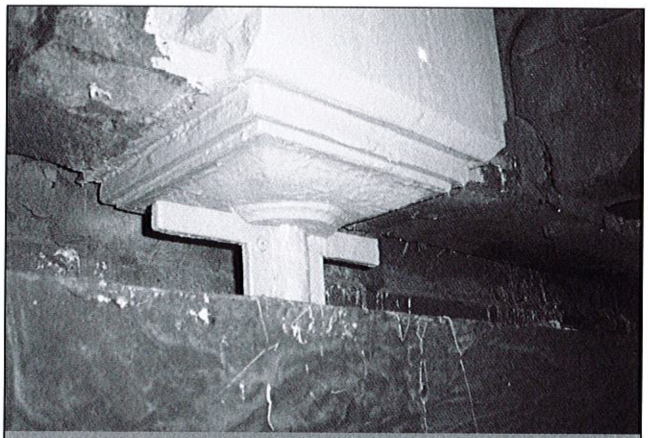


Figure 8. The original 'wedge and key' anchorage system was adopted for the replacements in sympathy with the structure

out within. The early 'safety critical' hanger replacements adopted a modern threaded bar with nut to facilitate ease of load transfer and confidence that hanger stresses had been reinstated. The design was subsequently modified to incorporate a replica of the original wedge and key anchorage system in sympathy with the rest of the structure (Figure 8). The future durability has been improved by the addition of drain holes, the application of a wax corrosion inhibitor and provision of inspection holes to allow convenient inspection and cleaning.

4.1.3. Concealed alternative load paths to 'fatigued' cast iron longitudinal girders. The cast iron longitudinal girders span between the columns and support the steel cross-girders of the road deck. Fatigue cracks were found at critical locations within the cast pockets that support the steel cross-girders. Cracks were widespread and the original cast iron girders were no longer considered reliable or capable of sustaining future loading aspirations.

The solution was to provide an alternative load path that, in the form of steel over-beams, was designed to isolate vertical load from the original cast iron elements. The new over-beams were designed and detailed such that all the original fabric was retained while concealing the new steelwork beneath the footpath. In all, 144 over-beams were fabricated, assembled and painted off site before being brought to site and connected to new steel intermediate suspension hangers and the new steel cross-girders (Figure 9).

4.1.4. Installation of vehicle impact protection. The cast iron columns of the road were assessed and found to be at risk of impact, which could have resulted in local loss of support to the rail deck and, ultimately, the potential for derailment of trains. The design incorporated impact protection to mitigate this risk. Special 'torsion beams' were necessary to support the barrier posts and distribute loads into a number of steel cross-girders and into the superstructure.

It was accepted that the introduction of the barriers was a modern intervention. The principle of reversibility was therefore adopted in this case. The barriers and torsion beams were designed such that they can be unbolted and removed.

Tensions can sometimes arise between conservation of place and fabric and the need for change, the need to carry more frequent

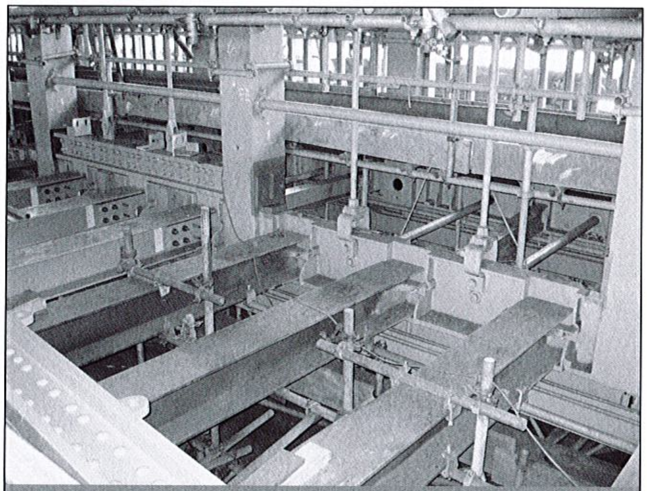


Figure 9. The original cast iron girder can be seen in the foreground with a new over-beam in the second bay

and heavier loads perhaps and the need to conform to modern safety attitudes. Applying principles of conservation has resulted in judgements being made as to the significance of parts and the whole, that is what is required to allow the bridge to cope with needs of modern traffic while keeping its historic value (Figures 10 and 11).

4.2. Restoration and electrification of the original lamp standards

The Railway Heritage Trust and the local councils provided funding for the refurbishment and electrification of the 34 cast iron lamp standards across the road deck of the bridge.

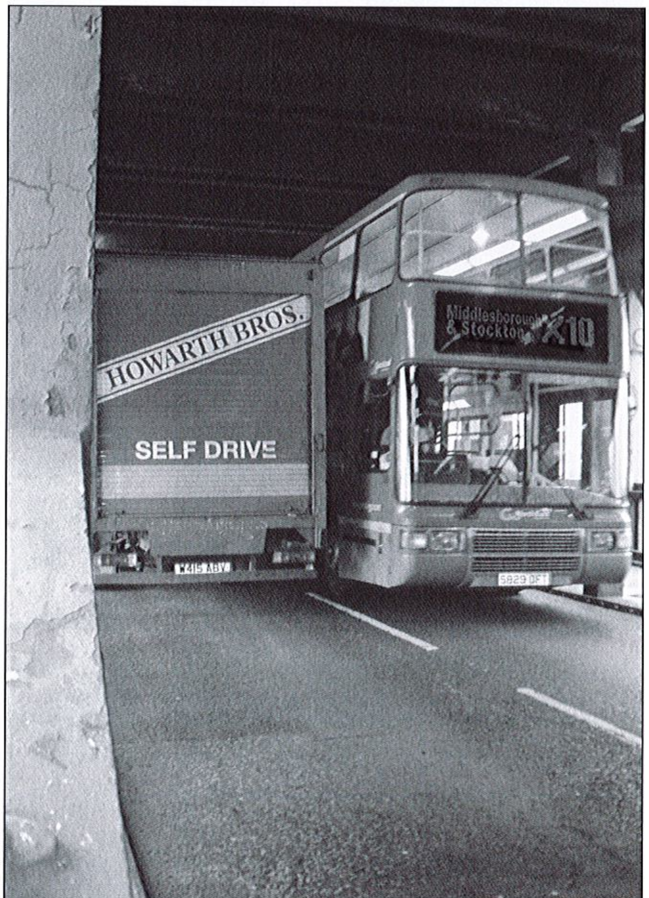


Figure 10. The substandard lane widths prior to the works meant that larger vehicles had to slow to a crawl to pass

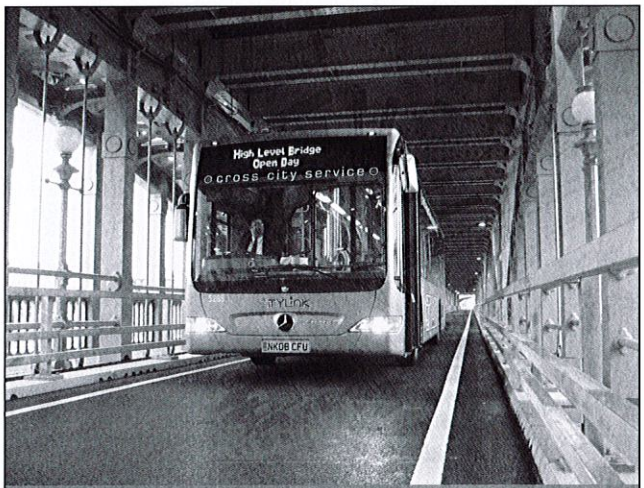


Figure 11. The road deck was reopened with impact protection and a single lane

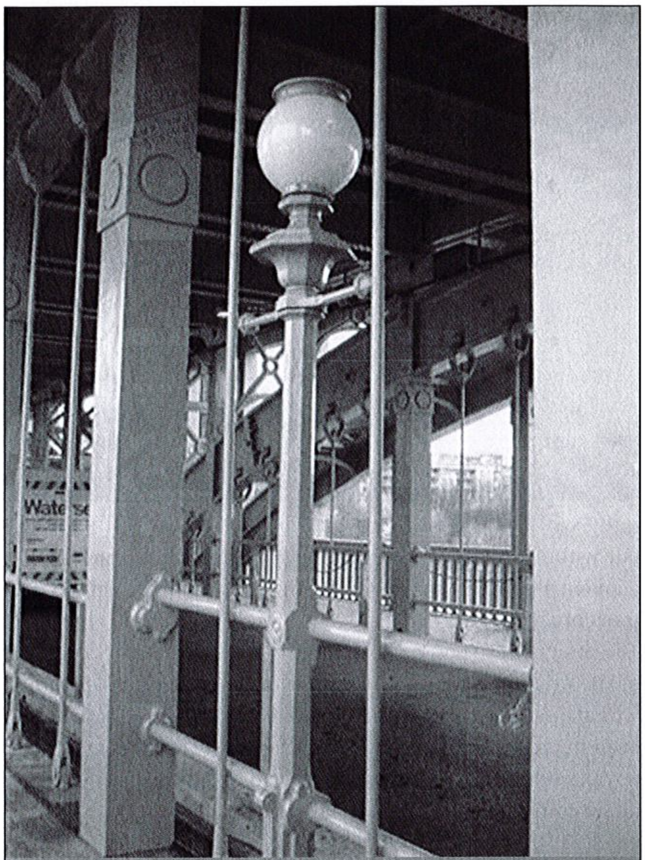


Figure 13. Restored cast iron heritage lamp standard

The lamp posts were in various states of dilapidation (Figure 12). All were removed from site, blast cleaned and inspected. Those in good condition were used as mould templates for the casting of missing components. Missing and cracked elements were connected and repaired using Metalock. Record drawings and archive photographs were referenced to allow informed restoration and detailing of the new lamp globes (Figures 13 and 14).

In order to avoid cutting holes into the lamp posts, the new electric cables were routed through existing voids within the adjacent column and hand rail tube. The new inspection hole at the base of the column was also used for this purpose.

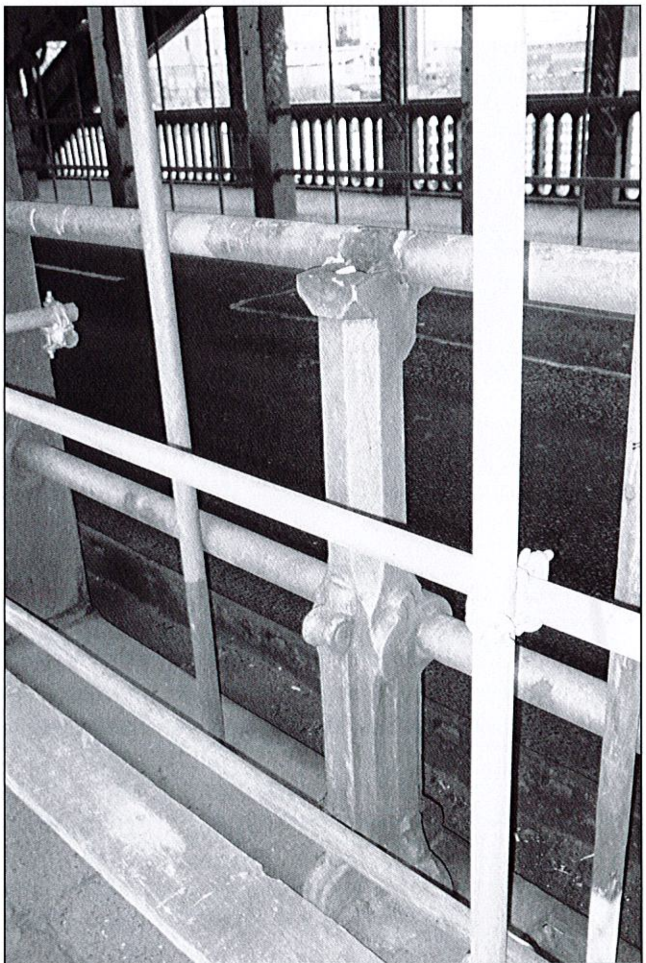


Figure 12. Lamp standards were in various states of dilapidation

4.3. Extensive metalwork repairs

4.3.1. Crack repairs. Metalock mechanical stitching was used extensively throughout the bridge to repair fractured cast iron members. This solution was favoured by conservation officers as retention of original fabric was maximised and, once painted, repairs were almost invisible. Steel plate bonding was also used extensively to bridge over cracks and provide non-intrusive and subtle strengthening solutions (Figure 15 and 17).

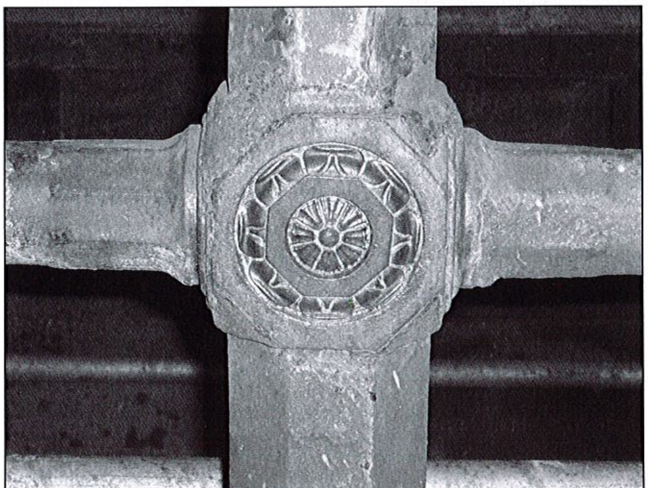
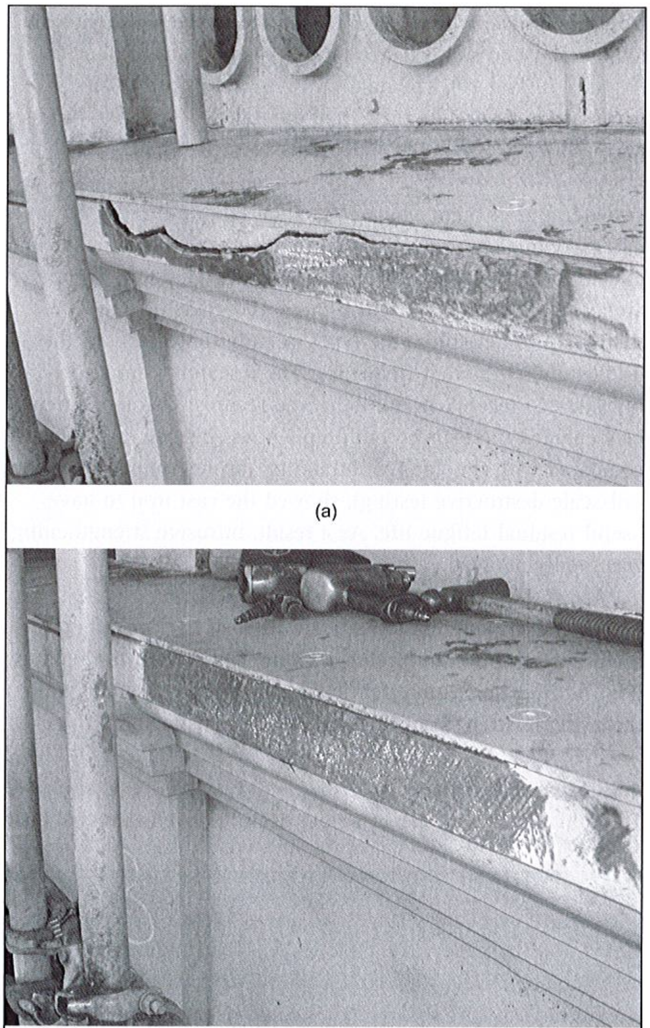


Figure 14. Workers were delighted to expose this ornate rose detail beneath 33 coats of paint



(a)

(b)

Figure 15. Cracks (a) were repaired using mechanical stitching (b)

4.3.2. Column replacement. Two cast iron columns within the last Newcastle span (at the location of a major warehouse fire in 1866) were so badly damaged they were deemed beyond repair. The decision was made completely to replace the two columns using like-for-like detailing in cast iron. The columns were slightly modified from the originals in order to facilitate their installation in a different sequence to that of the originals (Figure 16). This work was all the more challenging as it was carried out while the bridge was still open to road traffic. The lower part of the column was detailed in two parts to allow clamping around the dovetail connections at the ends of the adjacent longitudinal girders.

4.3.3. Repairs to cracked vertical bracing. The vertical bracing had also suffered cracking. Previous repairs had bridged the cracks with bolted angles, but this resulted in cracks forming at the next weakest location. Vertical bracing plays an important structural role and care had to be taken not to aggravate the situation. Analysis proved that the bracing would function satisfactorily using the 'compression only' members, so bridging across cracks to reinstate a tension load path was therefore not necessary. The solution adopted was to use subtle bonded plates that were glued to one side of the crack only (Figure 17). This ensured that the compression load path was maintained while allowing the crack to open slightly when in tension, all with minimum intrusion. Hand-crafted plates, when painted, resulted in a solution in sympathy with their environment.

Figure 16. Installation of new replacement cast iron column

4.4. Strengthening of rail deck cross girders

4.4.1. Strengthening of approach cast iron rail deck cross girders. The rail deck bifurcates at each end of the structure where cast iron cross-girders are supported on cast iron columns outside the line of the road. When strengthening became necessary in the 1890s, it was therefore a simple matter of adding an additional internal support column. When assessed, the cross-girders were found to be overstressed in

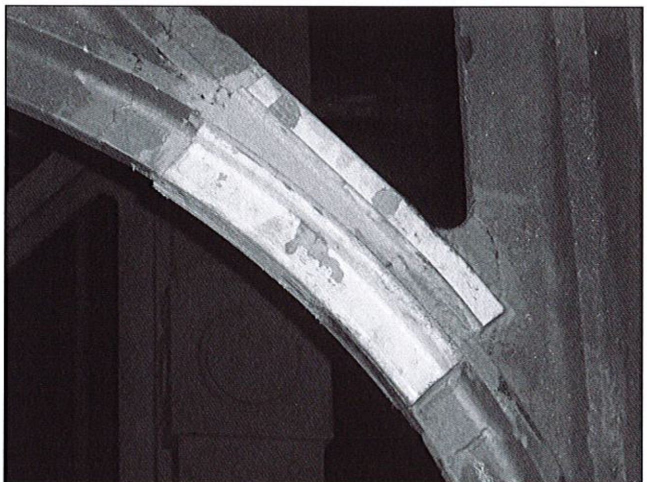


Figure 17. Hand-crafted steel fabricated plates were bonded to the cracked vertical bracing

'hogging', that is, breaking their back over the newer internal columns. The assessment assumed similar support stiffness to both the original supports and the 1890 additions, but trial pit investigations highlighted gaps beneath the simple pad stones. Rather than providing support to the cross-girders, the columns and their pad foundation were effectively being suspended by them. The assessment situation instantly went from a 'hogging' problem to a 'sagging' problem. Analysis proved that a 'half-way house' would resolve the overstress without the need for any intrusive strengthening to the girders. The solution did, however, require careful injection and pressure grouting beneath the internal pad foundations such that the desired support stiffness could be achieved (Figure 18). Pre-determined jacking loads were then applied at the column tops to redistribute the bending stresses.

4.4.2. Strengthening of main span rail deck cross-girders: cast iron testing. High Level Bridge still carries a live railway on cast iron members in tension bending—a situation that is thought to be almost unique. Following a detailed assessment of the structure, the cast iron cross-girders were found to be life-expired to the modern day assessment code.

With no less than 60 cross-girders to strengthen, work was estimated to cost several million pounds. All strengthening solutions were considered highly intrusive and consent would not have proved easy to obtain. Doing nothing would mean closure of the bridge to all but the lightest trains. With the bridge having been modified in the past to cope with 800 train movements a day,[2] partial closure would not be good conservation of this heritage asset.

An innovative solution was put forward that effectively re-wrote the rule book. Rather than determining theoretical strength using the well-established assessment code,[3] the proposal was to determine the actual fatigue damage that had occurred on the bridge and to compare it with the actual fatigue durability of the cast iron cross-girders; this would enable the residual life to be quantified. Any remaining fatigue life could then be utilised to agree future combinations of traffic (load and frequency) to best suit both Network Rail and the train operators.

The ambitious two-year programme of cast iron testing included the extraction of three full (12 m long) cast iron cross-girders from the bridge, which were transported to the University of Manchester and subjected to fatigue loading until failure (Figures 19 and 20). The data provided the information necessary to determine the actual durability of the cross-girders on the bridge.

To determine if there was any residual fatigue life left, it was necessary to go back over history to determine what damage had already occurred. The project team visited the public records archive in Kew and trawled through 160 years of railway timetables to determine the types of train that had used the bridge, and with what frequency. The research team also investigated local coal and industrial records. This monumental task enabled the team to build up a stress history that, when compared with the 'fatigue durability' (as determined from the full-scale destructive testing), showed the cast iron to have useful residual fatigue life. As a result, intrusive strengthening was totally avoided.

The three cross-girders tested were stitched back together (Figure 21) before reinforcing with bonded carbon fibre plates (Figure 22). The original fabric was therefore conserved while the working strength of the girders was reinstated.

4.5. Heritage repaint

The bridge paint had never before been removed to reveal base

Figure 19. Three 12 m long cast iron rail deck cross-girders were removed from an un-trafficked area

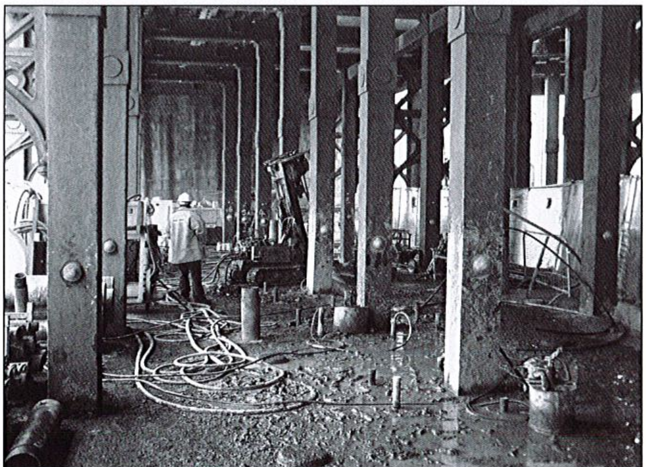


Figure 18. Pad foundations to the 1890 strengthening columns were pressure grouted

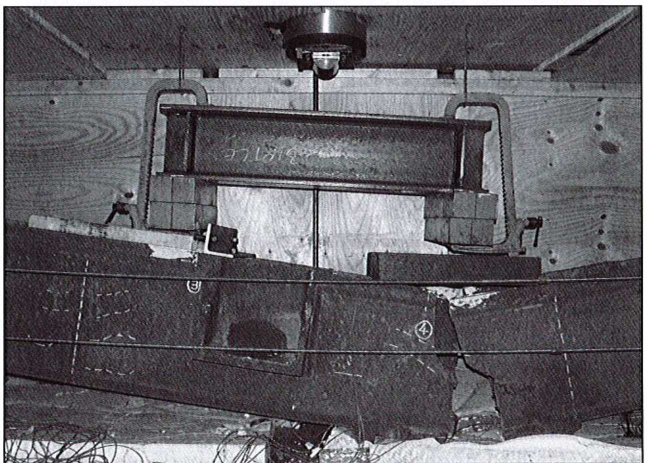


Figure 20. The cast iron cross-girders were subjected to fatigue loading

Figure 21. The fractured cross-girders were stitched back together

Figure 22. Carbon fibre plates were used to reinstate the necessary bending capacity

metal. Paint flakes were taken and analysed to clarify the type of paints used, the number of coats, the presence of lead, and the pigmentation and colour of the bridge when first opened. One of the principles of conservation[4] states that where there will be a loss, that loss should yield information about the past. This principle was adhered to in the form of a technical report on the paint coatings.

The original colour (1850) was confirmed as being off-white/cream, which would have matched the new masonry at the time; it was the desire of conservation officers to replicate this colour for the repaint. However, dirt layers exposed within the 33 layers of paint suggested that 17 redecorations had taken place and that the first repaint, to a dark colour, took place soon after opening. A darker beige/grey colour, which better matches the current colour of the weathered masonry, was thus chosen. A

Figure 23. Cast iron girders were painted and reinstated to their original locations

modern high-performance paint system was specified for the bridge which, with maintenance, should have a life of 25 years. Old buildings have a patina that goes with their age and the loss of this is regrettable; however, although a small section of original paint has been retained, the removal of paint for the inspection of possible defects outweighed this loss (Figure 23).

5. CONCLUSIONS

Regular maintenance work usually has a limited scope compared with that available in an extensive project of renewal and strengthening. High Level Bridge has undergone just such a renewal project that has enabled assessment of the root causes of apparent defects, the correction of inbuilt problems such as temperature-induced movement and applied defects such as caused by over-loading, corrosion and a serious fire in 1866.

English Heritage, as the government's advisor on the historic environment, works with local councils to manage change to the historic estate. It has published guidance[4] to build on earlier statements and experience to formalise an approach that takes account of a wide range of heritage values. Principle 1.1 of this guidance states

> Our environment contains a unique and dynamic record of human activity. It has been shaped by people responding to the surroundings they inherit, and embodies the aspirations, skills and investment of successive generations.

It continues (principle 1.3)

> Each generation should therefore shape and sustain the historic environment in ways that allow people to use, enjoy and benefit from it, without compromising the ability of future generations to do the same.

The renewal of High Level Bridge required enhancements and conservation, and all works were guided by these principles. Enhancements were required to give the bridge a working future with the demands of modern traffic and conservation principles needed to be applied due to the bridge's national importance. The owners, contractors and engineers worked in collaboration with the local authorities, Gateshead and Newcastle City Councils and English Heritage to produced designs that have satisfied these criteria.

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