RIO-ANTIRIO BRIDGE CONCRETE MAINTENANCE CONCEPT

MARCH 2016, M. DONADIO, A. STATHOPOULOS-VLAMIS, P. CORBETT ,
I. PAPANTONIOU AND N. ANAGNOSTOPOULOS
SIKA SERVICES AG, GEFYRA S.A., SIKA HELLAS SA

GEFYRA
RIO ANTIRIO
CHARILAOS TRIKOUPIS

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- MAINTENANCE STRATEGY
- CASE STUDY – PYLON BASE PRE-STRESSING CONCRETE COVERS
  - Location, Findings & Analysis
  - Requirements & Preselection of the process
  - Selection of Material Technology
  - Preliminary trials/Results
  - Application procedure
  - Quality control-Compliant with the Integrated Management System
- CONCLUSIONS

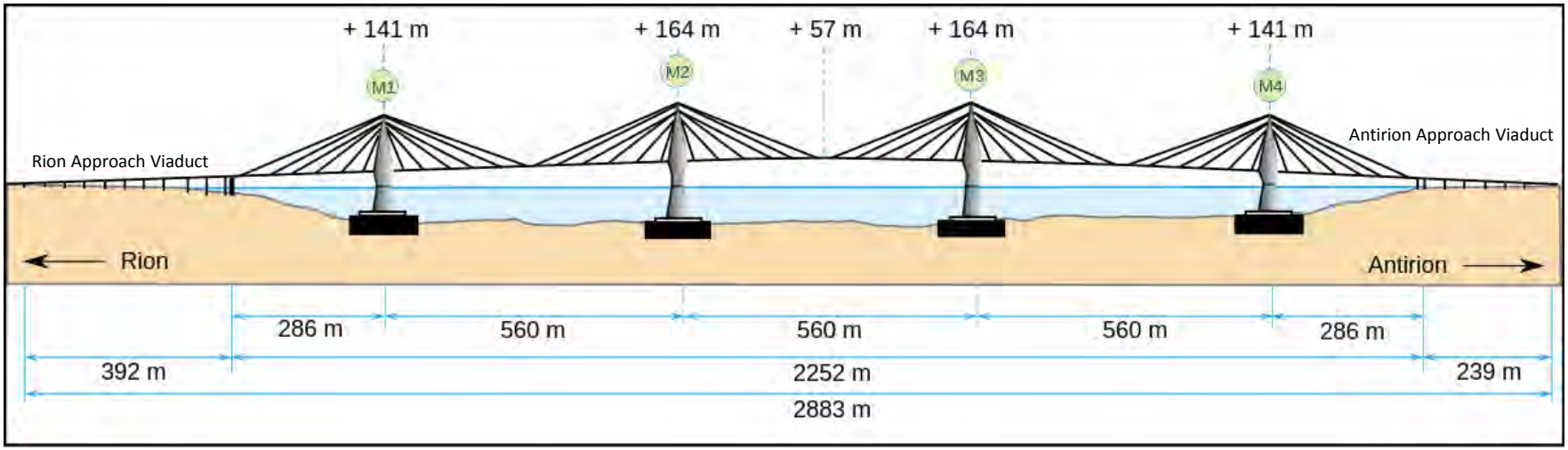
INTRODUCTION
OBJECTIVES OF THE PRESENTATION

- This presentation aims to
  - Outline the key points of the maintenance strategy for concrete elements which is applied by the Concessionaire.
  - Illustrate this approach by an example. In this application Hydrophobic impregnation was applied to concrete elements of the bridge.
  - Highlight the efficiency of Hydrophobic impregnation in dense concrete mixes.
  - Highlight the importance of high level of cooperation between the client & the supplier of the applied material.

INTRODUCTION
THE RION-ANTIRION PROJECT

- Located in the western end of the Gulf of Corinth in Greece, the Rion-Antirion Bridge links the Peloponnese to the Greek mainland.
- The Rion Antirion Bridge is a four span stay cabled bridge with total length equal to 2252 m which started operating in 2004 after 7 years for the financing, design and construction stage.
- The shipping clearance below the deck is 52 m in the middle of the strait, leaving ship traffic undisturbed. The navigation channel between the middle pylons and has a width of 300m.

INTRODUCTION
TECHNICAL DESCRIPTION



Description

- Cable-stay bridge. Continuous suspended deck (steel-concrete composite).
- Four pylons – Maximum foundation depth 65 m.
- Seabed reinforcement with steel inclusions (steel pipes 20 mm thickness).
- Diameter of footing 90/80 m.
- Maximum height +227 m from the sea bed.

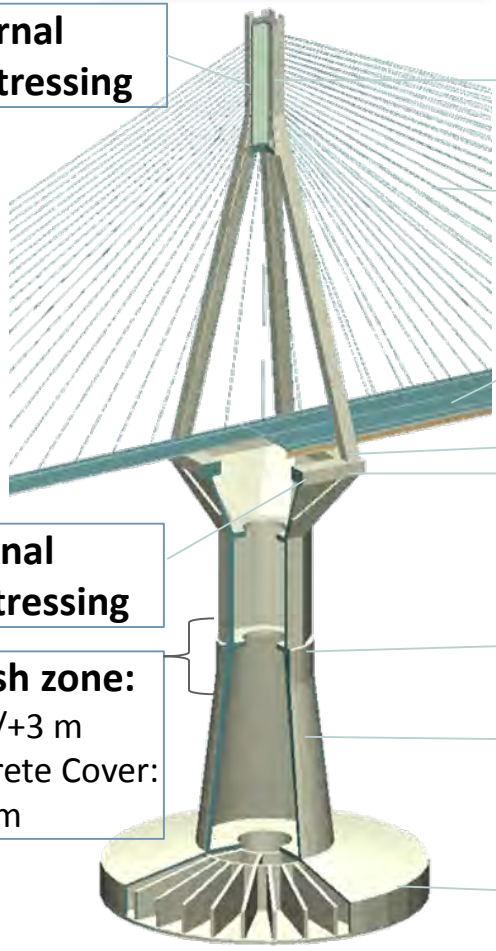
In numbers

- **190.000** m^2 concrete surface
- **125.000** m^2 steel elements
- **61.600 m** cables
- **283.000** deck bolts
- **20** dampers & **4** fuses
- **268** external pendular dampers (for cables)
- **5** maintenance gantries of 37 tons each
- **77** sensors for instrumented monitoring

INTRODUCTION

CONCRETE ELEMENTS /MAIN STRUCTURAL EQUIPMENT

Concrete Elements



External prestressing

Internal prestressing

Splash zone:
-5 m/+3 m
Concrete Cover: 75 mm

Pylon Head
Strength Class: C 60/75
Concrete Cover:50 mm

Deck
Strength Class: C 60/75
Concrete Cover:40 mm

Pier Head
Strength Class: C 45/55
Concrete Cover:75 mm

Pier Cone
Strength Class: C 45/55
Concrete Cover: 50 mm

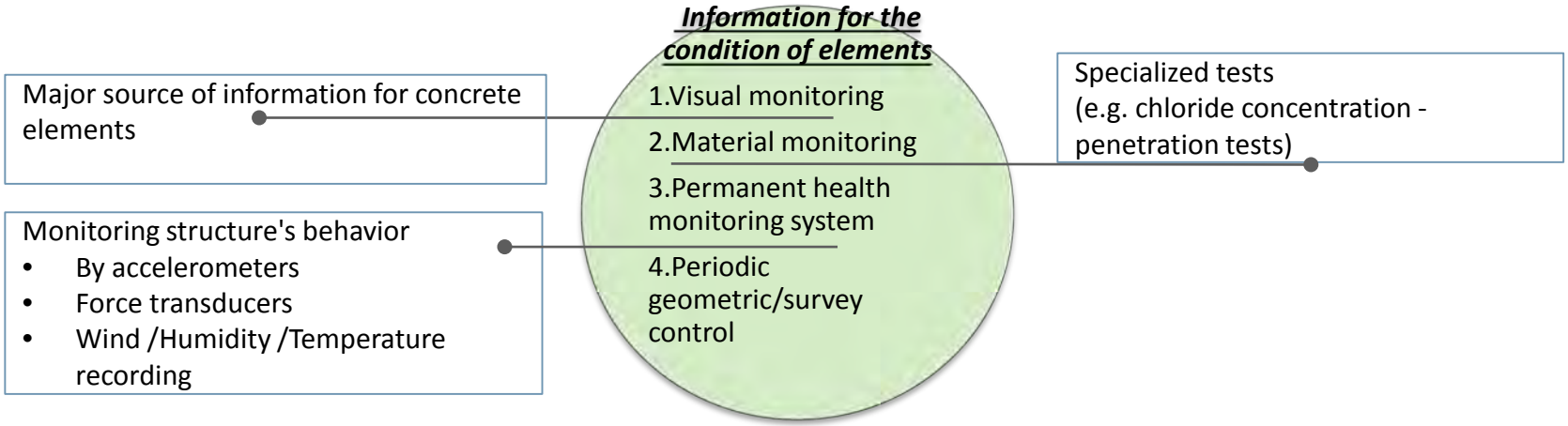
Pylon legs
Strength Class: C 60/75
Concrete Cover:50 mm

Pylon base
Strength Class: C 50/60
Concrete Cover:75 mm

Pier Shaft
Strength Class: C 45/55
Concrete Cover: 75 mm

Pier Footing
Strength Class: C 45/50
Concrete Cover:50 mm

MAINTENANCE STRATEGY
KEY POINTS



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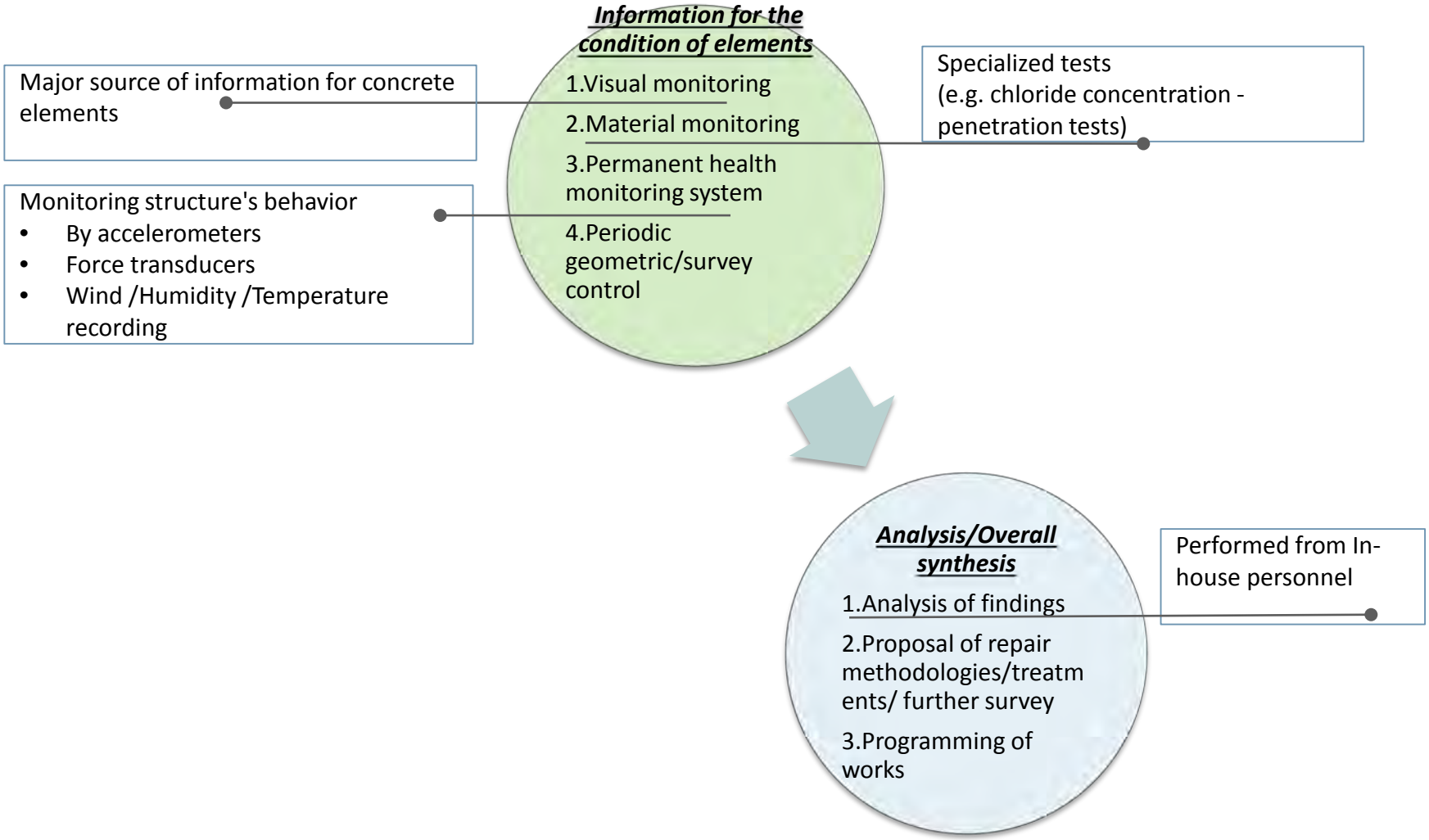

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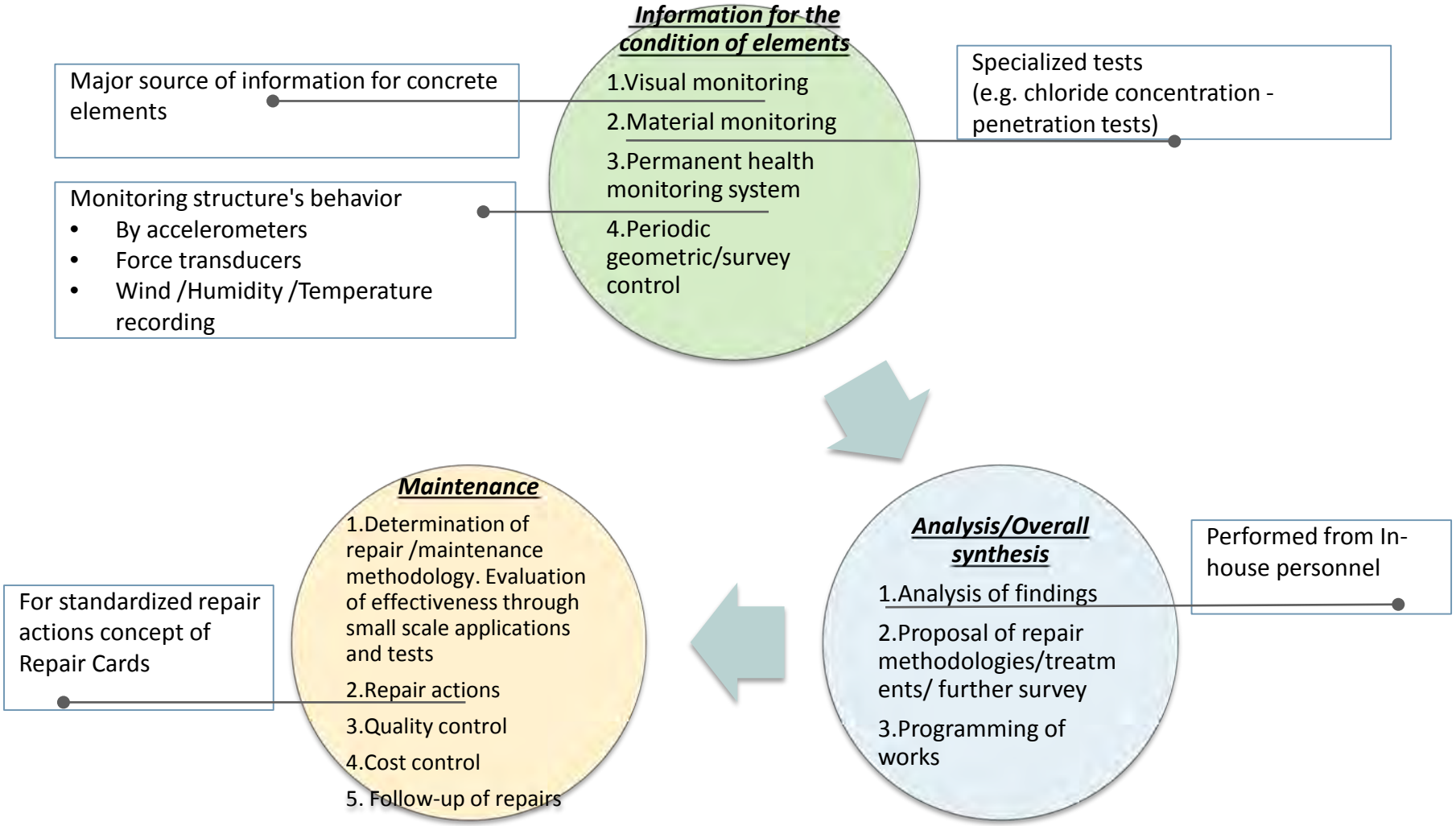


MAINTENANCE STRATEGY
VISUAL MONITORING

- Internal and external faces
- For areas with Regular Access → internal resources
- For areas with access difficulty→ Specialized Rope Access Team/divers
- Use of dedicated inspection software →Traceability of defects /irregularities

Rope Access Team

Regular Personnel

Inspection in the splash zone with divers

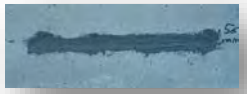
Underwater inspections with ROV

MAINTENANCE STRATEGY

INTEGRATED MANAGEMENT SYSTEM

Quality-performance validation

Exposed Reinforcement defects/Low cover treatment



Real and accelerated exposure conditions

Follow -up of corrosion products development

Repair Methodology follow up

- Repair Cards concept
  - Coded procedures for concrete repairs- Standardization of treatments
  - Description not only of repair materials but also treatment's special characteristics
  - Follow up of repair methodology performance through visual inspections
  - "Common language" for inspection-maintenance-rope access team

In total 88 procedures are currently issued

MAINTENANCE STRATEGY
INTEGRATED MANAGEMENT SYSTEM

Training of personnel

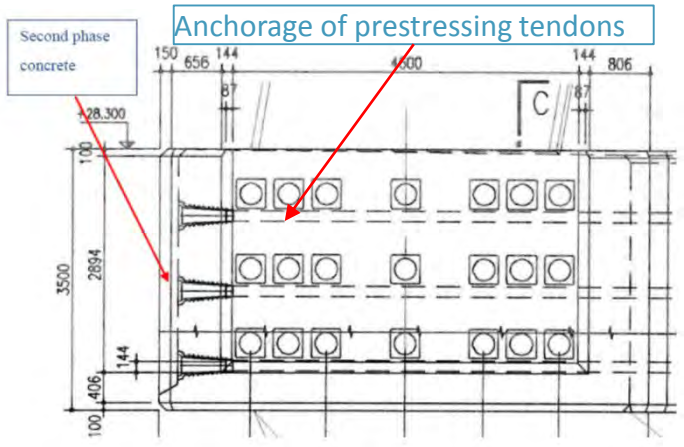


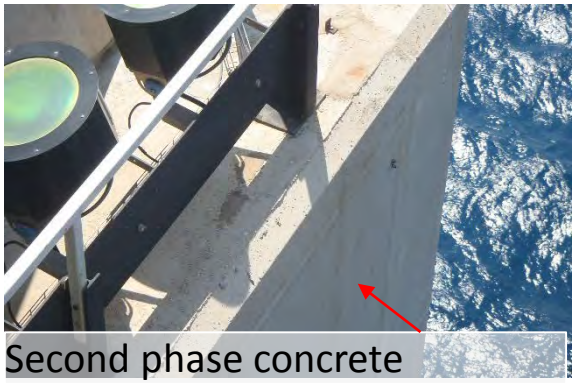





CASE STUDY
LOCATION, FINDINGS & ANALYSIS

- The Pylon Base acts as a restraining hoop for the base of Pylon Legs and ensures the transition of forces from the Pylon to the Pier.
- The restraining action is achieved by prestressing (P/T).
- The tendons are anchored in the corners of Pylon Base.
- The anchors are covered with “second phase” reinforced concrete /strength class C 60/75 (8 faces of P/T anchors per pier - 32 faces in total).
- Minor cracks (<0.200 mm) were found in a routine inspection in 2009. Also the exposed construction joint was highlighted by the inspectors.
- **Protection against water & chloride ingress was proposed after the analysis of findings.**




Second phase concrete


Construction joint

CASE STUDY
REQUIREMENTS & PRE-SELECTION OF PROCESS

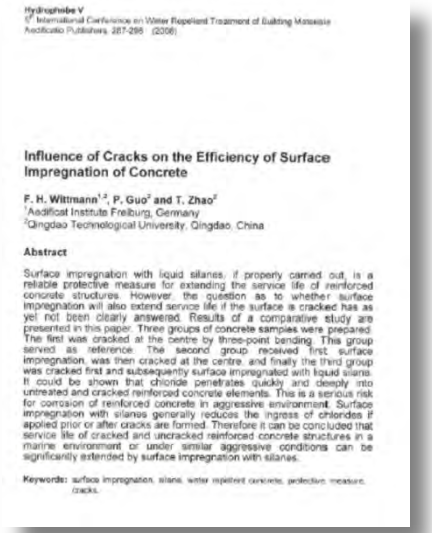
Requirements

- Durability of the technical solution (Technical efficiency, Durability against UV radiation)
- Aesthetic concern (Visible surfaces)
- Applicability : 90% of the surface would be addressed by Rope Access Team which creates a significant cost factor, so special attention should be given to the preparation & application method as well as the overall intervention time and reapplication interval.
- Removal cost in case of material failure
- Environmental consideration (for application and subsequent maintenance)
- Safety of personnel

According to EN 1504-2, Coating or Hydrophobic impregnation would be the favorable technical solution. These solutions were investigated from the Concessionaire.

CASE STUDY
SELECTION OF MATERIAL TECHNOLOGY

- Consider using hydrophobic impregnation treatment for the vertical surface
- Consider using crack bridging cement based coating for the horizontal surface



Hydrophobe V
5th International Conference on Water Repellent Treatment of Building Materials
Aedificatio Publishers, 287-296 (2008)

Influence of Cracks on the Efficiency of Surface Impregnation of Concrete

F. H. Wittmann[1,2], P. Guo[2] and T. Zhao[2]
[1]Aedificat Institute Freiburg, Germany
[2]Qingdao Technological University, Qingdao, China

Abstract

Surface impregnation with liquid silanes, if properly carried out, is a reliable protective measure for extending the service life of reinforced concrete structures. However, the question as to whether surface impregnation will also extend service life if the surface is cracked has as yet not been clearly answered. Results of a comparative study are presented in this paper. Three groups of concrete samples were prepared. The first was cracked at the centre by three-point bending. This group served as reference. The second group received first surface impregnation, was then cracked at the centre, and finally the third group was cracked first and subsequently surface impregnated with liquid silane. It could be shown that chloride penetrates quickly and deeply into untreated and cracked reinforced concrete elements. This is a serious risk for corrosion of reinforced concrete in aggressive environment. Surface impregnation with silanes generally reduces the ingress of chlorides if applied prior or after cracks are formed. Therefore it can be concluded that service life of cracked and uncracked reinforced concrete structures in a marine environment or under similar aggressive conditions can be significantly extended by surface impregnation with silanes.

Keywords: surface impregnation, silane, water repellent concrete, protective, measure, cracks.

Hydrophobe V
5th International Conference on Water Repellent Treatment of Building Materials
Aedificatio Publishers, 289-310 (2008)

Investigation of Chloride Ingress in Cracked Concrete Treated with Water Repellent Agents

J. Dai[1], Y. Akira[1], E. Kato[1] and H. Yokota[1]
[1]Life Cycle Management Research Centre, Port and Airport Research Institute, Japan

Abstract

In this paper, results of a test are presented in which reinforced concrete (RC) prisms treated with different water repellent agents have been exposed to cyclic seawater shower for one year. Purpose of the test was to investigate how the water repellent treatment influences the water absorption and chloride ingress into reinforced concrete with and without the existence of cracks. Uncracked RC prisms, some cracked before the water repellent treatment, and some cracked after the water repellent treatment were prepared for comparison. Four types of water repellent agents, i.e. liquid silane, liquid silane/oligomeric siloxane, silane-based cream and silane-based gel were applied to treat the concrete surface. Time-dependent water absorption of all the un-cracked and cracked RC prisms was monitored. After one-year exposure, all the specimens were broken open. The penetration depths of water repellent agents in the treated specimens were measured and corrosion areas of the inner steel reinforcement were quantitatively evaluated. The chloride ingress profiles in the cracked and un-cracked RC prisms were evaluated using electron probe microscopy analysis (EPMA). Based on the test results, effectiveness of water repellent treatment as a water and chloride barrier of cracked concrete under marine environment is discussed.

Keywords: cracks, concrete, water repellent agents, chloride ingress

Numerous independent papers report that the use of hydrophobic impregnation can prevent moisture ingress even in the presence of cracks

CASE STUDY
SELECTION OF MATERIAL TECHNOLOGY

Basis for the decision to use hydrophobic impregnation

Requirements	Proposed hydrophobic impregnation
Durability - technical	
Durability – UV radiation	
Aesthetic	
Applicability	
Removal cost	
Environmental aspect	
Safety of personnel	

CASE STUDY
SELECTION OF MATERIAL TECHNOLOGY

Basis for the decision to use hydrophobic impregnation

Requirements	Proposed hydrophobic impregnation
Durability - technical	Proven efficiency in presence of cracks and independent data has shown up to 20 years durability from field experiments with regards to chloride penetration in marine environment.
Durability – UV radiation	
Aesthetic	
Applicability	
Removal cost	
Environmental aspect	
Safety of personnel	

CASE STUDY
SELECTION OF MATERIAL TECHNOLOGY

Basis for the decision to use hydrophobic impregnation

Requirements	Proposed hydrophobic impregnation
Durability - technical	Proven efficiency in presence of cracks and independent data has shown up to 20 years durability from field experiments with regards to chloride penetration in marine environment.
Durability – UV radiation	Key success factor of the technology will depend on how much the product is able to migrate within the concrete. Although silicone networks are known to be highly resistant to UV, this is of little concern as the product is supposed to migrate in the concrete; hence it will be protected against UV radiation
Aesthetic	
Applicability	
Removal cost	
Environmental aspect	
Safety of personnel	

CASE STUDY
SELECTION OF MATERIAL TECHNOLOGY

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Aesthetic	“Invisible” protection as the product does not form a film at the surface of the concrete
Applicability	
Removal cost	
Environmental aspect	
Safety of personnel	

CASE STUDY
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Aesthetic	"Invisible" protection as the product does not form a film at the surface of the concrete
Applicability	Cream product will allow the Rope Access Team a fast and relatively easy application – with reduced number of passes
Removal cost	
Environmental aspect	
Safety of personnel	

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Applicability	Cream product will allow the Rope Access Team a fast and relatively easy application – with reduced number of passes
Removal cost	Only potential negative point as once applied at the surface of the concrete, it will be impossible to remove the product
Environmental aspect	
Safety of personnel	

CASE STUDY
SELECTION OF MATERIAL TECHNOLOGY

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Removal cost	Only potential negative point as once applied at the surface of the concrete, it will be impossible to remove the product
Environmental aspect	Water based product in cream form. Very little wastage and dripping of the material is expected
Safety of personnel	

CASE STUDY
SELECTION OF MATERIAL TECHNOLOGY

Basis for the decision to use hydrophobic impregnation

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Environmental aspect	Water based product in cream form. Very little wastage and dripping of the material is expected
Safety of personnel	Water based product. Only cleaning of the tools requires solvent. This operation can be done in safe environment

CASE STUDY
SELECTION OF MATERIAL TECHNOLOGY

Basis for the decision to use hydrophobic impregnation

Requirements	Proposed hydrophobic impregnation
Durability - technical	Proven efficiency in presence of cracks and independent data has shown up to 20 years durability from field experiments with regards to chloride penetration in marine environment.
Durability – [illegible]	Key success factor of the technology will depend on how much the product is able to migrate from the concrete. Although silanes and siloxanes are known to be highly resistant to UV, this is of little concern as the product is supposed to migrate in the concrete; hence it will be protected against UV radiation.
Aesthetic	"Invisible" protection as the product does not form a film at the surface of the concrete
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Key Parameter for Successful Treatment: Penetration Depth

CASE STUDY
PRODUCT SELECTION

- Hydrophobic impregnation:
  - Silane cream type, high active content (80%)
  - Comply with EN 1504-2, principles 1, 2 & 8
    - Class I for drying rate
    - Class II for penetration depth (>10 mm)

- Cement based coating:
  - 1-comp product – to be mixed with water
  - Comply with EN 1504-2, principles 1, 2 & 8
  - Crack bridging A3

CASE STUDY
PRELIMINARY TRIALS

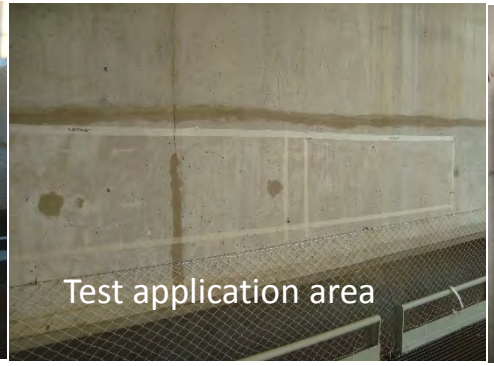
Questions about proposed remedial solutions…..

1. Is the impregnation able to penetrate into dense concrete structures?
2. Applied quantity required?
3. The application means (considering material losses & productivity)
4. Compatibility with other treatments (cementitious)

CASE STUDY

PRELIMINARY TRIALS FOR HYDROPHOBIC IMPREGNATION


Surface treatment


Test application area

Humidity substrate measurements

Area after the application of material


Area after the application of material


Extraction of cores

2 rates of application: 500 & 700 g/m^2

CASE STUDY

PRELIMINARY TRIALS FOR HYDROPHOBIC IMPREGNATION

- Hydrophobic Impregnation*:
  - Penetration depth
  - Capillary uptake

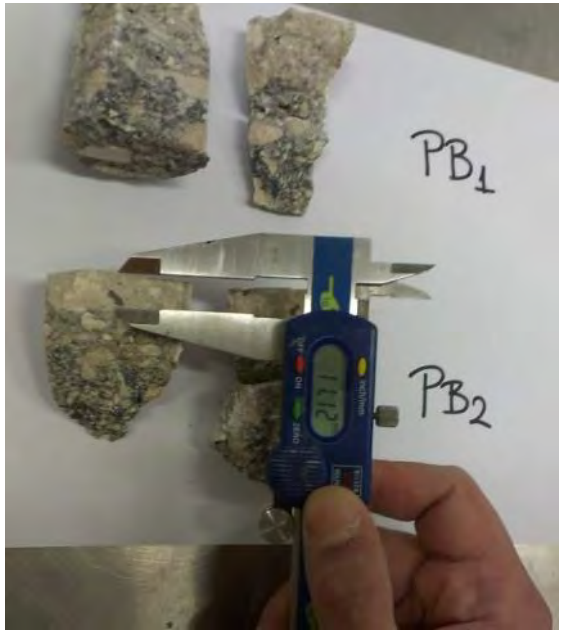
- Cement coating / Hydrophobic treatment
  - Adhesion test

Note*: The tests are planed to be performed after 90 days, 1, 2, 3, 4, 5, 8 & 10 years after treatment

CASE STUDY

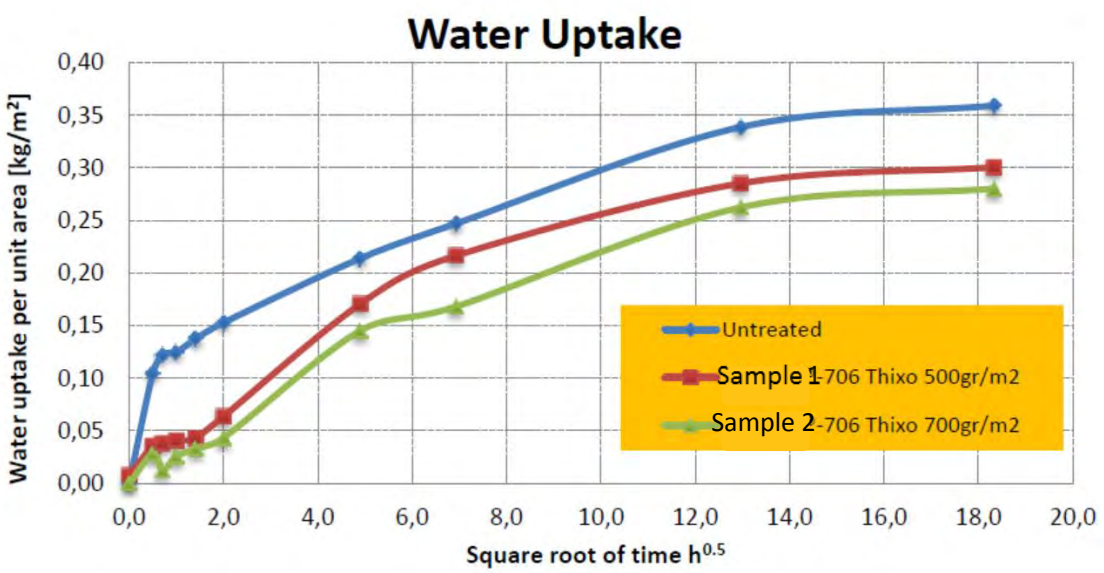
PRELIMINARY TRIALS FOR HYDROPHOBIC IMPREGNATION – TEST RESULTS

Consumption rate	Penetration depth	
	Achieved	Targeted
500 g/m^2	7.8 mm	> 5mm
700 g/m^2	10.2 mm	> 5mm



CASE STUDY

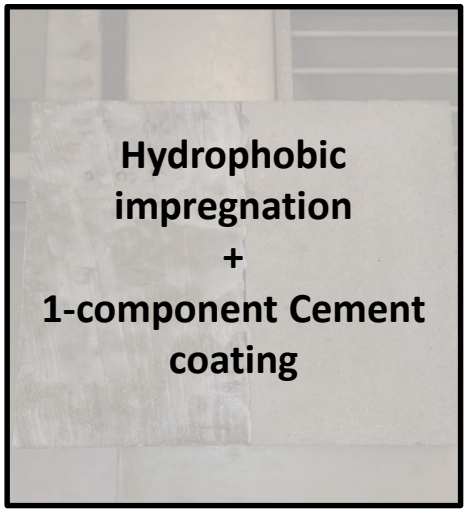
PRELIMINARY TRIALS FOR HYDROPHOBIC IMPREGNATION – TEST RESULTS

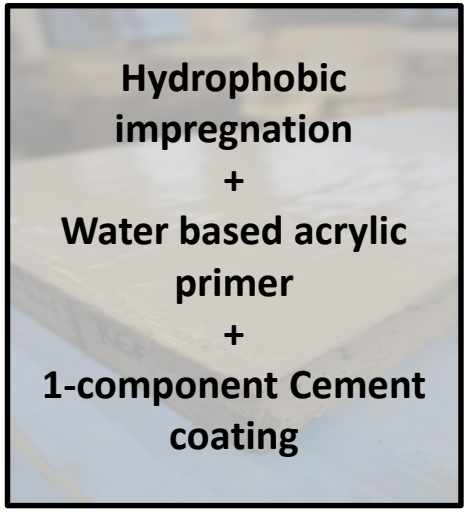


CASE STUDY

PRELIMINARY TRIALS FOR HYDROPHOBIC IMPREGNATION – COMPATIBILITY TESTING

- Concept of compatibility testing





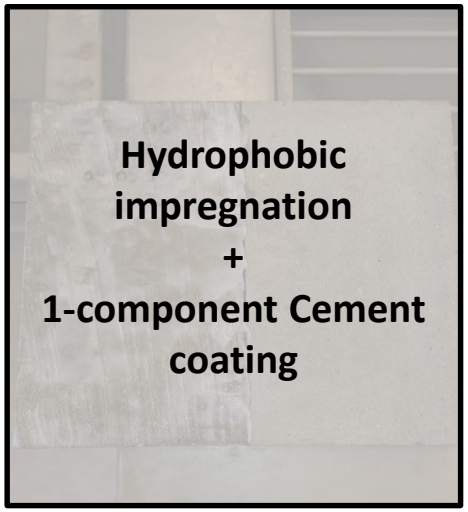
System	Delay between application
Hydrophobic – cement coating	7-days
Hydrophobic – acrylic primer	7-days
Acrylic primer – cement coating	2-hours

CASE STUDY

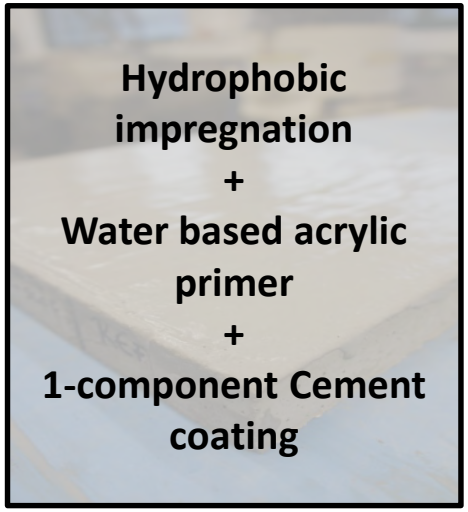
PRELIMINARY TRIALS FOR HYDROPHOBIC IMPREGNATION – COMPATIBILITY TESTING

- Pull off test

1.905 N/mm^2
Break in cement coating

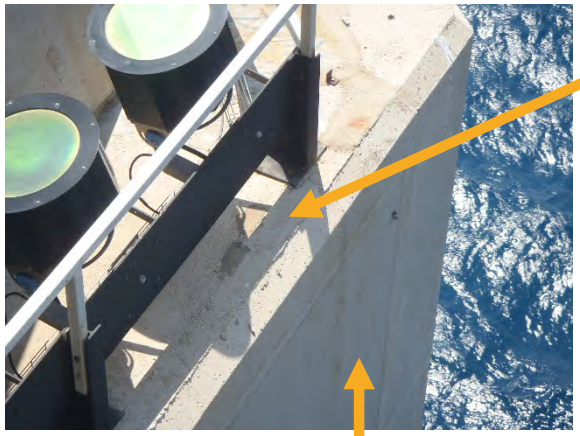


1.793 N/mm^2
Break in cement coating



1.964 N/mm^2
Break in cement coating

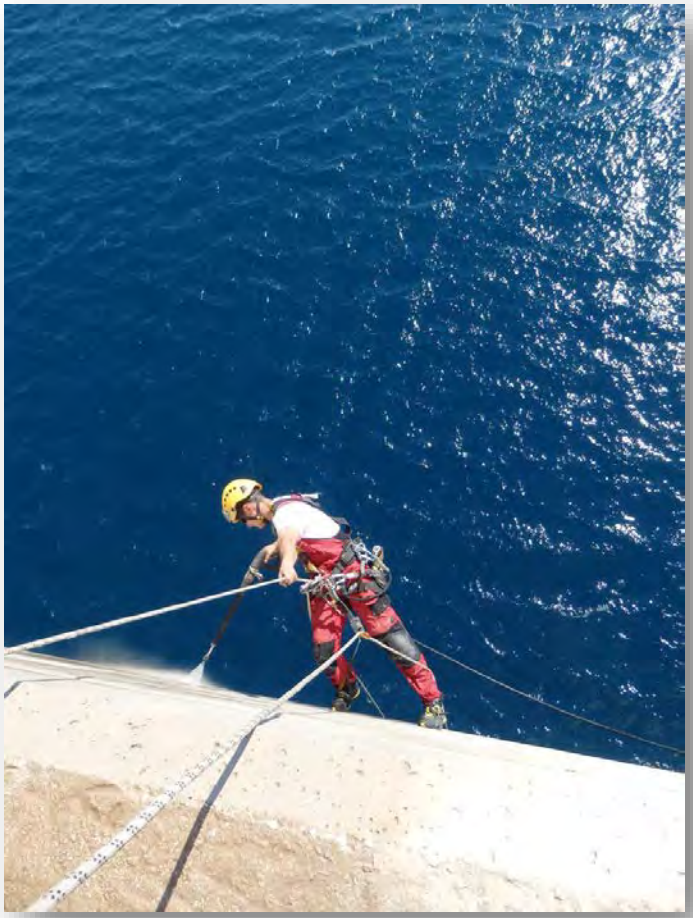
CASE STUDY
VALIDATED & AGREED REPAIR METHODOLOGY



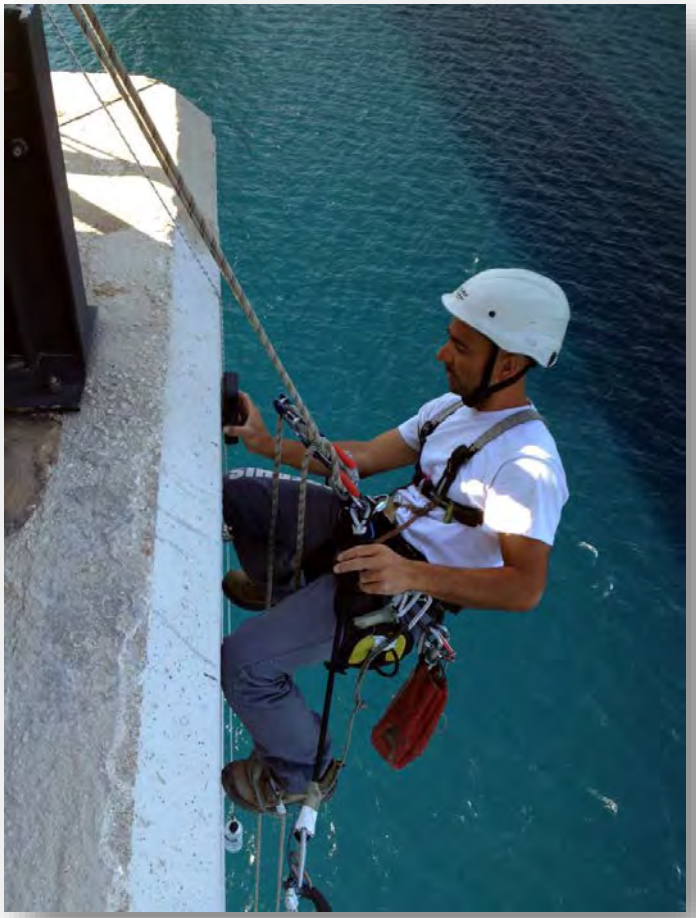
Application of cementitious waterproofing mortar on the top surface.

Application of Hydrophobic impregnation 600 gr/m^2 in the vertical surfaces.

CASE STUDY
APPLICATION PROCEDURE - VERTICAL SURFACE



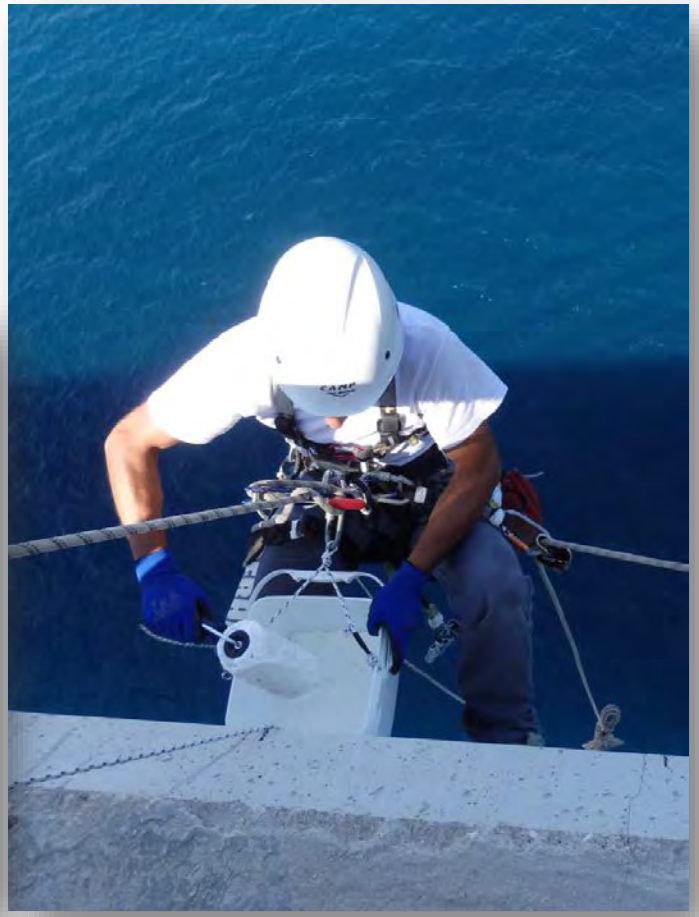
Surface preparation-Low pressure washing ≈ 80 bar



Substrate humidity measurements

CASE STUDY
APPLICATION PROCEDURE - VERTICAL SURFACE

Application with roller



CASE STUDY
APPLICATION PROCEDURE - TOP SURFACE

1) Temporary removal of steel supports in way of the repair area,
2) Application of cementitious waterproofing mortar

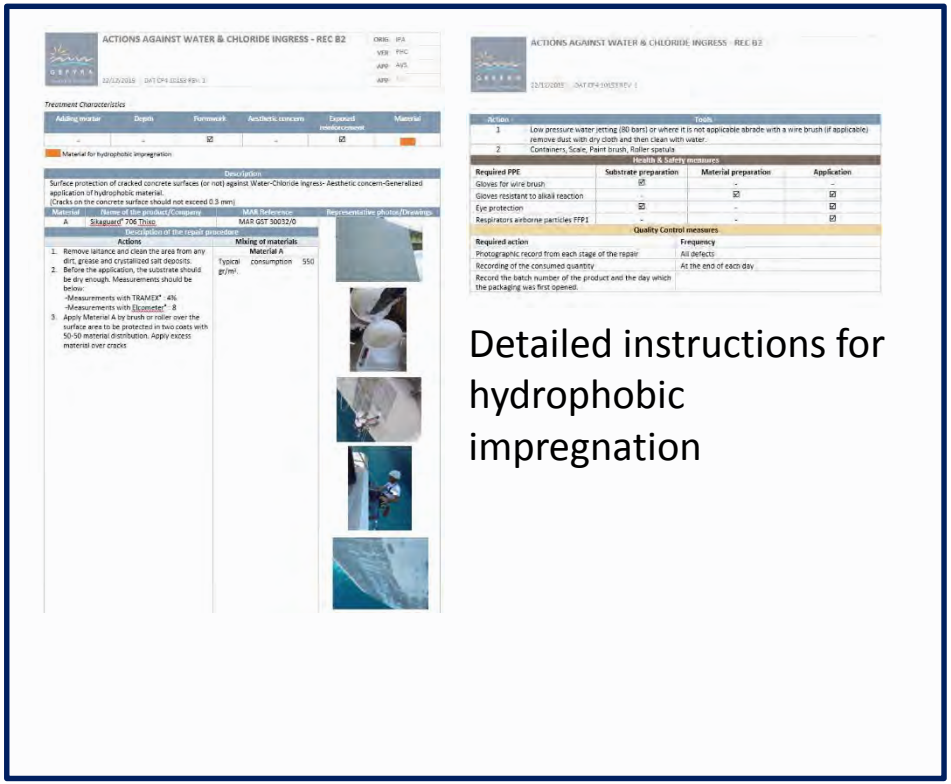
CASE STUDY
QUALITY CONTROL

- The application area was divided in zones in order to apply the pre-weighed batches of material.
- Before the application of material the following measurements were performed and recorded.
  I. Substrate humidity measurement
  II. Surface temperature measurements
  III. R.H (%) level and temperature in the atmosphere.

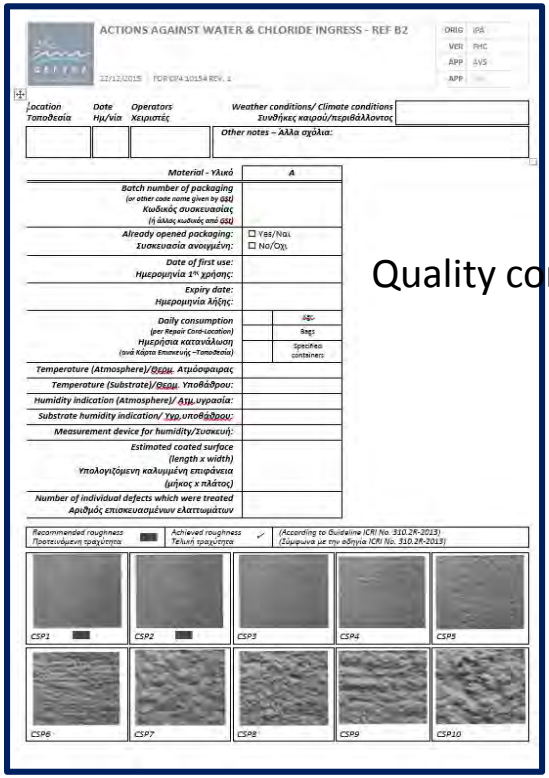
CASE STUDY

INTEGRATED MANAGEMENT SYSTEM – REPAIR CARDS

The maintenance team issued the Repair Card for Hydrophobic impregnation. Details for the application, the Personal Protective equipment and the necessary tooling are given. Also the respective quality control form was issued. In the form, the staff has to complete questions related to: applied quantity, the application surface & the quality control measurements



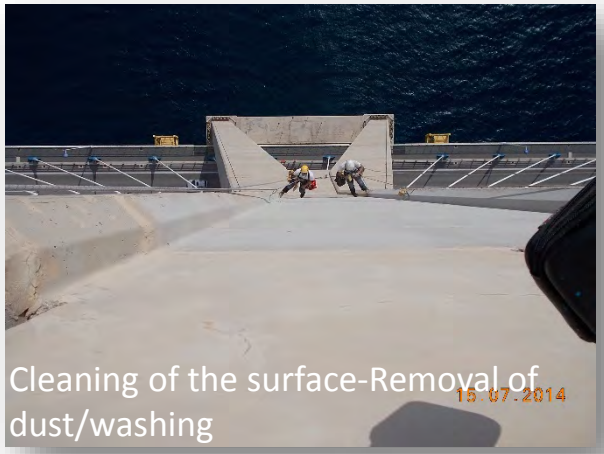
Detailed instructions for hydrophobic impregnation



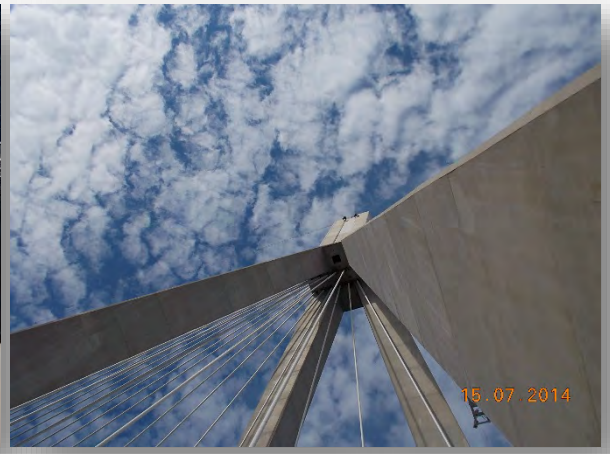
Quality control forms

Roughness characterization

CASE STUDY
OTHER APPLICATIONS OF THE VALIDATED SYSTEM



Cleaning of the surface-Removal of dust/washing




Application


View after the application

CONCLUSION

- Selection of product “by the book” following EN 1504 process; from the first identification potential defects to possible technical solution by the Concessionaire.

- High level of cooperation between the client and the supplier ensured the success of maintenance actions, through extensive dialogue, technical support and laboratory studies.

CONCLUSION

The thorough validation process prior to application:

- ✓ Showed good penetration achieved despite high quality concrete,
- ✓ Confirmed compatibility between cement based coating and surface treated with hydrophobic impregnation,
- ✓ Defined factors of applicability and quality control

CONCLUSION

- The presented maintenance strategy minimizes the risk for development of defects of high severity and high maintenance cost through a durable and aesthetically acceptable prevention of chloride ingress in the concrete.

- Maintenance team will continue monitoring the performances of the protection system over time

Thank you for your attention

Any questions ?