

NEWBRIDGE

Maintenance & Strengthening Feasibility Study



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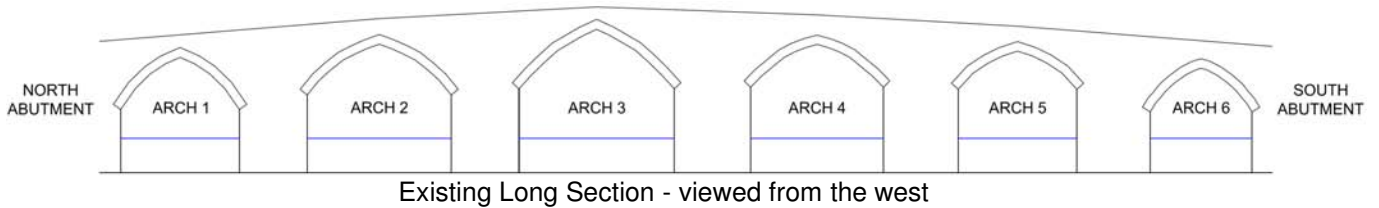
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1.0 Background

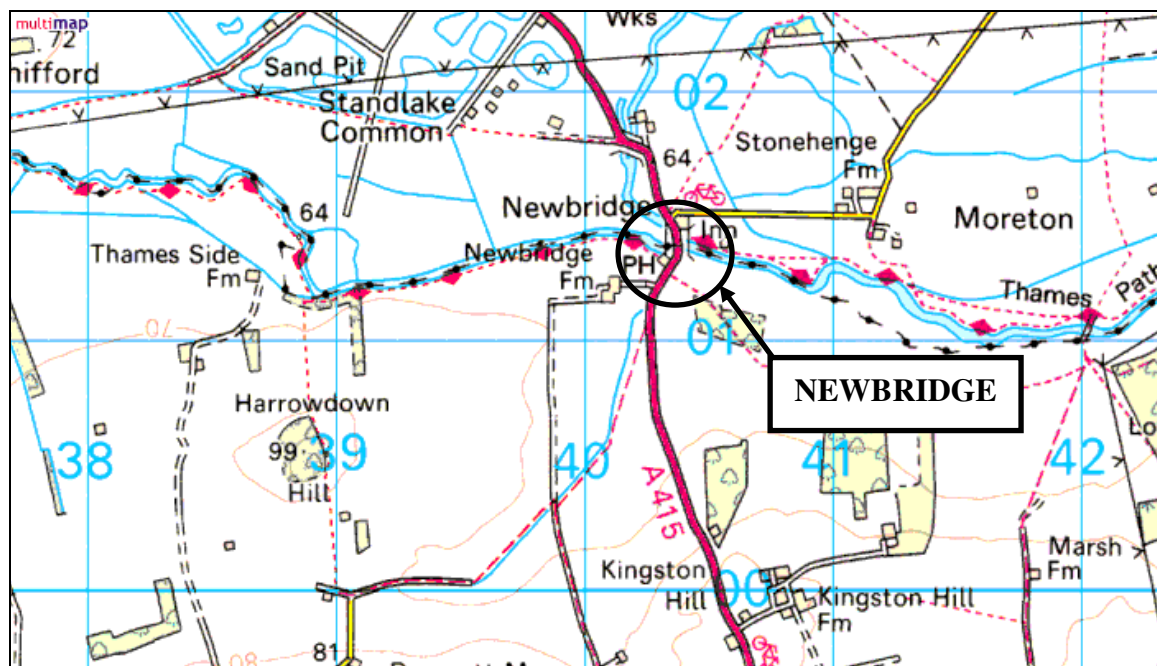
Newbridge (OCC Bridge Number 90) is a 13th century six-span stone masonry gothic arch bridge, with stone masonry piers, abutments, spandrel walls and parapets (foundation details are not known), which carries the A415 over the navigable River Thames at Newbridge, Oxfordshire (see location plans below). The bridge is a Scheduled Ancient Monument (No. 247) and a Grade II Listed Structure.



For consistency with previous reports, the arch numbering in this report will be as shown in the figure above.

The carriageway over the bridge is approximately 4.65m wide between the inside faces of the parapet walls, and has been controlled by shuttle working traffic signals since 1987. There is a 50mph restriction over the bridge. There are no raised footways over the bridge although the west parapet wall includes triangular refuges above the cutwater at each pier, and white lining indicates the edge of a pedestrian 'footway zone' in front of the west parapet.

Previous assessment of the bridge's load carrying capacity indicated a zero tonne capacity. Based on a risk assessment an 18 Tonne weight limit was applied by Oxfordshire County Council (OCC) on the 7th August 2006, and the movement and condition of the bridge is now being monitored.

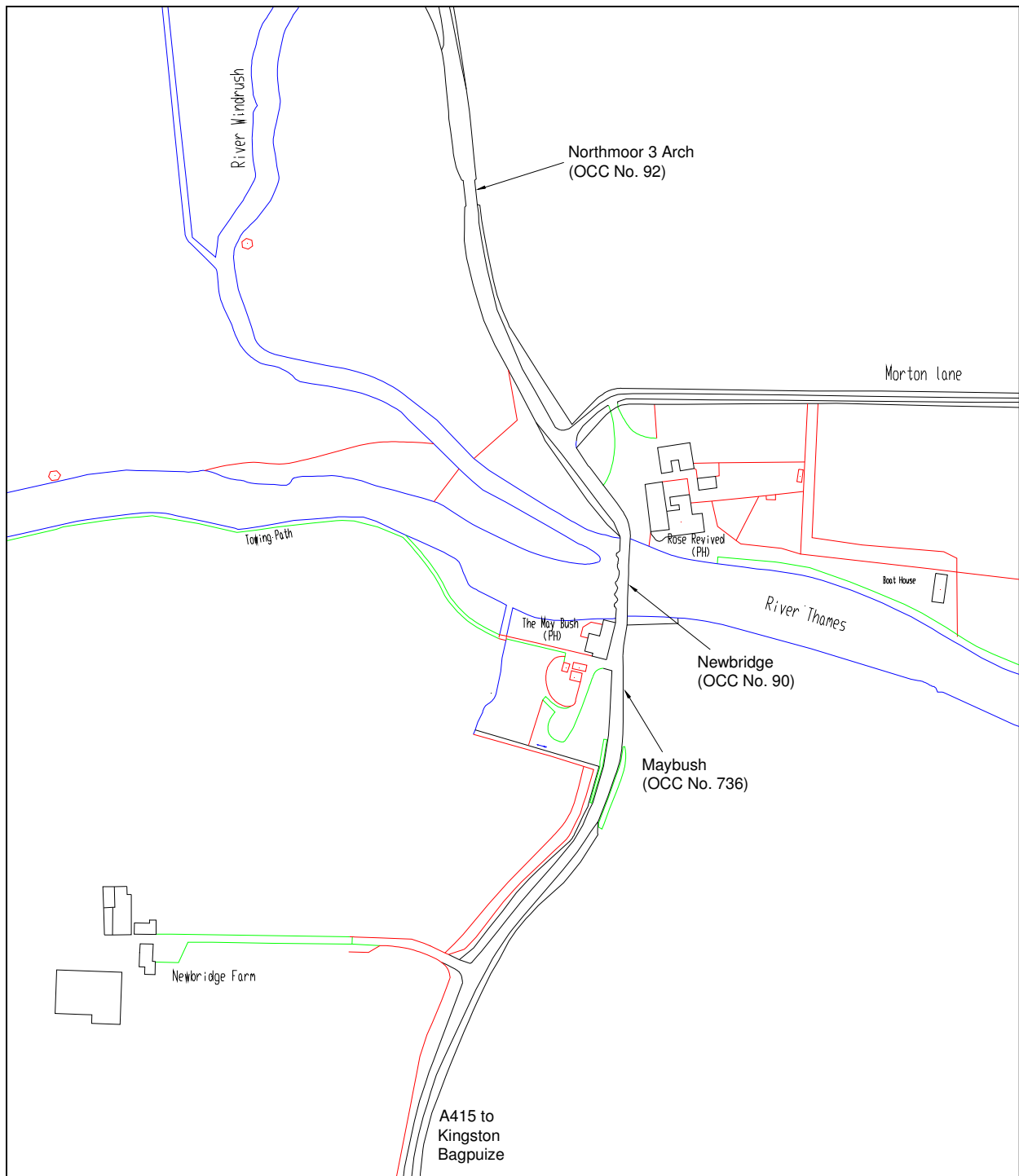


Location Plan – Newbridge, Oxfordshire
(Grid Reference SP 403 013)

In May 2006 a boat struck two of the stone ribs beneath arch 5, causing one rib to collapse and displacing the other. The remedial works to rectify this damage is the subject of a separate commission, and repointing work is to be undertaken at the same time.

Concern has also been raised regarding the poor containment capacity of the historic stone parapets.

The substandard horizontal and vertical alignment of the road is such that vehicular traffic has to significantly reduce speed whilst crossing the bridge. Sightlines across the bridge are significantly below standard.



Site Plan – Newbridge, Oxfordshire

2.0 Project Brief

A project brief was issued by Oxfordshire County Council to Jacobs on 22 Jan 2007, to carry out a feasibility study into the maintenance and strengthening of the bridge.

Summary of Brief – Sections 2.4 to 2.5:

- Investigate the pros and cons of strengthening options and methods
- Indicate the relative effectiveness of each option with regard to improved load carrying capacity
- Consider the objective to maintain a serviceable bridge, commenting on the impact of the options, with regard to Life Span & Replacement; Ongoing Inspection & Maintenance requirements; Reversibility.
- Consult English Heritage for comments on each option
- Document English Heritage's imposed limitations for works to the bridge against each option
- Consider the requirements of the Environment Agency & adjacent land owners
- Report in a form that can be used to justify a preferred option
- Recommend minor repairs (e.g. stonework & pointing) to improve the accessed capacity
- Make recommendations for the ongoing maintenance works that may be required

In addition the project brief asked for a study of land issues and records.

Summary of Brief – Sections 3 to 4:

- Consider adjacent land owners
- Examine available technical records

3.0 Review of Previous Assessment & Inspection Work

3.1 Available Records

A schedule of known events and records relating to Newbridge, including details of assessment and inspection work, is included in appendix A.

Dimensions of the arches' intrados, the piers' width & height, and carriageway levels have been surveyed during the course of previous assessments summarised in section 3.2. The construction of the arches and the fill above is indicated by the findings of a core taken in 1993. The bridge was resurfaced in 1995 but the depth and makeup of this resurfacing is not indicated in the available records.

3.2 Previous Load Capacity Assessment Work

Three stages of assessment were undertaken between 1993 and 2000, the findings of which are summarised below.

- December 1993 - Principal Inspection & Stage 1 Assessment (DHV Burrow-Crocker)

The stage 1 MEXE analysis assessment concluded a 40 Tonne capacity. This result was discounted because the depth of fill at the crown is greater than the thickness of the arch barrel. Highways Agency Technical Memorandum BD21 states that MEXE may be unconservative in such circumstances and requires that the results be confirmed using an alternative method, which was the conclusion of the report.

- March 1996 - Stage 2 Assessment (DHV Burrow-Crocker)

The stage 2 assessment used the ARCHIE & MULTI computer application to analyse the structure. The analysis was based on assumed levels of backing, and arch barrel and fill properties judged from the findings of the November 1993 core taken in span 6, and concluded that the bridge can theoretically only carry its own dead load, but has zero live load carrying capacity (arch #3 being the weakest).

The assessment also indicated that a high level of backing to the arches could raise the assessed capacity from zero tonnes up to 40 tonnes live load carrying capacity. Sensitivity of the load carrying capacity to variation of the assumed soil parameters, material strengths & fill densities was far outweighed by moderate increases in backing level. Investigation to establish the level of backing was recommended, but has not yet been undertaken because of the detrimental effect on the historic fabric and potentially the load carrying capacity.

- February 2000 - Further Assessment (Babtie Group Ltd, now Jacobs))

A further assessment was undertaken following a survey to confirm/ update the arch profiles used in the 1993 stage 1 assessment, and to determine of the carriageway levels. As with stage 2, the further assessment used the ARCHIE & MULTI computer applications to analyse the bridge.

An initial MULTI analysis determined that the piers can be considered to be stocky, such that each arch was then examined independently using ARCHIE. This is consistent with current guidance from a number of papers and Authorities (including Network Rail) that consider a height to width ratio of 2:1 as the upper limit of a stocky pier.

The results confirmed the stage 2 assessment result that arch #3 has no theoretical live load capacity:

Arch 1 – 3 Tonnes
Arch 2 – 3 Tonnes
Arch 3 – Fails Dead Loading
Arch 4 – 7.5 Tonnes
Arch 5 – 10 Tonnes
Arch 6 – 7.5 Tonnes.

Unlike the 1996 Stage 2 Assessment, the 2000 Further Assessment did not assume any backing to the arches, and as such concluded a lower capacity. Arch 3 for example was assessed to be unable to carry its own dead load. Clearly the analysis is conservative since the bridge is carrying live load. There will be some strength contribution from the spandrel walls that the analysis doesn't model, but this may also indicate that the arch barrels are actually thicker than supposed, and/or that effective arch backing is present. The report recommended that trial hole investigations be carried out to determine the level of backing and barrel thickness. The spandrel wall thickness should also be investigated.

Results of a preliminary review carried out with Archie-M analysis software (Outputs are included in Appendix D) using the survey and construction data recorded as part of previous assessments, is consistent with the results from March 1996 & February 2000 assessment of the bridge. It indicates that an increased backing level can raise the capacity of the bridge to 40/44 Tonne Assessment Live Loading. In order to fully investigate whether the assessed capacity can be improved analytically, it will be necessary to establish the level of effective backing to each arch and the thickness of the arch barrels. Boroscope examination of the larger cracks and joint openings in the arch barrel's intrados may help determine barrel thicknesses, but trial hole investigations will be necessary to determine the level of effective backing over the bridge. Such investigation will also allow the fill factor to be reviewed, 0.8 has been used in the analysis.

Regarding the suitability of MEXE application to gothic arches, consultations with authors of arch analysis applications, who have lead recent research in this field, indicates that MEXE is not a suitable method for the analysis of gothic arches. MEXE is a semi-empirical method based on analysis and testing of parabolic arches shapes, and the effect of the gothic's 'point' on the thrust line has not been tested. It is also generally recognised that MEXE can give unconservative results for short spans, which is applicable to the Newbridge span classification.

A number of the assessments have recommended that further investigation takes place; this has not been carried out for the following reasons:

- As a structure dating from the 13th century it is unlikely to have a consistent arch thickness and a large number of holes would be needed to determine the actual thickness with certainty. Similarly the arch backing is unlikely to be the same on each arch.
- As any investigation is intrusive the historic fabric of the bridge would be damaged.
- The structure is assessed as only being adequate to carry dead load but clearly has some hidden strength. Removal of some of the backfill or coring through the arch ring may compromise this hidden strength – potentially leading to collapse of the arch.

3.3 Previous Inspection & Investigation Work

Records exist for inspections and investigations carried out as part of the assessments undertaken between 1993 and 2000 (see section 3.2), and for the Principal Inspections carried out in November 1993 and in July 2004. The findings of these are summarised below.

- March 1991 – Telecommunication duct trench opened over the bridge

In 1993 two ducts were installed in trenches over the bridge in the centre of the carriageway. No records detailing the makeup of the carriageway's construction are available, but photographic records appear to show a relatively thin surfacing, laid over a loosely bound fill, laid over a gravelly/ sandy fill. The crown tops of arches 3 and 4 are shown, indicating that the loose fill continues down the back of the arch barrels.

- November 1993 - Investigation Coring of Span 6 - Nicholls Colton & Partners

In 1993 a 100mm diameter core was drilled through the crown of arch 6 indicating, from bottom to top, 340mm thick stone (weathered fractured sandy ferruginous limestone) barrel, 220mm thick clay and gravel fill, 355mm thick honeycombed concrete, 25mm surfacing.

- November 1993 - Principal Inspection - DHV Burrow -Crocker

The bridge is reported as being in generally good condition, with a few defects in each arch – small longitudinal cracks towards the edge of the arch barrels in arches 1, 2 and 3; spalled masonry up to 10mm at the water level; minor mortar loss in all arches; and collision damage to piers beneath arch 3 from boats. A slight deformation of arch four's west elevation was reported. The defects were accounted for in the 1993 Stage 1 Assessment with reduced factors, which were also used in the 1996 Stage 2 Assessment. A copy of defect drawing from the report, Drg. No. B2562/90/SK1, is included in appendix C.

The inspection recommended filling and monitoring of the longitudinal cracks, and repointing of the joints where necessary. Also pier damage beneath arch 3 needed repair.

- February 1995 – Carriageway Reconstruction

In 1995 the carriageway over the bridge was re-laid. The depth and makeup of this reconstruction is not evidenced in available records, but photographic records indicate that the road construction was planned off down to the clay/gravel fill.

- February 2000 - Further Assessment – Babtie Group Ltd.

A dimension and condition survey was undertaken for the 2000 Further Assessment. The assessment report stated that maintenance works had recently been carried out, but gave no detail.

- July 2004 - Principal Inspection - Jacobs Babbie

The inspection report is more comprehensive than that for the 1993 inspection, and details the condition of all the elements in each span (piers, arch barrel, invert, voussoirs and spandrel walls). Generally, spalling of the stonework and erosion of joints at the water line was observed throughout. The longitudinal cracking and joint openings in the barrels of arches 2, 3, 4 and 5 appears to have increased in magnitude and extent since the 1993 Principal Inspection. Some of the longitudinal cracks and joint openings run close to the spandrel wall, indicating that the spandrel wall is moving away from the arch. Movement of the spandrel wall relative to the arch voussoirs, together with settlement and cracking of the surfacing over the bridge supports this.

Seepage from the springing of arches was observed at the abutments and at several piers, indicating that water was penetrating through the surfacing and fill, and through the arch barrels. This action will wash out fines from the fill, and erode the mortar joints, and the stonework in the long term. Saturated fill will increase the lateral pressures on the spandrel walls, which could increase if the fill freezes in the winter, and exacerbate the observed lateral movements.

A copy of defect drawing from the report, Drg. No. BPN915/F5002, is included in appendix C.

The inspection report recommended repointing and replacement of spalled stonework throughout, and investigation/ monitoring of the longitudinal cracking at the edges of the arch barrels. The report also recommended that an underwater survey be carried out to check for scour and undercutting of the piers and invert; that consideration be given to waterproofing of the extrados, and introduction of drainage at the piers and abutments; that the wooden fenders around each cutwater be repaired/ replaced.

- August 2007 - Underwater Inspection – Sea Technical Services

Following the exceptional flooding event in July 2007, a diving inspection of the bridge identified scour undermining of up to 600mm against arch three's northern pier wall. The scour damage to the pier extended from the bridge's east elevation for a length of approximately 3.4m along the south side of the pier. Remedial works were undertaken in September 2007.

- June 2008 – Ecology Survey – Eco Consult

An ecology survey of the structure was carried in advance of the proposed repointing and stone replacement works to assess any impact the works may have on wildlife. The survey concluded that bats and birds inhabit the structure, and that works should be undertaken outside of the bird and bat nesting season. The bats will need to be resurveyed in September before planning the repointing and repair works to accommodate their presence.

The historical inspection record outlined above, indicates that the longitudinal cracking and opening of joints in the arch barrels is increasing. If the spandrel walls extend beneath the carriageway, load from HGV wheels running directly above the walls will be concentrated at the edge of the bridge, which may be causing the lateral separation.

The increasing lateral separation, together with the 2000 assessment result of zero tonnes live load capacity, led to the implementation of an 18 Tonne weight limit by Oxfordshire County Council (OCC) in August 2006. Monitoring of the bridge's condition and further movement is now being undertaken by Jacobs. As part of the monitoring, it is recommended that a Principal Inspection be carried out to update and compare the observations recorded out in the July 2004 inspection report.

3.4 Interim Measures

A study of necessary interim measures to Highways Agency Technical Memorandum BD79 for Newbridge was carried out by Oxfordshire County Council in 2006 to decide how best to manage the structure's substandard assessment result of having no live load capacity. The BD79 study concluded that the introduction of an 18 Tonne weight restriction combined with monitoring would permit its temporary continued use on the basis that:

- arch failure mechanisms are not sudden and that cracking and surface deformation would become apparent before any catastrophic collapse occurred
- the structure has clearly been carrying live load for sometime and does not show significant signs of distress indicative of the assessed failure mode. It is therefore likely that there are strength reserves that are not being modelled correctly.
- An 18 Tonne GVW limit would prevent the closely-spaced multi axle loading from any 3 to 6 axle HGV's, which significantly reduces the magnitude of the loading most likely to cause a short-span arch failure.

An 18 tonne GVW limit was selected rather than any lower limit as this permits a majority of traffic, including all two-axle HGV's and buses, to continue to use the A415 while significantly reducing the number of HGV axles crossing the bridge

Traffic surveys (12 hour daytime) carried out since May 2001 (see appendix D) show that the number of vehicles that have 3 axles or more (these generally exceed 18 Tonnes GVW) has reduced by 85-90% since the weight restriction was introduced in 2006, but shows that HGVs are still using the bridge. Trading Standards have successfully prosecuted a number of offenders, but resources do not allow a continual presence. Full time enforcement using fixed cameras is being investigated.

Following the guidance of BD79 Newbridge can be defined as a 'Monitoring appropriate structure'. The structure will be monitored in two ways; through regular site visits and remotely using electronic movement detectors. If significant movement is detected the weight restriction will be reviewed; the trigger levels for reviewing the restriction have still to be determined.

3.5 Review of Highways Agency Technical Memorandum BD89 – 'The Conservation of Highway Structures'

Newbridge is a Scheduled Ancient Monument, and as such requires Scheduled Monument Consent from the Secretary of State for Culture, Media & Sports who will consult English Heritage on the application. English Heritage is therefore being consulted on the maintenance and strengthening measures being investigated.

The principals of conservation against which any proposed works are to be evaluated are summarised below:

- Bridges are best used and maintained in their original form, performing the same function and structural action.
- Minimal changes are to be made to the structure and its appearance
- Works should involve no loss in character, and minimal loss of historic fabric
- Works should be non intrusive, and be reversible
- Works should involve minimal introduction of new material
- Works should be undertaken using appropriate materials & methods

3.6 Maintenance Recommendations

The measures recommended in the July 2004 Principal Inspection report should be carried out as soon as it is practicable:

- Repointing to replace damaged and lost mortar is essential to maintain the integrity and load carrying capacity of the structure, and prevent further loss due to vibration. This may raise the depth factor of 0.9 that was used in the assessments. Consent will be required for any works, and proposals will need to be developed in consultation with English Heritage (see section 5.3). The affects of the proposed works on wildlife inhabiting the bridge's fabric (such as bats and birds that maybe using exposed joints to nest and roost) needs to be assessed, and appropriately managed. This is currently being surveyed and assessed.
- Replacement of spalled stones is also essential to maintain the integrity and load carrying capacity of the structure. Consent will be required for any works (see section 5.3).
- Quantitative monitoring of the longitudinal separation (cracking and joint opening) that is taking place in the arch barrels. As part of the monitoring, it is recommended that a Principal Inspection be carried out to update and compare the observations recorded out in the July 2004 inspection report.
- Repair/ replace the wooden fenders around each cutwater.

The following measures should also be considered:

- Waterproofing over the bridge will help prevent seepage through the fill damaging the arch barrel's stonework. A surface to waterproof will however need to be constructed. Drainage may also be installed at the piers and abutments, though this would need to be run through the spandrel walls.
- Resurfacing the carriageway across the bridge will help improve ride quality and reduce vibration.
- A vibration survey will help gauge the relative damage being caused by different live loading.

4.0 Strengthening Options

4.1 Faults & Options

A number of strengthening methods have been evaluated for addressing the faults that have been identified during the previous assessments and inspections. These methods are set out in the table below, and are depicted in the sketches shown on pages 13-15. A description and discussion of each method is included in Appendix F.

Application of the conservation principals set out in section 3.5 means that it is certain that any permanent works extending beyond the structure's existing footprint will not be accepted. Options have therefore been limited to maintaining the existing width, alignment and appearance of the bridge.

Faults Identified	Repair & Strengthening (Ref. Appendix F)
Deterioration of the arch barrel stonework	Masonry Repairs (F.6) Replacement of Fill with Effective Structural Backing (see F.1 & F.2) Over Slabbing (see F.3) Concrete Saddling (see F.4) Retro Reinforcing the Arch Barrel (Externally or Internally) (see F.5, F.6 & F.7) Structural Lining to Intrados (see F.8)
Load capacity of the arch barrel assessed to be inadequate	Replacement of Fill with Effective Structural Backing (see F.1 & F.2) Over Slabbing (see F.3) Concrete Saddling (see F.4) Retro Reinforcing the Arch Barrel (Externally or Internally) (see F.5, F.6 & F.7) Structural Lining to Intrados (see F.8)
Longitudinal separation of the arch barrel beneath spandrel walls from the rest of the arch barrel	Replacement of Fill with Effective Structural Backing (see F.1 & F.2) Over Slabbing (see F.3) Concrete Saddling (see F.4) Retro Reinforcing the Arch Barrel (Externally or Internally) (see F.5, F.6 & F.7) Stitching (see F.9)

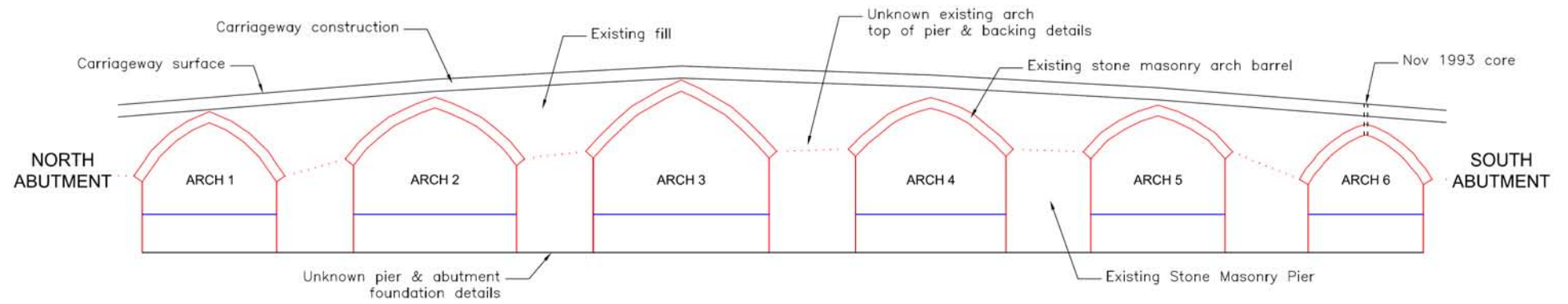
The effectiveness and feasibility of load capacity improvement has been considered for each method, as well as structural risk during the works, and longer term implications relating to durability, appearance, inspection and maintenance. These considerations have also been measured against the conservation principals outlined in section 3.5. A summary of the findings are presented in section 4.3, and the detailed discussion is contained in Appendix F.

4.2 Durability Issues of Strengthening Methods

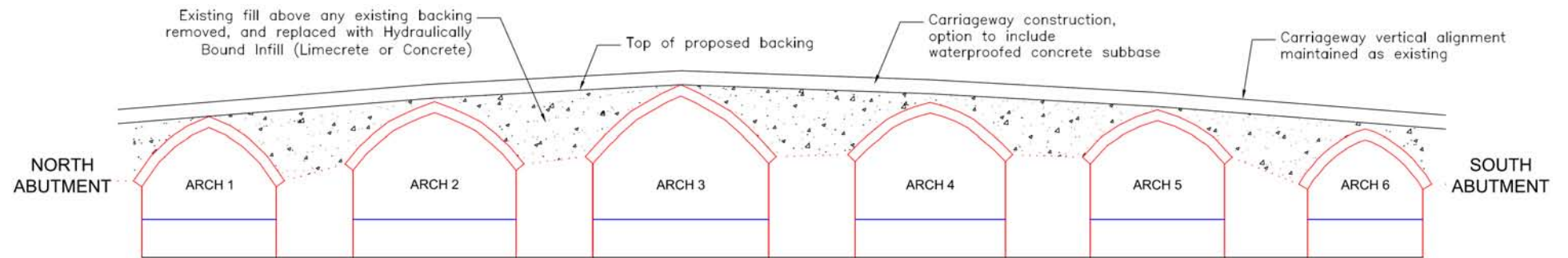
British standard bridge design codes have been compiled on the basis of achieving a design life for the structure as a whole of 120 years, provided that adequate and regular inspection and maintenance is carried out. Strengthening measures would be designed on the same basis.

Given the historical importance and age of the existing structure, it is very important that any measures be designed, implemented and maintained such that little or no long detriment is caused, and that the structure can be used and maintained in its present condition for the enjoyment of many future generations.

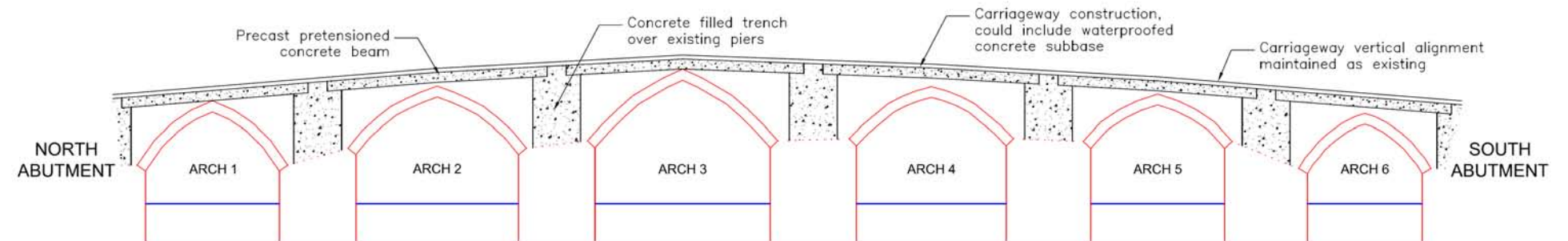
Given the relatively short design life of some of the modern components & materials used in the strengthening options described above, then aside from the effect on the visual appearance, priority should be given to maintenance and reversibility criteria when judging the suitability of the strengthening measures.



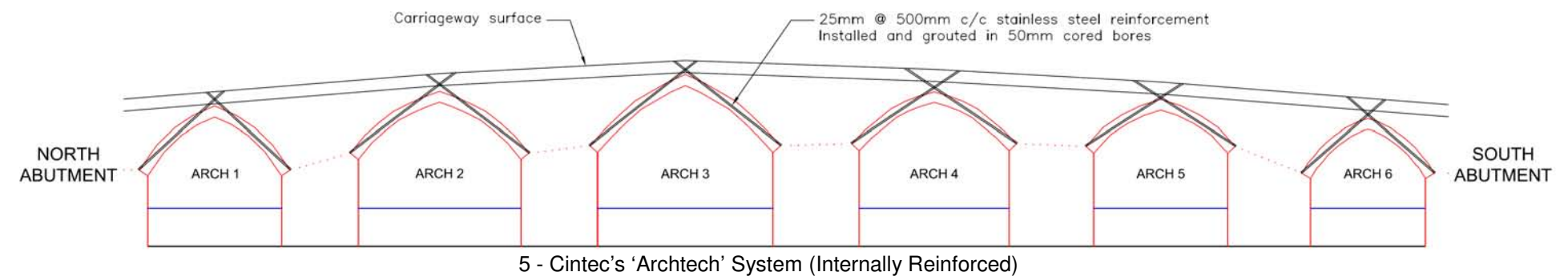
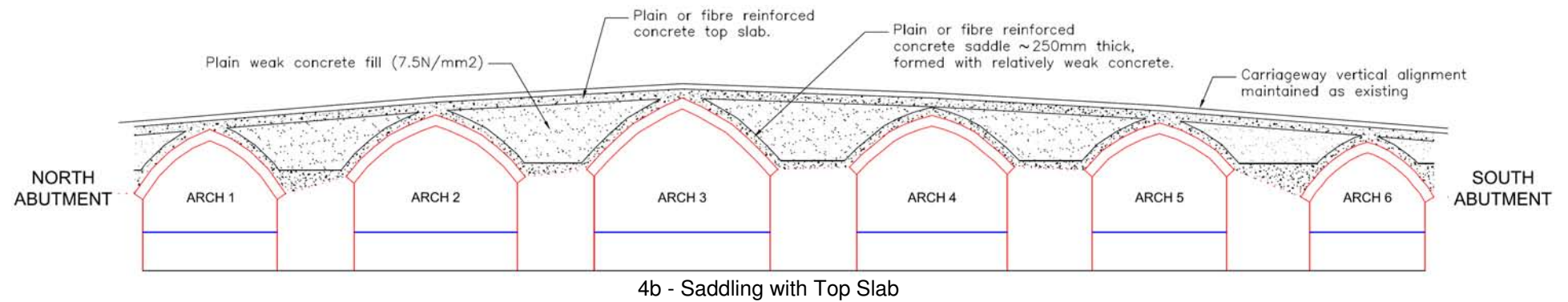
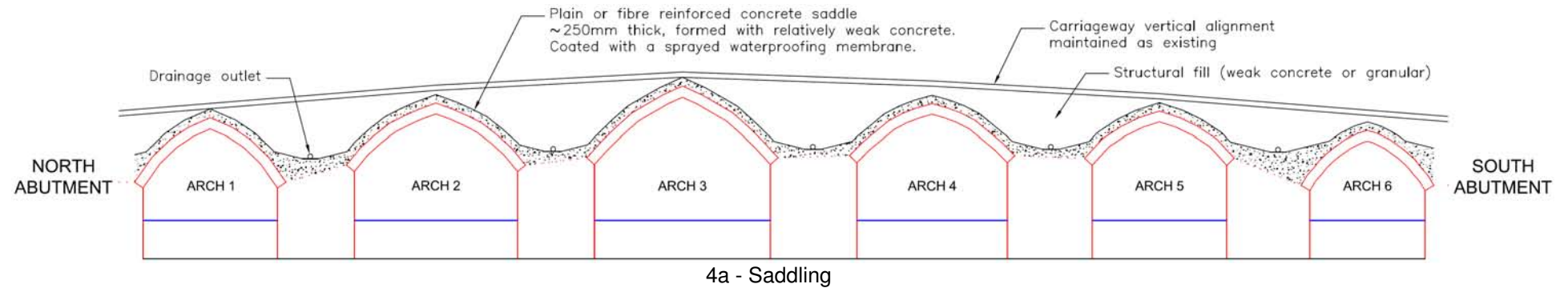
Existing Long Section (Section based on Feb 2000 Assessment Survey)

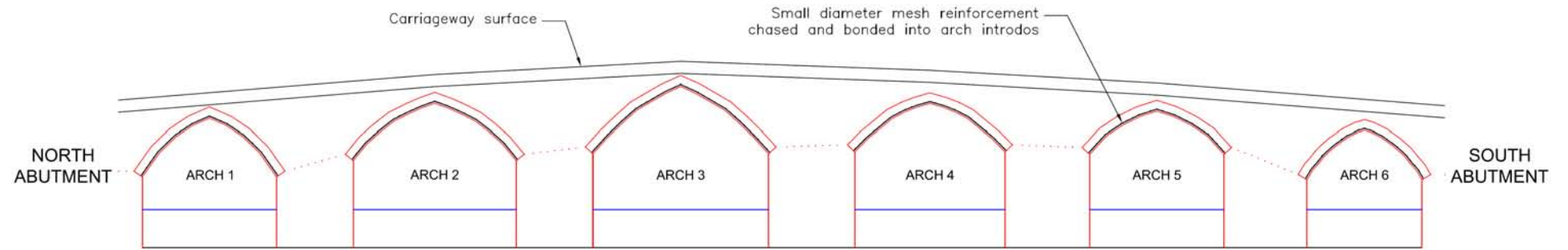


- 1 - Replacement of Fill (shown)
- 2 - Pressure Grouting (similar)

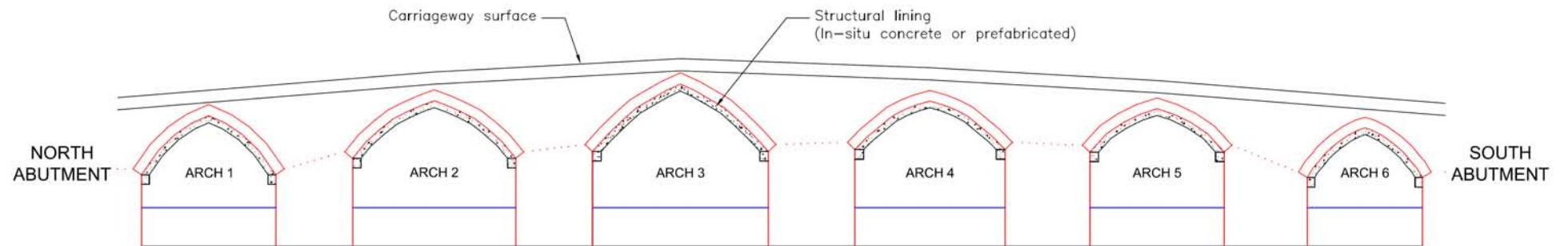


3 - Overslabbing





6 - Masonry Arch Reinforcement Strengthening (MARS) System (Externally Reinforced) (shown)
7 - Bersche-Rolt System (Internally Reinforced) (similar)



8 - Structural Lining to Intrados

4.3 Comparison of Strengthening Options

SYSTEM	STRENGTHENING AND REPAIR OR STRENGTHENING/ REPAIR ONLY	ABILITY TO STRENGTHEN TO 40/44 TONNES	RISK TO STRUCTURE DURING WORKS	LEVEL OF TRAFFIC DISRUPTION LIKELY	LEVEL OF INTRUSION & AFFECT ON STRUCTURAL ACTION	AFFECT ON UTILITIES	SIMPLICITY OF FUTURE ASSESSMENTS	LIFE SPAN, & INSPECTION OF MEASURES	MAINTENANCE & REPLACEMENT OF MEASURES	MORTARS & CRETES USED	EFFECT ON WATERWAY CLEARANCE	RISK TO ECOLOGY	ENGLISH HERITAGE COMMENT
ROUTINE MAINTENANCE	Necessary repointing and stone replacement	N/A	Low risk	Minimal, if any	Minimal, addition of matching materials	None	N/A	Unchanged form current regime	Ongoing routine work	Lime mortar & matched stone	N/A	Low, consent and mitigation required	Consent for necessary works considered and agreed on application
REPLACEMENT OF FILL	Strengthening and repair	Yes	High risk in removing fill- centering will be required but is vulnerable to flood/impact damage	Full road closure necessary for works duration. Significant disruption.	Invisible, but existing fill is removed	Will require protection and support	Standard analysis	Can be designed to be removed and replaced without damage to existing stonework.	Measures can be designed to be removable for replacement	Concrete or limecrete	None	Low, consent and mitigation required	Concern expressed over intrusive affect on existing fill.
GROUTING OF THE EXISTING FILL	Strengthening only. Doesn't address the lateral separation.	Possible, but requires physical investigation & testing of existing fill.	Minimal	Minor - road closure during works, open outside of working hours	Nature of existing fill material is modified. Grid of injection core plugs will be visible in intrados. Dead load increase may cause settlement.	None	Standard analysis	Can be designed with lime grout to be removable for replacement from above without damage to existing stonework.	Measures can be designed to be removable for replacement	Cementitious or lime based grout	None	High, no practical way to prevent grout entering water course or bat roosts	Concern expressed over intrusive affect on existing fill.
OVER SLABBING	Strengthening and repair. Can address the lateral separation	Possible, requires survey and investigation of extrados and tops of supports.	Temporary support to arch intrados may be required	Full road closure necessary for works duration. Significant disruption.	Invisible, but removes some existing fill and changes the structural action	Will require diversion	Standard analysis	Relief of dead load may destabilise arch barrels	Measures can be designed to be removable for replacement	Plain and prestressed concrete	None	Low, consent and mitigation required	Concern expressed over intrusive affect on existing fill & Stonework
PLAIN CONCRETE SADDLING	Strengthening only, though nominal reinforcement would provide lateral strength	Possible, if the saddling was combined with raising the effective arch backing	Temporary support to arch intrados may be required	Full road closure necessary for works duration. Significant disruption.	Invisible, but removal of existing fill and modifies structural action	Will require diversion	Standard analysis	Connection of materials to existing stonework likely to cause damage when removed	Measures are likely to cause damage to the existing stonework fabric when removed	Plain concrete	None	Low, consent and mitigation required	Concern expressed over intrusive affect on existing fill & Stonework, and life limiting modifications
RC CONCRETE SADDLING	Strengthening and repair. Can address the lateral separation	Yes	Temporary support to arch intrados may be required	Full road closure necessary for works duration. Significant disruption.	Invisible, but removes existing fill, and changes structural action	Will require diversion	Standard analysis	Relief of dead load may destabilise arch barrels	Measures are likely to cause damage to the existing stonework fabric when removed	Reinforced concrete	None	Low, consent and mitigation required	Concern expressed over intrusive affect on existing fill & Stonework and life limiting modifications
CINTEC's ARCHTEC	Strengthening and repair. Can address the lateral separation	Yes. Design by Gifford	Risk of fracture damage to stone barrel, resulting in spalling / loss of stone	Minor - road closure during works, open outside of working hours	Invisible, but intrudes into existing stonework, changes the structural action, and is vulnerable to differential settlement of supports	May require protection and support	Requires specialist assessment by Gifford's	Irreversible life limiting modification of stonework, difficult to inspect	Measures are likely to cause damage to the existing stonework fabric if replacement is attempted.	Cementitious grout	None	Low, consent and mitigation required	Concern expressed over intrusive affect on existing fill & Stonework and life limiting modifications
SSP's MARS	Strengthening and repair. Can address the lateral separation	Yes. Design by SSP Consult	Risk of fracture damage to stone barrel, resulting in spalling/ loss of stone	Minor disruption due to site activities	Grid lines visible on surface of masonry. Intrudes into existing stonework, changes structural action, and is vulnerable to differential settlement of supports	None	Future assessment by MARS	Irreversible modification of stonework. Surface embedded so can be inspected and replaced.	Measures may cause damage to the existing stonework fabric when removed.		None	Low, consent and mitigation required	Concern expressed over intrusive affect on existing fill & Stonework and life limiting modifications
BERSCHE-ROLT	Strengthening and repair. Can address the lateral separation	Yes. Design by Bersche-Rolt	Risk of fracture damage to stone barrel, resulting in spalling/ loss of stone	Minor disruption due to site activities	Some evidence of work will be visible where stones are temporarily removed to enable radial drilling. Intrudes into existing stonework, changes structural action, and is vulnerable to differential settlement of supports	None	Future assessment by Bersche-Rolt	Irreversible life limiting modification of stonework, difficult to inspect	Measures are likely to cause damage to the existing stonework fabric if replacement is attempted.	Cementitious grout	None	Low, consent and mitigation required	Concern expressed over intrusive affect on existing fill & Stonework and life limiting modifications
STRUCTURAL LINING TO INTRADOS	Strengthening and repair. Can address the lateral separation	Yes	Minimal	Minor disruption due to site activities	Significant visual impact. Increased dead load may cause settlement.	None	Standard analysis with thicker barrel	Measures can be designed to be removable for replacement	Various liner materials with cementitious or lime based grout		Significant	Medium, seals access to intrados. Consent and mitigation required	Unacceptable
HELIFIX	Stitching repair technique. Can address the lateral separation	No	Minimal	Minor disruption due to site activities	Visible	None	Standard analysis	Irreversible life limiting modification of stonework, difficult to inspect	Measures are likely to cause damage to the existing stonework fabric when removed	Cementitious grout	None	N/A	Concern expressed over intrusive affect on Stonework

5.0 Stone and Mortars Repairs

Proposals for necessary stone and mortar repairs, the subject of a separate commission, are being developed in consultation with English Heritage. English Heritage are reasonably sure that the stone in the bridge is Oolitic limestone probably from around Burford. Discussions with OCC's Bridges Section confirm the stone to be Taynton Stone from a now closed quarry north west of Burford.

The stone in the bridge was compared with samples of Stoke Ground (also an Oolite); Hartham Park, Guiting, and Doulling stone. English Heritage and the Stonemason procured for the repair works, agreed that Stoke Ground stone is the best match for the stone repair work. Lime mortars will be selected following site trials.

The affects of the proposed works on wildlife inhabiting the bridge's fabric (such as bats and birds that maybe using exposed joints to nest and roost) needs to be assessed, and appropriately managed. This is currently being surveyed and assessed.

6.0 Highway Standards

6.1 Highway Alignment & Cross Section

The highway over and either side of the existing structure is substandard. The horizontal radius at the north end of the bridge is approximately 45m, which is less than the minimum required for a 30mph design speed (DMRB, TD9). Currently traffic is controlled by shuttle working traffic signals over the bridge, so traffic speeds are relatively low. The vertical curve is such that the Stopping Sight Distance is also less than that required for a 30mph design speed. Accident records from 1/11/2000 to 31/10/2005 show no injury accidents on the bridge, although 28 casualties (6 serious, 22 slight, 0 fatal) were recorded on the A415 in the vicinity of Newbridge. There have been a number of collisions with the bridge parapets during this period although none of them involved a recorded injury.

The existing cross section is not wide enough for two lanes, and so is controlled by shuttle working traffic signals. There are no raised footways over the bridge, although the west parapet wall includes triangular refuges above the cutwater at each pier, and white lining indicates the edge of a pedestrian 'footway zone' in front of the west parapet.

6.2 Assessment of Existing Parapets

The existing stone masonry parapets have not been assessed due to lack of survey and structural information, but don't appear to be structurally connected to the spandrel walls, and are unlikely to contain heavy vehicles travelling at speed. The triangular cutwater refuges formed by the west parapet will also tend to increase impact forces in the event of a vehicular strike, as the wall will catch rather than deflect the vehicle.

The existing parapets could be strengthened with a retro reinforcement system, such as Cintec, Bersche-Rolt, or Helifix (see Appendix F) to increase their strength to modern standards. However, this would tie the parapets to the spandrel walls and risk damage to both the spandrel walls and arch barrels. This could result in structure that is more difficult to repair, or even increase the risk of structural collapse of an arch(s).

The containment capacity of and failure risk assessment for the existing masonry parapets should be carried in accordance with BD97 & BS 6779-4

7.0 Technical Consultations

As part of the final scheme, all statutory and some non-statutory interested parties will be consulted, but at this technical feasibility stage the following consultations have been made:

7.1 Environment Agency

The Environment Agency will not accept any permanent measures that intrude into the existing arch openings. Temporary works such, as centering, must be designed to be removable at short notice in the event of possible flooding.

7.2 English Heritage

The bridge is a Scheduled Ancient Monument (No. 247) as well as a Grade II listed structure. As such, consent from English Heritage is required for any proposed alterations. Ideally, important structures such as this should be 'conserved as found'. Where necessary, any repairs and strengthening must work sympathetically with the structure, cause minimum intervention with the existing fabric, and not change its character. See section 3.5.

English Heritage is therefore being consulted regarding the bridge maintenance and strengthening measures that have been considered as part of this feasibility study. Initial discussions indicate that strengthening options designed to minimise intrusion would be considered if there was no alternative. For example, construction of an alternative crossing may be favoured provided that it doesn't adversely affect the setting of the existing bridge. Further discussion with English Heritage will be necessary upon their review of this report.

Materials and methods for the proposed stonework repairs and repointing work are discussed in section 5.3.

7.3 Land Owners

It is understood that Greene King Ltd, the owner of the two public houses, owns the land to the East, and to the South-West of the bridge. A land search for the owner of the land to the North-West is being conducted. Access to the bridge for river based activities is being gained via the car park of the May Bush public house, South-East of the bridge, for which the tenant has been granting permission.

7.4 Utilities on Newbridge

The following utility information has been mainly established from responses to a C2 notice sent out in February 2008.

- | | |
|-----------------------------------|---|
| • British Telecom | - 2 Ducts in c/way (July 2004 PI Report & May 2008 Enquiry) |
| • OCC Traffic Signals | - 100mm ducts against the west parapet (Laid in 1986/7) |
| • OCC Street Lighting | - None (C2 Notice Return 11/2/08) |
| • Easynet Telecom | - None (C2 Notice Return 12.02.08) |
| • OCC (Private services search) | - None (C2 Notice Return 12.02.08) |
| • Global Crossing (UK) Orange PCS | - None (C2 Notice Return 12/02/08) |
| • OCC Highway Drainage | - None (C2 Notice Return 13.02.08) |
| • Thames water SW & FS | - None (C2 Notice Return 12/02/08) |
| • Fibrenet | - None (C2 Notice Return 20/2/08) |
| • SSE | - None (C2 Notice Return 22/2/08) |
| • Gas up to 7 bar Linesearch | - None (C2 Notice Return 3/4/08) |

8.0 Discussion & Recommendations

8.1 Discussion on Feasibility of Strengthening

Conventional analysis and improvement of associated condition factors is not sufficient to increase the assessed capacity of the existing structure to 40/44 Tonnes. Without thorough investigation of the existing backing, fill and arch barrel thickness, it will not be possible to prove an increased assessment capacity for the structure. Given the age of the structure however, investigation to adequately determine material types and sizes would be very intrusive and permanently damage the bridge. Consent for such investigation would be required.

All strengthening solutions will affect the fabric of the existing structure, and are therefore intrusive and non reversible to some extent. The substandard width and alignment of the bridge (see section 6.1) cannot be addressed within the constraints of the conservation principals (section 3.5), and as such the benefits to the A415 route as a whole will always be restricted. Some form of measure is however necessary if the lateral separation of the arch barrel and spandrel wall is to be controlled whilst HGV loading continues to use the bridge.

The least intrusive methods (e.g. installation of an effective backing) only affect the existing fill, do not intrude into the existing stonework, and are therefore the most sympathetic solution. Traditional materials can be employed, but will require a longer works period to implement, and cause more disruption to the road network. However, the fill is an integral part of the heritage of the bridge and its removal and replacement with a modern material will require archaeological input. The arch will require support during this operation to prevent collapse in the unloaded condition, and installation of arch centering will require the consent of the Environment Agency and is vulnerable to flooding and impact damage increasing the risk of arch collapse.

Viable saddling and over slabbing solutions change the structural action of the arches by relieving them of loading. It is not possible to be sure about the long term effects of this on the stone arch barrels that rely on compressive forces to perform structurally, but arches will certainly be more vulnerable to movement, vibration and impacts. The options rely on permanent connection(s) to the existing stonework and introduce modern life limiting materials that will be difficult to maintain and replace. Consequently these options are not recommended.

Construction of a structural lining against the arch intrados will result in significant visual change, as well as structural change and reduced clearance, and is therefore not viable.

The retro reinforcement strengthening methods can be implemented with minimal disruption to traffic, but change the structural action as well as intrude into the stonework fabric of the structure. Previous coring of the limestone (section 3.3) indicates that the stonework is particularly vulnerable to fracture when mechanically damaged, and so methods that use coring techniques close to the surface of the stonework may cause spalling damage during installation. The retro reinforcing options available are non reversible and so will compromise the life of the structure in the long term. The externally reinforced options also affect the visual appearance of the stonework, and are therefore not a viable solution. Further, because of the way the arch is tied together, the arches' ability to accommodate future movement is compromised. Although there are no signs or reports indicating past or ongoing settlement, there are no details of the existing foundations and so future settlement cannot be ruled out. Retro reinforcement methods are therefore not recommended.

Whether or not a strengthening method is implemented, it will still be important to establish whether, and at what rate, lateral separation of the arch barrel and spandrel wall is increasing. Further load restriction may prove necessary in the future. Monitoring is also recommended following the installation of any strengthening measures, as removal of the weight limit may result in increased vibration of the structure.

The existing parapets are substandard, and require retro reinforcing to bring them up to standard for anything but light to moderate impacts. Reinforcing would however involve tying them to the spandrel walls, which may result in their damage in the event of vehicle impact (see section 6.2).

8.2 Recommendations

Investigation to adequately determine material types and sizes, and possibly improve an increased assessment capacity, would be very intrusive and permanently damage the bridge. It is therefore not recommended whilst the current weight restriction and monitoring regime remain in place. However, the stone masonry parapets should also be assessed to BD97.

All viable strengthening measures to raise the capacity of the bridge to 40/44 Tonnes are intrusive, and any proposal needs to be balanced against the risks of doing nothing, or against the inconvenience and cost of further restricting the vehicles that are permitted to make use of the length of the A415 that the bridge serves. The substandard cross section and alignment of the bridge cannot be addressed within the constraints of the conservation principals, and as such the benefits of any strengthening to the A415 route as a whole will be restricted

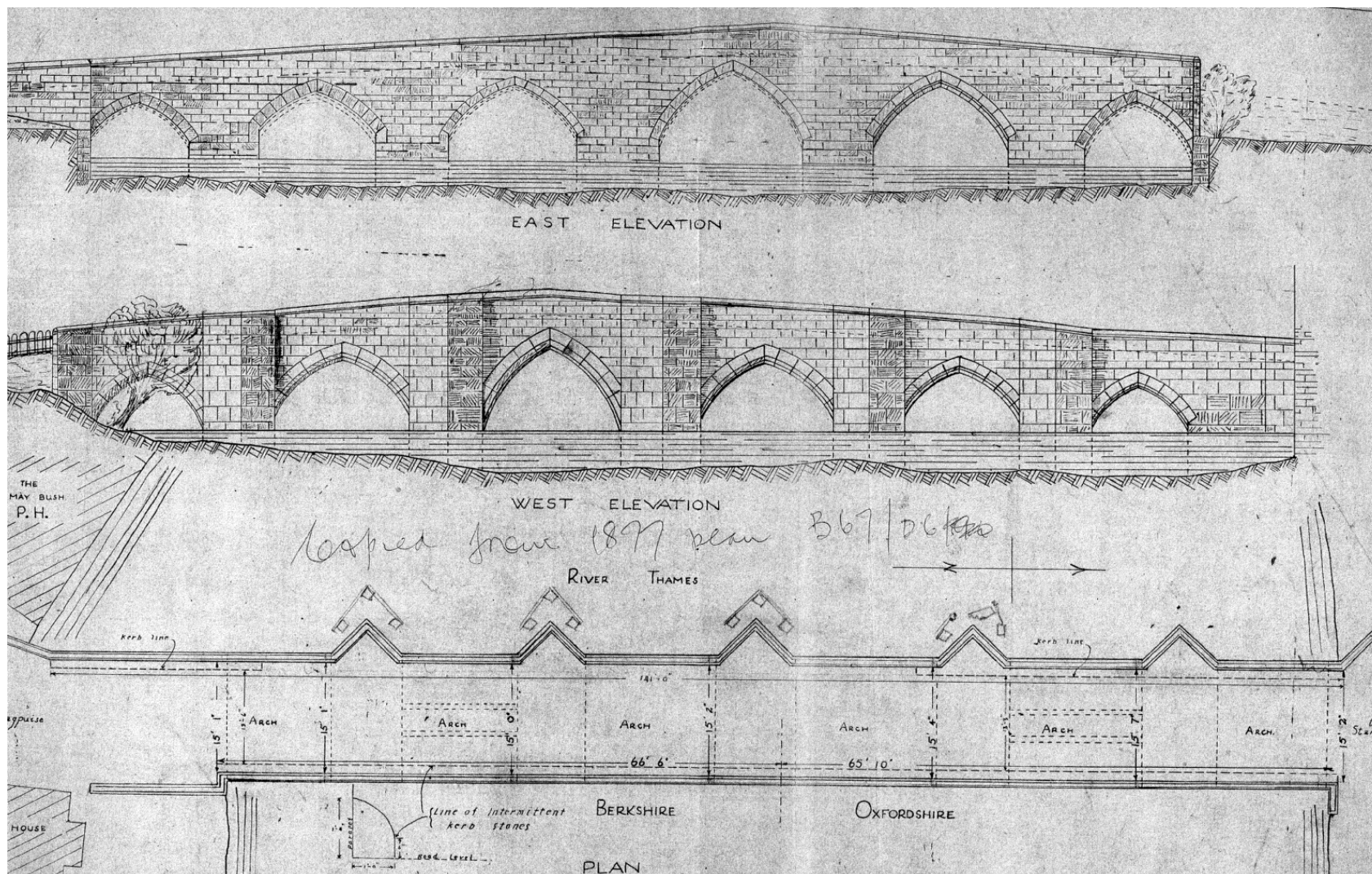
English Heritage have confirmed the acceptability of constructing a replacement bridge upstream to carry A415 traffic. This enables the existing bridge to be stabilised and conserved in its historic condition and to perhaps remain in service for local traffic. Decisions regarding the need for and form of future strengthening of the existing bridge should therefore wait for completion of the replacement bridge scheme proposals.

Routine repointing and stone replacement must continue to be undertaken in order to maintain and preserve the bridge's structural integrity as far as possible, see section 5.0. Monitoring of the lateral separation of the arch barrel and spandrel wall must be co-ordinated with the ongoing inspection and bridge management strategy as laid out in BD79.

If the lateral separation of the arch barrel and spandrel wall continues to increase, then some form of remedial measure may need to be considered if continued HGV loading of the bridge is to be permitted. Investigation of the internal arch backing and spandrel wall details may then be required.

APPENDIX A

Record Drawing B16/4c/90 Plan & Elevation



Extract from drawing B16/4c/90

APPENDIX B

Schedule of Events & Records

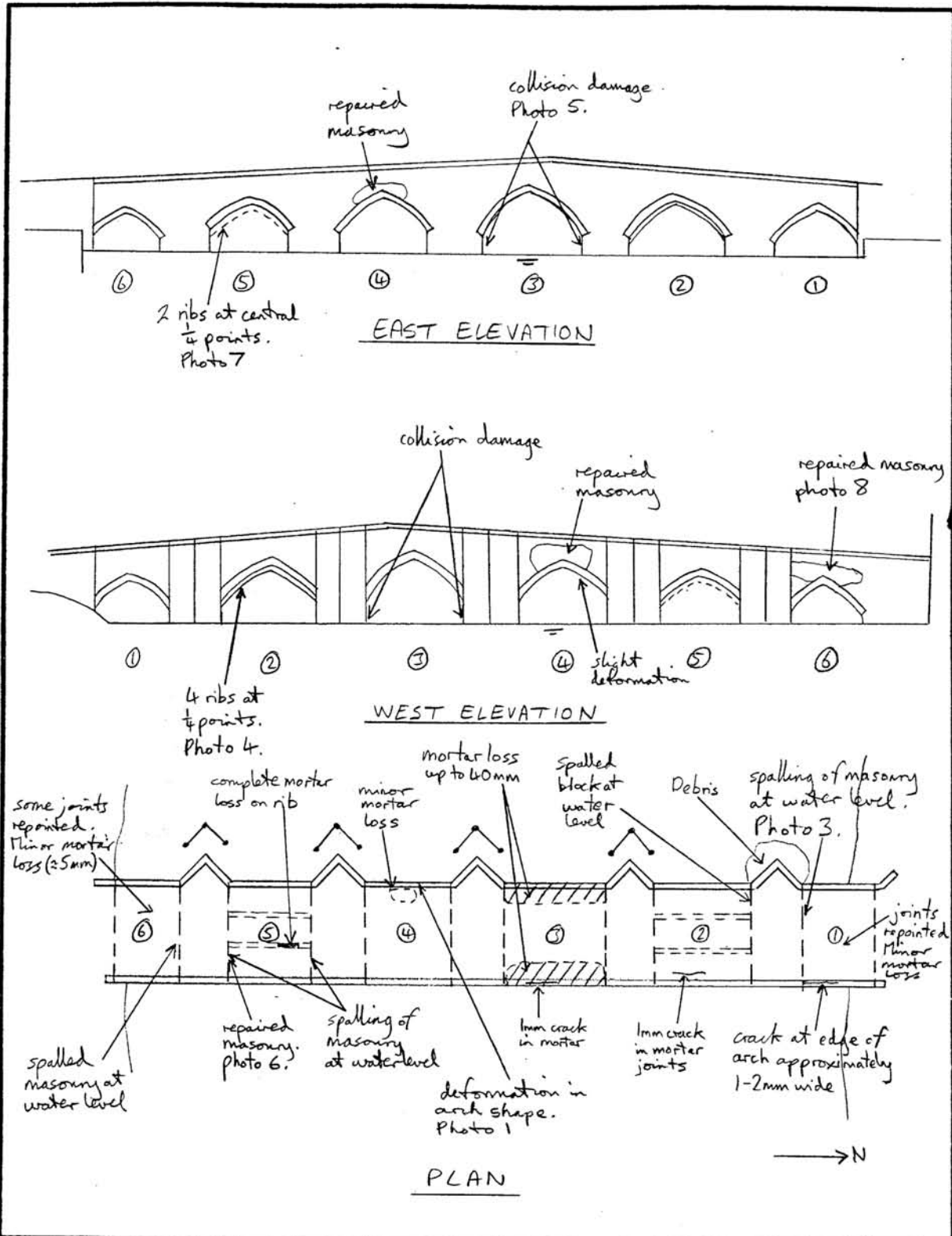
Chronology of Events & Record Documentation

Date	Event/ Record Documentation	Comment
c1250	Bridge Constructed	Various History Pamphlets
	Record Drawing B67/D6	Drawing Available
	Record Drawing B67/C4	Drawing Available
	Record Drawing B16/4c/90 - Plan & Elevations	Drawing Available
c1890 – c1930	Oxfordshire County Council Archive - Photographic Records	Available Digitally
1987	Shuttle Working Traffic Signals Installed - OCC	
Mar 1991	BT ducts laid across the bridge	Photographs Available
24 Nov 1993	Investigation Coring of Span 6 - Nicholls Colton & Partners	Report Available
24 Nov 1993	Principal Inspection - DHV Burrow -Crocker	Report Available
Dec 1993	Stage 1 & 2 Assessment Approval In Principle - DHV Burrow-Crocker	AIP Document Available
Dec 1993	Stage 1 Assessment - DHV Burrow-Crocker	Report Available
Feb 1995	Bridge Resurfaced	Photographs Available
Mar 1996	Stage 2 Assessment - DHV Burrow-Crocker	Report Available
Dec 1996	Record Drawing WO3S 3924/2A - River Soundings (Inc Crown Levels)	Drawing Available
Feb 2000	Further Assessment - Babtie (Trial Holes Recommended)	Report Available
July 2004	Principal Inspection - Babtie Group Ltd.	Report Available
28 May 2006	A boat strike beneath arch 5 caused damage to the stone ribs	
June 2006	Interim Measures Feasibility Study for Bridges to BD79/06	Draft Issue
07 Aug 2006	18 Tonne Weight Limit Implemented - OCC	
29 August 2007	Underwater Inspection - Sea Technical Services	Report Available
22 Jan 2007	Monitoring, Maintenance & Strengthening Feasibility Brief Issued - OCC	Brief Document Available
28 Feb 2008	Boat Impact Damage Repair Brief Issued - OCC	Brief Document Available
Mar 2008	Monitoring System (BOX telematics Ltd) Installed & Tested	
01 Apr 2008	Monitoring System (BOX telematics Ltd) Activated	Monitoring Report being drafted
June 2008	Interim Measures Feasibility Study for Bridges to BD79/06	Report Available
June 2008	Ecology Survey – Eco Consult	Report Available

APPENDIX C

Inspection Defect Record Drawings (scanned drawings not to scale)

November 1993 Principal Inspection - B2562/90/SK1
July 2004 Principal Inspection - BPN915/F5002 Sheet 1 of 2
July 2004 Principal Inspection - BPN915/F5002 Sheet 2 of 2



Project OXFORD BRIDGE INSPECTIONS (GROUP 26)		Drawn S. Pallatt
Title NEW BRIDGE OCC NO. 90		Scale N.T.S.
		Date DEC 93
		Checked
		Approved
		Drg. No. B2562/90/SK 1



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APPENDIX D
Traffic Count Summary Sheet

TRAFFIC COUNT

SUMMARY SHEET 2001 TO 2008

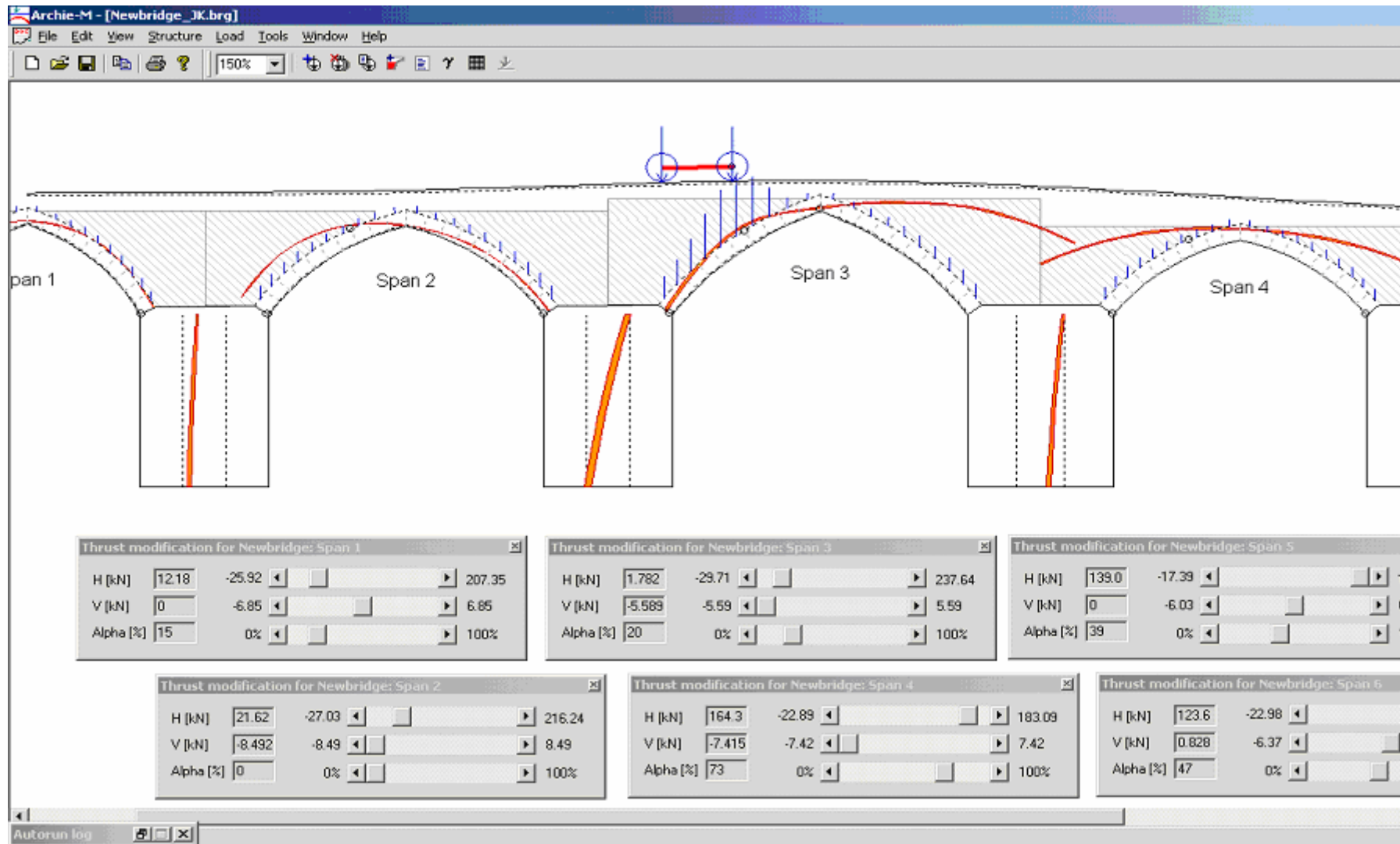
Date	Survey Period	Pedal Cycles	2 Wheel Motor Vehicles	Cars & Taxis	Buses & Coaches	Light Goods Vehicles	Heavy Goods Vehicles Rigid				Heavy Goods Vehicles Articulated or Trailer		TOTAL
							2 Axles	3 Axles	4 Axles	3/4 Axles	5 Axles	6+ Axles	
18/05/2001	12 Hour	9	95	6479	74	1180	392	54	42	55	60	36	8476
2002	12 Hour	1	38	6356	61	1227	345	89	80	50	80	44	8371
2003	12 Hour	15	43	6243	50	1266	297	80	63	64	72	34	8227
2004	12 Hour	8	45	6346	50	1292	305	51	33	28	63	41	8262
2005	12 Hour	12	124	6346	56	1142	290	40	54	37	61	53	8215
05/03/2008	12 hour	13	30	6518	70	1393	254	10	6	5	6	2	8347

Traffic surveys (12 hour daytime) carried out since May 2001 show that the number of vehicles that have 3 axles or more (these generally exceed 18 Tonnes GVW) has reduced from a range of 216 to 343 from surveys carried out between 2001 and 2005, to 29 vehicles during the same 12 hour daytime period in March 2008. Similarly, vehicles with six axles have reduced from a range between 34 to 53, to 2 in 2008. This indicates that although the number of HGVs has dropped significantly since the weight restriction was introduced in 2006, loads up to 40 Tonnes are still being applied to the structure. The traffic count surveys also indicate that the number of cars have remained at about 6500 during the same 12-hour period.

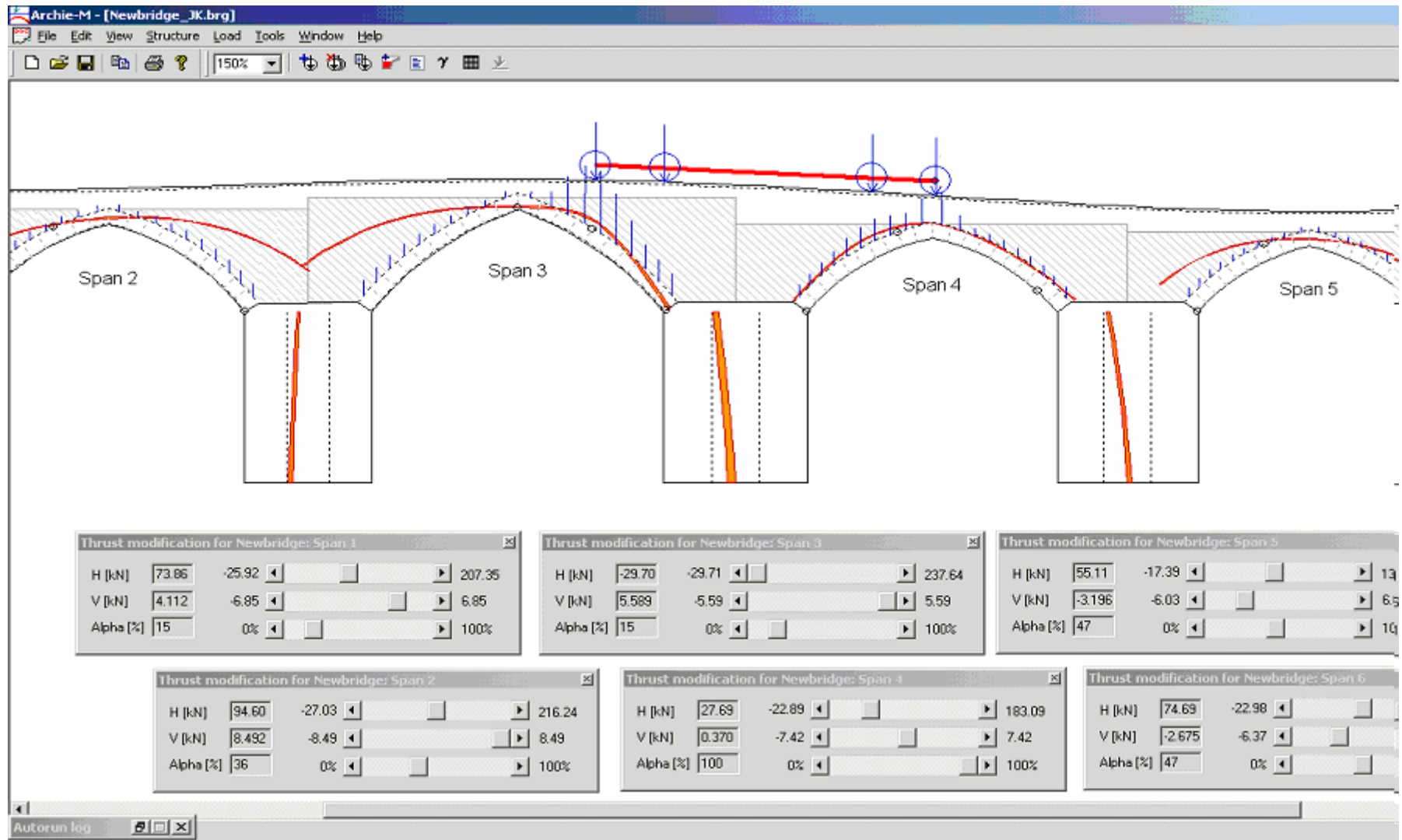
APPENDIX E

Preliminary Assessment Review

Results of a preliminary review carried out with Archie-M analysis software using the survey and construction data recorded as part of previous assessments



Worst Arch Case



Worst Pier Case

APPENDIX F

Details & Discussion of Strengthening Options Considered

- F.1 Replacement of Fill with Hydraulically Bound Material
- F.2 Grouting of the Existing Fill
- F.3 Over Slabbing
- F.4 Concrete Saddling
- F.5 Cintec's 'Archtec' System (Internally Reinforced) – Cintec Ltd
- F.6 The MARS System (Externally Reinforced) - SSP Consult Ltd
- F.7 Bersche - Rolt System (Externally/ Internally Reinforced) - Bersche-Rolt Ltd
- F.8 Structural Lining to Intrados
- F.9 Helifix Stitching System - Helifix Ltd

A number of strengthening methods have been evaluated for addressing the faults identified during previous assessments and inspections. These methods are set out in section 4.0, and are depicted in the sketches shown on pages 13-15. A description and discussion of each method is included below.

F.1 Replacement of Fill with Hydraulically Bound Material

This method increases the level of the effective arch backing (as recommended by the 1996 Stage 2 Assessment for achieving a 40 Tonne capacity, see section 3.2) in order to allow the thrust lines, generated by loads, to pass outside of the arch barrels.

The works would involve removing and replacing the existing fill above any existing effective backing over the arch barrels. If the existing fill extends for the full width of the carriageway down to the arch springing levels, i.e. there is no existing backing, approximately 225m³ of fill and 75m³ of road construction will need to be removed and replaced.

Mass concrete is usually used to form the structural backing for this technique, but a limecrete, or dry compacted lean mix could be used as an alternative. Before cement, lime was extensively used for foundation work, and for masonry mortar. It can accommodate some movement of the structure, as unlike concrete that fails with a few substantial cracks, limecrete tends to micro-crack to accommodate movement. Limecrete allows the passage of moisture and air through it, and so micro cracking can self heal as free Calcium Hydroxide reacts with air borne moisture.

Since hydraulic lime does not bond too tightly to the substrate it can be removed and replaced at a later date, whereas the bond formed by cement mortars is so strong that the original stonework could be damaged.

The nominal compressive strength achievable with limecrete is around 6-8N/mm², which will be adequate for this application. It does however develop strength more slowly than cement based materials and so longer term closure of the bridge to traffic, or at least HGV traffic, is likely to be necessary. Trial mixes should be carried out to establish the curing time and strength development.

Although the replacement hydraulically bound backing will relieve the lateral pressures exerted on the spandrel walls by live loading, stainless steel mesh reinforcement, or polymer geogrid reinforcement could be included in the backing above the arch barrels to prevent further lateral movement of the spandrel walls, longitudinal cracking/ joint opening of the arch barrels. The reinforcement can be specified with a design life of 120 years. Embedded in Limecrete, it can be easily inspected with trial hole investigation in the future, and a replacement scheme could be carried out when necessary. The strength of the parapet walls are not addressed by this method, and will need separate consideration. Refer to sections 6.2.

One could install a waterproofing membrane over a concrete slab above the raised backing to prevent ingress of water and salts.

Removal of the existing fill will affect the stability of the arches. The lack of detail currently available about the make up of the arch barrels and their backing makes it difficult to assess whether any temporary support will be necessary. Conservatively assuming that support is required, careful planning and control of the works will be necessary to gain approval from the Environment Agency. The stability of the spandrel walls will also need to be assessed for any hydraulic pressure the replacement fill exerts during placement.

Although the completed works would not affect the appearance of the bridge, the method is intrusive in that it disturbs and removes the existing fill over the arches. The fill is likely to be of historical value, and may lead to prolonged archaeological excavation work in order to permit and justify its removal. The significance of this could be established in the course of trial hole investigations to determine the level of effective arch backing and thickness of the spandrel wall over the bridge, that are necessary to help understand the load mechanisms that are causing the lateral separation of the arch barrel. It may be possible to leave a strip of original fill running along the centre of the structure in order to preserve an element of any in-situ historical value.

The road will need to be closed to carry out the fill excavation and replacement works. The round trip from the bridge, on roads of the same or higher classification as the A415, is approximately 45km. The diversion around the 12km link of the A road network that the bridge serves is about 34km.

The known utilities, see section 7.4, run above the arch crowns in the road construction. These can readily be supported, protected, and slewed in order to accommodate the proposed works.

F.2 Grouting of the Existing Fill

Similar to the replacement of fill method above, pressure grouting of the existing fill behind the arches aims to form an effective backing to carry thrust lines outside of the arch barrels, to potentially achieve a 40 Tonne capacity. The main advantage of this being that it would not be necessary to excavate the existing fill from over the arches, and the stability of the arches would then not be affected, and there would be a much reduced affect on the traffic using the A415. Although unlikely, any resulting heave of the carriageway could be rectified with inlay resurfacing. It is therefore a relatively economical method of strengthening.

The grout is injected under pressure through cores made in the intrados, typically 50mm diameter on a 600mm grid, until a fixed pressure is maintained for a specified time and evidence of spread is observed at adjacent holes. Although the spread and quantity of grout injected can be monitored, it is difficult to determine the exact extent and distribution the treatment has achieved.

As with the replacement fill method described in section F.1, the flowable cementitious grout that is usually used could be replaced with a lime based grout in order to work sympathetically with the arch's existing materials and structural mechanisms.

Repointing work will need to proceed any injection to prevent extrusion out through the joints, which may cause staining of the arch barrel and pollution of the watercourse. Extrusion will act to fill any voids and cracks at the back of the arch barrels, but may also seal roosts used by bats and birds.

It may be difficult to ensure that the injection nozzle is located at the extrados, and is neither too deep nor too shallow. It is therefore important that trial holes are opened across the bridge to understand the extent and make-up of the extrados and the backing.

Trial holes are also necessary to determine the nature (porosity & strength) and composition of the existing fill material. Fills with high silt or clay content may not be suitable for this technique as the grout needs to be able to pass through the material to achieve a in a uniform coverage. The 1993 core (section 3.3) indicated that the fill contained clay and gravel. The photos from the March 1991 utility trenching across the bridge indicate a sandy gravelly fill (see section 3.3). Trial mixes & possible trial grouting will be necessary to ensure that a viable grouting solution can be implemented. Partial coverage of grouting may only add problems, for as well as not achieving distribution of vehicular loads, water draining through the fill could be concentrated into fewer paths that could damage the remaining unbound fill by washing out fines.

Although the completed works would have little affect on the overall appearance of the bridge, the process would also result in a grid of core holes through the stone barrels, which although can be plugged with either the original stone core or a replacement stone core, may be noticeable on the intrados. Also, Injection of grout (lime or cementitious based) will change the nature of the existing fill, such that the historical value may be lost, or be unrecoverable.

Provided that the quality of the workmanship is good, and that the grouting achieves good penetration and consistent coverage through the backing, then ongoing maintenance will be no more onerous than the existing periodic requirements of repointing and stone replacement.

The solution doesn't fully address the lateral separation problems occurring in the arch barrels beneath the spandrel walls, though it will relieve the problem by increasing the distribution of wheel loads. The strength of the parapet walls are not addressed by this method, and will need separate consideration. Refer to section 6.2.

The known utilities, see section 7.4, run above the arch crowns in the road construction. These will not be affected by the proposed works.

F.3 Over Slabbing

At its simplest, this method comprises a load spreading slab to reduce intensity of live loads, though this is unlikely to generate a full load carrying capacity in this case due to the shallow depth of fill over the arches. Over slabbing can also comprise shallow prestressed slabs, arranged to be simply supported at the piers, and over-span each span. This changes the load carrying paths, such that the proposed over slabs would carry live loads, whilst the existing arch barrel is left to support the remainder of the existing fill. This would relieve the spandrel walls of lateral loads.

As with the fill replacement option F.1, the road will need to be closed to carry out the fill excavation and over-spanning works. The quantity of fill to be removed will be less in this case and so the stability of the arches during the works will be less compromised. The works themselves are however more complex, and so will most likely take longer.

Over slabbing doesn't change the structure's appearance, but is intrusive where supports are trenched across the structure above each pier. The proposed works will prevent access to the arches' extrados, which will affect future maintenance operations, and could obscure problems. The strengthening measures themselves will be shallow, and relatively easy to inspect and replace.

The existing utilities (see section 7.4) running across the tops of the arch crowns in the bridge are likely to cause difficulties if they cannot be raised above the over slabbing elements. Diversions may be required.

The strength of the parapet walls are not addressed by this method, and will need separate consideration. Refer to sections 6.2.

F.4 Concrete Saddle

Saddling involves the removal of existing fill and casting an in-situ concrete arch over the top of the existing arches. The saddle may be plain concrete (with optional articulation) to thicken the existing stone arch barrel and share the loads, or it can comprise reinforced concrete to relieve the stone arch of all of the live load. Given the level of increased backing that is required to bring the capacity of the bridge up to standard, the reinforced concrete option is the only viable saddling option.

Reinforced concrete saddles can be designed to carry the 40/44 Tonne independently of the existing arch, which can be used as permanent (debonded) formwork. However, relieving the existing arch of dead loads can have a detrimental effect in the long term, making them more sensitive to movement and vibration.

Saddling doesn't change the structure's appearance, but is a relatively intrusive option in that it removes the existing fill that may have historical value. The strengthening elements are buried, and so is difficult to inspect and maintain. The structural connection with the existing stonework above each support will result in its damage during future maintenance and replacement.

Saddle solutions provide a good solution where arches are deformed, or cracked, or where the lateral load on spandrels is causing problems. Saddling can also include a waterproofing membrane that seals the arch from the problems of existing and future water penetration and the resulting deterioration. However, water that does penetrate can be trapped within the structure, and so drainage should be installed at the back of each arch above the supports.

As with the replacement fill option, see section F.1, removal of the fill will affect the stability of the arches. The lack of detail currently available about the make up of the arch barrels and their backing makes it difficult to assess whether any temporary support will be necessary. Conservatively assuming that support will be required, careful planning and control of the works will be necessary to gain approval from the Environment Agency.

The existing utilities (see section 7.4) running across the tops of the arch crowns in the bridge are likely to cause difficulties if they cannot be raised above or accommodated within the saddling concrete.

As with the fill replacement option F.1, the road will need to be closed to carry out the fill excavation and concrete saddling works.

The strength of the parapet walls are not addressed by this method, and will need separate consideration. Refer to sections 6.2.

F.5 Cintec's 'Archtec' System (Internally Reinforced)
(www.cintec.co.uk)

Cintec's 'Archtec' system involves installation of stainless steel bars (rods) through the arch barrel, to work compositely with the masonry and provide the arch barrel with bending capacity. Holes are cored through the arch barrel from the carriageway level, into which the bars are inserted and grouted into place. A high performance grout delivered through a fabric sock system is designed to ensure a reliable grout to masonry bond over the full length of the bar, as well as filling voids that exist in the cored masonry. The figure below shows how the system would be applied to arch 3 of Newbridge.

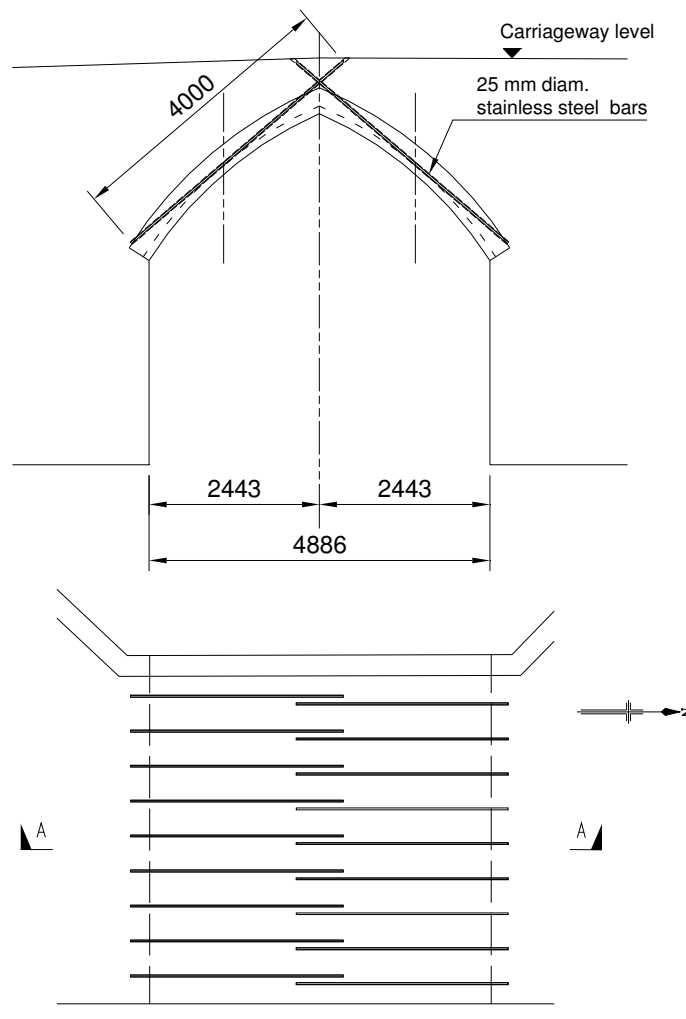


Figure: Cintec's 'Archtec' Strengthening System
(shown applied to Newbridge, arch 3)

Cintec bars (or Helifix, see F.9) can also be installed horizontally across the arch barrel to prevent further movement of the spandrel wall away from the arch barrel.

The system is installed entirely within the fabric of the structure, and so the appearance of the structure is unaltered. It has been used on a number of historically important buildings and structures with the approval of English Heritage.

Preliminary calculations carried out by Cintec's consultant Giffords, indicate that the method is able to raise the structure's capacity to 40/44 Tonnes. To facilitate efficient and reliable design, and assessment, Gifford have developed the use of FDEM for the analysis of masonry arches (see figure below).

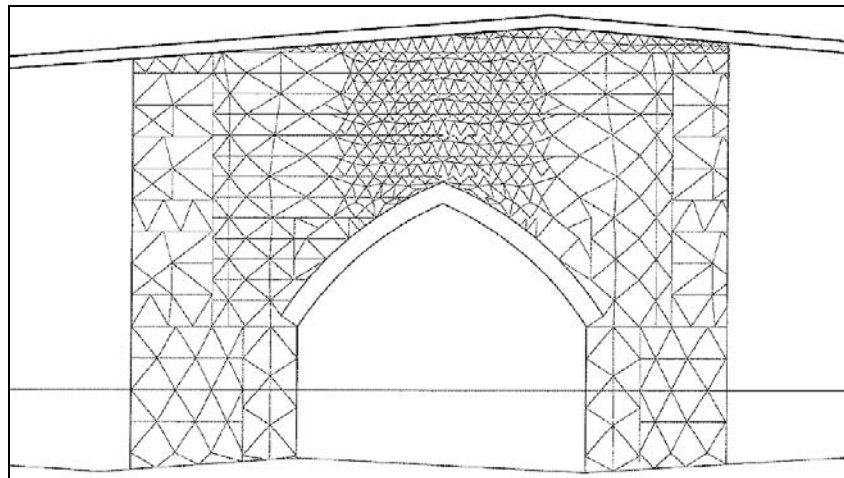


Figure: The Finite/Discrete Element Method applied to Newbridge, Arch 3

The stonework in the arch barrels of Newbridge has been shown to be vulnerable to fracture where compressive stress is released, and so coring close to the surface of the stonework may cause spalling damage. The coring and grouting of the reinforcing bars into the stone fabric is not reversible, so will compromise the life of the structure in the long term, and the internal nature of the system means that inspection will be difficult. Further, because of the way the reinforcement ties the stonework together, the arches' ability to accommodate future movement such as settlement will be compromised.

The installation of the strengthening does not require significant excavation or temporary works, and traffic can therefore continue to flow during busy periods or allow the passage of emergency services.

The existing utilities (see section 7.4) runs across the tops of the arch crowns in the bridge, and may therefore need to be slewed in order to accommodate the required coring locations. Alternatively it may be possible to design the coring positions around the existing utilities.

The Cintec system can also be used to strengthen the parapets, by coring and inserting vertical and horizontal bars through the wall. The vertical bars could extend down in to spandrel walls to anchor the parapet walls. This may however result in damage to the spandrel walls and arch barrels in the event of vehicle impact (see section 6.2).

F.6 The Masonry Arch Repair and Strengthening (MARS) System (Externally Reinforced) (www.sspconsult.com)

The MARS system is capable of raising the structure's capacity to 40/44 Tonnes. Installation involves chasing slots longitudinally and transversely into the intrados of the arch barrel, and installing small diameter stainless steel high yield reinforcement. The resulting 'mesh' is tied back in to the arch at each intersection with stainless steel dowels, and then encapsulated with a polyurethane structural adhesive (from Universal Sealants) which provides high bond strength with flexibility. In a similar way to the Cintec (F.5) system, the reinforcement works compositely with the arch to provide bending capacity. It also ties the arch barrels transversely to prevent further lateral separation.

The stonework in the arch barrels of Newbridge has been shown to be vulnerable to fracture where compressive stress is released, and so chasing in to the surface of the stonework arch barrels may cause spalling damage. Chasing of the reinforcing bars into the stone fabric is not reversible, and so will compromise the life of the structure in the long term. Further, because of the way the reinforcement ties the stonework together, the arches' ability to accommodate future movement such as settlement will be compromised.

The structural adhesive is finished to provide a mortar joint appearance, and forms a grid pattern as shown in the figure below. The system's surface embedded form means that inspection and maintenance will be relatively straightforward, however the obtrusive appearance of the system on the surface of the existing 13th century stonework is unlikely to be acceptable to English Heritage.

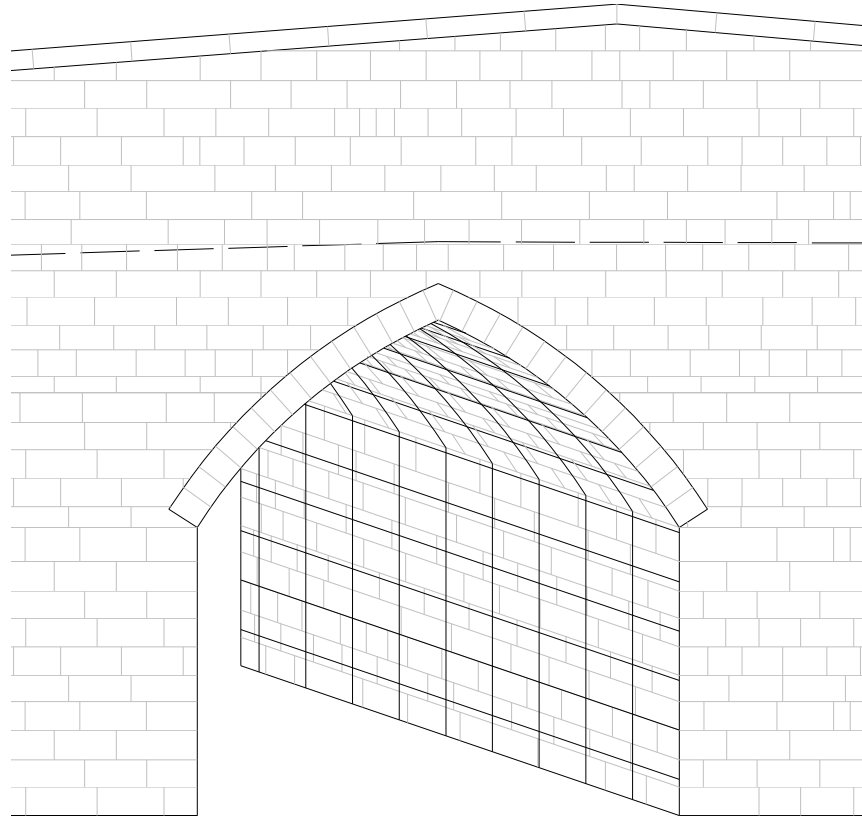


Figure: MARS system applied to the intrados of Newbridge, Arch 3

The installation of the strengthening is carried out from beneath and therefore does not affect traffic flows or existing utilities.

The Cintec (F.5), Bersche-Rolt (F.7), or Helifix (F.9) methods can be used in conjunction with the MARS system to strengthen the parapets, by coring and grouting vertical and horizontal bars through the wall. The vertical bars could extend down in to spandrel walls to anchor the parapet walls. This may however result in damage to the spandrel walls and arch barrels in the event of vehicle impact (see section 6.2).

F.7 The Bersche-Rolt System (Internally Reinforced) (www.bersche-rolt.co.uk)

The Bersche-Rolt system is capable of raising the structure's capacity to 40/44 Tonnes. Installation involves installing stainless steel reinforcement into near surface holes that are cored longitudinally around, and transversely across the arch barrel. In a similar way to the Cintec system (F.5), the core is injected with cementitious grout to bond the reinforcement into the arch, where it then works compositely with the arch to provide bending capacity. Stainless steel spacers are used to hold the steel in position, and help the grout to completely surround each bar to maximise bond. The horizontal bars also tie the arch barrels transversely to prevent further lateral separation.



Figure: Bersche-Rolt System

The system is installed within the fabric of the structure. In order to drill longitudinally around the arches, masonry needs to be removed to form a starting face. The picture above (left) shows this being carried out in a brick masonry arch, but removal and replacement of stone masonry at Newbridge may present a significant problem.

The stonework in the arch barrels of Newbridge has been shown to be vulnerable to fracture where compressive stress is released, and so coring close to the surface of the stonework may cause spalling damage. The coring and grouting of the reinforcing bars into the stone fabric is not reversible, and so will compromise the life of the structure in the long term, and the internal nature of the system means that inspection will be difficult. Further, because of the way the reinforcement ties the stonework together, the arches' ability to accommodate future movement such as settlement will be compromised.

The installation of the system is carried out from beneath, and therefore does not affect traffic flows or existing utilities.

The technique can also be used to strengthen the parapets, by coring and grouting vertical and horizontal bars through the wall. The vertical bars could extend down in to spandrel walls to anchor the parapet walls. This may however result in damage to the spandrel walls and arch barrels in the event of vehicle impact (see section 6.2).

F.8 Structural Lining to Intrados

This form of strengthening is capable of raising the capacity of the bridge to 40/44 Tonnes.

F.8.1 In-situ Sprayed/ Formed Concrete Lining

This method involves spraying or forming a concrete layer against the intrados of the arch barrel. The bond between the concrete and the relatively soft and porous limestone arch barrel is likely to be inadequate, and so reinforcement would need to be connected to the intrados prior to the application of the concrete in order to create a structural connection.

Research and testing has shown that the load capacity of a masonry arch can be significantly increased through the application of a layer of sprayed concrete to the intrados that is relatively thin in comparison to the thickness of the arch barrel.

F.8.2 Prefabricated Lining

Prefabricated liners (e.g. steel, fibre reinforced concrete, reinforced concrete, bonded fibre reinforced polymer) can be manufactured to accurately match the arch barrel, such that the resulting space between the liner and the arch can be grouted (lime or cement based) to achieve a structural connection. It would need to be connected to the existing bridge at the springing of each arch.

Both of these methods however would involve the attachment of structural components to the intrados of the bridge, which could damage the structure when removed.

Such an arrangement would fundamentally change the appearance of the structure and would need to be designed in keeping with the medieval structure to look architectural, otherwise it is likely to be unsightly. English Heritage have already stated that it would be an unacceptable solution. In any case, the option would permanently reduce the available waterway clearance beneath the bridge, and will be unacceptable to the Environment Agency. It can therefore be discounted as a viable form of solution.

F.9 Helifix Stitching System
(www.helifix.co.uk)

The Helifix system is a local stitching system that could be used to stabilise the lateral separation that is being observed in the barrel, but is not able to act as a whole arch strengthening technique in this case.

It involves the use of stainless steel ties, spiralled in profile, that are knocked in to holes drilled through the masonry, and filled with a cementitious mortar. This is a cost effective method of tying masonry together, however it cannot increase the assessed load capacity alone.

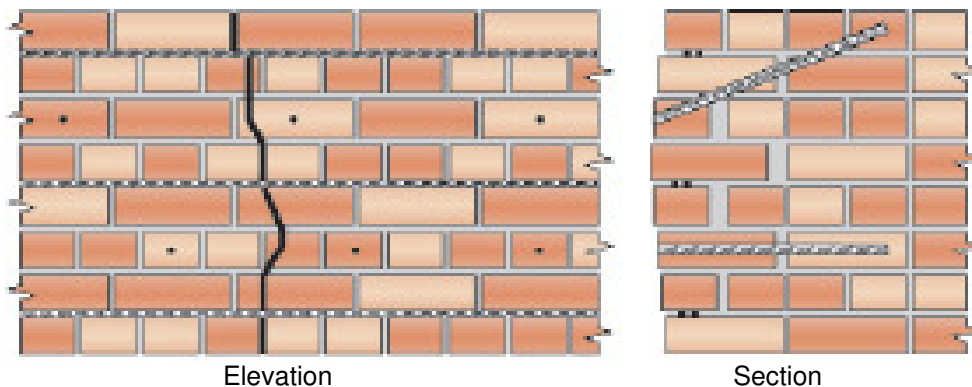


Figure: Helifix stitching system

The stonework in the arch barrels of Newbridge has been shown to be vulnerable to fracture where compressive stress is released, and so coring close to the surface of the stonework may cause spalling damage. The coring and grouting of the reinforcing bars into the stone fabric is not reversible, and so will compromise the life of the structure in the long term, and the internal nature of the strengthening means that inspection and maintenance will be difficult. Further, because of the way the reinforcement ties the stonework together, the arches' ability to accommodate future movement such as settlement will be compromised.

The installation of the system is carried out from beneath the structure, and therefore does not affect traffic flows or existing utilities.

The technique can also be used to strengthen the parapets, by coring and grouting vertical and horizontal bars through the wall. The vertical bars could extend down in to spandrel walls to anchor the parapet walls. This may however result in damage to the spandrel walls and arch barrels in the event of vehicle impact (see section 6.2).