(Photos: Leonhardt, Andrä & Partner)

Figure 1: The second bridge over the Orinoco River under construction.

Figure 2: View from the south side.

Over the Orinoco

With a total length of 2560km, the Orinoco is the longest river in Venezuela and the third longest in South America. Currently, the river is crossed by only one bridge, which is situated at Ciudad Bolivar, the capital of the state of Bolivar, in a region called Guayana. A new bridge that is currently being built over the Orinoco River in Venezuela will provide a vital second crossing once it opens at the end of 2005.

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The second crossing, which is now under construction, is about 100km downstream from the first and some 300km from the river delta, close to Ciudad Guayana. The project's official name translates as the 'combined transportation system, second bridge over the Orinoco river', and it will connect Bolivar state in the south with the states of Anzoategui and Monagas on the north bank of the river.

The city of Ciudad Guayana is the main centre for processing iron and bauxite for conversion to steel and aluminum. This city is also home to the heavy industries of Corporación Venezolana de Guayana (CVG), and one of the main reasons the crossing has been developed is to allow access for rail, as well as vehicular traffic, in order to transport the corporation's products to a deep-water port that is being built on the northern coastline of Venezuela. This will eliminate the problem faced by docks on the Orinoco River, which have to be dredged regularly to remove huge quantities of sediment.

The existing suspension bridge, which has a main span of 712m, was finished in 1967. Even at that time, the government was already considering developing a second crossing and its study of the economics indicated that such a project would be justified by the 1990s. Consulting engineers, Lustgarten y Asociados Ingenieros Consultores were involved in carrying out several studies that included possible alignments, economical analysis and conceptual engineering for various government agencies over a 30-year period. Eventually, in 1997, CVG selected Lustgarten y Asociados to carry out the preliminary design of the second crossing. Three years later, the Venezuelan government invited Brazilian contractor Construtora Norberto Odebrecht (CNO) to tender for several construction projects, including the second Orinoco River Bridge. The contract was awarded to CNO in 2001, based on the preliminary design drawn up in 1997.

The project

The project that is now under way involves the construction of approximately 4.5km of structures and more than 170km of new roads needed to connect it to the existing highway system. It includes the 3.2km-long Orinoco River Bridge, a 900m-long north access viaduct and several smaller structures. At the site of the bridge, the Orinoco is 3km wide and has flows that range from 66,000m^3/s up to 85,000m^3/s. Two separate navigation channels already exist at this location and these have dictated the positioning of the two main spans of the bridge. A small island is revealed between the two channels during the low water season, which is where the designers chose to locate the pier that acts as the fixed point for the horizontal loads on the main bridge. The river navigation mainly consists of barge convoys used for transporting minerals such as bauxite from the upriver mines to the processing factories at Ciudad Guayana.

Construction challenges

One of the main challenges for the builders of the bridge is the seasonal variation of the water level, which has a range of 12.5m. Another important consideration in the design and construction was the current of up to 2.6m/s. In some areas of the riverbed in the north channel, foundation design had to take into consideration the possibility of scouring up to 28m depths. In the early stages of the project, cable-stayed bridges with two, three and four towers were considered, but the chosen solution was a configuration of two typical cable-stayed bridges back-to-back with a fixed point in the connection. This fixed point is located over the small island separating the channels, which

Figure 3: View from the north side.

Figure 4: Fixed pier section.

enables all braking and longitudinal seismic loads on the main bridge to be transferred economically. The final solution was derived from the 1997 proposal and developed with German consultant Leonhardt, Andrä & Partner.

The bridge consists of two approach structures and the main cable-stayed bridge. The south approach is 1320m long, consisting of 22, 60m-long spans while the north approach of 636m total length has ten 60m-long spans and one of 36m. The main bridge itself is 1200m long and has a total width of 24.7m; it carries two traffic lanes in each direction and a single railway track in the centre. The cable-stayed bridge consists of two main spans, each 300m in length, and a series of 60m side spans. The vertical clearance of the soffit above high water level is 41m, matching that of the existing first river crossing in Ciudad Bolivar.

On the south channel, ground conditions consist of bedrock covered with a thin layer of sediment, and the bedrock level rises to form a small island between the channels. Along the north channel, the bedrock dips to more than 90m under the riverbed and re-emerges near the north abutment, covered by a thick layer of sediment, which carries a risk of major scouring. Most of the deep foundations consist of 2m-diameter piles to transfer the loads down to rock level. The piles were bored using steel tubes through the free length and the sand layer, and then cast in-situ; the steel tubes are permanent and act as the former for pouring the tremie concrete.

A Wirth 1.8m diameter boring machine was used to install the piles. In the north channel, the piles are longer and are designed with a larger diameter to counteract the expected scour. They are up to 83m long and 2.5m in diameter. Some of the approach foundations were built as raft foundations but most of the piers are founded on groups of four, six, eight or nine piles spaced 6.5m apart.

Bridge construction

The towers are founded on groups of 36, 2m or 2.5m-diameter piles, while the fixed-point pier with its double legs is founded on 34, 2m-diameter piles. The top of typical pile caps was placed at elevation +12m, hence they will disappear completely under high water while the tower pile caps, which have elevations of +13m, should be generally visible, even during the highest flood.

Construction of the foundations was a very difficult logistical challenge, considering that 90% of the foundations are under water half of the year; the task was also complicated by the huge variation in water level. Construction by contractor Construtora Norberto Odebrecht involved a lot of aquatic equipment and specialised personnel in order to meet the time schedule. The main bridge has four H-shaped reinforced concrete towers, each about 120m high, rising 74m above the bridge deck. This particular shape was selected for its clear form and ease of construction, and each tower consists of two hollow rectangular columns connected by a lower and upper cross-beam. To make the slipforming of the tower legs easier, the box-section was designed with a constant dimension of 4m in the transverse direction. In the longitudinal direction it decreases linearly from 7.5m at the bottom to 4m at the top. All 38 piers, with heights varying from 15m to more than 42m, have the same cross-section and were built by slipforming. The fixed point pier consists of two inclined hollow rectangular columns 4×8m high, arranged in a delta formation. At the top of both columns is a hollow box measuring $8.35 \times 7.2 \times 13.3$m, where the superstructure is connected monolithically and direct bearing and shear keys transfer all horizontal and

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vertical forces.

The deck is designed as a composite section with a steel box measuring 6 × 5.5m in the centre to support the ballasted rail track. At both sides are cantilevers that carry the roadway; these are spaced at 3m centres. Throughout the suspended length of the bridge, steel edge girders complete the section and the cables are anchored into these girders at 12m distances. A constant 250mm-thick reinforced concrete slab over the cantilevers is the basis for the roadway, while its thickness varies from 300mm to 360mm under the railway. The connection between the concrete slab and the steel elements is achieved by using typical Nelson shear connectors and in areas of concentrated load transfer by Perfobond strips. Provisions have been made to allow an inspection traveller to be attached to the bridge for carrying out routine maintenance.

Two planes of stay cables support the bridge in a fan configuration; the cables are made of parallel seven-wire strands with a 15mm nominal diameter and an ultimate tensile stress of 1770N/mm². The number of strands in each cable varies from 72 for the longest to 42 for the shortest cables near the towers. Most of the cables have typical Freyssinet internal hydraulic dampers. The two longest cables, in total at 16 locations, will receive special Freyssinet internal radial dampers. The cable anchorage at the tower is a steel element, which is incorporated in the concrete structure. The steel box has a system of plates that resist the cable forces and transmit them to the concrete structure via shear connectors. During construction of the upper part of the tower, the box acts as an internal former and has the additional advantage that the geometrically complex anchorage system elements are therefore factory-fabricated in steel. These elements, each of which anchors two pairs of cables, are lifted one by one and placed on top of the previous element. The outside slipforms had to be adapted for this.

Three different methods are being used to build the superstructure of the bridge. The deck for the south and north approaches and the side spans of the main bridge is assembled in construction yards adjacent to the south and north abutments. This process is carried out by assembling the lengths between expansion joints into complete sections, before launching each unit into its final position using greased polytetrafluoroethylene (PTFE) pads as a sliding surface and launching noses at the front and end of the sections. Between the two towers the section that includes the fixed pier is being erected by means of two sets of temporary trusses. These trusses are supported on the north tower, one pier and the central pier, making up two 60m spans. Each 24m prefabricated steel deck element was lifted off the barges by a temporary crane on the north tower. When sufficient elements were welded together, a launching nose was attached and the deck was ready to be launched southwards towards the other tower.

Figure 5: Free cantilever construction in progress.

The main spans are being built by the cantilever method; construction will progress from both north and south sides to final closure at mid-span. Prefabricated steel deck elements with a total length of 24m – two typical 12m deck elements – will be lifted from barges by mobile derricks positioned on the previous element. The new element will be suspended from the derrick and then welded to the cantilever. After the concrete deck has been poured, the cables will be installed and tensioned, strand by strand.

Conclusion

Construction started in the last third of 2001 and is due to be completed in 2006. Launching of the superstructure began in November 2004 on the first 205m-long segment of the main bridge. The 300m-long approach segments of the south and north approach are currently being continuously launched. Free cantilevering construction started in August 2005 on the south side. In a few months' time erection progressing from four cantilevers at the same time is planned. Requirements for protecting the bridge against ship impact are under investigation and the necessary protection structures will be built towards the end of the construction period or after completion. ■

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Owner:	Corporación Venezolana de Guayana
Main contractor:	Construtora Norberto Odebrecht
Steel structure:	Usiminas Mecánicas
Joints, bearings, cables, post-tensioning:	Freyssinet
Consultant for detailed design:	Consorcio Brave (Lustgarten & Asociados for the main bridge; Figueiredo Ferraz for the approach structures)
Consultant and official checking engineer for Consorcio Brave:	Leonhardt, Andrä & Partner, Beratende Ingenieure VBI
Erection engineering for CNO:	Leonhardt, Andrä & Partner, Beratender Ingenieure VBI with engineer on site Ingo Schiele