THE RION ANTIRION BRIDGE DESIGN AND CONSTRUCTION

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SUMMARY

The RION-ANTIRION Bridge (Greece) is located in a zone of difficult environmental conditions characterised by deep soil strata of weak alluviums, large depth of water and strong seismic design motion. All these constraints have called for an original design presenting innovative features, such as big, 90 m foundations, resting on soil reinforced by means of metallic inclusions and continuous cable-stayed deck, fully suspended for its total length of 2,252 m. Construction methods are also unconventional, particularly for preparation of the seabed.

INTRODUCTION

The RION-ANTIRION Bridge is located over the Gulf of Corinth, Western Greece, and is intended to replace an existing ferry system.

Its environment presents an exceptional combination of physical conditions which makes this project quite complex:

large water depth (up to 65 m)

deep soil strata of weak alluviums

a strong seismic activity

possible tectonic movements

The structure will span a stretch of water of some 2,500 m. The seabed presents fairly steep slopes on each side and a long horizontal plateau at a depth of 60 to 70 m.

No bedrock has been encountered during soil investigations down to a depth of 100 m. Based on a geological study, it is believed that the thickness of sediments is greater than 500 m.

General trends identified through soils surveys are the following:

- a cohesionless layer is present at mudline level consisting of sand and gravel to a thickness of 4 to 7 m, except under pier M4, where its thickness reaches 25 m.
- underneath this layer, the soil profile, rather erratic and heterogeneous, presents strata of sand, silty sand and silty clay.
- below 30 m, the soils are more homogeneous and mainly consist in silty clays or clays.

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In view of the nature of the soils, liquefaction does not appear to be a problem except on the north shore, where the first 20 m are susceptible of liquefaction.

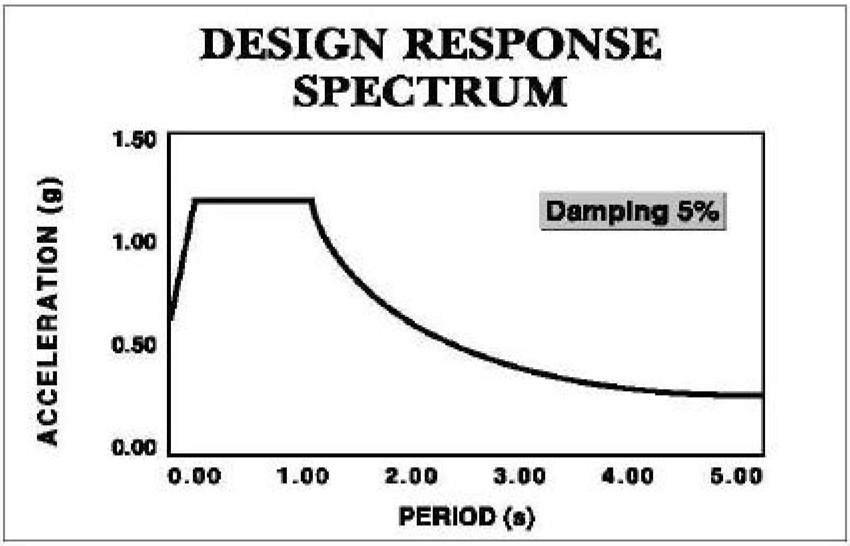

Figure 1: Design horizontal spectrum

The seismic conditions to be taken into account are presented in the form of a response spectrum at seabed level given in figure 1. The peak ground acceleration is equal to 0.48 g and the maximum spectral acceleration is equal to 1.2 between 0.2 and 1.0 s. This spectrum is supposed to correspond to a 2000 year return period.

In addition, the bridge has to accommodate possible fault movements up to 2 m in any direction, horizontally and/or vertically.

2. DESCRIPTION OF THE BRIDGE

These difficult environmental conditions called for an original design based on large foundations able to sustain seismic forces and large spans in order to limit the number of these foundations.

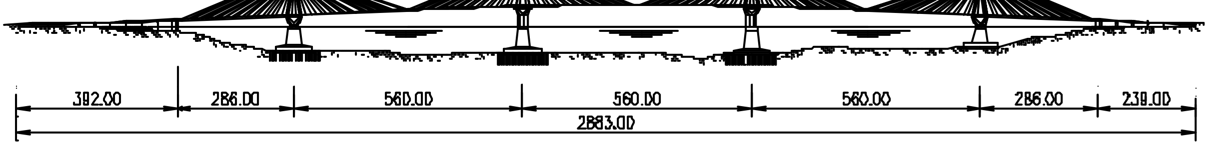

Figure 2: Bridge elevation

The bridge consists of (see figure 2):

- the cable-stayed main bridge, 2,252 m long, built on 4 large foundations with a span distribution equal to 286 m – 560 m – 560 m – 560 m – 286 m :

- the approach viaducts, 392 m on Rion side and 239 m on Antirion side, made of prefabricated prestressed beams.

Foundations consist of large diameter (90 m) caissons, resting on the seabed (see figure 3). The top 20 m of soils are rather heterogeneous and of low mechanical characteristics. To provide sufficient shear strength to these soil strata, which have to carry large seismic forces coming from structural inertia forces and hydrodynamic water pressures, the upper soil layer is reinforced by inclusions. These inclusions are hollow steel pipes, 25 to 30 m long, 2 m in diameter, driven into the upper layer at a regular spacing of 7 to 8 m (depending on the pier); about 250 pipes are driven in at each pier location. They are topped by a 3 m thick, properly levelled gravel layer, on which the foundations rest. These inclusions are not required under pier M4 owing to the presence of a thick gravel layer.

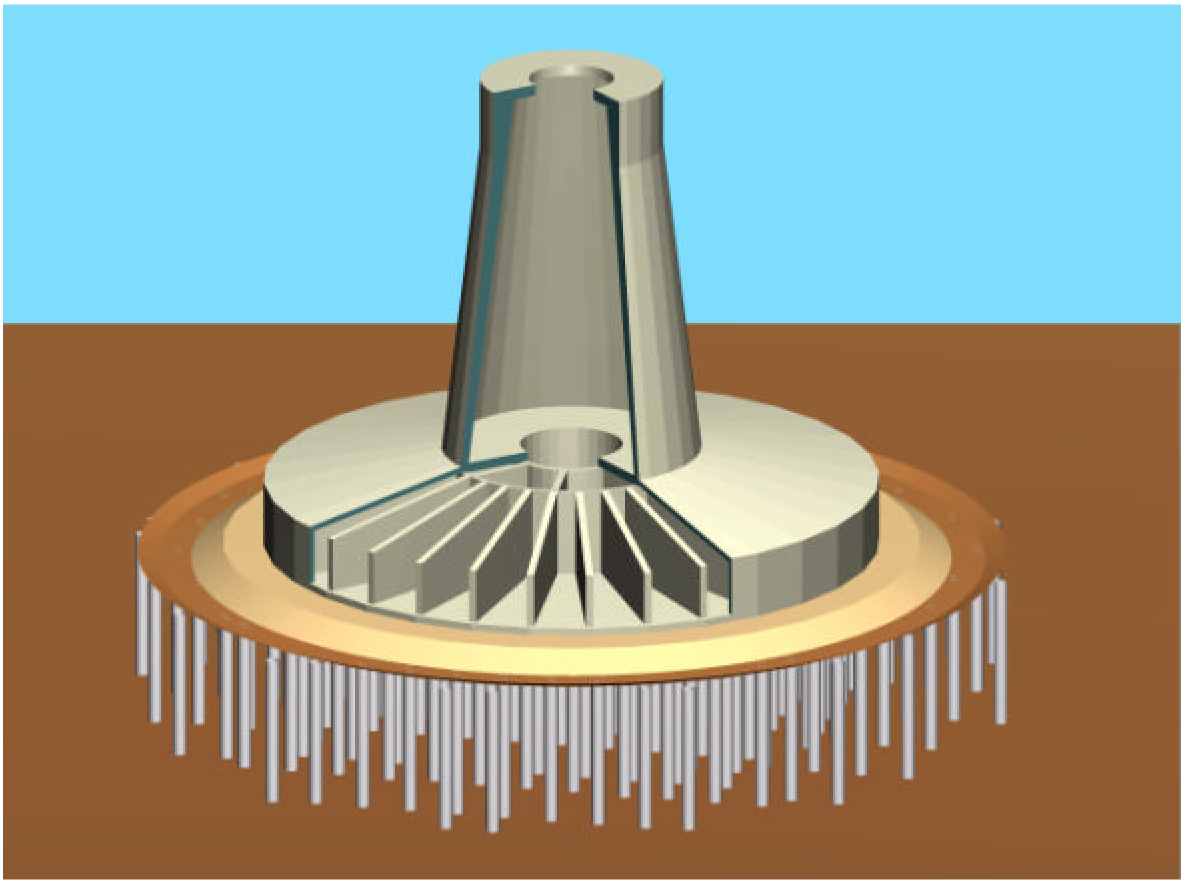

Figure 3: Foundation and inclusions

The cable-stayed deck is a composite steel structure made of two longitudinal plate girders 2.2 m high on each side of the deck with transverse plate girders spaced at 4 m and a concrete slab, the total width being 27 m (see figure 4).

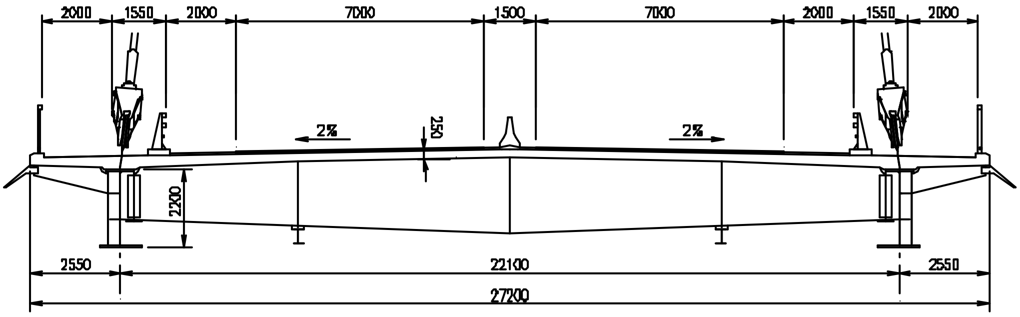

Figure 4: Typical deck cross section

Each pylon is composed of four concrete legs 4 x 4 m, joined at the top to give the rigidity necessary to support unsymmetrical service loads and seismic forces (see figure 5). The pylons are rigidly embedded in pier head to form a monolithic structure, up to 230 m high, from sea bottom to pylon top.

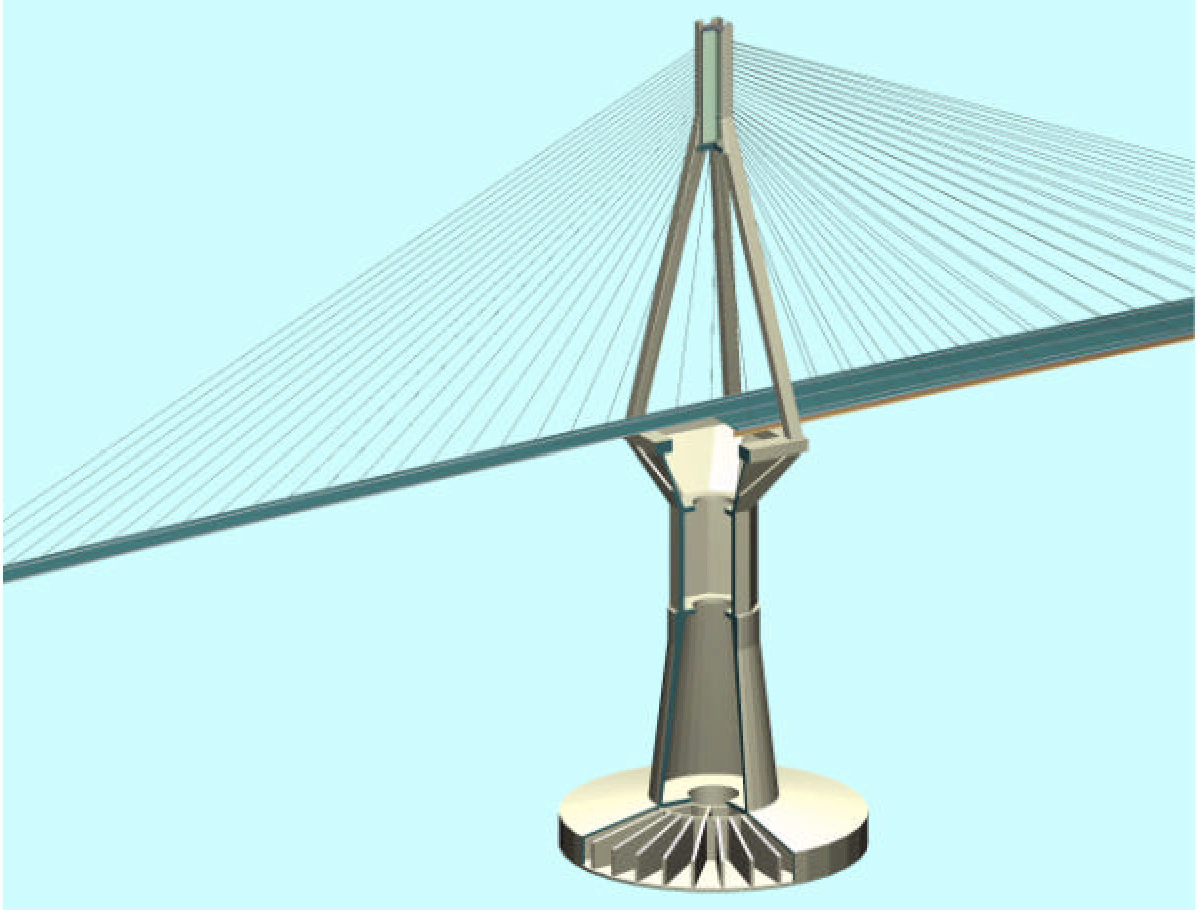

Figure 5: Pier and pylon

The stay cables, forming a semi-fan shape, are in two inclined arrangements, with their lower anchorages on deck sides and their upper anchorages at the pylon top. They are made of parallel galvanised strands individually protected.

The deck of the main bridge is continuous and fully suspended by means of stay cables for its total length of 2,252 meters. In the longitudinal direction, the deck is free to accommodate all thermal and tectonic movements. At its extremities, expansion joints are required to accommodate movements of 2 m.

In the transverse direction, the deck is connected to each pylon with 4 damping devices. The capacity of each device will be in the range of 3,500 kN, operating in both tension and compression. The dynamic relative movement between the deck and the pylon, during an extreme seismic event is in the order of ± 1.30 m, and the velocities reached exceed 1 m/sec.

3. DESIGN CONCEPT

From the beginning it has been clear that the critical load for most of the structure is the design seismic loading, despite the fact that the bridge also has to sustain the impact of a 180,000 dwt tanker sailing at 18 knots.

The choice of the present design of the bridge was made after examination of a wide range of possible solutions in term of span type (suspension spans vs. cable-stayed spans) and foundation concepts.

Particularly with regard to the foundations, the bearing capacity was a major concern in these difficult environmental conditions characterised by poor soil conditions, significant seismic intensities and large depth of water. Alternative foundation concepts (such as piles foundations, deep embedded caissons and soil substitution) have been investigated with their relative merits in terms of economy, feasibility and technical soundness.

This analysis showed that a shallow foundation was the most satisfactory solution as long as it was feasible to significantly improve the top 20 m of soils. This will be achieved by means of metallic inclusions, as described here above. Although the foundations resemble piled foundations, they do not at all behave as such: no connection exists between the inclusions and the caisson raft, which would allow for the foundation to uplift or to slide with respect to the soil; the density of inclusions is far more important and the length smaller than would have been the case in piled foundations. This type of soil reinforcement through metallic inclusions is quite innovative and necessitated extensive numerical studies and centrifuge model tests for its validation.

Another unique feature of this project lies in its continuous cable-stayed deck, which, in addition to being the longest in the world, is totally suspended. This creates an effective isolation system significantly reducing seismic forces in the deck and allowing the bridge to accommodate fault movements between adjacent piers. However, this disposition necessitates installing at each pylon transversal damping devices able to limit lateral displacements of the deck and dissipate large amount of energy during a seismic event. This isolation system must also allow slow tectonic movement and restrain the deck for wind action. These requirements demand large capacity dampers, which are still under investigation. Two solutions are being examined: hydraulic and elastoplastic dampers. Prototype tests will be conducted to confirm their performance.

4. CONSTRUCTION METHODS

Construction methods for the foundations are those commonly used for the construction of offshore concrete platforms:

- construction of the foundation footings in a dry dock up to a height of 15 m in order to provide sufficient buoyancy;
- towing and mooring of these footings at a wet dock site;
- construction of the conical part of the foundations at the wet dock site;
- towing and immersion of the foundations at final position.

However some features of this project make the construction process of its foundations quite exceptional.

The dry dock has been established near the site. It is 200 m long, 100 m wide, 14 deep, and can accommodate the simultaneous construction of two foundations. It has an unusual closure system: the first foundation is built behind the protection of a dyke, but once towed out, the second foundation, the construction of which has already started, is floated to the front place and used as a dock gate.

Dredging the seabed, driving 750 inclusions, placing and levelling the gravel layer on the top, with a depth of water reaching 65 m is major marine operation which necessitates special equipment and procedures. In fact, a tension-leg barge has been custom-made, based on the well known concept of tension-leg platforms but used for the first time for movable equipment. This concept is based on active vertical anchorage to dead weights lying on the seabed (see figure 6). The tension in these vertical anchor lines is adjusted in order to give the required stability to the barge with respect to sea movements and loads handled by cranes disposed on its deck. By increasing the tension in the anchor lines, the buoyancy of the barge allows the anchor weights to be lifted from the seabed, then the barge, including its weights, can be floated away to a new position.

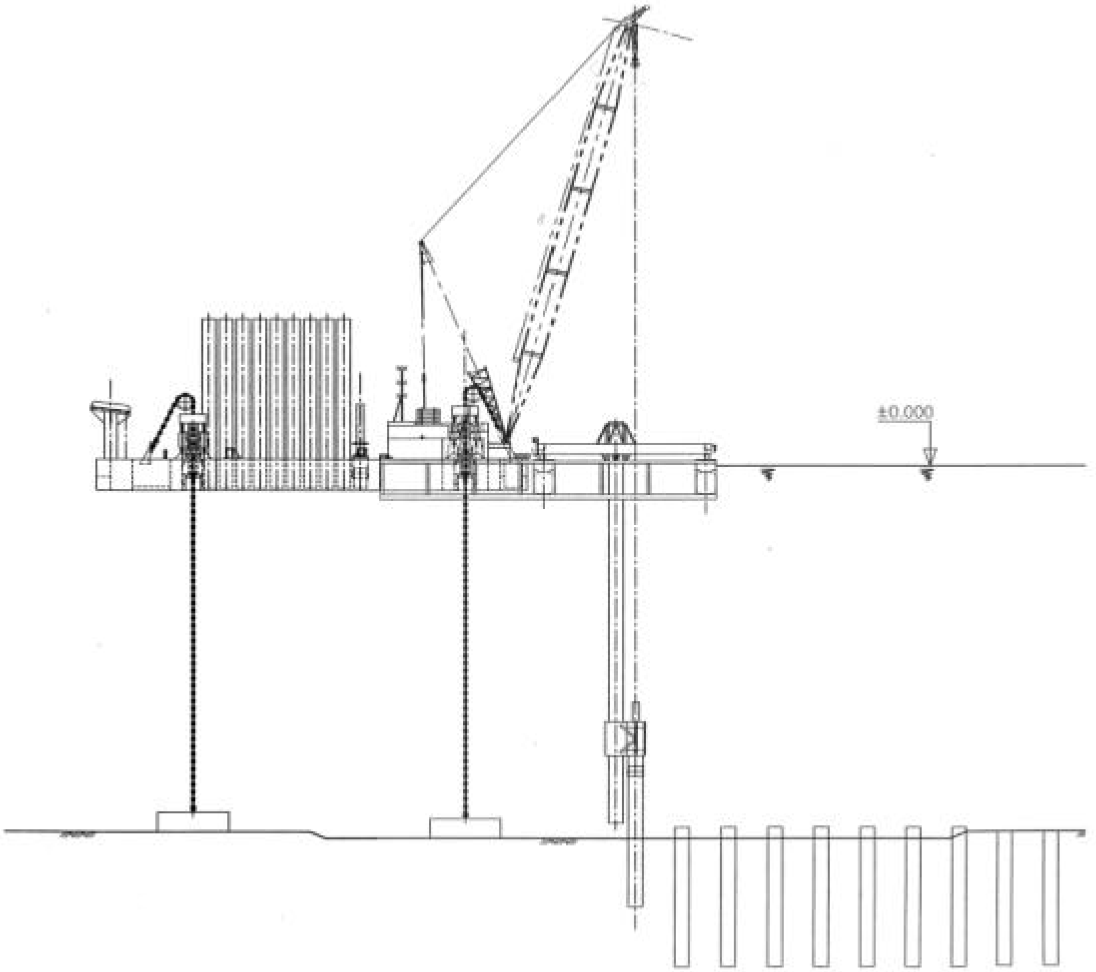

Figure 6: Tension-leg barge

As already stated, once completed the foundations will be towed then sunk at their final position. Compartments created in the footings by the radial beams will be used to control trim by differential ballasting. Then the foundations will be filled with water to accelerate settlements, which are expected to be significant (in the range of 0,5 m). This pre-loading will be maintained during pier shaft and pier head construction, thus allowing a correction for differential settlements before erecting pylons.

The deck of the main bridge will be erected using the balance cantilever technique, a usual construction method for cable-stayed bridges. The steel deck elements will be 12 m long, topped by a concrete slab formed of precast elements.

5. CONCLUSIONS

The Rion-Antirion bridge is a major structure, presenting exceptional features in term of design and construction methods, mainly commanded by its seismic resistance.

The design and construction of this highly innovative project have been undertaken under a private concession scheme, led by the French company Groupe GTM. The detailed design is in an advanced state and the construction of the first foundations will start before the end of year 1999, for a completion of the whole project due in 2004.

For more information on the design of the bridge, please refer to the paper "Structural response of the Rion-Antirion Bridge" by J. Combault in the present proceedings.

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