Kenley Revival

Evaluation Addendum 2

Thaumasite Sulphate Attack

Scope of this report

The purpose of this report is to explain the issue of Thaumasite Sulphate Attack (TSA) as it affected the Kenley Revival Project.

It is not intended to be a specialist report on the technical aspects of TSA itself, or how it relates to the conservation of impermanent architecture.

Background

In June 2014 a seminar was convened to discuss the challenge of conserving Kenley Airfield's historic assets in a professional forum that included architects, structural engineers and subject specialists from the heritage industry who had experience in conserving historic brick and concrete structures. The aim was to inform the development of a conservation philosophy for Kenley, leading to a specification of work to conserve Kenley Airfield's remaining WWII structures as part of the Lottery funded Kenley Revival Project.

Following an exploration of some case study examples, attendees visited site and returned to offer input into how Kenley Airfield's conservation philosophy could evolve. The following summary is presented in the Kenley Common Conservation Management Plan 2015:

'The seminar had been designed to consider how to approach the issues of conservation, and then discuss how the assets on the airfield should be treated, but not to start designing a programme of works. A clear context was provided in the morning, with presentations on current issues and some recent case studies. The round table discussion was wide-ranging and identified a number of lines in the sand. Removing assets or imposing a regime of benign neglect were considered wholly inappropriate. A modest degree of restoration of already compromised fabric was felt to be worth considering, along with the introduction of new elements to improve understanding of how the airfield functioned during the Second World War'.

It is noteable that none of the specialists involved in the seminar raised concerns about replicating 1930's methods or material choices in a modern context, although as noted above the session did not consider the detail of the work itself.

This picture of Fighter Pen KC44 taken in 2014 shows the extent to which Kenley Airfield's structures had deteriorated. The mortar remained reasonably intact, but the brickwork was badly eroded and spalled. The structures were not expected to survive much longer without intervention.

Specification of works

The Specification of Works that resulted from the conservation philosophy and submitted as part of the Second-round application was developed jointly by the City Corporation and Historic England. Precedence was given to selecting materials that authentically replicated those originally used, as exemplified by the following entry in the specification about bricks:

Source and supply new brick to exactly match the original LBC Phorpres bricks. Where the same brick is not available new, salvaged sources may be acceptable.

Where neither is available, source and submit samples of a near matching alternative for approval before placing an order. The bricks must match in size, shape, colour and texture.

The Specification also described the desired characteristics of the other materials involved such as tiles and mortar, but for each the emphasis was on look and visual match rather than performance. Generally, the assumption was made that since the original structures had survived (although badly weathered) for 75 years, modern replacements using like-for-like material choices would perform in the same way.

Additionally, the Specification detailed methods for waterproofing and drainage, but specifically in relation to protecting concrete air raid shelters nestling within the Fighter Pens (and in one case end walls) and generally not for the earth retaining walls.

Tendering, Principal Design and Contract Administration

The project outsourced responsibility for tendering the conservation work and the subsequent contract administration (clerking the work) to a firm of specialist architects. As part of its undertaking the firm was asked to review the design and act as Principal Designer for the implementation phase. The design was at RIBA Design Stage Four – Technical Design, which is the final detailed design used for tendering and construction. The specialist firm was asked to fulfil the role of Principal Designer at RIBA Five – Construction, under CDM regulations.

It is notable that the specialist firm appointed did not comment on or alter the stage four design. However, the overriding quest for authenticity and implications regarding Scheduled Monument Consent probably had a bearing on this. Nonetheless, as part of its function at RIBA five, the Principal Designer was involved in materials selection and sample sign-off.

Thaumasite Sulphate Attack

Work to conserve the assets commenced in April 2017, and a Practical Completion Certificate was issue on January 4th, 2018.

KC44 following conservation work in 2017.

Shortly afterwards it was observed that some of the mortar in newly conserved sections of brick wall had failed. Mortar joints had expanded, ejecting material to create spoil heaps of extruded paste laying at the foot of the walls. The mortar itself appeared to be soft and saturated. In places it was possible to push a finger into the mortar joints. This phenomenon had not affected all the 2017 conservation work, and where it had not to the same degree, but it was quite widespread across the site.

The situation was possibly exacerbated later in the winter with the arrival of the 'Beast from the East' a period of particularly cold weather that hit the UK on February 22nd. However, it is important to note that the mortar degradation was noticed before this date.

Investigations into the cause commenced. In April 2018 the project's conservation contractor commissioned a report from a specialist material testing consultancy that identified higher than expected levels of sulphate in the mortar. However, it was not until the project's Principal Designer involved the Buildings Research Establishment (BRE) that a definitive diagnosis was given. BRE reported to the Principal Designer in July 2018 identifying Thaumasite Sulphate Attack as the cause.

Thaumasite (pronounced tormasite) is named after the Greek word for surprise. Thaumasite Sulphate Attack (TSA) is a type of salt weathering that is dependent on a particular combination and concentration of salts, temperature and humidity. The TSA reaction degrades mortar, chemically changing it into thaumasite. It can occur where there is a source of sulphate, abundant carbonate and water at temperatures around 5 °C.

Example of TSA damage affecting the end wall of the new central spine in Fighter Pen KC12. Salt staining is also visible.

Trials

BRE was commissioned by the Principal Designer to devise a trial of alternative material combinations onsite using the new central spine wall in Fighter Pen KC12 as the test bed. In early November 2018 the existing (2017) brickwork on the side retaining walls was dismantled, and new walls were constructed using four separate mortar mixes including two cements and two hydraulic limes, three sands, two brick types and drainage. The bricks and mortars were:

- Two brick types
    - London Brick Company, common Fletton (as used in 2017)
    - Northcot, Nine Elms Common
- Four mortar mixes
    - Ordinary Portland Cement, Blue Circle Mastercrete (CEMII/A-L) (as used in 2017)
    - Low sulphate Portland Cement, Aarlborg White (CEMI)
    - Natural Hydraulic Lime, St Astier NHL 3.5
    - Natural Hydraulic Lime, St Astier NHL 5.0

Additionally, an impermeable high-density polythene sheet and permeable geotextile filter fabric were installed as waterproofing, and on one elevation a separate back up wall of 7N dense concrete blocks was constructed. Both sides were drained using slotted pipes and pea shingle.

The panels were left in situ during the winter of 2018-19 and examined and tested in January and May 2019. A range of laboratory tests were carried out by BRE on samples of brick, water and soil.

The trials failed to replicate the wholescale failure of the brickwork experience in 2017. However, some deterioration was noted in some material combinations, and performance in relation to strength and water saturation varied. The combination of Northcot Nine Elms bricks and Aarlborg White cement was found to be the most resilient, indeed it was found to be stronger than the original wartime construction.

Cause and liability

The City Corporation considered that the Principal Designer was liable for the failure of the 2017 work, and this view was backed-up by legal advice from a specialist law firm.

Consequently, much of 2019-20 was taken up with an attempt to initiate proceedings under the Pre-action Protocol for Construction and Engineering Disputes. Ultimately this approach failed, mainly because the technical complexities involved in establishing the cause of TSA made it impossible for the City's expert witness to give an opinion. The City, its legal advisors and expert witness relied on information provided by BRE. As can be seen from the following, there was a degree of uncertainty regarding both cause and solution:

BRE Report for the Principal Designer, July 13 2018

- *The failure was not caused by workmanship but a combination of the use of the London Brick and the type of cement used to make the mortar. There were no waterproof barriers between the retained earth and the brickwork, which allowed water to flow through the brickwork, exacerbating the sulphate attack.*

BRE Report for the City Corporation – Final Trial Investigation Report, July 31 2019

- *The soluble salt content results suggest that the bricks are a source of sulphate, which is likely to have contributed to the deterioration of the 2017 brickwork. The original and 2017 wall design together with the soluble salt content of the fletton brick has contributed to both new and old brick deterioration as the walls are earth retaining wall, in exposed location and lack a suitable coping detail* [sic].

BRE Report for Beale & Company Solicitors, December 18 2019

- *The use of modern Fletton bricks provided a source of sulphate salts, which allowed TSA to occur.*
- *The choice of premixed Mastercrete to make the initial mortar conservation works in 2017 was not appropriate as the mix is a CEMII A-L. A CEMII cement contains between 80%-94% cement clinker together with between 6%-20% limestone and 5% minor constituents. The presence of the ground limestone within the cement together with the active soluble salts from the brick, along with a sloping bank of wet soil and cold winter conditions resulted in TSA.*
- *It is likely that TSA would not have occurred if a sulphate resistant cement had been used, but sulphate resistant cement has been shown to be susceptible to sulphate attack in some circumstances.*

BRE Letter to Beale & Company Solicitors, April 30 2020

- *In our view there is no product based on modern OPC that would be suitable in this circumstance with this particular S2 brick.* [Note – S2 classification means the brick has a low active soluble salt content].
- *It is possible that the 1940's OPC, with its different mineralogy, etc. to modern OPC, may not have been as susceptible to TSA in these circumstances.*
- *Sulphate-resisting mortars are resistant to ettringite formation but not to thaumasite formation.*
- *The cause of the difference in performance between the 2017 and 2018 brickwork is likely to be a difference in water saturation and rate of flow of water through and across the brickwork.*

BRE Email to Beale & Company Solicitors May 7 2020

- *We only measured the soluble salt content of two bricks and these were both from KC44 and were manufactured in the 1940s. Therefore, the comment at 5.4.4 of our report (that the bricks are a source of sulphate) is correct and relates to the two old bricks from KC44. We cannot comment on the sulphate content of the new bricks other than to say that it is, in our view, unlikely that they did not achieve an S2 classification. And to reiterate for clarity, we think it is likely that the new bricks met the S2 classification.*

The confusion surrounding the exact cause of the thaumasite sulphate attack rendered it impossible to establish liability, but also made it difficult to determine how to rectify the failed 2017 work to avoid it happening again.

Rectification

In February 2021 architects and structural engineers working for the project's conservation contractor produced a condition survey and schedule of work for rectifying the 2017 defects. This aimed to replace failed sections of the 2017 work using the most resilient material combination from the trials – Northcot Nine Elms bricks and Aarlborg White cement. Additional waterproofing and drainage were prescribed for many of the replaced sections.

Rectification work commenced in July and continued through to November (material shortages caused by the pandemic led to delays).

2021 reconstruction of the central spine wall in KC12. The structure now includes waterproofing applied to soil facing areas of brickwork, drainage and a waterproof membrane.

Note – the colour match is reasonably authentic (see P2)

The pictures above also illustrate several design changes for the new central spine. The 2017 structure utilised high-density polystyrene blocks as a core for the tall central wall. The top courses of brickwork and the concrete coping sat on this polystyrene core, separated by a geotextile membrane. In their 2021 assessment of this structure the architect and structural engineer found that the brick and concrete ridge had expanded and contracted, slipping over the geotextile and pushing on the end walls, which were already weakened by thaumasite. This caused the end walls to bow out.

The 2021 structure has a full-length wall and expansion joints at both ends. Unlike the 1939 and 2017 structures, all the walls now sit on their own foundations. Interestingly, when digging the foundations, it was discovered that the concrete apron upon which the 1939 and 2017 structures sat varied greatly in thickness front to back; a fact that possibly further exacerbated rotation and cracking as the apron probably yielded inconsistently under their weight.

Also of note is the addition of a buttress at the outside end wall of the new 2021 structure. Volunteer researchers discovered that this was an authentic feature at Kenley, but not one that was present in 1939. In fact, the central spines were constructed in phases; first - a single wall, later the soil infill and end walls, finally the buttress. This final addition in particular indicates that the original wartime structures probably suffered from the same damaging movement that affected the 2017 work. The fact that the buttresses were constructed over a pre-existing pattress (as replicated in 2021), itself a feature designed to mitigate movement, further reinforces this notion.

All the above helps illustrate an important learning point for the project in relation to the assumption that the original structures faired ok to the present day. Although much of the 1939 construction proved to be robust and resilient, elements of it had failed earlier in its lifetime.

Conclusion

Thaumasite Sulphate Attack is a relatively unknown phenomenon, even within specialist circles. It is possible that TSA could have occurred at Kenley even if measures had been taken to mitigate the more common form of sulphate attack. However, some of the factors that gave rise to TSA at Kenley are known to cause other problems, and consequently would have been designed out under normal circumstances (by using F2 rated bricks and applying waterproofing for example).

The same characteristics that made the 2017 bricks prone to frost damage also made them prone to TSA (the Flettons used in 2017 had a water absorption rating of 23% by volume, as opposed the Northcot Nine Elms bricks with a rating of less than 12%). A degree of frost damage was expected to affect the 2017 work because the original structures suffered from this form of deterioration persistently over their lifetime. However, accepting this apparent low-level chronic risk opened the door to the hidden and acute danger of TSA.

At Kenley, the quest for authenticity relied on an assumption that conserved structures would behave in the same way as the original 1939 features. However, this assumption failed to take into account the fact (realised much later) that parts of the original wartime features had indeed failed, and that modern materials do not always share the same chemical properties as their 1940s counterparts, even if they are of the same lineage.

The establishment of exact cause and liability was ultimately impossible, and this meant that the City and project partners had to fund the full cost of rectification. No matter how comprehensive contracts and specifications are, professionals cannot be held accountable for failings specific to things they are not expected to know anything about. They can however be held accountable for not providing advice and warning more generally, but at Kenley the situation was clouded by the project's strive for authenticity and assumptions made about what was involved in meeting that aim.