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CONSTRUCTION CHALLENGES OF RION-ANTIRION BRIDGE

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Abstract:-- **Bridges are the structure's constructor cross obstacles like valleys or water bodies for the purpose of providing transportation facility across two inaccessible places. This paper is on construction challengers of Rion-Antirion Bridge located over the Gulf of Corinth in Western Greece linking the Rio and Antirio. The purpose of constructing this bridge is to replace an existing ferry system to cross the Gulf of Corinth. The physical challenges in this area made this project unique. The construction challenges are deep strata of weak soil, deep waters, strong winds, strong seismic activities and fault displacement. To overcome all these challenges the engineers came up with unique solutions which make this bridge soo unique.**

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1. INTRODUCTION

The Rion-Antirion Bridge is located over the Gulf of Corinth in Western Greece and its purpose is to replace an existing ferry system. Linking the Rio to the mainland of Greece over the Gulf of Corinth was a dream for more than a century but it has never been possible until now. The Rion-Antirion Bridge is the first bridge ever to cross the Gulf of Corinth. The construction of the Rion-Antirion cable-stayed bridge was a major technological achievement. Unique solutions were found to construct a span of about 2252 metres long to hold out against extreme conditions. The bridge is capable of withstanding an earthquake around the magnitude of 7.2 on the Richter scale. It is also capable of withstanding heavy winds of up to 260 kilometres. The piers of the bridge can take the collision impact of around 180,000-tons cargo tanker moving at around 30 kilometres an hour of speed. Few experts say that the bridge could be the safest place to be during an earthquake. The vehicles can now cross the Gulf of Corinth in 5 minutes instead of a 30 minutes ferry ride. It provides clearance by more than 50 metres leaving plenty of room for even the biggest ships. The design looks deceptively simple with 368 sleek cables holding the road deck with four conical towers and a yellow ribbon of roadway that glows at night. But the truly amazing thing about this bridge is how it came to be built here in the first place. The design and construction of this Rion-Antirion Bridge were undertaken under a private BOT scheme and led by the French company VINCI. The total cost of the project was about € 800 million. The whole project was started in July 1998 and completed by May 2004.

Figure 1: Rion-Antirion Bridge

2. HISTORY

The idea of constructing a bridge over the Gulf of Corinth about 3-kilometres long stretch is not at all new. Planning of constructing a bridge over the Gulf of Corinth was a century-old since the 1880s. In the past 40 years, the Gulf of Corinth had experienced around 10 earthquakes which have widened the distance between the Peloponnese area and mainland Greece by 8 millimetres. In the early 1990s, the project had become technically achievable. In 1996, Gefyra, a subsidiary (53%) of the VINCI Group, got the tender. The construction of the Rion-Antirion Bridge was started in July 1998. The 7-year work plan was divided into two stages:- The first two years were devoted to practicability studies and the next five years was the construction period. In May 2004, the construction of Rion-Antirion Bridge was completed by 5 months early to the given time. The Rion-Antirion Bridge was ready for the upcoming Athens Olympic games.

3. TECHNICAL OVERVIEW

The major technical challenge of this project was the subsoil in this region, which is not convenient for large construction. The sea here in the Gulf of Corinth is 65 metres deep and at the bottom of the sea bed, there is nothing but sand and silt for hundreds of metres deep.

The soil is too soft for any kind of construction. Rock bed is found 500 metres beneath thesubsoil. The only available solution was to build the piers with wide Caissons resting over the seabed. In addition, the Engineers had to reinforce the subsoil at a depth of 30 meters to make sure that the structures would resist earthquakes with a 2 metres shift in the position of piers. By reinforcing the subsoil, we make sure that the piers would absorb the seismic shocks instead of collapsing.

To construct the bridge, subsoil under each pier was strengthened with 25 to 30 metres hollow steel cylinders of 2 metres diameter were driven into the soil. The supporting caissons constructed 90 meters in dia are the largest ever built before. The piers of the Rion-Antirion Bridge can absorb seismic shocks during an earthquake to avoid the pears from damage. The road deck of the bridge was designed to overcome the seismic activities by swinging sideways. The road deck is not anchored to the piers, instead, they are suspended using cables. The road deck is attached to the viscous dampers with a fuse which protects the bridge from strong winds. During an earthquake, the fuse breaks apart and allows the dampers to absorb seismic energy during an earthquake and minimize movement.

4. SELECTION OF BRIDGE DESIGN

All Bridge designs are basically 4 types:- beam, arch, suspension, cable-stayed bridge.

Choosing the right design is always crucial as the main criteria were the length.

4.1 Beam Bridge

The longest bridges in the world are the beam type bridges, but this design does not work in the Gulf of Corinth. In the beam bridge flat road spans should be supported from the below approximately for every 100 metres. Hundreds of support piers like this may block major ship traffic.

4.2 Arch Bridge

An arch bridge can provide clearance for the huge cargo ship traffic, but to stretch The Gulf of Corinth it would need an arch bridge four times larger than any other arch bridge built before. This design was deemed highly risky.

4.3 Suspension Bridge

The Suspension bridge is able to leap the longest spans of any design. The enormous cables can suspend from one shore to the other, then shorter cables hang down to hold the roadway. But all these steel cables make the suspension bridge expensive, they cost hundreds of millions of pounds, Greece's government couldn't manage to build one.

4.4 Cable-Stayed Bridge

The only feasible option was a Cable-stayed bridge. In this bridge design, there are no expensive main cables. Instead, the smaller cables hung down from towers. But no cable-stayed bridge built till today can be able to serve the demands of the Gulf of Corinth.

5. DESCRIPTION OF THE BRIDGE

The total length of the Rion-Antirion bridge is 2883 meters (9,450 ft), and the three longest spans of the bridge are 560 meters (1,840 ft). The width of the bridge is about 27.2 meters (89 ft) and has two lanes per direction with an emergency lane and a pedestrian pathway on either side. Its 5 span, 4 pylon cable-stayed portion is of length 2,252 m (7,388 ft) is the world's third-longest Cable-stayed bridge, but the Rio–Antirion Bridge is considered as the longest Cable-stayed "Suspended" bridge in the world. The Rion-Antirion bridge is designed to hold out against earthquakes of 7.5 on the Richter scale. This Rion-Antirion bridge is considered to be an engineering marvel by solving many problems created in the site. These problems are deep water, soft subsoil, seismic activity, tsunamis and the extension of the Gulf of Corinth due to tectonic plates movement.

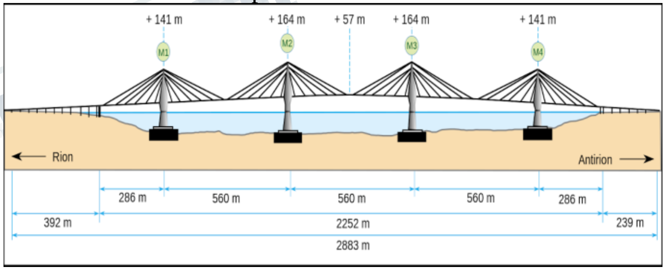

Figure 2: Bridge elevation

6. CHALLENGES DURING CONSTRUCTION

6.1 Foundation

For the engineers, the foundation of this bridge was a very huge engineering challenge, in fact when they still didn't know how they were going to lay their foundation. The sea here in the Gulf of Corinth is 65 meters deep and it is a big challenge by itself. At the bottom of the sea there is nothing but sand and silt for hundreds of meters depth and there is no solid foundation beneath. Solid foundations are curtailed to any structure especially when they are shaking due to frequent earthquakes. During an earthquake due to seismic activity, the sandy seabed loses its strength and converts into a liquid form known as Liquefaction. During trimmers, the soft and wet ground literally converts into a liquid which is very dangerous. Nobody in the world has ever before set out to build the bridge in these conditions. When a huge earthquake hit Koba harbour in japan in 1995 over 6000 people died, it measured 7.2 on the Richard scale as the ground was sandy and full of water. This is due to catastrophic liquefaction, literally, the previous solid ground became liquid. Normally, the engineers can drain the water from sand or compact the soil so that the water is forced out. But none of this was feasible in the Gulf of Corinth, we can't drain the bottom of the sea and sand to compact about 500 meters deep as it was an impossible task. There are no such solutions to the problems in the bridge builders manual. So, the engineers needed to come up with their own solution and they did. The solution was by strengthening the seabed by embedding 30 metres long and 2 meters wide metal cylinders, 250 cylinders or pipes are driven under each tower, during an earthquake these pipes should hold the soil firm, no one even tried ever before but the plan was convincing and the Vinci won the contract.

The huge metal cylinders were rammed into the sea bed using a hydraulic hammer by delivering 73 tons of force with each blow by which the seabed have been strengthened by holding the soil and the complete weight and load of the bridge is taken by these 4 piers. The engineers have been succeeded by keeping the bridge from descending into the ground during seismic activity.

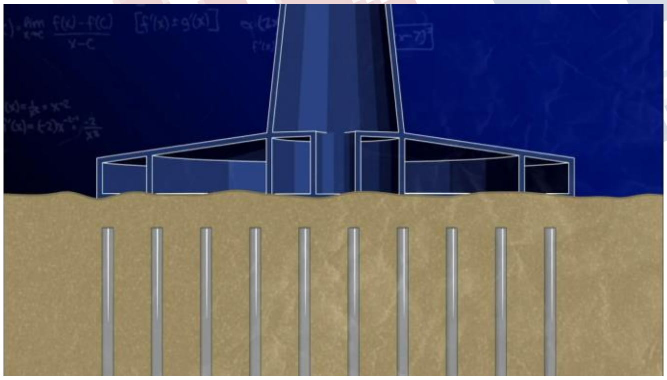

Figure 3: Soil reinforcement with inclusions

6.2 Toppling of towers during an earthquake

The piles or the cylinders are driven into the sea bed can prevent the piers from sinking but they cannot prevent the towers from toppling over. During an earthquake, the ground shakes strenuously side to side and moves huge piers with it, that would be a big problem for a big bridge.

The huge towers with 90 metres wide base need to move freely from side to side in order to keep it from falling over. If the base of the pier gets stuck, the entire bridge would topple over. The engineers needed to ensure that each pier can move independently during seismic activity.

During an Earthquake, the huge piers of Rion-Antirion Bridge would be forced sideways. When the piers move the leading edge of the pier puts more pressure on the sand under it until it's more than the sand could support it and piers dig in or tows in and the pier fall over.

The solution was by curling-up the pier base like giant sledge could be practically impossible to construct. The solution that Engineers chose was extreme, instead of changing the shape of the piers, the engineers decided to change the surface of the seabed beneath. Gravel was just what engineers needed, instead of changing the shape of the piers to make them curved up at the edges they changed the seabed with the layer of gravel. Clearly the solution for engineers to build the bridge on a layer of gravel at the bottom of the Gulf of Corinth. The Rion-Antirion bridge rests on a 3 metres thick layer of gravel laid over the steel cylinders. This allows the bridge piers to slide sideways without digging or towing into the sand bed. The engineers used enough gravel on the seabed beneath Rion-Antirion bridge to cover two football grounds and 3 meters thick. The towers are not anchored in any way, they simply rest on top of the 3-metre thick gravel. This means in the case of an earthquake the towers will slide on top of the gravel and the fiercest shaking will not be transmitted to the other parts of the bridge. Engineers calculated that the towers would be able to slide nearly two metres without compromising the bridge's integrity.

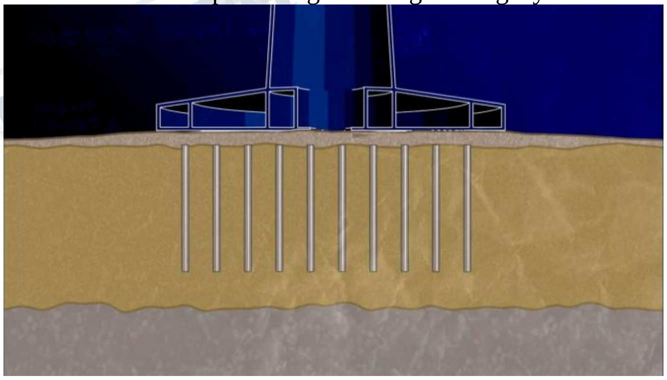

Figure 4: Foundation and soil reinforcement with inclusions

6.3 Settling of the foundation

Due to the added weight of the finished bridge, the foundation would sink into the seabed, but no one knows exactly how deep. It means disaster for the finished bridge so the engineers had to force the tower to settle before finishing by making them thousands of kilograms heavier.

To do this they used seawater to completely fill each pier, the plan worked and the water caused the foundations to finish settling. Now engineers knew that the bridge would be stable when finished.

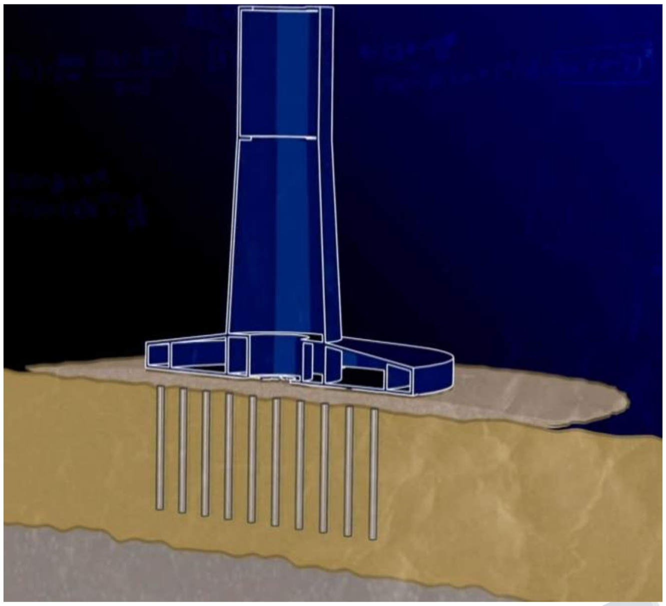

Figure 5: Cross-section of Pier and Foundation

6.4 Road deck during an earthquake

The bridge had transformed the lives of people in the northern and southern coast by becoming their everyday ride by converting a 14-minute ferry ride to 7-minute drive. On a normal day, 12000 cars use the bridge but on a busy day it could rise to 30000 cars, that's a lot of traffic. So, the bridge deck has 4 lanes and 2 safety lanes that could run for almost 3 kilometres in each direction. If the engineers fixed it to the piers and those piers that moved in an earthquake could buckle or break. To save the bridge deck during seismic activity, the engineers needed to build it in such a way that the road deck can move independently with respect to piers. So, engineers have taken the principle of a pendulum to help earthquake-proof the bridge. Just like a hammock, the road deck of the Rion-Antirion bridge fully swings from the top of the 4 piers using cables. When piers of the bridge shake during a seismic activity the deck swings freely on its own.

The road deck of the Rion-Antirion bridge can swing independently. But when it swings too far in either direction, it could smash into one of the four fine arts of the bridge piers, which is of 75000 tons of road deck hitting the piers of the bridge and it could destroy the bridge.

The engineers could not allow it to happen, but one of the objects as a huge road deck of the bridge starts to swing, needs something exceptional to stop from a collision. The solution was the viscous damper , an ultra-powerful braking system. Viscous dampers are widely used in many construction projects to cushion the movement. They are commonly used in aircraft carriers to stop an aircraft approaching at 200 kmph in short distance using catch wires which are attached to viscous dampers. The bridge is fitted with its own incredible safety system which looks like pistons are the viscous dampers which are the largest in the world. By which, the road deck does not move too much and hits the arms of the piers.

Figure 6: Viscous Dampers

6.5 Bridge during wind

The designers had designed this bridge particularly earthquake resistant to unpresidential solutions. But this flexibility of road deck created a new problem because not only earthquakes but other natural hazards occur in this region. The narrow stretch of the Gulf of Corinth having mountains on both sides makes a natural wind tunnel, where 110 kmph winds are common. The flexible bridge is excellent for Cushing seismic activities, but it is unstable during winds. Even when there are viscous dampers to soften the movements, the constant wind in the Gulf of Corinth can sway the bridge constantly.

An impossible choice for engineers to make the bridge flexible during an earthquake and on a normal day when there is no earthquake the bridge road deck would swing so violently and make it uncrossable for the vehicles due to wind in the Gulf of Corinth. But making it strong enough to withstand the winds by fixing it firmly in place and when there is an earthquake the bridge would snap and destroy. Engineers don't usually design things to fail, they build them to withstand the daily challenges they would face to be strong and rugged and to stay that way. At the right time making something fail predictably can make the difference between life and death. The solution was to implement a fuse in every viscous damper . It is designed to break at a particular limit when the load gets too high. The bridge can take the strongest winds but when an earthquake structs, the load exceeds the preset limit and the fuse attached to viscous dampers break.

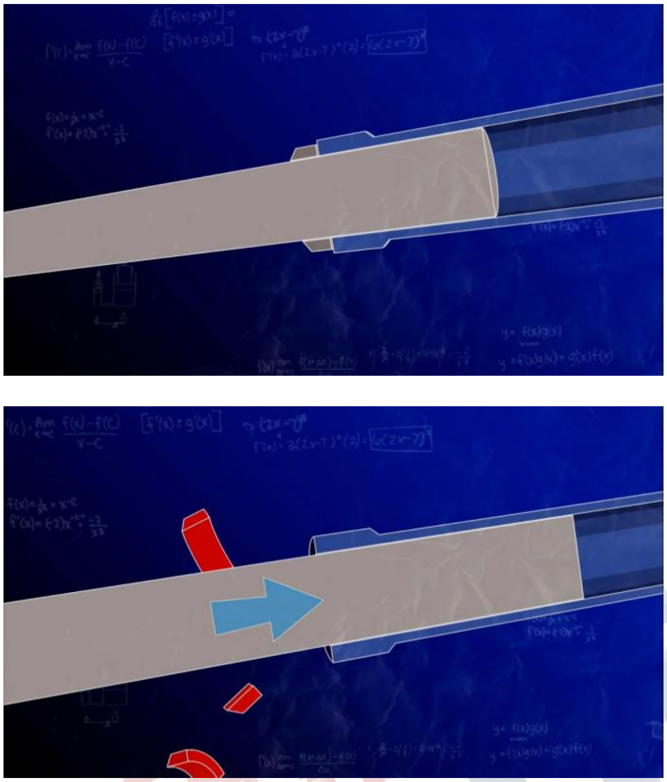

Figure 7: Fuse in viscous dampers

6.6 Vortex Shedding

Vortex shedding takes place when the wind blows across a cylindrical structure and vortices are shed alternately from one side to the other, due to which alternating low-pressure zones are created on the downwind side of the structure which gives rise to an alternating force acting at right angles in the direction of the wind. Due to this Vortex Shedding the cables can vibrate in such a way that it could tear the bridge apart and can move the towers of the bridge side to side and can move cables on bridges up and down. Luckily, British aerodynamicist Kit Scruton performed a study on how to overcome the danger due to vortex shedding and invented the helical strakes . It is an aerodynamic stabilizer provided on the cylindrical structures to protect it from the vortex shedding by breaking up the wind by hitting the cables. On the Rion-Antirion Bridge, each cable is provided with Kit Scruton helical strakes.

They break the wind hitting the cables by protecting cables from the phenomenon of vortex shedding.

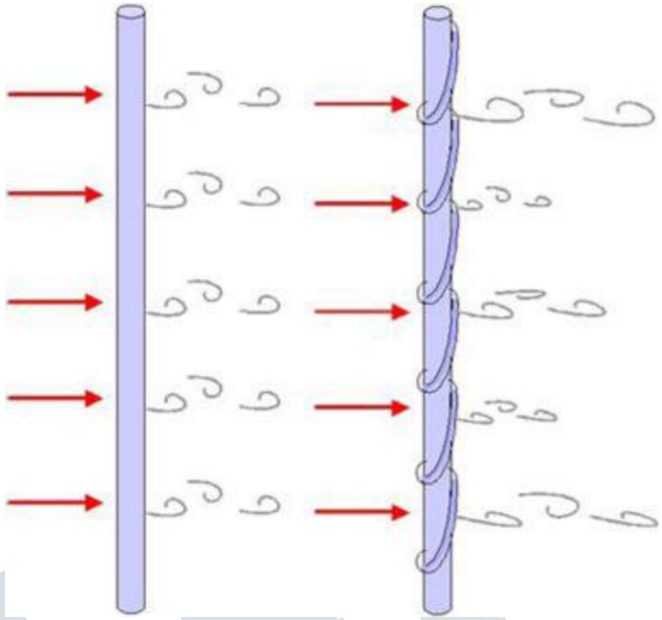

Figure 8: Working principle Kit Scruton

Figure 9: Kit Scruton helical strakes helical strakes

6.7 Moving costs

The fact is that Rion is moving away from Antirion. So, to solve this problem the Rion-Antirion Bridge is provided with the biggest expansion joints in the world, which allows the bridge to expand up to 5 metres due to two coasts drift away from each other. The Gulf of Corinth is stretching at the rate of nearly 30-mm every year.

Figure 10: Expansion Joints

7. CONCLUSION

The challenges faced by Rion-Antirion Bridge were previously impossible to achieve. It is the world's longest Cable-stayed bridge with the longest fully suspended road deck of 2252 m. It has the world's widest bridge foundation of about 90 metres dia and the deepest sitting 60 meters under the sea. Extraordinary engineering made the Rion-Antirion bridge to hold on, where other bridge designs would fail . The bridge was constructed in the region of active earthquake zones with natural wind tunnels and no solid foundation to construct. The engineers built a megastructure which can withstand all these hurdles. In Spite of all these construction problems, the engineers built the bridge 4 months earlier than scheduled by fulfilling a century-old dream of the bridge. Now it has become a part of the people in their daily life of people living in Rio and Antiri but the effect is felt far beyond these small towns because it has effectively redrawn the map of Greece.

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