A1 in Northumberland: Morpeth to Ellingham

Scheme Number: TR010059

6.49 Options Appraisal of River Coquet Bridge Foundation Stabilisation and Scour Protection System

Rule 8(1)(c)

Infrastructure Planning (Examination Procedure) Rules 2010

Planning Act 2008

May 2021

Infrastructure Planning

Planning Act 2008

The Infrastructure Planning (Examination Procedure) Rules 2010

The A1 in Northumberland: Morpeth to Ellingham

Development Consent Order 20[xx]

Options Appraisal of River Coquet Bridge Foundation Stabilisation and Scour Protection System

---

Rule Reference:	8(1)(c)
Planning Inspectorate Scheme Reference:	TR010059
Document Reference:	6.49
Author:	A1 in Northumberland: Morpeth to Ellingham Project Team, Highways England

Version	Date	Status of Version
Rev 0	May 2021	Deadline 7

CONTENTS

TABLES

1 INTRODUCTION AND BACKGROUND

1.1.1. This technical note has been produced to detail the options considered for the north bank of the proposed River Coquet underbridge.

1.1.2. The south bank pier design is not considered here and options considered and reflected have been detailed in the Preliminary Scour Assessment (Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] (Appendix F) and Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] (Appendix E)). The design at this location has few viable options or feasible alternatives given the location of the pier and relative slope stability.

1.1.3. The proposed design of the northern pier bridge foundations has changed from the original submitted design due to new geotechnical information obtained during the 2020 ground investigation. Geotechnical considerations and risks are detailed below.

1.1.4. The proposed design for the northern pier bridge foundation has been selected from a range of options. It has been determined that there is a requirement to protect the northern pier foundation from the potential loss of support which could occur as a result of scour along the toe of the northern valley slope. Scour protection measures are therefore required to maintain the integrity of the northern pier foundation.

1.1.5. Potential scour protection solutions are detailed below with the preferred solution being a rock armour revetment which aims to maintain the existing channel cross section profile as closely as possible within the relevant design parameters. This rock armour protects the stability piles and bridge foundation and also prevents scour from outflanking the solution through erosion of the banks in the downstream reach. Construction works also require regrading and impact to the natural riverbanks to form the temporary works and bridge crossing. Reinstatement of the banks to the original condition will require additional erosion protection measures until the disturbed banks are re-established.

1.1.6. The bridge has a design life of 120 years and climate change is predicted to lead to increased magnitudes of flow within this time, increasing the potential for scour. Current Design Manual for Roads and Bridges (DMRB) design guidance considers these extreme events and is summarised below in section 3.

1.1.7. This document provides a summary of the selection of the preferred option and is presented in the following sections:

2. Geotechnical considerations and risks
3. Scour protection design guidance
4. Summary of options considered for scour protection of the northern riverbank
5. Qualitative assessment of potential scour protection options
6. Conclusion

2 GEOTECHNICAL CONSIDERATIONS / RISKS

2.1.1. The geotechnical risks associated with the proposed bridge need to be managed in accordance with DMRB CD622 – Managing Geotechnical Risk. In accordance with this Standard, work to date has included detailed desk studies and geomorphological mapping, which has identified that the proposed bridge is situated in a deep, steep sided valley which on the north bank in particular contains significant evidence of slope instability, both historical and active.

2.1.2. Work carried out up to the end of PCF Stage 3, excluded any intrusive ground investigations within the valley due to the difficult and complex access requirements and as such, those investigations were only completed in 2020 as part of the PCF Stage 5 Early Works Order.

2.1.3. The recent ground investigation established that the northern valley side comprises of a mixture of recent made ground associated with the construction of the existing bridge in the 1970’s, colluvium associated with previous phases of instability and alluvium associated with the river. Intact bedrock, although exposed in the cliffs at the crest of the valley slope is not exposed in a large portion of the slope and only appears again at river level.

2.1.4. Instability of the northern slope is attributed in part to the erosion and undercutting at the toe of the slope with the loss of support triggering landsliding. Site observations and slope movement monitoring confirm active slope movement at the proposed location of the new bridge which is likely to be increased by any further erosion along toe of the slope.

2.1.5. The ground investigation showed a marked difference in the bedrock beneath the existing and proposed pier locations. The existing pier is founded on a competent sandstone unit, which extends slightly downstream and to the east whereas the rock present at riverbed level downslope of the proposed pier comprises a weak mudstone. Whilst the sandstone unit at the existing pier is relatively resilient to erosion the mudstone present at the proposed pier is more susceptible to erosion.

2.1.6. Considering the proposed structure is within the floodplain of the River Coquet and this is a dynamic environment in conjunction with climate change predictions, erosion of the toe of the valley slope is anticipated to continue and potentially worsen over the intended design life of the structure and ultimately lead to larger scale instability and the failure of the northern valley slope including the proposed location of the northern pier foundation.

NORTHERN PIER DESIGN

2.1.7. Following on from the ground investigation and the confirmation of current instability of the northern valley slope, an appraisal of six potential remedial options was undertaken to facilitate the construction of a new pier on the northern valley slope. The options were selected based on engineering judgement and consideration of typical engineering measures to address significant slope instability.

2.1.8. Considering the likelihood for future erosion along the toe of the northern valley slope and potential for this reduce the stability of the northern valley slope and adversely affect the northern pier foundation, a reasonable and prudent engineering assumption was made that scour protection in the form of rock armour to the toe of the northern valley slope would be permissible as required for all options.

2.1.9. The slope stabilisation options considered were:

a. **Soil nails to mitigate slope instability in combination with a conventional piled pier foundation –** This solution would comprise a series of rows of soil nails being installed into the slope to achieve stability. This solution would require the provision scour protection along the toe of the slope to prevent a progressive slope failure from occurring. It has been discounted because of the risk that excessive slope movements and resultant loading of the pier foundation could occur before stability is achieved.

b. **Anchored ground beams to mitigate slope instability in combination with a conventional piled pier foundation –** This solution would comprise the installation of anchored ground beams parallel to the slope to achieve stability. This solution would also require the provision scour protection along the toe of the valley slope to prevent a progressive slope failure from occurring. It has been discounted because of the risk that deeper-seated slope movement, beneath the ground beams, and resultant excessive loading of the pier foundation could still occur.

c. **A caisson pier foundation designed to accommodate additional loads from slope instability without other slope stabilisation measures –** This solution would comprise the construction of a large diameter caisson foundation designed to resist additional ground loads associated with potential slope movement. To prevent the potential loss of down slope support, exposure of the foundation and resultant excessive lateral loading, this solution would require the provision of scour protection along the toe of the valley slope. This option is not favoured because of increased structural complexity and reliance on only the adequacy of the bridge foundation to accommodate potential slope instability and associated ground movements.

d. **A piled pier foundation designed to carry additional loads from slope instability –** This solution would comprise a conventional piled foundation designed to resist additional loads associated with potential slope instability. To prevent the potential loss of down slope support, exposure of the foundation and resultant excessive lateral loading, this solution would require the provision of scour protection along the toe of the valley slope. This option is not favoured because of increased structural complexity and reliance on only the adequacy of the bridge foundation to accommodate potential slope instability and associated ground movements.

e. **Anchored slope stabilisation piles to mitigate slope instability with conventional piled pier foundation –** This solution would comprise the installation of anchored non-interlocking (contiguous) slope stabilisation piles. To achieve an efficient design and to prevent potential exposure of the slope stabilisation piles this solution would require scour protection to be provided along the toe of the valley slope. Whilst not discounted this solution is less favourable than conventional slope stabilisation piles because of its increased complexity, requirement for multiple construction techniques and the long-term maintenance requirement associated with ground anchors.

f. **Conventional slope stabilisation piles to mitigate slope instability with conventional piled pier foundation –** This solution would comprise the installation of a non-interlocking (contiguous) slope stabilisation piles without the provision of ground anchors. To achieve an efficient design and to prevent the potential exposure of the slope stabilisation piles this solution would require scour protection to be provided along the toe of the valley slope. This option is preferred because it provides a robust and relatively simple solution and does not require ongoing maintenance.

3 SCOUR PROTECTION DESIGN GUIDANCE (DMRB CD356)

3.1.1. With storms in the UK expected to become both more severe and more frequent as a consequence of climate change, there are potentially increased structural risks to highway bridges and other highway structures, due to severe weather events, with scour and flooding being a leading cause of bridge failure both in the UK and worldwide (CD356).

3.1.2. Prior guidance ("old DMRB") relevant to the hydraulic design of watercourse crossings are as follows:

a. BD97/12 The Assessment of Scour and Other Hydraulic Actions at Highway Structures (Standard).
b. BA59/94 The Design of Highway Bridges for Hydraulic Action (Advice Note).
c. HA107/04 Design of Outfall and Culvert Details (Advice Note).

3.1.3. The recent revisions to the DMRB ("new DMRB") show that BD97/12 is retained for the assessment of existing structures to fluvial scour. BA59/94 and HA107/04 have both been withdrawn and replaced with the following Works Specifications:

a. CD 356 Design of Highway Structures for Hydraulic Action (formerly BA59/94).
b. CD 529 Design of Outfall and Culvert Details (formerly HA107/04).

3.1.4. CD 356 is applicable to all new structures in or over rivers, estuaries and floodplains and includes the design of scour protection measures and other river training works for both temporary and permanent works. This applies to the River Coquet underbridge which is both over and has temporary and permanent structural elements within the channel confines.

3.1.5. In summary, there is a requirement under DMRB guidance to assess the hydraulic action on the structure, and if required provide appropriate scour protection measures. A preliminary scour risk assessment has been undertaken and is presented in Environmental Statement Addendum: Stabilisation Works for Change Request [REP4-063] (Appendix F) and Environmental Statement Addendum: Southern Access Works for Change Request [REP4-064] (Appendix E). Hydraulic modelling results have been examined and currently the findings of this preliminary assessment are under review. Initial assessment of channel hydraulics indicates that there is likely to be limited changes from the preliminary assessment and that scour protection measures are required to protect both the north bank.

4 OPTIONS FOR EROSION PROTECTION MEASURES FOR NORTH BANK

4.1.1. The proposed rock armour scour protection system compliments the overall stability of the northern valley slope and proposed northern pier foundation with the current slope stabilisation measures and pier design proposals dependent on the provision of scour protection.

4.1.2. The provision of rock armour scour protection would inhibit natural river processes and result in the loss of natural riverbank habitat. Therefore, a total of seven alternative options have been considered for stabilising the section of the northern valley slope and the riverbank located below the proposed northern pier location; these are:

a. **Option 1 Sheet pile wall (interlocking) without scour protection –** This option would comprise a row of sheet piles embedded in the riverbank in close proximity to the river channel with the riverbank reinstated using locally won stone and soil with no rock armour. The sheet piles would be designed to act as cantilevers to account for the potential loss of down slope support in the event of scour and erosion of the riverbank. The installation of sheet piles would create a potential barrier to natural groundwater flows in the valley slope which is likely to reduce the overall stability of the valley slope.

b. **Option 2 Non-interlocking (contiguous) small diameter piles without scour protection –** This option would comprise a row of small diameter reinforced concrete piles embedded in the riverbank but set back from the river channel. The existing riverbank and profile would be largely undisturbed following construction and there would be no provision for scour protection which would allow the riverbank to potentially erode up to the line of the piles. This solution would require allowance for potential ongoing maintenance and reinstatement of the riverbank in the event of scour. Without reinstatement of scoured material there is a risk that exposure of the piles would allow material to be washed out between and from behind the piles with resulting instability of the overlying slope.

c. **Option 3a Non-interlocking (contiguous) piles with strengthened soil scour protection –** This option would comprise a row of small diameter reinforced concrete piles embedded in the riverbank but set back from the river channel. The existing riverbank would be excavated and replaced with a strengthened soil solution comprising layers of embedded geosynthetic reinforcement and a ‘green / grey’ vegetated facing system. This would limit the potential for natural scour of the riverbank. The reinstatement of the riverbank with reinforced soil would allow the piles to be designed with a reduced allowance for loss of support but the long-term durability of the reinforced soil against scour would require further consideration – it would be very difficult to establish its longevity with respect to the required design life. Typically, strengthened soil solutions with a vegetated facing system are not used in environments with a high risk of scour because of the potential for unravelling and collapse to occur. This would be a bespoke solution with no directly comparable examples available to prove durability. A requirement for substantial maintenance interventions cannot be ruled out.

d. **Option 3b Non-interlocking (contiguous) piles with stabilised soil mass scour protection –** This option would comprise a row of small diameter reinforced concrete piles embedded in the riverbank but set back from the river channel. The existing riverbank would be stabilised by soil mixing which would limit the potential for natural scour of the riverbank. The stabilisation of the riverbank would allow the piles to be designed as slope stabilisation piles with a reduced allowance for loss of support. However, the long-term durability of the stabilised soil against scour would require further consideration – again it would be very difficult to establish its longevity with respect to the required design life. This would be a bespoke solution with no directly comparable examples available to prove durability. The use of stabilised soil to protect the riverbank would also create a barrier to natural groundwater flows in the valley slope which is likely to increase groundwater levels in the slope and reduce the overall stability. Provision of drainage to address this would be technically difficult to install and maintain as well as introducing a potential point of weakness beneath the stabilised material. This could risk destabilising the overall slope.

e. **Option 4 Non-interlocking (contiguous) small diameter piles with rock armour scour protection –** This option would comprise a row of small diameter reinforced concrete piles embedded in the riverbank but set back from the river channel. The existing riverbank would be protected against scour by partial excavation and replacement with rock armour. The rock armour would provide a durable solution against potential scour over the required design life and allow the piles to be designed as slope stabilising piles without a need to act as a cantilever retaining wall. To achieve stability given predicted peak flows, rocks placed for this purpose would be DN50 of c. 800-1000 mm. Over time natural colonisation could be expected to occur.

f. **Option 5a Interlocking (secant) large diameter piles without drainage or scour protection –** This option would comprise a row of large diameter interlocking (secant) reinforced concrete piles embedded in the riverbank but set back from the river channel. The existing riverbank and profile would be largely undisturbed and there would be no provision for scour protection which would allow the riverbank to potentially erode up to the line of the piles. The piles would need to be designed as a cantilever retaining wall with a retained height of c. 4-5 m to account for potential scour of the riverbank in front of the piles and associated loss of support to the piles. The use of interlocking piles would create a barrier to natural groundwater flows in the valley slope which is likely to increase groundwater levels in the slope and reduce the overall stability. This could adversely affect the stability of the existing bridge structure.

g. **Option 5b Interlocking (secant) piles with drainage but no scour protection –** This option would comprise a row of large diameter interlocking (secant) reinforced concrete piles embedded in the riverbank but set back from the river channel. The existing riverbank and profile would be largely undisturbed and there would be no provision for scour protection which would allow the riverbank to potentially erode up to the line of the piles. The piles would need to be designed as a cantilever retaining wall with a retained height of c. 4-5 m to account for potential scour of the riverbank in front of the piles and associated loss of support to the piles. Whilst the use of interlocking piles would create a barrier to natural groundwater flows in the valley slope the provision of drainage would allow groundwater levels to be managed reducing the risk of instability to the valley slope and the existing bridge structure.

5 SUMMARY OF QUALITATIVE ASSESSMENT OF ADVANTAGES AND DISADVANTAGES OF EACH OPTION

5.1.1. A preliminary qualitative assessment of the potential advantages and disadvantages of each erosion protection option are summarised in the Table 5-1 below.

Table 5-1 - Options for North Bank

Option	Technical suitability	Groundwater impact	Constructability	Expected relative construction cost	Maintenance	Visual Appearance	Natural processes/channel morphology	Ecology
Option 1 - Sheet pile wall embedded in riverbank within close proximity to river channel with no rock armour	Robust solution to scour. Heavy sheet pile sections located in close proximity to the edge of existing river channel likely to be required to satisfy slope stabilisation and structural capacity requirements. Risk that interlocking sheet piles will restrict groundwater flows resulting in potential slope instability adjacent to works (see next column).	Groundwater flows restricted by row of interlocking sheet piles with resultant destabilising effect to valley slope. Potential for concentrated groundwater discharges adjacent to works with potential to destabilise the existing bridge.	Conventional sheet piling not possible due to shallow bedrock. Installation would require difficult pre-augering and/or installation within backfilled concrete trough with associated significant disturbance. Access to install sheet piles close to the river bank more difficult than alternative set back options.	Medium – Costs increased by required method of installation.	Permanent solution requiring minimal maintenance. Permanent pedestrian / vehicle access not required.	Immediately following construction, the appearance of the riverbank would be similar to existing with the potential for natural re-vegetation. However, potential future scour could result in exposure of the embedded sheet piles and the creation of a c. 2-3 m high vertical sheet pile face.	Likely proximity of sheet piles to edge of channel will make it difficult to reinstate existing channel profile. Position will also restrict natural erosion to immediate edge of channel.	Construction would result in the loss of existing habitat. Re-vegetation likely to occur over a relatively short period following construction with the re-establishment of the natural habitat possible.
Option 2 - Non-interlocking (contiguous) piles embedded in riverbank with set back from channel with no scour protection.	No protection against scour. Risk that piles are overloaded and fail if scour occurs with consequent risk of instability to valley slope and bridge structure. Potential for rapid deterioration to occur without sufficient warning / time for remedial intervention.	No significant change to groundwater but risk that washout failure occurs through / between piles if scour and loss of down slope support occurs.	Solution constructable using conventional methods and techniques.	Low – Single operation.	Potential for frequent maintenance and risk that bridge closures may be required if substantial erosion occurs. Permanent pedestrian / vehicle access required.	Immediately following construction, the appearance of the riverbank would be similar to existing with the potential for natural re-vegetation. However, potential future scour could result in exposure of the embedded piles and the creation of a c. 4-5 m high vertical concrete face.	Existing channel profile can be broadly reinstated as existing. Allows natural erosion to occur up to position of piles.	Construction would result in the loss of existing habitat. Re-vegetation likely to occur over a relatively short period following construction with the re-establishment of the natural habitat possible.

Option	Technical suitability	Groundwater impact	Constructability	Expected relative construction cost	Maintenance	Visual Appearance	Natural processes/channel morphology	Ecology
Option 3a - Non-interlocking (contiguous) piles embedded in riverbank but set back from channel with riverbank reinstated as strengthened (geosynthetic reinforced) soil mass.	Strengthened soil will restrict scour but difficult to ensure long term durability of solution. Risk that piles are overloaded and fail if scour occurs with consequent risk of instability to valley slope and bridge structure.	Negligible change to groundwater. Groundwater able to flow between piles with limited reduction of flow through strengthen soil mass.	Solution constructable using conventional methods and techniques but reinstatement of existing bank with strengthened soil mass challenging because of required excavation and replacement of in-situ materials.	Medium – Multiple operations required.	Permanent solution requiring minimal maintenance. Permanent pedestrian / vehicle access not required.	Immediately following construction, the appearance of the riverbank would be similar to existing with the potential for natural re-vegetation. However, potential future scour could result in exposure of the embedded piles and the creation of a c. 4-5 m high vertical face.	Existing channel profile can be broadly reinstated as existing but strengthened soil mass would prevent natural erosion from occurring.	Construction would result in the loss of existing habitat. Re-vegetation likely to occur over a relatively short period following construction, but re-establishment of the natural habitat would not be possible because of the risk of damage to the strengthened soil by larger vegetation (e.g. trees). This would require ongoing landscaping / vegetation management to prevent damage.
Option 3b -Non-interlocking (contiguous) piles embedded in riverbank with set back from channel with riverbank reinstated as stabilised (soil mixed) soil mass.	Stabilised soil will restrict scour and provide assurance against rapid deterioration but potential risk with long term durability. Stabilised soil will restrict groundwater flows with risk of slope instability adjacent to works (see next column).	Groundwater flows restricted by stabilised soil mass with resultant increased destabilising effect to valley slope requiring heavier stabilisation measures. Potential for concentrated groundwater discharges and slope erosion adjacent to works with potential to destabilise the existing bridge.	Solution constructable but will require specialised techniques if in-situ stabilisation of bank proposed. Alternative ex-situ stabilisation challenging because of required excavation and replacement of in-situ materials. In-situ stabilisation also has an increased risk of pollution during the works associated with control of binders.	High – Multiple operations and construction techniques required (i.e. piling and soil mixing).	Permanent solution requiring minimal maintenance. Permanent pedestrian / vehicle access not required.	Immediately following construction, the appearance of the riverbank would be similar to existing with the potential for natural re-vegetation. However, potential future scour could result in exposure of the embedded piles and the creation of a c. 4-5 m high vertical face.	Existing channel profile can be broadly reinstated as existing but stabilised soil mass would prevent natural erosion from occurring.	Construction would result in the loss of existing habitat. Re-vegetation likely to occur over a relatively short period following construction, but re-establishment of the natural habitat would not be possible because the stabilised soil block would restrict root penetration. The different soil chemistry of the stabilised soil is also likely to change the type of vegetation establishment.

Option	Technical suitability	Groundwater impact	Constructability	Expected relative construction cost	Maintenance	Visual Appearance	Natural processes/channel morphology	Ecology
Option 4 - Non-interlocking (contiguous) small piles embedded in riverbank with set back from channel with riverbank reinstated with rock armour scour protection.	Robust solution to scour with long term durability and low risk of potential failure of piles and instability of valley slope.	No significant change to groundwater. Groundwater able to flow between piles and through rock armour.	Solution constructable using conventional methods and techniques.	Medium - Multiple operations required.	Permanent solution requiring minimal maintenance. Permanent pedestrian / vehicle access not required.	The rock armour would result in a more engineered appearance to the river bank compared to the existing condition; however, it would prevent future scour of the river bank and the potential future exposure of the embedded concrete piles. It is also possible that limited natural vegetation of the rock armour would take place over the long-term.	Existing channel profile can be broadly reinstated as existing, but rock armour would prevent natural erosion from occurring.	Construction would result in loss of existing habitat. Re-establishment of natural habitat would not be possible because of the rock armour but limited re-vegetation would occur in the longer-term.
Option 5a - Interlocking (secant) large diameter piles embedded in riverbank with set back from river channel without drainage or scour protection.	No protection against scour but larger diameter / capacity piles can be designed to prevent overloading / failure if scour occurs. Risk that row of interlocking piles will restrict groundwater flows resulting in potential slope instability adjacent to works (see next column).	Groundwater flows restricted by row of interlocking piles with resultant increased destabilising effect to valley slope requiring heavier stabilisation measures. Potential for concentrated groundwater discharges and associated slope erosion adjacent to works with potential to destabilise the existing bridge.	Solution constructable but will require larger piling plant. Solution also requires increased materials (e.g. volume of concrete).	High – Heavier piling plant and increased materials.	Potential for frequent maintenance if slope erosion occurs adjacent to works. Permanent pedestrian access required.	Immediately following construction, the appearance of the river bank would be similar to existing with the potential for natural re-vegetation. However, potential future scour could result in exposure of the embedded piles and the creation of a c. 4-5 m high vertical concrete face.	Existing channel profile can be broadly reinstated following works. Allows natural erosion to occur up to position of piles.	Construction would result in the loss of existing habitat. Re-vegetation likely to occur over a relatively short period following construction with the re-establishment of the natural habitat possible.
Option 5b - Interlocking (secant) large	No protection against scour but larger diameter /	Groundwater flows restricted by row of interlocking piles but	Solution constructable but will require larger piling plant. Solution	High - Heavier piling plant and	Periodic maintenance of drainage required	Immediately following construction, the	Existing channel profile can be largely reinstated following	Construction would result in the loss of existing habitat. Re-

Option	Technical suitability	Groundwater impact	Constructability	Expected relative construction cost	Maintenance	Visual Appearance	Natural processes/channel morphology	Ecology
diameter piles embedded in riverbank with set back from river channel with drainage provision but no scour protection.	capacity piles can be designed to prevent overloading / failure if scour occurs. Risk of slope instability associated with interruption of slope drainage mitigated by provision of drainage (see next column).	groundwater levels controlled by drainage mitigating the risk of destabilising effect to valley slope. Risk of concentrated groundwater discharges and slope erosion adjacent to works managed by appropriate outfalls to river.	also requires increased materials (e.g. volume of concrete).	increased materials.	to ensure it functions effectively. Permanent pedestrian access required with passive provision for access by maintenance plant for expected periodic maintenance / renewal of drainage.	appearance of the river bank would be similar to existing with the potential for natural re-vegetation. However, potential future scour could result in exposure of the embedded piles and the creation of a c. 4-5 m high vertical concrete face.	works. Allows natural erosion to occur up to position of piles with local restriction at drainage outfall.	vegetation likely to occur over a relatively short period following construction with the re-establishment of the natural habitat possible.

6 CONCLUSION

6.1.1. Option 3a (Non-interlocking piles with strengthened soil mass) and Option 3b (Non-interlocking piles with stabilised soil mass) are both considered to be unacceptable with respect to ensuring the integrity of the northern pier foundation. This is because of uncertainty over the long-term durability of the solution; therefore, both of these options are recommended to be discounted.

6.1.2. Option 2 (Non-interlocking piles without rock armour), is also considered unacceptable with respect to ensuring the integrity of the proposed northern pier foundation. This is because rapid deterioration could occur without the ability to undertake remedial works prior to the proposed northern pier foundation being adversely affected.

6.1.3. Option 1 (Sheet piles), is discounted because of the likely difficulty with installation and the risk that the sheet piles would create a barrier to natural groundwater flows which may destabilise the valley slope and existing bridge. The closer proximity of a sheet pile solution to the edge of the river would also restrict natural erosion.

6.1.4. Option 5a (Interlocking piles without rock armour and no drainage) and Option 5b (interlocking piles without rock armour but with drainage), whilst both enabling natural erosion to take place, require substantially more robust and costly engineering solutions to be provided to mitigate the potential loss of material along the toe of the valley slope. The removal of material along the toe of the valley slope could also result in the exposure of the piles and in the worst case the creation of a c. 4-5 m high vertical face formed by the exposed piles with associated visual impact. Option 5a will also disrupt natural groundwater flows in the northern valley slope, with an adverse effect to the stability of the northern valley slope, existing and proposed northern pier foundations. Whilst Option 5b addresses the risk of disruption to groundwater flows compared to Option 5a, the provision of drainage introduces an increased maintenance liability and associated increase in whole life cost.

6.1.5. Option 4 (Non-interlocking piles with rock armour) is preferred from an engineering perspective because it provides a relatively simple, robust and cost-effective solution to managing the risk of slope instability to the existing and proposed northern pier foundations. It is also advantageous because it reduces the potential requirement for future maintenance interventions. Option 4 would restrict natural erosion from occurring, but this would prevent the potential adverse visual impact associated with Options 5a and 5b if removal of material from the toe of the slope did result in exposure of the embedded piles. Option 4 also has some potential for establishment of vegetation which would improve long-term visual appearance.

6.1.6. On the basis of the assessment undertaken Option 4 (Non-interlocking piles with rock armour) is the preferred solution.

This document is also available on our website at **www.gov.uk /highways**

If you have any enquiries about this document A1inNorthumberland@highwaysengland.co.uk

or call **0300 470 4580***.