

--APPENDIX B - Table 1 STRENGTHENING OPTIONS

STRENGTHENING SYSTEM	Arches Requiring strengthening for 3, 7.5 and 18/40 tonne capacities			Further investigation required to ascertain if strengthening technique is viable	RISK TO STRUCTURE DURING STRENGTHENING WORKS	LEVEL OF TRAFFIC DISRUPTION LIKELY	LEVEL OF INTRUSION & POST WORKS EFFECT ON STRUCTURAL ACTION	EFFECT ON UTILITIES	SIMPLICITY OF FUTURE ASSESSMENTS	LIFE SPAN, & INSPECTION OF MEASURES	EFFECT ON WATERWAY	RISK TO ECOLOGY	Engineer comments 2009
	3 Tonnes	7.5 tonnes	18 / 40 tonnes										
<p>REPLACEMENT OF FILL WITH NEW WELL COMPACTED GRANULAR MATERIAL TO PROVIDE AN ANGLE OF SHEARING RESISTANCE OF 0= 40 DEGREES (ASSUMING EXISTING FILL IS ONLY 30 DEGREES) (note 1)</p> <p>Exposing the arch would also allow a new waterproof membrane to be installed to reduce possible future water damage and improve the durability of the structure</p>	<p>No works required to spans 1,2,4,5, and 6</p> <p>Analysis has shown that span 3 can not be strengthened to 3 tonnes with this method, and would require strengthening with an alternative technique.</p>	<p>No works required to spans 4,5 and 6</p> <p>Analysis has shown that span 2 will pass 7.5 tonnes, however spans 1 and 3 can not be strengthened to 7.5 tonnes with this method, and would require strengthening with an alternative technique.</p>	<p>Fill to be placed in spans 4,5 and 6</p> <p>Analysis has shown that span 1, 2 and 3 can not be strengthened to 18/40 tonnes with this method, and would require strengthening with an alternative technique.</p>	<p>The shearing resistance of the existing fill is unknown and should be investigated. Strengthening requirements shown are based on the existing fill having a 0 = 30 degrees.</p> <p>Ground investigation will entail rotary boreholes, to prevent vibratory damage to the structure which may result from percussive techniques. The bores would be 100mm diameter and located at each pier abutment.</p> <p>Trial pits also to be undertaken to investigate existing properties.</p>	<p>Careful removal / placement of new fill material symmetrically would be necessary to ensure integrity of arch. This would significantly increase the construction period.</p> <p>To limit vibration necessary to compact new fill a sand material which would be relatively self compacting should be used.</p> <p>Typically the maximum angle of densely compacted well graded sands (with angular particles) is 45 degrees.</p> <p>Centering (i.e. Supporting arch from below) may be required to support the arch but is vulnerable to flood/ river impact damage which may fail the arch.</p>	<p>Full road closure necessary for works duration. Significant disruption.</p>	<p>Once complete the appearance of the bridge will be unaltered, but existing fill is fully replaced in affected arches.</p> <p>The structural action will remain as existing.</p>	<p>Will require protection and support whilst fill is replaced</p>	<p>Standard analysis</p>	<p>Can be designed to be removed and replaced without damage to existing stonework.</p> <p>Will last for a significant number of years until overtaken by other failure factors such as arch deterioration.</p> <p>Measures will be removable for future replacement</p> <p>Likely to be greater than 120years design life.</p>	<p>During works: Potential to require centering which would necessitate supporting the arch from the underside which may affect the river thus requiring Environment Agency approval.</p> <p>EA may require works to be carried out in winter months when the centering is more likely to be damaged by flooding/fast flows.</p> <p>Post works: None</p>	<p>Low.</p> <p>Consent and Mitigation required</p> <p>Will not require use of cementitious materials.</p> <p>Bat roosts would be disturbed and full ecology survey necessary before works. May be necessary to provide further roost locations once works are complete.</p>	<p>Little gain of capacity with a significant alteration to the structural fabric of the fill. Method not considered further within main report.</p>
<p>GROUTING OF THE EXISTING FILL TO INCREASE BACKING LEVELS (note 1 and 4) (lime based grout material pressure grouted into fill – installed from carriageway level on a 600 – 1000mm grid)</p>	<p>No works required to spans 1,2,4,5, and 6</p> <p>Grouting of span 3 necessary. However backing level requires increasing to virtually full height of arch. (Note 2)</p>	<p>No works required to spans 4,5 and 6</p> <p>Spans 1, 2 and 3 will require varying degrees of backing level.</p>	<p>All spans will require varying degrees of backing level.</p>	<p>Requires physical investigation & testing of existing fill using rotary boreholes to ensure the fill material is of sufficient classification to permit / accept grouting.</p> <p>An archaeological survey is likely to be necessary, utilising trial pits within the carriageway fill before grouting could commence</p> <p>Generally Particle sizes of the existing fill less than 200 microns will not permit sufficient flow of grout under pressure.</p> <p>Ground investigation will confirm if existing backing level is present and possibly if internal spandrel walls exist.</p>	<p>Minimal – However whilst the grout would be placed under pressure this should not be too high a pressure as this could cause damage to the weak structure.</p> <p>If leaking does occur it could stain the exterior of the structure, unless carefully monitored and controlled during grouting operations.</p>	<p>Minor - road closure during works, open outside of working hours</p>	<p>Nature of existing fill material is modified. Grid of injection core plugs will be visible in carriageway until re surfaced.</p> <p>Dead load increase may cause settlement which would have to be determined and addressed within any detailed design.</p> <p>It is unclear unless a trial zone is undertaken to ascertain if sufficient strength can be gained to the material to class it as backing which would require sufficient strength to accommodate the line of thrust.</p>	<p>None. These will be worked around</p> <p>Possibility of filling ducts with grout if care is not taken.</p>	<p>Standard analysis with new backing levels.</p> <p>The effectiveness of grouting is determined by the ingress of the grout to adjacent injection holes, however the variable nature of the fill material can affect the effectiveness of the method.</p>	<p>Once in place it is not possible to visually inspect the strengthened fill, however cores should be undertaken during the works to ascertain the strength and effectiveness of the grouting. (can only be undertaken locally – see Engineers comments).</p> <p>Careful Records of volumes of grout and its distribution would have to be recorded during the works.</p> <p>Grouted fill can be broken out in the future, however fill removed would be a hard material and may cause vibrations to the structure during removal which could affect the stability of the arch unless specialist removal techniques are used.</p> <p>Likely to be greater than 120years design life.</p>	<p>None during or post works with the exception of pollution monitoring boats within river ensuring no grout leech into water is taking place.</p> <p>Potential for grout under pressure to leak through voids in stoneworks. All joints above water level to be reported. Dependent of findings of ground coring if there is potential for grout to leak from joints below water level it will be necessary to use divers to fill joints below water. However it would be unrealistic to expect all voids to be filled thus any grout leakage would cause pollution of the River Thames.</p>	<p>Bat roosts would be disturbed and full ecology survey necessary before works. May be necessary to provide further roost locations once works are complete.</p> <p>Potential for grout under pressure to leak through voids in stoneworks. All joints above water level to be reported. Dependent of findings of ground coring if there is potential for grout to leak from joints below water level it will be necessary to use divers to fill joints below water. However it would be unrealistic to expect all voids to be filled thus any grout leakage would cause pollution of the River Thames.</p>	<p>Intrusive effect on existing fill.</p> <p>Possible solution to be considered within main report. However concern that whilst the effectiveness of the grouting can be ascertained locally by coring, it is not possible to verify its effectiveness throughout the entire structure thus there remains an unknown risk element to this strengthening technique – i.e. not being fully effective</p> <p>This shall not be considered if fill within piers is likely to allow grout leakage into the watercourse.</p>
<p>OVER SLABBING Relieving pressure on the arch by placing concrete slabs over arches supported on existing abutments.</p>	<p>Works to span 3 only</p>	<p>Works to spans 1,2 and 3 only</p>	<p>All spans require over slabbing</p>	<p>Requires survey to determine level of top of arches by use of coring or trial pits at the arch crown.</p> <p>Ground investigation at piers required to ascertain if an over slab supported at the pier locations would settle and hence require mitigation measures to prevent or accommodate settlement which otherwise could overload and collapse the arch.</p> <p>There appears to be approximately 450mm (Min) between the carriageway surface and the top of arch 3.</p>	<p>Centering may be required to support the arch but is vulnerable to flood/ river impact damage which may fail the arches.</p>	<p>Full road closure necessary for works duration. Significant disruption.</p>	<p>Strengthening would not be visible on completion, but removes some existing fill and changes the structural action.</p> <p>Alters structural action of arch, as slab now carries live load.</p> <p>Slab must not induce point loads on crown of arch (possible insufficient room for slab), which could cause collapse of the arch.</p>	<p>Will require diversion if ducts can not be accommodated with slab.</p>	<p>Standard analysis</p> <p>The new over slab would be buried and cannot be inspected for deterioration for future assessment which would be necessary</p>	<p>The over slab would be designed for a 120 year design life to current standards.</p> <p>Break out of a concrete slab to replace in the future would cause vibration which could damage / collapse the arch.</p>	<p>During works: Potential to require centering which would necessitate supporting the arch from the underside which may affect the river thus requiring Environment Agency approval.</p> <p>Post works: None</p>	<p>Low.</p> <p>Consent and Mitigation required</p> <p>Bat roosts would be disturbed and full ecology survey necessary before works. May be necessary to provide further roost locations once works are complete.</p>	<p>Concern expressed over intrusive effect on existing fill & Stonework</p> <p>Significantly affects the behaviour of the existing structure. Option could be considered for arch 3, if sufficient room above the arch is found.</p>
<p>PLAIN CONCRETE SADDLING Nominal reinforcement would be provided to provide lateral strength.</p> <p>The saddling can also be combined with raising backing levels due to the fill having to be removed to accommodate the saddle.</p>	<p>Works to span 3 only</p>	<p>Works to spans 1,2 and 3 only</p>	<p>All spans require saddling.</p>	<p>Requires survey to determine level of top of arch and arch thickness utilising trial pits at the arch crowns.</p> <p>Soil investigation of existing fill required to ascertain if fill can be reused for backfill (thus maintaining the existing fill material within the structure), can be determined from trial pit investigations.</p>	<p>Centering may be required to support the arch but is vulnerable to flood/ river impact damage which may fail the arches</p>	<p>Full road closure necessary for works duration. Significant disruption.</p>	<p>The saddle would be designed to effectively increase the existing ring thickness to act in conjunction with existing arch.</p>	<p>May require diversion if they cannot be accommodated within saddle.</p> <p>They will need to be temporarily supported during the works.</p>	<p>Standard analysis</p> <p>The saddle would be designed as an increase to ring thickness (may need stainless steel ties to be installed if the stone extrados is insufficiently rough to key the concrete and stone)</p>	<p>Connection of materials to existing stonework likely to cause damage when removed</p> <p>The design life for the concrete would be classified for a 120 years, it would most likely greatly exceed this, particularly if stainless steel ties are used and the saddle waterproofed</p>	<p>During works: Potential to require centering which would necessitate supporting the arch from the underside which may affect the river thus requiring Environment Agency approval.</p> <p>Post works: None</p>	<p>Low.</p> <p>Consent and Mitigation required</p> <p>Bat roosts would be disturbed and full ecology survey necessary before works. May be necessary to provide further roost locations once works are complete.</p>	<p>Concern expressed over intrusive effect on existing fill & Stonework, and life limiting modifications</p> <p>As method would require the removal of fill to the arch option may be considered in conjunction with a permanent weight limit to mitigate the need for saddling all arches. Saddling is a conventional method of strengthening arches and is to be considered further within the report.</p>
<p>RC CONCRETE SADDLING Arch designed using RC arch theory.</p> <p>The saddling can also be combined with raising backing levels due to the fill having to be removed to accommodate the saddle.</p>	<p>Works to span 3 only</p>	<p>Works to spans 1,2 and 3 only</p>	<p>All spans require saddling.</p>	<p>Requires survey to determine level of top of arch</p> <p>Soil investigation of existing fill required to ascertain if fill can be reused for backfill (thus maintaining the existing fill material within the structure), can be determined from trial pit investigations.</p>	<p>Centering may be required to support the arch but is vulnerable to flood/ river impact damage which may fail the arches</p>	<p>Full road closure necessary for works duration. Significant disruption.</p>	<p>Strengthening would not be visible on completion, but removes existing fill and changes the structural action</p> <p>If backing levels are increased at the same time as saddling a check should be undertaken to determine if settlement will occur.</p>	<p>May require diversion if they cannot be accommodated within saddle</p> <p>They will need to be temporarily supported during the works.</p>	<p>Standard analysis for RC concrete arch</p>	<p>Permanent relief of dead load to arch ring may destabilise arch barrels and lead to collapse.</p> <p>Not possible to remove without causing significant damage or collapse of the arch.</p> <p>120 year design life.</p>	<p>During works: Potential to require centering which would necessitate supporting the arch from the underside which may affect the river thus requiring Environment Agency approval.</p> <p>Post works: None</p>	<p>Low.</p> <p>Consent and Mitigation required</p> <p>Bat roosts would be disturbed and full ecology survey necessary before works. May be necessary to provide further roost locations once works are complete.</p>	<p>Concern expressed over intrusive effect on existing fill & Stonework and life limiting modifications</p> <p>Identical fabric will be affected to that of plain saddling but with a greater risk of collapse to the existing arch, due to the relief of dead load and a reduced design life to that of plain saddling – therefore plain saddling considered rather than this form of strengthening within the report.</p>
<p>CINTEC's ARCHTEC (Specialist Design by Cintec)</p>	<p>Works to span 3 only</p>	<p>Works to spans 1,2 and 3 only</p>	<p>All spans require strengthening.</p> <p>Anchor installation required at 350mm spacings at arch 3 and 700mm at all other arches.</p>	<p>Due to friable nature of stone (previously reported when obtaining core in the 1990's) there is potential for the stone to crumble and the strengthening being ineffective therefore an early test bar installation would be necessary to ensure the system is viable before proceeding with a design based on this option. A trial pit exposing the arch / bar at the 1/4 point would be necessary to ensure the stone has accommodate the reinforcement without damage or fracture. An accurate survey of the arch would be necessary, including obtaining the actual ring thickness of each arch to allow an accurate design.</p>	<p>Risk of fracture damage to stone barrel, resulting in spalling/ loss of stone during construction or at a later date (testing of installation necessary).</p>	<p>Minor - road closure during works, however open outside of working hours where possible.</p>	<p>Invisible, but intrudes into existing stonework, changes the structural action, and is vulnerable to differential settlement of supports tracking levels.</p>	<p>May require diversion</p>	<p>Requires specialist assessment by Cintec</p>	<p>Irreversible life limiting modification of stonework, difficult to inspect</p> <p>Potential for reinforcement to corrode and not feasible to upgrade after 120 years, however the method uses stainless steel bars which may increase the life of the strengthening beyond this.</p>	<p>None</p>	<p>Low.</p> <p>Consent and Mitigation required</p> <p>Bat roosts would be disturbed and full ecology survey necessary before works. May be necessary to provide further roost locations once works are complete.</p>	<p>Concern expressed over intrusive effect on the Stonework and life limiting modifications</p> <p>This method has been used on a number of schemes including Listed Structures and should be considered within the report for a possible 40 tonne strengthening.</p>
<p>SSP's MARS (Specialist design by SSP Consult)</p>	<p>Works to span 3 only</p>	<p>Works to spans 1,2 and 3 only</p>	<p>All spans require strengthening.</p>	<p>Due to friable nature of stone (previously reported when obtaining core in the 1990's) there is potential for the stone to crumble and the strengthening being ineffective therefore an early test bar installation would be necessary to ensure the system is viable before proceeding with a design based on this option. (i.e. the stone does not crumble during installation) An accurate survey of the arch would be necessary, including obtaining the actual ring thickness of each arch to allow an accurate design.</p>	<p>Risk of fracture damage to stone barrel, resulting in spalling/ loss of stone during construction or at a later date (testing of installation necessary).</p>	<p>Minor disruption due to site activities.</p> <p>Due to the weak status of the structure limited road closures may be necessary even though the works are taking place from below.</p>	<p>Grid lines visible on surface of masonry, intrudes into existing stonework, changes structural action, and is vulnerable to differential settlement of supports</p>	<p>None</p>	<p>Further assessment by MARS</p>	<p>Irreversible modification of stonework. Surface embedded so can be inspected and replaced.</p> <p>120 year design life</p>	<p>During works Barge access to soffit required.</p> <p>Post works: None</p>	<p>Low.</p> <p>Consent and Mitigation required</p> <p>Bat roosts would be disturbed and full ecology survey necessary before works. May be necessary to provide further roost locations once works are complete.</p>	<p>Concern expressed over intrusive effect on existing fill & Stonework and life limiting modifications.</p> <p>Not considered further due to high visual impact to intrados</p>
<p>BERSCHE-ROLT (Specialist design by Bersche – Rolt)</p>	<p>Works to span 3 only</p>	<p>Works to spans 1,2 and 3 only</p>	<p>All spans require strengthening.</p> <p>Helifix bars to be installed not greater than 300mm centres.</p>	<p>Due to friable nature of stone (previously reported when obtaining core in the 1990's) there is potential for the stone to crumble and the strengthening being ineffective therefore an early test bar installation would be necessary to ensure the system is viable before proceeding with a design based on this option. An accurate survey of the arch would be necessary, including obtaining the actual ring thickness of each arch to allow an accurate design.</p>	<p>Risk of fracture damage to stone barrel, resulting in spalling/ loss of stone during construction or at a later date (testing of installation necessary).</p> <p>Possible displacement of stones as a result of raking out joints to guide directional drill.</p> <p>Method currently untested on stonework.</p>	<p>Minor disruption due to site activities</p> <p>Due to the weak status of the structure limited road closures may be necessary even though the works are taking place from below.</p>	<p>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</p>	<p>None</p>	<p>Future assessment by Bersche-Rolt</p>	<p>Irreversible life limiting modification of stonework, difficult to inspect</p> <p>Feasible to insert further bars between existing when they reach the end of their serviceable 120 year design life, however this would further affect the existing fabric of the structure.</p> <p>120 year design life</p>	<p>During works Barge access to soffit required.</p> <p>Post works: None</p>	<p>Low.</p> <p>Consent and Mitigation required</p> <p>Bat roosts would be disturbed and full ecology survey necessary before works. May be necessary to provide further roost locations once works are complete.</p>	<p>Concern expressed over intrusive effect on existing fill & Stonework and life limiting modifications</p> <p>It is necessary to locally open up a hole (approx 50mm diameter / 100mm deep) in the intrados (close to the spring point) and rake out further joints around the circumference of the intrados to guide the reinforcement, at each bar location. This method is to be considered further within the main report as an alternative to cintec.</p>
<p>STRUCTURAL LINING TO INTRADOS (Can be applied using a wet or dry process)</p>	<p>Works to span 3 only</p>	<p>Works to spans 1,2 and 3 only</p>	<p>All spans require strengthening.</p>	<p>Yes</p>	<p>Minimal</p>	<p>Minor disruption due to site activities</p> <p>Due to the weak status of the structure limited road closures may be necessary even though the works are taking place from below.</p>	<p>Significant detriment to visual impact of bridge. Increased dead load may cause settlement.</p> <p>Concrete used effectively increases the existing ring thickness of the arch and acts in conjunction with the existing arch.</p>	<p>None</p>	<p>Standard analysis with thicker barrel</p>	<p>50 – 75 years – easy to inspect</p> <p>120 year design life.</p>	<p>Significant – system reduces arch opening permanently</p>	<p>Medium - seals access to intrados. Consent and mitigation required</p> <p>Bat roosts would be disturbed and full ecology survey necessary before works. May be necessary to provide further roost locations once works are complete.</p>	<p>Unacceptable</p> <p>Not considered further due to high visual impact to intrados</p>

1. Analysis is based of the ARCHIE software package. Alternative systems may vary outcome.
 2. Using the software programme ARCHIE for arch 3 it has been found necessary to provide a backing level for virtually the full height of the arch, indicating that the geometry of arch 3 is the limiting factor. Alternative analysis may distribute loadings differently making geometry less onerous, and make increasing backing levels a viable solution.
 3. Refer to main report for recommendations for further investigation. The recommended investigation should be completed prior to a strengthening technique chosen.
 4. It is assumed within the assessment that no backing level is present. Intrusive site investigations should be undertaken to establish an existing backing level exists.