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# THE REHABILITATION OF A VICTORIAN CLAY BRICK RAILWAY VIADUCT

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## ABSTRACT

Larpool viaduct is a 13 span clay brick viaduct built between 1882 and 1884 to carry the Scarborough and Whitby railway across the picturesque Esk Valley in Whitby, North Yorkshire, England. The structure is of multi-ring clay brick arch construction supported on solid brickwork piers founded on mass concrete or concrete filled brickwork caissons. The railway was closed to rail traffic in 1965 but was re-opened to pedestrian and cycle traffic in 2000; it is now part of a regional sustainable transport network used mainly by tourists. Exposure to wind, driving rain and repeated freeze-thaw cycles has resulted in severe spalling of some of the brickwork, particularly that from the 30m high piers. This paper describes the original construction, the rehabilitation works including the historical context of the structure, site inspections prior to and during construction and a review of the rehabilitation works taking into account factors such as differential movement and the need to achieve a high standard of workmanship.

## 1. INTRODUCTION

### 1.1 Development of the Scarborough and Whitby Railway

Scarborough and Whitby, both situated on the North East coast of England in the county of North Yorkshire, have developed into popular tourist resorts due, in part, to their rich and varied heritage. Although there is evidence of Stone Age and Bronze Age settlements in Scarborough, the town was initially recognised as having a strategically important coastal location by the Romans and the Vikings. Kings Henry I and II built and strengthened a castle in the town which also developed into an important harbour for fishing and trading. Whitby, originally a Viking and early Christian settlement, gradually developed as a result of alum extraction, whaling, fishing, jet jewellery and shipbuilding. Three of Captain Cook's ships used to explore Australasia in the late 18th century were constructed in Whitby which also provided some inspiration for Bram Stocker's well known novel, Dracula.

Both towns developed as tourist destinations from the 1840s as a result of railway links with the surrounding towns and cities such as Hull, Leeds, Middlesborough, Sheffield and York. Scarborough's popularity with tourists was further boosted as a result of its natural spa water which was considered to have medicinal properties. In spite of the development of the aforementioned railway links, direct travel between Scarborough and Whitby remained difficult. It was recognised that a 32 km long direct railway line would halve the journey time between the two towns and would exploit the growing tourism industry, aid further commercial development of the region and permit more efficient transport of minerals and other goods. Accordingly, the Scarborough and Whitby Railway Company (SWRC) was established to develop, manage and operate a new single-track railway. The SWRC also entered into an agreement with the North Eastern Railway Company to facilitate connections with the main regional railway network. As a result, construction of the Scarborough and Whitby Railway started on 3rd June 1872. The completed line was officially opened on 16th July 1885; the total cost of construction was £649,813.

### 1.2 Larpool Viaduct

Larpool viaduct is the largest above ground structure on the Scarborough and Whitby railway. It is a 13 span, grade II listed, red clay brick structure located approximately 2 km south of the centre of Whitby. The grade II listing means that the viaduct has been included on a statutory list of structures in England that are designated to be of special architectural or historical interest "which warrant every effort being made to preserve them" (DCMS 2005). The viaduct was constructed to carry the Scarborough and Whitby railway across the picturesque valley of the River Esk and two other railways, namely the Whitby, Redcar and Middlesborough Union Railway and the Esk Valley line; see Figure 1, below.

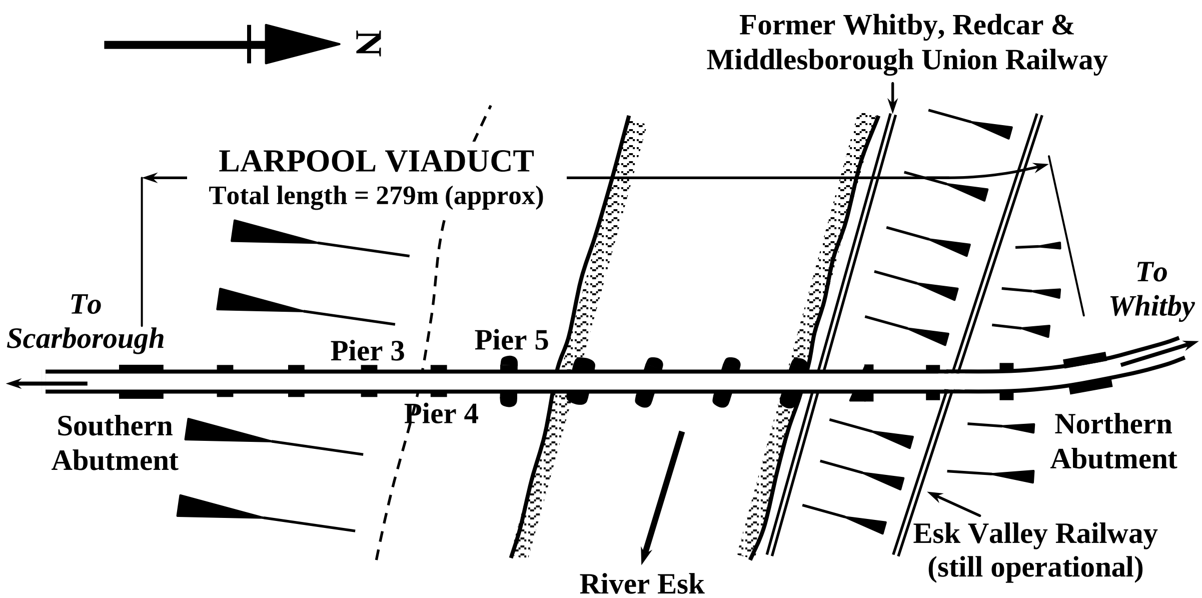



Figure 1. Outline Plan of Larpool Viaduct showing piers 3, 4 and 5.

The latter railway, which links Whitby and Middlesborough, is the only one that remains in operation. The Whitby and Scarborough railway was closed to rail traffic on 6th March 1965 as a result of an extensive review of Britain's entire railway network led by the then chairman of the British Railways Board, Dr. Richard Beeching (British Railways Board 1963). The viaduct remained under the ownership of Rail Property Limited then British Railways Board (Residuary) Limited until it was purchased by its current owner, Railway Paths Limited (RPL), for a nominal sum. RPL is registered as a charity in the UK. Its principal aims are to:

1. Preserve, restore, maintain and protect the structures it owns for public benefit;
2. Make available for public benefit, routes, roads and paths suitable for walking, cycling, horse riding and wheelchair use;
3. Safeguard any disused railway lines in its ownership for potential future public transport use;
4. Support, promote and encourage the charitable activities of Sustrans Limited. One of the principal aims of Sustrans is to develop a national cycle network in the UK.

In 2000, most of the former Scarborough and Whitby railway line, including Larpool Viaduct, was opened to public access and it has since become a popular tourist attraction particularly for walkers and cyclists. By 2006, visual inspections had revealed that some parts of the viaduct had become severely deteriorated and were in need of rehabilitation. Of particular concern were numerous pieces of clay brickwork spalling from piers 3, 4 and 5 of the viaduct. These posed a threat to the health and safety of the occupants of a number of new houses constructed on the South bank of the River Esk, beneath the viaduct. As a result, a contract was let by RPL to repair piers 3, 4 and 5. The work consisted primarily of removing the outer skin of damaged brickwork and replacing it with new brickwork bonded into the existing brickwork substrate.

At the early stages of the rehabilitation contract, RPL's site representative expressed concerns about the construction specification and its compliance with the guidelines for new masonry construction given in the UK code of practice

(BSI 2005). In particular, the means of accommodating the effects of any differential movement between the new and existing brickwork were questioned. As a result, the author was commissioned by RPL to:

1. Carry out an independent review of the capability of the proposed rehabilitation works to accommodate differential movement;
2. Consider the option of introducing horizontal movement joints and stainless steel angle supports into the replacement facing brickwork.

This paper describes the construction of the original piers; the condition of piers 3, 4 and 5 prior to the rehabilitation works and a review of the proposed works with particular reference to the standard of workmanship and the need to accommodate differential thermal expansion and moisture expansion.

## 2. LARPOOL VIADUCT CONSTRUCTION

The viaduct was designed by Sir Charles Fox and Sons, a firm of consulting engineers based in Westminster, London, UK. Brickwork was selected as the principal construction material instead of the more commonly used iron or steel because the near-coastal location was thought to present an unacceptable risk of corrosion. The viaduct was constructed by John Waddell and Sons of Edinburgh under the supervision of resident engineer Charles Arthur Rowlandson, of Sir Charles Fox and Sons. Construction of the foundations started in October 1882 and all thirteen arches were constructed between May and September 1884. The first train crossed the viaduct on 24$^{th}$ October 1884. It is estimated that approximately 5 million bricks were used in the construction; the total cost of the viaduct was approximately £40,000.

The location of piers 3, 4 and 5 is shown in Figure 1 and the principal details of the piers are shown in Figures 2, 3 and 4. The latter details are based on the as-built drawing of the viaduct produced by Rowlandson (provided by RPL) and on the drawing by Fox (1885-86).

Figure 2.  A view of the caissons and arches of the foundations for Pier 5

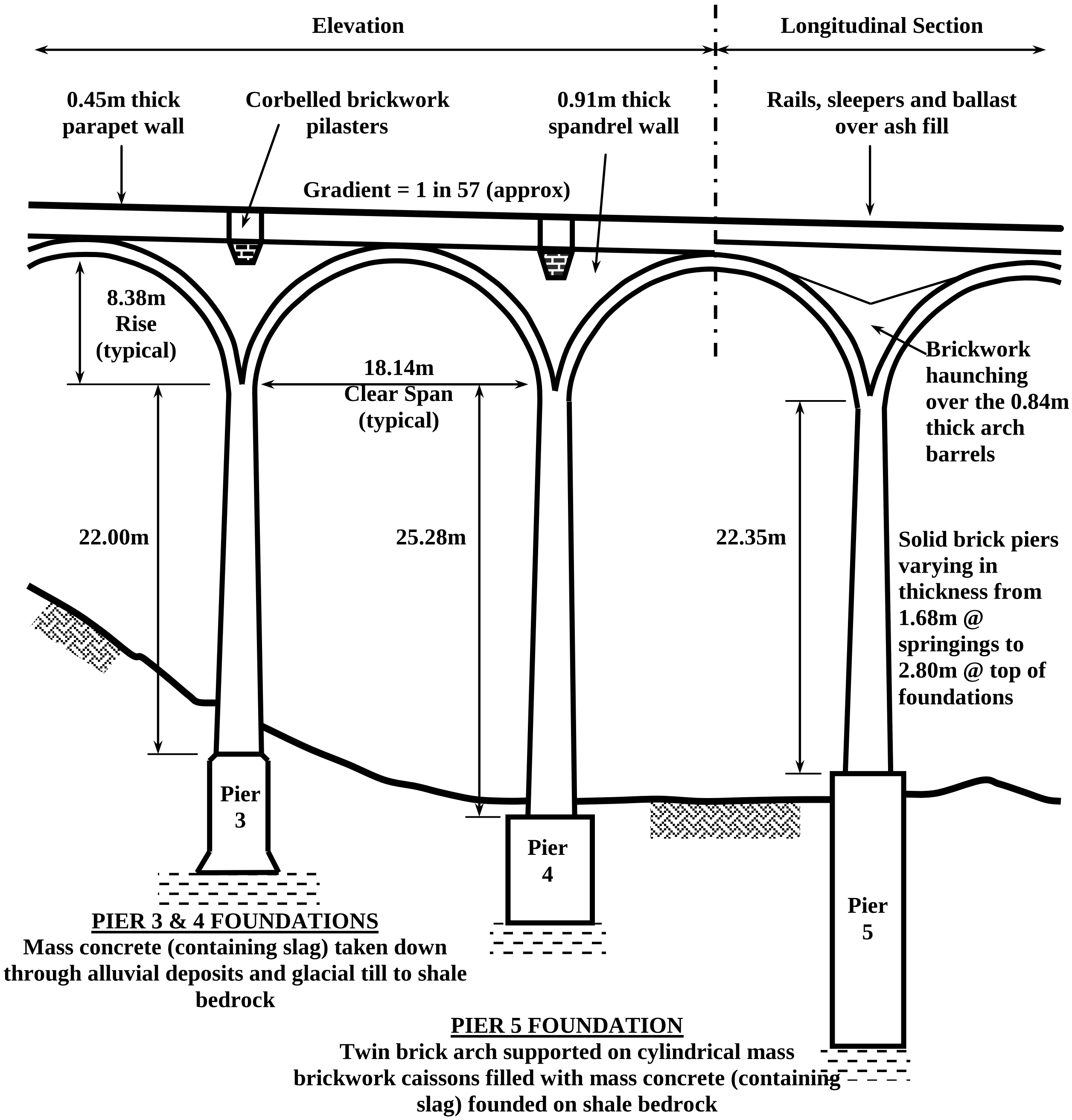



Figure 3. Elevation and Longitudinal Section of Piers 3, 4 and 5

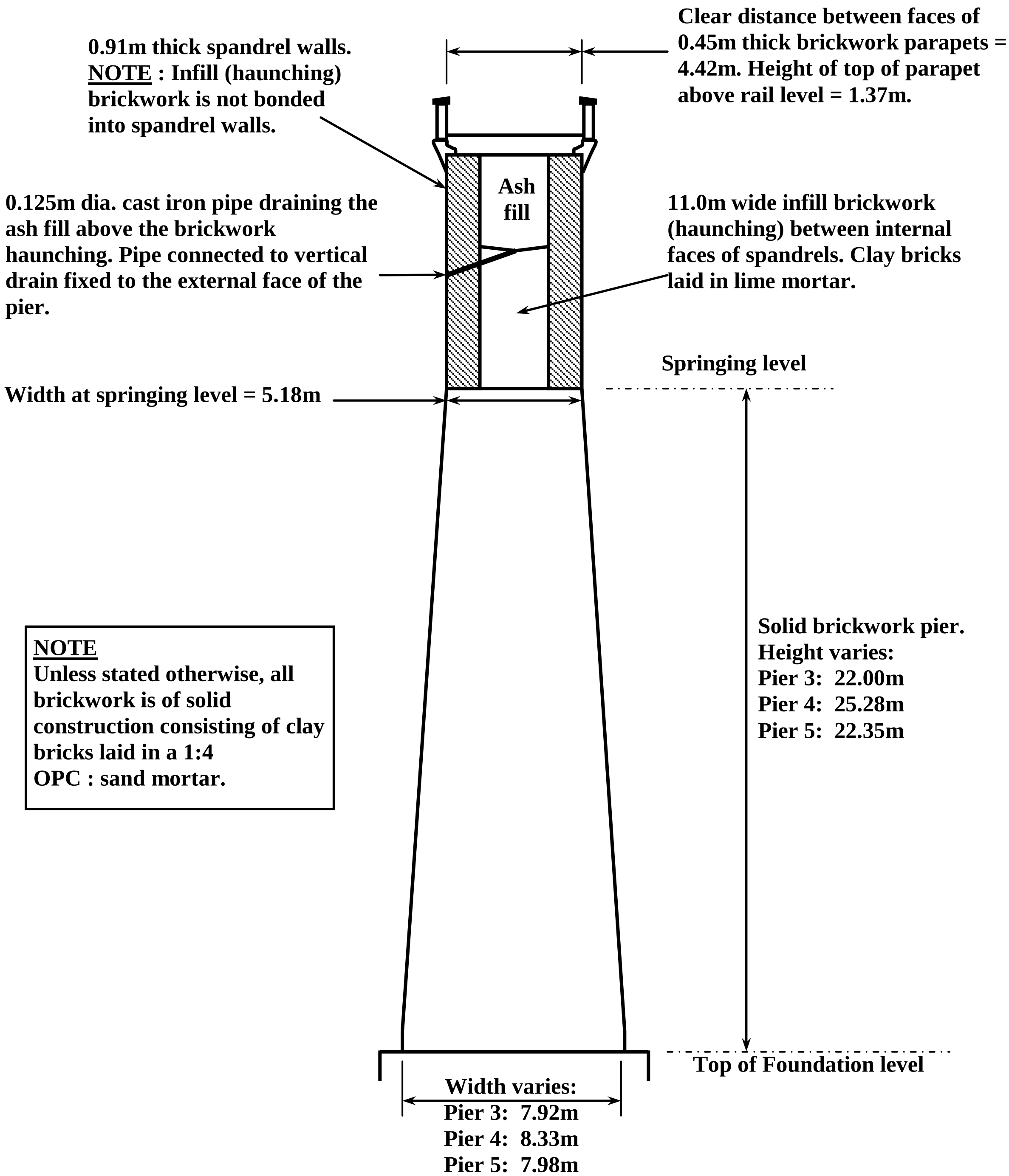



Figure 4. Typical vertical section through Piers 3, 4 and 5.

A detailed description of the construction of the viaduct is also given by Fox (1885-86). Of particular note were the problems encountered when constructing the foundations in the River Esk and the centring used for the construction of the arches. The near-surface ground conditions consist of alluvial deposits of sand, mud, silt and silty clay. The foundations were constructed on a thick layer of shale which is part of the sedimentary formations of the Middle Jurassic period. For each of the piers constructed within the tidal range of the River Esk (such as pier 5), three brickwork caissons of cellular construction were sunk down to the shale. The voids in the caissons were subsequently filled with mass concrete and the three caissons were connected by two multi-ring arches on which the piers were subsequently built. Details of the construction of pier 5 are shown in Figure 2. The remains of large oak and fir trees buried in the bed of the river, encountered during the sinking of the caissons, proved to be the greatest obstacle during construction. Eventually a diver managed to remove the trees with the aid of a saw, a hammer, a chisel and a steam-operated crane.

The centring for the main arches each consisted of four timber frames supported on diagonal struts which were supported on steel rails built into the piers below. Lateral stability was increased by the use of tensioned steel ropes connected to temporary anchor piles. Each arch barrel consisted of seven rings of clay bricks laid in a 1:4 (OPC : sand) mortar giving a total ring thickness of approximately 0.84m. The extrados of each arch ring was coated with two 20mm thick layers of asphalt and then backfilled with a drainage layer of clean ashes up to ballast level.

## 3. CONDITION SURVEY OF PIERS 3, 4 AND 5

The author carried out an initial inspection of the viaduct early in 2007 which revealed the following:

1. There was considerable evidence of surface dampness and moisture on many of the external faces of the existing piers particularly close to the arch springings at the tops of the piers. There was also evidence of leakage of rainwater through the arch barrels spanning between the piers.
2. There was considerable evidence of damage to the external surfaces of much of the clay brickwork. This was more marked on the upper sections of the piers, where there was most evidence of dampness and moisture. In addition, the damage seemed to be worst on the Eastern elevation of the viaduct. It is assumed that this is because the prevailing winds tend to blow up the river valley from the North Sea estuary onto the Eastern elevation. This damage was found to be in the form of spalling (sometimes fairly extensive) of the brick faces; this is typical of frost damage. There was no evidence of chemical attack, salt crystallisation damage or other similar forms of deterioration.
3. In many cases, bricks with vertical cracks running through them were noted in the otherwise undamaged zones of the existing piers. The author has noted similar cracks in the piers of other brick and stone masonry viaducts. It is very unlikely that these cracks would have existed in the bricks when the viaduct was constructed. It is possible that the cracks occurred subsequently as a result of excessive tensile strain in the bricks resulting from a redistribution of stress due to creep.
4. There was no visual evidence of damage or movement caused by settlement or subsidence. The condition of the upper parts of the foundations revealed at low tide appeared to be good.
5. A previous repair to pier 6 was noted. This was a fairly extensive repair to one of the corners and was several metres in height. Although the precise details of the repairs are unknown there was no evidence of the provision of any movement joints or any damage, although it should be noted that a close inspection was not possible due to a lack of access scaffolding.

## 4. THE REHABILITATION RATIONALE

The condition surveys carried out by RPL and the author indicated that the deterioration was mainly as a result of water ingress. Accordingly, the most logical rehabilitation strategy would have been to implement measures to minimise the ingress of water into the brickwork. Typically such measures would have included the provision of a new drainage system and waterproofing measures across the full length of the viaduct. In practice, a lack of funding and RPL's requirement to minimise disruption to the combined walkway and cycle track required the use of an alternative strategy. This consisted of repairing the highest priority damaged areas of the viaduct, namely piers 3, 4 and 5. Resilient and durable materials able to withstand the effects of future water ingress were specified. Guidance on the selection or appropriate materials and the construction methodology was based on the Venice Charter (ICOMOS 1964) and the British Standard code of practice for the cleaning and surface repair of buildings (BSI 2000). Due consideration was also given to the viaduct's grade II listed building status.

## 5. INSPECTION OF THE REHABILITATION WORKS

A further inspection of the piers was carried out by the author in February 2007. By this time, all the access scaffolding was in place and the contractor had started to install the rehabilitation works proposed by the client (RPL); typical details are shown in Figures 5 and 6.

**NEW BRICKWORK**

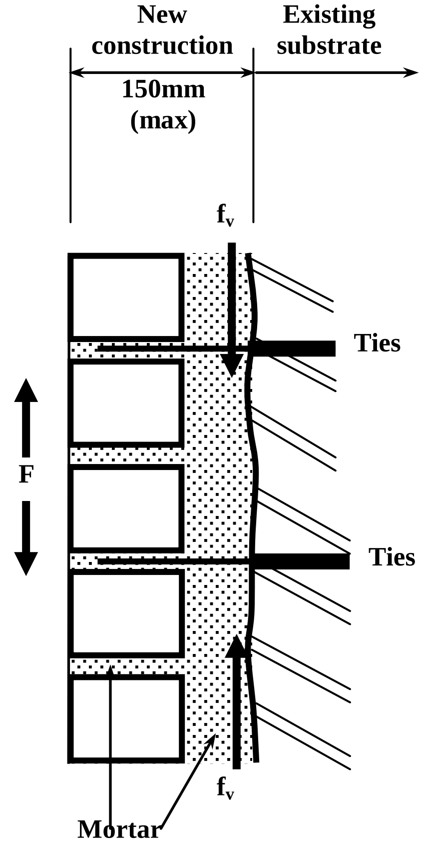
a). Red class B engineering clay bricks laid in a 1:½:4½ (Cement : lime : sand) mortar.

b). New brickwork facing to consist of alternate stretcher and snap header courses.

c). Snap headers to be cut from full bricks using a bolster to provide a rough end surface profile for maximum bond.

d). Space between new facing brickwork and existing substrate to be carefully filled with 1:½:4½ mortar as bricklaying progresses.

e). At the repair boundaries, new brickwork to be "toothed" into existing undamaged brickwork.




**TIES**

i). Single triangle 3.3mm dia. grade 304 austenitic stainless steel remedial ties (tensile strength = 750 N/mm$^2$).

ii). Ties anchored into 10mm dia. pre-drilled hole using a water -tolerant polymer resin grout.

iii). Min. anchorage length into existing substrate = 50mm.

iv). Ties provided every alternate course vertically and at a maximum spacing of 500mm horizontally.

v). At corners, ties are to be provided in every course vertically.

Figure 5. Typical detail of the pier rehabilitation works

Figure 6. View of the pier rehabilitation works

The additional inspection revealed the following:

a). The contractor used a power saw with a circular blade to break up the damaged parts of the surface brickwork using a series of vertical cuts. This facilitated removal of the damaged brickwork using small hand tools and created a very rough texture to the existing substrate. This was considered to be good practice as it was not only an efficient means of removing the damaged material but it also helped to maximise the shear connection between the new and existing brickwork through improved bond.

b). Following removal of the deteriorated brickwork, the existing substrate was found to be in good condition. Many of the original joints were completely filled with mortar which appeared to be in a sound condition. A high standard of workmanship appeared to have been achieved in the original construction.

c). Visual inspection of the bricks removed from the face of the existing piers and those forming the remaining substrate indicated that the original bricks were well-fired. The large amount of vitreous material present suggested that the bricks were made locally from the abundant supplies of shale available in the Whitby area. As expected of clay bricks made during the Victorian period, there was evidence of hearting (or over-firing). This was evident in the form of black or blue/black coloured regions in the brick cores and was not considered to be a problem, although it may have been responsible for thermal gradients and/or differential thermal strains that may have contributed to the formation of cracks in some of the bricks. Also, based on a limited number of visual inspections, there was very little evidence of stone inclusions in the original bricks. This suggests that they were of a very high and consistent quality. When inspecting the existing substrate there was evidence that some of the existing bricks had a laminated macrostructure in which the laminations were observed to be parallel to the bed face of the bricks. This indicates that the original bricks were probably hydraulically pressed and may be an explanation of the form of frost-induced deterioration in which the faces of the bricks appeared to peel off. This is typical of an exfoliation failure mechanism.

d). Samples of the new clay bricks used in the rehabilitation works were inspected. The bricks were “frogged” on one side indicating that they were probably formed by hydraulic pressing. The bricks appeared to be well-fired and it is understood that they had properties similar to those required for class B engineering bricks, namely a maximum water absorption of 7% and a minimum compressive strength of 50 $N/mm^2$. There was no evidence of any significant hearting and they were a similar colour to the existing bricks.

e). The new bricks were laid in a 1 : ½ : 4½ (OPC : lime : sand) mortar. Hence, although the OPC used in the 1880s would have been different to that produced commercially in the 21st century, the new facing brickwork was probably very similar to that used in the original construction.

f). Even at the early stages of construction there was evidence of poor backfilling of some of the facing brickwork with, in some cases, large voids between the new facing brickwork and the existing substrate. These voids were subsequently filled with grout by the contractor when instructed to do so by the Client’s site representative.

g). Many of the ties appeared to be well anchored into the existing brickwork substrate but the Client’s site representative confirmed that a small number could be pulled out from the existing brickwork by hand. These were subsequently replaced by new ties.

In summary, the materials selected for the new brickwork construction matched that of the existing viaduct as well as can be reasonably expected. Although some aspects of the contractor’s method of working helped to maximise bond between the new and existing materials, the standard of workmanship and quality control on site were in need of improvement. These issues were addressed by increasing the level of independent supervision on site and by carrying out a pull-out test on randomly selected ties at regular stages throughout construction.

## 6. REVIEW OF THE REHABILITATION PROPOSALS

The principal aim of the rehabilitation works was to ensure composite action, over a prolonged period, between the new brickwork and the existing substrate. Hence, it was important to consider any load, climatic or other environmental effects that might disrupt the shear connection between the new and existing materials. Forces and other actions due to dead, imposed and wind loading acting on the viaduct were considered to have an insignificant initial effect on the new brickwork. The main concern was that, in the short term, differential movement between the new brickwork and the existing substrate might destroy the shear connection between the two materials leading to premature failure. The proposed rehabilitation works, shown in Figures 5 and 6, are built in to the existing substrate without the provision of any movement joints. As a result, any moisture expansion of the new brickwork and differential thermal expansion will create a restraining force, F. Ignoring the effect of the ties, force F is assumed to be transferred into the existing substrate via vertical shear stresses ($f_v$) at the interface between the new & existing construction. When evaluating the capability of the proposed detail to accommodate such forces and stresses, based on the guidance obtained from Hendry (1998) and BS 5628 (2005), the author assumed a free irreversible moisture expansion of 0.045%; a coefficient of linear thermal expansion for the facing brickwork of 8 x $10^{-6}$ °$C^{-1}$, a design temperature difference between the new brickwork and the existing substrate of 30°C and an elastic modulus of the order of 7600 kN/$mm^2$ to calculate the force, F produced by restrained thermal and moisture expansion over a maximum thickness of 150mm of facing brickwork. Any reduction in the restraining force due to creep was ignored. Assuming a characteristic shear strength of 0.7 N/$mm^2$ and a partial safety factor of 2.5, a 1m wide section of facing brickwork would require to remain bonded to the substrate for a height of approximately 3m. This seemed to be reasonable given the provision of ties every alternate course (i.e. a vertical spacing of 150mm) and at a horizontal spacing of 500mm, should any partial de-bonding occur. The ties also provide lateral restraint against buckling in the unlikely event of a possible compression failure of the facing brickwork. In summary, the rehabilitation detail proposed by RPL was judged to be satisfactory.

At first glance, the UK code of practice for masonry (BSI 2005) might guide engineers to specifying external brickwork facing consisting of an unfilled cavity supported on horizontal angle supports with horizontal movement joints between the new and existing construction. Indeed, this was considered as a possible detail by the RPL site representative and it is a common form of external masonry cladding used in steel or concrete frame building structures. It would, however, be inappropriate for structures such as Larpool viaduct. This is primarily because water would collect in the cavity leading to the possibility of large magnitude hydrostatic pressures (some of the remedial works were up to about 12m in height) and an increased risk of frost damage. In addition, the isolated external leaf of masonry would be very vulnerable to compression failure should it attract compressive load from the existing structure in the future. Finally, the movement joints and support angles are likely to be maintenance liabilities requiring the provision of relatively expensive access works to carry out routine inspection and maintenance work.

## 7. CONCLUSIONS

1. A great deal of experience has been gained in the UK and other countries of the rehabilitation and repair of masonry structures. In spite of this there is little authoritative guidance available on the design, specification and construction of such works.

2. The guidance provided for new masonry construction in codes of practice and their associated standards should be treated with caution if applied to rehabilitation and repair works. In some cases, the guidance contained in codes of practice for new construction may be wholly inappropriate for repair or rehabilitation works.

3. Successful masonry construction, whether new or remedial work, requires the use of high quality materials and high standards of workmanship. Larpool viaduct is a durable engineering structure; it has withstood a 125 year test of time in extreme exposure conditions. The high quality materials used and high standard of workmanship achieved in the original construction have both contributed to the success of the viaduct. It is hoped that the quality measures used for the rehabilitation of the piers of Larpool viaduct will contribute to the continued future success of the structure.

4. Careful supervision of construction and frequent quality control testing are essential to increase the chances of achieving a high standard of workmanship. Supervisory staff must ensure that all construction staff are clear about the required minimum standard of workmanship at the start of any rehabilitation project involving masonry construction.

5. It would be useful to conduct field trials to monitor the strains in the new facing material and the existing substrate with a view to improving our understanding of composite action in remedial works to aid the development of future design guidance.

In the past, the author has indicated that masonry should be considered as a structural material for new highway and other structures where high levels of durability and low maintenance costs are among the principal design requirements (Garrity 1992, Garrity 1995, Garrity and Gregory 1995). The excellent performance of Larpool viaduct over a 125 year period in challenging environmental conditions has strengthened this view.

## 8. ACKNOWLEDGEMENTS

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## 9. REFERENCES

British Railways Board. 1963. "*The Reshaping of British Railways, Part 1 - Report*". Her Majesty's Stationery Office, London, England, UK.

British Standards Institution. 2000. "*Code of practice for cleaning and surface repair of buildings. Part 2: Surface repair of natural stones, brick and terracotta*", BS 8221 – 2: 2000. British Standards Institution, London, England, UK.

British Standards Institution. 2005. "*Code of practice for the use of masonry - Part 1: Structural use of unreinforced masonry*", BS 5628. British Standards Institution, London, England, UK.

Department for Culture, Media and Sport (DCMS). 2005. "*Principles of selection for listing buildings: planning policy guidance note 15*". Department for Culture, Media and Sport, Architecture and Historic Environment Division, Office of the Deputy Prime Minister, London, England, UK.

Fox, F. 1885-86. "Viaduct over the River Esk at Whitby, and the Embankments and Culverts in the Ravines". Paper No. 2117. *Minutes of the Proceedings of the Institution of Civil Engineers*, Vol. 86 (4): 301-311.

Garrity, S.W. 1992. "Reinforced clay brickwork highway structures". *Proceedings of the Sixth Canadian Masonry Symposium*, Saskatoon, Saskatchewan, Canada, 735-749.

Garrity, S.W. 1995 "Modern brickwork highway structures". Vol. 1, Conference Proceedings 7, *Fourth International Bridge Engineering Conference*, Transportation Research Board, National Research Council, Washington D.C., 358-367.

Garrity, S.W. and Gregory, P.H. 1995. "New brick arch highway bridges". *Proceedings of the Seventh Canadian Masonry Symposium*, Hamilton, Ontario, Canada, 1010 - 1021.

Hendry, A.W. 1998. "Structural masonry". Palgrave Macmillan Press, Basingstoke, England, UK.

International Council on Monuments and Sites (ICOMOS). 1964. "*International charter for the conservation and restoration of monuments and sites (The Venice Charter)*. ICOMOS, Paris, France.