Construction

# Technology and Concepts for the Repair and Protection of Reinforced Concrete

# Corrosion Management in Reinforced Concrete Structures
## The Key Stages in the Process

**The successful repair and protection of concrete structures which have been damaged or which have deteriorated requires professional assessment, then design, supervision and execution of technically correct principals – according to the forthcoming European Standard being developed by EN 1504.**

**This brochure is intended to give guidance on the correct procedure and on the appropriate products and systems for the selected strategy. The key stages in the process are:**

### 1 Assessment Survey of the Condition of the Structure

The assessment of the condition of a damaged or deteriorated reinforced concrete structure should only be made by qualified and experienced people.

The process of assessment will always include the following aspects:

- The current condition of the structure including visible, non-visible and potential defects.
- Review of the past, current and future exposure.

### 2 Diagnosis of the Cause of Deterioration

Following review of the original design, construction methods and programme, and the assessment survey, identify the "root causes" of damage:

- Identify mechanical, chemical and physical damage to the concrete.
- Identify concrete damage due to reinforcement corrosion.

### 3 Determine the Repair and Protection Objectives

With most damaged or deteriorated structures the owner has a number of options which will effectively decide the appropriate repair and protection strategy to meet the future requirements of the structure.

The options include:

- Do nothing.
- Downgrade the structure or its capacity.
- Prevent or reduce further damage without repair.
- Improve, refurbish or strengthen all or part of the structure.
- Demolition.

### 4 Select the appropriate Repair and Protection Strategy


It is necessary to clarify the owner's requirements and instructions in relation to:

- The required durability, requirements and performance.
- Intended design life.
- How loads will be carried before, during and after the repair.
- The possibility for future repair works including access and maintenance.
- Costs of the alternative solutions.
- The consequences and likelihood of structural failure.
- The consequences and likelihood of partial failure (falling concrete, water ingress, etc).

And environmentally:

- The need for protection from sun, rain, frost, wind, salt and/or other pollutants during the works.
- The environmental impact or restrictions on the works in progress, particularly the noise and the time taken to carry out the work.
- The likely environmental/aesthetic impact of the improved/reduced appearance of alternative solutions.

### 5 Definition of the future Maintenance Requirements and Procedures

- What is the mode and result of the selected materials deterioration, i.e. chalking, embrittlement, discolouration, delamination?
- What surface preparation and access systems will eventually be required and when?
- Who is responsible and how will it be financed?

Corrosion Management

# Assessment Survey and Diagnosis of Damage

## Concrete Damage due to Reinforcement Corrosion

### Carbonation

- Carbon dioxide ($CO_2$) in the atmosphere reacting with calcium hydroxide in the concrete pore liquid.
- $CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$
- Soluble and pH 12–13 → Almost insoluble and pH 9
- Steel passivated → Steel unprotected

Reinforcement corrosion following reduction of the passivating concrete alkalinity by carbonation.

### Stray/Electrical Current

- Metals of different electropotential are connected to each other in the concrete and corrosion occurs.
- Corrosion can also be due to stray electrical currents from transmission networks.

Reinforcement corrosion showing as rust staining from cracks after galvanized steel railings were fixed into the parapet.

### Corrosive Contaminants e.g. Chlorides

- Chlorides accelerate the corrosion process however originally caused.
- At above 0.2 – 0.4% they break down the passive oxide.
- Chlorides can be from marine exposure or deicing salts.
- Their use to accelerate concrete setting at low temperatures is now mostly banned in reinforced concrete.

The damaging effects of steel corrosion accelerated by chloride ingress from deicing salts.

## Concrete Damage and Defects

### Mechanical

- Impact, vibration and explosion
- Abrasion and wear
- Overloading
- Earthquake

Cracking caused by incorrect handling or fixing of precast panels.

### Chemical

- Alkali aggregate reaction
- Chemical exposure
- Bacterial action

Chemical attack (and subsequent reinforcement corrosion) on a factory roof.

### Physical

- Thermal movement
- Freeze/thaw action
- Efflorescence/Leaching
- Salt crystal expansion
- Erosion

Freeze/thaw effect on a parking structure.

# Determine the Objectives and select the Appropriate Strategy

**Having fully considered their options, owners normally face having to «improve, refurbish or strengthen all or part of the structure»:**

**For structural strengthening requirements refer to Sika Technical Services for full details of the innovative Sika® CarboDur® structural strengthening system.**

**For concrete structures there are now alternative solutions proposed for improvement and refurbishment that are considered as corrosion management. These include:**

## Apply Cathodic Protection

**Advantages**
- The only way to completely stop steel corrosion.
- Permanent solution (with full repairs and monitoring).

**Disadvantages**
- Ongoing cost to maintain.
- Many structures not suitable (access, non-continuous reinforcement, pre-stressing steel, etc).

## Provide Additional Concrete Cover

**Advantages**
- The old traditional approach.

**Disadvantages**
- Very expensive if correctly applied over all of the concrete surface.
- Has no effect on further aggressive influence ingress.
- Provides no protection against latent damages.
- Very poor appearance.


## Concrete Repair and Protection with Corrosion Inhibitors

**Advantages**
- All the advantages of conventional concrete repair and protection.
- Greatly reduced concrete break-out.
- Greatly reduced noise vibration and dust.
- Reduced contract periods.
- Provides protection against residual chlorides and against incipient anode formation.
- Extremely cost effective.
- Most structures suitable.
- No ongoing maintenance (except re-fresher top coatings after 10–15 years).

## Realkalization or Desalination

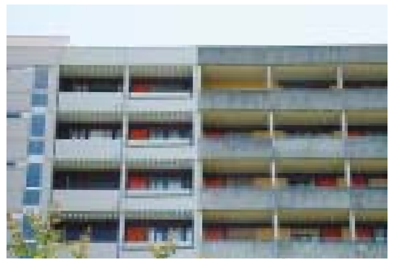
**Advantages**
- Based on reversing the principles of cathodic protection.
- Limited concrete removal.
- No ongoing maintenance (except protective coatings).

**Disadvantages**
- Very high installation cost.
- Not all structures are suitable (as cathodic protection).
- Where there is potential for ASR/AAR.
- Not environmentally sound (caustic waste disposal).

## Overcladding and Insulation

**Advantages**
- Greatly improves appearance.
- Provides the additional benefit of insulation.
- Provides a long-term solution.

**Disadvantages**
- Very expensive.
- Can hide latent defects.
- Extended contract period.



## Conventional Repair and Protection

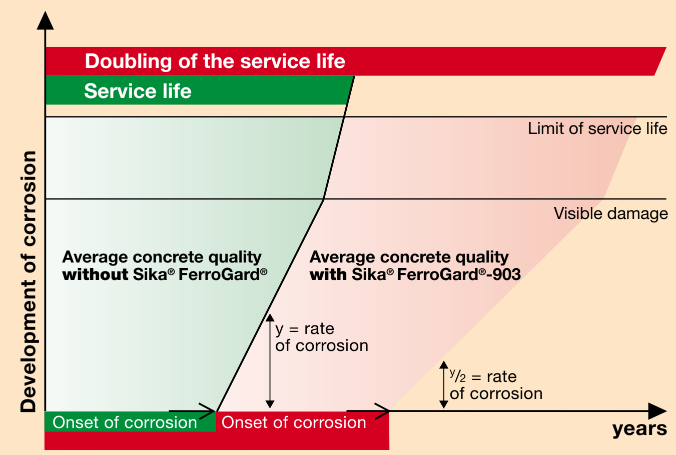
**Advantages**
- Meets existing national standards (DIN/BBA/SIS/NF, etc.).
- Proven performance (over 20 years with Sika systems).
- Provides some protection against latent carbonation damages.
- Cost effective.

**Disadvantages**
- No protection against latent chloride damage.
- Requires extensive concrete break-out.
- Considerable noise, vibration and dust.

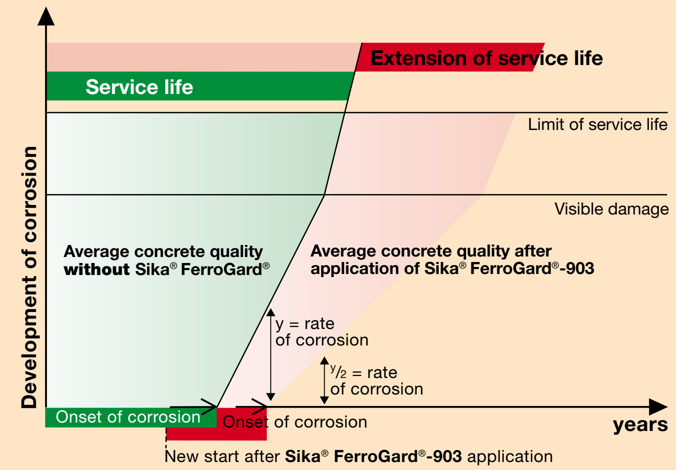
## System Positioning with Sika® FerroGard®-903 Corrosion Inhibitor

FerroGard®

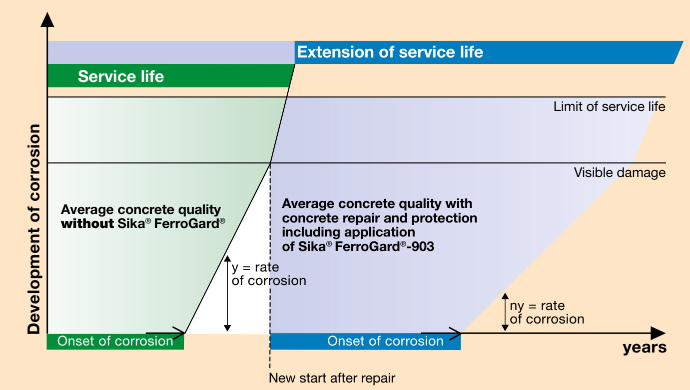
### In New Construction




### Protection before visible Damage




### As part of a Complete Repair and Protection Strategy after visible Concrete Damage



# The Sika® Principles of Concrete Repair and Protection

## Select the appropriate Sika® System

### Remove damaged Concrete and prepare exposed Steel

### Protecting exposed Reinforcement

**SikaTop®-Armatec® 110 EpoCem®**
- Protects reinforcement in a highly alkaline cementitious environment.
- Can be applied on damp surfaces.
- Increases barrier to chlorides and carbonation.
- Steel reinforcement primer and bonding bridge.
- Fully complies with load transfer requirements.

**Sika® MonoTop®**
- One-component steel reinforcement primer and bonding bridge.

### Replacing damaged Concrete

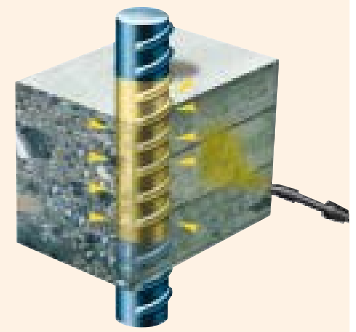
**SikaTop® Repair Mortars**
- Two-component prebatched polymer-modified repair mortars.
- Lower modulus for increased durability.

**SikaCem® Gunite Mortars**
- Ideal for use with Aliva dry-sprayed concrete equipment.
- Tested for application to structures subject to vibration under load.
- Tested for use with most cathodic protection systems.

**Sika® MonoTop® Mortars**
- One-component polymer-modified repair mortars.
- Suitable for hand and wet spray machine application.

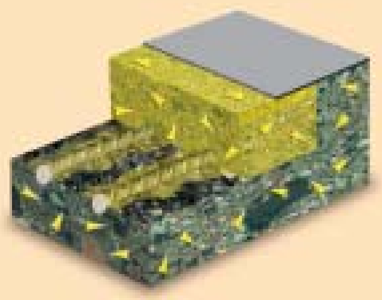
### Protecting against the Development of latent Damage

**Sika® FerroGard®-903**
- Penetrates via liquid and vapour diffusion.
- Film forming inhibitor.
- Mixed inhibitor acting on anodic and cathodic sites.
- Blended inhibitor combining special amino-alcohol and inorganic inhibitors.



Sika® FerroGard® Technology

### Levelling the Profile and filling Surface Pores

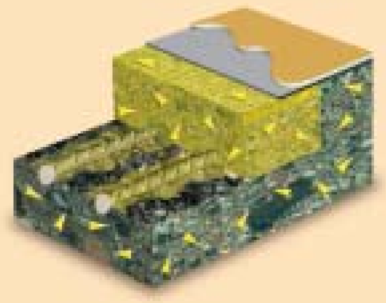


**SikaTop® Levelling Mortars coarse/fine**
- Use to fill surface defects to ensure continuous protective coating.
- Produce the desired surface texture.
- Provides uniform substrate.

**Sikagard®-720 EpoCem®**
- Unique epoxy cement technology.
- Integral curing ability.
- Also as a protective coating.
- Ideal for levelling and reprofiling after application of Sika Ferrogard®-903.

**Sika® MonoTop® Levelling Mortars coarse/fine**
- One-component levelling and reprofiling mortar.

### Sealing and Coating – preventing the Ingress of aggressive Influences



#### Hydrophobic Impregnations

**Sikagard® Impregnations**
- Prevents water and chloride ingress.
- Allows each way water vapour diffusion.

#### Anti-Carbonation Coatings

**Sikagard® Coatings**
- Effectively halts carbonation.
- Allows each way water vapour diffusion.
- Prevents water and chloride ingress.
- Outstanding colour retention.

**Sikagard® Elastic Coatings**
All the special properties of Sikagard® Coatings:
- Bridges dynamically moving cracks even at low temperatures.
- Water and solvent based primers.

# The worldwide independent Proof Statements

## Independent Assessment and Approval

### Product Performance

**The specific criteria that Sika uses to evaluate all of its products and systems for concrete repair and protection, are in accordance with the requirements of the European Standard EN 1504 where appropriate. They include the following:**

#### Protecting exposed Reinforcement

- Bond strength to steel and concrete
- Corrosion protection
- Permeability to water
- Permeability to water vapour
- Permeability to carbon dioxide

#### Replacing damaged Concrete

- Bond strength
- Compressive and flexural strengths
- Permeability to water
- Elastic modulus (stiffness)
- Restrained shrinkage
- Thermal compatibility

#### Protecting against the Development of latent Damage

- Penetration ability
- Film forming ability
- Corrosion inhibition
- Chloride displacement
- Hydroxide displacement (carbonation induced)

#### Levelling the Profile and filling Surface Pores

- Bond strength
- Permeability to carbon dioxide
- Water permeability and absorption

#### Sealing and Coating – preventing the Ingress of aggressive Elements

**Sealing with Hydrophobic Impregnations**

- Penetration ability
- Permeability to water
- Permeability to water vapour
- Freeze/thaw resistance

**Anti-Carbonation Coatings**

- Bond strength
- Cross hatch performance
- Permeability to carbon dioxide
- Permeability to water vapour
- U.V. light resistance
- Alkaline resistance
- Freeze/thaw resistance
- Fire resistance
- Cleanability

**Crack Bridging Anti-Carbonation Coatings**

As above for anti-carbonation coatings, plus:

- Crack bridging ability: statically, dynamically, at low temperatures (–20°C/–20°F)

### System Performance

There are functional and performance requirements which must be met by both the individual products and components of a system and by the system together as a whole.

### Quality Assurance

It is necessary for any product or component or system to meet well defined quality assurance and control standards in production. This is why Sika produces to ISO Standards at its factories throughout the world.

Certified Quality System
ISO 9000/EN 29001

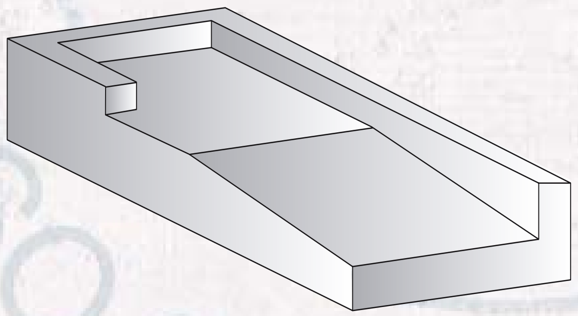
### Application Criteria

In addition to their performance in place, it is also essential to define and test the application properties of products and systems to ensure that they can actually be applied practically on site, and in the differing conditions that will be necessary.

For example: Sika mortars must be suitable for differing thicknesses and areas/volumes of repair and applied in as few layers as possible. **Sikagard**® coatings must have adequate thixotropy to obtain the desired wet and dry film thicknesses in the minimum number of coats, and with these they must also achieve adequate opacity.

### Sika has developed Product Performance Testing

**The "Bänziger Block" for Testing Repair Mortars**



- Direct comparison worldwide
- Application horizontal, vertical and overhead
- Realistic site dimensions
- Additional lab testing by coring
- Crack-free performance under different conditions

**Machine Application of Repair Mortars**

Spray application for test under live dynamic loading.

**Low Temperature dynamic Crack Bridging Testing of Coatings**

### Sika undertakes extensive Durability Testing

**In the Laboratory**

**Sikagard**® products are tested for their performance as anti-carbonation and water vapour diffusable coatings, both when freshly applied, and also after up to 10 000 hours accelerated weathering (equivalent to in excess of 15 years). Only this can give a complete picture of the product's true performance.

**Sikagard**® coatings therefore continue to perform long after other coatings have ceased to provide effective protection.

**In the Field**

An international review was undertaken by leading independent consultants and testing institutes. Major projects repaired and protected with Sika Systems between 1977 and 1986 were inspected and their durability and performance assessed in 1997.

# International Case Studies

## Mechanical Damage

**Structure**
24 storey housing block. Reinforced concrete frame with architectural precast concrete cladding panels.

**Problem**
Loading and impact damaged architectural precast cladding panels (from time of original construction). Cracks and inadequate cover over steel reinforcement.

**Sika Solution**
- Removal of loose concrete and preparation of exposed reinforcement.
- Protect reinforcement with: **SikaTop®-Armatec® 110 EpoCem®.**
- Replace damaged concrete with: Sika repair mortar.
- Provide a uniform, attractive surface finish and protection with: **Sikagard®-550 W.**

## Chemical Damage

**Structure**
Mönchaltorf sewage treatment plant, preliminary sedimentation, aeration and final sedimentation tanks.

**Problem**
The concrete surfaces of the sedimentation tanks were damaged by attack from the sewage (acids, sulphates, fats, etc.) and the routine high-pressure water cleaning. The surface of the concrete was severely eroded. A few reinforcement bars near the surface were also exposed following this erosion and were also now corroding from the chemical attack.

The existing joint sealants had embrittled and had disbonded from the sides of the joints.

**Sika Solution**
- Removal of the damaged and contaminated concrete by blastcleaning.
- Breaking out to fully expose the corroding reinforcement and the removal of all corrosion products by blastcleaning.
- Application of **Sika® MonoTop®-610** for corrosion protection and as a bond coat for patch repairs,
- Localized patch repairs with **Sika® MonoTop®** repair mortar.
- Watertight sealing of the joints by overbanding with the **Sikadur®-Combiflex® System.**
- Overall surface restoration and levelling with **Sikagard®-720 EpoCem®.**
- Overall surface protective coating with **Sikafloor®-390 Thixo** on the floors and walls and with **Icosit® 277** on the top horizontal surfaces of the walls.

## Chemical Damage

**Structure**
Factory roof over production facilities.

**Problem**
Aggressive chemical attack on the concrete. Followed by corrosion of the steel reinforcement in a high temperature, high humidity environment.

**Sika Solution**
- Removal of damaged concrete and preparation of exposed reinforcement.
- Protect reinforcement with **SikaTop®-Armatec® 110 EpoCem®.**
- Replace damaged concrete: **SikaCem®-133** Gunite.
- Protect the surface from future aggressive chemicals with **Sikagard®** high performance coating.

## Physical Damage

**Structure**
Multi-storey concrete parking structure.

**Problem**
Freeze/thaw damage on concrete columns and soffits from condensation and deicing salts exposure.

**Sika Solution**
- High pressure water jetting followed by blast cleaning.
- Repair and reprofiling with **SikaTop®** mortars.
- Protection against future water and deicing salt ingress with **Sikagard®-680 S** (columns and soffits) and **Sikagard®-550 W** (areas subject to cracking – parapets and external facades).
- Joint sealing with **Sikaflex®** sealants.
- Steel corrosion protection with **Icosit®** coatings.

# International Case Studies

## Physical Damage

**Structure**
150 metre (500 feet) long major road bridge.

**Problem**
Concrete damage on the parapet and underside of the bridge due to freeze/thaw action accelerated by deicing salts.

**Sika Solution**
- Surface preparation and defective concrete removal by high pressure water jetting.
- Parapet: **Sika® MonoTop®-610** as corrosion protection for exposed reinforcement and as a bonding bridge followed by **Sika® MonoTop®** repair mortar at 3 – 6 cm thickness.
- Substructure: **SikaTop®-Armatec® 110 EpoCem®** as corrosion protection, allowed to cure, and then repair by dry spray application of **SikaCem®-133** Gunite repair mortar.

## Carbonation Damage

**Structure**
Existing chimney H = 140 m in a combined heat and power station.

**Problem**
Exposed reinforcing steel corrosion from atmospheric carbonation of concrete in the lower zone, chemical attack of the concrete by sulphates eroding the concrete in the upper zone. Existing protective coatings deteriorated, with very poor adhesion and no longer providing any protective function. Many hairline cracks on the concrete surface in the lower zone.

**Sika Solution**
- Replacement of damaged concrete with dry spray fine concrete using EM I 42.5 N HSE, with **Sikacrete®-PP1 TU** and **Sigunit®-49 AF.**
- Surface patch repairs using **Sika® MonoTop®-600** PCC mortars.
- Levelling and sealing the whole surface with **Sika® MonoTop®-620,** and on the chimney annulus area with **Sikagard®-720 EpoCem®.**
- Elastic protective coatings on the lower zone with 3 × **Sikagard®-550 W Elastic** and chemically resistant protection on the upper zone with 1 × **Icosit® 2406 Primer,** 1 × **Icosit-Poxicolor®** and 1 × **Icosit® EG 5.**
- The most chemically exposed chimney annulus area coated with 2 × **Icosit®-277** and 2 × **Icosit® EG 5.**

## Carbonation Damage

**Structure**
Multi-storey residential housing block with concrete frame and precast cladding panels.

**Problem**
Inadequate concrete cover to steel reinforcement with extensive cracking and spalling after depth of carbonation reached the steel.

**Sika Solution**
- Concrete surface preparation by high pressure water jetting.
- Exposed steel reinforcement prepared by blast cleaning.
- Steel reinforcement protection and bonding bridge with **SikaTop®-Armatec® 110 EpoCem®.**
- Repair and reprofiling with Sika repair mortar.
- Crack-bridging anti-carbonation protection on large concrete surfaces with **Sikagard®-550 W** coating.
- Joint sealing with **Sikaflex®** sealants.
- Galvanized balcony handrail protection with **Icosit®** coatings.

## Carbonation Damage

**Structure**
Historic reinforced concrete drinking water tower.

**Problem**
Externally carbonation depth had reached the main steel reinforcement allowing expansive rusting to occur with subsequent concrete cracking and spalling.

**Sika Solution**
- Surface preparation by blast cleaning.
- Steel reinforcement protection and bonding bridge with **SikaTop®-Armatec® 110 EpoCem®.**
- Repair and levelling with **SikaTop®** mortars.
- Anti-carbonation protection and enhanced appearance with **Sikagard®-680 S.**

# International Case Studies

## Electrical Damage

**Structure**
Concrete parapet wall at an airport parking structure.

**Problem**
Galvanized steel handrail fixed into the steel reinforced concrete edge beam with direct contact between galvanizing and reinforcing steel leading to corrosion.

**Sika Solution**
- Remove and reinstall **Sikagard®** epoxy paint coated steel handrails. with **SikaGrout®-42** (epoxy grout).
- Patch repair and level damaged concrete with **SikaTop®** repair mortars.
- Protect against future water ingress with **Sikagard®-550 W.**

## Corrosive Contaminants

**Structure**
Second floor pedestrian walkway/bridge at a hospital.

**Problem**
Concrete damaged by freeze/thaw action and reinforcement corrosion accelerated by chlorides from deicing salts.

**Sika Solutions**
- Surface preparation by high pressure water jetting and exposed steel reinforcement prepared by blast cleaning.
- Steel reinforcement protection with **SikaTop®-Armatec® 110 EpoCem®.**
- Repair with **SikaTop®** mortars.
- Protection against latent damages by impregnation with **Sika® Ferrogard®-903** corrosion inhibitor.
- Crack-bridging surface protection with **Sikagard®-550 W.**

## Corrosive Contaminants

**Structure**
1200 metre (3/4 mile) viaduct consisting of 10 bridges over road and rail tracks.

**Problem**
Extensive chloride accelerated reinforcement corrosion particularly below expansion joints in the deck.

**Sika Solution**
- Following replacement of bridge deck joints.
- Removal of all damaged concrete.
- High pressure water jetting (also to reduce residual chloride levels).
- Blast cleaning to prepare exposed steel reinforcement.
- Repair and reprofiling with **SikaCem®-133** Gunite dry spray mortar.

## Corrosive Contaminants

**Project**
Saint Joseph's church in Le Havre.

**Problem**
Concrete surfaces had become stained, cracked and started to spall.

**Sika Solution**
After the necessary preparation work, a complete Sika Repair and Protection System was applied, consisting of
- **Sika® MonoTop®** Primer, **SikaTop®**, and **SikaLatex®** modified repair mortars,
- **Sika® FerroGard®** corrosion inhibitor with **Sika® Conservado** and **Sikagard®** protective impregnations.

# International Case Studies

## Corrosive Contaminants


**Structure**
Concrete viaduct, serving as motorway feeder.

**Problem**
Steel corrosion, bridge deck and parapets, in parts destroyed by frost and de-icing salts, need extensive repair and renovation under permanent traffic.

**Sika Solution**

- Concrete for re-decking and repair of parapets, resistant to freeze/thaw cycles and de-icing salts, with **Sikament®-10/-12 PLUS** and **Fro-V10.**
- Pier cap strengthening with SCC (self-compacting concrete) with **Sika® ViscoCrete®-1/-2.**
- Thin-layer mortar coating with moisture barrier for edge connections with **Sikagard®-720 EpoCem®.**
- Bridge deck priming and sealing with **Sikadur®-186** and quartz sand **Sikadur®-501.**
- Edge connections and sealing of bridge draining system with liquid membrane and melt primer **Sikalastic®-821/-823.**
- Concrete rehabilitation work in the girder boxes with **Sika® MonoTop®-610/ SikaTop®-Armatec® 110 EpoCem®,** and **SikaRep®-3N** repair mortar.
- Steel plate bonding for shear strengthening with **Sikadur®-30** Epoxy adhesive Type Rapid.

# Additional Complementary Sika® Systems

### Sika Deck Coatings

For crack-bridging balcony, podium and deck waterproofing plus elastic wearing surfaces.

### Sikaflex® Joint Sealing

A unique range of one-component sealants, specifically designed for compatibility with the Sika repair and protection systems.

### Icosit® Steel Coatings

For the protection of steel and galvanized steel surfaces such as handrails, window frames and support structures.

### Sikadur® Resin Injection

Structural resins for the injection and bonding of cracks and voids to restore integrity.

### Sika® CarboDur® Structural Strengthening

Externally bonded composite reinforcement system for structural strengthening and to increase load bearing capacity of floors, walls, beams, etc.

### Sika Structural Waterproofing

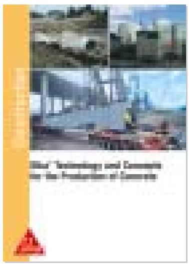
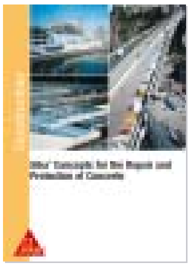
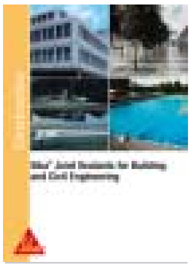
Well proven systems that provide internal waterproofing for both new and refurbishment projects in basements, lift pits, cellars, car parks, etc.

# Technology and Concepts for the Repair and Protection of Reinforced Concrete

## Sika – Your Local Partner with a Global Presence

Sika is a globaly active company in the speciality and construction chemicals business. It has subsidiary manufacturing, sales and technical support facilities in over 70 countries around the world. Sika is THE global market and technology leader in waterproofing, sealing, bonding, dampening, strengthening and protection of buildings and civil engineering structures.
Sika has more than 9'200 employees worldwide and is therefore ideally positioned to support the success of its customers.

## Also available from Sika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