



## **Design Engineers Support for Reinforced Concrete Chimneys and Cooling Towers Concrete Repair and Protection**

# Chimneys and their Exposure

Reinforced concrete chimneys are relatively high-rise and relatively slender specialized structures. They are also normally built by specialists to high standards of engineering with strict quality control of the concrete.

Traditionally they were not provided with any additional surface protection, the design relying on dense high-grade steel reinforcement, high-strength concrete and good cover to this embedded steel.

Chimney construction for many years has predominantly been using site assembled precast concrete sections or has been achieved by continuous slip-forming concrete on site.

However, even with the strict quality controls applied, it is always likely that there will be some site difficulties, i.e. during the concrete placement, finishing or assembly, some elements will move out of place and form voids, suffer grout loss, reduce cover thickness or be physically damaged.

The use of high-strength concrete and its relatively low slump or flowability, also means that it can be difficult to compact. By the nature and shape of the structure, the freshly placed concrete in these structures on site is always difficult to cure correctly.

Partially due to the exposed locations where these structures tend to be built, their height above associated or nearby structures and of course their function, chimneys are very exposed to aggressive influences on their external surfaces. The internal surfaces however are normally fully lined or channelled and so protected.

The aggressive external influences include: atmospheric carbonation, frequent wetting and drying, freeze-thaw cycles (the product of increased wind chill), high thermal variations and thermal gradients in sunlight, chlorides from marine atmospheres (even miles inland due to prevailing winds). Together with the contents and condensates of their own exhaust gases, plus those from neighbouring chimneys, as frequently several chimneys are built in close proximity on industrial complexes and in power stations.

The potential for concrete damage from these exhaust gases containing varying levels of acidic sulphurous (SO<sub>x</sub>), nitrous (NO<sub>x</sub>) and other aggressive materials, is probably the greatest overall threat, even when modern flue gas desulphurization equipment is fitted (FGDS).

The exposed external surfaces of chimneys are normally subdivided into zones, according to their level of exposure to these gases and the other potentially damaging influences.



Adjacent chimney structures means that their surface exposure is increased in modern power plants and industrial areas.



Aircraft warning colours to Zone 1 with high performance SikaCor EG 5 polyurethane top coat.

## Zone 1:

The top or head of the chimney and its upper shaft (0.2 – 1.0 of the diameter, minimum 5 m)

- High potential exposure to exhaust gases
- High thermal variations (sunlight and exhaust)
- High wind and weathering (possible airborne chlorides)
- Frequent risk of condensation
- Possible fuel ash

## Zone 2:

The middle of the chimney shaft (0.2 – 0.4 of the height)

- Medium potential exposure to exhaust gases (including neighbouring chimneys – high atmospheric CO<sub>2</sub>)
- Medium thermal variations (sunlight and exhaust)
- Medium wind and weathering (possible airborne chlorides)
- Medium of condensation

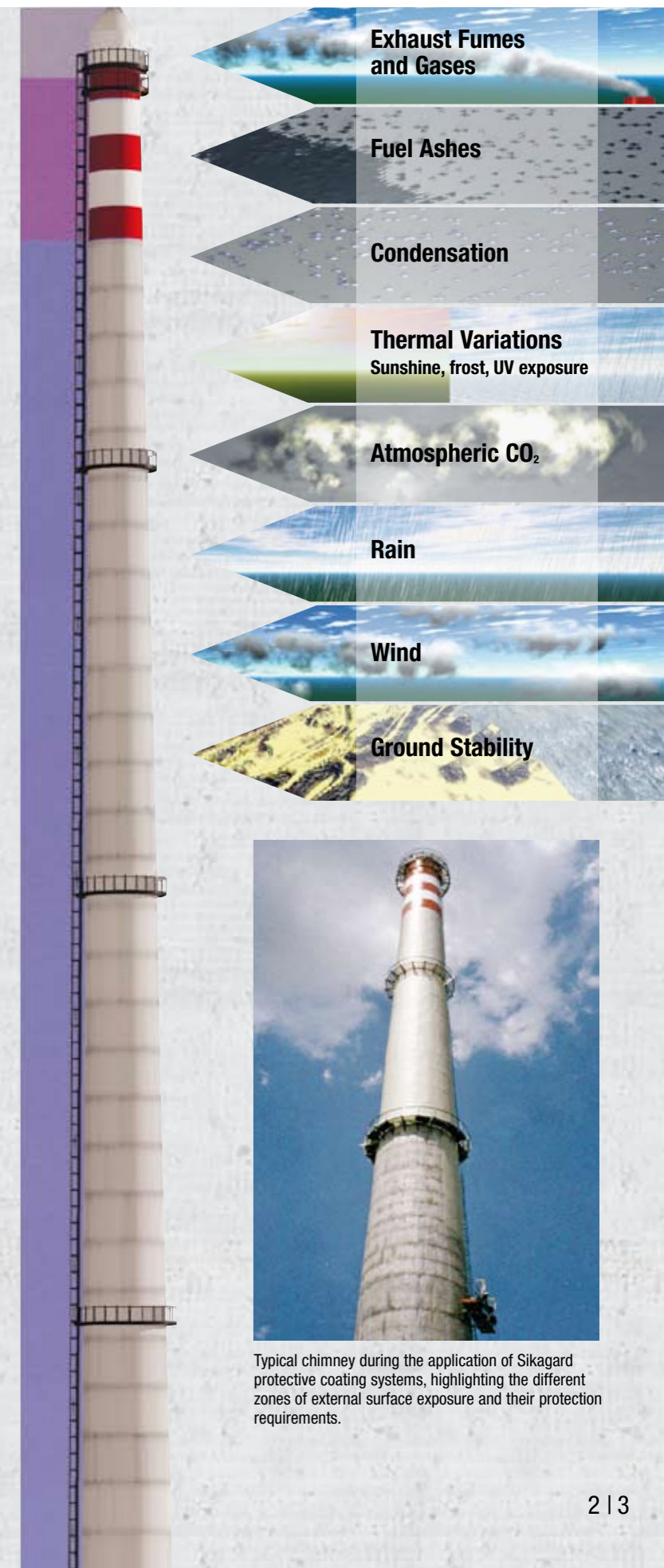
## Zone 3:

The lower shaft (the remainder of the height to the ground)

- General industrial area atmosphere
- Rain and weathering (possibly limited by other structures – can accelerate carbonation)



**Note:** With adjacent chimneys Zone 1 and Zone 2 of the surface both become larger.



Typical chimney during the application of Sikagard protective coating systems, highlighting the different zones of external surface exposure and their protection requirements.

# Cooling Towers and their Exposure



The severe combined exposure of multiple adjacent cooling towers and chimneys at power stations and industrial complexes.

**“Cooling Towers” are exactly as their name suggests, structures for water re-cooling, although these do not necessarily have to be large physical “natural draught” towers. The name is also used for smaller cellular coolers or hybrids, which combine a smaller natural draught structure with a mechanically ventilated system of cooling the flow to retain the condensates. This brochure primarily provides information in relation to the large natural draught towers constructed in reinforced concrete.**

Large reinforced concrete, natural draught cooling tower structures can be as tall or even taller than many chimneys. However due to their design and function, they have a very much larger surface area, with a much lower mass to surface area ratio.

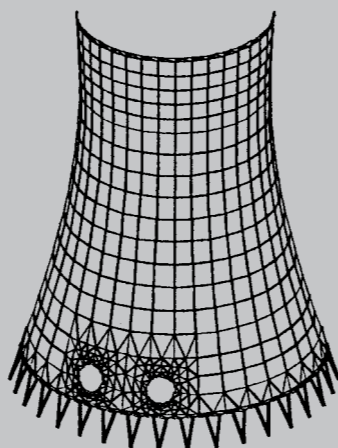
Unlike chimneys, both the internal and external concrete surfaces of cooling towers are exposed to aggressive influences. The external exposure and the potential damage is therefore similar and the internal surfaces are usually in much greater danger.

## The External Exposure

The external surfaces are exposed to very similar aggressive influences; however, because of their much larger circumference and diameter with a much lower mass to surface area, they are at much greater risk of cracking. This is due to settlement and adverse thermal gradients developing from thermal variations imposed on the surfaces.

## Exposure Classification

In terms of their exposure, the external surfaces of cooling towers can therefore also be divided into the same three zones as chimneys:



**Zone 1:**  
The top of the shaft and around the annulus from the top down approximately 5 m irrespective of the structure’s diameter

**Zone 2:**  
The central area which is from 5 to between 30 and 50 m down, dependent on the diameter of the structure

**Zone 3:**  
The rest of the height to the ground which is usually equivalent to around 70 % of the total surface area

## The Internal Exposure

The internal surfaces of cooling towers are also very large and exposed. Even though they are constructed with acid-resistant concretes, it has been recognized that they must be given additional surface protection. This is due to their direct exposure and contact with the exhaust gases and condensates, which are often aggressive and acidic at a pH as low as 2.5. This protection is usually achieved today using special epoxy resin based systems from Sika.

Sika has been the preferred partner with the pioneering specialist engineers, contractors and access equipment manufacturers, producing tailored products and systems for these very specific applications from this time.

The level and degree of exposure and potential damage to the different areas of the internal surface are firstly dependent on the internal level, location and direction of the flue gas discharge points. There are normally three different design types: low-level horizontal, low-level vertical and high-level vertical.

Secondly, it is dependent on whether the cooling tower is fitted or has been retrofitted with a modern flue gas desulphurization system (FGDS), to greatly reduce and in some cases almost eliminate the aggressive and acidic contents of the exhaust.

Additionally by design, cooling towers always have a relatively large opening at the top and therefore at least some of the internal surfaces are exposed to direct

solar radiation. This includes UV light which is very aggressive to most types of epoxy resin coatings, such as those that are normally used as chemically resistant coatings in applications out of direct sunlight. Special products are therefore required to be able to withstand this combined exposure inside cooling towers.

The total “loading” on the internal surfaces is also variable according to the daily position of the sun and the direction of the plume (reducing solar radiation but increasing exhaust gas attack on the contact areas). Obviously this effect gradually reduces vertically down the inside of the tower. However at the top it also increases the potential for thermal variations and potentially damaging adverse temperature gradients that can lead to cracks within the concrete walls.

Specialist equipment and materials are required for all of the internal works in these structures.



Severe internal exposure to aggressive gases and chemicals aggravated by direct UV light exposure and thermal variations at the top.

# The Key Stages in the Concrete Repair Process

The successful repair, protection and corrosion management of reinforced concrete chimneys and cooling towers always requires an initial professional assessment and an appropriately detailed condition survey.

Whilst some access and even some refurbishment works can take place while these structures are in service, the inspection and assessment work of external Zone 1 and most of the internal surfaces of cooling towers, which are integral to power production, can normally only be switched

off during boiler servicing or upgrading works.

The costs of any extended closure or downtime are absolutely huge, due to the complex national grid infrastructures, power transmission changes and the other works required. This will always lead to great pressures being applied to commence or complete repairs, **BUT** it is absolutely essential that firstly a full professional assessment and then the appropriate repair and protection works are completed.

To do otherwise is short-term and a false economy, as serious structural damage could follow, possibly putting the structure completely out of commission for a long period. Also possibly endangering people and other structures in the vicinity.

The second stage is the design, execution and supervision with technically correct repair "principles" and "methods", using products and systems which for optimum results and long-term cost effectiveness, should be selected according to the new European Standard EN 1504-9.

The key stages in the correct repair and refurbishment process can therefore be summarized as follows:

## 1 Assessment of the Structure

A condition survey by qualified and experienced people to include the condition of the structure and its surfaces, including visible, non-visible and potential defects.

## 2 Identification and Degree of the Cause(s) of Damage

A review of the original construction details and any previous refurbishment works, plus analysis and diagnosis from the condition survey to identify:

- Damage due to concrete defects or attack (mechanical, chemical or physical types)
- Damage due to reinforcement corrosion (carbonation or chloride attack)

## 3 Determine the Repair and Protection Objectives and Options

Owners and their engineers always have a number of options in deciding the appropriate refurbishment strategy to meet the future requirements of the structure. With chimneys and cooling towers, the most limiting factors are usually the difficulties for future access, plus the likelihood and consequences of any falling concrete or structural failure.

## 4 Selection of the Appropriate Repair Principles and Methods

In accordance with EN 1504-9 the appropriate "repair principles" should be selected and then the best "method" of achieving each principle can be decided.

Following this selection, the performance requirements of suitable products are defined, using European Standards EN 1504 Parts 2 to 7 in conjunction with Part 10, which also provides guidelines for the works preparation and site application including quality control. On these substantial structures with their very specific exposure and damage potential, the materials selected must also be tested and proven in these very specific conditions.

Sika provides a complete range of products and systems, to meet all of these possible requirements on both chimneys and cooling towers. These are outlined in the following pages of this brochure.

## 5 Future Maintenance

As with all refurbishment projects, the need and likely time schedule for future inspection and maintenance should be defined. Complete and fully detailed records of the works undertaken must always be maintained.



Specialist concrete repair and protection works in progress on the walls of a cooling tower.

# The Sika Principles in Accordance with European Standard EN 1504

Sika is the global market and technology leader in the research, development and production of concrete repair systems for all types of buildings and civil engineering structures.

Sika is also the clear global market and technology leader in all of these materials specifically adapted to the requirements of chimneys and cooling towers. We are established as the preferred partners of the specialist engineers, contractors and access equipment suppliers focussed on these important structures.

All of the necessary products and systems for their technically correct repair and protection are produced by Sika, already fully in accordance with the European Standard EN 1504. This includes products for application in all of the different exposure and climatic conditions that can be required to repair and protect these structures in their many different locations around the world.

Sika provides a complete package of documentation to assist chimney and cooling tower owners, engineers and contractors with the right selection of repair principles, methods and products, the production of specifications and tender documents.

The experienced Sika Technical Services Department is also available to train site engineers and contractors in the current use and application of the products and systems.

Sika provides extensive independent testing with all relevant approvals and certificates for all of these materials. This provides maximum security for everyone involved in these projects, fully supported by an equally extensive portfolio of successfully completed reference projects around the world.

Sika systems are available to meet all of the individual requirements of different chimney and cooling tower structures. Whatever the damage that has occurred, whatever their future exposure requirements and wherever in the world they are located.



Creative possibilities in conjunction with using technically correct repair and protection are also possible with the advanced Sika systems.

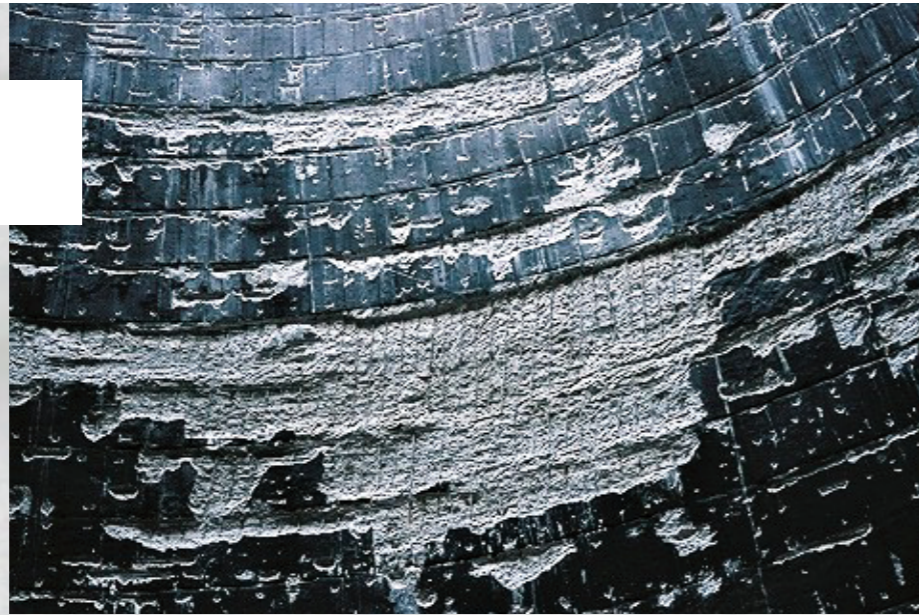
Chimneys and cooling towers in close proximity require technically correct repairs in accordance with EN 1504-9.



# Assessment of the typical Causes and Effects of Damage: From the Condition Survey

## Chemical

- Aggressive exhaust gases
- Condensation leaching



Severe corrosion of concrete and then of the steel reinforcement internally, despite a previously applied coating (coating was inadequate).

## Damage due to Concrete Defects or Attack

## Physical

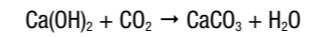
- Thermal movement cracking
- Adverse thermal gradient cracking
- Freeze/thaw action
- Shrinkage (from hydration)
- Erosion



Chimneys in direct sunlight indicating variations in thermal exposure which are further exacerbated by the effects of the downward flow of hot exhaust gases during periods of temperature inversions.

## Carbonation

- Atmospheric carbon dioxide ingress (loss of alkali protection)



Carbon dioxide from the atmosphere penetrates progressively into the concrete and reacts with the calcium hydroxide in the pore liquid. This eventually reduces the protective alkalinity around the steel, allowing corrosion to start



Concrete and previous overlay repairs spalling after carbonation has allowed the inadequately protected steel to corrode locally.

## Damage due to Steel Reinforcement Corrosion

## Chlorides, Carbonation and Acid Gases

- In these structures corrosion of the reinforcement can also occur due to attack from chlorides in marine atmospheres. However the steel is far more frequently attacked directly by the acidic exhaust gases in conjunction with carbonation of the surrounding concrete. This means that the steel corrosion is accelerated and spalling, plus erosion increases.



Carbonated concrete with spalling over corroded reinforcement accelerated by the steel being attacked by the acidic exhaust gases.

# Concrete Repair and Protection

## Removal of the damaged Concrete

The first stage in the execution of the works on site is to remove the damaged concrete and then clean any exposed steel reinforcement.

In most situations it is best to first carry out a programme of surface cleaning works, usually working from the top down as the first phase of the preparation. This already removes any loose or severely damaged concrete and by removing any surface contaminants or dirt deposits, also exposes additional areas of damage that will subsequently require removal.

As a general rule concrete removal should be kept to a minimum, particularly any sound concrete. However, where actively corroding steel reinforcement is present, it must be fully exposed to beyond its corroding length and around its full circumference. To allow for cleaning and preparation, a distance equivalent to the bar diameter and a minimum of 12.5 mm is normally required.

For this work on these relatively thin structures, it is particularly important to use only new, sharp chisels or precision-controlled hydro-demolition equipment, to prevent any non-scheduled puncturing or cutting through of the walls.

Removal of damaged concrete from inside a cooling tower.



Break-out and removal of damaged concrete areas marked for repair in the condition survey.

The breaking out must be kept fully under strict control and continuous monitoring by the responsible engineer.

In marine environments where the concrete has previously been exposed and contaminated by chlorides (even when they are at some distance from the ocean due to a combination of the structure's height and prevailing winds), the concrete and the steel surfaces should be washed with clean water to remove the chloride deposits.

The cleaned and prepared concrete surface should be free from dust and any other contaminants.

Corroding steel exposed after concrete removal.



Any exposed steel reinforcement should be cleaned to remove rust and corrosion products. Usually this is specified as being to "bare metal" or as "equivalent to Sa 2½", originally from a Swedish Standard, but now adapted into ISO 8501-1.

Any method of steel surface preparation may be used, with grit blasting normally recommended as the best and the fastest, particularly with the larger areas of steel that can be exposed on cooling towers.

This cleaning and preparatory work should all be carried out in accordance with the site works and application guidelines of EN 1504 Part 10 Section 7, which can also be referred to for additional information.

Concrete removal behind the steel bars to ensure room for corrosion protection to be applied.



## Protection of the Steel Reinforcement

### Exposed Steel

The protection of the cleaned, exposed reinforcement is achieved by isolating the reinforcement from the surrounding concrete. This uses a coating that is an electrical insulator to prevent both metal cations escaping from the steel and hydroxyl, or other anions arriving at the steel surface.

Sika has several products for this purpose, all using active corrosion inhibitors. The selection of the most appropriate is dependent on the chemical exposure level and the concrete replacement being used, plus the extent and volume of steel to be treated.

Particularly suitable for use on the large exposed steel areas frequently required on cooling towers are:

**Sika® MonoTop®-910** for the one-component **Sika® MonoTop®** repair mortars.

### SikaTop® Armatec®-110 EpoCem®

for use in highly corrosive environments with all Sika repair systems, where it provides an excellent barrier to chloride ion diffusion and penetration.

The coating must be applied around the full circumference of the steel bars and to beyond the areas that were corroding and wherever there is inadequate or insufficient concrete cover.

This conforms with EN 1504-9 Principle 11 (CA) Control of Anodic Areas: Method 11.2 Painting Reinforcement with Barrier Coatings.

### Embedded Steel

Additional protection can also be provided to steel that is not actually exposed, but is at risk of corroding, i.e. in carbonated concrete. This is done by the application of **Sika® FerroGard®** corrosion inhibitors.

**Sika® FerroGard®** products are based on aminoalcohol technology. These are known as "mixed" or "dual" inhibitors because they act on both the anodic and cathodic areas of the steel surfaces.

**Sika® FerroGard®** forms a mono-molecular passivating film or barrier layer over the surface of the steel. This prevents the escape of metallic cations and the arrival of any hydroxyl, or other anions.

**Sika® FerroGard®** inhibitors can be surface applied as the penetrating impregnation **Sika® FerroGard®-903**. This product can easily be applied to both repaired and non-repaired surfaces to prevent or significantly reduce the rate of any future steel corrosion. **Sika® FerroGard®** technology can also be used or as an admixture in the replacement concrete or repair mortar, **Sika® FerroGard®-901**.

This conforms with EN 1504-9 Principle 11 (CA) Control of Anodic Areas, Method 11.3 Applying corrosion inhibitors in or to the concrete.

Steel reinforcement prepared and protected with Sika MonoTop-610 ready for repair mortar application.



# Concrete Repair and Protection

## Replacing and Restoring damaged Concrete

Sika produces a complete range of repair concretes and mortars, which are specifically designed for restoring or replacing the original profile and function of the damaged concrete. These include cement-bound, polymer modified cement-based and polymer epoxy resin based products, according to their specific applications and performance requirements. All are in accordance with EN 1504-9 Principle 3 (CR) Concrete Restoration and compliant with EN 1504-3 Class R4.

### Applying Repair Mortar by Hand

Sika provides an extensive range of pre-batched hand applied mortars and systems for localized patch repairs. This includes chemically resistant materials to protect against the aggressive influences of acidic gases and liquids.

Sika hand placed repair mortars include the following:

- **Sika® MonoTop®** – pre-bagged, one-component, polymer and non-polymer modified, cement-based, hand applied mortars.
- **Sikadur®** – pre-batched, epoxy resin based chemically resistant mortars.



Hand applied Sika MonoTop repair mortar.

### Recasting/Pouring Repair Mortars and Concretes

Typical recasting repairs, which can also be described as “pourable” or “grouting” repairs, are employed when whole sections or larger areas of concrete replacement are required. For example: in the replacement of all, or substantial parts of tower or chimney sections.

This method is also very useful for the complex structural supporting sections, which can also present concreting or concrete replacement problems due to restricted access or congested reinforcement.

The most important criteria for the successful application of this type of products are their flowability and their ability to move around obstructions. Additionally they often have to be poured in relatively thick sections without thermal shrinkage cracking; this is to ensure that they can fill the desired volume and areas completely, despite the restricted access and application points. Finally they must also harden to provide a suitable finished surface, which is tightly closed and not cracked.



Hand applied local patch repairs completed on the external surface of a large cooling tower.

Sika produces suitable recasting and pourable products and systems including:

- **Sika® MonoTop®** – pre-bagged one-component, polymer and non-polymer modified cementitious pourable repair mortars.
- **SikaCrete® SCC** – pre-bagged silicafume enhanced self-compacting concrete (SCC).
- **Sika® ViscoCrete®** – admixture SCC technology for large volume, pumped and high density concrete replacement.
- **SikaRapid®** – technology for high early strengths or continuous replacement concreting at low temperatures.

### Spray applied Repair Concretes and Mortars

Spray applied materials are particularly useful for large volume concrete replacement, for providing additional concrete cover, or in any areas with difficult access for concrete pouring.

In addition to traditional “gunite” dry spray systems, there are also “wet spray” machines. These have lower volume outputs, but also much lower rebound and they produce less dust than dry spray machines. Therefore they can also be used economically from powered access equipment, for smaller areas, or for the application of repairs in more sensitive areas.

Sika produces quality controlled and pre-batched machine applied mortars, specifically for use in both of these methods of “spray” application.

The most important application criteria for all of these materials are minimal rebound, their high-build properties and also their non-sag layer thickness. Application with minimal or easy finishing and curing requirements is also important on these structures due to their difficulties in access.

Sika spray applied mortar systems are polymer and/or silicafume enhanced for increased durability and these mortars include:



Difficult shaped support structures easily repaired and strengthened with SikaCem-Gunite 133.



Sika Aliva dry spray equipment in operation applying SikaCem-Gunite 133 inside a cooling tower.

The **SikaCem®** and **SikaCrete®** ranges of “dry” sprayed mortars, with both polymer modified and cement-bound products with the capability of being sprayed over large distances and up to 180 m high with the correct equipment. This specialist equipment is also provided by the Sika Aliva company.

**SikaCem® Gunite®-133** is particularly suitable for large scale “dry sprayed” repairs on these structures because of all its high density and low permeability, plus its excellent strength correlation in service (compressive, tensile and e-modulus).

The **SikaCrete®** and **Sika® MonoTop®** ranges of “wet” spray applied mortars also include both polymer modified and cement-bound products.

The fiber-reinforced **Sika® MonoTop®-412 N** is particularly suitable for the high demands of localized repairs because of its high-build, low shrinkage and ease of use.



Internal application of Sika spray applied repair mortars in a cooling tower refurbishment.

# Concrete Repair and Protection

## Levelling and Restoring the Concrete Surface

All of the EN 1504-9 Principles for repair involve the application of a coating or treatment of the surface. It is a fundamental precondition for the success of a coating that the surface is not only clean, but also uniform and free of surface defects, otherwise these will simply be reflected through the coating. For example, most defects, voids or uneven areas previously damaged by attack or produced as the result of surface preparatory work, could all allow the entry of aggressive agents behind the coating.

The treatment and closure of these surface defects is therefore necessary to ensure complete, uniform and defect-free application of a protective coating system.

This type of product is also commonly known as a surface levelling mortar and a surface sealing mortar.

A surface smoothing coat should be suitably matched to the substrate condition, together with its subsequent exposure and overcoating requirements.

Sika produces a wide range of products for this purpose on chimney and cooling tower surfaces.

### Levelling of External Zone 2 and Zone 3 Surfaces

Due to the very large external surface areas involved in Zone 2 and 3, it is normal to apply a levelling mortar in areas where it is essential to the performance of the protective coating due to an excessive profile of the prepared concrete. In Zones 2 and 3 this is the case when the surface irregularities and blowholes etc. cannot be securely treated with the easily applied OS2 system using **Sikagard** hydrophobic impregnations and protective coating products (which is outlined on page 16).

The polymer-modified, cement-based surface levelling mortar **Sikagard MonoTop -620** is the most cost effective and appropriate for this purpose on chimneys and cooling towers.

### Levelling of External Zone 1 and the Internal Surfaces

**Sikagard -720 EpoCem** is a thin layer levelling mortar based on a combination of epoxy resin and cement binders. As such its properties provide the best advantages of both systems. **Sikagard -720 EpoCem** needs no additional curing and enables rapid overcoating with vapour-tight, abrasion and/or chemically resistant coatings. It is therefore extremely suitable for use in Zones 1 (and Zone 2 if or where deemed necessary) of the external surfaces, together with all of the chemically exposed internal surface areas.

## Protective Surface Coatings



Locally repaired surface ready for levelling on the left and afterwards on the right.



Application of Sika MonoTop-620 levelling mortar onto the patch-repaired concrete surface prior to coating.



The concrete surface without pore filling and levelling.

Surface levelling completed ready for protective coatings.

### Protection of External Surfaces for Exposure in Zone 1

In Zone 1 the concrete surface must always be levelled and sealed to ensure that a uniform and defect-free, protective coating system can be applied. **Sikagard -720 EpoCem** with its unique properties is ideally suited for this purpose in Zone 1 areas – as outlined on page 14.

These are the most severely exposed areas of the external surfaces, so the coating system must also be extremely resistant to the aggressive influences to ensure its durability in most situations: **Sika Poxicolor** is used as the priming and intermediate coating on the sealed and levelled concrete surface. This is a low-solvent, high-build epoxy combination. It is followed by **SikaCor EG-5** in a minimum of two coats, which is a coloured, chemically resistant and UV colour stable, polyurethane top coat.

**SikaCor EG-5** is available in all official aircraft warning colours worldwide, which are often required for safety reasons at the top of chimneys and cooling towers.

On surfaces that are potentially subject to future movement and cracking: **Sikafloor -390** is used as the coating system. It is a flexible high-build epoxy-based material with medium crack-bridging abilities, then **Sikagard -363** is applied as the coloured (aircraft warning colours available) and elastic, crack-bridging, polyurethane top coat that also has high UV stability and excellent chemical resistance.

All of the **Sika** materials comply with the requirements of EN 1504-2.



Aircraft warning colours using SikaCor EG 5 as the top coating in zone 1 of a concrete chimney refurbishment.



Sika protective coatings being applied to the external surfaces (all zones) of a cooling tower.





# Concrete Repair and Protection

## Protective Impregnations and Surface Coatings

### Protection of External Surfaces for Exposure in Zones 2 and 3

Firstly a hydrophobic impregnation is applied to produce a water-repellent surface. The pores and capillary network are not completely filled, but only lined with the hydrophobic material. This functions by reducing the surface tension of liquid water, preventing its passage through the pores, but still allowing each way water vapour diffusion.

Sika produces a full range of hydrophobic impregnations and systems for the protection of the exposed larger areas of Zones 2 and 3 according to EN 1504-2. These include:

- The **Sikagard®** range of silicone, silane and siloxane based hydrophobic impregnations, which are used to penetrate deeply and provide a liquid water-repellent surface, but still allowing water vapour diffusion.
- **Sikagard®-680 S**, an acrylic resin-based surface coating, which blocks surface pores against the entry of water and carbon dioxide, thus effectively halting carbonation, whilst water vapour diffusion can continue. This product is also particularly useful and suitable for application in the difficult environmental conditions of high humidity and/or low temperatures.
- The **Sikagard®-500** range of waterproofing and anti-carbonation systems that are also elastic and crack-bridging. They serve to accommodate thermal and dynamic movement in the structure, particularly where it is subject to wide temperature fluctuation.



Creative achievements are also possible with Sikagard protective coatings.

- The combination of a **Sikagard®** hydrophobic impregnations followed by **Sikagard®-680 S** anti-carbonation coating.

The combined system is frequently used for the larger lower areas of Zone 3 on chimney and cooling tower external surfaces. Where the steel reinforcement has good concrete cover, this combined system can be used without a prior levelling coat as the **Sikagard®** hydrophobic impregnations prevents water penetrating behind the **Sikagard®-680 S** coating through blowholes etc. and causing problems. This also conforms to the OS2 classification of the German Federal Regulations for concrete protective coating systems.



Abseiling specialists applying Sikagard-680 S.



External coatings can be exposed to exhaust gases from adjacent chimneys.

### Protection of the Internal Surfaces of Cooling Towers

As with Zone 1 surfaces externally, the repaired internal surfaces must always be levelled and sealed prior to application of the final protective coating system. The ideal material to achieve this on internal surfaces is again the unique **Sikagard®-720 EpoCem®** (as outlined on page 14 of this brochure).

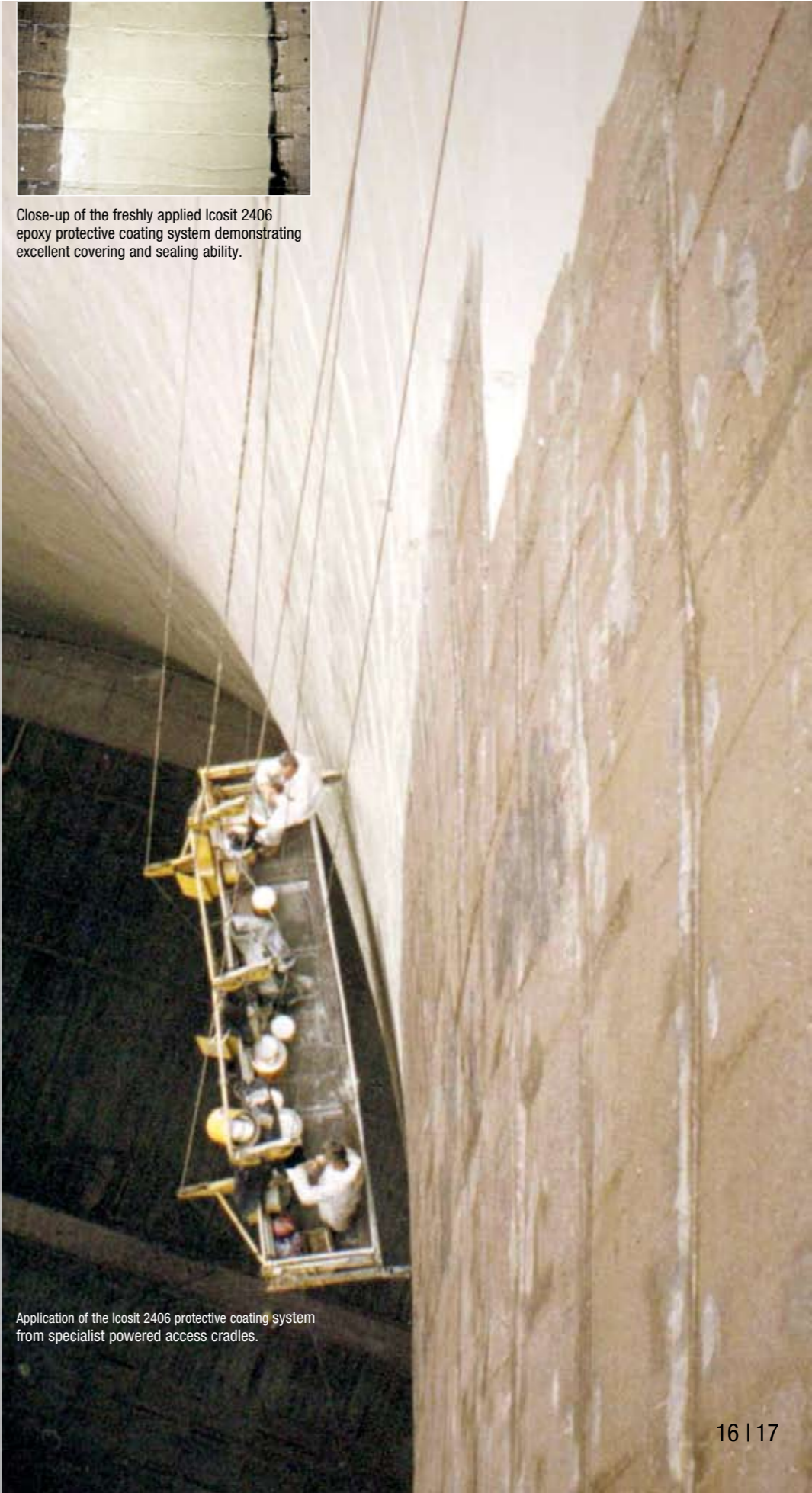
The protective coating system to be used internally is dependent on whether or not the tower has a modern flue gas desulphurization (FGDS) system installed. The products to be used are actually the same, but with the FGDS system installed, the chemical exposure is much lower and so only a single base coat is required: **Sikagard®-253** water-based, or **Icosit®-2406** solvented are the ideal two-component, pigmented and chemically resistant epoxy resin based coatings; both are specifically designed for this purpose.

However the top section of the tower is accessible to exposure from both diffusive reflection and direct solar radiation, which both attack polymer-based coatings. The degradation process is photo-catalytically accelerated by the combination of the UV part of the radiation and components of the flue gas, especially any nitrous and nitrox material (NO<sub>x</sub>).

The system to be used therefore consists of either one or two coats of **Sikagard®-253** or **Icosit®-2406** followed by **Sikagard®-363**, which is again applied as the specially developed UV and chemically resistant polyurethane-based top coat (as with Zone 1 internally). This is done to provide this necessary additional protection in the solar exposed upper section.



Close-up of the freshly applied Icosit 2406 epoxy protective coating system demonstrating excellent covering and sealing ability.



Application of the Icosit 2406 protective coating system from specialist powered access cradles.

# Concrete Repair and Protection

## Remedial Treatment Solutions for Cracks and Joints

Due to their slender structures and harsh environments, chimneys and cooling towers are frequently prone to cracking in the concrete. At the base of cooling towers, the containment basins can also often require the repair and sealing of leaking cracks as part of their overall refurbishment.

All concrete repair and protection works must therefore take account of the position and size of any cracks and joints in the concrete. This means investigating their nature and cause, then understanding the extent of any movement and its effect on the stability, durability and function of the structure.

This is therefore an important part of the condition survey and the identification of the nature and degree of the damage in these structures. Cracks in the concrete can obviously give aggressive gases and liquids direct access into the concrete and the embedded steel reinforcement.

Then the most suitable Sika system of resealing and bonding can be selected. **Sika® Injection** systems include both low and high pressure materials, designed

for application by different types of equipment, according to the requirements. Sika produces different viscosities and grades of the synthetic resins in the **Sika® Injection** range which are all solvent-free and include products for use in both dry and damp conditions. The products all have high chemical resistance, but different penetration capabilities to suit the nature, width and extent of different cracks.

**Non-moving Cracks** – These are cracks that have been formed by initial shrinkage for example; therefore they need only to be fully exposed and repaired / filled with the appropriate **Sika®** repair mortar, or **Sika®** levelling mortar, as outlined for surface defects on page 14. The selected surface treatments can then be safely applied successfully over these cracks.

**Fine Surface Cracks** – As outlined on page 19, fine surface cracks with a total movement of up to 0.3 mm can be safely repaired, then sealed and their movement accommodated by the elastic, crack-bridging coatings from the **Sikagard®-500 Elastic** range.

**Cracks to be transferred to a Joint** – Where the structural engineer has directed that an existing crack be treated to function as a movement joint in the structure, it should be sealed at the surface to prevent the ingress of any further aggressive agents. It can be sealed with the **Sikaflex®** range of joint sealants, primarily based on one-component polyurethane and **Sika® AT** polymers designed for easy application, high movement capability and excellent durability. Sika also produces special overbanding and crack-sealing, jointing materials for this application such as the **Sikadur®-Combiflex® System**. This is a special combination of **Sikadur®** epoxy resin adhesive and **Sika** modified hypalon strip that is extremely elastic. It can accommodate different joint and crack widths, excessively wide joints or joints that are contaminated with failed sealants. It is also very chemically resistant and suitable for exposure to many aggressive chemicals, including those in exhaust gases. This means that the **Sikadur®-Combiflex®** system is particularly good for use in the important lower containment basin areas.



Structural bonding of cracks to restore structural integrity with Sika Injection resin.



Crack-sealed with Sikaflex sealant and overcoated with Sikagard-680 S protective coating.

# Structural Reinforcement and Strengthening

**The Anchoring of additional or Replacement Steel Reinforcement in the Concrete:**

The selection of the appropriate size and configuration of such reinforcement and the locations where it is to be fixed or anchored, must always be determined by the structural engineer. The fixing points or anchorages into the concrete should then be designed, produced and installed in accordance with EN 1504 Part 6 and all of the relevant European Technical Approvals (ETA).

**Sikadur®** adhesives have extensive independent testing certificates, approvals and references on major power and infrastructure projects.

**Sika® AnchorFix®** cartridge-packed adhesive fixing system, includes epoxy and epoxy acrylate based anchoring adhesives.

**Sika® AnchorFix®-2** is ETA-approved for structural applications and it is particularly suitable for fast, secure and chemically resistant bonding of new or replacement additional steel reinforcement into the structural concrete of chimneys and cooling towers.

**External Strengthening by Plate Bonding:**

Structural strengthening by the bonding of external plates is carried out in accordance with the relevant national design codes and EN 1504-4. The exposed surfaces of the concrete to receive the externally bonded reinforcement should be thoroughly cleaned and prepared. Any weak, damaged or deteriorated concrete must be removed and repaired, to comply with EN 1504 Part 10 Section 7.2.4 and Section 8.

In 1990 Sika began working with modern composite materials, particularly glass, aramid and carbon fibres. These are now used extensively for structural strengthening works as **Sikadur®** epoxy adhesive bonded mortar, as **Sika® CarboDur®** preformed plates or as **SikaWrap®** fabric sheets which are built up and moulded on site with **Sikadur®** epoxy resins.

**Pre-stressing (post-tensioning) of Sika® CarboDur® plates:**

The extensive expertise and experience that Sika has gained with these materials also led to the exciting development of pre-stressing systems and techniques for post-tensioning applications with the **Sika® CarboDur®** plates. These include the **Sika® LEOBA CarboDur® (SLC)** and the **Sika® CarboStress®** systems.

Another useful technical innovation, the **Sika® CarboHeater®**, allows the plate bonding systems to be installed on site at low temperatures, or it can accelerate the adhesive's curing for rapid installations, with only minimal downtime. Therefore with this innovation, the strengthening works can be carried out with only short overnight closures or during the winter for example, which was previously not possible.



Sika CarboDur CFRP plates being bonded with Sikadur epoxy adhesive directly to the repaired external concrete surface at the top of a cooling tower for increased restraint.



Sikadur adhesive application to the Sika CarboDur plate.



Easy application of the Sika CarboDur plates from powered access cradles.



# Additional Sika® Solutions

## Steel Coatings for Corrosion Protection

During the closure and outage of concrete chimneys and cooling towers for substantial refurbishment works, the opportunity is usually taken to renew or refurbish the associated structural steelwork and other ancillary steel equipment.

This can include walkways, railings, water storage tanks and other different types of equipment in and around the structure.

These steel surfaces are exposed to the same aggressive conditions from the exhaust gases and condensates, UV light exposure and weathering. This means that the steel surface exposure is similar to the concrete in the zone classification of the external areas and also internally within cooling towers, dependant on its position. This exposure can be classified as at least according to ISO 12944 part 2 "Heavy Industrial", which therefore also requires durable and effective corrosion protection.

### Durable Corrosion Protection

For this level of corrosion protection to be achieved in this aggressive environment, the steel surfaces must all be prepared by blast cleaning to a standard equivalent to ISO 12944 part 1 Sa 2½.

Sika produces all of the necessary products to meet the stringent protection and durability requirements in these situations, with all relevant systems approvals and certification. These systems include active primers and then the intermediate and top coats according to the specific structure requirements, designed for use in shop and/or site applications.



SikaCor steel coatings and Sikafloor concrete protection applied to ancillary equipment and surfaces.

The **SikaCor®** coatings range also includes materials for direct application to exposed galvanized steel and aluminium surfaces.

- For functional equipment and its associated structural support steel surfaces with chemical contact and exposure: The **Sika Poxitar® System** is specifically designed for these extreme conditions. It is based on epoxy resin combinations.

- For structural steel and functional equipment surfaces with normal industrial area atmospheric levels of chemical exposure: The **Sika Poxicolor® System** is particularly suitable for this due to its high-build properties and it is also based on epoxy resin combinations.

- For the steel surfaces with the highest potential stress from both chemical and UV exposure in service, together with visual appearance requirements: The **SikaCor® EG System**, including **SikaCor® EG-5** polyurethane resin based top coating, is used extensively and successfully around the world on this type of structure for durable protection in these conditions.



Associated equipment protected with SikaCor steel coatings for durable corrosion protection.



Galvanized steel ladders protected with direct application SikaCor coatings.

## Construction and Protection of new Structures

Achieving durable construction with surface protection from the start, following the old saying that "prevention is better than cure", is certainly advisable with chimney and cooling tower construction.

Both of these types of structure are now normally built by slip-forming or similar climbing form methods. These all involve working to achieve almost continuous steel fixing, concrete pouring and then the early release and movement of the formwork. The concrete is almost always pumped into the slip-forms and therefore it is required to be extremely fluid for pumping and placement around the dense reinforcement. Yet it must also be suitable to achieve the high early strengths required to allow the formwork to be safely moved as soon as possible.

### High Performance Concrete

This is exactly what can be achieved with **Sika® ViscoCrete®** superplasticizer technology. In combination with **Sika-Rapid®** technology, the necessary concrete consistency and performance can now be produced in all of the different climatic conditions around the world. This allows high quality construction in all geographic locations, plus the construction

work can continue uninterrupted throughout the year, without costly delays in the winter. To achieve a dense, closed concrete surface for maximum durability, it must be cured correctly and efficiently. However this is particularly difficult on slip-formed surfaces which can easily dry out too quickly. This can result in lower surface strengths, increased porosity and therefore reduced quality, increased risk of surface shrinkage and cracking.

### Concrete Protection

Sika pioneered an innovative method of overcoming these difficulties, by applying a protective coating to the concrete surfaces immediately after striking. This is not by using so-called "concrete curing agents", but by the early application of the first or the primary coats of the special **Sika®** protective coating systems. This is achieved with the physically hardening, acrylic-based **Sikagard®-680 S** for External Zones 2 and 3. The reaction hardening epoxy-based materials from the **Sikagard®-200** range are used for External Zone 1 and also internally in cooling towers.

The secret of success with this concept is in the high moisture tolerance and displacement capabilities of the products, plus the penetrative capabilities of these

special **Sika®** systems. This procedure has now become well known as "direct curing". This early-age coatings application also allows the concrete to achieve its maximum strengths and prevents any initial carbonation.

### External Zones 2 and 3: Protective Coating System from the Start:

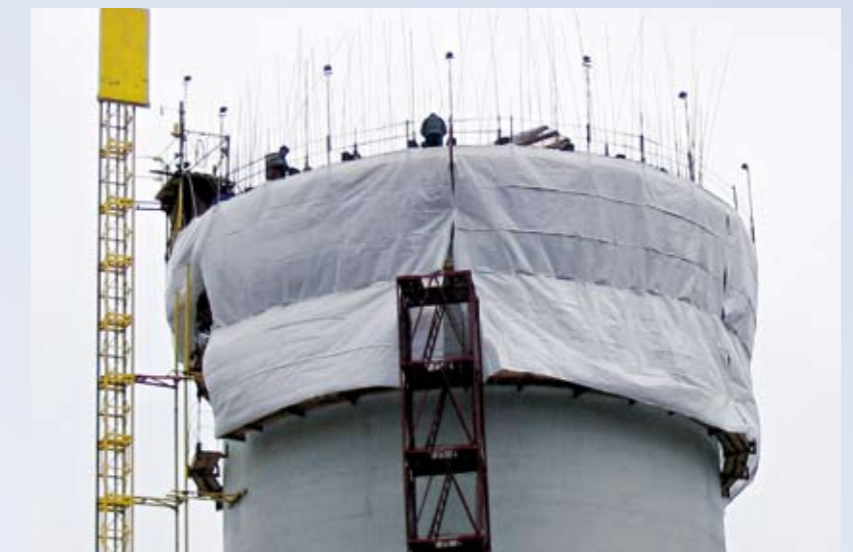
Use **Sikagard®-680 S** the single-component acrylic-based, pigmented anti-carbonation and water-repellent coating system. Alternatively as an external coating system with crack-bridging properties use coatings from the **Sikagard®-500 Elastic** range.

### External Zone 1 and Internal Surfaces: Protective Coating System from the Start:

Use **Sikagard®-253** water-based, or **Sikagard®-2406** solvented, two-component, pigmented and chemically resistant epoxy resin based coatings. Plus **Sikagard®-363**, as the UV and chemically resistant top coat, which should be applied in the solar exposed upper section.



Icosit-2406 epoxy coating applied inside a cooling tower.



Slip-forming a new concrete chimney base structure with Sika ViscoCrete technology.

# Reinforced Concrete Chimneys and Cooling Towers: Case studies

## EKO, Germany

### The Project:

#### The EKO Steel Works, Eisenhüttenstadt, Germany

Now owned by Arcelor, the world's largest steel producer, the plant had 4 natural draught cooling towers built in the early 1960's. Each tower was 55 m high with an average diameter of 33 m and a total combined internal and external surface area of more than 10,000 m<sup>2</sup>.

### The Problem:

During the 1990's three of the towers became unsafe and had to be demolished, they were then replaced with costly forced-draught coolers. The fourth was also under threat in 2003 due to the extent of continuing concrete damage that had occurred. Traditional repair and strengthening techniques were considered to be impractical and extremely costly, therefore its demolition was also proposed. However one of the leading German Consulting Engineers, Leonhardt Andrea and Partner (LAP), proposed an innovative solution.



Quality control of the concrete. Core drilling on the wall.



Autumn 2004, surface fully coated with Sikagard®-680 S concrete color.

### The Sika Solutions:

The solution involved using the latest Sika structural strengthening techniques from Sika Germany, in combination with the established **MonoTop**® cementitious repair system and well proven **Sikagard**® protective coatings.

With this cost effective proposal the Cooling Tower was repaired and strengthened in 2004 and then resumed operations without major disruption to steel production and without the huge cost of demolition and replacement.

The repairs included hand applied patch repairs with the **Sika**® **MonoTop**® System and large volume repairs with **SikaCem**® **Gunite-212**, which was dry spray applied.

The structural strengthening was readily achieved by using the extremely lightweight but incredibly strong **SikaWrap**®-200C **CRFP** incorporating **Sikadur**®-330 impregnating epoxy resin adhesive. Protective coatings systems were applied internally as the **Sikagard**® **VGB** approved system and externally with **Sikagard**®-680 S including over the fabric reinforcement to also improve the overall visual appearance.

## Grootvlei, South Africa

### The Project:

#### Grootvlei Power Station, Balfour, South Africa

This coal fired power station has six 200MW power producing units that were first commissioned in 1969, however due to the increased cost of coal and transport, 3 were mothballed in 1990. Then in 2005 it was decided to reopen these and also to refurbish the whole plant to meet increased power demands and the different economic situation. Full running of the plant is planned for December 2009.

### The Problem:

For a combination of all the usual reasons including carbonation and aggressive exhaust gas attack of the concrete of the cooling towers, support structures and also the main chimneys had suffered some concrete attack and damage in the more than 30 year period since their original construction. There were also a substantial number of structural cracks in the Cooling Towers due to a combination of loading and ground settlement / movement, which were also at risk of allowing water ingress to put some of the post tensioned steel at risk.



After 30 Years the concrete showed many cracks.

### The Sika Solutions:

The structural cracks in the concrete were sealed at the surface and then filled and re-bonded with the Sikadur structural epoxy injection system and the damaged concrete was patch repaired with the **Sika**® **MonoTop**® hand applied system with **SikaGrout**®-214 for poured repairs. **SikaTop**® **Armatec** -110 **EpoCem**® was used as the steel reinforcement primer onto the prepared steel, where concrete spalling over corroding reinforcement had occurred to provide long term corrosion protection.

The external surfaces of the repaired Cooling Towers were protected with a **Sikagard**® hydrophobic impregnation and the external Chimney surfaces were protected with **Sikagard**®-550W coatings due to the more aggressive exposure and possible risk of future cracking from the adverse thermal gradients that can occur in service.



Crack Injection.

## Turow, Poland

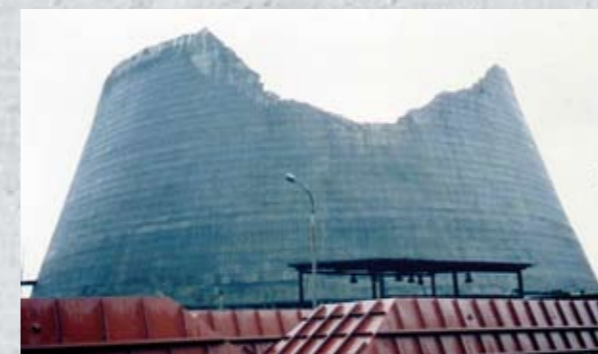
### The Project:

#### Turow Power Station, Bogatynica, Poland.

The Turow Power Station in Bogatynica, Poland, is the main energy supplier in this area at the borders of Poland, Germany and the Czech Republic. In the past the area was known as the 'Black Triangle' due to its heavily polluted environment with up to 50 power plants within a 50 km radius. The environmentally aware residents of the area now have the aim to be known as the 'Green Triangle'.

### The Problem:

In 1988 one of the nine cooling towers in this power station collapsed due to the advanced deterioration of the reinforced concrete structure caused by the aggressive exposure. This triggered a major condition survey of all such structures in Poland to be ordered by the Government – several were found to require immediate repair due to similar concrete damage and reinforcement corrosion.



Collapsed Tower.

The Turow No. 2 Cooling Tower was one that required immediate repair. Due to the Authority's lack of experience in the repair of these structures, a well known specialist contractor in this field from Germany was appointed to carry out the work and develop the skills of local contractors for similar works in the future. This specialist contractor used Sika as their repair materials supplier because Sika had worked successfully with them on earlier projects in Germany and elsewhere to develop and adapt products specifically for the special requirements on these structures.



Protective coating being applied.



Inspection.

### The Sika Solution

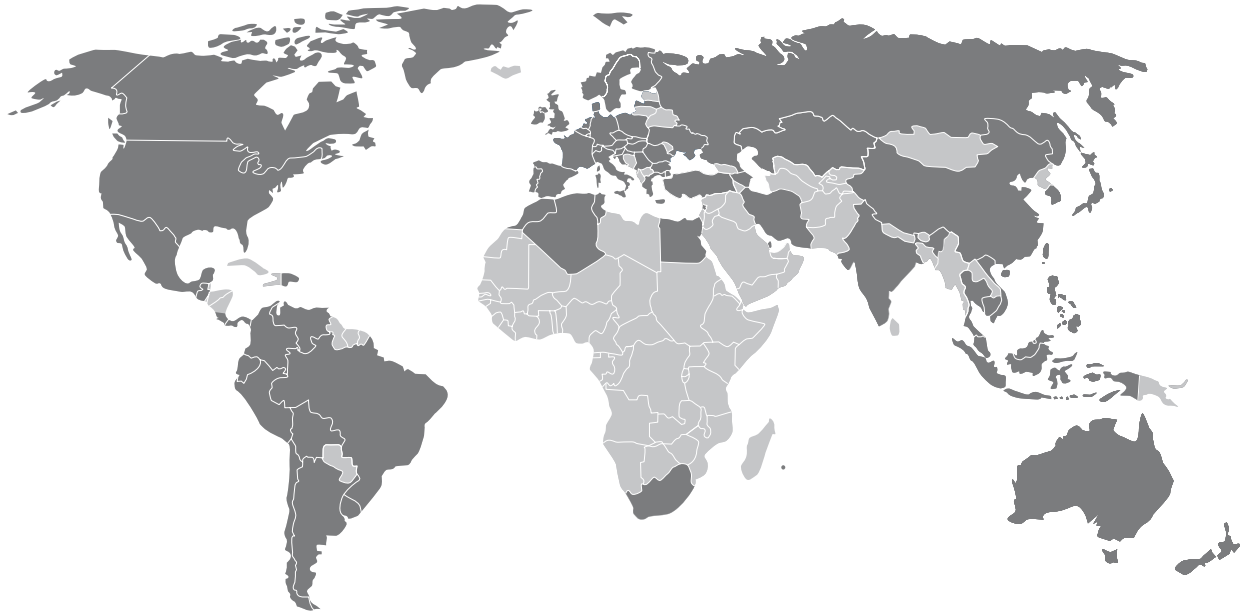
Cooling Towers	
Internally	Externally
Hand applied patch repairs using the <b>Sika</b> ® <b>MonoTop</b> ® system	Hand applied patch repairs using <b>Sika</b> ® <b>MonoTop</b> ® system
Large Volume repairs using dry spray shotcrete modified with <b>Sikacrete</b> ® <b>PP1 TU</b>	Large volume repairs using dry spray shotcrete modified with <b>Sikacrete</b> ® <b>PP1 TU</b>
Internal protection with <b>Sika</b> ® <b>Icosit</b> ®-2406 epoxy coating	<b>Sikagard</b> ®-700 S hydrophobic impregnation followed by <b>Sikagard</b> ®-680 S and the elastic coating <b>Sikagard</b> ®-550 W on areas at risk of future cracking
Chimneys	
Internally	Externally
Patch repairs using <b>Sika</b> ® <b>MonoTop</b> ® system	Patch repairs using <b>Sika</b> ® <b>MonoTop</b> ® system
Internal steel duct protection with <b>Sika</b> ® <b>Icosit</b> ® <b>Poxicolor</b> and <b>Icosit</b> ® <b>Elastic</b> system.	Zone 1 and into Zone 2: <b>Sika</b> ® <b>Icosit</b> ® <b>Poxicolor</b> and <b>Sikafloor</b> ®-363 <b>Elastic</b>
	Rest of Zone 2 and Zone 3: <b>Sikagard</b> ®-700 S Hydrophobic impregnation followed by <b>Sikagard</b> ®-680 S or <b>Sikagard</b> ®-550 W

Due to the success of this initial project all of the cooling towers and Chimneys at the power station in need of repair have used the same system for the past 18 years with Polish contractors now fully trained and competent in the works.

Up to now, more than 240000 m<sup>2</sup> of concrete surfaces on these structures have been repaired with the Sika Systems at this plant. In 2007, laboratory testing, assessment and an in-situ investigation were carried out by the Building Research Institute of Poland, to check the suitability and durability of the system used, this was confirmed, furthermore, an extended approval for the Sika systems was granted in Poland for these structures.

# Design Engineers Support for Reinforced Concrete Chimneys and Cooling Towers

## Concrete Repair and Protection



## Your Partner in any Part of the World

Sika is a globally 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 approx. 12'000 employees worldwide and is therefore ideally positioned to support the success of its customers.

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