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Cathodic Protection for Masonry Buildings Incorporating Structural Steel Frames

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Foreword

The cracking, displacement, and spalling of stone and masonry because of the corrosion of steelwork is becoming increasingly common in masonry-clad steel-framed buildings constructed between the late 1800s and the 1950s. This is a serious condition that results in significant deterioration and loss of the original facade, necessitating methods of treatment that are costly and disruptive. In recent years, the problems of corrosion-related deterioration of the steel frame and associated fixing details have led not only to costly cycles of repair, but also a risk of serious injury and even death caused by masonry spalling from the building.

This technical committee report presents a state-of-the art review of cathodic protection (CP) technology used in both Europe and the United States over the past decade to combat corrosion deterioration of masonry buildings with structural steel frames.

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This report:

- Gives an introduction to the subject;
- Details issues of importance in applying CP to heritage buildings;
- Provides examples of applications;
- Provides information on specific issues relating to heritage buildings;
- Provides considerations for planning work, based on the current state of the art; and
- Lays the foundations for developing a NACE standard on this subject.

This report is intended to be useful to architects, structural engineers, architectural conservators, masons, and consulting engineers/contractors who are engaged in refurbishing steel-framed masonry buildings. A glossary that includes many of the terms used in this report is provided in Appendix A.

This report was prepared by NACE Task Group (TG) 329, "Reinforced Concrete: Steel-Framed Buildings," in association with the Corrosion Prevention Association (CPA).[1] This TG is administered by Specific Technology Group (STG) 01, "Reinforced Concrete." It is issued by NACE International under the auspices of STG 01.

NACE technical committee reports are intended to convey technical information or state-of-the-art knowledge regarding corrosion. In many cases, they discuss specific applications of corrosion mitigation technology, whether considered successful or not. Statements used to convey this information are factual and are provided to the reader as input and guidance for consideration when applying this technology in the future. However, these statements are not intended to be recommendations for general application of this technology, and must not be construed as such.

History

Prior to the late 1700s, masonry buildings were constructed with load-bearing masonry walls to support floor loads. Construction was slow and the higher the structure, the thicker the walls became. This form of construction limited the development of large structures, and prior to this period large structures were built only for military or religious use. This form of construction did not meet the needs of the industrial revolution, with its requirements for large manufacturing facilities and warehouses.

The late 1700s saw the development of mill structures using cast iron columns and timber beams to support floor loads in lieu of thick masonry walls. Eventually, cast iron columns were mixed with wrought iron beams to form a cage structure. These structures contained minimal internal walls and the external walls had the outer elements of the frame incorporated in the masonry. By the mid 1800s, iron frame construction was applied to commercial office buildings, and increasingly taller buildings evolved in inner-city locations.

However, cast iron proved to be a brittle material, limiting its use, and wrought iron was an expensive material with variable properties. As such, building heights became restricted. It was not until the invention of the Bessemer steelmaking process in 1856 and the more important basic open-hearth processes of 1868 that building technology progressed. The development of steel had a marked effect on design, and the inner-city landscape became rapidly populated with stronger structures having increased heights and wider window openings.

The construction of the Home Insurance Building in Chicago by William Le Baron Jenney in 1884-5 marked the development of steel-framed construction techniques and the modern era of multistory buildings. Regarded as

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the first skeleton-framed building, the top six of its ten stories used a Bessemer steel cage with the lower frame adopting cast iron columns in combination with wrought iron beams. However, the full load-bearing potential of the steel frame was not fully exploited in this early design, and the external walls were partially load-bearing masonry. In 1889 the Chamber of Commerce Building, Chicago, marked the next major step toward modern steel-framed design as the structural frame carried all loads without the need for structural masonry.[1]

In the United Kingdom, engineers looked to the development of skyscrapers in the United States and constructed Selfridges Department Store in 1908, modeled on the Marshall Field's building in Chicago. This first application of non-load-bearing masonry in the United Kingdom led to the introduction and acceptance of the London Building Act of 1909, and linked construction techniques across the Atlantic.[2]

During the development of steel-framed buildings, both British and American engineers did not fully appreciate the destructive nature and risks of corrosion when steel was built into a porous masonry wall. At the time, experience with cast and wrought iron built into thicker load-bearing walls had not shown major corrosion problems. As such, it was assumed that the masonry surrounding the steelwork with a cover often exceeding 150 mm (6 in) would prevent moisture ingress and avoid corrosion problems.

Although problems with corrosion were not fully understood, publicized, or addressed, problems had become evident. George Post, an early American designer of steel-cage buildings, even questioned the design life of a steel structure embedded in masonry as early as 1894. Post was particularly concerned with the move toward thinner cladding, which offered a minimal cover of only 100 mm (4 in), as in his experience, he had found it necessary to remove corroded beams from brickwork encasement. However, despite some early and isolated concerns, building codes (e.g., 1892 New York Building Code) allowed reduced thickness of cladding systems with minimal corrosion protection applied to the steel. Even forensic investigations of pioneering buildings failed to fully highlight the potential for corrosion-related problems. For example, a 1914 demolition study of the Tower Building, New York, constructed in 1888, noted severe corrosion but dismissed it as being caused by defective flashing.

It was inevitable that the early lack of appreciation for corrosion in steel-framed buildings would lead to the current problems of cracking, displacement, falling masonry, and structural losses in steel sections.

Even modern-day engineers often fail to appreciate the causes of steel frame corrosion. Corrosion problems are still often wrongly assigned as being solely caused by defective detailing as in the 1914 Tower Building study. Ineffective detailing, neglected maintenance of gutters and downpipes, and similar factors are not the only issues of concern; basic corrosion caused by water ingress through mortar joints and porous masonry facing materials are major contributors to this problem.

All too often, modern engineers fail to sufficiently address corrosion repairs effectively in steel-framed buildings. Repairs continue to involve the injection of sealants (caulk) into cracks or the isolated removal of defective masonry, the application of a coating system, and alteration of the assigned faulty building detail. These repair methodologies, although providing some immediate benefit, are expensive, requiring continued maintenance and damage to the historic fabric of the building, and do not provide a solution to the cause of the problem.

In the early 1990s, as an alternative to damaging repair techniques, impressed current cathodic protection (ICCP) was developed as a tool for assisting in the repair of steel-framed buildings. The technique has been developed to provide an approach to the repair strategy that is suitable for heritage buildings and mitigates the major ongoing and underlying cause of deterioration, namely corrosion.

Corrosion

The early stone and steel buildings were constructed such that any space between the masonry and the frame was filled with rubble or with mason's mortar. This practice itself has led to problems in buildings in which water has penetrated the weathering and has soaked the rubble or mortar and allowed development of ideal conditions for the initiation and continuation of corrosion. Problems then only become obvious when either the spread of dampness through the fabric becomes visible, when corrosion products cause staining of the building, or worse, when expansive corrosion products cause cracking and other physical damage to the stone.

In early steel-framed buildings, it was uncommon to protect the steel frame from corrosion in service by painting or other means; it was thought that the masonry would provide sufficient protection. Some examples exist in which a bitumen coating or a red lead paint has been applied. However, such examples are rare and are not typical. The use of cement mortars could assist to some small extent in inhibiting corrosion because of the alkaline environment produced by the cement itself. However, because such mixes, particularly when a rubble/mortar combination was used, were generally not adhered to the steel members, a crevice often exists between the infill and the steel, allowing any moisture to penetrate and to collect. Nor was the infill fully compacted and consolidated, allowing moisture paths through the body of the infill itself. After long periods of such moisture penetration, any minor passivation effects are lost, and corrosion takes its course.

In later buildings and certainly in modern steel frames with stone cladding, a cavity is generally maintained between the stone and the frame. Steel (or iron in early examples) fixings are used to support the cladding, and a ventilation cavity is maintained to allow the drying out of any ingressing moisture. However, even with this design, detailing and ventilation may not be adequate if large amounts of water are present. Also, there are many locations, particularly at floor levels, where the cavity may be bridged by major stone supports, insulation materials, or materials designed to inhibit the spread of fire and smoke between floors.

Other aspects of many steel-framed, stone-clad buildings that influence the onset of corrosion in the frame are the very features used to demonstrate the “solidity” of the organization housed within. Many of the buildings present solid yet ornate features, which themselves can lead to problems. Cornices are often used, and to avoid waterfalls of rainwater onto the pavement beneath, are sloped inward to the building. While any waterproofing measures such as asphalt and rainwater management systems such as gutters and downpipes are in their as-new condition, the problem is contained. However, failure or cracking in asphalt caused by weathering or building, thermal, or other (earthquake, traffic, etc.) movements or vibration can allow water to penetrate into the fabric of the building and reach the steel frame. Similarly, failure to ensure that gutters and downpipes remain unblocked can cause water ingress by the overtopping of upstands or flashings. When downpipes are constructed within the structure, problems can be caused by internal (and therefore unseen) damage sustained during building movement or by corrosion of the downpipe itself.

The fallacy that stone cladding is impermeable to water also has allowed damage to occur from neglect or ignorance. In fact, some stones act like sponges in absorbing rainwater and allowing saturation. Mortar or lime putty bedding, if incomplete, can also allow penetration. When either of these occurs in severe exposure conditions, the results can be catastrophic. Stone/mortar combinations can allow moisture that penetrated to evaporate, when external conditions allow. However, the balance between these can be upset by inappropriate replacements or repairs, such as cases in which lime mortar pointing has been replaced by a cement mortar. The use of hard cement mortars in pointing generally has the effect of increasing, rather than decreasing, the risks of water penetration.

Intricate stone detailing also can allow the collection of moisture and the subsequent entry to the fabric caused by the stone being constantly wet.

It is typical to find 2 to 10 mm (0.08 to 0.40 in) of corrosion product on structural steel members, and greater levels of corrosion are not uncommon. Because rust generally occupies a volume greater than that of the consumed steel, these levels of corrosion do not usually represent widespread structural problems, although isolated areas of high section loss leading to structural deterioration do occur.

The expansive nature of the rust is usually the most common and major issue of concern in corrosion-related building deterioration. The resultant stresses of the expansion process cause cracking (see Figure 1), displacement (see Figure 2), and spalling (see Figure 3), leading to the need for restoration and repair of the external masonry. In circumstances in which structural problems (see Figure 4) have been found, strengthening, steel replacement, or both by specialists has been used in addition to general corrosion protection and facade repair.

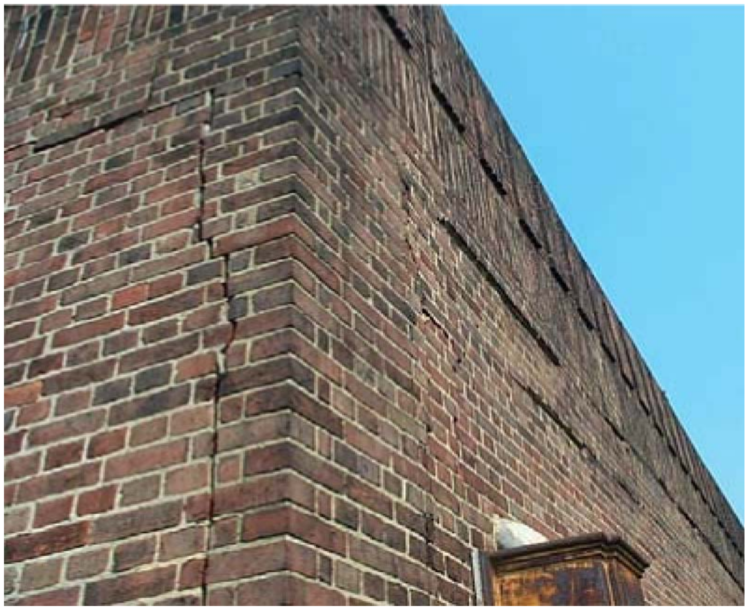

Figure 1: 25 mm (1 in) wide cracking of brick corner detail caused by corrosion of the underlying steel column.

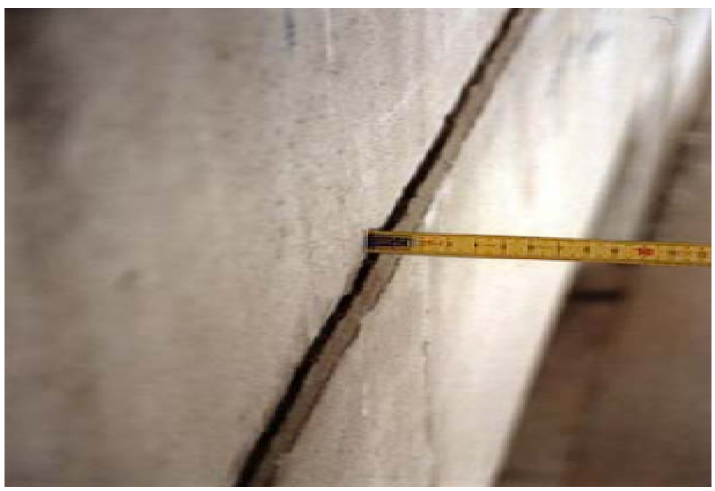

Figure 2: 15 mm (0.6 in) displacement of the limestone facing block caused by beam corrosion.