Maintenance experiences with installed CP systems in the Netherlands and their expected and unexpected maintenance needs during the past 35 years.

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Abstract. This paper presents the results of a study based on practical experiences and cases with regard to the need for maintenance of installed CP systems over the past 35 years in the Netherlands. CP is a proven technique for long-term protection of steel in concrete against corrosion. Corrosion can lead to significant damage to reinforced concrete and ultimately result in a reduction in the load-bearing capacity of the structure. Correct application of CP can prevent this. Over 35 years, CP has been successfully applied in the Netherlands to all kinds of concrete structures in the industry, residential buildings, infrastructure and even monuments. CP normally distinguishes itself from other repair techniques by its long service life and durability. With careful application and professional monitoring, a service life of 15-30 years or even longer can be achieved. Nevertheless, there have been applications in which the CP system had to be maintained in the shorter or longer term or even completely replaced. Although every application requires maintenance, this maintenance sometimes came completely unexpectedly or much too soon. This paper gives an overview of a number of such projects and identifies the causes and consequences (in scope, costs and effects) of the relevant maintenance measures.

1 Introduction

Cathodic protection (CP) is a proven technique that was developed more than 200 years ago to protect steel structures against damage due to corrosion. For 45 years, the technique of CP has also been successfully used for the long-term protection of steel in concrete. Without CP, corrosion can lead to deterioration of the structure and reduction of its bearing capacity and to significant (consequential) damage to the concrete.

Over the past 50 years, several national costs of corrosion studies have been conducted. Using different approaches, the studies all arrived at (direct) corrosion costs equivalent to about 3%–4% of each nation's gross domestic product (GDP). Using a 3.4% of global GDP (2013) the global cost of corrosion can then be estimated to be 2 trillion euro. Worldwide, approximately 5 tons of steel are lost every second due to corrosion. A correct application of CP can improve this and prevent damage to constructions and loss of invested capital. It is estimated that savings of between 15% and 35% of the cost of corrosion could be realized [1].

In the Netherlands, CP of steel in reinforced (and pre-stressed) concrete has been applied since 1987. On a limited scale initially, with a varying number of projects every year. After this pioneering phase, CP gained more fame, more and more companies were able to offer and implement this technique and the number of applications increased. As a result, CP has often been successfully applied in the past 35 years to all kinds of concrete structures such as viaducts, bridges, tunnels, swimming pools, floors, cantilever beams, balconies and industrial buildings and installations, but also to monuments [2, 3].

CP normally distinguishes itself from other repair techniques by its long service life and durability. With an expert application [4] and professional monitoring, a service life of 15 to 30 years or even longer can be achieved [5]. Nevertheless, in the aforementioned period of 35 years there have been applications in which the CP system had to be maintained in the shorter or longer term or even completely replaced. An overview of a number of such projects is presented in the following chapters and the causes and implications (in scope, costs and effects) of the relevant maintenance measures will be identified and indicated.

2 Cathodic Protection (CP) – the basic principle in concrete structures

In concrete structures, the reinforcing steel acts alternately as a cathode and anode when corrosion occurs, whereby in the anodic places the steel is converted into iron oxide. The principle of CP is based on regulating or intervening in this process [6]. To achieve that, an anode is applied on or in the concrete surface with the steel to be protected. This is either a durable electrode (often made of titanium), which is connected to the plus pole of a power source, or a sacrificial (less noble/more reactive) metal (usually zinc), which is 'short-circuited' with the steel reinforcement (without the intervention of a power source). The reinforcement then only functions as a cathode and is therefore 'protected'.

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The first system is referred to as 'active' cathodic protection (or impressed current cathodic protection; ICCP), the second system is known as 'passive' or 'galvanic' cathodic protection (GCP).

The durable electrode or the less noble metal acts as the new anode (+) in the CP system and the reinforcement is thus forced in its entirety into the (protected) cathode function (-), which stops the corrosion. Between the reinforcing steel and the applied anode, electrons and ions are constantly exchanged (the so-called protective current) through the cabling and the concrete respectively. As long as this process is maintained, the steel is protected.

By measuring and monitoring the CP system, using built-in reference electrodes (RE’s), it is possible to demonstrate its proper functioning. Through continuous monitoring the CP system can (if necessary, and only in case of impressed current CP systems) be adjusted. This can even take place remotely via a link to the internet.

3 Maintenance of installed CP systems

3.1 In general

CP usually requires a considerable (extra) investment at the start. But with the execution of the repairs, costs will be saved on concrete removal, reinforcement preparation and concrete reinstatement. The execution time is also shortened, which saves on construction site costs.

On the other hand, costs must be incurred for the installation of anode material and other facilities. These costs are largely determined by the specific wishes and requirements that apply to a project (imposed by the customer, the environment, or other external factors).

However, given a period of 10, 20 or 30 years, this investment can be amply recouped because in that period of time the costs for maintenance of the structure with an applied CP system are normally limited. Regularly recurring repair rounds are not necessary for a well-designed and installed CP system because the corrosion of the reinforcement is stopped. This ultimately results in lower total costs and greater security (financial and operational) and safety (personal and structural). An important condition is of course that the usual costs for maintenance of the CP system are not exceeded. Every CP system needs maintenance, but usually with active CP systems, durable anodes are used and maintenance in the first 20 to 30 years after installation is limited to the electrotechnical components (power supply, rectifier unit, modem, cabling and connections, junction boxes) and possibly the reference electrodes. In galvanic CP systems, the sacrificial anodes are usually the main items in relation to CP maintenance.

According to the nature and cause of the maintenance, some examples of CP systems with (unexpected or unnecessary) maintenance will now be discussed and illustrated.

3.2 Maintenance due to design errors

3.2.1 Case A6 Highway – viaduct (Naarden)

- Type of construction: prestressed abutment beams (with a support surface of approximately 1 m deep)
- Cause of the concrete damage: chloride induced corrosion due to leaking joints
- CP system type: GCP (galvanic)
- Type of anode system: Vector Galvashield XP (zinc anodes)
- Built-in in cut locations, every 0,75 m
- Only in the front surface of the beams

Fig. 1. Built-in zinc anodes, every 0,75 m

Fig. 2. Built-in zinc anodes in cut locations

- Year of installation: 2010
- Year of maintenance: 2017
- Type of maintenance / maintenance measures:
- Extensive concrete repairs
- Replacement of the GCP system for an active (ICCP) system with 1 m long titanium anodes, in drilled holes underneath the reinforcement of the support surface of the beams

Fig. 3. Titanium anodes in 1 m deep (drilled) holes

Fig. 4. Grout injection after placing the titanium anodes

- Cause of (unexpected) maintenance:
  - Zinc anodes 'loosely' connected to the steel with only a mechanical binding wire
  - Application of an epoxy primer on the reinforcement, for corrosion protection, acting as an electrical insulator
  - Repaired with an unsuitable mortar (resistance too high)
  - Zinc anodes applied in the wrong locations
  - Small zinc anodes applied with a spacing (0,75 m) too large for a good current distribution, resulting in a dysfunctional application
  - Maximum distance from an anode to reinforcement to be protected: over 1 m
- Typing of the error: design flaw and lack of competence and expertise with CP installation
- Consequences of the maintenance:
  - Extent: large
  - Cost: significant
  - Effects: significant

3.3 Maintenance due to errors in the execution

3.3.1 Case A9 Highway – viaduct (Amstelveen)

- Type of construction: prestressed table column (with a support surface of approximately 0,9 m deep)
- Cause of the concrete damage: chloride induced corrosion due to leaking joints
- CP system type: ICCP (active)
- Type of anode system: drilled in titanium anodes
  - Spacing: 0,4 m
  - Usage of a drill rig to avoid prestressing cables

Fig. 5. Prestressed support column of prestressed beams

Fig. 6. Drilling holes with a rig to avoid damaging the prestressed cables

- Year of installation: 2015
- Year of maintenance: 2017
- Type of maintenance / maintenance measures:
  - Replacement of the anode material
- Cause of (unexpected) maintenance:
  - Usage of incorrect filling mortar (with too high resistance): unfortunate mix-up of product numbers, resulting in a dysfunctional application
- Typing of the error: insufficient material verification during installation of the anodes (calamity)
- Consequences of the maintenance:
  - Extent: large
  - Cost: significant
  - Effects: small

3.3.2 Case Apartment building – Groningen

- Type of construction: gallery plates and portals
- Cause of the concrete damage: mixed in chlorides
- CP system type: ICCP (active)
- Type of anode system: Ahead® conductive coating
  - With primary anode of silver wire fabric strip (PDR)

Fig. 7. Front side with CP system on plates and portals

- Year of installation: 1993 / 2004
- Year of maintenance: 2021
- Type of maintenance / maintenance measures:
  - Extensive concrete repairs
  - Replacement of the anode material
- Cause of (unexpected) maintenance:
  - Limitations of the first generation of this type of anode material, with a maximum driving voltage of 2 V (versus drying concrete & increasing resistance)

    • Rupture of the primary anode, placed over joints and in corners (error in execution)
    • Discontinuity of the reinforcement in the concrete structure (error in the execution)

Fig. 8. Red sections: CP system is dysfunctional due to rupture of the primary anode (green sections are still active)

Fig. 9. Replacement of the anode material

• Typing of the error: development of new materials, lack of competence and expertise with CP installation
• Consequences of the maintenance:
    • Extent: total project
    • Cost: high
    • Effects: significant

3.3.3 Case Apartment building – Tilburg

• Type of construction: cantilever beams
• Cause of the concrete damage: mixed in chlorides
• CP system type: ICCP (active)
• Type of anode system: drilled in titanium anodes
• Year of installation: 1993
• Year of first maintenance: 2005 (replacement of all of the junction boxes and renewal of electrical connections)
• Year of second maintenance: 2020 / 2021
• Type of maintenance / maintenance measures:
    • Replacing 10% of the cantilever beams
    • Concrete repairs
    • Replacement of the electrical installation
    • New cathode connections
• Cause of (unexpected) maintenance:
    • Inaccurate sealing of electrical connections
    • Lost cathode connections
    • Plus and minus in the CP system reversed during the maintenance carried out in 2005 (due to confusing electrical cable colours)
• Typing of the error: calamity, lack of competence and expertise with CP installation and inaccurate monitoring
• Consequences of the maintenance:
    • Extent: 10% of the cantilever beams were severely and dangerously damaged
    • Cost: significant
    • Effects: large

Fig. 10. Severely damaged cantilever beam

Fig. 11. Damage due to reversed connections in a junction box

Fig. 12. Reversed connections due to confusing cable colours: red (main) anode cables are connected to a blue cable to the titanium anode (and sometimes to orange as a return cable) and brown (main) cathode cables are connected to a blue return cable (and the blue cables where sometimes switched)

Fig. 13. Inaccurate sealing of anode connections

3.4 Maintenance due to errors caused by the owner of user

3.4.1 Case factory - Tata Steel (IJmuiden)

• Type of construction: industrial floor in production facility
• Cause of the concrete damage: salt-water spilling during fire accident
• CP system type: ICCP (active)
• Type of anode system: titanium strip anodes in slots

Fig. 14. Titanium strip anodes in slots

• Year of installation: 2006
• Year of maintenance: 2010
• Type of maintenance / maintenance measures:
  • Repairing the anode system
• Cause of (unexpected) maintenance:
  • Drilling anchors through the anode material and various cables during additional installation work by third parties
• Typing of the error: calamity and bad ownership
• Consequences of the maintenance:
  • Extent: small
  • Cost: limited
  • Effects: significant

3.5 Maintenance of the anode material

3.5.1 Case A1 Highway – viaduct (Kootwijk))

• Type of construction: prestressed support beams
• Cause of the concrete damage: chloride induced corrosion due to leaking joints
• CP system type: GCP (galvanic)
• Type of anode system: Zinc Layer Anode (ZLA)
• Year of installation: 2002
• Year of maintenance: 2013
• Type of maintenance / maintenance measures:
  • Replacement of the anode material
  • Application of ICCP system (conductive coating)
• Cause of maintenance:
  • (Sacrificial) anode material consumed
• Typing: expected
• Consequences of the maintenance:
  • Extent: large
  • Cost: high
  • Effects: significant

Fig. 15. Application of ZLA on prestressed support beam

Fig. 16. ZLA after 10 years

Fig. 17. Replacement of ZLA

Fig. 18. Consumed zinc material

3.5.2 Case Apartment buildings – Groningen

- Type of construction: roof construction and cantilever beams
- Cause of the concrete damage: mixed in chlorides
- CP system type: ICCP (active)
- Type of anode system: Ahead conductive coating
  - With primary anode of silver wire fabric strip (PDR)
- Year of installation: 1996 - 1998
- Year of maintenance: 2019 - 2022
- Type of maintenance / maintenance measures:
  - Replacement of the anode material
  - Replacement of the entire electrical installation

Cause of maintenance:
  - Aging
  - Wear and tear
  - Limitations of the first generation of this type of anode material, with a maximum driving voltage of 2 V (versus drying concrete & increasing resistance)
  - Inaccurate cathode and anode contacts, partly no longer functional due to insufficient insulation and shielding of the connections

Fig. 19. Debonding of aged anode material

- Typing: expected
- Consequences of the maintenance:
  - Extent: total project
  - Cost: high
  - Effects: moderate

- Typing: expected
- Consequences of the maintenance:
  - Extent: total project
  - Cost: moderate
  - Effects: small

Fig. 20. Loose cabling

Fig. 21. Distorted conduits

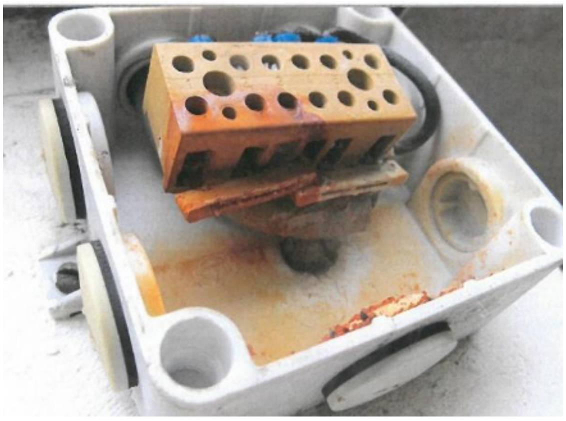

Fig. 22. Corroding connections

3.6 Maintenance of electrical components

3.6.1 Cases Apartment buildings – Groningen & Tilburg

- Type of construction: cantilever beams
- Cause of the concrete damage: mixed in chlorides
- CP system type: ICCP (active)
- Type of anode system: drilled in titanium anodes
- Year of installation: 1993 / 1998
- Year of maintenance: 2020 - 2022
- Type of maintenance / maintenance measures:
  - Replacement of the entire electrical installation (power source, rectifier, modem, cabinets, cabling and connections, conduits, junction boxes)
  - Anodes in excellent condition
- Cause of maintenance:
  - Aging, UV, wear and tear
  - Moisture in the junction boxes (oxidation of copper cables at connections)

Fig. 23. Inaccurate sealing of anode connection

Fig. 24. Inaccurate cathode connection

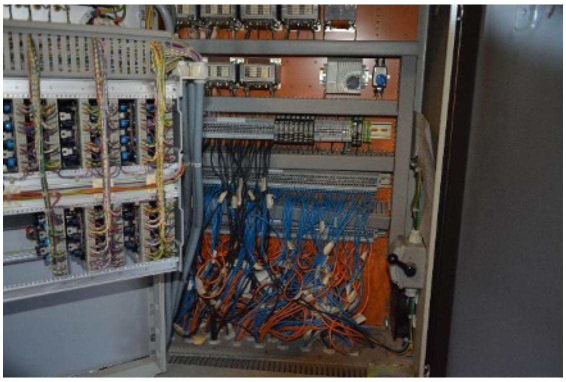

Fig. 25. Outdated electrical installation

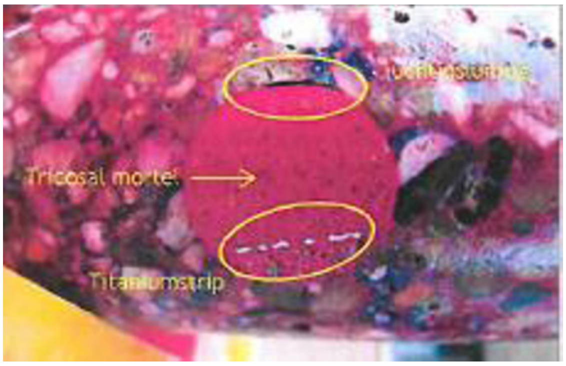

Fig. 26. Drilled core with anode material and mortar

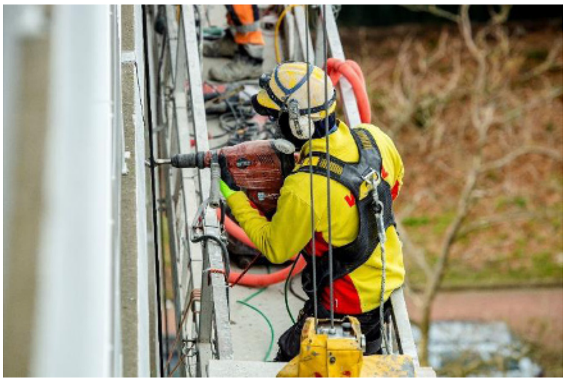

Fig. 27. Replacing the cathode connection

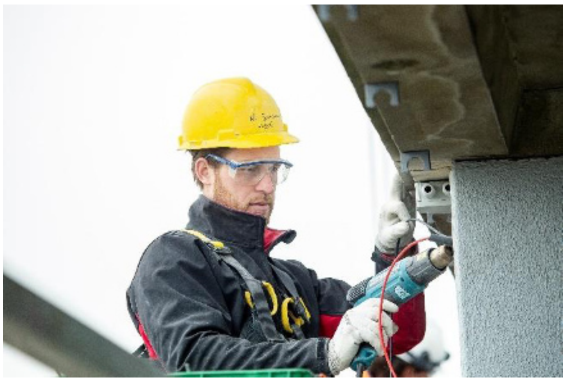

Fig. 28. Replacing the anode connection

4 Conclusions

Well-designed and expertly installed CP systems stop corrosion of the reinforcement in concrete structures of all kinds. This has been proven beyond doubt in recent decades with many successful applications.

Where traditional concrete repair, especially in the case of corrosion initiated by the presence of chlorides, often fails within a period of 10 years, CP is normally distinguished by its long service life and durability and with a minimum of maintenance, even in extreme conditions. In combination with a regular thorough and professional monitoring, many of the older CP systems in the Netherlands have been functioning for more than 20 years. In addition, in the last 10 years various projects have been concluded with contractual maintenance periods ranging from 15 to 30 years.

The examples presented in this paper show that normal maintenance also applies to well-installed CP systems, but that unnecessary, extensive, expensive and premature maintenance due to errors and incompetence should be prevented at all times or at least as much as possible.

Therefore, attention is required with regard to the design, choice of materials, installation and monitoring of CP systems. Practice has shown that expertise, knowledge and accuracy are of great importance at all the stages mentioned. Learn from past mistakes and avoid mistakes in the future.

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