REHABILITATION OF MASONRY FACADES DAMAGED BY REINFORCEMENT CORROSION

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SUMMARY

This paper presents results from a project dealing with rehabilitation of clay brick facades damaged by reinforcement corrosion. Based on laboratory tests and results from pilot projects, practical recommendations for appropriate removal of bed joint reinforcement and repair of joints are issued for facility owners, contractors and designers.

INTRODUCTION

During the 1930s autoclaved aerated concrete has massively been introduced for construction of the load bearing walls in multi-storey buildings. In the facades, clay brick masonry was often used. Later, clay brick facades were extensively used also in multi-storey concrete buildings and timber-frame houses.

Introduction of the relatively slender masonry facades required use of stronger mortars and joint reinforcement. The use of reinforcement was mainly motivated by insufficient bending strength in masonry beams above large windows and doors. Control of crack width due to thermal and moisture movements was a further reason for providing bed joints with reinforcement.

In analogy with concrete, standard steel bars were used as bed joint reinforcement. Based on limited experience, it was erroneously believed (Hamann and Burridge 1939; Granholm 1943) that the presence of lime in the mortar provide a permanent chemical protection against the corrosion of the reinforcing steel. Subsequent use of unprotected steel caused severe corrosion damages and by the mid 1970s made the Swedish design recommendations to be more restrictive. Nevertheless, use of unprotected reinforcement in facades has never been forbidden explicitly, which explains the occurrence of corrosion damage also in facades built after 1975.

DESCRIPTION OF THE DAMAGE

Steel embedded in lime-cement mortars is protected from corrosion by high alkalinity due to the presence of hydroxide ions. Through the process of carbonation, carbon dioxide enters the mortar and reacts with the hydroxide ions. Carbonation starts at surfaces in contact with air and progresses towards the interior of the mortar. As a result, alkalinity is diminished and the mortar loses his protective effect on steel. During corrosion, iron oxides, with a free volume

five to six times larger than the steel, are produced. Due to this volumetric expansion cracks are formed in mortar joints with reinforcement. Under Swedish conditions, the first cracks appear typically 20-30 years after construction. Corrosion is triggered by high temperatures – at the same location the first cracks appear usually in walls with south-western exposure. Corrosion can also be initiated when the mortar contains chlorides.

Cracked joints above openings and in the upper part of solid walls are often detectable by ocular inspection. Typically, cracks have a width of 1-2 mm. Pieces of the mortar cover are often pushed out of the bed joints due to the volumetric expansion of the corroding reinforcement bars. In the inferior part of walls, where the self weight of the masonry can be considerable, cracks are not always visible. In such situations, bed joints containing reinforcement bars can be detected by drilling, examination with metal detectors or by visual inspection, as bed joints with reinforcement tend to be thicker than those without.

Corroding bed joint reinforcement impairs the exterior of facades, initiate increased water penetration with subsequent enhanced risk for frost damage and, in a worst case scenario, can damage transversal anchorage with risk for failure.

CASE STUDY – MUNICIPAL BATH, LUND, SWEDEN

The municipal bath Högevall in Lund, Sweden, was built during 1979-1980. The external walls consist of a cavity wall of clay brick masonry with stabilising reinforced concrete columns spaced at 6-7 m, see Figure 1.

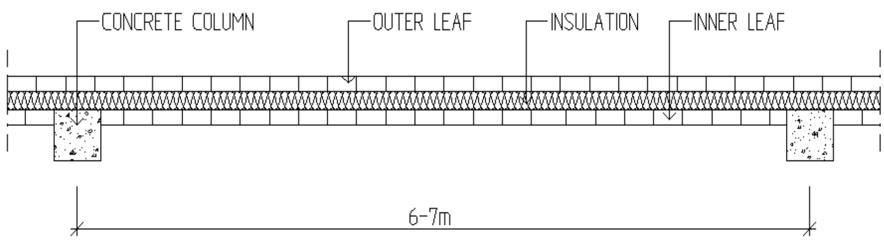

Figure 1. Horizontal section through the external cavity walls, Municipal Bath, Lund, Sweden.

The outer and inner leaves of the wall are connected to each other and the stabilising columns by corrosion resistant ties. Both leaves are reinforced with two unprotected steel bars with 8 mm diameter in every sixth bed joint. The roof is supported by trusses as primary and corrugated sandwich elements as secondary load bearing elements, see Figure 2. The trusses are supported by columns, whereas the sandwich elements are connected to the outer leaf of the wall by metal coping.

The bath management has since the beginning of the 1990s been aware of problems with corroding bed joint reinforcement. In the mid 1990s, a rehabilitation of the outer leaf of the wall was carried out.

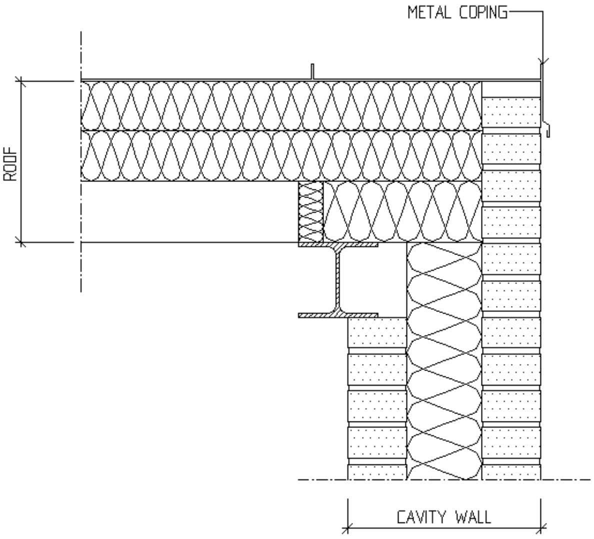

Figure 2. Vertical section through the external cavity walls, Municipal Bath, Lund, Sweden.

During the rehabilitation, the outer reinforcement bars in the outer leaf of the walls has been removed and replaced by corrosion resistant reinforcement. The inner reinforcement bar was not removed, probably due to higher costs associated with this measure. With progressing corrosion in the inner reinforcement bar, new cracks appeared already five years after the rehabilitation, see Figures 3 and 4.

Figure 3. New cracks five year after rehabilitation due to progressing corrosion in the inner reinforcement bar.

Figure 4. Inner corroding reinforcement bar causes new cracks.

After the storm in January 28, 2007, it was discovered that the upper two meters of the facade walls facing south respectively west have been dislocated. The dislocated wall parts were hindered from falling down by a metal coping, which exhibited large deformations, Figure 5.

A subsequent inspection of the building disclosed that the outer leaf of the wall has been elongated by 60 mm in the vertical direction relative to the inner leaf and caused failure in the wall ties in the upper part of the wall. Corrosion expansion in the bed joints was diagnosed to be the main cause of the damaging wall elongation. The dislocated wall parts were removed and replaced by plywood as rehabilitation of the entire facade and an expansion of the bath was already scheduled for 2008-2009. For security reasons, the bath was closed during the inspection and demolition works.

Figure 5. The metal coping hinders the upper part of the facade from falling down

RESEARCH AND DEVELOPMENT PROJECT

A pilot study carried out by the authors in 2003 disclosed widespread problems with corroding bed joint reinforcement and insufficient transversal anchorage in clay brick facades from the period 1940-75. The total area of clay brick facades in Sweden from the period 1940-1975 has been approximated to 80 million m^2. In spite of the large extent of the problem, the pilot study found that facility managers in general were not aware of the consequences of problem with corroding reinforcement. Further, a range of malpractices during rehabilitation work were identified, such as:

- All the corroding bed joint reinforcement during rehabilitation is not removed, which causes new cracks and continuing deterioration of the technical condition of the facades

- Rehabilitation works are carried out with little concern to good craftsmanship, which results in deterioration of the character of the facades, Figure 6.

Figure 6. Use of bricks and mortar with deviating colour compromises the character of the facade

- Tying of the facades to the stabilizing structures is not checked, which results in occasional failures during storms and maintenance works, Figure 7.

Figure 7. Collapse of a facade after a storm in January 2005, Lund, Sweden.

In order to develop and promote proper rehabilitation techniques, a research and development project involving researchers, facility owners, contractors and material suppliers was carried out during 2004-2007.

DEVELOPMENT OF REHABILITATION TECHNIQUES

In order to obtain practically useful results emphasis was laid on experimental work in laboratory and verification in pilot field projects. Two of issues treated in the project are presented in the next sections.

Reattachment of Window Beams

In today's practice window beams damaged by corroding bed joint reinforcement are removed and replaced with pre-manufactured pre-stressed clay brick beams. As finding bricks with size, texture and colour similar or close to the original is difficult, rehabilitation often deteriorates the character of the buildings. To eliminate these shortcomings, a procedure based on reattachment of the existing beams was developed and tested in practice. The rehabilitation work is carried out as follow:

1. The damaged beam is secured from falling down by means of a re-usable and adjustable fixture, (Kruglyak and Olsson 2007). In order to avoid damage on the window sheets, the fixture is anchored in the masonry joints, Figure 8.

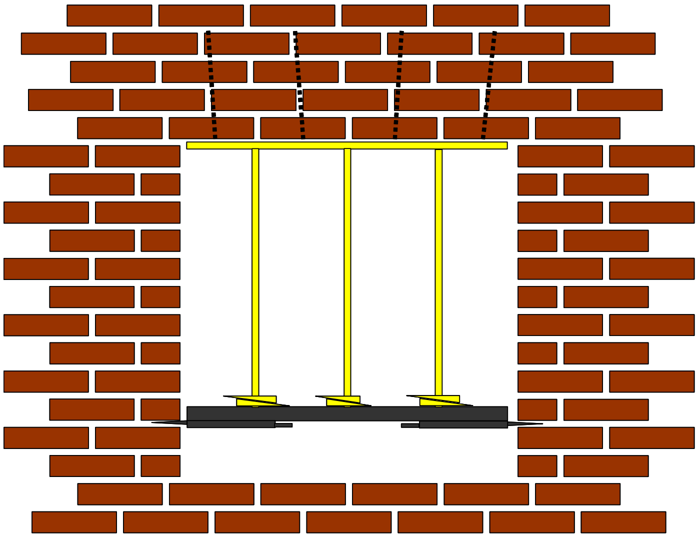

Figure 8. Fixture used to avoid damage on window sheets and to secure the beam from falling down.

2. Holes are drilled for subsequent reattachment with screws. The depth of the holes is adjusted to secure enough mechanical anchorage above the line of thrust in the masonry vault which is created be removal of the bed joint reinforcement. To obtain proper contact area, the holes are bored inclined with 15-25 degrees to the vertical. This measure is especially important in perforated bricks.

3. The stainless steel, case-hardened screws with screw head at right angle are introduced in the prepared hole. To avoid crushing or splitting of the bricks, a plastic washer is used. Approximately 70 mm of the screw closest to the screw head is not threaded, which permits subsequent adjustments.

4. Corroded reinforcement bars and surrounding mortar is removed by a masonry saw. During work, filling the air gap with mortar waste shall be avoided. The width of bed joints is adjusted to match that in the surrounding masonry.

5. After cleaning with vacuum cleaner, the joint is refilled with mortar in a way to obtain sufficient bond and to avoid stains on surrounding masonry. Best results were obtained with mortar injection by means of a pumping device combined with manual compaction by pointing trowel, (Horvath and Pilav 2006).

6. In order to match the appearance of surrounding masonry, it is desirable that pointing is carried out by skilled craftsmen who use adequate materials and techniques, (Bergkvist 2006).

After rehabilitation of window beams by reattachment, vertical loads are carried by arching. In order to use arching, sufficient lateral support is required. Further, there are limitations on the size of the window span. In Sweden, this shall be shorter than two meters and the length through height ratio of the vault shall not exceed four.

Facades without Openings

Cavity walls from the period 1940-1975, in e.g. sport arenas, have been heavily provided with bed joint reinforcement. Usually, reinforcement was placed in every 5th or 6th bed joint. Due to the large amount of work and thus costs associated with removal of both reinforcement bars, only the outer reinforcement bar is usually removed at rehabilitation. This practice causes new damages within a couple of years. In many situations, damaged facades are demolished and rebuilt, a measure which according to (Persson 2007) is 40 - 60 % more expensive than rehabilitation. In the research project, the following rehabilitation procedure was elaborated and tested in pilot projects:

1. Reinforcement and mortar are removed by masonry saw. The length of the chase created is limited by the ability of the masonry to carry vertical loads by arching or beam action. With reinforcement bars in every 5th or 6th bed joint, the chase length is often limited to 2-2.5 meters and close to movement joints or free ends, half this length.

2. Joint are refilled according to work step 5 in the previous section.

3. In many situations, reinforcement was applied in excess. A check of the design at rehabilitation can often show that new reinforcement is not needed or it is only needed to a limited extent. To be able to introduce reinforcement bars longer than 2 – 2.5 meters without splicing, bed joints are in the first step filled to about 60 % of the joint width. In the next step the reinforcement is introduced and the joint is filled with mortar.

4. Pointing is carried out according to work step 6 in the previous section.

INFORMATION DISSEMINATION

The results of the project are summarised in a handbook for practitioners, (Gustavsson et al. 2007). Owners of high rise buildings with clay brick facades from 1940-75 will be contacted by letter and informed about the problems and risks associated with corroding masonry reinforcement. Courses for contractors, facility managers and designers will be organised in collaboration with trade associations.

CONCLUSIONS

Corroding bed joint reinforcement and ties in clay brick facades from 1940-75 constitute a severe technical, economical and conservation problem. Awareness concerning the problem among facility owners is low and malpractices at rehabilitation works are common. In the present research and development project a series of correct rehabilitation techniques have been developed and tested. To achieve largest possible impact, efforts are

made to disseminate information about the problem and the rehabilitation opportunities to facility managers, contractors and designers.

ACKNOWLEDGEMENTS

Financial support from The Swedish Research Council Formas/BIC, The Development Fund of the Swedish Construction Industry, Byggrådet i Malmö - Lund, AF Bostäder, Akademiska Hus, Lundafastigheter, LKF and Malmö Stadsfastigheter is acknowledged.

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