A tale of two bridges: the Iron Bridge and Coalport Bridge, Shropshire

Andrea Parsons and Shelley White

ABSTRACT: *The Iron Bridge (SAM Salop 106), built in 1779, and Coalport Bridge (SAM Salop 341) built in timber in 1780, rebuilt in 1800 and again, in iron, in 1818, span the River Severn in the World Heritage Site of the Ironbridge Gorge. They were surveyed from 1999 to 2001 and 2001 to 2004 respectively. The Iron Bridge proved to be a palimpsest of minor and major repairs. The Coalport Bridge survey highlighted the apparent lack of alterations to the ironwork of 1818, whilst supporting the documentary evidence for the three major phases of construction in the bridge's history. Despite this, both structures retained some similar major component parts albeit comprising individual methods of construction. Evidence from both bridge surveys pointed to advances in the understanding of bridge construction from the eighteenth to the nineteenth century.*

Introduction

This project included the most comprehensive survey yet undertaken of the Iron Bridge, although much was known from work by Hume (1980). Hume had detailed specific joint formations and components by means of drawings and photographs, emphasising the series of numbered radials found on frames A and E. Much of the history of the bridge appears in the two editions of Cossons and Trinder's book on the bridge (Cossons and Trinder 1979 and Trinder and Cossons 2002), and is not discussed here. Due to this accumulated knowledge of the structure, the Iron Bridge has long been accepted as an iconic symbol of Britain's industrial endeavour, constructed in 1779 'at Coalbrook Dale' under the direction of Abraham Darby III (Trinder 1979, 114–115). The bridge was unique in appearance, creating much interest among foreign industrialist travellers to the area.

Modern metallurgical interest in the bridge's parts has led to some analysis of components, undertaken from 1947 to 2003. However, the results of only one test related to original ironwork, as the others were of later components.

The new project expanded from a programme of repainting the bridge organized by English Heritage in 1999, the scaffold for which gave access to all areas of the structure. This new work has added to our understanding of the bridge, of the typology of its radials, of component manufacture, erection sequence, and previously unrecorded joint details (IGMTAU 2002A).

The survey undertaken by Ironbridge Archaeology aimed to produce a three-dimensional computer-based model of the bridge which was to aid future research and analysis of the structure, and to support the record of the historical research and surveys (De Haan 2004). The three-dimensional CAD model was completed, and further analysis, such as input of stress-related programming, was planned by English Heritage.

A similar survey project was begun on the Coalport Bridge in 2001, accompanying engineering work to the structure. This bridge, built in timber in 1780 and rebuilt in timber and iron in 1800 after a flood (Blackwall 1985, 21), was replaced in iron in 1818. Few bridges from this period of building in iron survive, although many design contracts were undertaken (Trinder 1979, 118–119); the majority were based

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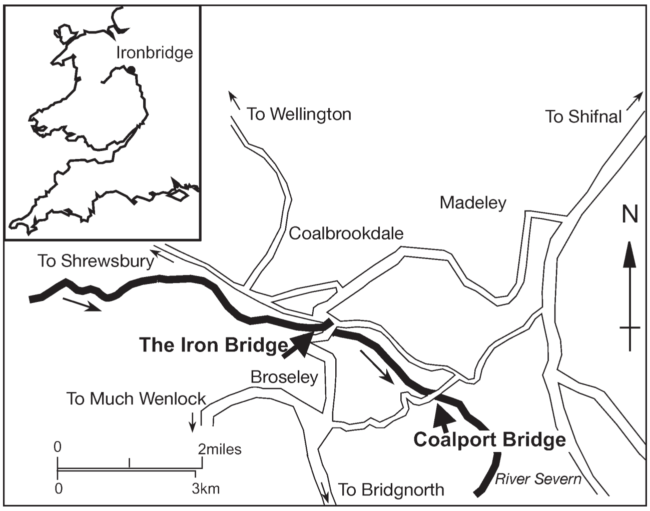

Figure 1: Location map of the two bridges.

upon voussoir formations (James 1979, 1–7).

The two bridges were proposed and constructed in quick succession; the Iron Bridge was proposed from 1773, and Preens Eddy (Coalport) from 1775, with parliamentary acts obtained in 1776 and 1777. Each provided a route between industrial parishes of the gorge, Broseley and Madeley, as shown in Figure 1.

This paper compares and contrasts the two bridges in design, function, casting technology, construction and metallurgical characteristics.

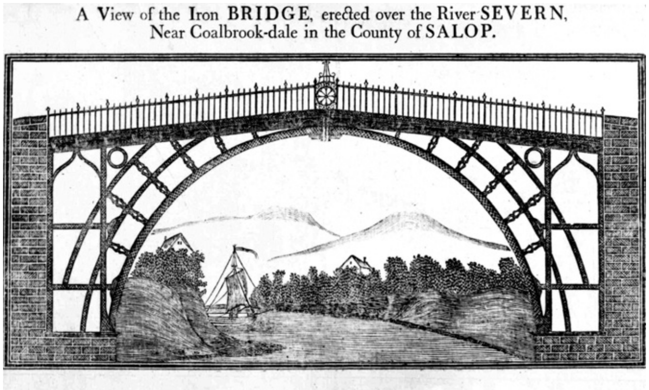

Figure 2: An early wood-cut of the Iron Bridge. (Ironbridge Gorge Museum Trust - CBD 1981.20)

The Iron Bridge (1779)

The general form of the Iron Bridge is clear from its appearance (Fig 2), and was described in detail by Hume (1980). Despite this basic understanding of the bridge's known components, examination in 1999 showed that further interpretation of the relationships between components was required (Fig 3).

Hume's report does not describe in detail the history of either the substructure or the superstructure, comprehensively dealt with by Trinder and Cossons (2002), and briefly reiterated here, to emphasise the variety of alterations and the extent of archaeological evidence dealt with during the substructure survey.

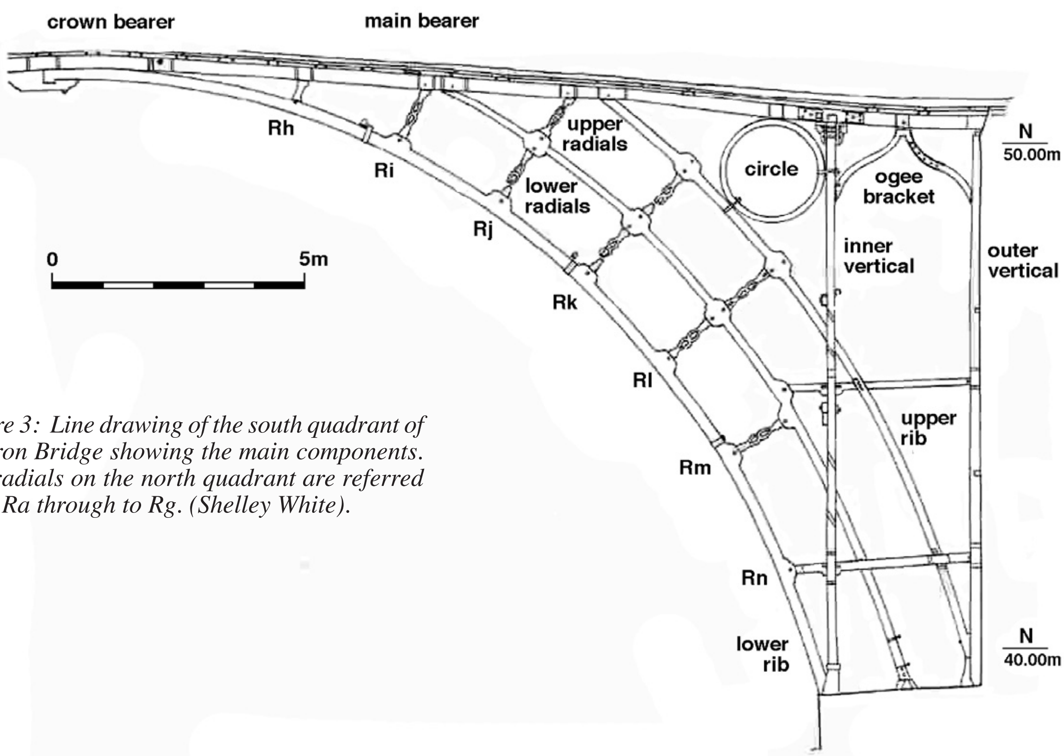

Figure 3: Line drawing of the south quadrant of the Iron Bridge showing the main components. The radials on the north quadrant are referred to as Ra through to Rg. (Shelley White).

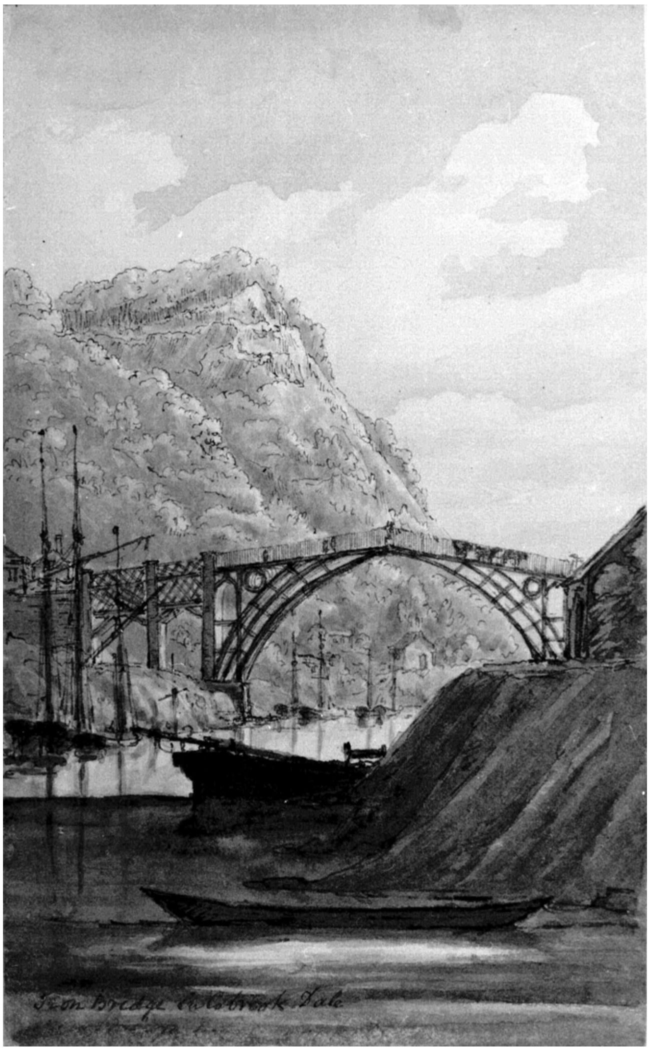

Figure 4: 1804–21 Pencil sketch showing the first large-scale alteration of the bridge with wooden trellis arches in the South Abutment. (Ironbridge Gorge Museum Trust – CBD 1978.225).

The bridge originally comprised a single main arch, supported by the substantial north and south masonry abutments, each housing a small accommodation arch allowing the passage of traffic on the riverside toll path (Fig 12). By 1804 the southern masonry abutment was altered by the construction of the inner and outer south arches, alleviating structural strain. Originally both these arches were of trellis wood construction (Fig 4).

This side formation was replaced in 1821 by cast-iron structures, in imitation of the main arch. Subsequently, breaks in the cast iron were caused by external stresses exceeding its tensile strength; these were repaired in 1845 with numerous fish-plates. Later in the nineteenth century and in the twentieth century, cast iron additions were made to the substructure of the bridge (IGMTAU 2002A, 68–99). In 2002 the railings (posts, rails, swan-necks, dog-bars, and fascia plates) underwent a survey, also conducted by Ironbridge Archaeology, which does not feature in Trinder

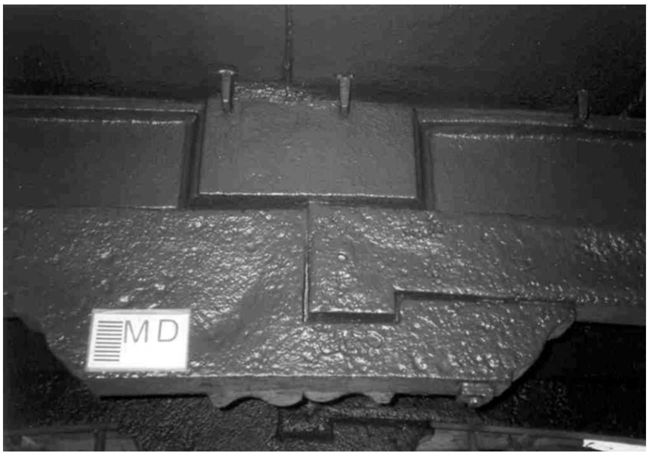

Figure 5: The rear view of the crown which locks all the major components together, thus guarding against vertical and lateral movement. These components clearly show the up-cast and down-cast faces of the ironwork (Ironbridge Archaeology Archive – F13/8).

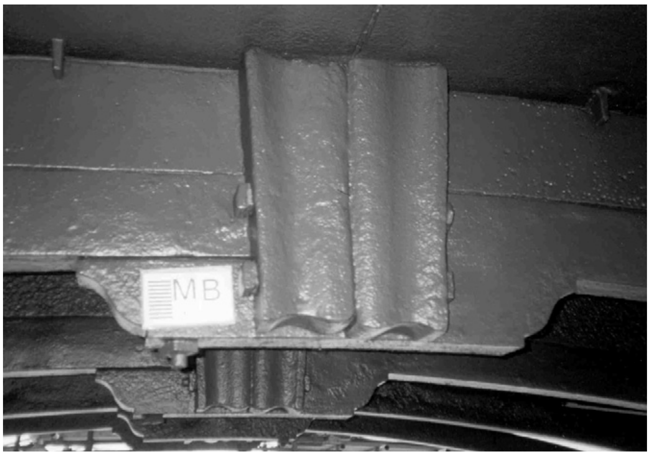

Figure 6: A front view of the crown joint showing the crown bearer and upper ribs A and B (Ironbridge Archaeology Archive – F9/10).

and Cossons' work. This report showed replacements of cast iron and steel (IGMTAU 2002B, 32–38).

New discoveries

Originally wholly constructed from cast iron components, the substructure comprised five semi-circular frames (A – E: upstream to downstream), each comprising a north and south quadrant. Further components, the lower rib, upper rib, radials, vertical and flanged bearers formed the substructure to the main arch. These components were cast to form interlocking joints, or were surrounded by the sandstone abutments (Fig 3).

The crown joint

Although the crown joint with false key had been drawn by Hume (1980), its significance and complexity were not fully appreciated until the 1999 survey. On further

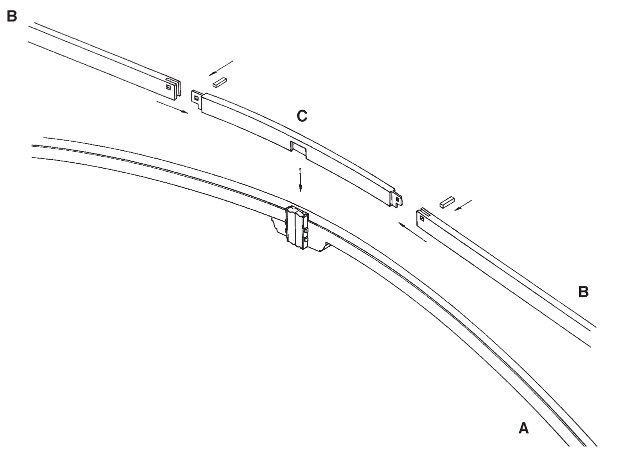

Figure 7: A line drawing showing the relationship between the component parts. Part A is the upper rib, B is the two main bearers per frame and C is the crown bearer. (Shelley White)

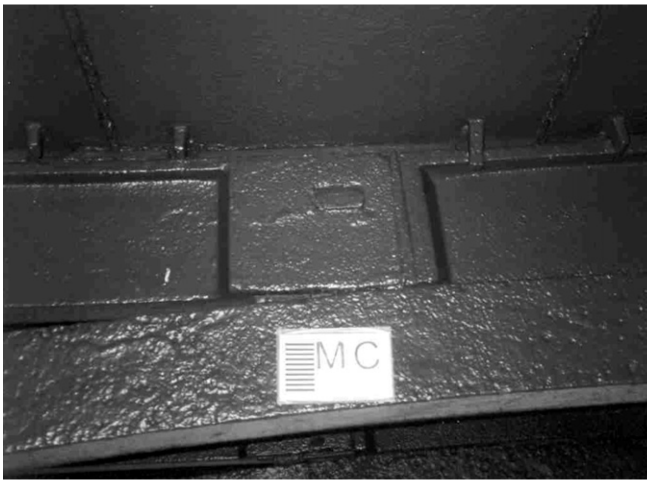

Figure 8: A view of the crown bearer to main bearer joint (Ironbridge Archaeology Archive –F11/19).

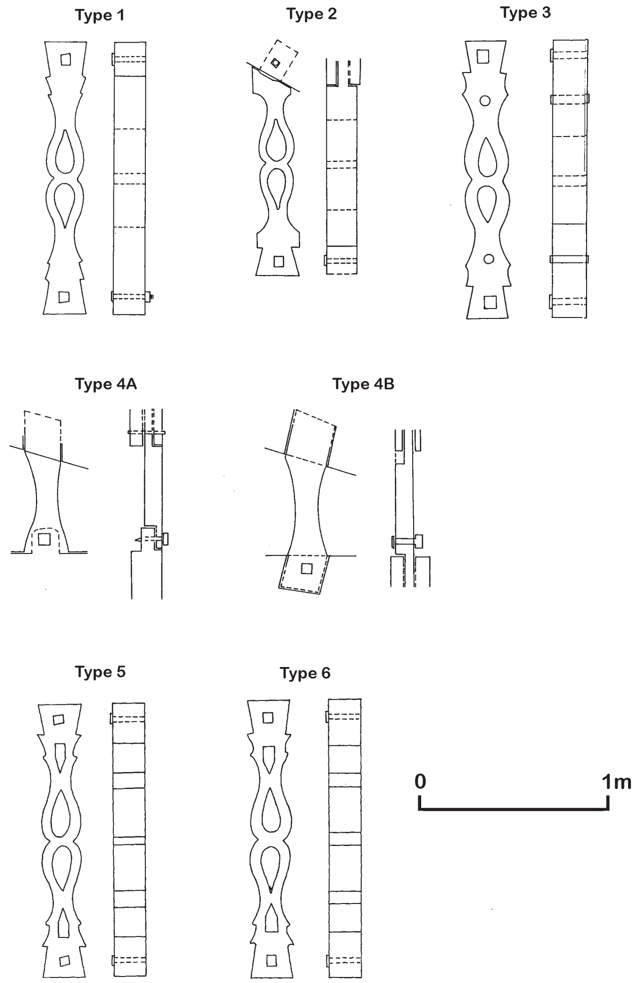

Figure 9: The typology of upper and lower radials

examination the crown joint was found to be a fully-housed longitudinal lap joint, bolted across the lap, with an additional lap joint forming the false 'key' feature. To the rear of this sat a bevelled mortice, which fits into a half-housed tenon on the crown bearer (Figs 5 and 6). The complexity of the joint was due to its purpose, *ie* to hold together the north and south quadrant lower ribs, forming a stable centre point with load-carrying ability. In the 1980 report no relationship was given between the lower ribs A and B, and the crown bearer C.

The crown joint is the one feature of the bridge of which the upstream and downstream views differ, presumably for the sake of appearance. On frames A, B and C the false 'key' feature faces upstream. Therefore, part A forms the north quadrant of frame A; part B forms the south quadrant of frame A. This situation is reversed on frames D and E where the false 'key' feature faces downstream.

Prior to this survey, the bearers were each thought to be individual single castings, forming the upper extent of the south or north quadrant. However, previously unobserved joints to either side of the crown joint created a new component; the 'crown bearer' which sat upon the lower ribs (Fig 7). This was a single curved open-floor casting which sat equally above the central terminal of the lower ribs of the north and south quadrants. Either end of the crown bearer was connected to the main bearer with a longitudinal dovetail, and located in place with wedges and pegs (Fig 8). The gentler curvature of the 'crown' bearer reduced the bridge's curved profile, assisting the positioning of the roadway components.

The survey highlighted technological aspects of the design and construction of the bridge. The over-riding feature not only of these joints, but also of those previously surveyed, was the extent to which they relied on what are commonly referred to as woodworking techniques, such as dovetails, pegs and wedges. In fact, there were few wooden bridges from which these skills could have been derived. Therefore, the expertise in the formation, design and configuration of the Iron Bridge could not have been replicated wholly from timber bridges, but perhaps from the domestic timber buildings built in the Shropshire region until the advent of large-scale brick manufacture in the nineteenth century.

Many of the joints, such as the crown joint, on the crown and main bearers, proved to be more complicated and stronger than timber equivalents. Iron and wood react very differently under tension and compression; as a consequence the iron joints had been altered from their original timber inspiration. The use of individually complicated configurations suggested that understanding of the material's properties was more advanced than initially thought. Therefore, these new discoveries raise the importance of the design and craftsmanship of the bridge in national terms.

Other building materials were locally sourced; sandstone for the abutments came from quarries on either river bank, which were discovered by David De Haan of the Ironbridge Institute and Dr David Jefferson of English Heritage. The Benthall site was re-opened to supply replacement sandstone blocks for this project.

Casting phases and construction

As the survey continued, variations became apparent in the radial components, which were the most common components of the bridge; there are 18 radials on each frame, totalling 90 in all. They were found to display the greatest deviation from a standard form. A radial typology was created (although the upper and lower cross stays did not form part of this typology) in the hope that analysis might inform the erection sequence.

The typology encompassed all 90 radials, and was set up on site with regard to form, dimensions and casting technology. Six types of radials were identified, each with distinguishable yet subtle features (Table 1, and Figs 9 and 10); from these, two other typologies were derived; a structural typology taken from the location of the various components (Table 2) and a relative chronology of casting type and phases – a manufacturing typology (Table 3).

Table 1: The typology of radials with descriptions

Type 1	Original sand-cast radial
Type 2	Original sand-cast 3/4 sized radial
Type 3	Robust flask-moulded radial cast with two mould gates
Type 4A	Later addition/repair small half-radial
Type 4B	Thought to be an original small sand-cast radial
Type 5	Thin sand-cast radial
Type 6	Thin sand-cast radial

Table 3 identifies six types of component. Four different main radial sand-cast formers were used, and one radial was cast in a two-part flask mould. Differences in the casting methods implied that separate casting locations were used, as did small variations in the patterns. It is reasonable to have expected these to be standardized across one casting site.

The evidence did not point to use of specific types on specific frames, although it can be said that the majority of Type 1 (of poorer casting quality) were located upon

Figure10: A view across the five frames of the bridge, showing at least two of the differing radials.

Table 2: Structural typology of radials showing the location and number of types per frame

	Type 1	Type 2	Type 3	Type 4A	Type 4B	Type 5	Type 6	radials per frame
Frame A	0	0	9	2	0	3	4	18
Frame B	2	0	6	2	0	2	6	18
Frame C	12	0	0	0	2	0	4	18
Frame D	3	0	4	2	0	2	7	18
Frame E	4	1	6	2	0	2	3	18
Total	21	1	25	8	2	9	24	90

Note: this table does not include the radials Ra, Rb upper, Rm upper and Rn.

Table 3: Table of manufacturing chronology of the radial types indicating casting phases.

Type	Chronology	Casting Technique	Casting Phase	Furnace
Type 1	1	sand cast	casting phase 1	Furnace 1/2
Type 4B	2	sand cast	casting phase 1	Furnace 1/2
Type 6	3	sand cast	casting phase 1	Furnace 1/2
Type 4A	5	sand cast	casting phase 2	Furnace 1/2
Type 2	6	sand cast	casting phase 2	Furnace 1/2
Type 5	4	sand cast	casting phase 2	Furnace 1/2
Type 3	7	flask mould	casting phase 2A	Furnace 3

frame C, implying that their location was based more on aesthetics than availability. As the radials are an integral structural component of the bridge, their inclusion in the construction of each frame probably occurred within a short time. Therefore, the fact that more than one of the types is extant upon all of the frames, suggests that the different radial castings were produced either concurrently or with a slight overlap. They were therefore a consequence of differing casting regimes, perhaps at different furnaces, which could account for the variations in form.

This information was linked to new documentation on the erection of the bridge. In the past, a number of theories for the raising of the frames have been suggested, each involving a large amount of preparation work (Hodson 1992, 37–41). Examination of the small Elias Martin watercolour sketch re-discovered in 1997 (Fig 11), provided a new hypothesis for the raising of the frames. Martin illustrated a single lightweight derrick construction by which three of the five frames (A, B and C) and inner verticals had already been erected. This derrick formation and the new form of the central 'key' were at odds with popular erection theories (*ibid* 1992, 37–41). As Martin was not an artist of whim or conjecture, his other works suggesting understanding of constructional technicalities, we accept this as a true representation of the technique of erection of the bridge.

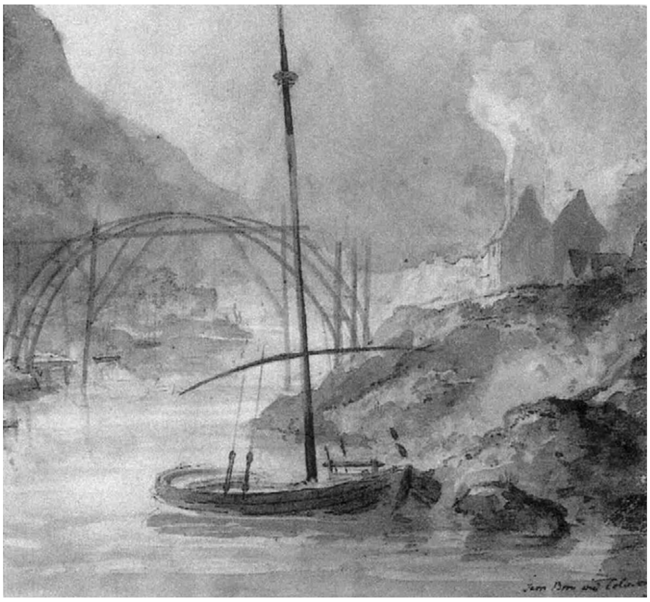

Figure 11: The Martin sketch identified two standing derricks with a cross bar: in essence forming a simple crane. (Skandia Insurance Company Ltd, Stockholm, Sweden, photographed by Ake Cyrus).

From this and experimental archaeological evidence (De Haan 2004, 16–17), it is apparent that the scaffold was not moved, but tilted and secured to enable the raising of each frame, starting with Frame E; D followed, leaving the scaffold between frame C and D, from which other components could be raised to the appropriate level.

This evidence suggests that the lower ribs of frames A, B and C were the first components to be erected. The sequence of erection of radials indicated by the structural radial typology suggests that frame C was the first to be completed, using the majority of the earliest (Type 1) radials. Their positioning may also in part be due to their poor-quality finish, which was kept from view. Unfortunately, the Elias Martin sketch could not provide a means of assessing whether there was a pre-organized type system, and the data capture showed no correlation between type and specific recurring location. Although duplicates are present between the quadrants, these were not numerous enough to be classed as anything other than a best-fit procedure.

It is worth while to remember that during the bridge's construction and for some time afterwards, the most accessible and impressive views of the bridge were from western and eastern approach roads on the north bank of the Severn. The majority of the artistic representations of the bridge were indeed made from the north bank (Fig 4 and Fig 12); therefore on-lookers saw either frame A or E. The evidence supports the premise that greater thought was put into the aesthetics of these frames, as the outer radials were numbered and related to a correspondingly numbered housing (Table 4), indicating an attempt at the casting of made-to-fit radials.

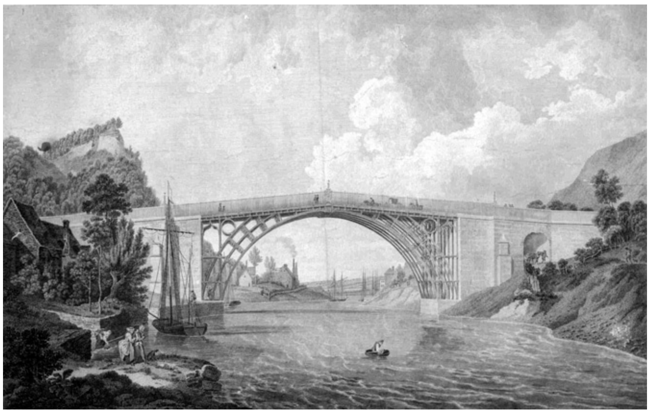

Figure 12: The Cast Iron Bridge near Coalbrookdale *by Michael Angelo Rooker (Ironbridge Gorge Museum Trust – CBD 59.85.3)*

Evidence from the numbering system suggests that frames A and E were respectively referred to as frame one and two. The allocation of the numbers to either frame was as follows:

Frame A: South Quadrant 1–6; North quadrant 7–12,
Frame E: South Quadrant 13–18; North quadrant 19–24.

Numbered radials appear on other frames, implying that complete interchangeability was not achievable.

Table 4 demonstrates that some correlations between location, type and numbered housing occurred. The evidence suggests that by the time frames A, B, D and E were constructed, all the radial types had been cast. Further, the numbering sequence was confined to the location of specific radial types and was not associated with the sequence of construction, *ie* radials 1–24 were not erected in this sequence.

Therefore, the proposed sequence of construction had been assigned to paperwork prior to construction and was modified at a later stage on site, after the casting of the superstructure was completed.

At some point prior to construction, it is thought that each completed frame was laid out on the ground, as implied by the journal of John Wesley (Trinder and Cossons 2002, 25), with radials fitted into their final location and probably numbered up in chalk, these chalk numbers in many cases overriding the cast number. The structure of the bridge and what we know of the initial sequence of components suggests that the lower and upper radials of each quadrant were probably erected at the same time, thus stabilizing the structure. However, the Martin sketch (Fig 11) supports the site evidence that the sandstone superstructure, the abutments and piers were built around the ironwork substructure after much of it was in place.

Metallurgy of the Iron Bridge

Since 1947, metallurgical tests have been undertaken on various parts of the structure to ascertain the type of iron and the originality of component parts. Unfortunately, easily accessible components for metallurgical analysis were confined to the superstructure, many components of which were found to be later additions. Only the 1966 sample was taken from a main arch. Unless a systematic analysis of radials and ribs is made, little evidence for the metallurgy from the original furnaces and the likeli-

Table 4: Structural typology in relationship to location and numbers.

Radial	Frame A (upper)	Type	Frame A (lower)	Type	Frame E (upper)	Type	Frame E (lower)	Type
Ra	*1/1*	1	*1/1*	1	*2/2*	1	*2/2*	1
Rb	*1/1*	1	10	5	*2/2*	1	22	5
Rc	11	3	9	3	23	3	21	3
Rd	*12/12*	5	8	3	24	5	20	3
Re	1	5	7	3	2/2	-	19	6
Rf	-	-	1	6	-	-	*2/4*	1
Rg	-	-	-	-	-	-	-	4A
Rh	-	-	*1/1*	4A	-	-	2	4A
Ri	-	-	-	-	-	-	2	1
Rj	1	6	4	3	-	1	16	3
Rk	-	-	3	3	17	6	15	3
Rl	6	3	2	3	-	6	14	3
Rm	*1/1*	1	1	6	*2/2*	1	2	1
Rn	*1/1*	1	-	-	*2/2*	-	-	-

Note: Italicized numbers indicate retained correlating numbers on radials and housing hood of site-based air (reverberatory) furnaces can be gained.

The 1966 test showed that the main arch was an ordinary grey cast iron containing 1.22%Si, 0.102%S, 0.46%Mn, 0.54%P and 2.65%C. In such a grey iron, slow cooling after casting produces a coarse structure with a high proportion of soft ferrite. Thus, large sections which cool more slowly in the mould have a lower strength than thin sections. However, the chemical composition is very important as are other factors such as pouring temperature, the mould material, and the design of the pouring and feeding systems, all of which influence casting integrity.

Sulphur, introduced when coke replaced charcoal for iron smelting, can cause casting failure if too much iron sulphide is produced. It is questionable if the ironmasters of the time understood the benefits of manganese in neutralizing the sulphur in cast iron, but certainly the manganese content of the main arch was over twice that needed to combine with the amount of sulphur present.

The bridge survey shows that both large- and small-section radial castings had failed, and the reason for this is still unclear. Cast iron structures are designed as far as possible to carry compressive stresses, as the compressive strength of ordinary grey cast iron is ten times that of its tensile strength, and the bridge appears to have been designed with this in mind. Further chemical analysis of the differing types of radial components may aid us in understanding if the failure of radial components is due to their metallurgical make-up or to design deficiencies, but the possibility of movement of the bridge supports introducing excessive tensile stresses must also be taken into account.

Coalport Bridge

In 1776 an Act of Parliament was passed for the erection of the Iron Bridge at Coalbrookdale and in 1777 an Act was passed for a new bridge two miles to the east of the Iron Bridge at a place then known as Preen's Eddy, which in the subsequent decade developed into the industrial settlement of Coalport. The reasons stated in the Act for the construction of a second bridge were twofold. The Trustees (later Proprietors) of the bridge were keen to improve communication across the river. In addition, the Trustees, who were responsible for the erection and maintenance costs of the bridge, would be able to charge tolls to traffic using the crossing, securing a return on their investment, as at the Iron Bridge. Indeed, the bridges shared a number of Trustees who invested in both enterprises.

One of the most important and obvious differences between the original designs and construction of the two bridges was that the Iron Bridge, constructed and completed in 1779, was built in cast iron from the beginning, whereas the bridge at Preen's Eddy, completed in 1780, was originally built in wood. The latter bridge required two spans to cross the width of the River Severn, in contrast with the single span of the Iron Bridge (Fig 13). During the floods of 1795 the wooden bridge was severely damaged and became unusable until substantial repairs were undertaken in 1800.

The 1800 bridge was a hybrid of wood, brick and cast-iron parts cast by John Onions (Proprietor's Minute Book 1791–1827). The two original spans were removed and replaced by a single span of three cast iron ribs, which sprang from the original outer sandstone pier bases. The bridge deck was further supported by two square brick piers, the northern one constructed directly on top of the stone pier base and the southern one set back slightly towards the river bank. The remainder of the superstructure was built of wood and may have re-used some of the original beams. By 1817 this bridge was failing, attributed to the insufficient number of cast iron ribs, proving inadequate for the volume of traffic. Consequently, the bridge proprietors decided to rebuild Coalport Bridge once again, but this time chose to do so completely in iron.

Design

The 1818 re-construction of Coalport Bridge has largely survived to the present day, with later minor repairs and replacements, and several re-paintings. The recent repair programme, completed in March 2005, has further strengthened and refurbished the bridge, adding some twenty-first century technology to the design.

The archaeological survey and recording carried out between 2001 and 2004 was the first comprehensive investigation of the design, materials and construction of

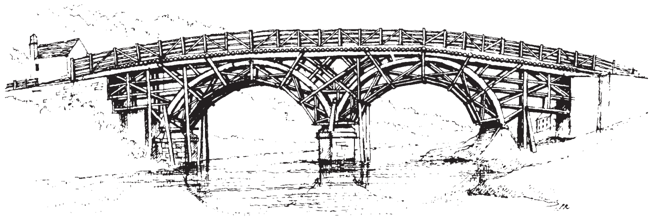

Figure13: Sketch of the wooden Preen's Eddy (Coalport) Bridge c 1789 by J Farington.

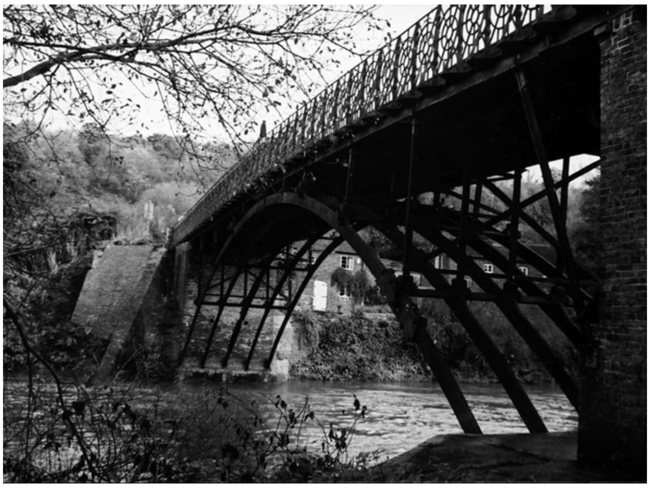

Figure 14: View of Coalport Bridge from the west.

Coalport Bridge (Gifford & Partners Ltd 2002). A prime objective of the survey was to ascertain and understand how the components of the bridge had been designed, manufactured and assembled. One feature previously commented upon by observers (especially Blackwall 1985) was the apparent twisting of the ribs spanning the river. In addition it was clear that many other parts of the structure were also at a slight angle, raising the concern that the bridge was twisting out of alignment. These and a number of other queries became the focus of the survey work.

The results of the archaeological survey largely agreed with the conventional chronology for the construction of Coalport Bridge (Blackwall 1985 and Trinder 1979) and established the following development.

The span of the bridge is composed of five cast-iron ribs in two sections (Fig 14). The ribs of the centre span have eight vertical cast iron frames (spandrel frames) placed symmetrically along the north and south half ribs with an additional raking brace support spanning the gap between the south pier and the deck above. Five cast iron deck bearers in the form of inverted 'T' beams are supported on the vertical frames and these in turn support cast iron deck plates (four across) which overlie the bridge structure and form the base of the roadway. The bearers and deck plates extend from the centre span over the north and south brick piers, and then cross the approach spans to continue for a short distance into the roadway. Cast iron parapets constructed of panels with circular motifs run the length of the bridge on each side. Each parapet elevation has a central panel with a decorative semi-circular crest with the inscription 'Coalport Bridge 1818' and the initials JO (John Onions) in the centre (Fig 15).

Figure 15: The centre panel of the bridge parapet with initials of John Onions, who supplied the ironwork for the 1818 bridge.

The north and south piers are of rectangular form, built in brick, and are hollow. The north pier sits directly over an ashlar sandstone base formed into a cutwater to deflect the flow of the river; the south pier is set back slightly from a parallel sandstone and brick pier base. The north abutment is built of sandstone blocks and brick, with a brick buttress on its south-east and south-west faces, and acts as a revetment to the earth banking behind its face. The south abutment consists of a massive sandstone block wall with brick repairs and internal stone rubble core. The space between the south abutment and the earth embankment supporting the roadway is filled by a brick undercroft consisting of four barrel-vaulted chambers with a central east-west wall enclosed by east and west elevations. A later battered buttress of roughly-cut slag blocks supports the south face of the abutment wall between the north-east and north-west chambers of the undercroft.

Casting and construction

The archaeological survey provided an opportunity to examine the fabric of Coalport Bridge and allowed observation of similarities and differences between the two iron bridges. One key difference is that the Iron Bridge has a multitude of individual cast iron components making up its structure which lend themselves to typological analysis. By comparison, Coalport Bridge is relatively simple and homogeneous in its cast components and so lacks the variety and quantity necessary to create design typologies. Therefore no typological sequences are presented in this section, but where different phases of construction have been identified in the bridge, these are discussed.

Ribs

The ribs are a critical element of Coalport Bridge and were the focus not only of the archaeological survey work but also of the structural and materials investigation. The five cast-iron ribs forming the centre span have average dimensions of 17.2m length (per half rib), 300–320mm depth and 60–95mm thickness, and are spaced between 1.00 and 1.09m apart. The ribs are of two phases (1800 and 1818) and features of the ribs provide information for their manufacture and chronological relationship. The ribs of the 1800 phase have been referred to previously, and it is important to discuss their characteristics and the evidence for dating. The Proprietors' Minute Book makes it clear that two ribs were added to the existing three in 1818, and the central rib was replaced because it had broken in two places, on the north side. Several types of evidence found on the ribs support this description.

Ribs 2, 3 and 4 on the south side and ribs 2 and 4 on the north side have a common feature: the presence of angular lugs projecting from the upper edge of the ribs, which became redundant in the 1818 re-design (Fig 16). These fin-shaped lugs are placed in a consistent pattern along each of the ribs in question, and are located between the base plate and outer spandrel frame, between the outer and middle spandrel frames, between the middle spandrel frame and the second transverse brace and between the second and first transverse brace. The lugs always face towards the crown joint. However, no lugs are present on ribs 1 and 5 and the northern half of rib 3, all of which are considered to be later than the ribs with lugs.

The lugs are small, averaging 205mm long by 76mm high and follow the thickness of the rib. They form an approximate right angle with the rib being at slightly less than 90°, and it would seem that, whatever form

Figure 16: Ribs 2, 3 and 4 showing the redundant lugs of 1800.

of vertical framing they located onto the rib, they were not designed to act as a joint like the double-lugged transverse joints elsewhere on the ribs. These rather insubstantial features may have simply positioned a horizontal beam with vertical posts similar to the present spandrel frame design. Related to the redundant lugs are the double-lugged shoulder joints on ribs 2, 3 and 4 south and 2 and 4 north, which have a different character to those on the 1818 ribs.

The casting of the ribs was relatively simple, although anomalies have been observed which indicate that even simple casting could have its problems. The ribs were cast in open moulds made by placing a former in a bed of sand to provide the shape of the rib; molten iron was poured into the mould. This left a distinctive difference between the faces of the rib, the upcast face being rougher, as out-gassing from the iron had formed pits and lumps on the surface; the downcast face was smoother and more even. Another feature is the slight curve on the corners of the upcast face due to surface tension. All the ribs on Coalport Bridge show these casting features.

The rib curvature – the south ribs curve towards the west and the north ribs curve to the east, forming a soft reversed 'S' shape – was quite a difficult anomaly to explain prior to the survey. The issue of the curve had been raised by Blackwall (1985) but he did not reach a satisfactory explanation as to its origin. The curvature was usually presumed to be due to surface contraction during casting, due to faster cooling of the upcast and therefore exposed face, but when Coalport Bridge was looked at more closely, the upcast faces did not follow this pattern. It would appear that the original three 1800 ribs had warped, most likely in the casting process, but possibly from an error during erection which caused subtle deflection. The two new 1818 ribs appeared to have

Figure 17: Fishplates connecting the centre span ribs.

Figure 18: Typical inverted 'T' beam bearer, supported by the spandrel frames transverse tie beams.

been cast deliberately curved to fit the bridge's existing profile. When the pattern of upcast faces and curvature was examined it was clear that the half ribs had been paired when cast, but placed diagonally to each other's respective position during the bridge's construction (*ie* south rib 2 pairs with north rib 4, south rib 4 pairs with north rib 2, *etc*. The only exception was the central rib 3 which was a composite of an 1800 south half rib (with lugs) and an 1818 north half (no lugs).

Crown joints

The crown joints of Coalport Bridge are relatively straightforward when compared with the complicated 'false key' crown joints on the Iron Bridge. Each joint is formed from two cast iron plates placed on either side of the ribs to cover the join where they meet at the centre (Fig 17). These are bolted together, and have flanges at the top in order to connect with the central transverse tie beam and deck bearers above. The connections from the fishplate flanges to the bearers have a range of variations, some of which relate to chronological changes and some of which are a response to the defects and anomalies found in the bearers and joints. It is clear that the original connectors (1800 phase), which ran from the fishplate flange upwards into the bearer flange, have been altered or replaced. Crown joints 2 and 4 have a similar mix of connectors, several of which have been altered as a response to earlier iron being left in the receiving holes of the posts. This indicates that an earlier form of fixing was used in 1800 and was replaced or altered when the bridge was rebuilt in cast iron in 1818. In addition to this are the faint imprints or 'shadows' on the faces of the fishplates, of the original fixings that took the form of iron wedges rather than bolts. Curiously these wedges are still in place in crown joint 3, an anomaly which is hard to explain, considering that the joint must have been taken apart to receive the new north half rib, and the fishplate corresponds with those of ribs 1 and 5, in being shorter. This perhaps implies that the wedges were re-used from an earlier fishplate in rib 3, but then altered to take account of a short, mis-cast bearer that was placed above the joint in 1818.

There are nine cast-iron transverse tie beams providing lateral support and stiffness for the bridge; these sit beneath the vertical spandrel frames, seated in the double-shouldered joints of the ribs. The method of connection between the ribs and the tie beams is of interest, as during the bridge survey it was noted that a number of these connections were made with wrought iron wedges rather than bolts, reflecting wood-construction technology. These wedge connectors were used exclusively on the 1800 ribs, with bolts being used on the later ribs 1 and 5. It was also observed that on ribs 2, 3 and 4 most of the tie beam joints were packed with wrought-iron shims to fill gaps probably left by an earlier and larger transverse tie beam from the 1800 bridge. Ribs 1 and 5 had been manufactured to fit the tie beams more precisely.

Bearers, deck and parapet

Each of the five cast-iron deck bearers is made up of four sections, two primary bearers spanning the centre span and two secondary bearers spanning the approach spans (with a third short length of bearer on the south side). The bearers, in an inverted 'T' beam form, had two types of casting marks on them: a ridge across the bearer flange ('wave') and a domed 'button' which in some instances had corroded, leaving a void in the bearer itself (Fig 18). The cause of the wave marks was thought to be due to the bearers being cast in a two-piece closed mould (known as a 'cope and drag') or a sand mould with a 'lid': lengths of the lid were roughly butted up, allowing a small up-swell of cast iron (under pressure) which formed a ridge when cooled. The cause of the button marks was probably the result of a 'whistler' or vent hole in the cope (top section of the mould) to allow hot gases and steam to vent off during casting; the pressure build-up during the process sometimes left a void behind the cooled protrusion. The bearers are connected to each other and the spandrel frames by flanged plates bolted to each other.

The cast-iron deck plates which cover the bearers and form the foundation of the road surface are not connected to the bearers directly, but are loosely located by small projecting lugs cast on the underside of the plates. The plates are set into shallow square trays, four across and connected to each other by bolted, semi-circular flanges and are set at a slight camber transversely across the bridge.

Form versus function

Comparison of Coalport Bridge in its final form with the Iron Bridge shows the following main differences. Firstly, the decorated features of the Iron Bridge contrast with the functional design of Coalport, the only adornment on the latter being the parapet panels. Further, the greater height of the Iron Bridge arch creates the effect of a much lighter structure, whereas the lower-slung arch and unsymmetrical piers at Coalport gives the impression of a more cumbersome bridge. The reality is somewhat different, for the ribs of the Iron Bridge are in fact thicker in section than those at Coalport, their length and curvature giving an illusion of slenderness.

The connections and jointing of the individual members also differ considerably, much more use being made of interlocking joints and struts on the Iron Bridge than at Coalport. Additional small decorative details on the Iron Bridge, such as moulded struts and ties, and moulded raised shoulders on the ribs on the latter, also distinguish the two bridges.

Based on the plain component design on Coalport Bridge, the archaeological survey work indicated that the original design concept was purely functional, rather than to demonstrate the designer's ability, as may have been the case with the Iron Bridge. The need in 1818 was for a storm-proof and economical structure: the rebuilding, indeed, cost only £1260, compared with over £6,000 for the Iron Bridge (Cossons & Trinder 1979), and such economy may be reflected in rather haphazard construction and the poor quality of its castings.

The metallurgy of Coalport Bridge

Prior to the most recent bridge survey and repair programme, Coalport Bridge had not been subject to any metallurgical analysis, so the investigation of its fabric was added to the objectives of the bridge survey. A limited amount of on-site and laboratory testing was undertaken by the Castings Development Centre (CDC), Birmingham, to ascertain the location and quality of both cast and wrought iron elements in the bridge (Fallon 2001). The brief investigation confirmed that all of the major components such as the ribs, posts, bearers and deck plates were made of cast iron and that all of the spandrel frame cross braces and packing pieces were produced from wrought iron. The nuts and bolts holding the bridge together were also of wrought iron.

The CDC report commented on the poor quality of the castings with blow holes, slaggy material and mould faults evident in the components. The blow holes and slaggy material supported the idea that many of the bridge components had been cast in open moulds, most probably basic sand moulds as these casting faults were generally only found on one side of the casting, indicating the upcast side. The mould faults were thought to have resulted from the partial collapse of parts of the sand mould during casting, allowing the molten iron to fill the voids left behind and consequently producing lumps on the closed (downcast) sides of the components (*eg* a number were located on the ribs).

Areas were examined where material had adhered to the sides of cast-iron beams. Metallography showed this to be wrought iron, although the analytical results quoted are higher than expected (1.7%C and 1.93%Si). Unfortunately, no detailed analysis was undertaken on the cast iron (primarily because nothing could be easily removed to be tested) so its precise metallurgical contents remain untested. A detailed structural inspection of Coalport Bridge revealed many small faults and failures in the metalwork of the structure, the most common being small cracks and pitting in the supporting frames.

Design technology

During the archaeological research, the technology and materials used to cast Coalport Bridge and the possible locations of the furnaces used to produce the cast parts were explored. The half ribs that comprise the centre span have average dimensions of 80mm x 310mm by 17.21m which gives a total volume of 0.43m^3 per half rib. The nominal weight of cast iron is 7.5t/m^3 giving an average half rib weight of 3.22t. The capacity of John Onions' Broseley furnaces was between 24 and 28 tonnes of iron per week, sufficient to cast several of the main structural members (Riden and Owen 1995).

The lower half ribs of the Iron Bridge each weighed

5.75t (384t in total) having a section of 140–150mm x 230mm by 21.3m long. It would have been possible to hold sufficient iron in the hearth of a typical blast furnace of the period to cast members of this weight (James 1988). However, in 1779, when the Iron Bridge was erected, and certainly by 1818 (the date of the rebuilding at Coalport), re-melting selected grades of pig iron in an air (reverberatory) furnace, was becoming more common in the foundry, and it is possible that parts for these bridges may have been produced in this way. However, the poor quality of parts of the Coalport bridge might argue against this.

Both of the Broseley furnaces would have been convenient for transportation of the finished parts, Broseley being only a mile or so from Coalport. It is also logical that, with the involvement of the Onions family in the construction of the earlier bridges, it may have been one of their furnaces that was chosen to produce the new components of the bridge. Clearly, Onions was considered economical as his firm was chosen to provide castings twice for the bridge by the Proprietors (in 1800 and 1818). Onions' experience in bridge design may have been fledgling compared with contemporary engineers such as Pritchard, Rennie, Telford and Wilson, but his casting experience in 1800 clearly stood him in good stead in 1818.

Conclusion

The archaeological and historical survey work undertaken at both the Iron Bridge and Coalport Bridge since 1999 has provided new information on the design, manufacture, construction and development of these nationally important bridges. The combination of historical research, archaeological and scientific techniques to investigate the bridges, interrogate the data gathered and draw fresh conclusions on their history and development has been almost as significant as the conclusions themselves. The greater understanding generated by both sets of bridge investigations has allowed the development of repair and maintenance plans so that the bridges can continue to serve their original purpose of providing a crossing of the River Severn. In the case of the Iron Bridge, this is now restricted to foot and cycle traffic, but for Coalport Bridge, it means the continuation of road traffic providing a much needed route from Broseley to Madeley for local people.

The Iron Bridge and Coalport Bridge were constructed to fulfil similar infrastructure requirements, and at first glance they seem similar in character. However, closer examination has shown that despite the parallels in materials and components, the construction of the two bridges is dissimilar, Coalport Bridge being less sophisticated in terms of its aesthetic appeal and casting technique. The conclusion suggested by the archaeological research is that the Iron Bridge, with its high-quality cast components, was built not only to provide a crossing of the river, but as a showpiece of cast iron design and construction. The publicity and investment that the Iron Bridge attracted suggests an attempt to create an icon by Abraham Darby III.

The archaeological investigations at Coalport Bridge concluded that the rationale for building this bridge was similar to that of the Iron Bridge: to provide a crossing of the River Severn, but at a more functional level. This was demonstrated by the construction of the first bridge in wood rather than in iron, suggesting that the crossing was more important than the design. Further, it was more by chance of flood damage—notably in 1795, than through any planned programme, that the bridge was finally changed to a totally iron structure in 1818.

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The authors

Shelley White is Deputy Museum Archaeologist at the Ironbridge Gorge Museum Trust from where she undertakes many built heritage projects across the country, whilst specializing in the care, recording and investigation of the Gorge's industrial monuments.
Address: Ironbridge Archaeology, The Ironbridge Gorge Museum Trust, Coalbrookdale, Telford, Shropshire TF8 7DQ.

Andrea Parsons is Conservation Consultant with TFT Cultural Heritage, and specializes in the recording, interpretation and conservation of historic structures and buildings. She was the Project Archaeologist for the investigation and repair programme at Coalport Bridge between 2001–2005.
Address: TFT Cultural Heritage, Bridge House, 14 Bridge Street, Taunton, Somerset TA1 1UB.