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DETERIORATION OF HISTORIC BRICK MASONRY DUE TO COMBINED GYPSUM, ETTRINGITE AND THAUMASITE: A CASE STUDY

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Abstract

A case study is presented of severe deterioration of historic late 19th century brick masonry due to combined gypsum, ettringite and thaumasite. The case is remarkable, because these minerals developed in the original mortar made up by a mixture of Rhenish trass and lime, in which in particular for ettringite, no specific precursor (such as C_3A in ordinary Portland cement), could be identified. The case study demonstrates that, regardless the sulphate resistant reputation of trass cements, trass – lime mortars may suffer from sulphate attack.

Key Words

Gypsum, ettringite, thaumasite, trass – lime mortar

1 Introduction

Historic brick masonry may be damaged severely. Proper restoration requires prior assessment of any damage. The nature and amount of damage has a huge influence on both restoration techniques to be used and associated costs. In the present paper, a case of severely deteriorated historic brick masonry is described. The investigated structure, Moerputten Bridge, is a discarded railway bridge near the city of 's Hertogenbosch in the south of the Netherlands (Fig. 1). The bridge was built late 19th century and discarded in 1972. The bridge is made up by a steel construction based on 35 piles and 2 abutments of brick masonry. The piles have dimensions of 10.5 (L) x 2 (W) x 5 (H) metres. Brick masonry is covered by Belgian limestone ('petit granite'). Part of the masonry has been restored in the past. Planned re-opening of the bridge for the general public and its conservation as a state monument, required restoration of the masonry.

The masonry displays a damage pattern similar to that of masonry cracking due to high compressive forces and frost damage. Petrographic investigation, however,

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showed that cracks were caused by chemical reactions between sulphate and mortar components, resulting in the formation of gypsum, accompanied by ettringite and thaumasite, in the mortar. The presence of these minerals, causing swelling of the mortar, required a change of the original restoration plan. Due to presence of sulphate, some binders were excluded from use.

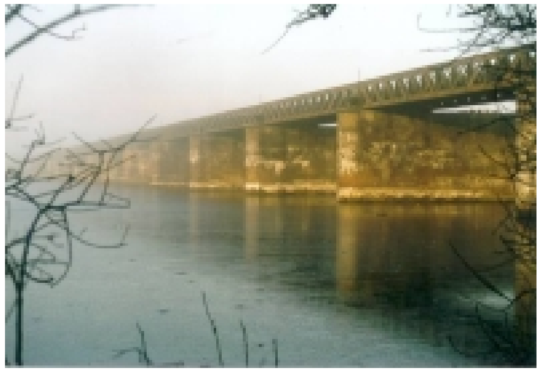

Figure 1. Overview of Moerputten Brigde.

2 Macroscopic damage

Many of the piles show deterioration, notably:

- White efflorescence, notably in the lower part of the piles; the efflorescence is probably due to washing out of mortar components (Fig. 2)
- Absence of pointing (Fig. 2)
- Absence of limestone cover plates and partial absence of masonry
- Development of algae, moss, and, locally higher plants
- Cracking through both brick and joints, up to several centimetres wide (Fig. 3-5), as well as internal cracking in the mortar, not visible from the outside (Fig. 4-5)
- Crumbling of mortar behind debonded pointing (Fig. 4)
- Debonding of brick and mortar

Figure 2. Absence of pointing below limestone plate and wash out (notably in the lower part of the picture).

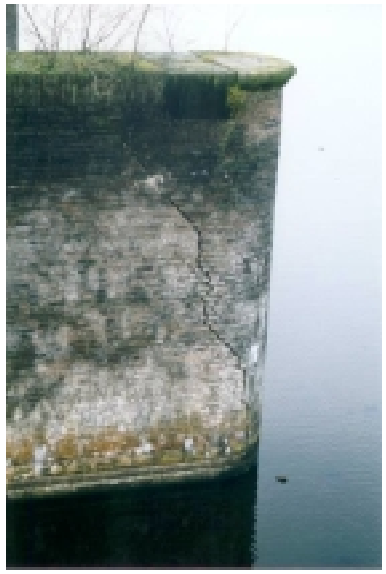

Figure 3. Example of cracking in one of the brick masonry piles.

Figure 4. Cracking and crumbling of mortar behind the pointing in a core removed from the pile in fig. 3; cracking is not visible from the outside.

Figure 5. Cracking of mortar in a core removed from the pile in fig. 3; again, cracking is not visible from the outside.

3 Laboratory investigation

3.1 Moisture and hygroscopic salt content of masonry

Determination of actual moisture contents, as well as hygroscopic moisture contents after equilibration at 95 RH show the masonry being very moist, with raising water from below and rain water from above being sources in the lower and upper parts of the piles (Fig. 6). Hygroscopic moisture contents are variable, for example 2 to 12 wt.% in the pile shown in fig. 3-5, indicating the presence of hygroscopic salts in the masonry,

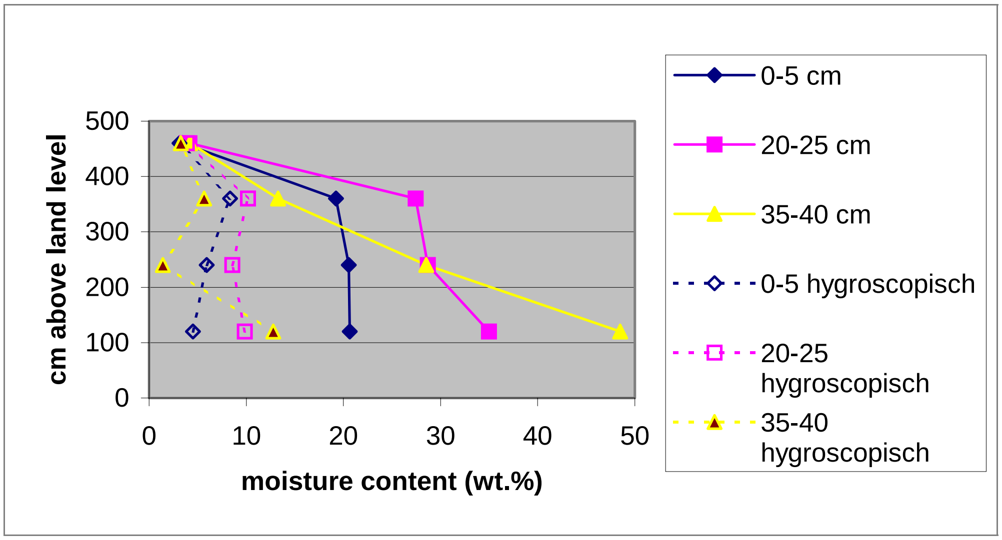

Figure 6. Distribution of actual and hygroscopic moisture contents in one of the piles with depth in the masonry and centrimetres above land level.

3.2 Characterization of bricks

Bricks applied to the external, visible part of the masonry have specially been produced for Moerputten Bridge. Relevant charachteristics of bricks removed from the structure are given in table 2. Results show that compressive strenghts of the original bricks are in line with that time requirements. Sulphate contents are low, even compared to current standards.

Table 2. Characteristics of bricks, Moerputten Bridge.

type of brick	**internal**	**external**	**previous restoration**
compressive strength (N/mm^2)	34.9	31.4	50.7
sulphate content (% m/m)	0.005	0.006	0.03
water absorption coefficient ($kg/m^2s^{1/2}$)	0.28	0.27	-
water absorption under atmospheric pressure (vol.%)	21.3	24.3	-
porosity (vol.%)	33.3	35.0	-

3.3 Polarization-and-fluorescence microscopy

Polarization-and-fluorescence microscopic investigation was performed on four samples, in order to determine the types of binder and aggregate used, as well as assess causes of damage.

Original masonry mortar was made with a trass – lime binder with remarkably little aggregate.Besides the silicious aggregate, limestone is present, which may orginally have been a component of the binder. The morater is very dense, with sparse voids only. The original pointing was based on ordinary portland cement, and has a dense, non-porous microstructure, less porous than is common nowadays. Repair mortar was based on a 'ferro portland cement', to some extent comparable of composition of current CEM II/B-S.

On a microscopic scale, both original mortar from a pile with visible cracking (Fig. 3-5) and from a pile without visible cracks, show cracking in the masonry mortar. In the sample from the pile with visible cracking, the cracks are (partially) filled by portlandite, gypsum, ettringite and thaumasite (Fig. 7-8). In the pointing, ettringite is present in some voids, but not causing any damage (Fig. 9). In the sample from the pile without visible cracking, microcracks and voids are filled with thaumasite (Fig. 10), whereas the interface between brick and mortar contains abundant calcite.

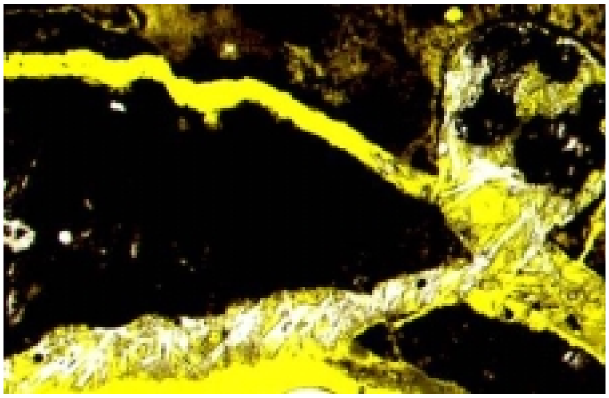

Figure 7. Microphotograph showing elongate gypsum crystals in a microcrack in the original masonry mortar from the pile in fig. 3. View 1.8 x 0.9 mm.

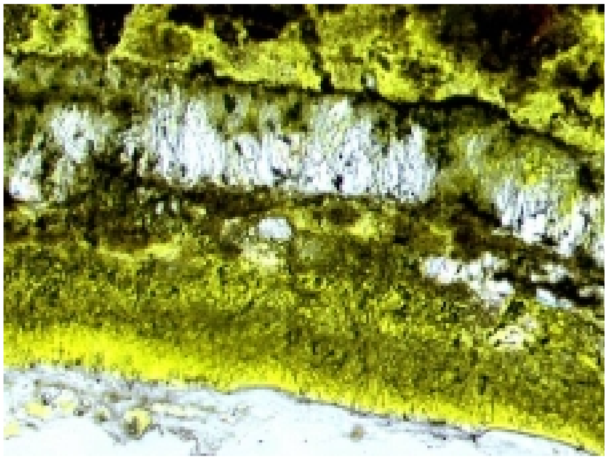

Figure 8. Microphotograph showing crack filled with (dominantly) ettringite in the original masonry mortar from the pile in fig. 3. View 0.7 x 0.45 mm.

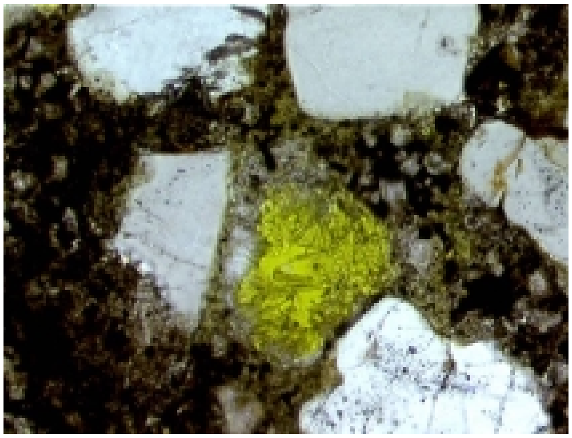

Figure 9. Microphotograph showing non-deleterious ettringite in a void in the new pointing in the sample from the pile in fig. 3. View 0.7 x 0.45 mm.

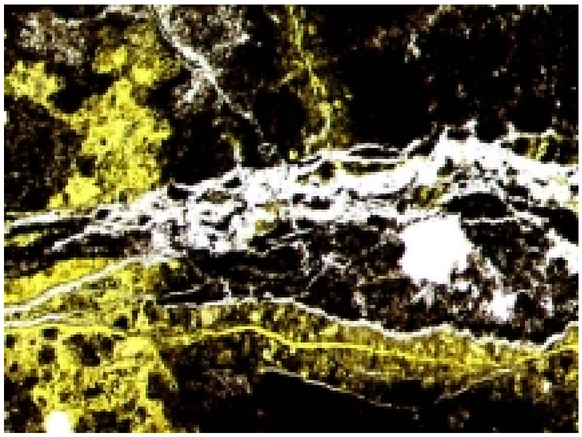

Figure 10. Microphotograph showing cracks and voids filled with thaumasite in the masonry mortar from a pile without externally visible cracking. View 1.4 x 0.9 mm.

4 Discussion and conclusion

Trass cements, i.e. mixtures ordinary Portland cement and trass, are known in several European countries, and have a long standing reputation of sulphate resistance (e.g. Dreyfus 1950; Biczök 1972). Trass – lime mortars in masonry also have a durable reputation. Nevertheless, microscopic investigation clearly demonstrated that cracking of the mortar and resulting deterioration of the masonry was caused by the formation of sulphate-bearing phases, viz. gypsum, ettringite and thaumasite, of which the latter is most important. As far as known, the combined occurrence of these minerals in trass – lime mortars has not previously been reported. The source of components for their formation is not in all cases evident. Applied bricks are (nowadays) low in water soluble sulphate, which may represent an original feature of the brick, or due to removal of the sulphate and transport to the mortar joint. In the formar case, sulphate may be derived from external sources (either ground or river water or possibly air pollution, which contained much higher sulphate contents in the past), or, possibly, from the trass used. Gypsum has been identified as a component of quarry samples of tuff stored in open air (Nijland et al 2003). Both calcium and reactive silica, required for the formation of thaumasite, are present in a pozzolanic trass – lime mortar.

The presence of ettringite in the mortar is more remarkable, as trass – lime mortars are free of portland clinker, and hence contain no C_3A. Another source of alumina

necessary for ettringite has not been identified, but most likely derives from the trass. Rhenish trass represents ground volcanic tuff from the German Eifel area added as pozzolana. Rhenish tuffs contain abundant zeolites, notably philipsite and chabazite, hydrated Ca-Al-silicates (Sersale and Aiello 1964; Nijland et al 2003), which may be the source for alumina in ettringite. Ettringite has, however, also been identified by optical and electron microscopy in historic mortars with hydraulic lime as a binder (Brocken and Nijland 2004) and the genesis of ettringite in lime mortars and role in degradation of masonry deserves further investigation (van Balen et al 2003).

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