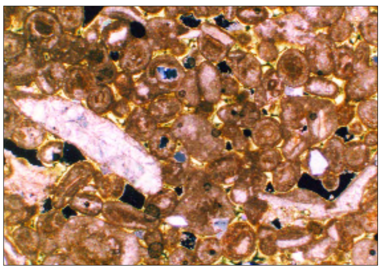
remedy for steel frame corrosion

Cathodic protection technology is being increasingly used to control the corrosion of steelwork in masonry clad steel framed buildings. This article by Kate Turnpenny and Jeremy Ingham from Halcrow's Asset Management & Engineering (AM&E) team provides a review of the issues involved in using cathodic protection and the wider investigation of corrosion-related deterioration in masonry structures.

Fig1 (above). Regent Street has given its name to the problem of rusting frames cracking masonry.

Fig 2 (below): Scaffolding to protect pedestrians following the fall of a large piece of stone from a stone clad steel framed building.

Fig 3 (bottom). Microscopical view of Portland stone in thin-section (x35 magnification).



Introduction

For buildings greater than three storeys high, construction using traditional load-bearing stone masonry requires walls of great thickness, which are slow and expensive to construct. Consequently, for taller buildings, framed construction techniques were developed that support the floors and walls on the beams of the frame. From 1910 to 1957 many high-rise office blocks and medium-rise commercial buildings were constructed in the major British cities using masonry clad steel frame techniques. Many of these buildings are now listed and they include a considerable number of historic stone buildings.

In recent decades, it has become apparent that deterioration caused by corrosion of the steelwork represents a considerable challenge to the conservation of stone clad steel framed buildings. As many of the buildings in London's Regent Street were constructed using masonry clad steel frames in the 1920s, the term 'Regent Street Disease' was coined to describe the problem.

As the steel frame corrodes the structural integrity of the building becomes compromised due to the expansive corrosion products and serviceability issues arise as the pressure cracks the abutting masonry, which can then spall and become displaced.

Falling pieces of masonry are of particular concern as they represent a potential danger to building users and passers by.

Conventional repair options involve disruptive removal of external masonry to allow the corroded steel frame to be treated. Despite treatment, the steel frame may start to corrode again after as little as 10 years in unfavourable circumstances.

Cathodic protection is an increasingly popular alternative / complementary technique involving the use of electrical current that, if correctly installed and monitored, can reduce or permanently halt the corrosion process.

Cathodic protection is commonly used to control corrosion and has been used to protect buried and submerged steel structures for more than 100 years.

Over the past 30 years it has been used on reinforced concrete structures to protect the reinforcement. The first installation of a cathodic protection system to an historic stone structure was undertaken in 1991 at the Government Buildings in Dublin.

The corrosion problem and corrosion condition assessment

The corrosion problems are largely a result of the early 20th century construction systems used for steel framed buildings, where the frame was closely embedded in masonry (stone, brick or terracotta) and the remaining cavities around the steel infilled with mortar and bricks or other porous rubble.

The rate of corrosion of the steelwork is initially governed by the resistivity of the stone or mortar in contact with it. Some masonry is relatively porous. For example, Portland limestone comprises approximately 20% well connected macropores (Fig 3). As corrosion takes place a layer of corrosion product (rust) develops on the steel surface. Since moist corrosion product has a much lower resistivity than that of the surrounding masonry, the rate of corrosion can then accelerate.

The process is exacerbated as the building ages, with moisture reaching the steel frame through deteriorated mortar joints, damaged or blocked drainpipes or failed roof waterproofing.

With continued availability of moisture, significant levels of corrosion become inevitable, as the porous infill around the steel collects

Fig 4. Cracking of stonework caused by corrosion of underlying structural steel frame.

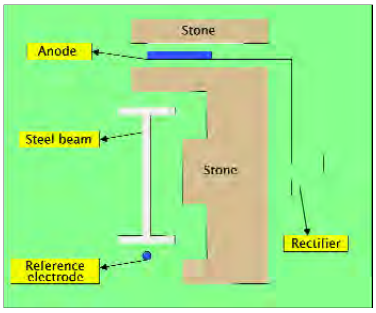


Fig 5: Schematic diagram for cathodic protection of stone clad steel framed buildings.

Fig 6. The corroding steel frame is revealed after opening up the stonework.

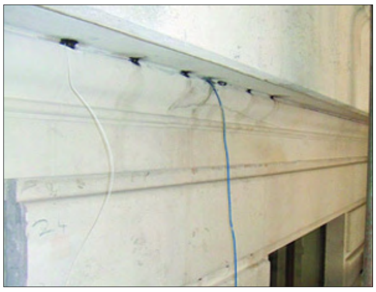


Fig 7. Cathodic protection wires being connected.

moisture and holds it against the steel surface. As rust occupies 7-8 times the volume of the parent metal, it exerts expansive pressure on the surrounding masonry, which cracks and spalls it (Fig 4). A cycle of decay is established with water ingress through cracks in the masonry and further corrosion and delamination of the steel frame.

As the steel frame is embedded it is difficult to detect the early stages of corrosion. As corrosion proceeds, opening of joints and cracking of masonry units can be observed on the building façade if regular inspections are carried out.

Investigation of suspected corrosion typically involves the opening up of selected locations of the frame to observe the degree of corrosion directly. Alternatively, observations may be made by borescope inspection through drilled holes.

The inspections may be supplemented by non-destructive tests such as half-cell potential mapping and resistivity checks of the masonry.

Infrared thermography may be useful for detecting cracks and damp areas in external masonry, as heat loss is exaggerated through evaporation of moisture.

Samples of the masonry materials can be taken for microscopical examination to determine their identity and nature. This is particularly useful for historic buildings where there is a requirement to provide a like-for-like match for masonry repairs.

The principles of cathodic protection

Cathodic protection is a proven method for protecting reinforced concrete against spalling resulting from corrosion of the reinforcement. It is now an increasingly acceptable long-term solution to prevent and control the further deterioration of embedded steel and iron contained within masonry structures, historic brickwork, framed structures and statuary.

Corrosion of iron and steel is an electrochemical process that cathodic protection can reduce or stop by altering the electrical potential of the affected metal.

An impressed current cathodic protection (ICCP) system comprises a number of basic components that include anodes, a DC electric supply, the steel or iron to be protected and the surrounding stone or masonry.

The positive terminal of the DC power source is connected to a conductive material (the anode). The negative terminal is connected to the steel or iron (the cathode) and a small current is applied at low voltage, typically 12V.

The DC current renders the iron or steel cathodic relative to the surface anode, stopping corrosion. The anodic reaction now occurs at the external or embedded anode, which is designed to resist deterioration over the design life of the system.

The ICCP system is regularly monitored and adjusted to ensure the protection is sufficient to stop corrosion. Figure 5 shows a schematic diagram for an ICCP system.

With improvements and advancements in technology, ICCP is now an accepted repair technique and can be commercially viable. It also offers conservation benefits such as minimal intervention and the retention of the original fabric.

However, in all cases the installation of ICCP needs to follow a structural engineering appraisal of the building to ensure significant section loss has not occurred, followed by a site trial to confirm its suitability.

Cathodic protection in practice

As mentioned above, traditional methods for repair of corrosion damage to steel framed structures typically involves extensive removal of the masonry to provide direct access to the steelwork. The corroded steelwork is then cleaned by techniques such as needle gunning or grit-blasting prior to treatment with an appropriate protective coating, which is typically paint based or can be cement mortar or reinforced concrete (if there is adequate space). The masonry is then reinstated leaving a cavity between the masonry and the steel frame that is usually filled with a compressible material.

Despite its validity and correctness, this method of repair can be intrusive, time-consuming and costly. By comparison, if cathodic protection is appropriate, it can be applied to combine longevity with minimum disruption to the structure, realising conservational benefits as well as clear financial advantages. This makes ICCP a cost effective method of protection compared with alternative repairs and / or protection options.

The first application of a cathodic protection system to a masonry structure was for the limestone façade of the entablature of the entrance colonnade to the government buildings in Dublin.

The system was installed in 1991 after a site trial confirmed the practicality and effectiveness of ICCP application on the steel frame.

The system uses a discrete anode system that was applied without damaging the architectural appearance of the stone façade,

Case study

The Wellcome Building, London

Halcrow's AM&E team provided project management for the design and installation of an ICCP system at the Wellcome Building in London (pictured above).

The building comprises a sub-basement, basement and ground to 6th floors with a lightwell around the basement and sub-basement of the building. The building is a steel frame construction of 'I' section columns and beams with three façades faced in Portland limestone and Fletton brickwork to the rear.

During extensive cleaning and renovation works carried out in 2006, cracking was observed in some of the Portland stone ashlar, with opening of the vertical and horizontal bed joints and some displacement.

Further investigation was undertaken and areas were opened up for inspection.

The inspection identified that in general, the steelwork was in good condition. However, there were some notable exceptions at several locations on two of the floor levels and significant localised corrosion was found along one edge beam.

Following a detailed inspection and testing of these areas, Halcrow concluded that an ICCP system should be installed on one floor level only to mitigate the corrosion of the steel frame and prevent further corrosion-related deterioration of the façade.

A feasibility trial installed at two locations demonstrated that cathodic protection could be applied successfully using discrete anodes embedded from the external face of the façade and that it would provide corrosion protection to the steelwork.

A design specification was provided, based on the required design parameters and cathodic protection criteria.

Specialist sub-contractors were employed to install the system, during which Halcrow provided technical support and supervision. The cathodic protection system was energised and commissioned on time and to budget.

creating a barely detectable repair.

The performance of the system is monitored remotely via embedded electrodes so that, in the unlikely event of a failure in the ICCP system, maintenance can be carried out before corrosion-induced damage of the stonework occurs.

The structure is also inspected annually to confirm the validity of the monitoring data.

Further 'invisible' ICCP systems were successfully installed during the early 1990s to several strategic renovation projects, including English Heritage's Grade I listed Inigo Jones Gateway at Chiswick House, London, and the iron staircase supports embedded in brickwork at Kenwood House, Hampstead.

With improved anode design and associated technology within the cathodic protection industry, cathodic protection has been applied increasingly to steel framed buildings.

Since 1996, installations have been completed to facades and buildings across the UK and several in the United States.

However, historic stone and masonry clad structures represent a relatively new area of application for cathodic protection and it may not be applicable to all structures.

The following design issues should be considered for any steel framed structure where installation of a cathodic protection system is being proposed:

- For listed buildings, the architectural appearance of the building must not be affected by the works. Installation of the cathodic protection system must minimise any disruption and damage to the façade and the anode systems should be selected with this in mind.
- Current distribution is also important and this is controlled mainly by anode spacing (as well as the mortar and stone resistivity). System installation can involve cutting chases for cabling and drilling small diameter holes into the exterior surfaces and bed joints for the anodes and monitoring probes, but these should be back-filled with an appropriate material, followed by final pointing with a colour-matched material.
- It is essential to ensure electrical continuity of the circuit by connecting together all components of the metal frame, reinforcement and any other embedded metallic items. Failure to do so may result in accelerated corrosion of any discontinuous metallic items or adverse effects of the installation or operation of the cathodic protection system.
- For the system to be effective, large voids between the steelwork and masonry may need to be grouted. Identifying and filling any voids around the steelwork with a suitable material is an important part of the cathodic protection design and installation. Once the voids are filled (and gaps around the steel are eliminated), if the cathodic protection system fails the risk of masonry cracking is increased as a small amount of corrosion can cause it. Effective and regular monitoring is therefore important to prevent future damage.
- It is prudent to conduct a pilot study, representative of the whole cathodic protection system, carried out over a small section of the building. This should adequately demonstrate that cathodic protection is an effective and feasible technique to protect the structure. The study should confirm continuity of the steel frame, the anode type, the required anode spacing and the practicalities of installation, in addition to providing confirmation of the nature of the fill material surrounding the steelwork and any need for grouting.
- Cathodic protection should only be contemplated where the building is large enough to have a full-time building management team, or where the system is managed remotely under a maintenance contract. There also needs to be a clear responsibility for ensuring that the corrosion protection system is operated and maintained.

Conclusions

Since the development of the first cathodic protection system for iron and steel in masonry, the improvements and advancements to technology mean that cathodic protection is now a highly cost effective and accepted repair technique for masonry buildings and historic structures. It also offers conservation benefits such as minimal intervention and the retention of the original fabric.

However, cathodic protection is not suitable for all situations and specialist advice should be sought when considering installing an ICCP system. Ultimately, the solution chosen will depend on the extent of corrosion, the owner's aspirations for the building and the service life of the required solution.

Nevertheless, when applied and installed correctly, the technique is a good example of how modern technology can reduce the need for damaging intervention when repairing architectural buildings or monuments. ■

Acknowledgements
The authors gratefully acknowledge The Wellcome Trust for their participation in this article.