Editorial

Deborah Lazarus MA (Cantab), CEng, FStructE, FICE, FRSA
Consultant, Arup, London, UK

Bridges have been used for thousands of years – in the UK, the oldest recorded bridge is thought to be Tarr Steps, a ‘clapper’ bridge on Exmoor, built just after 1000 BCE. Other bridges in the UK are generally thought to date from around 1000 CE. Stone bridges from around 1000 BCE have been identified in Greece and Turkey, with the Arkadiko Bridge – a stone arch bridge on the Peloponnese in Greece – still in use today (Wikipedia, 2019). Sometime later, the Romans left an impressive legacy of bridges and aqueducts, often quite spectacular structures, across Europe. Bridges constitute an essential part of our infrastructure, facilitating communication in its broadest sense. From ancient times they have formed an important link in military operations, with Caesar’s bridges built across the Rhine in 55 and 53 BC (during the Gallic War) being impressive examples of temporary structures. They remain a vital transport link for trade, people and services.

While they may be considered superficially as no more than part of a route to a predetermined destination, these particular elements of infrastructure in many places have a critical and strategic role in the local communities, whether within an urban environment or in a rural and possibly extremely remote setting. The organisation Bridges to Prosperity sets out a clear message as to the vital part they play, both physically and socially, in connecting isolated rural communities safely, allowing access to healthcare, education and employment at all times and not only when river levels are low enough for more hazardous forms of crossing to be attempted (Bridges to Prosperity, 2019)

Bonnet (2019) succinctly captures their importance, reminding us that these structures are also important as a part of our culture and heritage. They are an integral part of the landscape, from the reinforced-concrete Ganter Bridge along the Simplon Pass (Switzerland), the Pont du Gard (France) built almost 2000 years earlier from precision-cut stone blocks, or one of the much smaller packhorse bridges built across Great Britain and Europe (Figure 1). The number of listed bridges in the UK, of which a significant proportion has a Grade I listing, has increased in recent years. For example, the Humber Bridge was listed in 2017 and the Tyne Bridge listing was raised to Grade II* in 2018. Some of these, including several of the packhorse bridges, are several hundred years old; others, such as the Humber Bridge (1973–1981, Grade I), the Kingsgate Bridge (1963, Grade I) and the Severn Bridge and Aust Viaduct (1961–1966, Grade I) all date from the second half of the 20th century. Of particular significance is the Iron Bridge in Shropshire (Grade I), built in 1779, one of the earliest bridges in the world to be constructed from cast iron.

Given the age, use and varying construction materials of these assets, it is unsurprising that they constitute a challenge for

the authorities responsible for their upkeep and maintenance, particularly at a time when budgets are severely constrained. This makes the formulation of, and adherence to, inspection and maintenance plans, together with allocation of budgets to carry out, as a minimum, essential works to ensure the safety of these structures an absolute requirement. The tragic collapse of the Polcevera Viaduct in Genoa in August 2018, which was reported comprehensively at the time in the international and technical press, provoked extensive discussion of these issues and is a reminder that this is a universal requirement for heritage and non-heritage structures of all periods of construction.

Less than a year later, the importance of such structures and the issues associated with them has been highlighted once more by the precipitate closure in April 2019 of Hammersmith Bridge, a road bridge with Grade II* listing that crosses the River Thames in south-west London. At the time of closure, which followed the discovery of hairline fractures in the cast iron pedestals of the bridge, there was, understandably, no confirmed timescale for reopening. The closure has raised a number of serious issues about the responsibilities for infrastructure maintenance and the wider impacts of transport connections, together with how these are appropriately addressed in the context of significant heritage value. Crucially, it also emphasises the role of the engineer in inspection, monitoring and assessment of these structures.

Hammersmith Bridge is heavily trafficked, with buses, cars and other motor vehicles sharing the narrow roadway with bicycles, and the

Figure 1. The 18th century, Grade II listed Stockley Bridge in Cumbria, UK

Figure 2. Hammersmith Bridge seen from the south bank of the Thames river, London, UK

footpaths used by pedestrians and joggers. It provides an important route across the river in an area of London that has a busy traffic network. The impact of the extended bridge closure has repercussions not only for those affected in the direct vicinity but also for a much wider area. There has always been congestion at peak times on the approaches to the bridge, particularly from the south, even without roadworks or other incidents; Hammersmith is a primary entry point to central London for traffic coming from the west, including Heathrow.

London's transport networks are fragile, with high traffic volumes and vulnerability to both planned roadworks and unpredictable incidents; the disruption caused may be disproportionate to the nature of the incident. For Hammersmith and the immediate locality, the termination of the bus routes affects groups such as school communities, commuters, shoppers and those with more limited mobility.

Although further information was subsequently provided, initially the London Borough of Hammersmith and Fulham (LBHF), who own the bridge, issued a notice that simply stated 'We've had to close Hammersmith Bridge urgently to motorists because of safety concerns. Our weekly safety checks have revealed critical faults and we had no choice but to shut the bridge. We're sorry we couldn't give you more warning. We have been in close conversation with Transport for London and have begun the first phase of the work to restore the bridge to full working order and bring it back to its former splendour' (LBHF, 2019a).

The ownership and management structure are perhaps unusual here. Information on the bridge and the bridge closure was given on the LBHF website. This noted that 'While the bridge and road surface is owned and maintained day to day by Hammersmith & Fulham Council, Transport for London is responsible for managing daily bus services across the bridge' (LBHF, 2019b). It appears that Transport for London have been the project managers for the programme of bridge repairs, which has been ongoing since 2015, and have already

Figure 3. Puente Romano, Merida, Spain

committed £25 million to the repairs needed. The Transport for London website in turn stated that they are working closely with the borough council 'to confirm the final plan for this work as soon as possible' (TfL, 2019). The London Borough of Richmond-upon-Thames, whose boundary is just to the south of the bridge, has no responsibility for its maintenance and operation, but its residents are affected by its closure.

By mid-June a possible timescale for closure of 'up to three years' had been indicated, with the anticipation that a full diagnosis of 'all aspects of the bridge's state of health' would be completed by mid-August, at which time both the scale of the works and the timescale would be more precisely understood. By the beginning of September there had been progress. It appeared that the works needed had been agreed and the first stage of repairs had commenced (LBHF, 2019a). The time for the works was still estimated at around three years, with a cost of around £120 million, but unsurprisingly definitive figures for both cost and timescale could not be given. The contract for 'the next stage of the works' was likely to be awarded in the spring of 2020, but it appeared that the question of funding had still not been fully resolved (LBHF, 2019b).

From the outset there had perhaps been some lack of clarity more generally as to where decisions were taken on the timetable, budget and prioritisation for necessary works and the extent to which there was a jointly agreed plan for funding and implementation in this somewhat unusual shared interest/ownership arrangement. Specifically, how was responsibility for the works and their timing agreed between LBHF, as the owners of the structure, and Transport for London, who have the responsibility of maintaining public transport links?

Hammersmith Bridge, opened in 1887, was designed by Sir Peter Bazalgette. It is a well-known landmark in London (Figure 2), due in part to its distinctive design (it is a suspension bridge, the first to cross the Thames, approximately 250 m in length, with mild

steel chain links and ornate decoration) and also as one of the main markers in the annual university boat race. Its predecessor was designed some sixty years earlier by William Tierney Clark, who also designed the Chain Bridge in Budapest (Sandor, 2011). The listing particulars (Historic England, 1970) provide details of its special architectural and technological interest; it was constructed on the foundations of the earlier bridge and the 'monumental anchorages' also survive from that time, albeit substantially rebuilt 'in the interests of greater strength'. While a temporary bridge was erected to allow traffic to cross the river during construction, this is not an option that can be implemented during the current closure.

Questions about the behaviour and load-carrying capacity of the bridge were raised as early as 1959. A report was commissioned by the London County Council, responsible at the time for the bridge, from Rendel, Palmer and Tritton, their consulting engineers (Holloway and Wadsworth, 1977). As a result of this, the load restriction at the time of 15 t was reduced to 12 t, with the exception of buses. It was also recognised that future traffic use was likely to increase and peak-hour traffic conditions were studied (Holloway and Wadsworth, 1977). More detailed information on both its design and construction is given in a description of the extensive strengthening of the bridge and repairs carried out in the mid-1970s (Holloway and Wadsworth, 1977). Further repairs and restoration were needed after a terrorist bomb attack in 2000 (not the first experienced by the bridge). A weight limit was imposed on the bridge after it reopened. Only single-decker buses were able to use the bridge and a control system was intended to ensure that only one bus was on the bridge at any one time, although this was not always effectively operated. Certainly, it does not appear to have been enforced with the same degree of rigour as that implemented on the Grade I listed Clifton Suspension Bridge (Clifton Bridge, 2019).

Bridges need to be adequately maintained and significant works may be required at various times in the life of these assets to ensure continuing safe use. Hammersmith Bridge itself has seen numerous lane closures, weight restrictions and even short-term full closures to allow necessary works to be carried out. However, unless there are urgent repairs due to unforeseen events such as flooding or traffic impact (or even terrorist activity), the expectation is that these will be planned in advance with due warning to those likely to be affected and provision made for alternative routes and transport assistance as required. Wark Bridge in Northumberland, for example, which was opened in 1878, was repaired in phases and with community involvement (Sharma, 2015). Such options may not always be available, but the community is entitled to expect some advance planning of major work that is foreseeable. The ongoing deterioration of the surface of Hammersmith Bridge, evidenced by unevenness and resulting vibration, had been apparent to users of the bridge, whether lay or qualified engineers, for some time, with irregularities making it hazardous for cyclists and causing levels of vibration that are likely to have ultimately contributed to the failure of certain elements of the structure. It is possible that the rate of deterioration was faster than anticipated since the last resurfacing, but it is not clear why this had not been dealt with earlier, given the ongoing programme of work.

This is a listed structure, which may impose some constraints on the works that can be undertaken, although the potential difficulties of meeting the absolute requirements to ensure its safe use simultaneously with protecting its heritage significance are acknowledged. Its historical importance of course raises further questions as to how the bridge has been allowed to deteriorate to the state that is now apparent. The bridge has to be maintained and operated to ensure all health and safety requirements are met, but safeguarding the structure as a heritage asset should also be seen as a significant responsibility for the owner.

The loss of an established crossing even in urban areas has an impact that extends beyond inconvenience to those who regularly use it. Local traffic becomes more congested, traffic levels with attendant noise and fumes increase on roads in the surrounding areas, travel times increase and public transport is disrupted. For more vulnerable people, their routine is disrupted and alternative means of transport may be needed, possibly requiring longer journey times. For all these reasons and more, there is a strong imperative to keep bridges operating safely and to the greatest extent possible, continuously, accepting that lane closures, single-way traffic and even short-term closures may be needed to achieve this.

Not all bridges will sensibly remain operational, at least in respect of their original use. Repurposing redundant structures to give them a sustainable future can be an interesting challenge for engineers. The popular High Line in New York (NY, USA), which is effectively 'an elevated linear park' has been constructed along a disused railroad spur. Specifically reusing a bridge, the Walkway over the Hudson at Poughkeepsie (NY, USA), also described as a 'linear park', uses the former 19th century railroad bridge across the Hudson River and for some time was the longest pedestrian bridge in the world (WotH, 2019). There are examples in other parts of the USA of truss bridges, now deemed unfit for vehicular use, being reallocated for public use, such as walkways and cycle paths. In the Lake District (UK), the former railway bridge in Keswick now forms part of an elevated walkway following closure of the railway line, and the Iron Bridge is now only open to pedestrians following a major conservation project by English Heritage.

A spectacular example of a Roman bridge, constructed between 97 and 117 BCE in Extremadura, Spain (Figure 3), is also no longer used for vehicular traffic but is maintained as a pedestrian bridge. Its replacement is located nearby, with traffic rerouted accordingly.

The impacts of climate change and extreme weather events on infrastructure can also be responsible for additional costs for the authorities who own and maintain them. Flooding in the Lake District in the past few years has led to the closure of roads and road bridges in addition to significant numbers of pedestrian bridges. Inconvenience and disruption to varying degrees is inevitable for all users. In February 2016, it was reported that in the national park there were '46 footbridges which are not useable... and are in need of either replacement or significant repairs...' (Lake District National Park, 2019) following earlier

severe flooding. In other parts of the park, roads, including major trunk roads, and road bridges were closed for some considerable time, necessitating lengthy diversions for traffic. Torrential rain in July this year caused the Grinton Moor road bridge in Yorkshire to collapse, and a further collapse of a pedestrian bridge was reported in Turkey the following month. It may be anticipated that such events will become more frequent, bringing continuing challenges for engineers in securing a future for our heritage infrastructure.

This journal provides a broad spectrum of some of these challenges, looking at both case studies and research work, with the current issue illustrating this well. The briefing paper by Walker (2019) describes the construction, with a variety of challenges, not least in relation to the topography, of a 'narrow-gauge tourist railway' and associated facilities to access a recently restored Jacobean mansion and estate in Barbados. This project shows great vision. It incorporates elements such as the use of recycled plastic sleepers and it is encouraging to also see that the locomotives, one of which is a restored 1916 steam engine, have all been repurposed.

In an absorbing account of early seismic research in New Zealand, McCarthy (2019) provides a reminder of the importance of 20th century heritage. The earliest research project, with the installation of instrumentation including strain gauges and accelerometers, in the Gordon Wilson Memorial Flats in Wellington, began around 60 years ago. The building, dating from the late 1950s, is a ten-storey, post-modernist shear-wall structure on piled foundations, located in a seismically active area. It is noted as the last high-rise state housing block to be built in the country and has significance in relation to both its architecture and the research programme. The programme is described further in relation to international seismic research and the current plan to install accelerometers in 400 buildings in Wellington.

Continuing the theme of seismic behaviour, here in relation to historic timber structures, Xie *et al.* (2019) look at the enhancement with modern materials of a traditional connection system used in historic timber buildings within the seismic belts in East Asia. This system, the Dou-Gong, has been studied in some depth in recent years and while it is known that such connections play an important role in providing seismic resistance, its limitations have also been identified. It incorporates a conventional wooden peg, which has been found at worst to pull out of its hole, or in other cases to undergo permanent deformation. Research has been carried out using metal bars as a replacement for the wooden pegs; these are fabricated from high-strength steel and from a super-elastic alloy. A test programme is described using bars of both materials, with encouraging results and the added benefit of reversibility where this technique is employed. The application of modern materials and test methods to look at ways to protect these historic structures here adds to our understanding of traditional

construction and how this can be enhanced while preserving the original principles employed.

As ever, we continue to look for new members of the Editorial Panel to reflect the extensive range of subjects covered, and we also encourage the submission of new papers from practising engineers and academics across the wide field of engineering history and heritage internationally.

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