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“Greece – A Sea & Land Transportation Hub Through the Centuries”

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Infrastructure Projects Production

Ways of producing Infrastructure Projects

- Public works (e.g. Egnatia Odos, Evripos Bridge, etc.)
- Concession (e.g. Attiki Odos, Rion-Antirion Bridge, Olympia Odos etc.)

**Concessionaire/ SPV** = private company (special purpose vehicle) comes to an agreement with the Public entity in order to provide a public service against a long-term exploitation and remuneration.
The following obligations are among those arising from the Concession Agreement (C.A.):

1. Implementation of the infrastructure (T1, with specific cost and time schedule, particularly important for technologically innovative constructions);

2. Safety of the user, availability of the infrastructure, ensuring the level of service (T2);

3. Safeguarding the Public Property (maintenance during the T2 period, technical improvements, dealing with crises, requirements for delivery/acceptance).
1. Brief Description of Rion Antirion Bridge

2. Structural Maintenance Dept: Scope & Organization

3. Access Means

4. Monitoring Overview

5. Regular/Heavy Maintenance

6. Special Events management

7. General Conclusions
Bridge Location

BRIEF DESCRIPTION OF RION ANTIRION BRIDGE
Environmental Site Conditions & Main Design Loads

- Weak sea-bed up to 500 m deep
- Water depth up to 65 m
- High-Seismicity & Strong Wind area
- Tectonic movements

- Return period 2000 years
- PGA 0.48 g, max Sa 1.20 g (0.2 up to 1.0 sec)
- Tectonic movements up to 2m (between adjacent piers)
- Design Wind speed 50 m/sec (hour mean at deck level)
- Ship collision:
  1. 86000 dwt bulk carrier (full laden) at 16 knots
  2. 180000 dwt tanker (on ballast) at 16 knots
Shallow foundation on reinforced soil
4 R/C piers (189m to 227m height) and 2 hinged steel frame abutments
2,252km continuous, composite section deck fully suspended from the top of pylons. Expansion joints are provided only on the two extremities.
- **in service:** +1,26/-1,15m (longitudinal direction)
- **in ultimate conditions:** +2,81/-2,20m (longitudinal direction) and ±2,6m (transversal direction)

- Dissipation system (consisted of 4 dampers on each main pier and 2 on each transition pier).
  - **in service:** the deck is laterally supported by means of a restrainer (nominal load: ±10,5MN for main piers, 3,4MN for TP)
  - **in ultimate conditions:** it fuses allowing the dissipation system to absorb the induced energy (dampers stroke: 3,5m)
Construction (cont’d)

Construction of pier base footing in dry dock
1) Underwater foundation
2) Transportation of floating part of pier (height 67m)
Construction of pylons

Cantilever deck construction

Installation and adjustment/tensioning of cables
The infrastructure management is a major issue for the economy of all countries. It requires the elaboration of a management system that shall have the following main objectives:

- Guarantee the safety of the users;
- Ensure a targeted level of service (that varies depending on the roads);
- Respond promptly to special events (crisis management);
- Upgrade the infrastructure (corrective works, technical improvements);
- Ensure that the heritage is preserved for future generations (long-term safeguarding of the asset).

The management system consists of a set of procedures that shall aim at ensuring the sufficient maintenance of all constructions. It includes methods, detailed models, data processing tools, organizational processes and the required data bases for its implementation.
Data base / records / analyses

- Inspection and Maintenance Manual, As-built drawings, Quality Records, Equipment maintenance & operation manuals, FEM etc. ... to the Concessionaire and the Project Owner by the Constructor. These documents, which are easily manageable through a Document Management software, are necessary for the appropriate analysis of the monitoring data as well as for any possible corrective works or technical improvements;

- The main Designer (VCGP), the technical advisors and the specialized suppliers are directly accessible by means of a specific procedure in case of Special Events.

- Annual inspection and maintenance reports are submitted to the competent authority (EYDE-LSEP) of the Project Owner (Greek State), while technical meetings are held on an annual basis with the competent authority and its technical advisors.
Rion Antirion Bridge - Maintenance Organization Chart

GEFYRA S.A.  
(Concessionaire)

Structural Maintenance Dpt.
• Structural elements
• Structural equipment
• Non-Structural equipment

Gefyra Litourgia S.A.  
(Operator)  
Maintenance Dpt.
• Non-Structural equipment
  ▪ E/M equipment
  ▪ Other equipment
• Toll Plaza Structures  
  (Operation Blg & Underground Gallery, Backfill)
Structural Maintenance Dept: “Scope of works” Chart

GEFYRA S.A. (Concessionaire)

Structural Maintenance Dpt.

- MB & AV Structural elements & equipment
- Toll Plaza Structures
- Non-Structural equipment (E/M & other)

Monitoring
- Visual Monitoring (inspections)
- Material Monitoring
- Instrumented Monitoring
  - Structural monitoring system (permanent)
  - Geometrical monitoring

Maintenance
- Regular Maintenance (Planned)
- Heavy Maintenance

Special Events Structural Management
- Earthquake
- Strong wind
- Fire
- Ship Collision
- Major Accident

Other projects
- Additional works
- Technical improvement works
- Remedial works
Access to piers & pylons internal and deck intrados (cont’d)

**Negative platform**
(Rion Viaduct Offshore)

**Secondary platform**
(under the deck)

**AWP**
(expansion joint & viaducts on land)

**Mobile aluminium scaffolding**
(footing)

**Cradle**
(Cone inspection)

**Cradle**
(Pier shaft)

**Cherry picker**
(Internal platform)
Access to piers & pylons external (cont’d)

- Inspection/maintenance of cable stays
- Inspection of pylon head
- Inspection of pylon head underside
- Inspection of pylon legs (1 alpinist per face)

Equipping the pier head for inspections
Pier head inspection
Expansion joint inspection
Underwater access

Potential measurement on Rion pile

Cleaning splash zone with hydraulic brush

ROV preparation on support vessel

Following ROV on CAD drawing from inside pier
## Visual Monitoring: Inspection levels

<table>
<thead>
<tr>
<th>Location</th>
<th>Level A inspections Every Year</th>
<th>Level B inspection Every Two years</th>
<th>Level C inspection Every Four years</th>
<th>Level D inspection Year 4 then every 8 years</th>
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</thead>
<tbody>
<tr>
<td>Antirion Viaduct</td>
<td></td>
<td>Localized inspections close to bearings &amp; dampers. Inspection of extrados and expansion joints.</td>
<td>Visual inspection of surfacing without specific accesses except for inspection at mid-span.</td>
<td>Complete detailed concrete inspection</td>
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<tr>
<td>Rion Viaduct</td>
<td>Inspection of the anticorrosion protection system</td>
<td>Localized inspections close to bearings &amp; dampers. Inspection of extrados and expansion joints. Steel/Concrete Interface for corrosion</td>
<td>Check of specific checkpoints on steel and concrete. Inspection of anti up-lift device on P7 and T0.</td>
<td>Complete detailed concrete inspection</td>
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<tr>
<td>Main Bridge Piers/Pylons</td>
<td>Inspection of the anticorrosion protection system of the pylon head</td>
<td></td>
<td>Complete visual inspection except submerged zone but including splash zone</td>
<td>Inspection of scour protection and external faces of footing &amp; cone (submerged zone).</td>
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</table>
Visual Monitoring: Tools (cont’d)

Computerized Inspections performed by in-house inspection engineers:

- Inspectors use *Rugged Tablet PC* on site
- Rope access inspectors use a specially prepared paper support on site, then data & photos are integrated by inspection engineers

Steel deck inspection with Secondary platform  
Concrete inspection on Intrados with Secondary platform  
Concrete inspection with rope access in pier head
→ Inspection Data Management
- Data are stored in a single database (easy historical retrieving)
  - Minimized interfaces from inspection to analysis
  - Automatic factual reports
  - Statistical analysis for the number of defects, location, evolution over the years.

- Customized software for data management (Scanprint)
Data Management Strategy Plan

MONITORING OVERVIEW

Data Management

Monitoring data → Data Storage → Data analysis → Decision

Strategy Plan

Visual Monitoring (inspections)
- Regular Inspections
- Specialized Inspections

Material monitoring
- NDT/DT on
  - Concrete
  - Pavement
  - Steel welds

Instrumented Monitoring
- Structural monitoring system (permanent)
- Geometrical monitoring

No Action
- Specific Monitoring
- Regular/Heavy Maintenance or Major remedial/Technical Improvement works
Material Monitoring: Concrete durability (Cont’d)

Risks:

- Chemical attack by seawater
- Corrosion induced by chlorides
- Corrosion induced by CO2

The solution adopted to protect the reinforcing steel relied on concrete durability (exposure zones & concrete cover definition, strict concrete specifications validated by testing, QC)

Monitoring is performed through DT on samples taken by a sacrificial wall built with the same procedures and materials in splash zone in 2004.
Scope of tests:

1. Update of the chloride diffusion coefficient.

2. Measurement of total and free chlorides contents as a function of the depth (from the face of the concrete to 80mm).

3. Numerical simulations for the current term and for a 120 year duration.
DATA RECORDS AND APPLICATIONS (cont’d)

Data files categories

• **History files** (0.5 sec averaged values recorded at regular intervals)

• **Dynamic files** (High sampling frequency >100 Hz)
  - Automatic (recorded every 2 hours)
  - Alert (Recorded due to threshold overpass)
  - Request (on end user demand)

Variation of induced force on deck with respect to wind

Calculation of deck creep and shrinkage
DATA RECORDS AND APPLICATIONS (cont’d)

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Single mode vibration identification

Modal identification of deck

Mode 1

Mode 3
Earthquake events

- Earthquake Identification/false alert prevention/ignore small events
- Real time evaluation of structural response (3 cases)
- Real time transmission of information-message to CR (traffic management)
- Notification of selected personnel (email/SMS/phone message)
- Automatic report creation within short time after the event and transmission to selected personnel

➢ The specific project was awarded in the category “Management” of International region of 2011 Vinci innovation awards prizes.
1. Regular maintenance (e.g. steel corrosion protection, etc.);
2. Specialized maintenance (e.g. cables, joints, etc.);
3. Special events (e.g. earthquakes, strong winds, etc.);
4. Heavy maintenance (e.g. asphalt pavement replacement, etc.);
5. Technical improvements / upgrading (e.g. lighting protection system, dampers).
Civil Maintenance works: Steel Elements

- Maintenance on flaking & low DFT
- Maintenance on corrosion protection defects from construction (pinholes)
- Maintenance on fasteners of HSFG joints
- Maintenance on corrosion defects on non-HSFG joints at the connections of the gantry rail
- Maintenance on flaking & low DFT
Civil Maintenance works: Cables

Maintenance of gussets (localised flaking of top coat + fading requiring complete recoat for aesthetic finish)

Complete restoration of corrosion protection of bichromated surfaces
Civil Maintenance works: Concrete Elements

Exposed reinforcement (low cover)

Treatment of Inserts in Concrete (from construction)
SECONDARY PLATFORMS (5 platforms of 38Tons each, dimensions: 4.2m x 31.2m)

- Design & fabrication of specific tooling is required for HM works.

Colors Designation:
- **Blue**: Traction Bogie
- **Red**: Supporting Bogie
- **Black**: G.R.& Drive Chain
- **Olive Green**: Swivel Crane
- **Magenta**: Main Motor/Gearbox
- **Green**: Emergency Brake
- **Orange**: Elevating Table
- **Cyan**: Parking Jack
E/M Maintenance : Secondary Platform

REGULAR MAINTENANCE
## Heavy Maintenance Program for 2013-2022

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<td>1</td>
<td>Maintenance of pavement &amp; joints</td>
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<td>1.1</td>
<td>Pavement asphalt &amp; concrete, footpath waterproofing</td>
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<td>1) Applying micro-surfacing on the Bridges</td>
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<td>2) Corrective works at the Toll Plaza</td>
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<td>HM Replacement of asphalt pavement</td>
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<td>1.2</td>
<td>Main Bridge expansion joints</td>
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<td>1.3</td>
<td>Approach viaducts expansion joints</td>
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<td>Maintenance of concrete, steel surfaces &amp; Cables, IEDD system, non-structural &amp; E/M equipment</td>
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<td>Cable stays &amp; Lighting Protection Cables</td>
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<td>Specialized inspection - maintenance</td>
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<td>2.6</td>
<td>Concrete surfaces</td>
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<td>Main Bridge seismic damping system</td>
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<td>Approach viaducts seismic damping system</td>
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<td>Non-structural &amp; E/M equipment</td>
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**MAINTENANCE ➔ HEAVY MAINTENANCE**
On 27th of January 2005 Cable C1S23W was set on fire

First actions:
- Traffic interruption
- Verify the structural integrity of the Bridge in order to be set back in traffic through:
  - WEASHM recorded data
  - Visual inspections
  - Geometric control
- Affected cables were removed

Post event actions:
- Exhaustive investigation to identify the origin of fire
- Improvement of lightning protection of the bridge based on investigation results

Bridge was open at 31st of January 2005 after verification of its integrity

2 Cables were replaced within about 40 days from incident
Investigation of fire origin

Tests performed:

• Mechanical
• Metallurgical
• Flammability
• Lightning reproduction
  • General (Elenko, Greece)
  • High Voltage (CEAT France, Airbus laboratory)
  • Current (DEHN, Germany)

Most probable scenario:

• Lighting strike of exceptional electrical characteristics stroke the cable duct at the edge of the collar (cross tie provision)
• Lightning punched a hole of the exact configuration found during the testing (orientation, size and location)
• The energy was sufficient to initiate a fire, that could persist through the interaction of the punched duct and the sealant mastic
• Under the produced heat, the cable strands lost their mechanical characteristics and collapsed.

Proposed and implemented improvement

• Earthing of the upper collars
• Replacement of joint mastic
• Protection of the upper cable stays by a stainless steel conductor placed above them (LPUC)
• Enhance pylon protection
Special Event: 23rd OF JANUARY 2006 WIND STORM (cont’d)

EVENT CHARACTERISTICS

- Eastern winds ~120° from deck axis
- Maximum wind speed (2’ average) 31.2 m/sec M1M2 28.3 m/sec M3M4
- Lower temperature 1.2 °C (ice formation on cables)

Wind speed during event

Ice formation on cables

Vibration amplitude (Gmr)
23rd OF JANUARY 2006 WIND STORM

Evaluation of bridge response (Strong wind event)

Evaluation of bridge response (after improvement works)

Implementation of selected improvement (dampers on long cable-stays)

Commissioning tests of selected improvement (M2SW12, target damping ratio $\xi=1\%$)

CSTB Analysis
An earthquake with magnitude $M_w = 6.5$ took place on June 8, 2008 at 15:25:28 local time.
The epicenter was located about $36\text{km}$ from Rion-Antirion site. Focal depth: $31\text{km}$
Max PGA recorded from on-shore accelerometers: $0.127g$ (at Rion bank)
8th OF JUNE 2008 EARTHQUAKE

Level 1 inspection
Elapsed time: 15 min
Inspector: on duty (not technical)
No findings

Level 2 inspection
Elapsed time: 4 hours
Inspector: Trained structural inspectors
Sign of movement on fuses (Pylon)

Level 3 inspection
Elapsed time: 2 days
Inspector: Trained structural inspectors
Minor non structural damage

Level 4 inspection & geometric control
Elapsed time: 2 months
Inspector: Trained structural inspectors and specialized suppliers
Minor non structural damage

Remedial Works
Elapsed time: 5 months

Deck re-alignment and fuse replacement

Analysis of Monitoring data
Expertise analysis on collected data
Evaluation of similar EQ’s return period
T= 80 to 120 years

Level 1 Monitoring report
First review of monitoring data recorded
SLS was not exceeded

Evaluation of return period through Arias intensity (Ia) and cumulative velocity (CAV)

8th OF JUNE EARTHQUAKE
Conclusions

The management strategy adopted on the “Charilaos Trikoupis” Bridge offers:

- Safety for the users
- Preservation of the asset
- Decisions based on rational monitoring data
- Structural health assessment whenever necessary
- Optimization of the processes through return of experience
- Trained local resources (supported by external expertise)
- Regulate & optimize maintenance cost
- Accuracy during long term budget forecasting
- An engineering reference for future projects
THANK YOU

FOR YOUR ATTENTION