Cathodic Protection of Tie Bars and Ring Beams in Church Towers

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ABSTRACT

Corrosion of wrought iron tie bars and ring beams is becoming an increasing problem in church towers. Although the rate of corrosion is relatively low, in the long term it ultimately results in fracture of stones and sometimes in 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 structure 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 and ring beams were usually made from wrought iron, which is susceptible to corrosion when exposed to air and moisture. Corrosion rates are 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 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 it cracks or spalls. The volume ratio between iron and rust can be as high as 1:7.

An example of corroding iron tie bars, which are connected together to form a ring beam within a church tower, is shown in Figure 1. This shows spalling of the central mullion due to ongoing corrosion. 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, Figure 2. 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 an alternative, non-intrusive approach to the treatment of rusting iron buried in masonry and stone.

CATHODIC PROTECTION TECHNIQUE

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. CP technology has, over the past 30 years, been applied to concrete to protect steel reinforcement from corrosion and, over the past 15 years, it has also been applied to iron and steel embedded in brick, masonry and stone in heritage buildings.

The design of a CP system should also take into account many 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

APPLICATION OF CATHODIC PROTECTION TO CHURCH TOWERS

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 3. This has the added benefit in 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 4.

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.

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 require 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. 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 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 which 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, a cathodic protection 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 the cramps had been protected by CP. 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.

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 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 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.

Figure 1 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 2 Corroding wrought iron fitments, which were readily removed from the tower, St Mary's church, Balderstone.

Figure 3 Anode ribbon being installed externally above and below the wrought iron to provide cathodic protection, St Mary’s church, Kiddlington.

Figure 4 Anode ribbon being installed internally either side of the ring beams using rope access, St Aldheimes church, Doulting.