
Transportation of the 128.65m-long central section of La Concordia Bridge took place in April

# READY TO FLY

A newly installed arch bridge to the west of Madrid-Barajas Airport in Spain features an unusual four-layered diagrid mesh structure that was inspired by aeronautical design. Francisco Millanes Mato, Miguel Ortega Cornejo and Jesus Martín Suarez explain the details

La Concordia arch bridge is the winning design solution of a tender promoted by the Junta de Compensación Parque de Valdebebas for the provision of a singular bridge that would improve access between Madrid Airport's Terminal 4 and a new urban development. The new crossing carries two lanes of traffic in each direction and two pedestrian/cycle paths, extending José Antonio Fernandez Ordóñez Street over the M-12 highway.

Together with the architects Francisco Domouso, Lorenzo Fernández-Ordóñez and Emilio Rodríguez, Ideam proposed the solution that was finally developed in the detailed design. Ideam undertook the role of construction management with Ferrovial as the constructor.

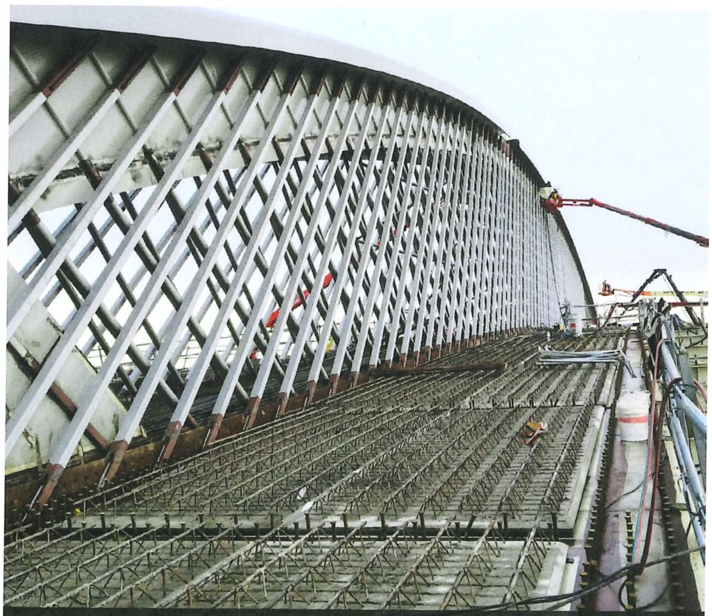
The tender specifications included very stringent clearance conditions both below the bridge (highway traffic) and above it (aeronautical clearance), in addition to the approx. 160m-long span. These restrictions led us to consider a through arch bridge as the best possible solution.

La Concordia Bridge features a very peculiar design whose shape stems from an inverted T variable section, a typology usually associated with the shallow bowstring arch. This structural configuration allowed the desired length of 162m to be spanned without the transfer of horizontal forces to the foundations.

The most relevant and singular feature of the structural design consists of the double 'diagrid' - or permeable structural mesh - from which the deck hangs and which, as a plane of great stiffness, materialises as a latticed web of a haunch beam, that is to say, the bowstring arch itself. The diagrid was designed as a double plane at each side of the structure's symmetry plane, constituting a four-layered mesh. The structure's novelty and its formal and aesthetic singularity was inspired by designs from the aeronautical industry. This was further enhanced by the choice of metal grey paint matching the roof cladding of the neighbouring T-4 Airport Terminal, as well as by the use of ornamental lighting within the diagrid, which generates a suggestive and subtle interplay of dim lights and shadows.

The whole deck is suspended from the arch with a rise of 10.3m and a span of 124m (considering only the arch above the deck), yielding a 1/12 rise/span ratio - that is, a shallow arch. The arch cross section is almost rectangular, with two ledges jutting out at the top, where the 'diagrid' planes are attached. The arch has a constant depth of 1.5m and variable width ranging from 4m at the springing to 2m at the crown. It is made of S-355-J2+N steel that is connected to the interior concrete, creating a composite steel/concrete cross section. The arch follows a circular line of 150m in radius and continues at a tangent below the deck. The lower part becomes wider and remains linked to the deck, creating a massive triangular spandrel of striking visual impact.

The deck consists of a multicellular S-355-J2+N steel hollow box girder 3m deep at its centre line, on top of which rests a 0.25m-thick layer of concrete. The deck's bottom follows a circular curve, 30m in radius,



View of the diagrid during construction

which continues at a tangent up to the abutments. The deck's cross section comprises five cells by means of four webs. In order to easily handle the section's elements and to attach the diagrid to the inner webs, the latter have the same inclination as the diagrid planes.

Transverse trusses are located within the section and every 5m, so that torsional effects derived from eccentric actions can be transferred to the diagrid, which acts as a plane of inclined hangers and diverts the loads along the arch. Torsional moment, quite important owing to the bridge's width, is withstood in the intermediate 124m thanks to the high torsional stiffness of the deck's composite section.

The deck is linked to the arch by means of a mesh or lattice of S-355-J2H steel tubes - the diagrid. Its structural mission is to transfer the vertical loads acting on the deck to the arch. Therefore, it basically responds under tension. Each diagrid mesh consists of two co-planar, mutually perpendicular families of tubular profiles arranged at angles of 45º with respect to the horizontal plane. There are two diagrid planes at each side of the arch, one in each direction.

The diagrid's stiffness within its own plane suppresses any in-plane arch instability. Likewise, the two diagrid planes at each side of the arch are braced together by means of trusses to prevent wind-induced vibrations. These trusses are parallel to the direction of the diagrid tubes, thus preventing disruption to the visual and inner lighting effects.

The bridge is in equilibrium at its end by a concrete counterweight placed across the deck's width.

The acting forces are; the deck's tension; the counterweight's vertical force; and the compression along the concrete strut which links the counterweight to the arch's support section.

In order to facilitate transmission of stresses, the deck's final metres, hidden within the abutments, were designed in prestressed concrete in such a way that the steel deck - where the prestressing cables are connected - transfers its tension adequately. The deck's upward lift is withstood with a buffer and six spherical bearings.

The longitudinal structural scheme can be interpreted in either of two different ways, both of which describe the same structural concept.

Firstly, the 156m-long apparent span, equivalent to 162m between the abutments' hidden supports, is dealt with by means of a 124m-long bowstring steel arch with a composite deck, or tie beam. The inclined suspension hangers (network type bowstring arch) are replaced by a quadruple diagrid mesh arranged on two planes with conventional rectangular hollow sections at angles of 45º that create a stiff suspension plane, preventing in-plane arch buckling.

The bow-string's vertical reactions act at the end of the spandrels, 19m from the support lines. The reaction can be projected in two directions: a compression strut along the spandrel's lower face (bottom compression head) and a horizontal tension force withstood by the steel upper box girder. This scheme is self-balanced in a traditional triangular cell arrangement: the upper tension force goes on by means of a 25m-long prestressed concrete tie anchored at the end of the composite deck, and hidden within the abutments. This force can be split into two: an upward vertical force compensated by the counterweight anchored at the end of the abutment, and an inclined compressed concrete strut which, heading to the main span support, closes the cell transmitting the vertical resultant force to a deep foundation.

Alternatively, the structural scheme can be explained as a 162m-long doubly embedded span. The positive bending area stretches 124m and is withstood by a variable depth beam with a latticed web (diagrid). The arch acts as the compression chord and the deck as the tension tie. In the negative bending areas, 19m long, next to the supports, the composite deck carries the upper tension and the spandrel, with double composite action, the lower compression. The bending moment, through the triangular cell scheme, is provided by a short hidden compensation span, whose extreme negative reaction is balanced by a counterweight.

The arch bridge has a 1/12 rise/span ratio *(render)*

To optimise the structure's behaviour during the erection process, once the bridge is continuous and before placing the dead loads, jacks are applied to readjust the reactions. By doing so, the position of the zero-moment point of the three-span beam can be controlled, taking it to the intersection of the arch and the deck (approximately) and reducing bending in the structure's weakest sections. A time-dependent analysis was made to obtain the long-term force and reaction redistribution.

As regards construction, the approx. 2,400t-heavy central segment of La Concordia Bridge - 128.65m long and 24.5m wide - was assembled in a lateral zone adjacent to one of the abutments parallel to the M-12 highway. When the steel structure of the central section had been completed, the whole section was rotated and transported in a single operation that took place in April this year. Two Mammoet self-propelled modular transporters moved the structure to its final position perpendicular to the M-12 at a height of 15m to allow the bridge to cross over the highway's intermediate embankment. This complex operation took four days to complete, working day and night [a video showing the operation is available on bridgeweb.com].

Among the steps remaining ahead of the planned opening in September/October is the placement of precast panels on the reinforced concrete deck, which is currently being poured

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**Client:** Junta de Compensación Parque de Valdebebas
**Construction:** Ferrovial
**Detailed engineering and project management:** Ideam
**Architects:** Francisco Domouso, Lorenzo Fernández-Ordóñez, Emilio Rodríguez
**Fabricator:** Dizmar