Rion-Antirion Bridge Project

LOCATION:

Rion-Antirion Strait, USA

SUBMITTING FIRM:

GEFYRA S.A.

FIDIC MEMBER:

HELLASCO - Hellenic Association of Consulting Firms

"Rion-Antirion Bridge – An Ode to Poseidon"
Rion & Antirion, Greece

PROJECT BACKGROUND

One million years ago the Peloponnese, Greece's southern-most peninsula, was firmly connected to the mainland, and the Gulf of Corinth that separates Peloponnese from Northern Greece did not exist. Over the course of several millennia, the Peloponnese drifted southward creating the gulf that now separates much of the peninsula from the Greek mainland.

The Rion-Antirion Bridge completes a vision that reaches back more than 100 years. Prime Minister Charilaos Trikoupis (1832-1896), who served as Prime Minister seven times during the early years of Greece's independence, had a vision of a bridge joining the people from Achaia (Peloponnese) and Etoloakarnania (Northwestern Greece) over the Gulf of Corinth. He applied a generalized program of modernization by carrying out the first "grand scale projects" of Greece's modern history, such as the expansion of the railway network, the opening of the Isthmus of Corinth, and the construction of ports, roads, bridges, and lighthouses. In 1889, Trikoupis announced his vision of a bridge between Rion and Antirion to the Greek Parliament, a 3-km crossing over seawater, and a technical project beyond anything that existed at the time around the world.

The Rion-Antirion site has a unique and exceptional combination of physical conditions: considerable water depth of 65 m requiring off-shore construction techniques, weak alluvial soil deposits, high seismicity, and tectonic movements, coupled with strong currents and winds blowing almost constantly from the west. As a result of these challenges, Trikoupis' vision remained a dream for over 100 years and until the late 1900's, the Gulf continued to be underutilized as a sea crossing with limited vehicular transportation between Peloponnese and Northern Greece to a single road in the eastern part of the country. The ferry service with its irregular schedule could not meet the ever-growing demands, and land use and development focused to the eastern portion of the country. The western side of Greece, which is separated from the east by a substantial mountainous range, remained mostly underdeveloped.

Following a 1993 tender, Gefyra, SA (a French/Greek joint venture led by Vinci of Paris, France), was awarded a Concession Contract to design, build, finance, operate and maintain the bridge over a 42-year period – seven years for design and construction, and 35 years for operations. Financial closing was achieved in December 1997 following evaluations by the Technical Advisors, and rigorous negotiations with the Banks. The contract was ratified in the Parliament in January 1996.

A Concession project of this magnitude and technical difficulty required an unprecedented team of professionals. Each member of this truly international team contributed in many different and significant ways, each safeguarding the diverse interests of the various stakeholders. Yet, the team worked collaboratively throughout the project with a singular goal in mind — the completion of the world's longest and certainly most challenging cable-stayed bridge. It is due to the incredible collaborative mindset fostered by the Vinci Consortium, and in particular its leader Jean-Paul Teyssandier, that the Trikoupis dream became a reality and the bridge opened ahead of time in August 2004.

INNOVATION

The winning tender proposal by the Vinci Consortium was based on an original and innovative design concept consisting of a four pylon/five span cable-stayed bridge structure with a total length of 290 m and

approach viaducts on each end. The design also included five "drop-in-spans," each 60 m long, to be placed between each of the three main 560-m long cable-stayed sections and at each approach viaduct end; these were meant to accommodate the significant 2-m tectonic movements specified in the tender documents. Traditional pile foundations were ruled out due to the depth of rock or other satisfactory bearing material, so it was determined that the seabed was to be reinforced with 2-m diameter steel inclusions driven open-ended and connected to the base piers via a 0.5-m thick layer of high strength cement grout. The design also utilized a unique, highly specialized base isolation system of shock absorbers, bearings, cables and stoppers at each bridge pier head immediately below the bridge deck, to reduce or "isolate" the enormous horizontal seismic forces transferred from the foundation piers to the superstructure pylons and vice versa.

All of the above constituted first-time innovative applications that went significantly beyond the current state-of-the-art, driven by the challenges resulting from the exceptional combination of deep water, weak alluvial deposits, strong seismic activity and tectonic movements. As such, they presented significant risks to the financial partners (lenders and loan guarantors) and were the focus of extensive and sophisticated evaluations during final design.

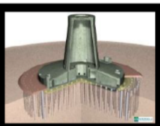
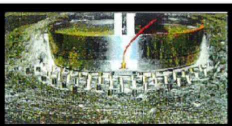
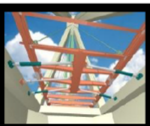
In the period between tender and financial closing, the project Technical Advisors identified five key issues of concern:

- The behavior of the soil reinforcement concept and the validity of the relevant theoretical model.
- The soil reinforcement pier foundation connection, including the evaluation of the effects of foundation uplift during seismic excitation.
- The behavior of the intricate base isolation system at each of the main bridge pylons (the proposed novel application constituted a tremendous leap forward in this type of utilization).
- The design details and behavior of the drop-in-spans to accommodate very large vertical and horizontal tectonic and seismic movements.
- The shape of the below water portion of the piers believed to possibly induce higher-than-desired hydrodynamic forces at foundation level.

All technical issues were resolved by advancing the initial design concept and adopting alternate solutions, intertwined with each other given that the solution of each issue had a direct and distinct effect on the other, and on the construction methods that were available and could be deployed. In the end:

- The 50-meter drop-in-spans were eliminated, with the cable-supported deck becoming a continuous composite system (the longest ever) suspended from each pylon head.
- An unprecedented system of dampers and fuses replaced the original base isolation system to control movement of the deck where it runs through the pylon legs. Transition piers were provided at the two ends of the deck where it meets the more rigid pile supported approach viaducts.
- The foundation grout connection was eliminated, and the piers rest directly on a 3.5-m thick gravel ballast layer placed over the soil reinforcing inclusions. This allows all piers to act as gravity base structures free to slide during seismic events, reduces the build up of pore water pressures in the foundation materials, and provides additional isolation of seismic forces.
- Preloading of the piers was incorporated into the construction procedures to ensure that all future foundation settlement was induced before the pylon superstructure was completed, thus allowing for verticality corrections during construction.

As the design evolved, so did the construction methods, which are quite unique and involved techniques typically used in offshore platforms. A horseshoe shaped dry dock was created for the construction of the

submerged portion of the pier bases, while a second staging area, a wet dock, was used to complete the main piers in lifts prior to being towed to their final locations.

The seabed at the final pier locations was prepared by excavating the upper soils, driving the soil reinforcing pipe inclusions and installing the gravel ballast, all using a barge and "catamaran" assembly specially designed and manufactured for the project. All below-water work was GPS guided and controlled.

In the end, this bridge has defined new standards for innovative application of engineering principles and construction techniques. Along the way, it has set numerous world records as:

- The first bridge with four consecutive cable-stayed modules (five spans).
- The longest fully suspended continuous deck with a total continuous length of 2,252 m.
- The deepest bridge foundations set at sea depths of 65 m.
- The largest bridge foundations, with each pylon base being 90 m in diameter.
- The first use of deep steel pipe inclusions to reinforce weak subsurface foundation soils.
- The most innovative foundation system of "floating" pier bases bearing on a gravel bed over reinforced soils.

The unique nature of this project and the innovative design and construction techniques applied attracted unusual attention from the media. Numerous articles have been published in both the general and trade press, including cover stories in Engineering News Record, Civil Engineering, and Bridge and Design Engineering. The project also drew the interest of the Discovery Channel and National Geographic; both produced comprehensive documentaries.

QUALITY

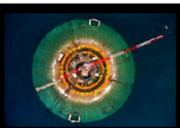
Construction for a bridge spanning the Gulf of Corinth, founded in 65-m deep waters on marginal soils was not without risks. The key for the Concessionaire/Contractor to mitigating these risks was identification, assessment of probability, and development of contingency and/or risk management plans. Risks due to construction cost overruns were mitigated by the fact that the Concessionaire and the Contractor were solely responsible for all design and construction methods and associated costs, and had the foresight to heavily invest in the design, and achieve a combination of minimum cost and practical time allocation.

The Contractor obtained critical highly specialized and often unique/build-to-suit pieces of equipment at the start of the project to achieve the desired results. The availability and capabilities of this equipment were factored in the design. The risk of potential accidents that could result in short term or permanent loss of this equipment was covered by insurance policies.

Extensive analytical and numerical studies confirmed that the steel inclusions are effective soil-reinforcing elements. The behavior of the innovative foundation system was evaluated using analytical and numerical methods, including limit analyses based on yield design theory, and 2D and 3D non-linear infinite element concepts by providing information on the ultimate capacities of the foundations and their failure behavior.

Settlements were estimated for each pier base. The vertical stress distribution was analyzed using 3D foundation sub grade and to account for the length and spacing of inclusions. The stress distribution was computed to a depth of 120 m taking into account the unloading stresses due to excavation. Compressibility parameters of the soil were determined coinciding with the available CPT records. The direction cosines of the vector normal to the plane were computed to obtain the direction and magnitude of the maximum foundation tilt for each pier.




Inclusion installation records were kept during driving. Unlike typical piles, there were no driving criteria for the steel inclusions. Instead, hammer blows and total transferred energy were plotted with depth on an inclusion basis and most importantly on a quadrant basis for each pier. The intent was to identify potential weaker areas that could result in excessive settlement and/or tilt. Water ballast preloading begun soon after each pier was in position and movements were monitored. Recorded settlements and tilt would be accounted for as the pylon superstructure construction progressed. There was remarkable correlation between the recorded inclusion total driving energies and the corresponding tilt.

The system of dampers and fuses that substituted the original intricate base isolation system between the bridge roadway and each pier base was designed to control the movement of the deck where it runs through the pylon legs not only during an earthquake event but also during high winds. The intricate system of the huge dampers and fuses were modeled extensively and then scaled and tested at the University of California San Diego. They were then manufactured specifically for the Rion-Antirion Bridge. The fuses act as restraints during minor earthquake events designed to break when seismic forces exceed a certain level, at which time the dampers are mobilized.

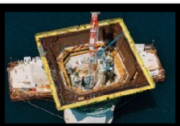
INTEGRITY/TRANSPARENCY PRINCIPLES

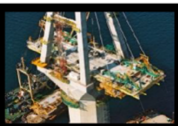
The assembling and organization of an international team was crucial not only in tackling the technical challenges of this project but also in ensuring transparency between members and enforcing integrity throughout the process. The structure of the team enabled an effective system of checks and balances, helping to encourage innovation while bolstering efficiency, facilitate dynamic communication, and safeguard the diverse interests of the many stakeholders involved.

The Contractor, Gefyra, SA (Vinci Group and five Greek contractors), was responsible for the design and construction of the bridge, while two independent engineering firms reporting to the Concessionaire and to the Greek State filled the roles of Design Checker and construction Supervision Engineer. The Design Checker provided an independent confirmation of the design developed by the Contractor including design reviews, approvals and certifications; they were assisted by an impressive group of highly-regarded geotechnical and seismic Technical Advisors/specialists, which included Dr. R.B. Peck, Prof. R. Dobry, Prof. N. Priestley, Prof. F. Seible, and Prof. M. Calvi. The Supervision Engineer had the primary responsibility of monitoring the progress of the works, the workmanship, and conformance with the specifications and construction documents. The Lender's Technical Advisors (Langan and Parsons Transportation Group) provided independent technical review for the financial partners prior to Financial Closing and throughout the design and construction periods. The role of all the Technical Advisors, who were interacting with and reporting to both the Concessionaire and the Lenders, was critical to this project given the number of innovative design solutions and unique construction techniques employed.

It is also worth mentioning that at the start of the project there was a shortage of skilled laborers for the unique type of work involved in this project, and the Concessionaire was also required to work with strong labor unions in Greece. To mitigate the risks inherent in these issues, the Contractor undertook a proactive approach with the establishment of an on-site training center and program designed to develop a skilled labor pool of foremen, gang leaders and laborers necessary to meet the demands of the project.

The Contractor opted to train locally rather than import skilled labor due to language advantages and the local workers' good spirit and willingness to learn. While proper training may have caused some initial delays in the early stages of construction, the long-term benefit has been justified.




RESPECT FOR THE ENVIRONMENT/SUSTAINABILITY

The bridge is a vital link to and part of the Trans-European Transportation Network, and provides efficient distribution of goods to the region and ports of Italy, helping to spur commerce with Western Europe. The bridge was critical in not only strengthening commercial ties with other parts of Europe but also with Western Greece, which prior to its construction had been severely underdeveloped and had high rates of unemployment.

Building a bridge to link Rion with Antirion was considered the most environmentally-friendly alternative compared to other modes of transport. Previously, when the cities were connected using ferry service, the frequent trips back and forth heavily polluted the marine environment and moreover, during periods of high traffic, cars and trucks would release emissions while idling for hours in both ports. Apart from pollution concerns, a tunnel or other submerged structure could have had serious impacts on the marine environmental and seabed, which were originally considered as viable alternatives. The use of the dry and wet docks for construction of the pier bases and main piers, as opposed to constructing these elements in-situ, was also instrumental in minimizing disturbances to the seabed and local marine ecosystem.

"Green" considerations are also incorporated into bridge operations. State-of-the-art technologies are used to mitigate greenhouse gas emissions, which are employed in the lighting and heating/ventilation systems used in operations facilities, as well as the operating company's vehicles. Such applications have influenced marine environmental protection policies and activities in the Gulf of Corinth, and the operating company continues to promote awareness and educational campaigns regarding eco-driving.

CONCLUSION

In closing, we cannot overstate that partnering among the various members as a team assembled from around the world was instrumental in achieving the desired end results. The Concessionaire fostered an unprecedented spirit of collaboration and focus to a common goal. The design and construction process was a remarkable experience that allowed significant challenges to be identified, solutions developed and construction executed.

The Rion-Antirion Bridge was completed within budget and opened four months ahead of schedule following the passing of the Olympic flame on 8 August 2004, in time for the 2004 Athens Olympic Games.