Making **Connections**

By Jacques Combault

A cable-stayed composite steel and concrete bridge creates a long-needed crossing for Greece's Corinth Strait.

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Buckland & Taylor Ltd., Canada
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Géodynamique & Structure, France
Ingerop, France
Vinci Construction, France

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The Rion-Antirion bridge spanning Greece's Corinth Strait was the culmination of a long-time dream to link Peloponnese, in southern Greece, with the mainland. The bridge reduced travel time across the strait from 45 minutes to less than five. Approximately 10,000 vehicles now cross each day, up from the 7,000 that were ferried across daily before.

This cable-stayed crossing consists of a main bridge, approximately 2,252 m long (7,389′) and 27 m wide (89′), and two approaches of 392 m (1,290′) and 239 m (784′). The design team opted for a composite of steel and concrete. This decision laid the foundation for the rest of the design and served as the starting point for several other innovations.

Foundation Concept

The contracts for the bridge, one of Greece's first design-build-finance-operate-transfer projects, were signed in early 1996. The team was unable to obtain final financing for the $750-million project until late 1997, however. In the interim, the planning team conducted sophisticated parametric studies. These studies were vital because they provided the design team with verifiable data that directed and supported some of their most important design decisions.

Considering the site's potential for seismic activity, less-than-desirable soil conditions, and water depths of up to 65 m (210′), the team's goal in developing a foundation concept began with simply making construction of the bridge feasible. This required ensuring that the soil was strong enough and the structure flexible enough to resist the design earthquake (6.5 to 7.0 on the Richter scale with a 2,500-year return period) and a 2 m (6.6′) displacement of a pylon in any direction with regards to the others without incurring serious damages.

With the luxury of extra time provided by the contract delay, the team was able to verify the viability of an innovative plan to use reinforced soil and a 3 m (10′) layer of gravel to support

The deck is suspended from the stay cables for its full 2.3-kilometer (1.4-mile) length without any support at the pylons.

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the heavy loads generated by the design earthquake.

The parametric studies were performed according to the following steps:

1. The possible failure mechanisms of the reinforced soil were studied using the yield design theory.
2. The results of these studies were controlled by an important centrifuge test program on a 1/100 model made of a sample of in situ soil and a set of small appropriate steel pipes.
3. A finite element analysis was finally conducted in order to check some of the previous results and get the global stiffness of the reinforced soil with regards to the structure.

The results showed that the foundation concept would withstand the high horizontal forces and overturning moments generated at the foundation level during the extreme earthquake. This was determined on the basis of the lower and upper bounds of the soil characteristics.

The results also provided the team with invaluable data that assisted in determining the optimal size, length, and number of steel pipes (inclusions) that were eventually placed beneath the deep water of the strait.

Substructure

The four pylons rest on large concrete substructure foundations, 90 m (300′) in diameter and 65 m (210′) high, which distribute all forces to the soil. These include the horizontal forces that result from the inertia of the structure in relation to the action of the hydrodynamic forces generated by motion in the ground during an earthquake, as well as the overturning moment generated by the horizontal forces and their level arm.

Below this substructure, designers improved the bearing capacity of the soil by adding inclusions, which consist of 20 mm-thick (.79″) steel pipes, approximately 25 to 30 m (82 to 98′) long and 2 m (6.6′) in diameter, driven into the soil at 7 to 8 m (23 to 26′) intervals. The gravel layer acts as a fuse, limit-

Above: The team pushed the central span length as far as it conceivably could—to go further than 560 m (1,837′) would require a steel box girder design for aerodynamic stability.

Below: The bases of the concrete pylons—the rafts—were constructed in dry docks. Two bases were constructed at a time.

Deck elements, 12 m (39') long and including the concrete slab, were prefabricated. They were placed in their final location by a floating crane and bolted to the previously assembled segments using the balanced cantilever erection method.

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ing to acceptable levels the horizontal force and the overturning moment.

The structure is free to slide on the gravel layer, which met the need for flexibility. Associating twin steel girders to a concrete slab for the deck, which is also fully suspended on its entire length, provided further flexibility.

Cable-Stayed Design

The project site's soil conditions and deep water also played a role in the type of bridge that was selected. The site favored a suspension bridge because it required only two pylons on either side of the strait and minimized the impact of the unfavorable site conditions.

However, slope stability problems—specifically the potential for soil liquefaction—precluded any possibility of a suspension bridge. To do so would have required a main span of 2.5 km (1.6 miles). The only other option was a cable-stayed bridge with relatively few supports and relatively long spans.

The final design consisted of four slender pylons, three central spans 560 m (1,837') in length, and two side spans 286 m (938') long.

The parametric studies helped the team make the determination that the pylons could be continuous—monolithic from the sea bed to the top—because the deck could be suspended from the stay cables for its full 2.3-kilometer (1.4-mile) length without any support at the pylons.

The realities of erecting a light, flexible bridge deck drove the design team to opt for a composite steel-concrete structure for three primary reasons:

- Steel would provide the lightness and flexibility necessary for the required seismic performance.
- Steel and concrete could be strategically placed to provide the necessary resistance of tension and compression.
- Large prefabricated deck elements could be easily placed in the marine environment, using to the balanced cantilever erection method. This method already had been successfully used for the construction of the Second Severn Crossing cable stayed bridge connecting England to Wales.

Bridge Deck

The 27 m-wide (89') deck consists of concrete slabs, 25 to 35 cm (10 to 14") thick, connected to twin longitudinal steel I-girders. Each girder is 2.2 m (7.2') high, braced every 4 m (13') by transverse cross beams. It is continuous over its total length of 2,252 m (7,389'), with expansion joints at both ends, and is fully suspended by eight sets of 23 pairs of cables. The twin girders of the deck therefore fully support each side of its full length at a regular spacing of 12 m (39').

Deck elements, 12 m (39') long and including the concrete slab, were prefabricated. They were placed in their final location by a floating crane and bolted to the previously assembled segments using the balanced cantilever erection method. Contractors quickly assembled the deck segments using a fast-assembly device designed especially for this purpose. Only small joints providing enough space for an appropriate steel reinforcement overlapping had to be cast in place.

The approaches, made of six simply supported spans on one side and 10 spans on the other, were initially intended to be built using prefabricated, pre-stressed concrete beams. To simplify the erection and save money, one approach was altered to a composite steel-concrete structure.

The deck of the Rion-Antirion Bridge was erected in less than 14 months, an impressive feat given the size and complexity of the project. The bridge opened to traffic in August 2004, four months ahead of schedule and a few days before the start of the Summer Olympics in Athens.

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