THE ARCH BRIDGES OF DURHAM CITY, ENGLAND

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SUMMARY

The ancient city of Durham in northern England is a world heritage site, part of its character being due to the stone arch bridges which give access to the Cathedral and Castle over the River Wear, and the railway viaduct which dominates the north end of the town. The river bridges were built at different times by the church, but are now maintained by the local authority or their agents. The coming of the railways resulted in the construction in the 19th Century of Durham Railway Viaduct, built over the main highway route out of the city to Newcastle. The paper will discuss the reason for bridges, their construction, who was responsible for them, and how they are maintained currently.

Keywords: *Durham, Norman, railways, river.*

1. INTRODUCTION

The ancient city of Durham in northern England has a recorded history going back to the latter half of the 11th Century, although there is evidence of occupation prior to that in the form of Roman remains and other architectural remnants. The most prominent buildings, the castle and the cathedral, were begun by the Normans in 1072 and 1089 respectively.Prior to the coming of the Normans after 1066 Durham City had been a seat of religion, being the last resting place of Saint Cuthbert and the Venerable Bede, but it is the Normans who were responsible for establishing the castle and the cathedral which can be visited today. The River Wear surrounds these two buildings, and the old town around them, in an incised meander running between steep banks, as a result of which a number of bridges were required for access from the south, east, and west. Access to the town from the north was, for many decades, the only land link from the north, protected by a town wall with gated access (Fig. 1).

Durham City is now a designated World Heritage site. The earliest bridges, Framwellgate and Elvet, were originally built by the Normans, in 1120 and 1170 respectively, while Prebend's Bridge, with its Palladian parapets, was built much later, in 1772-1778 as the town developed around the cathedral and castle, at a location where once there had been a ferry for pilgrims, and where earlier footbridges, a wooden one built in 1574, and a stone bridge built in 1612, had been swept away in successive floods.

Water mills, for producing flour, or fuller's earth (essential to the tanning of leather), or even mustard, were part of life in mediaeval times, and required weirs to be built in the river to provide the necessary head of water, which had an influence on the water level from which the bridges sprang.

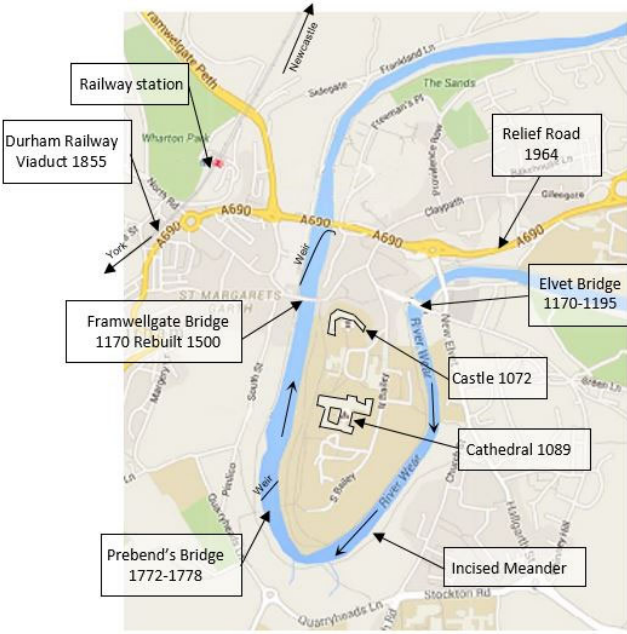

Fig. 1. Durham within its incised meander [1].

It is easy to look at the bridges now and believe that they are now as they were when first built, but the Wear is a volatile river, prone to flooding, and from time to time over the centuries both Framwellgate and Elvet Bridges have been damaged or even had spans swept away, while Prebend's Bridge is located just downstream of the site of previous footbridges which had been swept away. At the same time, as the city developed from being wholly dependent on the Church to a more outward-looking trading community, the bridges changed from being defensible restrictions to entry into the city into more free-flowing accesses to stimulate trade and allow the free flow of people into and out of the city. Eventually, in the 19th Century, the two mediaeval bridges, Framwellgate and Elvet, were doubled in width to accommodate the increasing traffic as the city expanded commercially. An internal relief road was built within the city in the 1960s, with two modern concrete bridges at river crossing points, so traffic over Framwellgate and Elvet Bridges is now restricted to limited commercial traffic at certain parts of the day, freeing the city centre for pedestrian circulation and limited services to the cathedral and castle, plus the colleges which form the university. There are other foot crossings of the river built in more recent times, being two concrete bridges, Baths Bridge and Kingsgate Bridge, designed by Ove Arup, neither of these being arch bridges, and a cable-stayed bridge of more recent design to the north of the relief road, called the Penny Ferry Bridge, in honour of a ferry which once operated nearby.

No masonry arch bridges which remain today were constructed after Prebend's Bridge in the 1770s, until the coming of the railways resulted in the construction in the 19th Century of a major multi-arch viaduct in brick and stone. This is the Durham Viaduct, built in 1855 over the main highway route out of the city to Newcastle, and now crossed by countless trains between London and Edinburgh, as part of a contract to construct three viaducts on the railway line between Newcastle and Darlington, these being Brasside, Durham, and Newton Cap Viaducts, the latter being built near Bishop Auckland.

Durham City was not at that time on the main line from London the Edinburgh as it is today, and the rail route was from Gateshead, a main sea port on the River Tyne, to Bishop Auckland, deep in Durham County to the south (Fig. 2).

Durham Railway Viaduct was completed as part of the Newcastle to Darlington Junction Railway, as it was then called, and was opened to passenger traffic in 1857 when the new Durham Station was opened and a more direct route north of Durham to Newcastle was under construction.

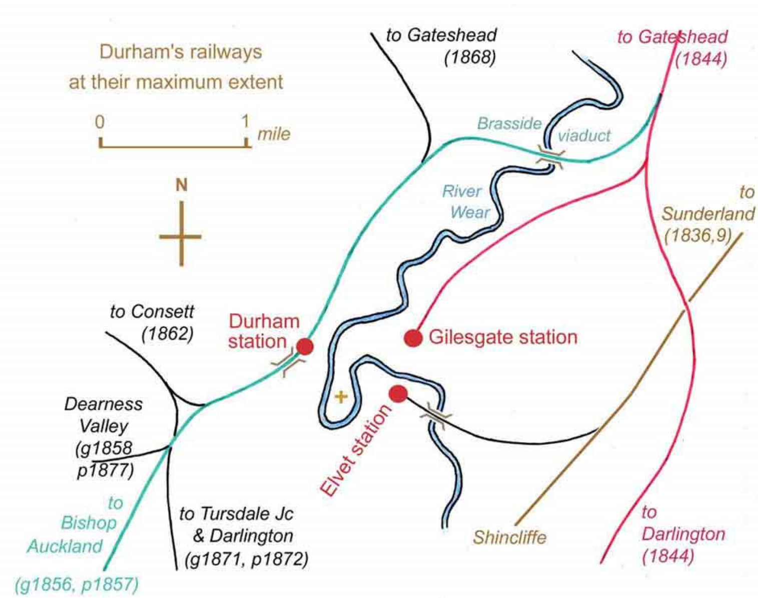

Fig. 2. Historical Railways of Durham City [2].

2. INDIVIDUAL BRIDGES

Each bridge will now be discussed individually.

2.1. Framwellgate Bridge

Framwellgate Bridge is a two-span stone arch, which today carries pedestrian traffic and limited service vehicles, but it is not the original structure. It is Grade 1 listed, which means that it cannot be changed without wholly acceptable justification. Grade 1 listing represents the highest level of protection by Historic England, under the National Planning Policy Framework (NPPF) [3].

The original Framwellgate Bridge, built in 1127, was once known as the Old Bridge, to distinguish it from Elvet Bridge, which was built between 1170 and 1195. It was built with six spans, and carried shops and other premises. It is located close to the castle from where it could be defended from attack as necessary. It originally incorporated a gate to control entry to and exit from the city, which was only removed in 1760 when it was decided it was no longer necessary.

The construction of the original bridge is normally ascribed to Bishop Flambard, who was also responsible for part of Durham Cathedral. However, it was washed away in a flood of 1400, and replaced by the present bridge under the direction of Bishop Langley later in the 15th Century. This has two river spans of 90ft (27 m) each, with a low rise; this is a much bolder span than those of Elvet Bridge, which has a number of smaller spans with a greater rise, indicating the improved understanding of design and construction techniques which occurred between the 12th and the 15th Centuries (Fig. 3).

Fig. 3. *Framwellgate Bridge – 15th Century Reconstruction.*

A concrete weir can be seen when looking downstream from the bridge; this is at the site of an earlier weir which raised the water level to power the Bishop's Mill, and would have set the level of the river from which the pier and arch springing levels would have been set out (Fig. 4). Some of the original stones can still be seen within the concrete weir. It is recorded that the previous weir fell out of use due to the action of the river in 1543, which suggests that it would have been in use in the previous century when the replacement bridge was constructed, hence the bridge being constructed at the present level.

Fig. 4. *Weir fixing the springing level of the bridge.*

The width of the bridge was increased in 1859; seven arch ribs are visible from beneath, five of them being original, two being added in 1859. The whole bridge is tied together using tie rods and cast iron plates which can be seen on the spandrels (Fig. 5).

Fig. 5. *Ribbed arches and through-ties of Framwellgate Bridge.*

The most recent change to the bridge occurred when the major traffic through the city was transferred on to the new Inner Relief Road, in the 1960s. In this case the walking surface was changed from the previous flexible surfacing with paved footways, to stone setts with larger flagstones set at a track width to suit service vehicles.

This has the effect of visually tying in the bridge with the rest of the city centre, which is largely pedestrianised, while reducing the impact from modern traffic, with a view to preserving the life of the bridge.

2.2. Elvet Bridge

Elvet Bridge was built between 1170 and 1195, and is Grade 1 listed. It consists of three river spans, early English in form, plus two flood spans (Fig. 6). One of these spans includes a riverside walk. There is a further span at the higher end, closed by a metal barred gate. This is believed to have once provided access to overflow prison cells within the arch of the bridge which took prisoners that the nearby House of Correction could not accommodate. It was originally constructed under the direction of Bishop Hugh Le Puiset, who had also been responsible for the construction of the Galilee Chapel within the Cathedral, and had buildings on it. However, the two central spans were replaced in the 13th Century after damage by floods. The bridge is on a comparatively steep gradient, and once had a chapel at each end. It also included a guard post to control entry and exit to the city, but this was removed in 1760.

Fig. 6. *Elvet Bridge – early English arch form.*

Fig. 7. *Widened Elvet Bridge – photograph shows additional ribs.*

It was doubled in width in the 19th Century as the city developed commercially. This can be seen in the different forms of construction of the arch barrel. The original arches barrels are in one plane between the north elevation and the centreline, but the bridge from the centreline to the south elevation is of much more modern ribbed construction (Fig. 7).

As with Framwellgate Bridge, the most recent change to the bridge occurred when the major traffic through the city was transferred on to the new Inner Relief Road, in the 1960s, and the walking surface was changed from the previous flexible surfacing with paved footways to stone setts with larger flagstones set at a track width to suit service vehicles, tying in the bridge with the rest of the city centre, which is largely pedestrianised, while reducing the impact from modern traffic, with a view to preserving the life of the bridge (Fig. 8).

Fig. 8. *The pedestrianised Elvet Bridge.*

2.3. Prebend’s Bridge

Prebend’s Bridge was built between 1772 and 1778, to the design of Richard Nicholson, and is Grade 2 listed, which is less stringent than Grade 1 . It leads from west of the city into the South Bailey, which is a reference to the motte and bailey plan of Durham Castle. The river crossing was served by a ferry until 1574, when a wooden footbridge was constructed just upstream of the present location of Prebend’s Bridge. This bridge was swept away by the river, and replaced by a stone bridge in 1612, and a temporary bridge was put in place until the present bridge was completed [4].

It is a three-span bridge with circular arches and Palladian parapets in stone, which was very fashionable in that era, and was built on the instruction of the Dean of Durham, Thomas Dampier. The design was by George Nicholson, who was architect to the Dean and Chapter, with advice from Robert Mylne, who was a leading bridge designer of the time. It is reputed to have been located both to provide the famous view of Durham Cathedral, seen on a thousand postcards, and to complement the view of the cathedral from Framwellgate Bridge. It is still owned by Durham Cathedral, who are responsible for its upkeep.

Fig. 9. *Prebend's Bridge from the south.*

It has three spans of 20.4m each, semi-circular in form, with cutwaters on the leading and trailing sides of the river piers. These extend upwards to form refuges or viewing points. The parapets on the two side spans are Palladian balustrades in stone (Fig. 9).

The overall height is 12.2m above water level. The river level at the point of the bridge crossing is fixed by a weir just downstream of the bridge; this can be dated to the construction of a fulling mill which is recorded as operating in the 17^{th} and 18^{th} Centuries, for which power was provided by the river.

The bridge once provided vehicular access to the South Bailey, but in July 2011, after an inspection revealed erosion of the stonework, the bridge was closed to any vehicular traffic, including emergency and service vehicles, which now have to go through the town centre.

The roadway of the bridge is at a higher level than the Elvet and Framwellgate Bridges, to suit the level of the approaches from both the southern river bank and the South Bailey sides, and the fact that it could be built with longer spans in comparison with the two older bridges indicates the improvement in construction techniques which had occurred in the intervening years.

It has now stood at the present site for over 230 years without major flood damage, indicating the benefit of building it at a higher level, which avoids the problem of floating debris being trapped within the arches and forming a dam, as this has been the major cause of destruction by flood, and still is at other locations.

However, it has been the subject of major maintenance due to damage by vandals in 1797 or 1798 who pushed off part of the parapet, and by water penetrating from the top. In 1863 a recommendation to waterproof and drain the bridge was made; this was carried out in 1899 when the fill was stripped out and asphalt laid over the arch barrels and up the inside of the spandrels. A parapet collapsed in 1951, as a result of which a contract was carried out in 1955-56 to rebuild the parapets, replacing stone as necessary, to re-waterproof the arch barrels, and to improve both drainage of the arches and install cut-off drains to reduce entry of surface water to the bridge. Further works to the parapets are being carried out in 2015-16, prior to more extensive repairs to eroded stonework.

2.4. Durham Railway Viaduct

This viaduct, built in 1855-1857 (Fig.10), was part of the route then known as the Newcastle and Darlington Junction Railway, from Bishop Auckland to Newcastle over Brasside Viaduct, but remains as part of the east Coast Main Line to this day.

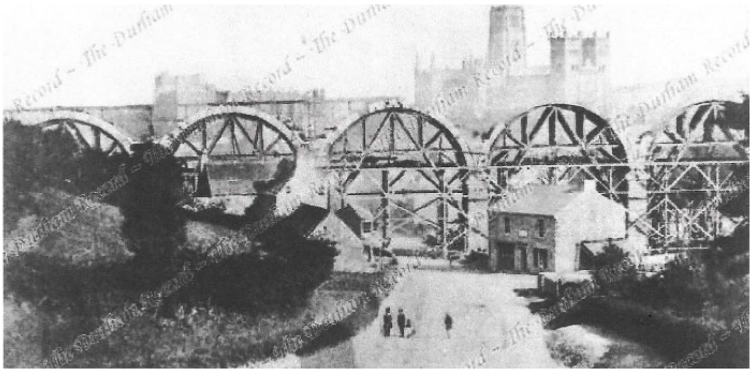

Fig. 10. *Durham Railway Viaduct under construction in 1855 [5].*

Durham became an important stopping place with the opening of a new station in 1857, this being located directly at the north end of the viaduct, and coinciding with the railway from York to Newcastle taking a more direct route to the west of the original route.

Fig. 11. *Durham Viaduct in 2016.*

The viaduct is built on stone piers, with stone voussoirs and spandrels, and brick arch barrels. There are 11 spans of circular arch form, the viaduct being approximately 500m long (Fig. 11). The designer was Thomas Elliot Harrison, and it was built by the Tyneside contractor Richard Cail as part of a contract which included Brasside Viaduct just north of Durham, and Newton Cap Viaduct on the same line to the south near Bishop Auckland. It is built on both a radius and an up-gradient to the south, and is founded on boggy land. The engineers at the time were praised for their success in constructing the bridge on such poor ground; it is reputed to be built on a mixture of 'withy mats and sheep's wool', and it was predicted that the bridge would not last long, but it is still there, 159 years later, taking modern railway loading, firstly following the adoption of diesel traction in the 1960's, then following the electrification of the line in the late 1980's. However, the appearance of the overhead line electrification supports which can now be seen was subject to aesthetic scrutiny and had to be submitted to the Royal Fine Art Commission for approval before they could be put up, which is a measure of the importance of the appearance of the bridge in a city such as Durham (Fig. 12).

Fig. 12. *Fixing of the Overhead Line Equipment to the Viaduct.*

3. INSPECTION AND MAINTENANCE OF BRIDGES

3.1. Introduction

The bridges fall into different ownership and different obstacles crossed, so are dealt with differently. Elvet and Framwellgate Bridges are highway structures which belong to the local authority, Durham County Council, and cross the River Wear. Prebends Bridge also crosses the Wear, but is owned by the Dean and Chapter of Durham Cathedral. Durham Railway Viaduct crosses the North Road out of Durham, plus a number of other highway routes out of the city, and commercial and other premises. It is owned by Network Rail.

3.2. Inspection

3.2.1. Elvet and Framwellgate Bridges

As highway bridges, Elvet and Framwellgate Bridges are inspected in accordance with the British Department of Transport Document BD63 [6].

The inspection regime consists of a General Inspection every two years, and a Principal Inspection every 6 years, with Special Inspections as necessary.

A General Inspection is purely visual, involving binoculars or telephotography as necessary.

A Principal Inspection is more searching, and involves access to within touching distance of the structure, or approaching to within a distance of 1 metre.

It has been found that the most suitable form of access for inspection is by the use of an underbridge unit, because it is not influenced by the state of the river as it would be if a boat were used.

Being stone-built bridges it is necessary for the inspector or inspectors to be familiar with the way that stone deteriorates, to enable an opinion to be formed on the best method of repair, should any be needed.

A diving survey is also carried out to inspect for any damage to the foundations.

3.2.2. Prebend’s Bridge

Prebend’s Bridge is not a highway bridge, but for conformity uses the same inspection regime as the other two river bridges, since this is the best guidance available.

However, it is different in that the “air draft” is much greater, so using a boat as access for inspection of anything other than the piers is not practical, and the use of one of roped access, suspended scaffolding or an underbridge unit is necessary. Given that the weight of an underbridge unit may exceed the assessed capacity of the bridge, either roped access or suspended scaffolding is most appropriate.

3.2.3. Durham Railway Viaduct

Durham Viaduct is an underline bridge on a major rail route, and is subject to inspection rules detailed in a document issued by its owner, Network Rail, entitled “Handbook for the examination of Structures”, published in January 2014. Two sections of this document are of particular interest to Durham Viaduct, Part 1C: Determining the Examination Regime [7], and Part 2A: Bridges [8].

There are two levels of inspection, a Visual Examination and a Detailed Examination. An Examination Regime has to be established by the Route Asset Manager in which it is determined how frequently these are to be carried out, but will always include an annual Visual Inspection unless it falls at the same time as a Detailed Inspection. The frequency of the Detailed Examinations is determined by what is found at the Visual Examinations, but there is a maximum interval between Detailed Examinations allowed.

This interval is determined by the risk category into which a bridge falls, Higher, Medium or Lower.

The risk category of the bridge is decided by

- its condition, decided by a Detailed Examination, and expressed in a BCMI score (Bridge Condition Marking Index)
- its Capability, decided by an assessment being carried out, and
- the highest EMGTPA (Equivalent Million Gross Tonnes Per Annum) of the line carried by the bridge.

The assessment will indicate the Capability of the bridge, whether it has spare capacity, or can be defined as being “marginal” or if there is any evidence of “discrepancy” in the assessment, in other words there is a doubt as to its accuracy.

However, a provisional interval between Detailed Examinations can be determined from two tables in the document, one based on the materials from which it is made, the other referring to whether a masonry bridge is on a radius or not,

If the viaduct is put into the Higher Risk category because of its condition, capability and EMGTPA, this process leads to intervals of 6 years because it is built in brick and stone, reduced to 3 years because it has over 4 spans, and is built on a radius.

The examinations themselves are self-explanatory; a Visual Examination is just that, binoculars and telephoto lenses or other long-range optical devices being necessary because of the height of the bridge. The use of drones carrying cameras is obviously being discussed, but their use will be limited by regulations preventing their use within prescribed distances of dwelling houses or other occupied premises, noting that there are houses alongside and under Durham Viaduct, and particularly within the proximity of 25kV overhead line equipment (OHLE).

A Detailed examination involves approaching the fabric of the bridge to within touching distance or within 1 metre, therefore involves a choice having to be made between the use of Mobile Work Platforms, roped access from above, or the use of a rail-mounted underbridge unit. Anything which involves access from track level requires either specific track closure and isolation of the OHLE for the examination, or fitting in the examination with the programme of closure and isolation for other reasons, such as track maintenance, which may influence the frequency of the Detailed Examination if the two events, examination and maintenance, do not coincide.

The examination will look for typical failure of arch bridges; detachment or bulging of the spandrels, loose bricks in the arch barrel, spalling of stone due to weathering, and any other defect prejudicial to the life and safety of the viaduct. It is clear that increasing rail loading over the decades has led to potential bulging of the spandrels, because patress plates, which are the terminations of through-ties, are visible in various strategic places on the face of the spandrels.

3.3. Maintenance

Repairs to the bridges are stonemason’s work, and are carried out with varying degrees of difficulty.

All of the bridges suffer from the same type of deterioration due to weathering of the stone or brickwork, but the treatment of the masonry depends on the location of the repair. Repairs to the parapets on Elvet, Framwellgate and Prebend’s Bridge, which cross the river, can be can be carried out from a suspended scaffolding which can be held down by the use of counterweights; repairs to the spandrels can be carried out similarly as long as the scaffolding does not extend down to the river flood level. The lowest level of the scaffolding must be agreed with the river authority.

Repairs to the piers in the river, or to the arch ring or barrel, have to be approached differently. Repairs to stone and brickwork are a slow process, involving cutting out of the damaged material and letting in new pre-cut stone or brick which, if they are to be held in place using traditional mortar, will require the need for some means of holding them until the mortar has gained strength, which is when difficulties arise because of any intrusion of the access or support structures below maximum flood level.

Carrying out repairs to masonry is only done when absolutely necessary because of the difficulties of working over the river.

Repairs to Durham Railway Viaduct can be approached differently because any access scaffolding can be supported from the ground below, bearing in mind that it is built over houses and the highway. Repairs to the outside of the parapet can also be carried out from scaffolding supported at ground level, so as not to interfere with operation of the railway.

4. CONCLUSION

The masonry arch bridges of Durham City are integral to its history and appearance. The river bridges are made from the same stone as the castle and the cathedral, and the two oldest ones, Framwellgate and Elvet, were first constructed by the bishops who were responsible for parts of the Cathedral, and reflected the construction techniques available to the builders at that time. Because of the damage to the bridges caused by flooding of the River Wear, and because of the development of the city, the original bridges have changed in detail and width, but they remain essentially mediaeval bridges.

The later river bridge, Prebend's, reflects the era in which it was built, the 1770s, and the changing in attitude to bridges from mere functional accesses to an attractive part of the landscape which, in the case of Prebend's Bridge, provided the best viewpoint from which to admire Durham Cathedral, and formed a pleasing scene when viewed from upriver from Framwellgate Bridge.

It was also built to connect the river banks at a higher level than the other two, reflecting improved construction techniques and the realisation that building the bridge high above flood level improved its chance of survival.

Durham Railway Viaduct is of proportions that are a response to the topography of Durham City, and the materials that it is built in reflect the landscape and appearance of the area, so the piers and arch rings are of stone, while the arch barrels are built in brickwork because it is easier to work with bricks, and because they were readily available as a result of the boom in housing construction, and of the spread of brickworks to provide the building materials for these houses which had resulted.

Durham Viaduct dominates the north end of the town in a way which planning laws would now doubtless not allow, but it is an essential part of the character of the city when viewed from street level, and provides a pleasing part of the landscape when viewed from a higher level.

A number of bridges have been built over the river since Prebend's Bridge was completed in 1778, but this was in the 20^{th} Century, and have been variations on the beam bridge, built in concrete or steel.

The present Baths Bridge was designed in concrete by Ove Arup in the early 1960s, and replaced a former steel lattice bridge.

The famous Kingsgate Bridge was also designed by Ove Arup, reputedly the last bridge he designed himself, and is a high level bridge, cast in situ in two halves on conventional formwork, and then rotated through 90 degrees to meet in the middle. This was completed in about 1963.

Two concrete bridges were built in the late 1960s as part of the Inner Relief Road; these are 3-span balanced cantilever with a drop-in span.

The most recent bridge is a steel cable-stayed footbridge, completed in the 1990s, linking new hotels and other commercial establishments built west of the river with the commercial centre of the city.

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