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# The Exceptional Structure of the Rion Bridge in Greece

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**Summary**

The Rion Antirion Bridge will cross the Gulf of Corinth near Patras, in western Greece. An exceptional combination of physical conditions makes the project quite unusual. Upon signature of the contract in December 1997, the final design phase began, including the careful study of the methods of construction to be used.
Although still subject to possible improvements, the conceptual design of the structure is carried out in view of challenging the earthquakes and ensuring the every day serviceability of the link as well. Innovative techniques have been developed to solve the critical problem of high degree seismicity in conjunction with a weak soil.

## Introduction

The Rion Antirion crossing consists of a main bridge, measuring 2290 m long and 26.30 m wide, connected to the land by two approaches, respectively 378 m and 252 m long, on each side of the gulf.

The main bridge is located in an exceptional environment which consists of a high water depth, a deep soil strata of weak alluvions (the bedrock being approximately 800 m below the sea bed level) and finally a strong seismic activity with possible slow but important tectonic movements.

If all these difficulties could be considered separately , there would be no problem. However, the conjunction of all these problems leads to a tough design.

As the seismic activity is severe, the soil structure interaction is the center of high forces. As high forces are generated in the weak top layers of the soil, they have to be reinforced and such reinforcement is not an easy task under 60 m of water.

## Design features

The seismic conditions to be taken into account are given by the response spectrum at the sea bed level which corresponds to a 2000 year return period. The peak ground acceleration is 0.5 g and the maximum spectral acceleration is equal to 1.2 g on a rather large period range.

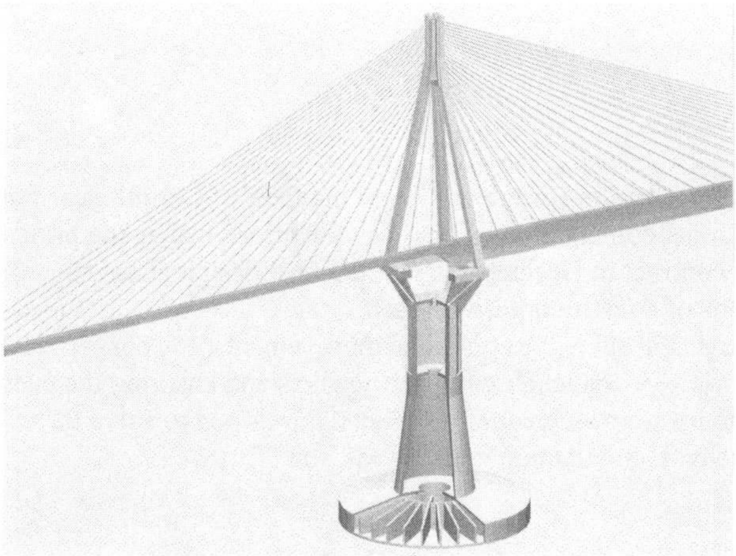
As previously mentioned the bridge also has to accommodate possible fault movements which could lead to a 2 m horizontal displacement of one part of the main bridge with regard to the other part, the pylons being simultaneously the subject of small inclinations due to the corresponding rearrangement of the sea bed below the foundations.

In addition to that, the pylons have to withstand the impact of a big tanker (180 000 t) sailing at 16 knots.

## Main bridge concept

Taking into account this range of possible disasters, the first thing to do was to adjust the span length with regard to the cost of the supports (pylons) of the main bridge, in order to reduce as much as possible, in terms of global project cost, the number of pylons in the strait.

This lead to an exceptional multi-cable stayed span bridge made of 3 central spans 560 m in length and 2 side spans 305 m long.



*Main Bridge Concept - General view*

The corresponding 4 pylons rest on the sea bed through a large concrete substructure foundation, 90 m in diameter, 65 m high, which distribute all the forces to the soil.

Below this substructure, the heterogeneous and weak soil is improved by means of inclusions which consist of 20 mm thick steel pipes, 20 to 30 m long and 2 m in diameter, driven at a regular spacing equal to or less than 7 m.

Initially, these huge foundations supported, through octagonal pylon shafts, pyramidal capitals which were the base of 4 concrete legs converging at the top of the pylons and giving them the appropriate rigidity.

This was absolutely necessary as long as each pylon supported a symmetrical cantilever 510 m long and each cantilever was connected to the adjacent one or to the approaches by a simply supported deck girder 50 m long.

But this concept has been revised as it lead to a tremendous set of bearing and spring dampers under each pylon with characteristics never reached before.

## Parametric Studies and Design Improvements (Preliminary Design Phase)

As long as the signature of the contract was delayed by the banks and the bridge is really an enormous undertaking, it was decided to spend about one year to proceed with sophisticated parametric studies in view of optimising the concept and the structure as well.
Careful analyses of the behaviour of the reinforced soil and improvements of this innovative concept lead to give up the initial statical scheme of the main bridge and to definitely move towards a much more efficient structure with a continuous pylon (from sea bed to head) and a continuous deck fully suspended and therefore isolated as much as it can be. This made possible to reduce the height of the deck girders and therefore to reduce also the wind effects on the bridge.

Nevertheless, the main bridge concept is not fully finalised yet, but it is undergoing a spectacular evolution, which takes into account all the aspects of the project economy and which is the result of the close interaction between design and study of realistic construction methods.

## Some unusual aspects of construction methods:

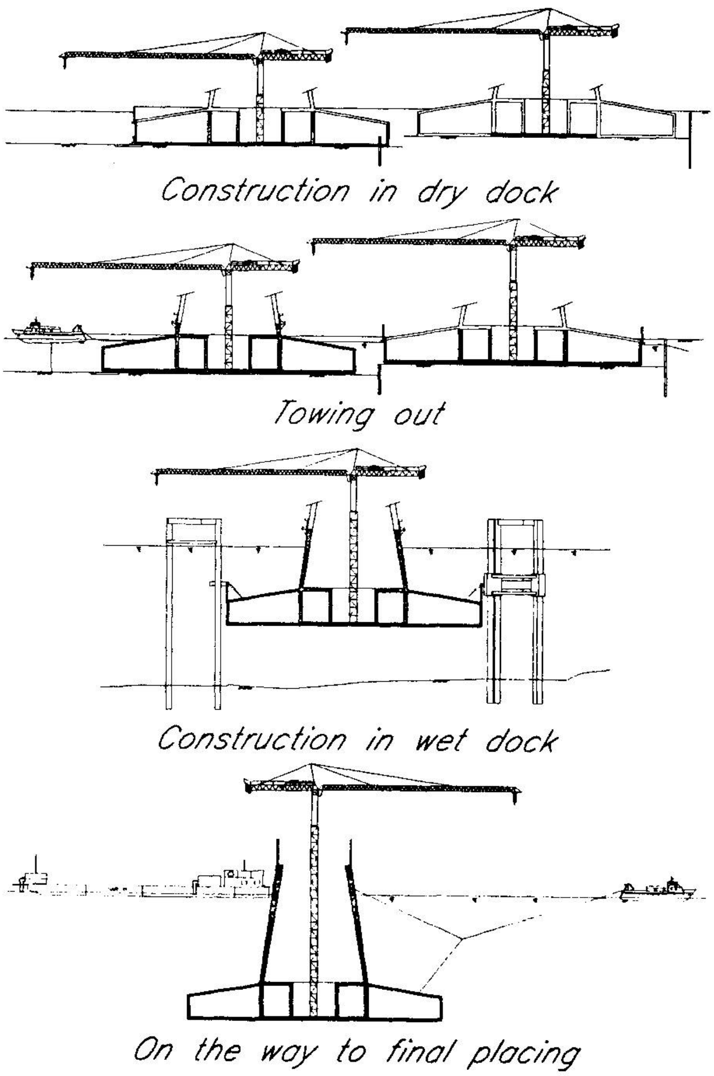
Construction of the main bridge is facing a major difficulty in the depth of the seabed, which reaches 65m for central piers. In relation with this, foundation works, including dredging, steel pipes driving but also exceptional works like precision laying of a 8000 m$^2$ gravel bed, are forming a impressive package requiring unusual skills and equipments.

To achieve this challenging task, offshore technology, with respect to GBS platforms construction and specially designed heavy duty pontoons and vessels, will be extensively called for.

**Pier construction:**

Piers up to mean sea level are built in two phases:

. the footing, 90 m diameter, 9 m high in the periphery, 13,5 m in the center, is a hollow piece of 65.000 tons of concrete, with an external volume around 72.500 m$^3$, thus providing a sufficient buoyancy. It will be cast in a dry dock and



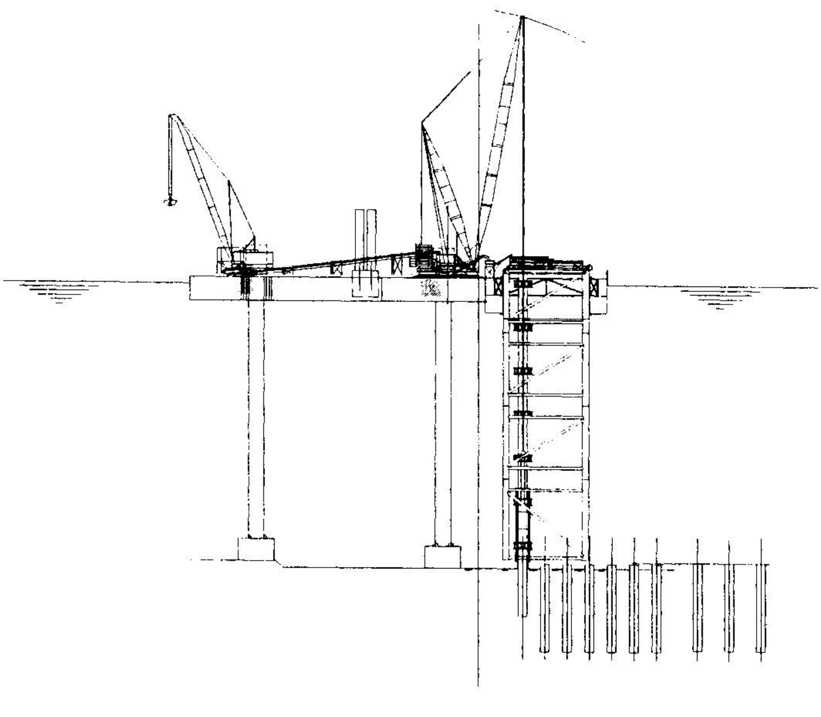

*Pylon Base Erection and Placing Stages* floated out once completed. This dry dock is 200 m long by 100 m wide, to allow for simultaneous fabrication of 2 footings. Its closure system is quite unusual: the first footing is built behind the protection of a dyke, but once moved out, the second one, which construction was started backward, is floated in the front place and used as a gate to close the dock.

. the cone, 38 m diameter at the bottom, 26 m at the top, 53 m high for central piers. It will be cast with classical jump forms atop the footing in a wet dock, floating and attached by dolphins or mooring lines, with a final draft of around 50 m.

Once completed, the pier bases will be towed to their final immersion site and sunk on previously prepared foundations. Compartments created in the footing by the radial beams will be used to control trim by differential ballasting. Then the piers will be filled with water (and maybe some sand) to anticipate and speed up settlements. This preloading will be maintained during pier shaft and pier head construction, thus allowing a correction for differential settlements when erecting the pylon.

**Foundation works-Tension leg platform** :

Foundation works will include dredging to level the seabed, driving the inclusions, and placing the final layer of selected granular materials. Pier n°3 will also require a substitution of the top 5 m clay layers, by dredging, then placing sand and gravel and finally densification by vibroflotation, which technique should also be used to improve sand and gravel top layers found under pier n°4.



*Inclusions driving with the tension leg platform*

*Tension Leg Platform*

Tolerance in altitude for the 8.000 $m^2$ gravel bed is the most demanding dimensional constraint : between ± 3 and ± 5 cm. This can be achieved either with a floating pontoon and a sophisticated placing system able to compensate for sea surface movements, which is the option chosen in the Oresund project between Denmark and Sweden, or a platform providing a stable elevation. A jack-up barge is a possible solution, even with 65 m of water, but soft soil would impose huge spuds at the legs bottom. Thus, the preferred solution is a tension leg platform.

This type of barge is based on active anchorage with dead weights lying on seabed straight under the barge, and chain anchor lines tensioned to force it down in water, so that its elevation will not, to a certain extent, be influenced by sea surface movements and loads handled by cranes disposed on its deck: if sea goes down, or if a load is added, the tension in the chains decreases, but the platform's elevation does not change. A reserve of buoyancy is provided so that by increasing the tension, the anchor weights can be lifted from seabed, and the whole thing can move floating.

This concept provides a better stability than usual barges with 8 mooring lines, without the problems induced to navigation by the huge area where these lines are in the way, and displacements are easy with a cargo barge, quick coupling devices ( "docking rollers", a licensed product of GTM group) , DP system and GPS positioning.

For Rion project, the platform should be obtained by retrofitting a jack-up barge used for heavy lift during Second Severn Crossing. Existing jacking houses would be converted to handle anchor chains ( typically ∅168mm grade 4). Nominal working tension would be 750 tons each, thus providing 3.000 tons with 4 chains, mobilizing 1.5m of draft for 2.000 $m^2$ of deck. A Manitowoc 888 ringer, with 600 metric tons capacity, and a weight of 1.000 tons, is considered as main crane, far above the capacity required to handle the 100 tons packages formed by one inclusion and the pile-driver on top of it, but well suited for heavy lifts to be performed during superstructure construction.

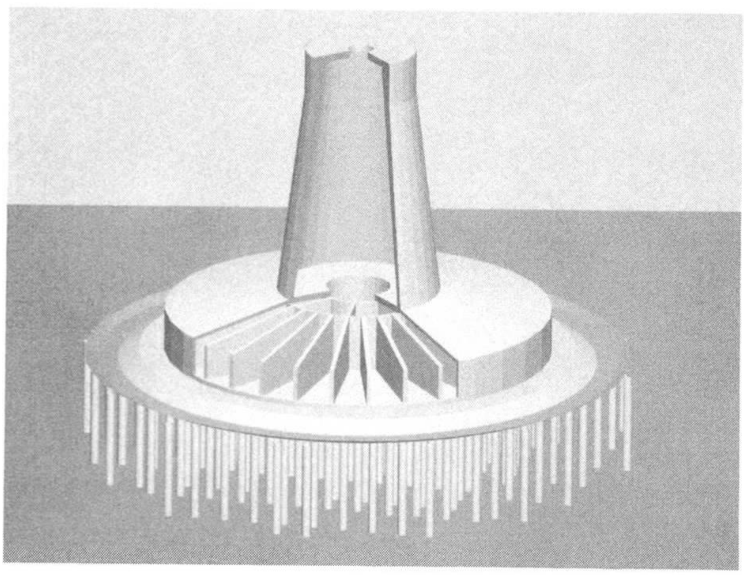
All handling operations will be performed from this barge. Then, a catamaran semi-floating pontoon, attached to this stable platform, will provide the transfer system between surface and sea bed: it will support a mobile riser with guides for inclusions and a tremie pipe for gravels, covering around 400 $m^2$ of seabed. Gravels would be laid in parallel berms, 2 m wide, separated by V shaped cuts around 30 cm deep to provide some flexibility when placing the pier, distributed and leveled by a rectangular open frame at the bottom of the tremie pipe, kept full up to a minimum of 2 m.

## Some indications about the schedule:

Contract Effective Date:
- December 24th, 1997

Construction time limit:
- 7 years (December 24th, 2004)

Start of works:
- Dry dock: September 1998
- Foundation works: Spring 1999
- Pier n°4 construction: January 2000
- Pier n°4 immersion: beginning of 2001
- Pier n°4 deck erection: mid 2002



*Reinforced soil - Pylon base - Final concept*

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