CATHODIC PROTECTION OF THE HISTORIC BOERENTOREN (KBC TOWER)

ANTWERP, BELGIUM

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HISTORY OF THE BOERENTOREN

With the World Exposition coming to Antwerp in 1930 to celebrate the establishment of the Belgian Kingdom in 1830, the mayor wished to showcase Antwerp on the European stage.

Fig. 1: The Boerentoren building in the 1930s

Fig. 2: The Boerentoren (KBC Tower) in Antwerp, Belgium

A plan was developed to build a modern skyscraper in the medieval city center which, when completed at 287 ft (87.5 m) high, would be the tallest in Europe. The Art Deco-style building (Fig. 1) would house the offices of Krediet Bank and became known as the Boerentoren (Farmer's Tower) in honor of the bank's most important shareholders. Today, the building is officially known as the KBC Tower and is occupied by the largest bank of Flanders (Fig. 2).

The tower was built in the same fashion as contemporary American high-rise buildings of the time such as the Chanin Building in New York, NY, and the Carbide and Carbon Building in Chicago, IL. The use of load-carrying steel frame construction, a method later employed for constructing the Empire State Building, allowed buildings to reach new heights compared to traditional stone construction. However, the design of the Boerentoren was regulated by the city council so that it would not compete with the gothic-style Cathedral of Our Lady and its 404 ft (123 m) high spire.

The Boerentoren, designated as a Protected National Monument in 1981, consists of 24 floors in the tower and nine floors in the side wings. The steel frame is encased in concrete or brick masonry depending on the location. The entire exterior of the building is covered with white limestone (Jaune de la Forge) attached to the steel frame.

In December 1928, construction began by demolishing war-damaged houses and placing a 6.5 ft (2 m) thick concrete foundation. The lower-level shops opened in 1930 and the majority of the apartments and business offices opened in the summer of 1931.

During the war, the tower was hit by at least 50 grenades and a German V-bomb tore open the right wing in 1945. But, in testament to its construction, only one main column was bent.

The height of the tower was increased to 315 ft (96 m) in 1976 when a panoramic room and sign were added.

FAÇADE INVESTIGATION

In the 1970s, cleaning and minor repairs to the façades were completed with approximately 18,837 ft^2 (1750 m^2) of new or replaced stone. Additional façade repairs were specified in 1992 and temporary repairs were made in 2003.

Inspections in 2009 and 2010 again detected severe stone damage, including long vertical cracks near steel columns (Fig. 3) and horizontal cracks beside the beams. As such, KBC commissioned a thorough study of the building.

Results of the building study include:

- The masonry covering did not provide sufficient corrosion protection;
- The volume of corroding steel increases by a factor of seven and damages the outer rigid stone, leading to high maintenance costs and safety concerns;
- Water-repellent treatments applied in the 1990s have not been effective because the stone is highly adsorptive and is dampened by water penetration through the joints; and
- Previous repairs have been damaged by corrosion, and if the corrosion problem is not addressed, a durable repair is not possible.

The investigation concluded that damage was caused by corrosion of the structural steel frame and that traditional repairs would not succeed in mitigating ongoing corrosion damage. Although the concrete or masonry mortar infill that encapsulated the steel frame (Fig. 4) is naturally alkaline and allows the formation of a stable thin protective oxide layer on the steel, carbonation combined with moisture from rain penetration, porous stone, unsealed joints, and internal condensation over 80 years caused the steel frame to corrode.

A conventional repair approach requires exposing the steel frame, applying a protective coating, then rebuilding the stone façade. Given the need to address corrosion in large areas of the structure, this approach was deemed to be too costly and disruptive. For this reason, an alternate technique of applying cathodic protection was considered.

CATHODIC PROTECTION

Cathodic protection has been successfully used to mitigate steel frame corrosion in historic structures for approximately 15 years in the United Kingdom. When using cathodic protection, conventional repair occurs only in areas with corrosion-damaged stone and the remaining stone stays in place with the structure being protected by embedded impressed current anodes. This means that cathodic protection can limit the inconvenience, cost, and potential damage caused by conventional repair methodologies.

Fig. 3: Vertical cracking at column

Fig. 4: Brick infill around steel column

Based on the investigation, various areas of the structure were categorized based on their condition (refer to Table 1 and Fig. 5).

Corrosion is an electrochemical process whereby an electrical discharge occurs between different sections of the steel (Fig. 6). Anodic sites, where electrical current leaves the steel, cause oxidation and rust formation. In cathodic locations, the current flows to the steel, where a chemical reaction improves the corrosive conditions around the steel.

When using cathodic protection, the detrimental corrosion reaction is controlled by imposing an electrical current to the steel such that the steel surface is cathodic. Ideally, active corrosion is stopped and future corrosion is prevented from initiating. At a minimum, the corrosion rate is substantially reduced to an acceptable level.

Most steel-frame buildings with cathodic protection have used impressed current cathodic protec-

TABLE 1: AREAS OF THE STRUCTURE CATEGORIZED BASED ON THEIR CONDITION

Zone	Description	Conventional repair	Repair with cathodic protection	Approximate area
Zone 1	Very substantial damage Large cracks in stone Severe rust Risk to pedestrian and vehicular traffic	Façade reconstruction Disassemble to reveal steel frame, remove all rust products, coat steel beams Repointing joints and waterproofing	Repair/replace individual stone as needed Non-damaged areas susceptible to corrosion are cathodically protected Repointing joints and waterproofing	6684 ft^2 (621 m^2) (5.7%)
Zone 2	Limited damage Minor cracks in stone Less evidence of corrosion Less risk to pedestrians Will evolve to Zone 1 with continued exposure to moisture	Façade reconstruction Disassemble to reveal steel frame, remove all rust products, coat steel beams Repointing joints and waterproofing	Individual stone restoration; replacement is kept to a minimum Non-damaged areas susceptible to corrosion are cathodically protected Repointing joints and waterproofing	10,032 ft^2 (932 m^2) (8.6%)
Zone 3	No damage, but similar conditions to Zones 1 and 2 High risk of corrosion now or in the future	Repointing joints and waterproofing Future corrosion damage is likely	Cathodic protection used preventively Repointing joints and waterproofing	8643 ft^2 (803 m^2) (7.4%)
Zone 4	No damage present and not reasonably to be expected	No repairs needed Repointing joints and waterproofing	No cathodic protection; monitor sample areas for corrosion initiation	91,493 ft^2 (8500 m^2) (78.3%)

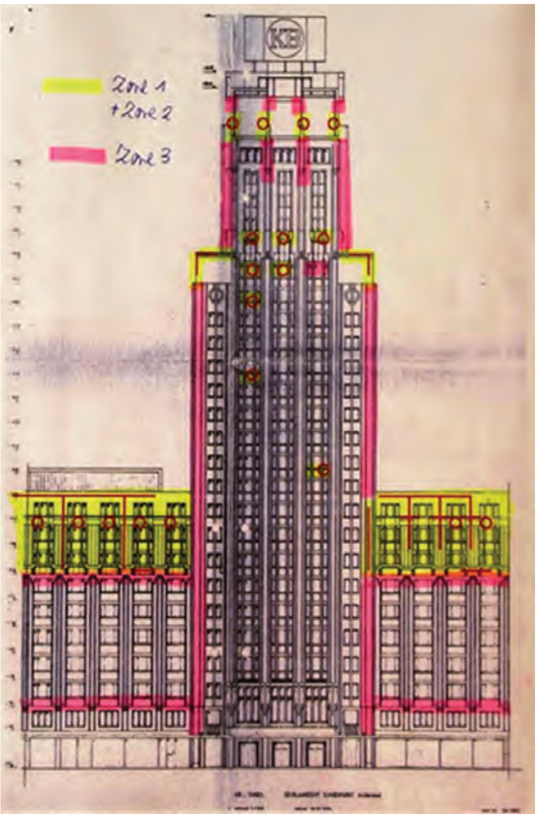

Fig. 5: Illustration of damage zones


Fig. 6: Beam corrosion above window

tion (ICCP), whereby the electrical current is provided by an external power source connected to a long-lasting inert anode. A voltage is created such that protective current flows from the anode to the steel. The cathodic protection transformer/rectifier is powered by the main building power supply.

PILOT INSTALLATION

Because of the size and historic importance of the structure, it was determined that a cathodic protection pilot installation would be performed. The pilot installation was designed to:

- Evaluate the acceptability of cathodic protection;
- Evaluate polarization of the steel;
- Gather data for economical anode configuration;
- Develop project-specific installation details;
- Develop project-specific budget costs; and
- Evaluate the impact on the historic aspect of the building.

Even though cathodic protection has a demonstrated history of use for protecting steel frame structures, every building is unique, many with old, vague detail drawings. For the pilot installation at the Boerentoren, two test zones were installed using various types of anodes at varied spacing. Each anode system would be evaluated for installation, performance, and aesthetic effects.

The pilot installation occurred during May and June of 2011. Observations include:

- The columns and beams were electrically continuous and would not require special attention to establish continuity;
- The position of the columns deviated from the original plans and were more deeply embedded in the masonry than expected;
- Visual inspection of the steel indicated that the deeper sections were adequately protected by the dry environment, but the outer surface portions showed visible corrosion; and
- The discrete anodes (Fig. 7) were providing protection to a reasonable distance outside the zone in which the anodes were installed.

The pilot installation proved the feasibility of cathodic protection as a solution to the façade corrosion problem and a specific, final design was prepared. Discrete ICCP anodes were selected to minimize the risk of near shorts to the anchors and allow for easier resealing of the joints versus titanium ribbon mesh anodes. Because they are installed in the joints, the discrete anodes are not visible after installation.

Fig. 7: Discrete anode in masonry joint

The information collected from the pilot installation was used to refine the preliminary design. The pilot project proved that a single vertical line of discrete anodes could effectively protect the outer flange of the large steel columns at an anode spacing up to 35 in. (900 mm). The final design spacing was 24 in. (600 mm, two blocks high) but the anodes could technically be further apart if required during the cathodic protection implementation. At the beams, the anodes were to be placed in a plurality of rows to protect flanges and the web (Fig. 8).

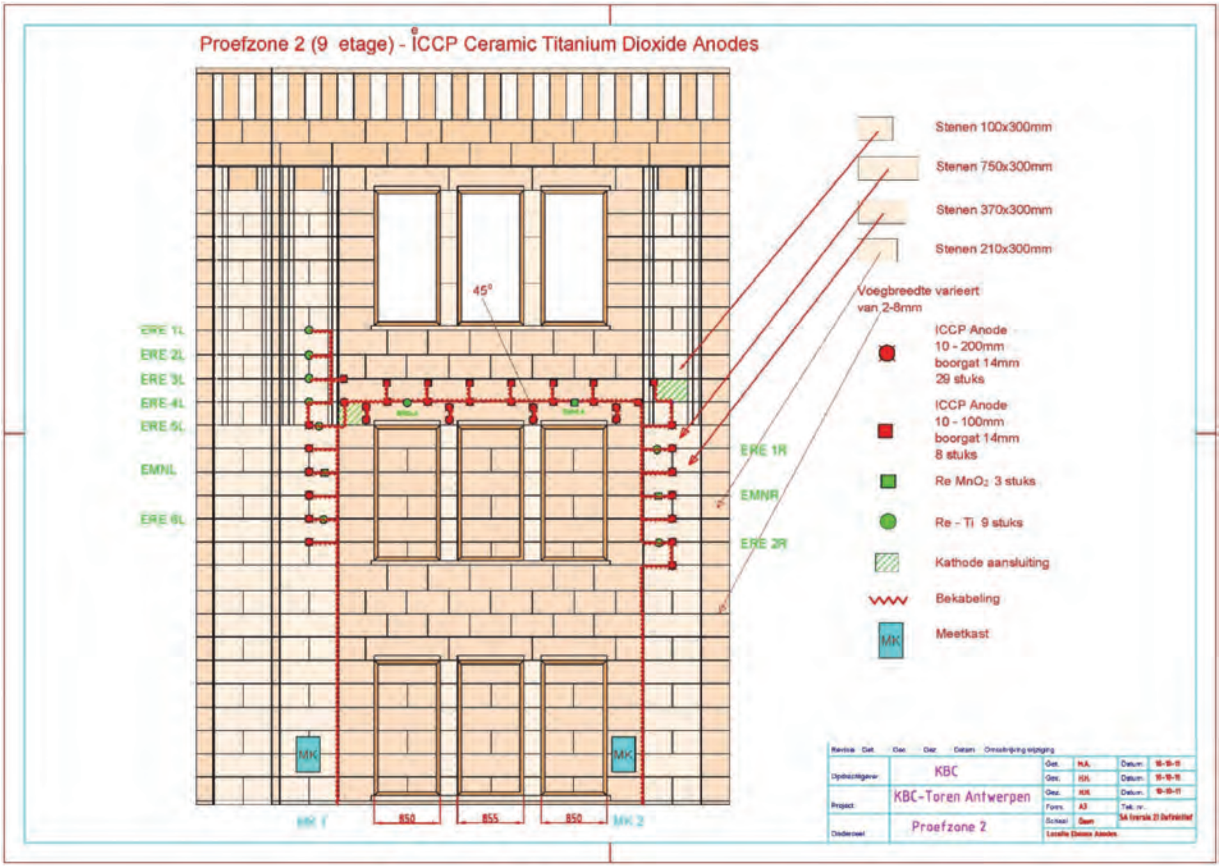

Fig. 8: ICCP anode layout

REHABILITATION PROGRAM

Implementation of the façade repair program occurred from March to December 2014. The scope of work included scaffolding the building for access (Fig. 9), light general cleaning while retaining existing patina, repair/replacing stone cladding affected by corrosion, moss-repellent treatment, concrete repairs, new sealant around windows where needed, flashing repair, downspout replacement, cleaning/repairing of the roofs and terraces, and painting of two iron stairways. Cathodic protection was provided to approximately 25% of the surface area, Zones 1 to 3, as classified during the inspection.


Fig. 9: Scaffolding at building façade

The final cathodic protection design is summarized as follows:

- Provide ceramic titanium dioxide probe anodes, 0.28 in. (7 mm) diameter by 3.94 and 7.87 in. (100 and 200 mm) long (Fig. 10);
- Protect column with one row of anodes placed at 24 in. (600 mm) spacing in the middle of the outer flange;
- Protect beam with eight anodes placed in several rows;
- Drill holes at 0.47 in. (12 mm) diameter by a depth at least 1.38 in. (35 mm) greater than length of anode;
- Test down hole for potential shorts to steel;
- Provide redundant cathode connections to the steel frame (Fig. 11);
- Saw-cut and drill anode holes in joints (Fig. 12);
- Use conductive, acid-resistant grout around anodes (Fig. 13);
- Install conductive ceramic ICCP anodes into drilled and grouted holes, assuring no air pockets exist around anodes (Fig. 14);
- Install manganese dioxide reference electrodes;
- Install cathode, anode, and reference electrode wiring in joints saw cut to a minimum dimension of 0.31 in. (8 mm) width x 0.70 in. (20 mm) depth (Fig. 15);
- Fill slots and top of drilled holes with mortar to match adjacent masonry joints (Fig. 16); and
- Provide power supplies with remote monitoring and capabilities to adjust system voltage.


Fig. 10: Ceramic titanium dioxide ICCP anodes


Fig. 11: Cathode connections to steel column

Fig. 12: Joints saw cut and holes drilled for anodes and associated wiring

The ICCP system should be regularly monitored and adjusted to assure that adequate protection exists. After the system was commissioned, testing and adjustments were conducted after 2, 4, 8, and 12 weeks. Thereafter, depolarization testing was conducted quarterly and a visual inspection and report due annually.

The phasing of the work was conducted to keep the nuisance to an absolute minimum for those living in the vicinity, pedestrians and staff working at the Boerentoren, and in neighboring premises.

The following quantities of materials were used in the repair of the Boerentoren:

- ICCP discrete anodes 9121
- ICCP wiring 7.95 miles (12.8 km)
- Stone repair 967 ft^3 (27.39 m^3)
- Stone replacement 890 ft^3 (25.21 m^3)
- Joint repair 9.13 miles (14.7 km, including repointing for ICCP wiring)

Fig. 13: Conductive anode grout placement

Fig. 15: Wiring concealed in the mortar joint

Fig. 14: Conductive titanium dioxide ICCP anode placement

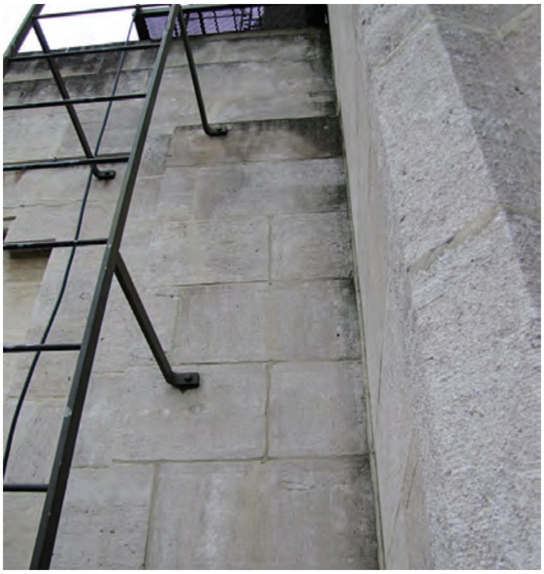

Fig. 16: Anodes and wires concealed

SUMMARY

An investigation at the historic KBC Tower (the Boerentoren) in Antwerp, Belgium, indicated that traditional masonry repair would not solve the underlying corrosion problem with the structural steel frame. For that reason, an ICCP system was installed through joints in the exterior façade to protect about 25% of the structure.

This was the first time that cathodic protection technology was used in Belgium for the large-scale restoration of a historic steel-frame structure with masonry cladding. First conducting a pilot installation proved to be a successful approach, as the technology was verified and the most economical design accomplished. Over 9000 ICCP anodes were installed as part of the cathodic protection system, protecting the steel structure with low-voltage protective electrical current.

Cathodic protection offers an environmentally friendly, permanent solution to both the consequences of existing corrosion and against future corrosion formation, and stabilizes the load-bearing steel frame structure.

Historic Boerentoren (KBC Tower)

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