# Cathodic Protection of Embedded Iron in Church Towers


**ABSTRACT**

Corrosion of iron tie bars, ring beams and cramps is becoming an increasing problem within our heritage building stock. Although the rate of corrosion is relatively low, in the long term it ultimately results in the fracturing of stones and sometimes the loss of structural integrity. Architects have, in the past, attempted to remove as much as possible of the original iron fittings and replace them with more corrosion resistant materials. The policy now followed in the UK for heritage buildings is that of 'minimum intervention' with the intention of retaining as much of the original fabric as possible.

Cathodic protection, the application of a small negative charge to the iron or steel, is being used increasingly to control corrosion of embedded iron within historic buildings. This paper provides an insight into cathodic protection techniques and illustrates how it can be used to conserve embedded iron in the most demanding applications of church towers.


## INTRODUCTION

In the 18th and 19th centuries, tie bars, ring beams and cramps were usually made from wrought iron, which is susceptible to corrosion when exposed to air and moisture. The situation may be exacerbated if sedimentary stones, such as Portland or Bath, are used in the construction. These sometimes contain chloride and/or sulphate salts which result in the depassivation of the iron surface and an acceleration of corrosion. Corrosion rates are also significantly higher where iron is in direct contact with damp stone as compared to exposure to air.

For major construction work during this period the wrought iron was sometimes surrounded by lead. Lead corrodes at a very low rate in this environment and, if it completely surrounds the fitting, then the iron should be protected from corrosion. However, this is rarely the case for heritage buildings, and especially for church towers, where the melting of lead on wooden scaffolding during construction would have been minimised. For unprotected iron the corrosion results in expansion forces, which eventually exerts such pressure on the stone that the stone cracks or spalls. The volume ratio between iron and rust can be as high as 1:7.

Examples of corroding iron tie bars, which are connected together to form ring beams around church towers, are shown in Figures 1 and 2. Both these examples show spalling of the stones. Ring beams were originally incorporated into the towers to resist the masonry buckling outwards and to strengthen the walls to resist wind loading. Normally they are embedded within the external masonry to maximise support to the tower, but sometimes they are embedded within the internal masonry if the thickness of the wall changes due to windows or louvres being present.

The conventional remedy has usually involved surgery to remove the iron fittings and cramps, Figure 3. They may sometimes be replaced with non-corroding phosphor bronze or stainless steel, or even left without replacement, prior to repair to the stonework. Conventional treatments can sometimes be highly invasive involving large-scale opening up to expose and treat affected components or even demolition to replace the iron. Cathodic protection offers a non-intrusive, alternative approach to the treatment of rusting iron embedded in masonry and stone.

## CATHODIC PROTECTION TECHNIQUES

Cathodic Protection (or CP) is not a new process: in 1824 Sir Humphrey Davy presented a series of papers to the Royal Society describing how CP could be used to prevent the corrosion of copper sheathing in the wooden hulls of British naval vessels. Since then it has been applied to many other areas, including marine applications and for the preservation of buried underground structures such as pipelines and tanks [1]. CP technology has, over the past 30 years, been applied to concrete to protect steel reinforcement from corrosion and, over the past 20 years, it has also been applied to iron and steel embedded in brick, masonry and stone in heritage buildings [2,3,4,5].

### Theoretical Principles

Corrosion is an electrochemical reaction involving both anodic and cathodic sites on an iron or steel surface. At the anodic site corrosion occurs as iron gives up electrons and forms soluble iron salts ($Fe \rightarrow Fe^{2+} + 2e^-$). At the adjacent cathodic site the electrons released by the corrosion process combine with water and oxygen to form hydroxyl ions ($\frac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2OH^-$). Both these partial reactions have to proceed at the same rate otherwise a build-up of electrons would occur and this would suppress the anodic process. In CP systems, the metal to be protected is supplied with electrons from an external source and the entire metal surface is thereby forced to act as a cathode (hence the term 'cathodic protection'), so controlling further corrosion.

When CP is used to protect embedded iron, small DC currents are supplied to the metal via the building material. This constant stream of electrons (which move in the opposite direction to the conventional current flow) satisfies the cathodic reaction and suppresses the anodic (corrosion) reaction.

CP may be achieved by two somewhat different techniques, although the principles described above hold true for both. These are sacrificial anode cathodic protection and impressed current cathodic protection.

### Sacrificial Anode Cathodic Protection (SACP)

SACP systems use sacrificial anodes (made of zinc, aluminium, magnesium or alloys of these) which corrode preferentially to the metalwork. These are placed in close proximity to the corroding metalwork and are electrically connected to it. As the sacrificial anode corrodes it generates a current that passes through the building material to provide protection to the embedded metalwork, Figure 4. The current is conducted ionically though the building material by means of pore water contained within it.

The main restriction in using an SACP system is that these anode materials have only a small natural ‘driving’ potential (i.e. the force which drives the electrons through the CP circuit - typically less than 1.5V), when coupled to the embedded metalwork, and this is further reduced by having to overcome the ionic resistance encountered in the building material. For this reason, the distance between the sacrificial anode and the embedded metalwork is normally restricted to a few metres. Another restriction is that the anodes are consumed and will need replacing at some stage in the future. These anodes (normally buried in the ground) are capable of protecting small metal components, such as embedded iron cramps and small tie rods, set into floors or at low level in walls of buildings.

<u>Impressed Current Cathodic Protection (ICCP)</u>

ICCP systems require an external power supply, normally mains powered transformer rectifiers, to provide the DC current to the iron or steel to be protected. These systems use non-corroding anodes, located close to the metalwork, to provide part of the current pathway, Figure 4. ICCP systems are generally more complex than the SACP systems but, with their much higher driving voltage, they are suitable for providing current to much larger areas of embedded iron, such as ring beams, or where the stone or masonry has an inherently higher electrical resistance.

As the ICCP system forces the metal to become cathodic, and therefore protected, the other side of the CP circuit (the current emitter) becomes anodic and therefore more ‘corrosive’. Materials for these current emitters (or ‘anodes’) therefore have to be highly resistant to corrosion. A variety of commercial anodes are available for use with ICCP systems. However, for extended use embedded titanium anodes are normally used.

Titanium on its own is unsuitable as it readily oxidises in air and especially when acting as an anode: it builds up an electrically resistive barrier. A conductive ceramic mixed metal oxide (MMO) coating is therefore applied to titanium substrates to give a low resistance layer to emit the current. The MMO coated anodes (typically containing mixtures of iridium, ruthenium, titanium and tantalum oxides) are now available as mesh, ribbon or wire. These are suitable for supplying high currents (up to 110mA/$m^2$) and have a reported lifetime in excess of 75 years.

The design of a CP system should also take into account many other factors including:

- The surface area of iron to be protected
- The resistivity of the masonry or stonework
- The distance and uniformity of the anodes to the embedded metalwork
- The service lifetime of the CP system
- The aesthetics of the building

## APPLICATIONS OF CATHODIC PROTECTION TO CHURCH TOWERS

Example applications of cathodic protection systems are given in this section for controlling corrosion of iron fittings in church towers.

### Tie Bars and Ring Beams

Iron tie bars are commonly encountered in the masonry of church towers and are frequently bolted or riveted together to form ring beams to provide integrity to the structure. If the bars are already mechanically connected together, then only a single (duplex) electrical connection is required to allow it to become the ‘negative’ side of the CP circuit.

The ‘positive’ side of the CP circuit is formed by the anode ribbon, which should be installed equidistantly above and below the tie bars or ring beam. If the ring beams are fitted externally then the anode ribbon should also be fitted in the external joints, Figure 5. This has the added benefit that the external faces of the stones normally have higher moisture contents, as compared to the inner faces, and their electrical resistance will therefore be lower, requiring a decreased driving potential. Sometimes the ring beams are mounted internally and this may require internal scaffolding, or possibly working with rope access specialists, to install the system, Figure 6 and 7.

Reference electrodes should also be embedded close to the protected iron surfaces to monitor the performance and to enable adjustment of the cathodic protection system.

### Cramps

Wrought iron cramps are commonly found between stones in many church towers. Corrosion of the cramps results in expansion and cracking of the stones, Figure 8. If the situation is left unchecked, rainwater may have direct access to the iron cramps and the rate of corrosion increases, Figure 9.

Many of the corroded iron cramps could be removed when the wounded stones is repaired and/or stainless steel cramps re-inserted. For the remaining cramps which have not yet damaged the stones; these require ‘daisy-chaining’ to form a single ‘negative’ side for the CP circuit. The positive side again using MMO coated titanium anode ribbon and reference electrodes are again located close to the iron cramps.

## LIFETIME AND PERFORMANCE OF CATHODIC PROTECTION SYSTEMS

The transformer rectifier and other electronics may be expected to have a lifetime of between 20 to 40 years after which they can readily be replaced. The external wiring may also suffer long-term decay and may also need replacement after 40 to 60 years. However, the embedded anodes and internal wiring within the masonry and stonework are not easily replaced and should therefore be selected to give a maximum service life.

MMO coated titanium anodes are reported to have lifetimes in excess of 75 years and any embedded wiring on the anodic (positive) side of the circuit should use titanium wire. The DC negative wiring, which connects to the iron or steel, is effectively under cathodic protection and should not therefore suffer deterioration. Embedded reference electrodes, used to monitor the performance of the CP system, have a reported life of around 20 years although some have been known to fail within 5 years. Surface mounted reference electrodes may be substituted in their place. These may be fixed to the outer masonry or stonework to assess the performance of the system and then removed.

The first cathodic protection system installed in the UK on a heritage structure was carried out by English Heritage to protect embedded iron cramps on Inigo Jones Gateway, Chiswick House, in 1996 [1]. The transformer rectifier failed within the first few years and the CP system was converted to a modified SACP system. This structure is still monitored on an annual basis and shows no corrosion or iron staining of the masonry surrounding the cramps.

A second cathodic protection SACP system was installed in 1999 to protect rusting cramps in the stone façade of four Grade II listed almshouses in Whitchurch. The stones formed an interlocking frontage with iron cramps fitted between adjacent blocks. Water ingress had permeated into the stonework joints and had allowed the iron cramps to corrode. The expanding corrosion products had introduced internal stresses that had resulted in cracking and spalling to some of the stones.

Damaged stones, located on the outer edges of the façade, were replaced with new stones fitted with stainless steel cramps. For the remaining, as yet undamaged stones, an SACP system was installed to control further corrosion of the iron cramps. Magnesium anodes were buried in the pavement in front of the cottages and these were connected directly through to the cramps in a 'ring circuit' arrangement.

The cottages were inspected in 2009, ten years after installation, and a visual assessment showed no spalling or iron staining where CP had protected the cramps. However, a stray cramp within the chimney, which had not been detected in 1999 and which had been omitted from the SACP system, had continued to corrode and blown the stone, Figure 10.

**BENEFITS FROM USING CATHODIC PROTECTION**

One of CP's principle advantages is that it provides corrosion control without changing the immediate physical environment; there may still be now, or in the future, damp stone, masonry or concrete adjacent to the metal which would previously have allowed corrosion to continue. Cathodic protection provides the electrochemical conditions to control this corrosion process.

In many instances, the removal and replacement of iron tie bars and ring beams is likely to be both disruptive and expensive. Installation of a CP system is significantly easier, requiring opening up of the joints either side of the iron, insertion of anode ribbon in the joints and re-pointing up afterwards. The cost, for example in a church tower, may typically be between £2,000 to £8,000.

## CONCLUSIONS

Cathodic protection, in one of its two forms, has now become a useful tool for conservators to control one of nature's most forceful degradation mechanisms, that of corrosion of embedded iron components. With the correct and sensible approach, cathodic protection can be used to oppose the natural degradation of the historic components without detriment to the overall aesthetics of the structure. The application of cathodic protection can be achieved by allowing a more reactive metal to corrode preferentially in place of the important metallic components, or by the application of an induced current from an external power source.

The application of cathodic protection to historic structures is now becoming widely accepted and the list of projects where it has been used is increasing as the process is fully reversible and is in accord with modern day conservation principles.

## REFERENCES


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4. D. Farrell, K. Davies and I. McCaig, Cathodic Protection of Iron and Steel – Recent Developments to Heritage Buildings, The Building Conservation Directory 2001.

5. D. Farrell and K. Davies, Cathodic Protection of Iron and Steel in Heritage Buildings in the United Kingdom, The Association for Preservation Technology (APT) Bulletin, Vol XXXVI, 2005.

Figure 1 Tie bars embedded in the outer masonry and judged to be too disruptive too remove, St Mary’s church, Balderstone.

Figure 2 Large tie bars embedded in the inner masonry and passing through the mullions, resulting in fracture of the granite, St Aidan's Cathedral, Enniscorthy.

Figure 3 Corroding wrought iron fitments, which were readily removed from the tower, St Mary's church, Balderstone.

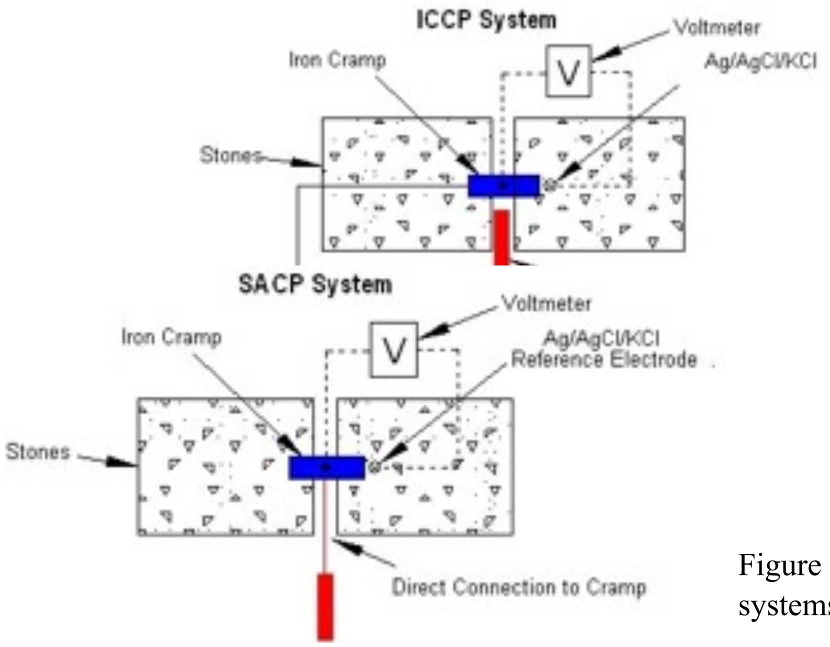


Figure 4 Schematic of ICCP and SACP systems.

Figure 5 Anode ribbon being installed externally above and below the wrought iron to provide cathodic protection, St Mary's church, Kiddlington.

Figure 6 Expansion and re-pointing of the joints associated with ongoing corrosion of three ring beams, St Aldhelms church tower, Doulting.

Figure 7 Anode ribbon being installed internally either side of the ring beams using rope access, St Aldhelms church, Doulting.

Figure 8 Internal damage to the stones due to corrosion of an iron cramp, St Michael and All Angel’s church, Great Witley.

Figure 9 External damage to the tower due to corrosion of iron cramps, St Michael and All Angel's church, Great Witley.

Figure 10 Whitchurch Almshouses ten years after the installation of cathodic protection – showing an unprotected cramp on the chimney has now fractured the stone.