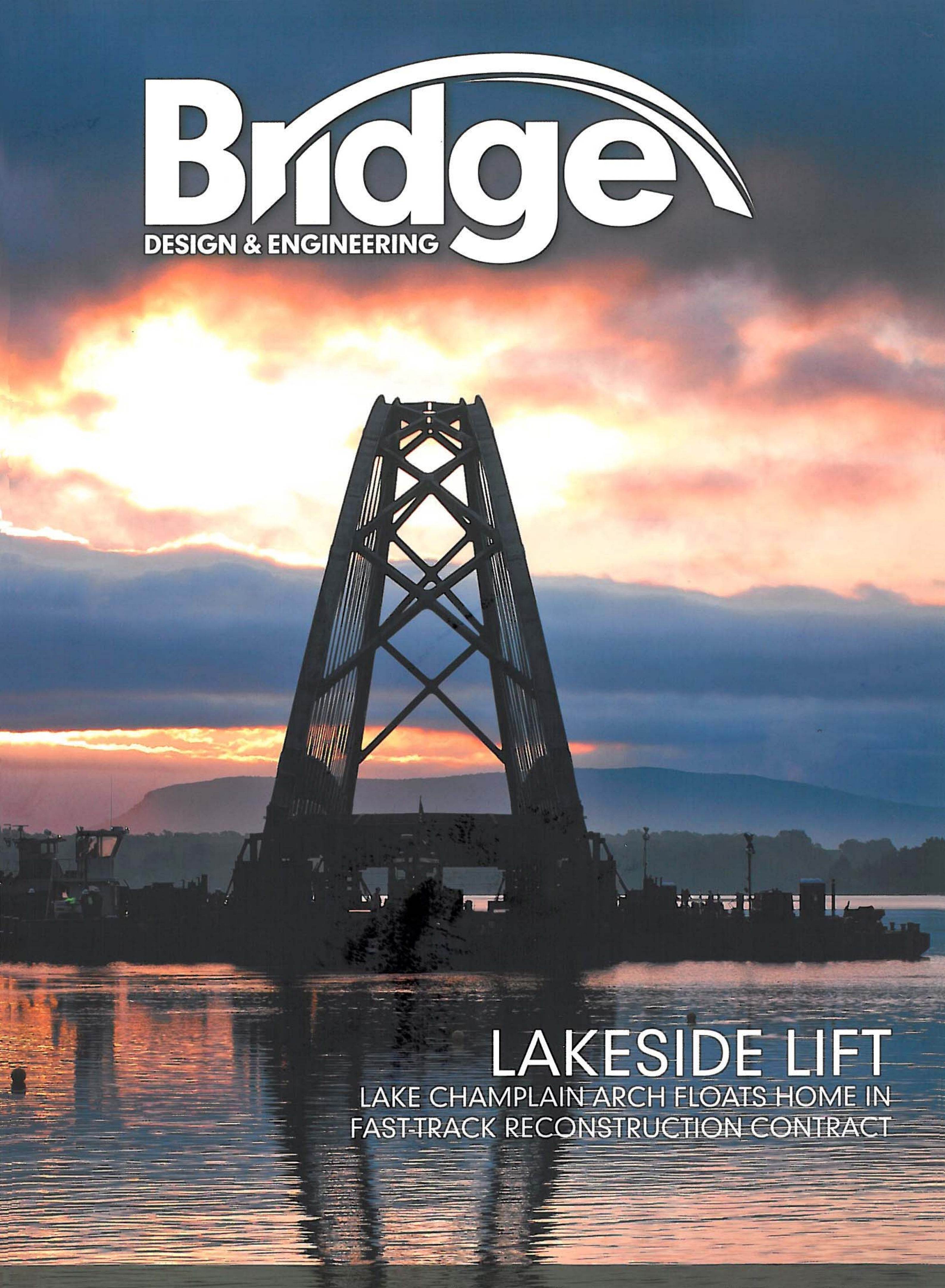
Bridge
DESIGN & ENGINEERING



LAKESIDE LIFT
LAKE CHAMPLAIN ARCH FLOATS HOME IN FAST-TRACK RECONSTRUCTION CONTRACT

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The Buenavista Footbridge has a span of 99m and a width of 4m.

DOUBLE DEAL

The city of Toledo in central Spain has recently seen construction of two new cable-stayed footbridges. **Ramón Sánchez de León** describes the design and construction of these singular structures.

Urban expansion in the Spanish city of Toledo has resulted in the boundaries of the city overspilling its ring road during the last few years. The need to establish safe routes for pedestrians who have to travel between the old and the new parts of the city has led to the completion of two new footbridges this year.

The Buenavista Footbridge, which was completed in April, provides a connection from a new residential area across the highway to the other parts of the city. Meanwhile the Santa Maria Footbridge, which was opened in August, creates a link between a residential area and an industrial zone; the bridge crosses one of the city's busiest highways and hence the city authorities wanted the bridge to establish a new landmark for the route. Aesthetics was crucial in the design of both structures, as the city is a World Heritage site.

Both structures are cable-stayed bridges; the Buenavista Footbridge has a span of 99m and a width of 4m, while the Santa Maria Footbridge is much longer, at 170m total span, but narrower with a width of just 3.2m.

The main span of the Buenavista Footbridge is supported by eight pairs of cables that are anchored every 6m, transferring the forces through the stays to the single tower, which has two inclined legs. Above the point at which these two legs meet, the cables are anchored into the vertical tower head, which brings the tower up to 43m height above ground level. The tower is stabilised by the use of six pairs of back-span stays, which consist of steel bars, and which are anchored to a mass concrete element in the abutment.

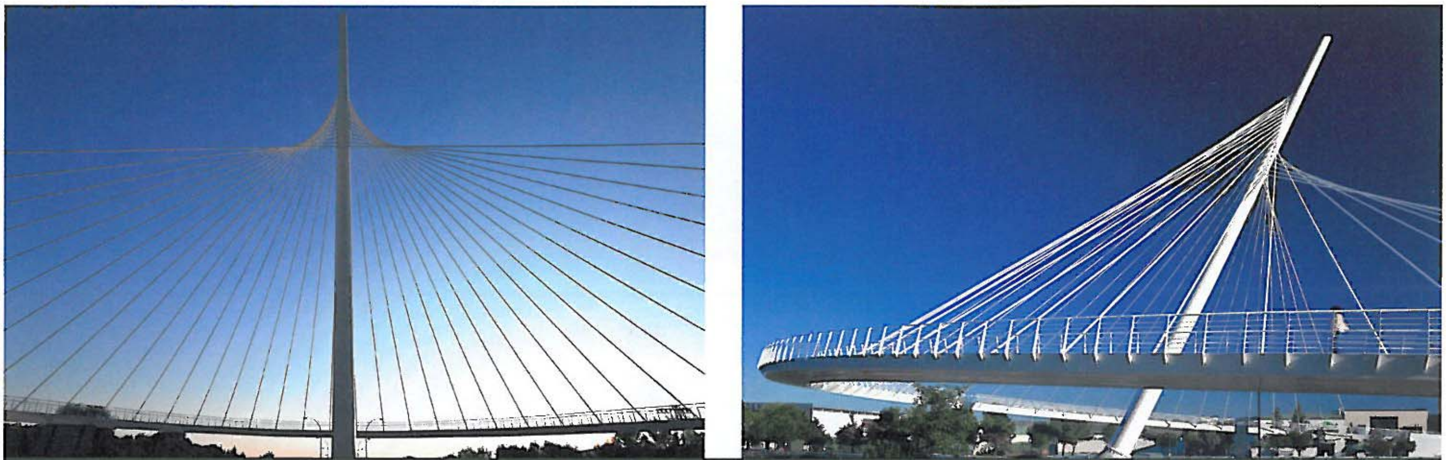
The tower and the deck are entirely formed of S-355 steel. The deck is a steel box cross-section formed of 10mm thickness over almost the entire length of the span. Meanwhile the tower is a steel box section formed of a range of thicknesses, up to a maximum of 35mm. Tower and deck are joined by two inclined beams, which ensure that only vertical forces are transmitted to the foundations. These specially-designed beams connect to the abutment, where the tower legs and deck are fixed. At the other abutment, the deck is filled with concrete to increase its weight and to eliminate uplift at the supports. Inside the deck there are diaphragms at 3m centres along the span, and the tower has internal diaphragms at 5m centres.

Because the steel used in the deck and tower panels is very thin, several stiffeners had to be designed to increase the section capacity in the deck and tower. In order to anchor the stays in the deck, special 50mm-thick steel elements were designed for installation on both sides of the deck.

The stays are made of steel bars of diameters ranging from 30mm to 42mm with an ultimate strength of 700MPa and a yield strength of 540MPa. The maximum tension in the stays is less than half of the ultimate strength. Each steel bar is galvanised and is enclosed in a white HDPE pipe in order to improve the aesthetics of the bridge.

The abutment foundations are formed of white reinforced concrete; they are relatively superficial due to the fact that the forces imposed on them are not very high. The tower absorbs high vertical forces, hence it was necessary to install 12, 220m-diameter piles under each tower leg. These piles are each 12m long, and are concrete-filled steel tubes. Reinforced concrete pile caps of 5.5m by 4m cross-section, and 1.5m depth, were built over the top of the piles. These pile caps were then connected by a concrete beam of 1m by 0.6m cross-section, which absorbs the horizontal component of the forces that come through the tower.

Corrosion protection of the steel elements is achieved by several layers of paint; all of the structure is painted white except for the tower head, which is painted red. ▶



The Santa Maria Footbridge has a single, inclined steel tower and the curved deck is supported by cables along the inner edge.

Moreover, the footbridge is illuminated at night. Several finite element models were developed to assist engineers predict the behaviour of the structure, using linear and non linear analysis. The construction of the footbridge took about six months, during which traffic was maintained on the highway below.

Once the piles had been installed, the pile-caps and abutments were built. The steel deck and tower were factory-fabricated and transported to the site in several pieces, at which point they were installed and joined on site, using provisional supports.

All the stays were installed with a minimum force to reduce the catenary form, after which the force in the stays was increased in a particular order based on a specially developed programme.

During this process, the provisional supports were removed, after which a final adjustment of the stay forces was carried out. Vehicles were used for the load test of the bridge. Total cost of the Buenavista Footbridge was US$1.35 million. The bridge owner is the Toledo Municipality, the design is by Estudio AIA, and construction was carried out by Sogeoso - Estructuras Marcos; cable stays were supplied by DSI.

The second of the new structures, the Santa Maria Footbridge, was opened to the public in August of this year, connecting two districts across a busy dual-carriageway highway in the city. The 170m-long deck is supported by a single, inclined tower, which is located on the central reservation of the road. The deck follows an elliptical geometry in plan, and is supported by 38 cables that are anchored every 4m.

All the stays are anchored along one side of the deck - the inner side of the curve - and transmit the forces to the tower. To accomodate this, it was necessary to design a deck section with a very good torsional behaviour. Estudio AIA designed two additional tie-down stays that connect the deck with the ground, in order to reduce the deflection under asymmetrical loads.

The bridge has a single steel tower which is inclined at 24.6° from the vertical and rises to a height of 40m above ground level. The tower has a conical geometry, with a diameter that varies from 2.1m at the bottom to 840mm at the top.

The tower and the deck are entirely fabricated of S-355 steel, with the deck cross-section made of plates varying in cross-section from 10mm to 35mm. The tower is a steel circular hollow section with various thicknesses up to a maximum of 30mm. As with the Buenavista Footbridge, the relative thinness of the steel on the tower and deck made it necessary to design stiffeners in order to increase the section capacity.

The steel bar stays have diameters ranging from 27mm to 52mm with an ultimate strength of 700MPa and a yield strength of 540MPa. The maximum strength in the stays is under 50% of the ultimate strength. Again, each steel bar is galvanised enclosed in white HDPE pipe for aesthetic reasons.

The abutments must absorb high loadings from the horizontal reaction caused by the deck. The tower transmits high vertical forces, hence it was necessary to install 30, 220mm-diameter concrete-filled steel piles below the tower leg. Piles extend to a depth of 17m, and are topped by a pile cap of 7.5m by 6.5m, and 2.1m deep. The inclinations of the piles differ, depending on their position, and absorb mainly axial forces. A white paint system with several layers is used for corrosion protection.

The US$1.68 million footbridge was built in a similar manner to the Buenavista Footbridge, and by the same design and construction team. Cable stays for this bridge were also supplied by DSI. Again, the highway was kept open to traffic during the majority of the process

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