja

FUNDACION EDUARDO TORROJA

Museum Project

Pepa Cassinello
Curator
Managing Director
Fundación Eduardo Torroja

EDUARDO TORROJA MUSEUM

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La Zarzuela Racecourse
Restoration
and Museum Hall Adaptation
Junquera Arquitectos

Location and Use

The Eduardo Torroja Museum is located at Madrid's La Zarzuela Racecourse, under the north stands. This building, one of Torroja's most emblematic works, marks an international milestone in the history of Modernist architecture's thin shells. The site is, then, a privileged location, for container and content were authored by one and the same engineer: Eduardo Torroja.

Fig 1. La Zarzuela Racecourse, Madrid, 1941

The museum is more than just a vast space for displaying a representative selection of Eduardo Torroja's legacy, however. With a view to maintaining an attractive programme and creating synergies with La Zarzuela Racecourse's many activities, it is also endowed with a hall for temporary showings of present and future Spanish avant-garde architecture and engineering. Yet another is devoted to the history of horse racing at La Zarzuela Racecourse, which this year is celebrating the 75th anniversary of its opening in 1941.

Given the diversity of race track audiences, the museum aims to appeal not only to architects, engineers and horse racing experts and fans, but also to their retinue of youths and children. The museum's projection hall will show A/V productions revolving around three subjects: Eduardo Torroja, innovation in the constantly changing architectural and engineering avant-garde, and the world of horse racing. With this inter-related, multi-purpose approach, the aim is to create a museum that actively serves a plural and likewise constantly changing society.

Spatial Organisation and Exhibitory Language

The straight-lined layout mandated by the distinct linearity of the museum's architectural space favours the sequential continuity of the planned uses. With a view to perceiving the museum as a single space and yet differentiating its several functions, the halls are designed to an open plan with crosswise panels that only partially conceal the full length of the museum while focusing attention on the theme addressed in each showroom.

The overall museum space consists in a 55 metre long box 5.50 metres wide and 2.80 metres high, in which the ceiling and wall opposite the entrance are black while the floor and porticoed longitudinal wall are grey. Like intermediate milestones, the staggered transverse panels (2.20 m high) set off halls and uses, adopting the colours of the Modernist movement with which Eduardo Torroja was so closely associated: **red**, grey, yellow, **blue** and **black**. Geometry and colour consequently speak the same exhibitory language, vaguely reminiscent of Mondrian's famous canvases. This same language is used for the base under Eduardo Torroja's scale models and the cubic textile cushions of different sizes and colours strewn throughout the museum to serve as seating for visitors of all ages.

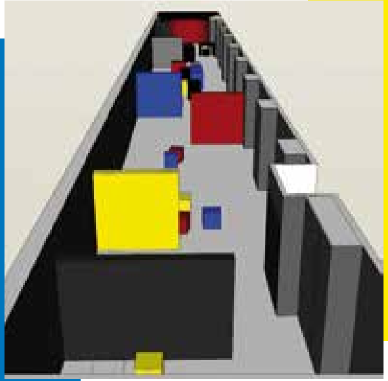


Fig 2. Spatial layout from the entrance

The first part of the museum houses a permanent exhibition of Eduardo Torroja's oeuvre. This display is divided into three visually inter-connected halls, S1, S2 and S3. They are followed by temporary exhibit hall S4 that transitions from the permanent Torroja exhibition to the hall showing the history of horse racing, S5, and lastly the projection hall, S6.

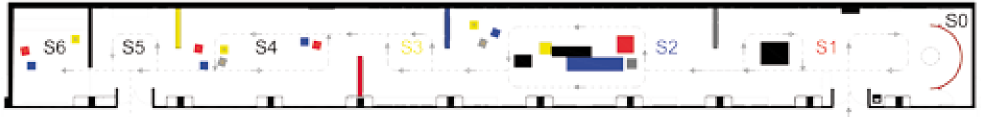
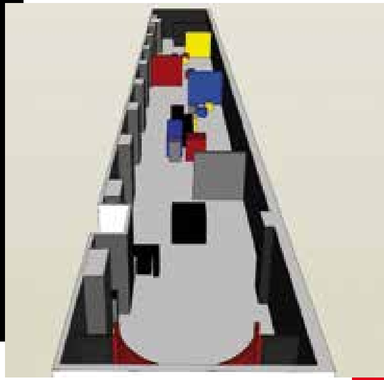


Fig 3. General ground plan

Fig 4. Spatial layout from rear



Displays

Permanent exhibition / Eduardo Torroja

Whilst Eduardo Torroja's extensive and polyhedral legacy is far too vast for the physical space available in the museum, it would hardly be reasonable in any event to display it in its awe-inspiring entirety, for most of the archives (designs, writings, essays…) have been digitised by CEDEX and are available online and at the National Research Council institute that bears the illustrious engineer's name.

The museum's 'raison d'être' is to provide a permanent place at which to clearly and concisely describe Torroja's most prominent contributions to progress in construction, architecture and civil engineering, highlighting the reasons for his status as an international and timeless model for professionals and students.

The idea is to steer the visitor's gaze to reasons converted into images and scant and concise words. That is the ultimate objective of the museum design. To that end a series of built works, research endeavours and publications have been selected for display, most of which were chosen by Torroja himself for his two most famous books, *Razón y Ser de los tipos estructurales* (1957) and *The Structures of Eduardo Torroja; an Autobiography of an Engineering Accomplishment*, published in English in New York in 1958 and in Spanish in 1999. As the words explaining each image were also taken from texts authored by Torroja, the engineer himself is the visitor's guide.

"While many of my works are not included here, I believe that the ones that are exemplify what I was seeking and ultimately found"

Eduardo Torroja, 1958

The works selected are shown in three consecutive halls: S1, S2 and S3. The order of the displays is based essentially on chronology, structure and use, for museum staging sometimes leapfrogs in time and space to highlight certain landmarks, such as La Zarzuela Racecourse, to which more exhibition space is devoted.

HALL – S1

An enormous photograph of Eduardo Torroja, located opposite the entrance, captivates visitors from the outset. It is located on the sole element that protrudes from the vertical plane of the 55 metre long black wall bounding one side of the museum.

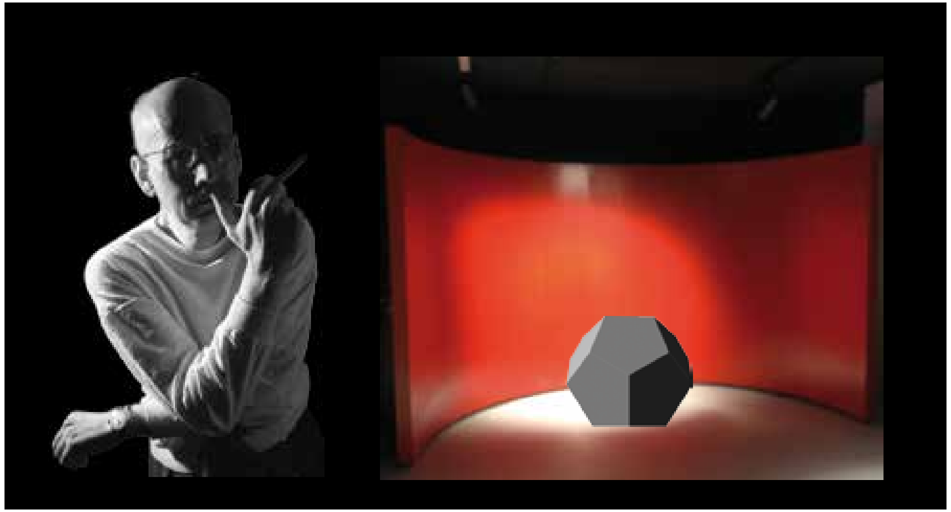


Fig 5. Eduardo Torroja- Cylindrical wall and dodecahedron

The first hall is also presided by large geometric figures to the right of the entrance, a reference to the prominence and variety of the pure geometric forms used by Eduardo Torroja in his works. Painted on a huge, curved, red wall is a fragment of a cylinder and behind it a white, 1 metre high dodecahedron, the pure geometric form used by Torroja to build a coal storage for the Institute for Construction and Cement Engineering (1949-1953). That 8 metre high sculpture-like element quickly became one of the symbols of the institution that now bears its author's name: Eduardo Torroja Institute for Construction Science, a National Research Council body. Today it forms part of the Fundación Eduardo Torroja logo.

This hall is an introduction to Eduardo Torroja in the form of a biographical sketch and a selection of his most prominent works. It displays some of his earliest works, with a focus on La Zarzuela Racecourse, which is not only one of his most emblematic and internationally reputed achievements, but also home to a museum.

Subjects and Works on Display

- **Eduardo Torroja** (1899-1961) Biographical timeline, including a showcase with medals and other distinctions received during his lifetime.
- **1923-1927** Earliest works with Hidrocivil, a private company: Santi Petri Bridge foundations.
- **1930-1935** University campus: 'Quince Ojos' Viaduct, 'Aire' Viaduct, Faculty of Science building,.....
- **1934** La Zarzuela Racecourse / 2004 Restored by Junquera Arquitectos / Dragados, S.A. (Grupo ACS)

Fig 6. Eduardo Torroja-Family coat of arms

Biographical Timeline

Eduardo Torroja Miret (1899-1961) was one of the most prominent international proponents of the history of progress attained in civil construction and architecture in the Golden Decades of Modernism.
He played a major role in the scientific and technical revolution that preluded the brisk development of reinforced and pre-stressed concrete in the first half of the twentieth century and the concomitant evolution in the construction industry, structural typologies and the new aesthetics championed by Modernism. He was internationally acclaimed not only for his innovative works, but also for his many-faceted professional activity: designer, scientist, researcher, manager and teacher.

He was born in Madrid on 27 August 1899. 1923 He graduated from the Madrid School of Civil Engineering. 1923-1927 He worked at Hidrocivil, a company headed by José Eugenio Ribera, where he authored his first innovative reinforced concrete designs.

1927 He founded his own design office. That same year he joined the Technical Team that was building Madrid's university campus, as design engineer.

1930 He founded "Investigaciones de la Construcción S. A.", ICON, which under his management specialised in testing models as a method for analysing structural behaviour. That approach enabled him to build large-scale thin shells at a time when there were no reliable structural engineering methods able to ensure their feasibility. His micro-concrete models for the Algeciras Market Hall and Recoletos Jai-alai Court, both on a scale of 1:10, received particular acclaim.

1934 He founded the Instituto Técnico de la Construcción y Edificación (ITCE, technical institute for construction and building) with a small group of engineers and architects, including José Mª. Aguirre Gonzalo, Alfonso Peña Boeuf, Modesto López Otero, Manuel Sánchez Arcas, Gaspar Blein Zaragoza and José Ángel Petrirena. ITCE was the first private sector organisation 'freely' created in Spain to conduct, further and publish research on construction and related areas to foster progress. Years later, in 1939, it joined the newly created Spanish National Research Council, CSIC, as an 'associate institute'.

1939 He was appointed professor of Structural Engineering. From then on, university teaching would be one of his lifetime callings. Over the years, he taught a number of subjects at the Madrid school: Properties of Materials and Elasticity, Fundamentals of Reinforced and Prestressed Concrete Design and Construction, Structural Engineering and Structural Typology.

1941 He was designated Director of the Central Laboratory for Testing Construction Materials.

1944 He delivered his acceptance address as fellow of the Royal Academy of Mathematics, Physics and Natural Sciences.

1945 He was elected President of the newly created Réunion internationale des Laboratoires d'Essais de Matériaux, RILEM. He took an active part in the creation of the Comité européen du Béton, CEB, whose membership, despite the name, included both the United States and Russia, and which played a decisive role in the development of European technical standards for reinforced concrete. He was also a prominent member of the Fédération internationale de la Précontrainte, FIP, founded by Freyssinet, whom he succeeded as president in 1958. In that role, he promoted the creation of the FIP-CEB Joint Committee to harmonise reinforced and prestressed concrete standards.

1957 He published his famous book, *Razón y Ser de los tipos estructurales*, which was translated into English, German, Italian and Japanese.

1959 He co-founded and presided the International Association for Shell Structures, IASS. In the United States, he published *The Structures of Eduardo Torroja;* translated into Spanish in 1999.

Eduardo Torroja died on 15 June **1961** in his office at the Institute that today bears his name, after signing an endearing letter to his collaborators in which he made it clear that he knew his life was drawing to an end.

Eduardo Torroja Miret's significant achievements were acknowledged in the form of a number of distinctions: honorary doctorates awarded by the Swiss Federal Institute of Technology, University of Toulouse, University of Buenos Aires, University of Louvain and the Catholic University of Chile. He was corresponding member of the Royal Academy of Science and Art of Barcelona and the Academy of Science, Plastic and Liberal Arts of Cordoba. He was appointed Knight of the Grand Cross of Alfonso X the Learned and Knight of the Grand Cross of Civil Merit. After his death he was granted the title Marquis of Torroja.

Pepa Cassinello
Curator

Fig 7. Medal of Civil Merit

Sancti Petri Bridge Foundations

Bridge design: Eduardo Torroja Miret and José Eugenio Ribera Dutaste
Construction company: Compañía de Construcciones Hidráulicas y Civiles (HIDROCIVIL)
Location: Sancti Petri, Cádiz, Spain
Date: 1926
Bridge length: 144 m; Structural form: hyperboloid of revolution;
Diameter at top: 7.00 m; Diameter at bottom: 7.60 m; Height: 8.90 m

One of Eduardo Torroja's first commissions was to design the compressed air caissons for the Sancti Petri Bridge foundations.

Torroja deviated from convention in the structural form for this type of foundations, using lightweight, doubly curved shells to optimise structural effectiveness and loading, along with worker safety and costs. The double wythe masonry brick wall on these caissons was just 7 cm thick.

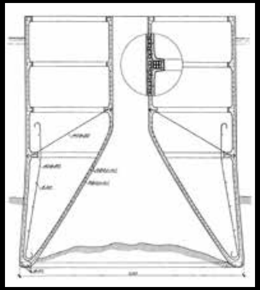
'To obtain a light structure of low draft, a circular design was chosen with a double wall in the shape of hyperboloids of revolution. This shape has marked advantages. The slightly larger diameter of the lower part of the outer wall reduces the friction generated when the caisson is submerged. The shape of the inner wall prevents the caisson from sinking too rapidly into muddy soils and consequently the danger that the available height of the working chamber, between the soil and the roof, may become too small. Caissons with conventional horizontal ceilings sometimes encounter this difficulty.

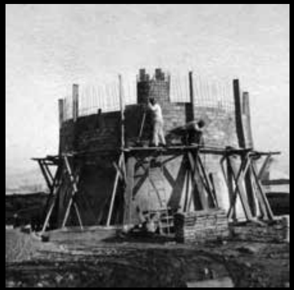
Circular, thin-walled cross sections are the most appropriate on for withstanding hydraulic pressure.'

Eduardo Torroja, 1958

1926
Sancti Petri Bridge foundations, Cádiz, Spain

Cross-section





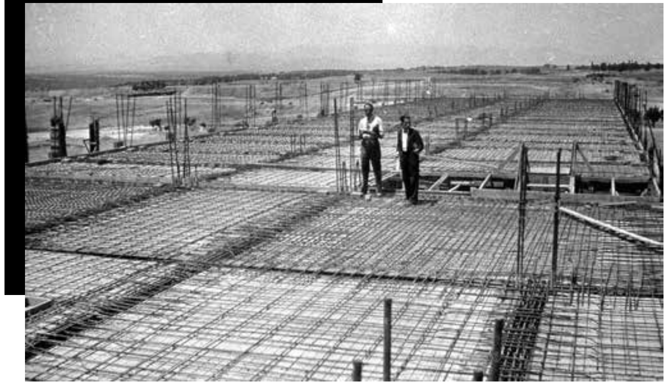
Construction

University Campus

In 1927 he was nominated by José Eugenio Ribera to sit as one of the engineers on the Technical Committee for the Construction of the University Campus, to be built under the leadership of Modesto López Otero in conjunction with architects Agustín Aguirre, Pascual Bravo, Miguel de los Santos, Manuel Sánchez Arcas and Luís Lacasa.

His involvement was not confined to engineering design and works, however, but included his inestimable participation in most of the architectural construction. From the outset, he assimilated and integrated the new Modernist architectural aesthetic in his innovative and original structures. Fruit of his activity in 1933 includes the 'Quince Ojos', 'Aire' and Sports Grounds Viaducts, the retaining wall for Cantarranas Stream and the stadium tramway station. In 1934 he also took part in the structural engineering for the Faculties of Science, Medicine and Pharmacy, and in 1935, for the students' residence, the steam power plant and the university hospital.

1934
Faculty of Science, University Campus, Madrid, Spain



1935
University Campus, Madrid, Spain

University hospital
Architect: Manuel Sánchez Arcas
Engineer: Eduardo Torroja Miret

Reinforced concrete slab terraces

Skylight structure

‘Quince Ojos’ Viaduct

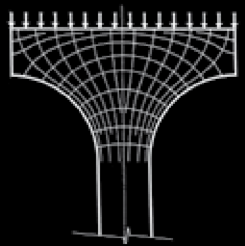
Engineering: Eduardo Torroja Miret
Architect: Modesto López Otero
Developer: Junta de la Ciudad Universitaria (1927-1936)
Construction company: Agromán, S.A.
Dates: 1929-1933
Location: Madrid, Spain
Height: 22 m
Length: 84.70 m

Initially known as the ‘Alfonso XIII Viaduct’, the ‘Quince Ojos’ [fifteen portholes] Viaduct is so-named for its sequence of 15 large arches with 7 m spans that rest on 1.7 m square section piers. It is 35 m wide and has transverse arches similar to the longitudinal structures. Each of these three-dimensional structural units consists of four arched cantilevers that meet at right angles over a vertical support. It was an aesthetic and ingenious way to include expansion joints.

‘The great length and rigidity of this structure made it essential to place expansion joints at frequent intervals and in places where they would not spoil its appearance. It was therefore decided -as the least undesirable solution- to situate the joints exactly at the arch crowns. This positioning transformed the arches into double cantilevers’.

Eduardo Torroja, 1958

1929 - 1933
‘Quince Ojos’ Viaduct
University Campus,
Madrid, Spain



Statically determinate system

‘Aire’ Viaduct

Engineer: Eduardo Torroja Miret
Architect: Modesto López Otero
Construction company: Agromán, S.A.
Date: 1933
Location: University Campus, Madrid, Spain

The ‘Aire’ Viaduct is one of the designs authored by Eduardo Torroja while he was contracting as an engineer for the Technical Committee for Construction of the University Campus. Its name alludes to its slender structure.

The entire structure of this deck arch bridge was built with reinforced concrete. Its twinned 36 m span arch supports the studs on which the deck rests. Seeking to improve the aesthetics of the viaduct, Torroja spaced the studs non-uniformly, narrowing the distance between them inwardly, from the ends to the centre.

‘.... [this] is a clear example of the technical and plastic potential of using very slender longitudinal elements, as befits a linear and geometric aesthetic.’ The stresses on the arch were calculated graphically using the ellipse of inertia method.’

Eduardo Torroja, 1958

La Zarzuela Racecourse

Engineering: Eduardo Torroja Miret
Architects: Carlos Arniches Moltó and Martín Domínguez Esteban
Construction company: Agromán, S.A.
Dates: 1934 (design); 1935 (initial construction); 1941 (opening ceremony)
Location: Madrid, Spain
Thin shell roof and stands - Eduardo Torroja Miret
Cantilever: 12.80 m; **Thickness**: 5.00 cm – 14.50 cm

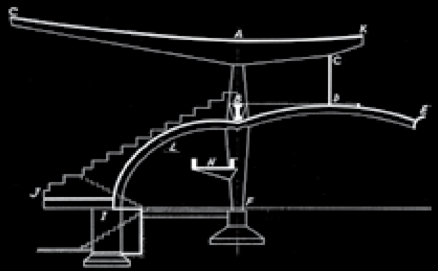
In 1934 the Technical Office of Access Roads and Outskirts organised a competition for La Zarzuela Racecourse, which was won by a threesome: architects Carlos Arniches and Martín Domínguez and civil engineer Eduardo Torroja. Although construction was begun in 1935, as it was suspended during the Spanish Civil War (1936-1939), the racetrack was not completed until May 1941.

The reinforced concrete stands and their thin shell roofs are among Torroja's most emblematic and internationally renowned works. La Zarzuela Racecourse seating is divided into three stands: its two outer 60 m long structures flank a 30 m long central grandstand. This transparently Modernist suite of structural forms defines the entire architectural space, including the betting halls below and the grandstands above. Each stand consists in transverse portal frames spaced at 5.00 m. These structures support the intersecting (two-lobed) vaults that both roof the betting halls and support the grandstands and their 12.80 m cantilevered thin shell canopy. A threaded steel tie positioned at the rear provides the balance for these bold structural forms.

The innovative, slender thin shell roof is only 5 cm thick at the edge and 14.50 cm thick at the springline. It comprises a series of hyperboloid-like doubly curved thin shells. As its specific structural form could not be engineered with the methods available at the time, after doing some preliminary structural engineering, Eduardo Torroja verified shell performance empirically with a full-scale module built on site by the contractor, AGROMAN.

'I have often been asked how I came to decide upon the design of the Zarzuela Hippodrome ....And the question now arises: is the invention of an especially adapted form to solve a specific problem strictly an imaginative process, or is it the result of a logical reasoning based on technical training? I do not think it is either of the two, but rather both together. The imagination alone could not have reached such a design unaided by reason, nor could a process of deduction, advancing by successive cycles of refinement, have been so logical and determinate as to lead inevitably to it -whatever the reader of these lines may have inferred. '

Eduardo Torroja 1958

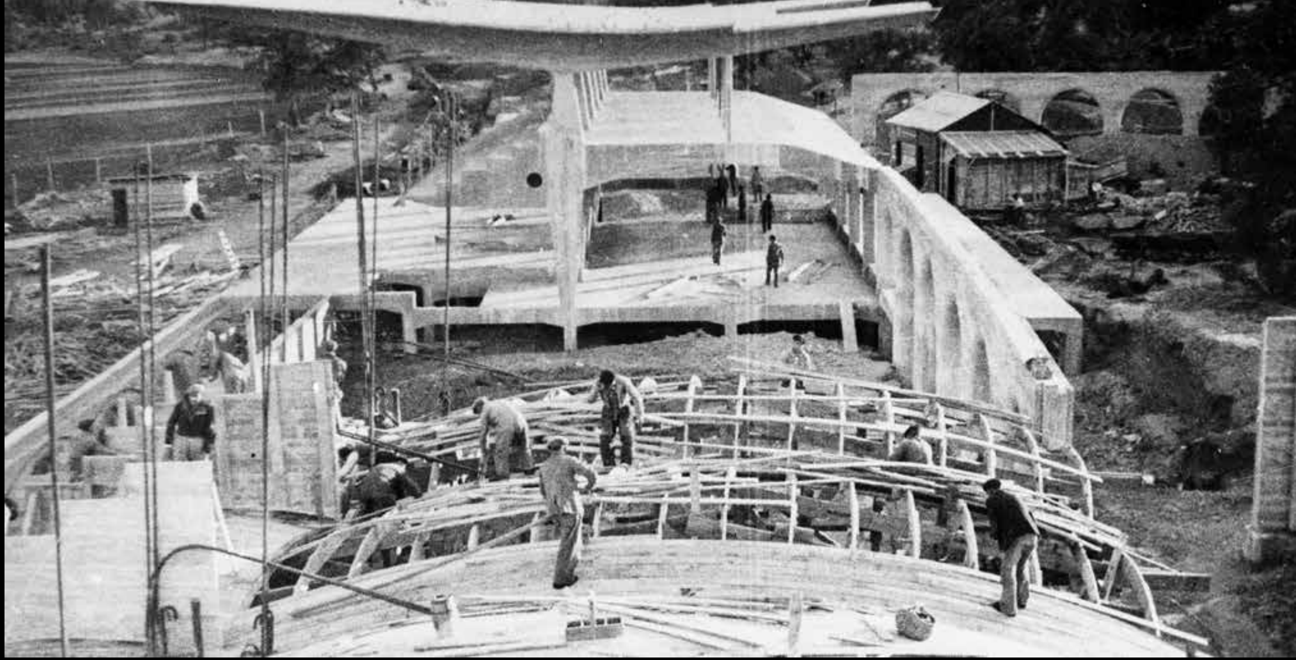


Cross-section

Stands - side elevation view. © S.V. Kaskel

1935
La Zarzuela Racecourse,
Madrid, Spain

Construction



1934
Full-scale model test
conducted by Agromán

La Zarzuela Racecourse Restoration

Architect: Junquera Arquitectos - Jerónimo Junquera García del Diestro
Engineer: Leonardo Fernández Troyano (Structure), Úrculo Ingenieros (Services)
Construction company: Dragados, S.A.
Partnering institutions: Eduardo Torroja Institute for Construction Science
SIKA, España
Dates: 2004 - 2007 (design); 2008 – 2015 (construction)
Location: Madrid, Spain

In 2004, Junquera Arquitectos won the competition to restore and rehabilitate the La Zarzuela Racecourse compound organised by Hipódromo de la Zarzuela S.A., the course managers.

The works began in 2008 with the restoration of the canopies over the stands, affected by weathering, water damage and past construction. At the same time, the buildings and structures in the complex were investigated to analyse the original values and systems that had been distorted or impaired by enlargements and other changes. Those investigations revealed substantial structural damage that required consolidation and repair.

Structural rehabilitation was followed by restoration of the compound's architecture to recover the essential values of the design authored in 1934 by Arniches, Domínguez and Torroja.

In the restoration, the beauty of the future racecourse drew from the enhancement of the original values and recovery of those that had disappeared. La Zarzuela Racecourse was redeemed for the city, its optimal facilities for racing and other equestrian sports in balance with the use of the monument.

2004-2015
La Zarzuela Racecourse restoration. Junquera Arquitectos

HALL – S2

In 1927 Eduardo Torroja founded his own engineering studio, where he authored any number of innovative works that contributed to progress in civil and architectural construction, consistently in line with the precepts of the (at the time) young Modernist movement.
Torroja indisputably owed the breadth of his knowledge to his multi-faceted activity as designer, researcher, professor, businessman and manager. That knowledge, together with his creative sensitivity, afforded him the freedom to turn his ideas into what David Billington would later call 'structural art'.

'My final aim has always been for the functional, structural and aesthetic aspects of a project to present an integrated whole, both in essence and appearance.'

Eduardo Torroja, 1958

Using the same exhibitory language as in the rest of the museum, the second permanent exhibition hall devoted to Eduardo Torroja displays a series of works dating from 1927 to 1957 in chronological and typological order, based on structural types and uses. Civil engineering works, including bridges, dams, aqueducts and viaducts, are exhibited on the grey wall, along with horizontal showcases in spaces swept by more intense light. The architectural works in turn, such as markets, hangars, stadiums and churches, are displayed on the longitudinal black wall.

Further to the decision to imbue the museum with Modernism's pure geometries and colours, the centre of this hall houses a longitudinally staggered, multi-coloured stand displaying a number of scale models (Algeciras Market Hall, Tordera Bridge, Alloz Aqueduct, Recoletos Jai-alai Court, Pont de Suert Church, water tower at Fedala, Tachira Club) in a way that determines the order in which they are viewed by visitors.

Works displayed: 1927, Tempul Aqueduct; 1935, Algecrias Market Hall; 1936, Recoletos Jai-alai Court, Madrid; 1939, Alloz Aqueduct; 1940, Tordera Bridge; 1940, Pedrido Bridge; 1941, Martín Gil Aqueduct; 1942-1945, hangars at Torrejón and Cuatro Vientos; 1943, Las Corts Stadium, Barcelona; 1953, Sancti Spirit Chapel; 1954, Pont de Suert Church; 1956, water tower at Fedala; 1956, Canelles Dam.

Tempul Aqueduct

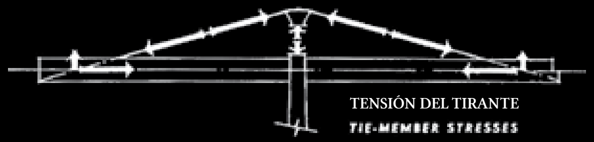
Engineers: Eduardo Torroja Miret and Francisco Ruiz Martínez
Construction company: Compañía de Construcciones Hidráulicas y Civiles (HIDROCIVIL)
Date: 1925 (design).
Location: Jerez de la Frontera, Cádiz, Spain

With this aqueduct, Eduardo Torroja built one of the world's first prestressed concrete structures, deploying an ingenious prestressing system.

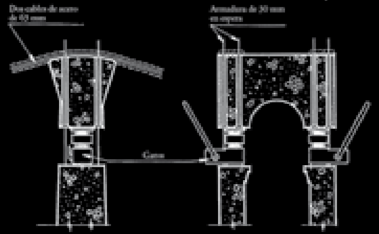
The aqueduct comprises eleven 20 m long reinforced concrete girders and a 57 m cantilevered centre span. To avert possible foundation problems, Torroja decided to eliminate the two centre piers from the initial design that were to be sunken into the riverbed. He replaced them with high-strength stay cables running over the two innermost of the remaining piers, one on each bank, and anchored at the far ends of the two adjacent sections on either side of those piers.

'The tie members, including the anchorage, were to be about 50 m long. In 1926, however, there was no prestressing technique available to handle such lengths, nor was welding sufficiently advanced to trust to it a structure of this importance. I decided to use twisted cables of high tensile steel. With these, tie members could be easily made in one piece.
The solution consisted in supporting the cables at the top of the piers on independent seating. Thus, once the overhanging spans anchoring the ends of the cables had been concreted, the height of this seating could be lifted by means of hydraulic jacks. The additional elevation would stretch the cables until they reached their proper working stress.'

Eduardo Torroja, 1958



Tensiones en el tirante/ Stresses on tie



1925 - 1926
Tempul Aqueduct, Jerez de la Frontera, Cádiz, Spain

Algeciras Market Hall

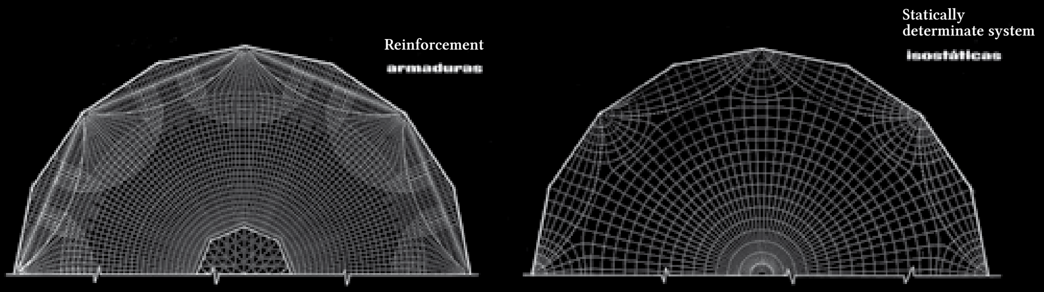
Engineer: Eduardo Torroja Miret
Architect: Manuel Sánchez Arcas
Construction company: Ricardo Barredo, S.A.
Dates: 1934 – 1935
Location: Plaza de la Palma, Algeciras, Cádiz, Spain

The roof over Algeciras Market Hall was the first large reinforced concrete thin shell dome built in Spain and for over 30 years the largest such structure in the world. This unprecedented feat called for a number of innovations, introduced by Eduardo Torroja, that form part of the history of 'Modern Architecture's Thin Shell Adventure'. Although several large-scale thin shell domes, such as Franz Dischinger's roof over the market hall at Basel, had been erected a few years before, Eduardo Torroja instituted a new structural form characterised by a wide span, continuous thickness and the absence of exposed ribs on the edges, along with an ingenious form-stripping method consisting in post-tensioning the perimetric tie beam, all of which created a resounding image of Modernity.

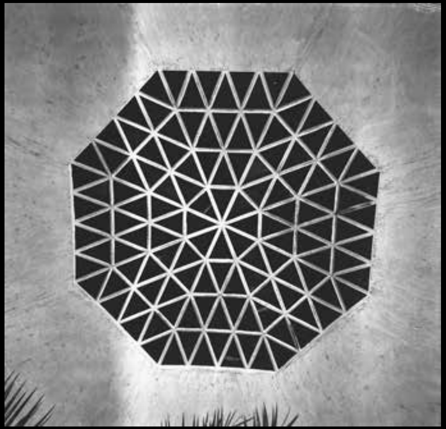
The market has an octagonal ground plan, with each side measuring 18.20 m. The thin shell domed roof spans the entire 47.76 m distance between opposite sides of the octagon. This 41.20 m diameter spherical cap features eight smaller visor-like shells around the edge that rest on columns. The arched edges of these horizontal cylindrical shells transfer the stress from the roof to the columns, thereby enhancing overall structural stiffness. This continuous thin shell, which has no ribs, is 50 cm thick over the supports, tapering to just 9 cm in the centre. The thin shell contains an octagonal skylight (10 m, diagonal) on its top. The glass panels rest on prefabricated reinforced concrete triangles.

'... the vertical force component is resisted by the vertical support itself, whereas the horizontal radial thrust component is balanced by an octagonal hoop consisting of 16 steel rods, each of 1.2 in. diameter. This hoop must stretch to develop stress, whereas the dome, being in compression, tends to contract. Hence the hoop rods were provided with turnbuckles so that they could be shortened and stressed, and the vault in turn compressed in radial direction at the points of support. The compressed vault began to lift up and slightly away from the supporting formwork.'

Eduardo Torroja, 1958



Domed roof over Algeciras Market Hall



1934-1935
Market hall at Algeciras, Cádiz, Spain

Recoletos Jai-alai Court

Engineer: Eduardo Torroja Miret
Architect: Secundino Zuazo Ugalde
Developer: Nueva Empresa de Frontones, S.A.
Construction company: Huarte y Cia.
Date: 1935
Location: Villanueva Street, Madrid, Spain (no longer standing)

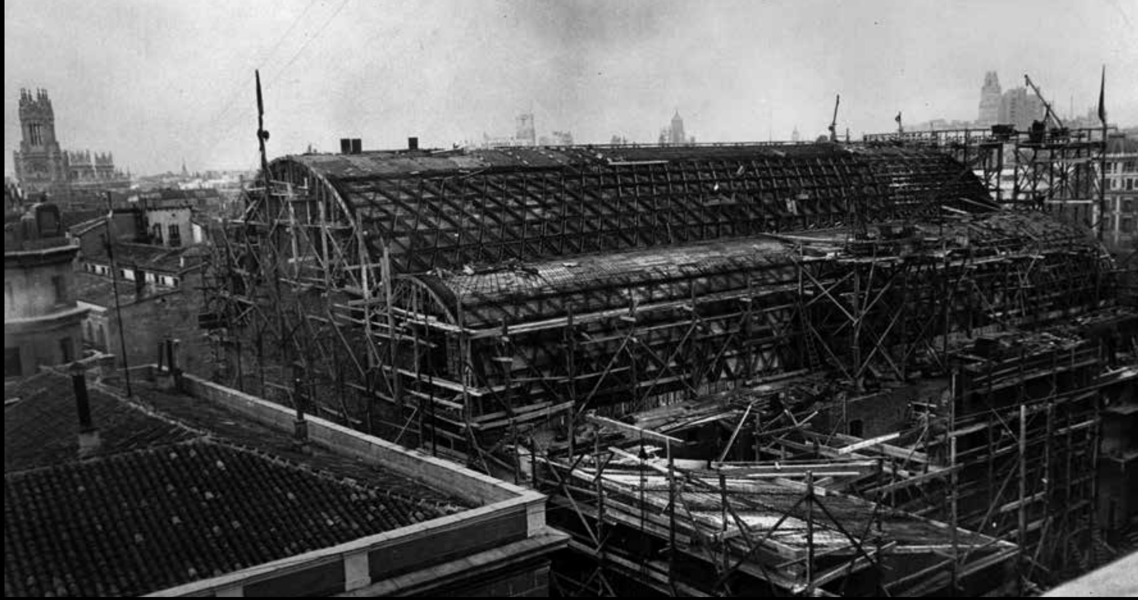
The Recoletos Jai-alai Court, one of the most prominent examples of Madrilenian Modernism, was the fruit of an admirable meeting of two creative minds: engineer Eduardo Torroja and architect Secundino Zuazo.

Its reinforced concrete thin shell roof was one of Torroja's most innovative and singular works. Unfortunately the roof was severely damaged during the Civil War and collapsed in 1939. This 'two-lobed thin shell beam' had a 55 m span and consisted in two length-wise intersecting semi-cylinders, one with a radius of 12.20 m and the other 6.40 m. It measured 32.50 m wide and spanned the entire area below with no intermediate supports. It was a constant 8 cm thick except at the intersection between the two lobes, were it measured 16 cm. Natural light poured into the court through two longitudinal skylights resting on a series of equilateral triangles with 1.40 m sides.

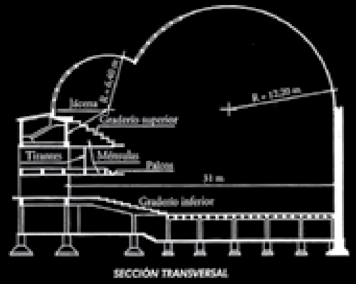
'Because of the complexity of the design calculations and ever present danger of error, the theorical work was supplemented with an experimental investigation on a reduced scale model.'

Eduardo Torroja, 1958

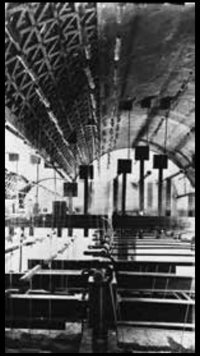
1935
Recoletos Jai-alai
Court, Madrid, Spain

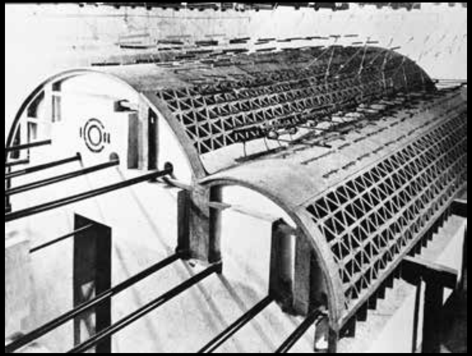


1935 - 1936 Construction



Test on 1:10 scale model





Alloz Aqueduct

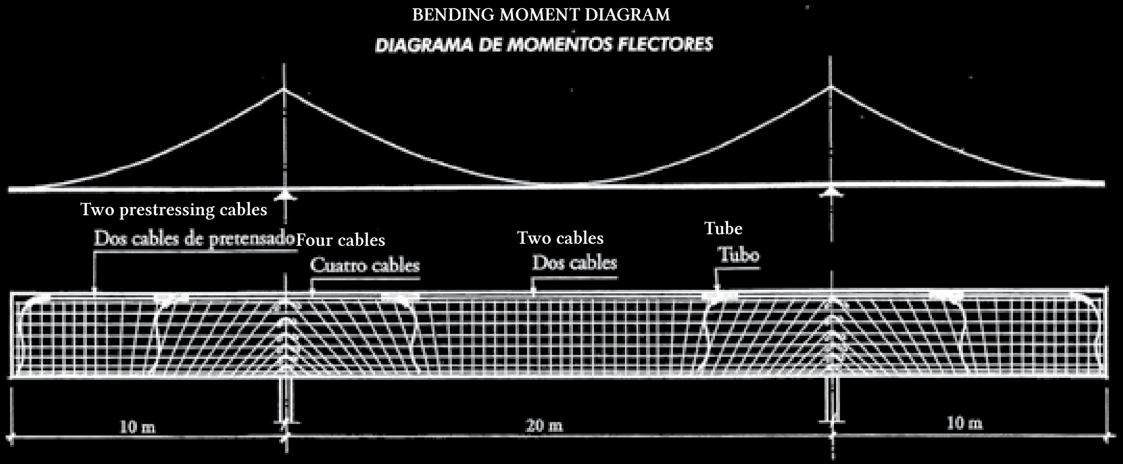
Engineering: Eduardo Torroja Miret
Construction company: Huarte y Cia.
Dates: 1939 -1942
Location: Road to Santiago, Cirauqui, Navarre, Spain
Channel length: 218 m; **Height**: 2.75 m; Thickness: 15 cm

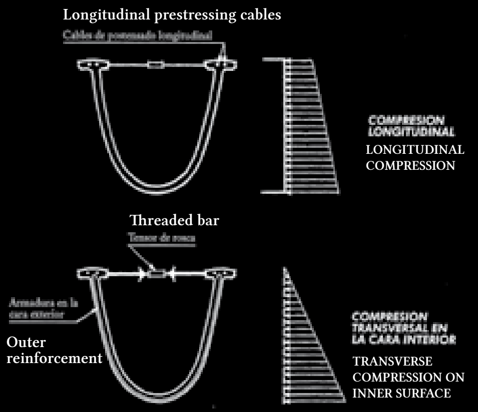
Alloz Aqueduct is one of the pioneering works of prestressed concrete designed by Eduardo Torroja. In it he applied ingenious, non-conventional prestressing. It consists of a self-supporting cubic-parabolic canal, prestressed in two orthogonal directions to ensure impermeability. The canal rests on huge scissor-like supports spaced at 20 m intervals. Each 40 m section comprises a 20 m central length and two 10 m cantilevered lengths, one on each side. The two twisted wire cables positioned on the upper edges of the canal that form the longitudinal prestressing are inter-connected by threaded transverse bars spaced at 4 m intervals. An ingenious longitudinal prestressing system was devised, consisting in setting clamps between the two members of each pair of cables, which were then pulled apart with a steel pivot lever and a hydraulic jack. Concrete was subsequently cast on the stressed cables.

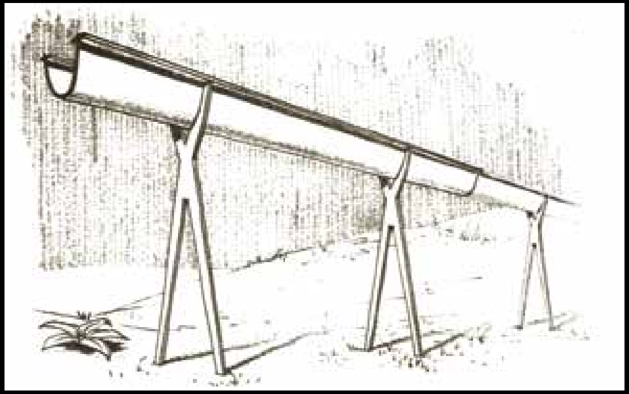
This is not merely an example of the early use of prestressing, however. Its transparently Modernist aesthetics have a forceful visual impact on pilgrims travelling along the Road to Santiago.

'The fundamental idea in the design of this aqueduct was the elimination of any possibility of fissuration or water infiltration through the channel walls by subjecting them to two-way compression on their inside face.'

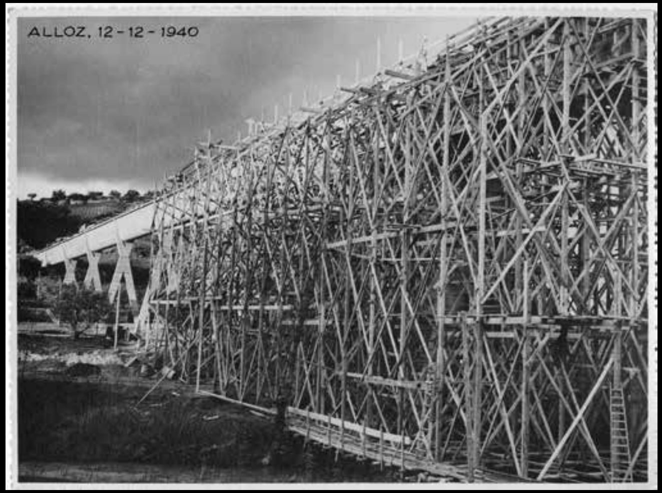
Eduardo Torroja, 1958







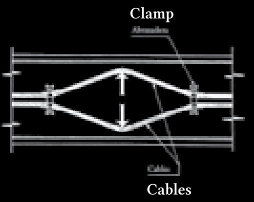
Elevation sketch, Alloz Aqueduct

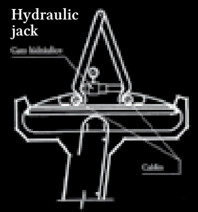


1939 - 1942
Alloz Aqueduct

Construction

Cable stressing with hydraulic jack





Tordera Bridge

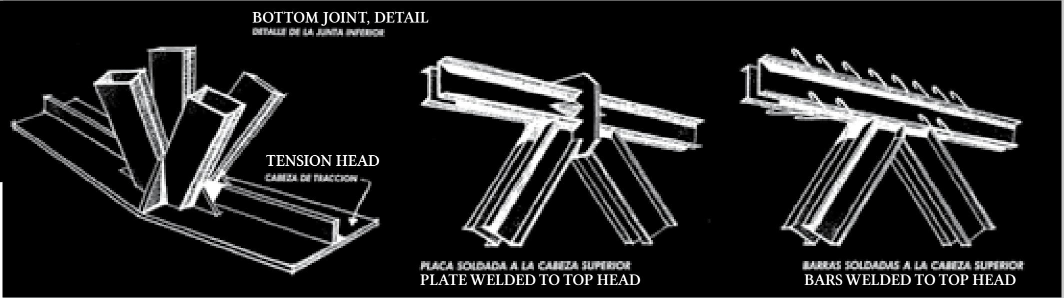
Engineers: Eduardo Torroja Miret, César Villalba Granda and Gabriel Andreu Elizaicin
Construction company: Obras Metálicas Electro-Soldadas (OMES) and Investigaciones de la Construcción, S.A. (ICON)
Dates: 1939 (design); 1939-1944 (construction) .
Location: Barcelona-Gerona Road, Spain

Eduardo Torroja was a pioneer of composite construction, a system that capitalises on the mechanical properties of these two materials, steel and reinforced concrete. He designed a number of composite bridges, the first of which, Tordera Bridge (1939), had been entirely destroyed during the Civil War, except for the piers. Reconstruction involved laying a new reinforced concrete deck over elliptical steel girders, supported by the existing piers. The bridge has two 45.70 m side spans flanking its 54.70 m centre span. The reinforcement bars in the concrete deck slabs were welded to the upper chord of the steel beams so the slabs would act as head compression for the girders.
The nodes of this bridge were the subject of international recognition (Sweden).

'The tension beam follows an elliptical arch. This design was chosen after trying several other methods for achieving a fairly constant load along the whole length of the chord while keeping the compressive stresses in the diagonals low enough to avoid buckling.'

Eduardo Torroja, 1958

1939-1944
Tordera Bridge, Barcelona-Gerona Road, Spain



Pedrido Bridge

Engineers: Eduardo Torroja Miret and César Villalba Granda
Construction company: Ricardo Barredo, S.A.
Dates: 1939 (design); 1939-1943 (construction).
Location: Betanzos Estuary, Corunna, Spain
Type: Arch bridge

Engineer César Villalba Granda began to build Pedrido Bridge before the Civil War. Its 520 m length is divided into three sections. When the outbreak of the Civil War interrupted the works, only the two side spans had been erected: one with a 340 m long deck resting on 19 double arches and the other with a 102 m deck on three double arches.

Eduardo Torroja designed the centre span in 1939 to complete construction. His 78.40 m, doubly hinged reinforced concrete bowstring arch rises 12.50 m over the deck. Its two main ribs have a variable depth but a constant width throughout. The 3.65 m through arch deck is a continuous slab secured to the arch with hangers.

'The two halves of the main reinforcement for the arch, to be made with welded flat profiles, are designed to be launched from opposite sides of the bridge and, once joined at the key and with the tie in place, to be cast in concrete.'

Eduardo Torroja, 1940
(Design specifications)

1939
Pedrido Bridge

Construction

Martín Gil Viaduct – Esla Arch

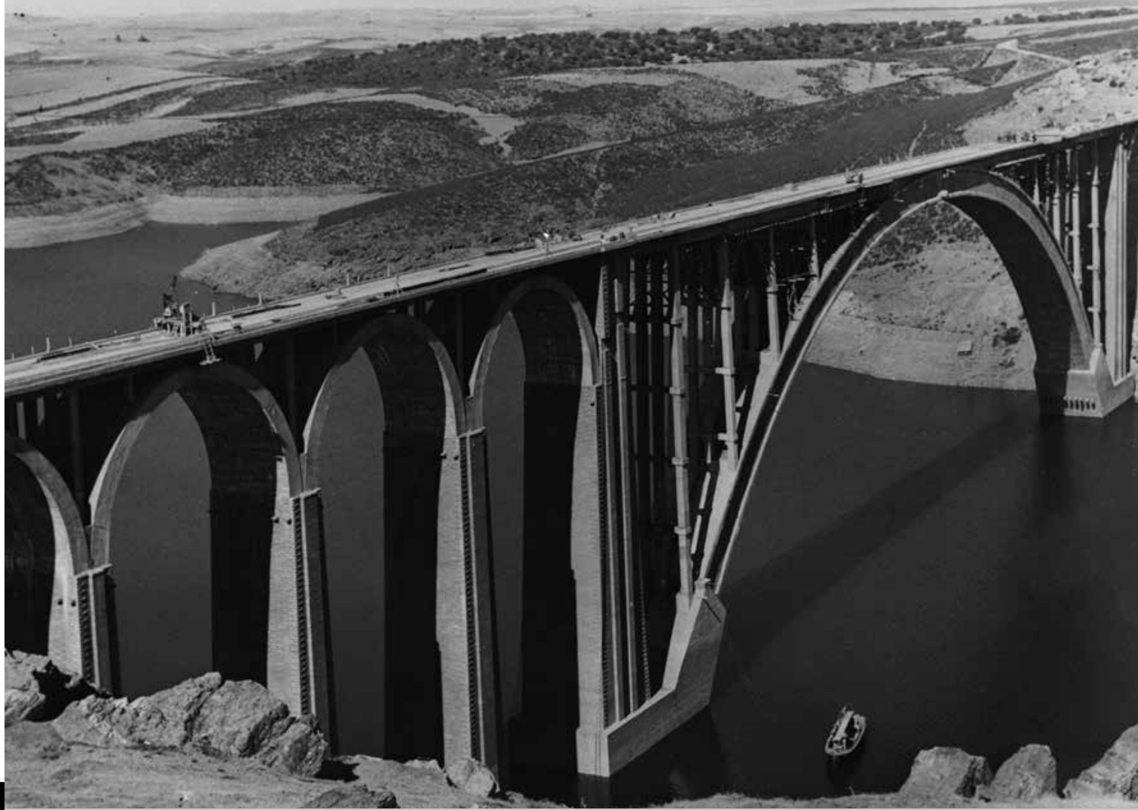
Engineers: Francisco Martín Gil, César Villalba Granda, Antonio Salazar Martínez, Eduardo Torroja Miret
Developer: Spanish Ministry of Public Works
Construction companies: Max Jacobson, S.A., Ricardo Barredo, S.A., Esab Ibérica, S.A., Investigaciones de la Construcción, S.A. (ICON)
Dates: 1932 (1st design); 1935 (2st design); 1939 (3rd design); 1934-1943 (construction).
Location: River Esla, Manzanar del Barco, Zamora, Spain
Total length: 479 m; Height: 84 m
Central arch: 209 m

The Martín Gil Viaduct was another of the many works interrupted with the onset of the Civil War. When the war ended in 1939, Eduardo Torroja built the reinforced concrete centre arch with its record-breaking 209 m span.

To optimise construction and costs, Torroja designed sacrificial steel centring for the arch: cross-braced trusses to be packed into the concrete as permanent reinforcement. The concrete for the huge arch was cast in longitudinal lifts of increasing thickness, for once the previously poured concrete had set, the centring could bear greater stress.

'A set of hydraulic jacks was placed both at the springing and at the crown of the bottom chords as a means of compressing these chords and thereby partly relieving the upper chords from the compression loads that up to this stage had been entirely borne by them'.

Eduardo Torroja, 1958



1934 - 1943
Esla Arch, Manzanar del Barco, Zamora, Spain

Construction

Hangars

Engineer: Eduardo Torroja Miret
Architect: Rafael de la Joya Castro
Construction company: Obras Metálicas Electro-Soldadas (OMES)
Date: 1942
Location: Torrejón de Ardoz Airport, Madrid, Spain
Developer: Spanish Air Force
Construction company: Obras Metálicas Electro-Soldadas (OMES)
Dates: 1946 - 1949
Location: Real Aero Club de España, Cuatro Vientos, Madrid, Spain

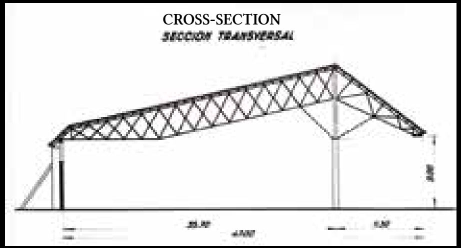
Between 1942 and 1949, Eduardo Torroja designed and built three large steel-roofed hangars in Madrid, after winning competitive tenders held by the Air Force. The first, for Torrejón Airport, later also served as the model for the Barajas Airport hangar. The clear area was to measure 182.88 m x 47.24 m, although a centre support to be located no farther than 10 m inward from the perimeter was allowed at the entrance, located on one of the long walls. Torroja designed the roof to have a 13° upward pitch along the four sides to reduce the wind load on the walls as much as possible. In its structure, cross-braced trusses rest on a longitudinal girder.

The third and entirely different hangar was built for Cuatro Vientos Airport. The steel arches on its roof, each of which spans 35 m, intersect to form a very stiff ribbed vault. These arches were assembled on the ground and later hoisted into position.

'Each of the two halves of the roof structure functions like a girder of great strength and rigidity although very light in weight'

Eduardo Torroja, 1958

1942
Hangar at Torrejón de Ardoz, Madrid, Spain



1946 - 1949
Hangar at Cuatro Vientos, Madrid, Spain

Las Corts Football Stadium

Engineer: Eduardo Torroja Miret
Architect: José Mª Sagnier Vidal
Developer: Club de Fútbol Barcelona
Construction company: Pubasa
Dates: 1943-1945
Location: Barcelona, Spain

This composite concrete and steel stadium has an innovative steel roof that rests on large reinforced concrete supports and cantilevers 25 m over the grandstands. The design is yet another example of Eduardo Torroja's continuous pursuit of both the most appropriate structural form for each functional space and of the materials that optimise its cost.

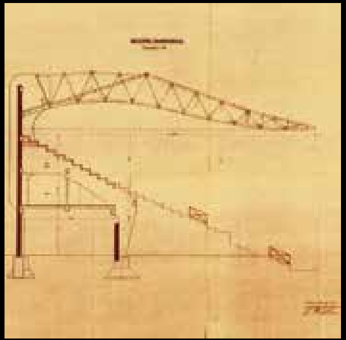
The roof structure consists in a grid of triangular steel brackets spaced at 5 metres. The tops of the brackets are secured to the concrete steel reinforcement with bolts. The pleasing curvature of the roof intrados is enhanced by its orange timberwork cladding. The reinforced concrete structure that bears the roof and grandstands was designed to reduce its depth and cost while limiting the rise in the bending moment. Torroja's ingenious solution to achieve all three was to divide the 8 m span on the sloped beams in the stands with a centre tie.

'It was difficult to find alternatives for the structural materials and methods to be used in this great cantilever roof. Calling for an overhang of 83 ft over the spectator stands, it had to be made in metal in order to reduce weight and cost'

Eduardo Torroja, 1958

Load test

1943 - 1945
Las Corts Football Stadium, Barcelona, España



Cross-section

Sancti Spirit Chapel

Engineer: Eduardo Torroja Miret
Developer: Empresa Nacional Hidroeléctrica del Ribagorzana (E.N.H.E.R.)
Date: 1953
Location: Valle de San Nicolau, Aigües Tortes, Lérida, Spain (no longer standing)

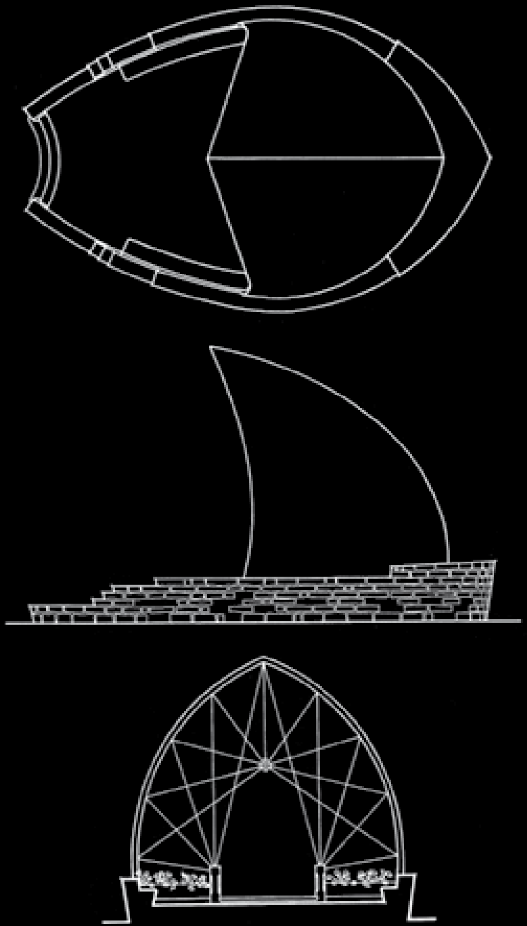
In a charmingly remote bend in the River San Nicolau in the Pyrenees, Eduardo Torroja built a gem of thin shell Modernism, which has unfortunately disappeared. This small open chapel constituted a sort of hemispheric refuge. Its thin shell sprang from the ground, roofing the entire indoor area and resembling a sail billowing in the wind.

Its structural form was a half dome made of reinforced brick masonry, a very cost-efficient solution in Spain at the time. The system devised to stiffen the edge of the dome was particularly original: a family of lightweight, post-tensioned, radial ties secured it to two points of fixity.

'No practical method exists at present whereby the stress calculation of such a shell can be made. But this drawback should be no reason why such shells, even ones much larger than this small shelter, should not be constructed.'

Eduardo Torroja, 1958

Sancti Spirit Chapel, side and front elevation views



1952
Eduardo Torroja
Pont de Suert module

Pont de Suert Church

Engineer: Eduardo Torroja Miret
Architect: José Rodríguez Mijares
Developer: Empresa Nacional Hidroeléctrica del Ribagorzana (E.N.H.E.R.)
Dates: 1952 - 1955
Location: Pont de Suert, Lérida, Spain

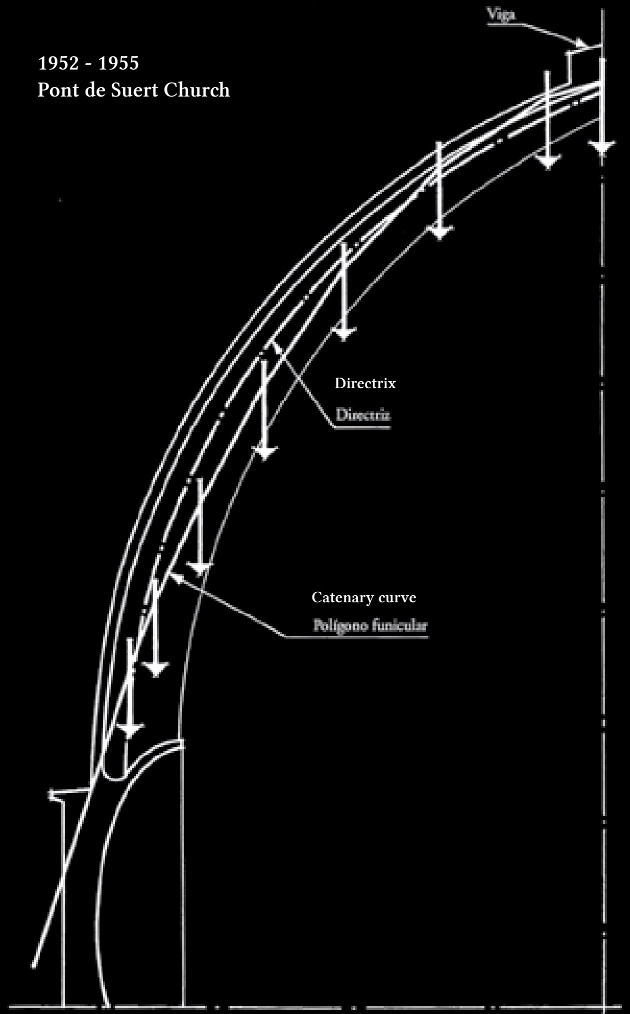
Spatially speaking, the most prominent feature of the thin shell roof over the Pont de Suert parish church is that it is not only a roof: rather, this single structure that springs from the ground defines the entire indoor space. The church is quite visibly the fruit of its structure, whether viewed from inside or out.

The sole aisle of the church consists in a continuous series of vaulted shell modules in which the main (roof and walls) vaulted lobe connects to small, likewise vaulted, apsidal chapels. The section of the lobe is an ogive arch, although its curvature varies transversally, flattening near the key. Its geometry is adapted to the bending moments. A reinforced concrete beam running across the keys in all the modules comprising the aisle stiffens and stabilises the structure. The thin shells were built with three wythes of 3 cm thick brick masonry laid to a timbrel vault arrangement. The cement mortar facing on the church exteriors was laid over a fine steel mesh.

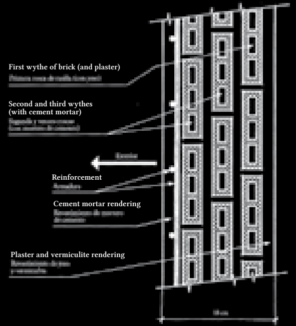
'Such shells are cheap to make and may be adapted to any desidered shape, even to continuously changing curvaturas, as evidenced by all the roof vaults of this church.'

Eduardo Torroja, 1958

1952 - 1955
Pont de Suert Church



COMPRESSIVE STRESS ON VAULT
COMPRESIONES EN LA BOVEDA



VAULT DETAIL

Fedala Water Tower

Engineer: Eduardo Torroja Miret
Associates: Alfredo Páez and Florencio del Pozo
Construction company: F. Fernández, Société marocaine des Entreprises Fernández
Location: Fedala, Morocco
Dates: 1956 (design); 1956-1957 (construction)

Eduardo Torroja built his most innovative and attractive water tower at Fedala, designing its various parts to different structural forms and materials to optimise structure, functionality and construction process.

While the walls of the vat were built with prestressed reinforced concrete, the thin shell roof, which has to bear no load or thrust from the stored water, was erected with lightweight brick masonry that required no formwork. The bottom of the vat is a reinforced concrete toroidal vault. Its outside ring is post-tensioned with threaded strands, while in its wall, a hyperboloid of revolution, the post-tensioning runs along its two families of straight lines, called generatrices and directrices. Their simultaneous compression prevented the vat from cracking. In this aesthetically harmonious solution, each element has its ideal structural form and material.

'The main problem in designing this tank, 925 000-gal capacity, was finding a satisfactory method of water-proofing. As a result, the initial shape – a truncated cone- was changed to that of a hyperboloid of revolution, which was post-tensioned along the two families of straight lines typical of the hyperboloid. Simultaneous compression along the generators and directrixes was thereby achieved and the danger of fissuration avoided.'

Eduardo Torroja, 1958

1956 - 1957
Water tower at Fedala, Morocco

Construction

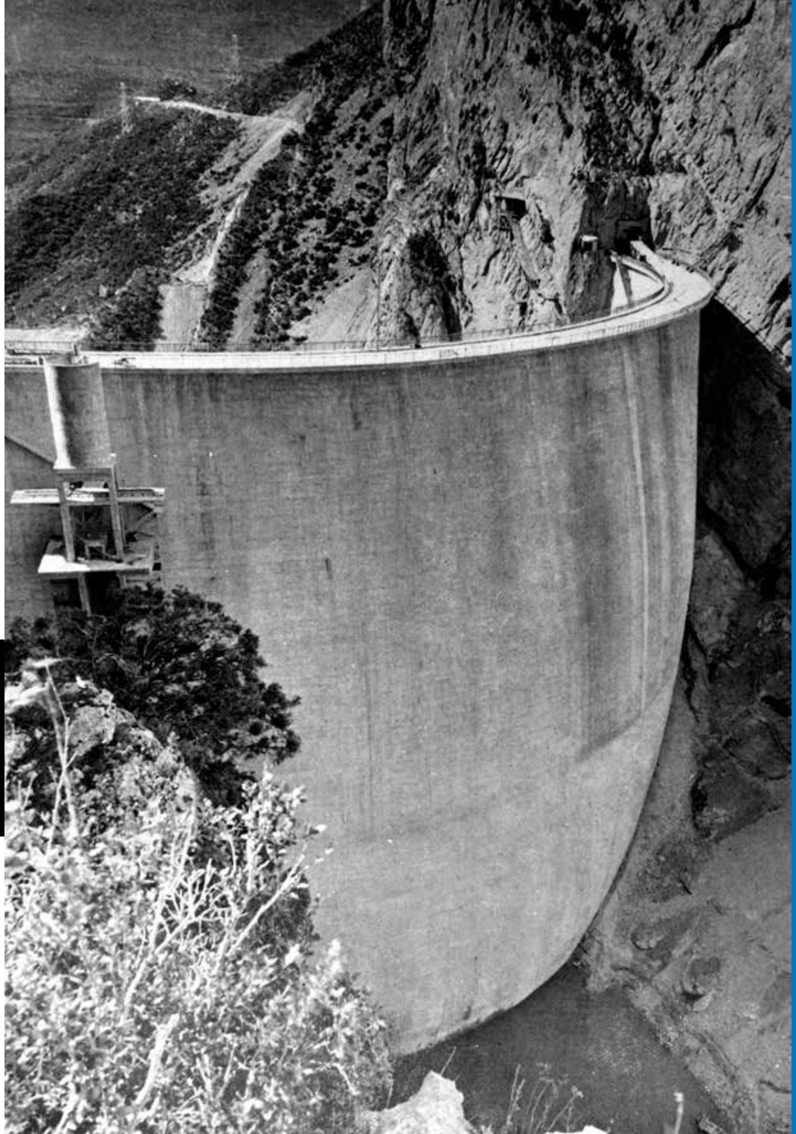
Canelles Dam

Engineers: Carlos Benito Hernandez and Eduardo Torroja Miret
Developer: Empresa Nacional Hidroeléctrica del Ribagorzana (E.N.H.E.R.)
Construction company: E.N.H.E.R.
Dates: 1953-1964
Location: Río Noguera. Ribagorzana, Lérida, Spain
Length: 210 m
Height: 140 m

In its day, the 140 m high Canelles Dam was the tallest ever built in Spain. The variable horizontal and vertical curvature on this arch dam is the result of the successive scale-model structural analyses conducted by Eduardo Torroja to optimise its structural form. Construction was completed in 1964, three years after Torroja's death.

'Seventeen reduced models were made before the final design was reached. The result of the tests on one model determined the modifications to be introduced in the next, the altered form of which was again subjected to experimental investigation. The investigation was regarded as complete when a dam shape was developed with a maximum compressive stress of 700 psi and negligible tensile stress on the upstream face.'

Eduardo Torroja, 1958



Scale-model testing

1953 / 1964
Canelles Dam.
Lérida, Spain

HALL – S3

The third and last permanent exhibition hall in the Eduardo Torroja Museum is devoted to what is now known as the Eduardo Torroja Institute for Construction Science, a National Research Council body.

It covers the construction of its new and revolutionary headquarters (1949-1953) and its research, dissemination and educational activities, headed by Eduardo Torroja during the golden age of Modernism. The institute was the venue where the International Association for Shell Structures, IASS (1959), as well as many other national and international organisations, were founded.

‘Others will judge our work better than I.’

Eduardo Torroja, 1961 *(extract from a letter to his colleagues)*

Works displayed: the construction of the institute’s new and present headquarters, its unique elements, as well as its publications; the experimental shells built by Torroja in 1959; and the ‘ribs’ built in 1969 in Eduardo Torroja’s honour as a tribute to concrete and steel.

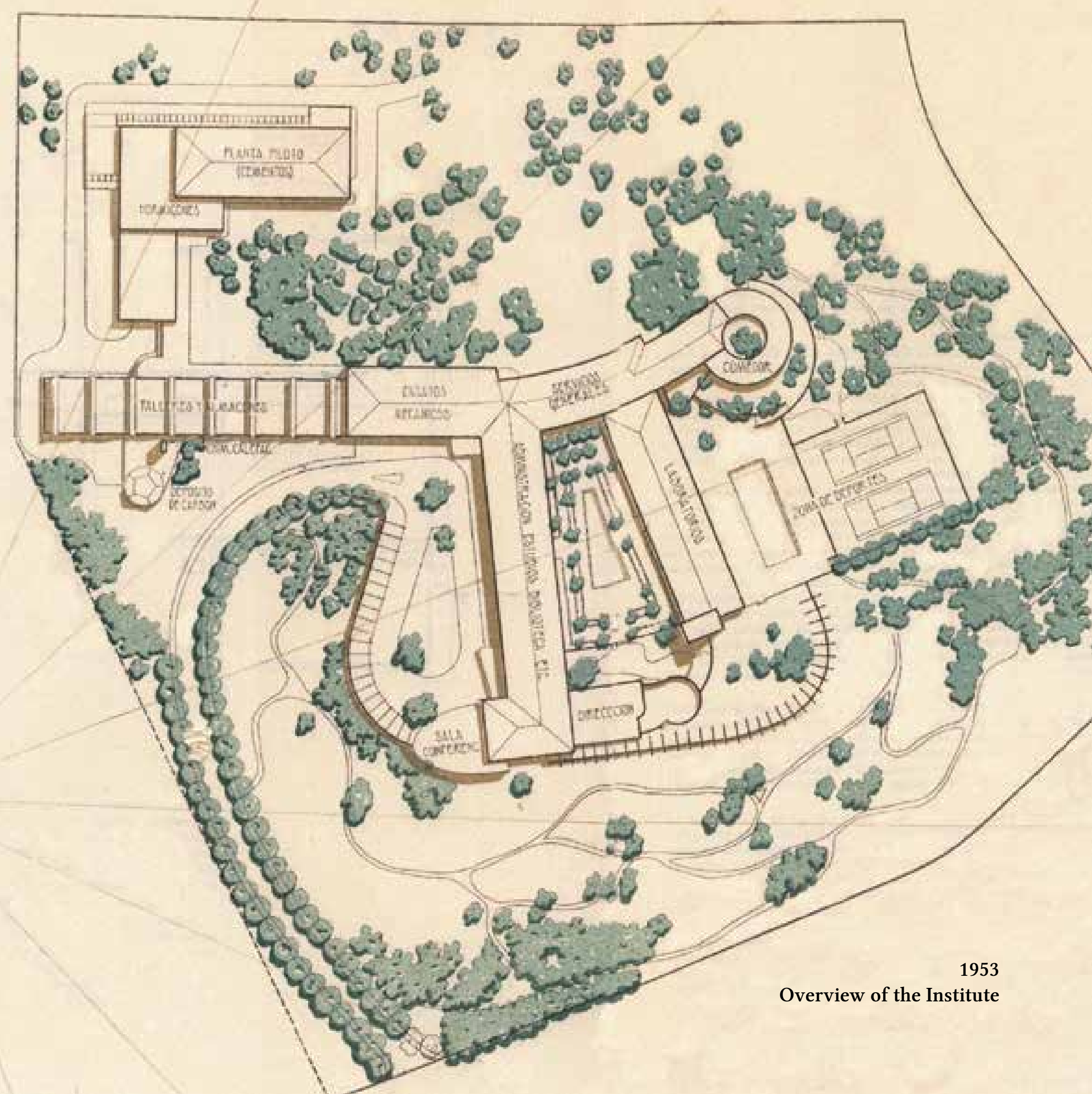
Eduardo Torroja Institute for Construction Science

Engineer: Eduardo Torroja Miret
Architects: Gonzalo Echegaray Corriba and Manuel Barbero Rebolledo
Developer: Eduardo Torroja Miret
Construction Company: Agromán, S.A.
Dates: 1949-1953
Location: Madrid, Spain

The Eduardo Torroja Institute for Construction Science (IETcc), founded in 1934 under the name Technical Institute for Construction and Building (ITCE) and later denominated Institute for Construction and Cement Engineering, is indisputably Eduardo Torroja's most significant and highly valued legacy. To it he devoted a considerable portion of his career (1934-1961), heading it until the very day of his death. His philosophy and approach to its management helped make it one of the world's most prominent research institutions throughout the golden years of Modernism.

In 1949 Eduardo Torroja started to design the institute's new headquarters. It was a revolutionary habitat for research. The architectural design of its main building consists in eight interconnected one- or two-storey wings. The ground plan of the eight-wing building resembles a comb with uneven teeth adapted to the terrain. It intentionally adopts the form of the Greek letter 'phi', generating five open landscaped courtyards that wrap around the long façades.

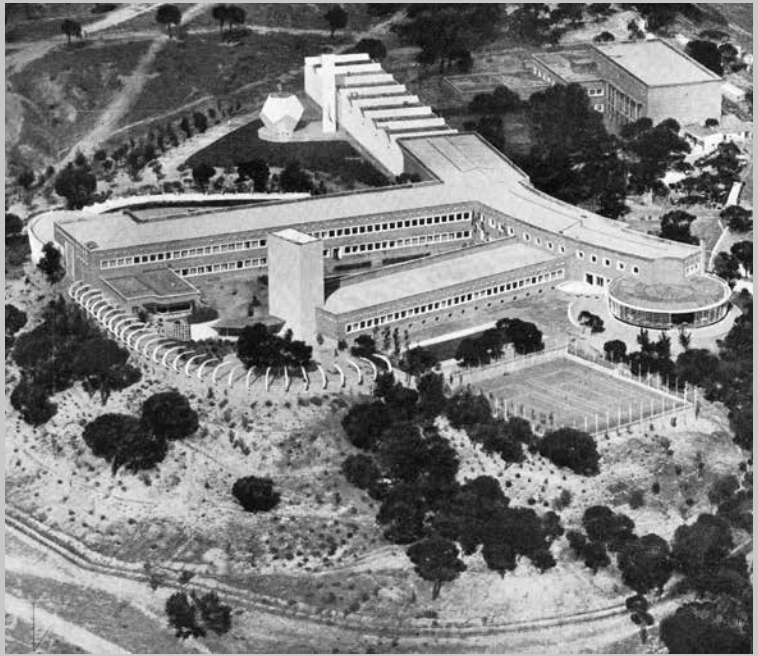
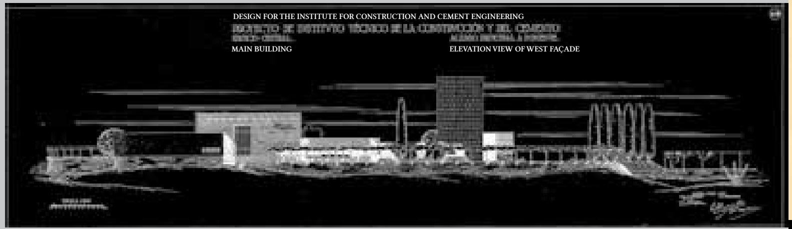
Torroja seized the opportunity afforded by the construction of the new headquarters to implement the institute's research findings on the rationalisation of traditional construction, prefabrication and precasting. He turned the construction site into a huge laboratory, a 'prefabrication school' purporting to enhance the precarious resources available in Spain at the time. The innovative structures and architectural spaces in the institute's new headquarters were the fruit of Torroja's creativity: the circular dining hall, the dodecahedral coal storage, the triangulated thin shell roof over the workshop and testing bays, and the peripheral pergola. Significantly, he selected all these structures from among his oeuvre for inclusion in the book entitled *The Structures of Eduardo Torroja; an Autobiography of an Engineering Accomplishment*, published in 1958 by F.W. Dodge Corporation, New York.



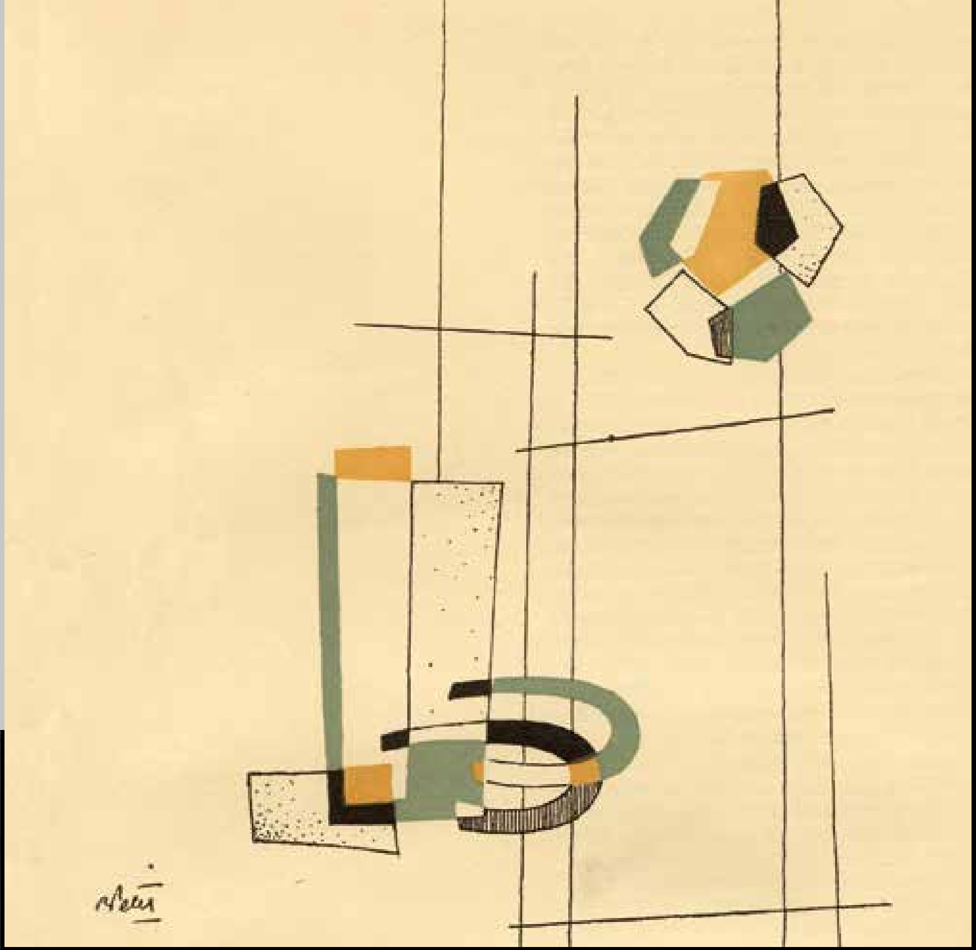
1953
Overview of the Institute





1953
Institute for Construction and Cement Engineering, new headquarters



1955
Bernard Petit - 'The institute's Dodecahedron'

The Institute: Unique Elements

Engineer: Eduardo Torroja Miret
Developer: Eduardo Torroja Miret
Construction company: Agromán, S.A.
Dates: 1949-1953
Location: Madrid, Spain

The institute's dining hall is an architecturally appealing and unquestionably attractive space, with a curved glazed skin that blends into the adjacent, pine tree-flanked grounds. It has a circular ground plan 22.44 m in diameter and a clear height of 3.50 m. Its curved stone-cladded reinforced concrete side walls are separated by a huge sliding glass door/window with a 180° curvature. When open, the door disappears between the two wythes of the walls, enlarging the dining hall to include the landscaped surrounds. Variable depth (0.84 m to 0.22 m), radially arranged cantilevered steel trusses form the roof structure. The reinforced concrete columns in the dining hall on which they rest skirt a circular indoor plant bed.

The institute's workshops feature a triangulated thin shell roof over a 15.00 m x 87.70 m rectangular floor plan. Each of its nine cylindrical vaults, set at right angles to one another, spans 10.00 m. The roof was built with small (I-80) steel shapes arranged in a welded-joint lattice in which all the triangles are equilateral and of the same size. The resulting triangulated thin shell vaults were light enough to be assembled on the ground and hoisted to their 7 m high final position.

' ......while reinforced concrete shells have often been used to build this type of roofs, here, for reasons of economy, we opted for a very lightweight triangulated lattice adapted to the cylindrical roof.'

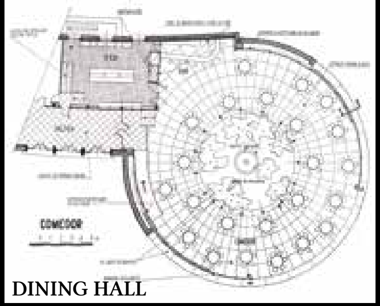
Eduardo Torroja, 1958

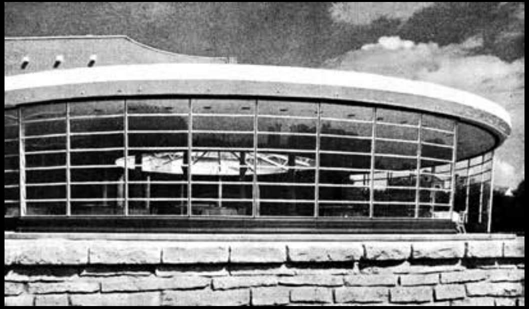
The pergola sited on the west edge of the garden comprises an interrupted sequence of reinforced concrete ribs forming a lemniscate of Bernoulli. Their zero end curvature represents the mathematical symbol for infinity. Here also, Torroja chose a geometric shape laden with significance, in this case to mark the institute's boundary. Each rib is a curved cantilevered beam springing from the reinforced concrete wall that retains the adjacent soil. The ribs are crowned by a steel mesh cover consisting of smooth steel rods and vaguely reminiscent of a hyperbolic paraboloid.
The dodecahedron was designed as a coal storage. This completely regular, unengaged sculptural structure that stands just outside the main entrance soon became an IETcc icon.

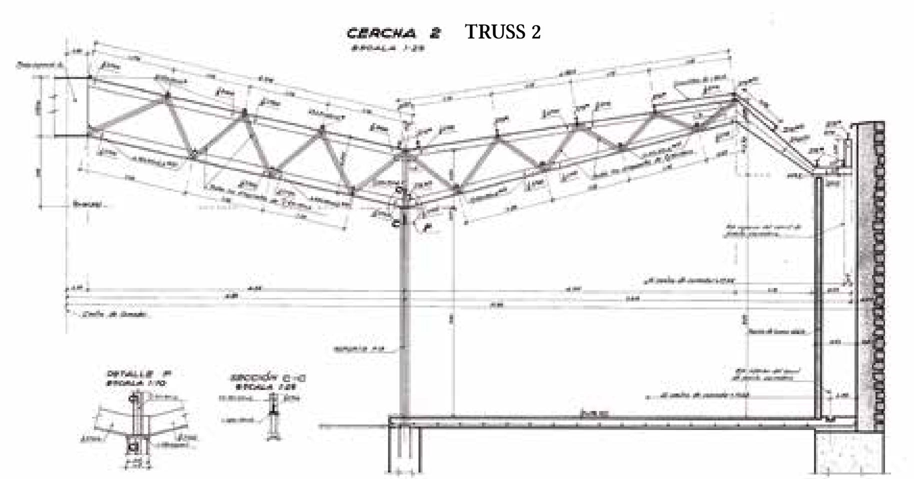
This 8.60 m high thin shell with 22 cm thick reinforced concrete walls looks like it was folded into place. Torroja acknowledged that while the sphere is the geometric form with the highest volume-to-surface ratio, he explained that the dodecahedron, which encloses only a slightly smaller volume, is easier and less expensive to build and given the size of the storage, its geometry is aesthetically pleasing. One of the platonic polyhedra, it is attributed high spatial honours, generated as it is to the 'golden ratio'. One year after the dodecahedron was built in 1954, reputed architect Richard Buckminster Fuller was awarded a patent for his famous geodesic (icosahedral and dodecahedral) domes. Fuller stressed the ease with which these figures could be built, although in his case the surfaces consisted not of planes but of bars.

'...in these polyhedral objects, the light and shadows adapt exactly to the arris drawn by the designer, highlighting their sharp outlines.'

Eduardo Torroja, 1959

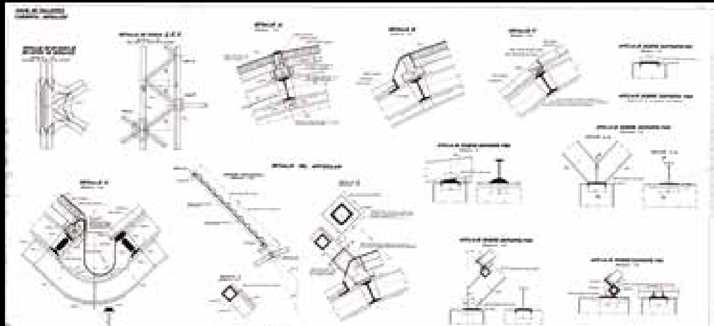


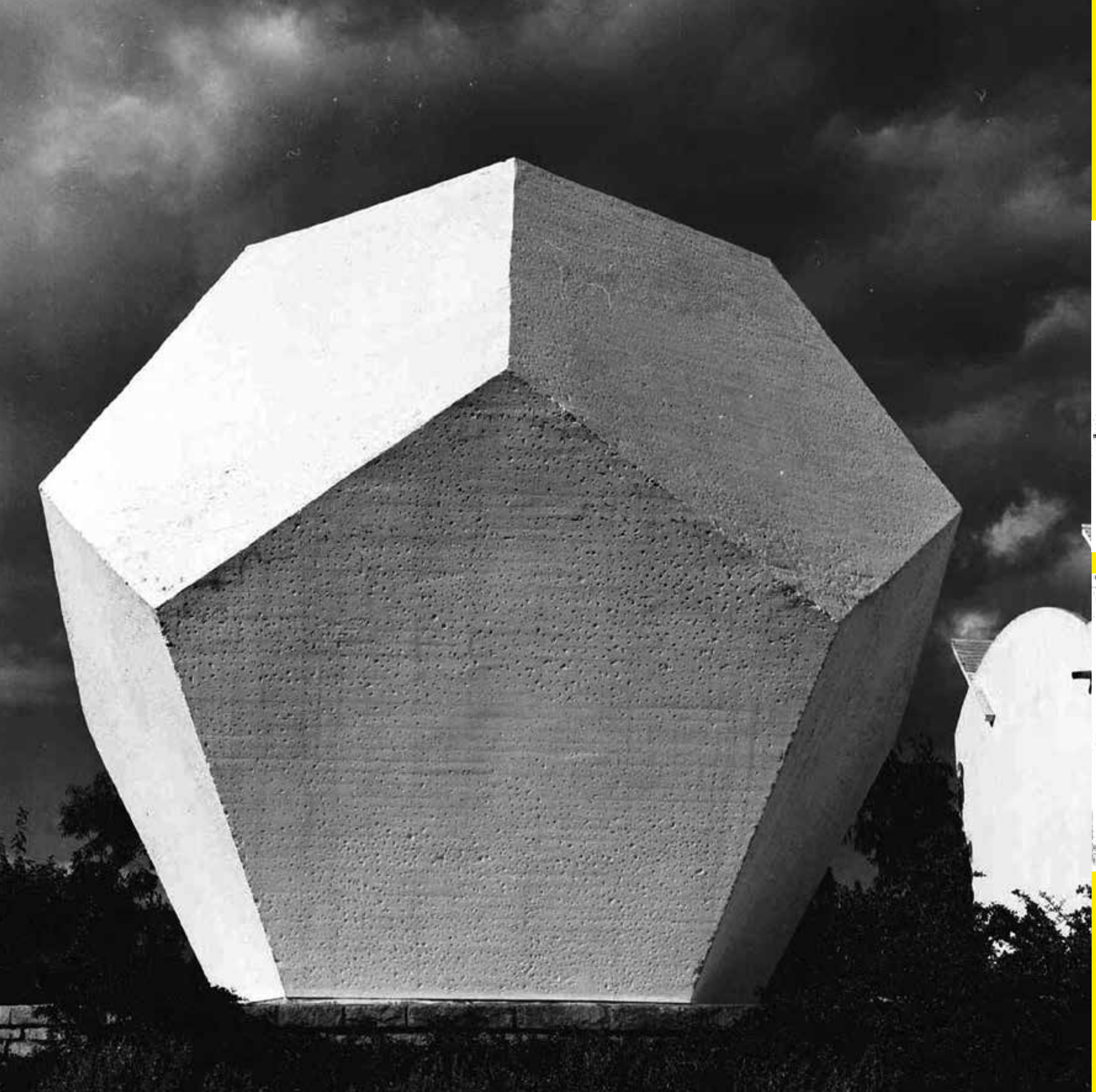


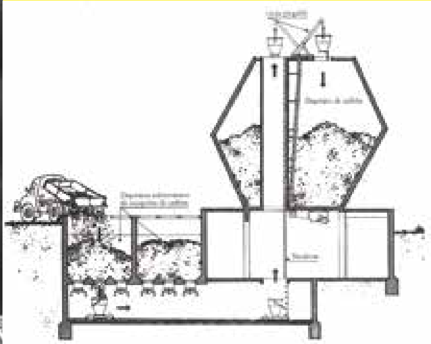


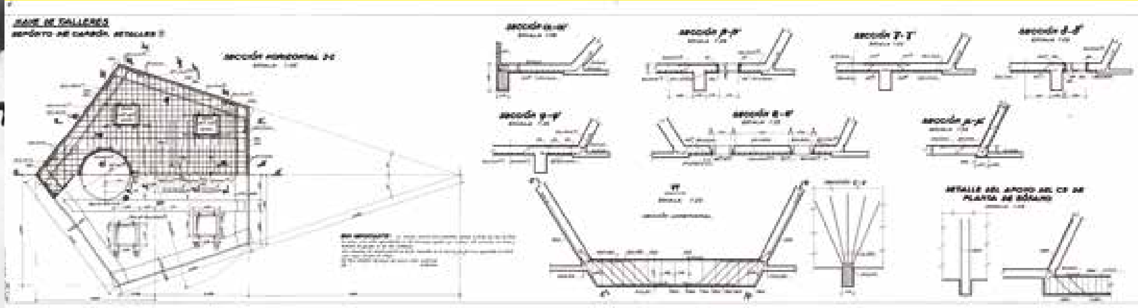
Dining hall, ground plan and truss drawing

1953
Workshop and testing bays;
design drawings









1953
Dodecahedron/coal storage; design drawings and building process

1955
Eduardo Torroja with participants in a specialised course delivered at the Institute for Construction and Cement Engineering

IASS

Eduardo Torroja's legacy is not confined to his innovative designs and works, contributions to structural engineering, use of scale models to verify structural feasibility or solutions that drove the development of reinforced and prestressed concrete. He was also a gifted organiser and natural leader. In his lifetime he founded a number of national and international associations which, like the IASS (1959), continue to spur progress in civil and architectural construction.

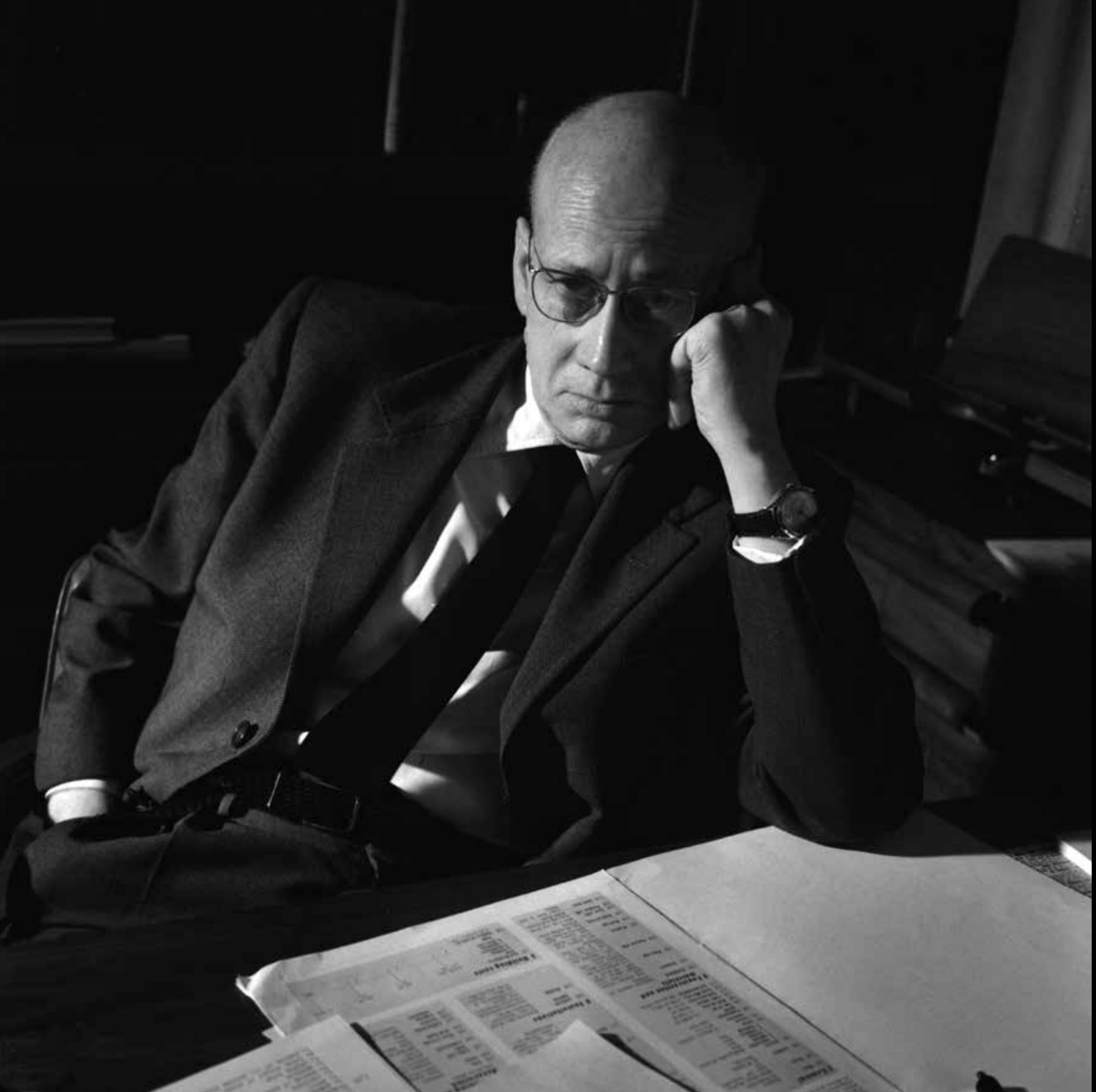
In September 1959 the Institute hosted the "International Colloquium on Non-traditional Processes for Thin Shell Construction". The outcome of that meeting was the decision, further to a proposal sponsored by Eduardo Torroja, to found the International Association for Shell Structures (IASS). The meeting was organised by Torroja himself, with the collaboration of Spain's Central Materials Testing Laboratory, which he also headed. The specialists participating in the colloquium, more than 100 in all, haled from over a dozen countries: Argentina, Belgium, Brazil, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Poland, Portugal, Spain, Sri Lanka, Sweden, Switzerland, United Kingdom and Uruguay. Some of the most prominent designers and builders of thin concrete shells chaired the working sessions and/or read unpublished papers on their works. A. Paduart, W. Zerna, K.W Johansen, H. Rüle, F. Müller, R.S. Jenkins, W. Poniz, A. L. Parme, E. Giangreco, A.M. Hass, M. Hahn, N. Esquillan, Y. Tsuboi, O. Arup and H. Isler, among many others, were present.

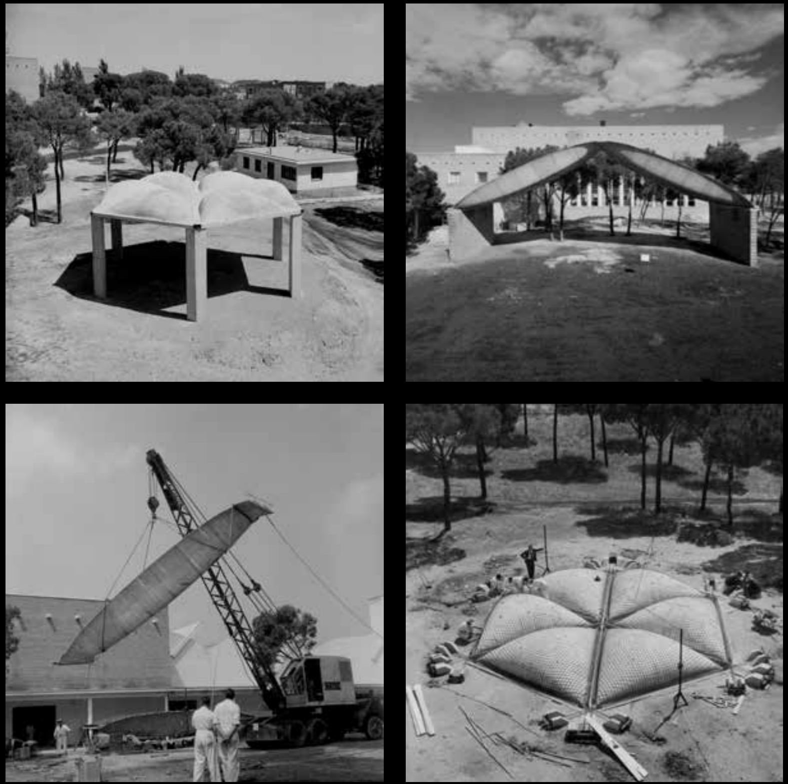
Eduardo Torroja had, in fact, been preparing the colloquium since 1958, for he realised that the time had come to create an international association on thin concrete shells. He thought that as a tribute to the participants, the institute should build two full-scale experimental models on its grounds, and specifically in its 'Master Builders' Courtyard'. These were the last two thin shells to be designed and built by Eduardo Torroja. On 16 September 1959, during the IASS's founding colloquium, Torroja held a reception for the participants in the courtyard to show them these experimental shells. One, known as 'The Whales', was a thin shell roof 3 cm thick consisting in 10 precast double curvature members joined by prestressed concrete and forming a modular shell 10.25 m long and 1.85 m wide. This basic module was attached to an identical member by a tie beam on the underside. The result was a slanted roof resting on two walls, one at each end. The transverse geometry of the precast members was a sinusoid, while longitudinally they consisted in two intersecting elliptical arches. The final shape of the module optimised the distribution of forces.

The other experimental structure built by Eduardo Torroja, designed in conjunction with his son José Antonio Torroja Cavanillas, consisted in triangular moduli 4 cm thick. Positioned on supports arranged hexagonally, this structure was to roof an underground water tank and designed to bear loads on the order of 20 kN/m^2 exerted by the overlying earth. All six modules were cast simultaneously on the ground, separated by joints, and subsequently raised and set onto the supports.

Pepa Cassinello
Curator

IASS
Eduardo Torroja Medal





1959
Experimental structures, ‘Master Builders’ Courtyard’

Thin Shell Rib

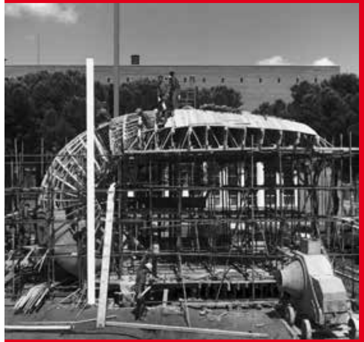
Monument to Concrete and Steel

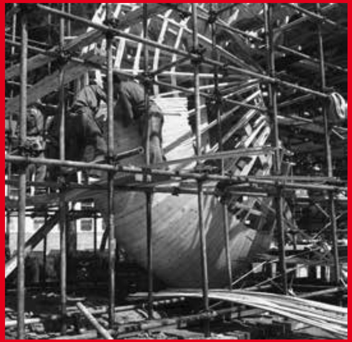
Architect: Fernando Cassinello Pérez
Engineers: José Antonio Torroja Cavanillas (structure)
Francisco Morán Cabré (geometry)
Rafael Fernández Sánchez (construction)
Developer: Instituto Eduardo Torroja for Construction Science
Date: 1969
Location: Eduardo Torroja Institute for Construction Science, Madrid, Spain

On the occasion of the International Association for Shell Structures (IASS) congress held in Madrid in 1969, a monument to concrete and steel was built at the Eduardo Torroja Institute. It was set in the same ‘Master Builders’ Courtyard’ where Eduardo Torroja had built experimental shell structures to welcome the participants at the international congress that created the IASS in 1959.

Likewise in 1969, the IASS decided to expand its remit to include new spatial structures built with other materials. While retaining its acronym, it changed its name to the International Association for Shell and Spatial Structures. Reinforced concrete thin shells had ceased to be cost-effective. Although their raison d’être had disappeared in the new social, economic and technological context, prominent works continued to be erected in several countries, authored by the last of the technique’s champions. For all those reasons, the monument in question was designed as a thin shell covering an open space suitable for use as a chapel or commemorative events.

The structural form, a thin shell ‘rib’ measuring 40 cm thick at the base and from 6 cm to 10 cm in the cantilevered roof, was reminiscent of the pergola that runs along the west edge of the institute’s grounds.





1969
Thin Shell Rib, Monument to Concrete and Steel after completion and during construction in ‘Master Builders’ Courtyard’

While many of my works are not included here, I believe that the ones that are exemplify what I was seeking and ultimately found.

Eduardo Torroja, 1958

The Structures of Eduardo Torroja: an Autobiography of an Engineering Accomplishment

Production

Fundación Eduardo Torroja

Premises

Hipódromo de la Zarzuela S.A

Sponsorship

Ministry of Public Works / Directorate General of Architecture and CEDEX

Fundación ACS

Ferrovial agroman

Fundación Banco Caminos

Collaboration

Universidad Politécnica de Madrid

Fundación Juanelo Turriano

SIKA, España

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First of all, I wish to thank Fundación Eduardo Torroja for this fantastic and rewarding commission to curate the Eduardo Torroja Museum and edit its catalogue, an abridged version of which has been published in five languages to broaden the international dissemination of Torroja's oeuvre.

Our gratitude, the Foundation's gratitude, goes not only to the institutions, bodies and organisations that have helped bring the museum and its catalogue to life, but also and very specifically and especially to the people who have shared our enthusiasm for this project. Thanks to Faina Zurita, President of La Zarzuela Racecourse, for promoting the agreement with the Foundation to grant space in the racecourse facility to house the museum. Thanks to Antonio García Ferrer, Vice-president of Fundación ACS, who from the outset put his zeal behind the institution of the Eduardo Torroja Museum and largely arranged for its funding. Thanks to the Ministry of Public Works' Deputy General Directorate of Architecture and Centre for Public Works Studies and Experimentation (CEDEX), which have not only lent their documents and scale models for display in the museum, but have also shouldered part of the work and the worries and shared the zest: Deputy Director General of Architecture Javier Martín, Chief Dissemination Officer Eduardo Aragoneses and Sara León. Thanks to Director General of CEDEX Ángel González, as well as Dolores Romero and Javier Plasencia. Thanks to the Eduardo Torroja Institute for Construction Science for its cooperation and the loan of part of its archives, and very particularly to Virtudes Azorín, Angela Sorlí, Rogelio Sánchez, Antonio Blázquez and Maribel Sánchez Rojas. Thanks to Fundación Juanelo Turriano, its President Victoriano Muñoz Cava and its Director Bernardo Revuelta, for funding the scale model for the Algeciras Market Hall, one of Eduardo Torroja's most emblematic works.

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Pepa Cassinello
Director, Fundación Eduardo Torroja

What is more valuable, a kilo of stone or a kilo of gold? Adolf Loos poses that question at the beginning of his famous essay on building materials. The answer is simple. If the kilo of stone forms part of the Egyptian pyramids, the Abu-Simbel Temple, Rome's Pantheon or Seville Cathedral, it is indisputably worth more than a kilo of gold.

Exercising the freedom won by its cognitive understanding of the surrounding world, humanity can expand the bounds of the matter that embodies an idea to vest it with inestimable value. The foregoing is indisputably applicable to any material.

If Loos's question were formulated in terms of concrete rather than of stone, the reply would certainly need to refer to Eduardo Torroja's works, many of which are among the most valuable reinforced and prestressed concrete structures in the history of civil engineering and architecture. The same could be said, of course, albeit to a lesser extent, about brick masonry, steel or composite structures, for Eduardo Torroja was an atypical historic figure in Modernist structural art.

Pepa Cassinello
Curator
Director, Fundación Eduardo Torroja

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