Access to Argyll and Bute (A83)

Strategic Environmental Assessment & Preliminary Engineering Services

Preliminary Assessment Report

Structures Appraisal Technical Note

A83AAB-JAC-SGN-XX_XX-TN-CB-0001 | C01

18/03/21

Transport Scotland

TS/MTRIPS/SER/2018/11

Document history and status

Revision	Date	Description	Auth	Checked	Reviewed	Approved
C01	18/03/21	Issued to Transport Scotland for Publication	J.R	M.M.	M.M	J.R.

Distribution of copies

Revision	Issue approved	Date issued	Issued to	Comments
C01	18/03/21	18/03/21	Transport Scotland	Issued to Transport Scotland for Publication

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Project No:	A83AAB
Document Title:	Strategic Environmental Assessment & Preliminary Engineering Services Preliminary Assessment Report - Structures Appraisal Technical Note
Document No.:	A83AAB-JAC-SGN-XX_XX-TN-CB-0001
Revision:	C01
Document Status:	A1 – Accepted - Brief
Date:	18/03/21
Client Name:	Transport Scotland
Client No:	TS/MTRIPS/SER/2018/11
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1. Introduction

1.1.1 The following is an initial assessment of potential structures solutions for the major bridges requirements for the 11 route corridors identified in the Access to Argyll and Bute (A83) study area.

1.1.2 The range of major structures includes viaducts, debris flow shelters and fixed link bridges. The locations of the bridges are shown in Figure 1.

1.1.3 Tunnels have been considered at various locations and are covered in a separate appendix to the Preliminary Assessment Report. There are a large number of other more minor structures that would be required within each route corridor. These are summarised in the Assessment Summary Tables (ASTs) but are not considered in this appendix.

1.1.4 The technical note is set out for each route corridor in separate sections.

Figure 1: Principal Marine Crossings

2. Route Corridor 1 - Glen Croe (Existing A83 Trunk Road)

2.1 Route Corridor Description

2.1.1 Various possible route options exist within Route Corridor 1, largely based on options considered as part of the 'A83 Trunk Road Route Study Part A - A83 Rest and Be Thankful' report, published in 2013. These routes have been evaluated and named as follows based on the 2013 report option colour coding:

- Yellow route option: The viaduct option
- Brown route option: The debris flow shelter (DFS) option
- Green route option: The South-west alignment option
- Purple route option: The valley floor-tunnel alignment option
- Pink route option: Tunnel option (not included in the 2012 report)

2.1.2 The indicative alignment of these possible route options within Route Corridor 1 is shown overleaf in Figure 2.

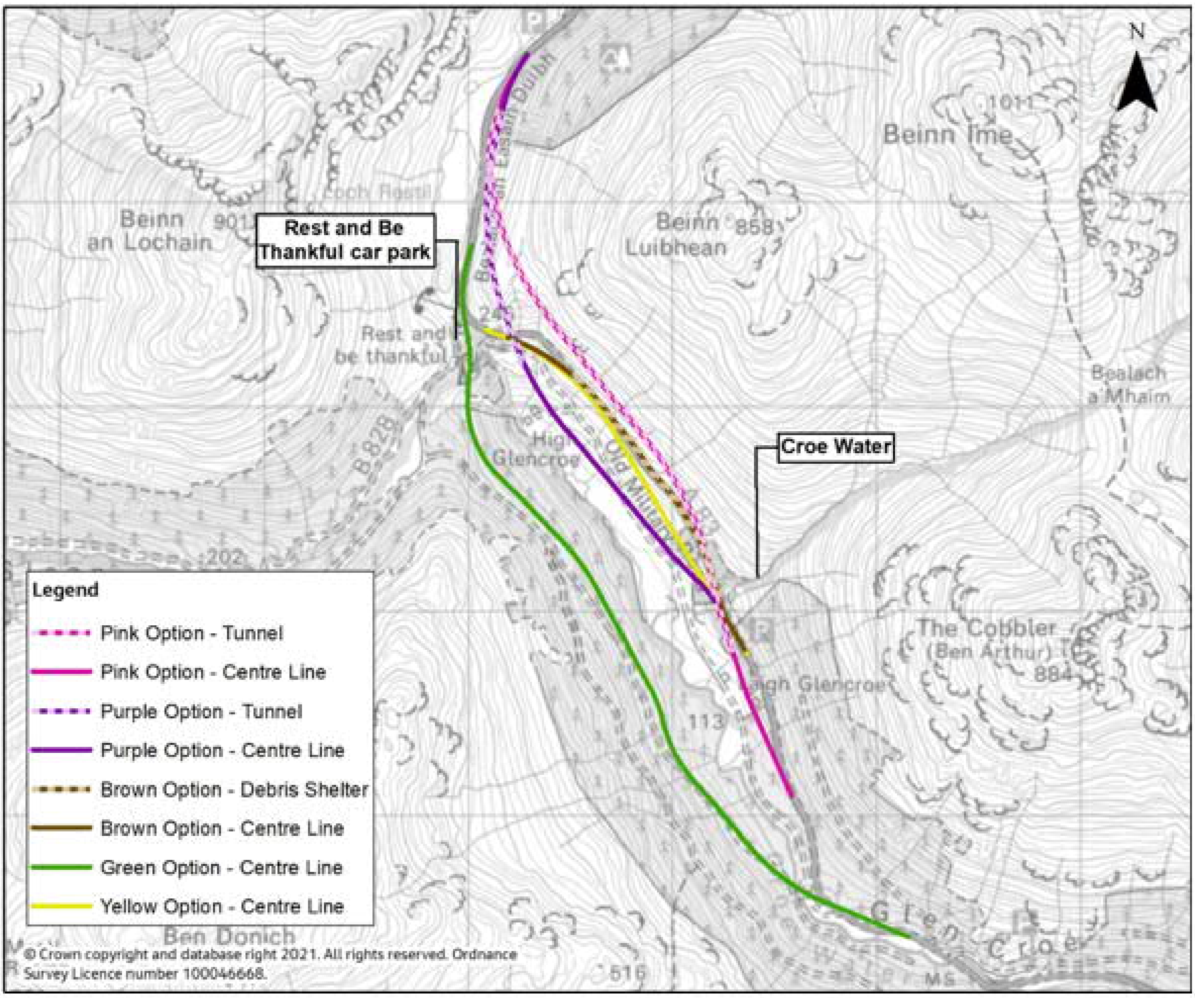


Figure 2: Route Corridor 1 - Possible Route Options

2.1.3 The following summarises the structures assessment of these five possible route options. These options represent routes within which variations are possible in road alignment and/or the structural form of supporting or auxiliary structures. For assessment purposes a potential outline alignment and/or structural form has been assumed to allow consideration of the main implications associated with the major structures. It is noted that this may be subject to refinement if the route corridor is taken forward for further stages of Design Manual for Roads and Bridges (DMRB) assessment.

2.2 Yellow Route Option: Viaduct Option

Description

2.2.1 The viaduct option is an offline sub-corridor starting from the bridge over the Croe Water between the Cobbler and Beinn Luibhean and ascending to the Rest and Be Thankful car park tie-in. A route visualisation is shown in Figure 3.

2.2.2 It runs approximately parallel to the existing A83 Trunk Road and re-joins the alignment of the existing A83 Trunk Road before the bend prior to the junction with the B828 local road and the access to the Rest and Be Thankful car park. This possible route option would provide a new 2.1km long single carriageway with approximately 1.8km on viaduct. This structure would be built on side-long ground, which is prone to landslides, and requires protection and deflector structures. It would generally follow a similar profile to the existing road with an average climbing gradient of approximately 5%.

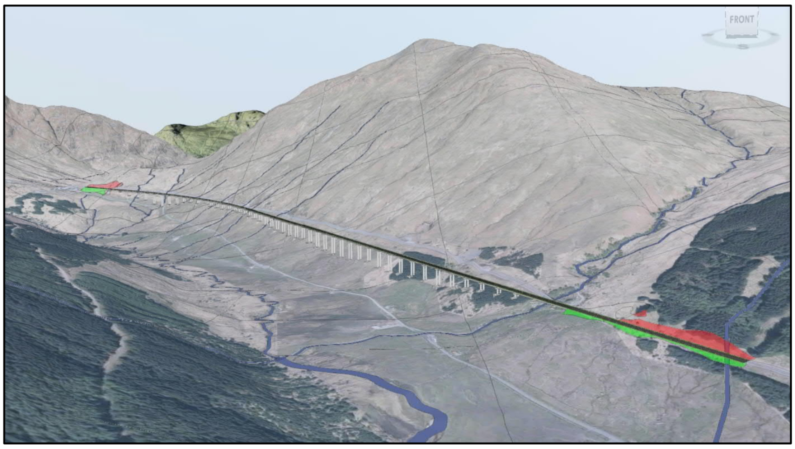


Figure 3: Yellow Route Option: Viaduct Visualisation (Autodesk InfraWorks 360, 2021)

Structures

2.2.3 The viaduct structure would be set at a sufficient level to permit debris flow events to pass below the A83 Trunk Road. There is no specific guidance on clearances to permit potential landslide, debris flow or rock-fall events to pass beneath structures; however, design development of any viaduct structure would have to consider factors such as, but not necessarily limited to; the magnitude of any event, source locations and pathways, relative position and spacing of piers and any deflector structures.

2.2.4 Arrestor or deflector structures would be located uphill from the viaduct posing a challenging construction sequence; the deflector structures themselves would necessarily be located on or close to the existing A83 Trunk Road which would require to remain open while these were under construction.

2.2.5 The viaduct would generally follow a similar profile to the existing road with an average climbing gradient of approximately 5%.

2.2.6 Existing road culverts may be removed, and natural gullies opened up. Whist the existing road construction might be broken up, advantage could be taken of the excavated ‘terrace’ to deploy arrestor or deflector structures to protect the piers of the viaduct.

2.2.7 Single leaf piers would be preferable for a sidelong viaduct to maximise the space below the deck. The leaf piers would be positioned as remotely as possible from known debris channels bearing in mind the requirement for an acceptable aesthetic. Nevertheless, their robust form will be designed to resist what errant debris bears against them (that might evade the deflectors). In addition to the piers’ structural resilience, upslope deflectors will also be required.

2.2.8 The deck level would preferably be set to match the level of the existing A83 Trunk Road carriageway to limit the visual broadening of the linear feature against the hillside, but depending on the route horizontal alignment to avoid impacting the Old Military Road (OMR), this may not be possible in all cases.

2.2.9 The deck would maintain the appearance of a linear feature by having a constant deck thickness and, commensurate with the spacing necessary to avoid existing debris runoff channels, spans of between 40m and 70m are likely to be required.

Construction

2.2.10 There are various methods by which to construct the deck. These include by post-tensioned segmental construction by balanced cantilever, incremental segmental span launching by gantry system or segmental or insitu launching from one end. For smaller structures, other methods such as use of precast deck sections or insitu concrete pours may be appropriate.

2.2.11 For the A83 Trunk Road to remain open during construction of an extended viaduct, access from the A83 Trunk Road to the pier locations is precluded. The more likely option is for pier access to be taken from the OMR or a temporary additional 'haul road' formed alongside; the OMR will have to remain serviceable during the Works in case of a landslide diversion.

2.2.12 Personnel access to the superstructure construction would be via these temporary roads. Material delivery and the progression of the superstructure construction would occur on the piers by one of the span-by-span or launched methods outlined above.

2.2.13 As an offline option with access from the valley floor and a span-by-span or launched deck construction, the viaduct's construction is likely to have only limited disruption to the A83 Trunk Road. This disruption would be limited to the locations where the proposed alignment would tie-into the existing A83 Trunk Road at the north and south ends of the route corridor. It would also be dependent on the construction methodology used for the sections of viaduct, with the use of temporary carriageways creating local diversions to allow sufficient working areas for construction a possibility. There would, however, be considerable disruption to the OMR, at least until a temporary haul road is constructed alongside.

2.2.14 At the southern abutments the alignment has a potentially significant impact to the A83 Trunk Road, so it would be recommended to divert the road offline at grade before commencing construction of the approach embankment. It may also be advisable to utilise a reinforced earth wall or similar system to prevent the earthworks encroaching onto the existing A83 Trunk Road.

2.2.15 Abutment works at the northern end of the structure have the potential to impact the A83 Trunk Road and the Rest and Be Thankful viewpoint, as well as the OMR, due to the constrained working area on a steep slope. Final positioning and design of the abutment will need to take cognisance of working space requirements.

2.2.16 Construction of piers on steep slopes presents a potential challenge for creating working access and supply of materials in some areas, which may require significant temporary works solutions.

2.2.17 Along this section of the A83 Trunk Road it is anticipated that rock could be up to 15m below ground level, depending on the alignment, and is likely to necessitate piling onto rock. This would require access to all pier locations to form the working areas necessary to construct the individual foundations. Reinforced concrete piers would then be constructed from the pile caps by insitu construction with a climbing formwork system.

2.3 Brown Route Option: Debris Flow Shelter Option

Description

2.3.1 The debris flow shelter option considers the possibility of an online solution following the route of the existing A83 Trunk Road. However, the challenge in providing such a structure, especially over the length required, is considerable.

2.3.2 The route generally maintains the alignment of the existing A83 Trunk Road. It is anticipated that the alignment may require some minor modification to attain a balance between cut on the upslope and fill on the downslope whilst accommodating the geometry of the structure. This may afford some opportunity to improve the existing alignment although this will be limited.

2.3.3 There is little opportunity to significantly modify the existing vertical alignment so this would be maintained at the existing approximately constant 5% gradient.

2.3.4 The following, therefore, sets out in some detail, a form and construction methodology that might successfully be deployed but recognises that considerable risks attach.

2.3.5 The construction of a single or series of debris flow shelters (DFS) is considered. These are sometimes referred to as rockfall sheds, to protect traffic and the road in the event of future debris flow events. The length over which this solution applies is approximately 1.3km.

2.3.6 DFSs, which are of a similar form to widely used rockfall or avalanche shelters, are engineered structures that form canopies over a section of road prone to debris flows. These structures are usually constructed from reinforced concrete and allow landslides to slide over the top of the structure without disrupting traffic flow.

2.3.7 However, for the A83 Trunk Road, the design aim must be, as far as is practicable, to enable construction over the existing road with live traffic and this greatly increases the construction difficulty.

2.3.8 The uphill topography varies with a number of channels eroded by existing watercourses and past material slips and the downslope from the existing road is itself prone to some instability. The width available to construction of such a structure is severely limited and includes only the width of the existing road and some very limited space created by the existing catchpits alongside the road. These exist only on a limited length and in places, the available width is further constrained.

2.3.9 Where structures such as these are deployed to arrest rock fall, impact energy is dissipated by placing a depth of granular material on the roof of the structures. However, the nature of the A83 Trunk Road landslides is such that the structure must be able to deflect a mixture of large boulder rock falls, gravel and slurry and water movements.

Design

2.3.10 The following outlines a form of DFS conceived to suit the requirements of the A83 Trunk Road. As part of the design development a comprehensive ground investigation would be required, in particular to determine the most suitable founding horizon; the nature of the ground to be excavated within the cuts; and slope stability for temporary works and the final design.

2.3.11 An insitu reinforced concrete structure is considered not to be practically feasible. Traditional insitu construction works would necessitate a prolonged closure of the A83 Trunk Road and reliance on the OMR for up to two or more years.

2.3.12 An alternative possible precast construction approach is proffered that could potentially be employed to minimise, although not eliminate, diversion onto the OMR during construction. The feasibility of any such scheme is heavily reliant on the practicalities of the construction phase.

2.3.13 A conceptual structural arrangement has been conceived to enable online construction which seeks to minimise the lengths of time during which the A83 Trunk Road is closed with a temporary diversion onto the OMR and allows for transit of traffic through the Works during construction.

2.3.14 The proposed structural form is modular enabling construction of the whole affected length to be undertaken in parts where sequence priority is given to lengths where the landslip risk is highest.

2.3.15 A DFS also has the potential for significant visual intrusion in a location such as the Glen Croe valley so particular attention would need to be given to the aesthetic form of the structure.

2.3.16 It is therefore proposed that a DFS would take the form of an open sided arch structure exemplified by the form shown in Figure 4.

2.3.17 Construction access to the site is severely limited and it is assumed that material delivery will be by road predominantly from the south via the A82 Trunk Road. The outline proposal assumes therefore that the limitations of the delivery route and the very constrained space for craneage and construction vehicles on site favour assembly of relatively small scale components. Small scale precast components could be manufactured elsewhere and transported to site or could be cast in a yard at the foot of the valley.

2.3.18 Two precast forms are outlined;

- Discrete precast concrete blocks arranged in a stretcher bond pattern; an annotated conceptual arrangement for the block shell is shown in Figure 5 and Figure 6, or an alternative;
- Precast arch rings in a similar configuration.

2.3.19 All watercourses and the slip planes for potential debris flows are across the top of the structure with debris being deposited on the down slope by means of a cantilevered canopy. The normal flow of watercourses are carried by pre-formed channels traversing the shell structure overhead and dropping to downslope cascades.

2.3.20 The form of the DFS structure comprises precast blocks or arch rings arranged to form a square ended circular arch. In the conceptual arrangement illustrated in Figure 5 for the block variant, these would be notionally 2m in length with depth and height approximately 1m. Arch rings would also typically be approximately 2m wide.

2.3.21 The ring units would inevitably be individually heavier than the block thus craneage and placement would be more difficult given the very constrained space on site.

2.3.22 The precast arch form derives support from springing beams supported on vertical piles on the downslope and spread footings on rock on the upslope. A detailed ground investigation would be required to determine rockhead levels on the line of the upslope springer beams. It may be that, as with the downslope springer beam, the upslope beam may need to be supported on vertical piles socketed in rock at some depth yet to be determined.

2.3.23 For the block variant, the constant thickness joints between blocks would be filled with mortar. The mortared block shell carries the force thrust lines to the springings directly on the upslope and via a series of regularly spaced tapering open columns on the downslope. However, the earth loading on the arch is asymmetrical and the depth of the arch shell would have to be examined to ensure that the thrust lines remained within the depth of the ring under the pressure from the backfill. The columns would have to be raked to carry the line of thrust to the downslope springing.

Figure 4: Example of a Debris Shelter to Protect Road from Rockfall

2.3.24 If the arch arrangement was unable to accommodate the asymmetrical loading practically, reinforced arch rings may be the better alternative with reinforcing in the ring section to resist bending in the arch.

2.3.25 At this conceptual stage, a number of options are available for the transmission of force to ground and the optimum solution would be subject to consideration of the greater geotechnical detail available at later stages and to more detailed consideration of the spatial constraints particularly with regard to the operation of traffic through the Works.

2.3.26 Sliding stability is obtained by rear (upslope) inclined ground/rock anchors but there would be additionally, a contributing resistance to sliding by friction and/or rock socketing on the upslope spread footed springing beam and by the shear resistance/stiffness of the downslope rock socketed piles. Maintenance of stressed tensile components is important, so the ground anchors are shown as being accessible from within the shell structure via access hatches in the upslope footway.

2.3.27 The downslope springing beam is supported on piles socketed into rock. These are envisaged as vertical piles to assist with maximising the availability of the existing corridor width for plant and for running traffic during construction. The lateral thrust from the arch via the open columns can be carried either by a number of raking piles as space permits or alternatively, and as shown, a series of ‘bowstring’ ties in ducts passing under the road from the downslope to upslope springing beams. These are accessible by access hatches on the internal footway and on the exterior in front of the springing beam.

2.3.28 The precast block arch barrel is covered by an insitu reinforced concrete layer and is waterproofed on its top surface. An anti-erosion/abrasion run-on slab can be provided where necessary upon which the granular overburden material is placed. Finally, the backfill/cover-fill is topped with indigenous topsoil and may be planted with native species. However, the nature of the design arrangement is that the soil covering will likely be disrupted at intervals by landslips and will have to be remediated and replenished over time.

2.3.29 It is intended that there is minimal, if any, disruption to traffic flow by channelling all debris and watercourses over the top of the structure. The arrangement avoids transport of water and debris under the structure to avoid blockage and maintenance.

2.3.30 The modular form assists construction as the arch barrel, once closed at its crown for the block variant, is immediately self-supporting and limits the time during which the part constructed Works are vulnerable to landslides. Whilst shorter lengths of shelter could be installed at priority areas, the longer term aim would be to provide a continuous shelter over the affected length of the A83 Trunk Road.

2.3.31 A modular approach with installation first at priority areas also enables accumulated landslip behaviour to determine future deployment and it may be possible to reduce the length of shelter construction in the longer term based on accumulated knowledge of ongoing landslip events.

2.3.32 The disadvantage of the installation of a series of individual sections of shelter with gaps in-between is that this arrangement may not be acceptable owing to the adverse driver experience caused by frequent changes in lighting conditions and the fragmented external appearance on the valley side.

2.3.33 The ‘open’ structure on the downslope side provides light, assists ventilation and a degree of landscape view for vehicle occupants. The ‘open’ side may obviate the special requirements which would normally be required for a tunnel – this would require careful assessment, i.e. ventilation, fire suppression systems, etc. and allows a means of emergency escape in the event of fire or breakdown although it is not intended that vehicles will be permitted to stop in the shelter for other than emergency purposes.

2.3.34 The material in the backfill volume is envisaged to be a standard compacted backfill material with permeable drainage conduits on the rear of the upslope springing beams. It may be that in the areas where there is currently a watercourse and eroded channel, a ‘run-on’ slab may have to be provided to resist ongoing slurry erosion and landslip and enable landslip transport of the material to the curve over the shell structures.

2.3.35 Excessive slurry type events have the potential to ‘back up’ on the downslope verge on the external surfaces adjacent to the columns. A continuous slurry trap channel is provided on the downslope (outer) side inside the shelter to prevent slurry accumulation backflowing onto the carriageway. A solid barrier is set back from the carriageway to provide this channel. This channel also provides operator maintenance access throughout the length of the shelter.

2.3.36 In time, land erosion and landslips would tend to govern the overall appearance of the landform on the up and downslopes next to the DFS. The formed backfilled volume on the upslope side would tend to reduce the relief of the existing slopes within the vicinity which may result locally at the watercourse channels in an unnatural topography. Normally this might be masked by judicious placing of vegetation, but this might in time be negated by landslips.

2.3.37 The arch barrel must provide the current overhead clearance required for a Trunk Road. The conceptual arrangement shown in Figure 5 provides 5.4m clearance at the channels of the 7.3m wide carriageway but this can be varied.

Construction

2.3.38 Referring to Figure 5; whether the full length of the DFS is provided in a single operation or the option is taken to provide prioritised part-lengths, the modular nature of the structural form assists the aim of minimising traffic disruption during construction.

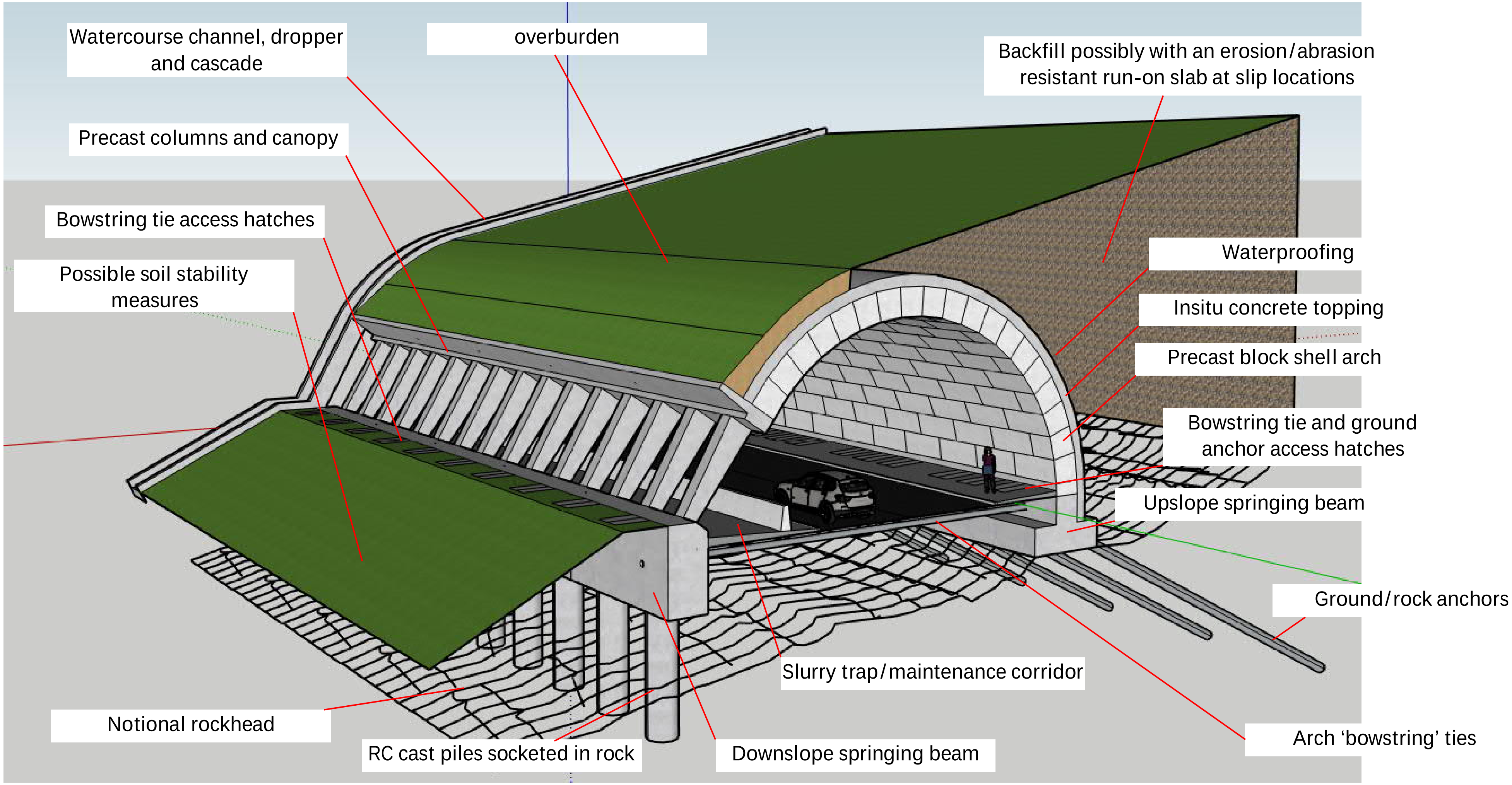
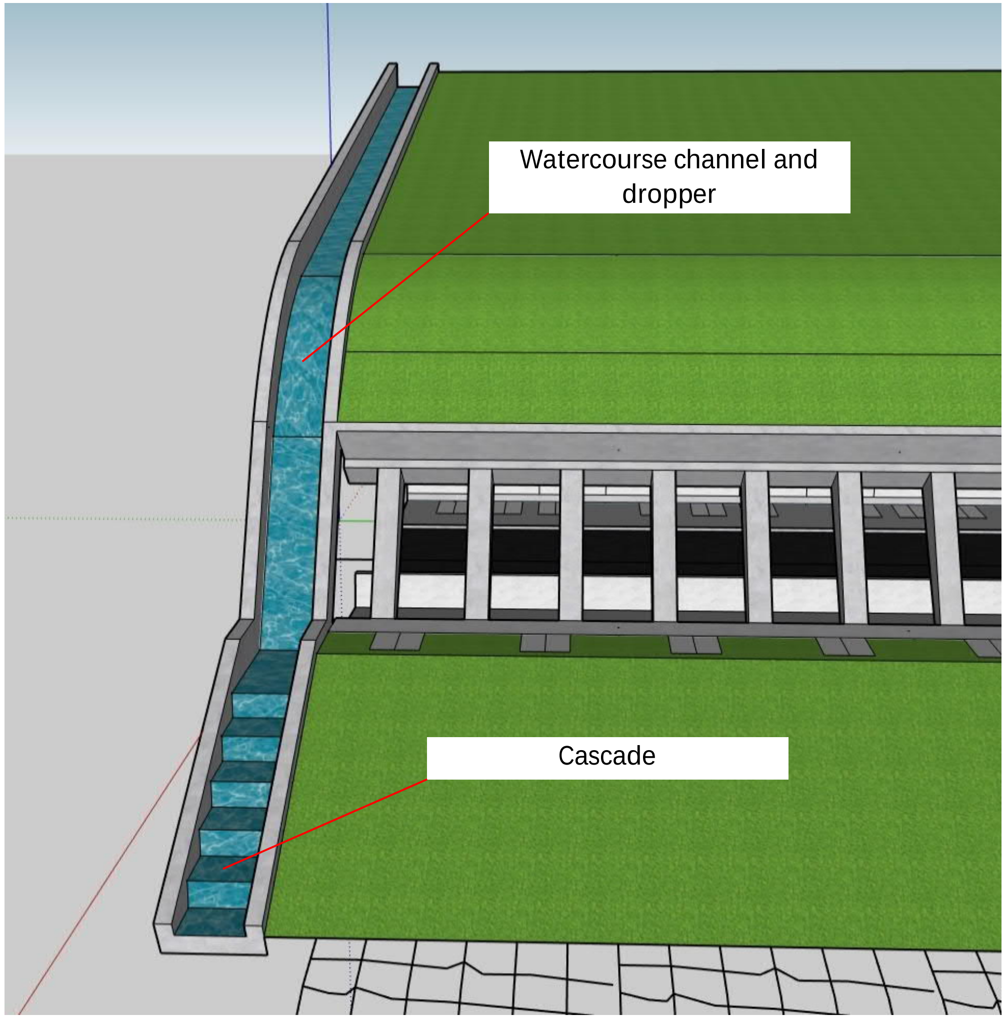


Figure 5: Brown Route Option: Debris Flow Shelter



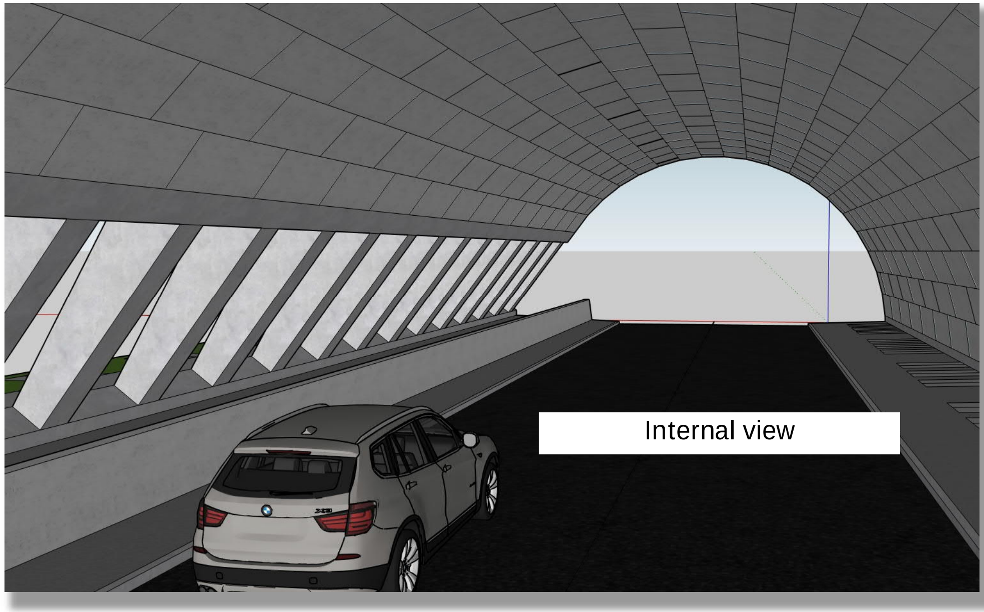


Figure 6: Brown Route Option: Debris Flow Shelter

2.3.39 The following discussion outlines a conceptual construction sequence that seeks to minimise traffic disruption. However, it is recognised that during construction, unrestricted two-way traffic flow on the A83 Trunk Road will not be possible. It is anticipated that some full road closures will be necessary for some activities throughout construction with the OMR being utilised for temporary periods.

2.3.40 The arrangement considers that the shelter would be assembled in discrete modular lengths over which traffic-light controlled alternating one-way traffic would operate. The lengths would be short enough so not to necessitate convoy control. The light-to-light length would be short enough for drivers to observe possible inter-green blockages on the one-way length.

2.3.41 The construction is considered by examining a 100m module for example.

2.3.42 Construction would require a degree of excavation in the existing upslope and this would be carried out with one-way working on the downslope side. The upslope spread footing/socketed springing beams would be constructed alongside the carriageway (for the 100m module).

2.3.43 Throughout the construction period, there would be a risk of landslide. Temporary protection measures may be needed to mitigate associated risks. This may include local temporary slope stabilisation measures such as soil nailing. A detailed assessment of the existing alignment together with ground investigation would be required. It is possible if there are significant events during construction that it may be necessary to resort to the use of the OMR whilst the debris is cleared.

2.3.44 Once completed, one-way traffic would be diverted onto the upslope side and the vertical piles installed. If raking piles were opted for, it becomes more difficult to maintain one-way traffic owing to the intrusion of the inclined pile mast into the traffic envelope, but this spatial relationship would be investigated.

2.3.45 Once the 100m length of the pile supported downslope springing beam is complete, the ground anchors and bowstrings can be installed. The ground anchor drilling requires inclined drill masts and their spatial requirements with respect to the carriageway would have to be evaluated. The bowstring ducts installed below the surface of the carriageway can be constructed by normal alternate side pipe laying methods or by transverse boring under the carriageway.

2.3.46 An assessment of the downslope may necessitate permanent works soil nailing or other slope stabilisation measures. The slope has to be capable of carrying the sudden deposition of a water-laden overburden that might fall from the shelter's canopy.

2.3.47 Once the springing beams/anchors are in place, it is possible that one-way traffic can be maintained throughout the works during construction of the arch shell. This will require careful consideration of risk but a temporary works arrangement that provides protection to traffic is conceivable.

2.3.48 Construction access to the site is limited and it is assumed that materials delivery will be by road almost exclusively from the south via the A82 Trunk Road. The limitations of the delivery route and the very constrained space for craneage and construction vehicles on site favour assembly of relatively small-scale components. Small scale precast components could be manufactured elsewhere and transported to site or could be cast in a yard at the foot of the valley.

2.3.49 The conceptual construction arrangement is illustrated Figure 7. In essence, one-way traffic flow is maintained in a 3.65m single lane at the centre of the carriageway. The clearance to the crown of the arch over this central lane is in excess of the maximum clearance required for normal traffic. This additional clearance enables a temporary falsework shelter to be constructed to support the timber former shell upon which the precast blocks will be placed.

2.3.50 With sufficient precautions and safety practices in place, it is possible for one-way traffic to continue to flow within the temporary falsework 'tunnel'.

2.3.51 Once the temporary works are in place, all subsequent construction activities take place overhead but are effectively isolated by the temporary falsework. The precast blocks obviate the fluid pressures and leakage considerations that would be the case for insitu concreting. The block shells contain no reinforcement, so the erection time of the arch barrel is rapid. Self-stability can be reached quickly as the arch becomes self-load supporting upon completion of the crown; a construction sequence may prioritise crown completion rather than longitudinal 'row' completion.

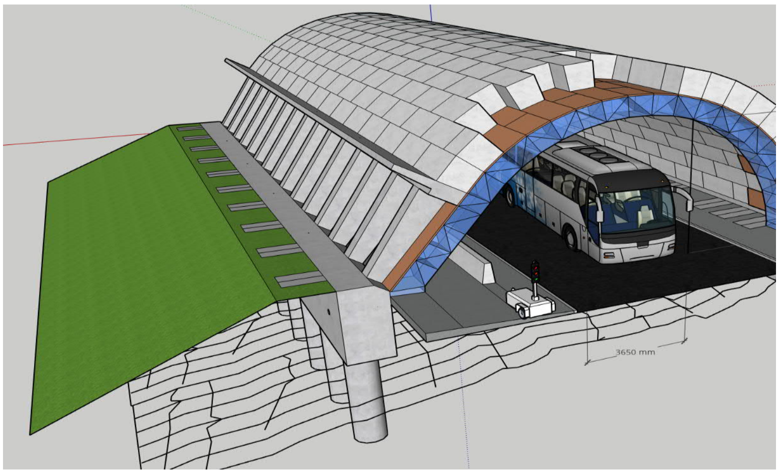


Figure 7: One-way Traffic During Construction

2.3.52 It is envisaged that the columns on the open side and canopy may also comprise precast units.

2.3.53 Transport of all precast units will run on a rail system on top of the arch barrel with loading at one or both ends; delivery of the precast units to one end of the module and placement by means of a transportable rail borne davit system.

2.3.54 With the completion of the precast arch barrel, an insitu concrete topping is formed. This is effectively isolated from the interior of the arch by the sealed shell. The arch barrel itself supports the weight of the insitu concrete and the soil fill above. The safety of maintaining live traffic through the works is analogous to the normal practice of allowing rail traffic to continue under the lattice of precast beams in composite concrete deck construction.

2.3.55 Throughout the construction of the arch barrel, watercourses would have to be temporarily diverted. Upon completion of the composite precast/insitu barrel, the watercourse channels, droppers and cascades would be constructed. Consideration would be given to their precasting to enable rapid installation.

2.3.56 In addition to the DFS, some construction work would be required on the lower slopes remote from the structure to provide erosion protection from the runoff tails of any debris directed across the shelter into this area, including on the remaining section of the existing A83 Trunk Road. This may include the use of gabion mattresses or other revetment works.

2.3.57 For sections where the DFS is proposed to be constructed to the west of the existing A83 Trunk Road, there would be a requirement to construct a new road to the side of existing before the debris shelter is constructed to allow traffic to continue to use the A83 Trunk Road under traffic management during construction. This would likely require the closure of the northbound lane of the A83 Trunk Road or potentially the full road width to enable this section of new road to be constructed.

Operation/Maintenance/Inspection

2.3.58 Depending on design options, inspections and occasional maintenance will be required for the ground anchors and 'bowstring' ties. These are accessible from access hatches flush with the internal footway and the external downslope verge. The block arch barrel is unreinforced so long term durability in a relatively wet environment should be superior to reinforced concrete. The external canopy and columns will require to be able to resist harsh weather and freeze/thaw conditions. The factory controlled conditions of their precasting will ensure a high concrete quality and consistency of reinforcement cover.

2.3.59 Routine maintenance and inspection would be required as for any structure, with specific requirements relating to carriageway drainage, lighting and road surfaces. Occasional maintenance will be required to remove large debris from the roof of the shelter and accumulated debris on the downslopes.

2.3.60 Inspection and maintenance access ramps onto the DFS would be provided at the ends or at intervals along the length to allow access for small plant to remove debris.

Risks

2.3.61 The principal technical risk relating to this option is considered to be the stability of the slopes affected by the construction works. This includes the risk of slope failures during construction due to disturbance of the ground, not only localised small scale failures on temporary slopes, but also major debris slides following prolonged periods of heavy rainfall. However, it is considered that these risks affecting both construction and use of the road could be mitigated. The rapid completion of the block shell structure minimises the time during which the structure is vulnerable.

2.3.62 The design of the structure will require a clear understanding of the ground conditions to ensure that the structure is able to resist ground forces from upslope failures and soil creep. It is anticipated that the foundations and structural type should have a minimal impact on the stability of the existing slopes. The road construction itself is expected to be largely replaced under this proposal.

2.4 Green Route Option: South-West Alignment Option

Description

2.4.1 The south-west alignment option is offline within Glen Croe in the area of forestry on the south-west side of the valley. Options in this sub-corridor tie-in with the south-east end of the existing A83 Trunk Road approximately 3.2 km north-west of Ardgartan, in the vicinity of the A83 Trunk Road /Forestry Commission track and the OMR junction. At the north-west end of the sub-corridor the possible route option ties into the north side of the Rest and Be Thankful car park. The route is visualised in Figure 8.

2.4.2 Potential route options in this corridor would provide a new 4.4km single carriageway from the A83 Trunk Road near the start of the OMR to the A83 Trunk Road /B828 junction north of the car park at Rest and Be Thankful. The alignment is close to the forestry track in places and road structures and ground engineering measures would be required to fit the new road in the topography of this side of Glen Croe.

2.4.3 The principal structures in the route comprise a viaduct at the foot of the valley crossing Croe Water and a bridge crossing a tributary higher in the valley. A geotechnical appraisal is required to determine landslide risk for the valley side. Auxiliary structures such as deflector/arrestor retaining structures or debris flow shelters may be required at intervals to be determined along the length of the route.

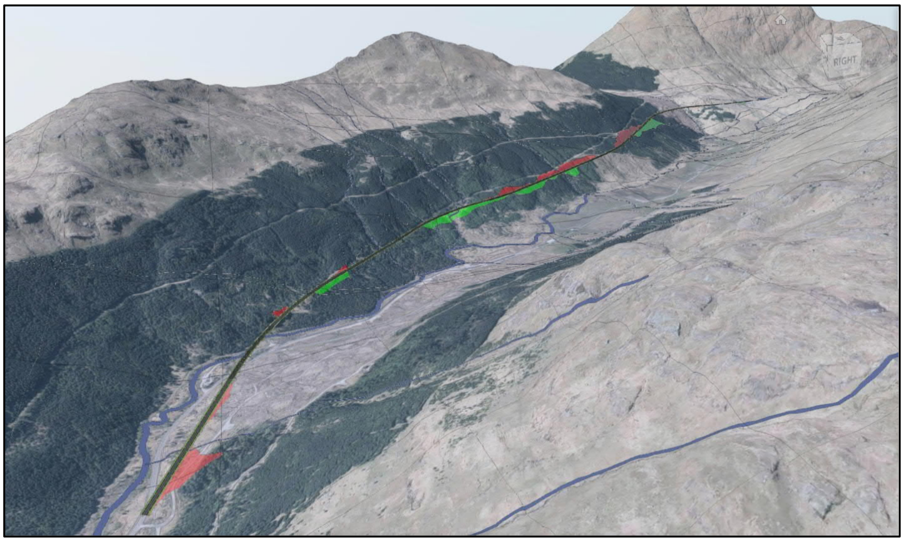


Figure 8: Green Route Option: South-west Alignment (Autodesk InfraWorks 360, 2021)

Structures

2.4.4 An approximately 200m long viaduct would be required at the foot of the valley crossing the Croe Water. The Croe Water floods at this location and as a result the viaduct would be elevated to be above the floodplain.

2.4.5 A bridge or viaduct structure, approximately 300m long would likely be required for this possible route option to span a gully in the valley near the north end.

2.4.6 It is possible that measures to protect against landslide risk may be required. This could be in the form of sections of viaduct similar to the Yellow route, debris flow shelter similar to Brown route or geotechnical measures to stabilise slopes.

Design

2.4.7 The principles of the viaduct designs would likely be similar to that described for the Yellow route option in Section 2.2 of this technical note.

2.4.8 If any debris flow shelters are necessary, the principles of the design could be similar to that described for the Brown route option in Section 2.3 of this technical note. However, it may also be possible for a reinforced concrete structure to be considered as the route does not require provisions to maintain existing traffic flow during construction.

Construction

2.4.9 The principles of the viaduct construction would likely be similar to that described for the Yellow route option in Section 2.2 of this technical note.

2.4.10 If any debris flow shelters are necessary, the principles of the construction could be similar to that described for the Brown route option in Section 2.3 of this technical note.

2.4.11 Construction along the Green route option would be offline, avoiding interface with live traffic on the existing A83 Trunk Road with the exception of the tie-ins at either end. This makes construction less complex in this regard when compared with the Yellow and Brown route options; however, significant engineering challenges remain and the exact nature and scale of these is unknown at this stage. There is evidence of landslides and associated instability on the southwest side of the glen which would require further investigation and assessment to inform the mitigation measures required.

2.5 Purple Route Option: Valley Floor – Tunnel Option

2.5.1 Please refer to Appendix F of the Preliminary Assessment Report for details on tunnels within the route corridors.

2.6 Pink Route Option: Tunnel Option

2.6.1 Please refer to Appendix F of the Preliminary Assessment Report for details on tunnels within the route corridors.

3. Route Corridor 2 - Glen Kinglas

3.1.1 Please refer to Appendix F of the Preliminary Assessment Report for details on tunnels within the route corridors.

4. Route Corridor 3 - Glen Fyne

4.1 Description

4.1.1 The Glen Fyne route corridor is offline within Glen Fyne and follows the wide valley floor, from the A83 Trunk Road at the head of Loch Fyne, heading north-east, to the A82 Trunk Road north of Inverarnan.

4.2 Structures

4.2.1 A structure is required to cross the River Fyne and a tributary to the north of the A83 Trunk Road, as shown in Figure 9.

Figure 9: Viaduct in Route Corridor 3 (Autodesk InfraWorks 360, 2021)

Note: In Figure 9, the design modelling software is showing a structure indicative of a viaduct and does not necessarily indicate the proposed form of the bridge structure.

4.3 Design

4.3.1 The bridge is likely to be a three span steel composite deck (Spans between 40 and 70m) on reinforced concrete piers/bankseats on piled foundations to rock (alluvial surface deposits assumed).

4.4 Construction

4.4.1 The bridge over the watercourses should be relatively simple to construct using standard methods. The viaduct construction would include prefabricated components (steel or prestressed beam) transported by road. During the bridge construction the works may be susceptible to flooding and dewatering of excavations for the abutments and piers will need to be managed.

5. Route Corridor 4 - A82 - Cowal - Cairndow

5.1 Description

5.1.1 This route corridor would be a combination of new offline carriageway and online upgrading works which generally follows the existing road network with a new fixed link crossing at Loch Long.

5.2 Structures

5.2.1 The major structures within Route Corridor 4 are:

- Loch Long (N) Bridge
- Cairndow multi-span viaduct

5.3 Loch Long (N) Bridge

Design

5.3.1 Loch Long (N) Bridge would be a suspension bridge from the eastern shore south of Portincaple (Figure 10) to the headland at Rubha nan Eoin on the west shore. The bridge would be approximately 1600m long.

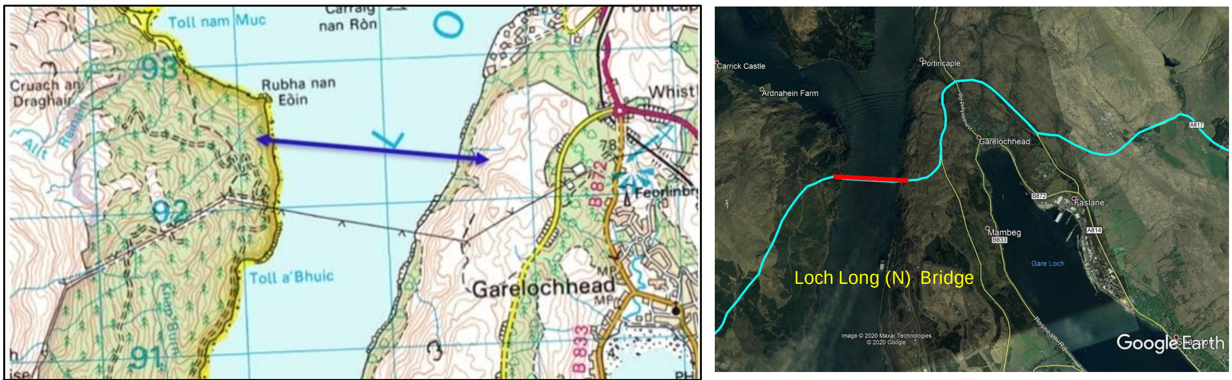


Figure 10: Loch Long (N) Bridge

5.3.2 The central channel extends to a depth of between approximately 72m and 82m[1]. The channel is a submarine exercise area. Note also that power lines cross the loch at the location of the crossing.

5.3.3 The high and steep topography of the Loch Long shorelines dictates that a crossing is not principally governed by the plan arrangement but by the vertical profiles of the valley and the alignment and gradients of the crossing approaches.

5.3.4 The elevation of the existing Ministry of Defence (MOD) road on the east side is comparatively high in relation to the surface level of Loch Long. Moreover, the MOD road rises as it runs south from the Portincaple roundabout.

5.3.5 For a bridge structure, the aim would be to minimise its length while setting its deck level at a height above Loch Long to enable the passage of commercial and military marine vessels. The Defence Infrastructure Organisation (DIO) have advised that the required clearance is +75m above sea level. For the purposes of initial estimation, an allowance of 5m is made for the maximum deflection of a suspension bridge deck and 5m for its construction depth. Thus, the carriageway height would require to be approximately 85m above sea level.

5.3.6 The steep slopes either side of the loch are competing geometric restraints; the east side of the bridge would preferably be as high as possible to enable a satisfactory eastern approach gradient while the west end of the bridge would preferably be as low as possible to assist the descent to the shoreline at Barnacabber. It is considered that owing to the resulting gradients, the approaches would be in tunnel to avoid considerably deep cuttings. An economic appraisal of the relative cost of a bridge with a higher level deck against the costs of the tunnelled approaches would be carried out at design stage.

5.3.7 The loch depth is approximately 80m and the bathymetry suggests a 'fjord' like profile with relatively steeply inclined sub-shore profiles on both east and west sides. The depths and the marine traffic preclude a multi-span/multi-pier fixed link bridge such as the Tay[2], Dornoch[3] or Cromarty[4] Road Bridges. A long span bridge form is necessary and both suspension and cable stayed bridge forms are considered.

5.3.8 The bathymetric profile has consequences for the tower(s), whether for suspension or cable stayed bridge forms.

5.3.9 To minimise tower foundation depth, the towers would preferably be closer to the shorelines resulting in a lengthened single suspended or stayed span. The valley profile dictates that there is limited space for the backspans and cable foundations. However, towers would have to be located on fairly steeply sloping sub-shores and this has consequences for foundations and the placing of caissons.

5.3.10 For a bridge with deck set at its lowest level, i.e. sufficient only to provide a +75m clearance above sea level, or carriageway at +85m, the channel profile and the depth indicates that a single span of approximately 1,200m to 1,250m is necessary. A span of this length exceeds the current longest cable stayed type in the world (the Russky Bridge at 1,104m). Such is the geometry of the valley, there is no practical space in which backspans or the back cable array could be founded. The remaining option would be for a suspension bridge form.

This type of 'fjord crossing' is exemplified by the Hardanger Bridge in Norway, completed in 2013[5].

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1 Bathymetry is estimated by reference courtesy of gpsnauticalcharts.com http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Loch+Long+and+Loch+Goil+boating+app#13.25/56.0819/-4.9058

2 https://structurae.net/en/structures/firth-of-tay-road-bridge

5.3.11 Hardanger Bridge provides a single span of 1,310m with a total length of 1,380m. The comparatively short back spans are required for the bridge's location across the Hardanger fjord – steep shore topography necessitating towers close to the shorelines; the shore topography is similar to that at Loch Long (N) Bridge. Google Street View indicates that the single carriageway and cycle/pedestrian access is similar to the anticipated requirements at Loch Long (N) Bridge[6]. The shoreline terrain is indicated in Figure 11.

5.3.12 Examination of the interface of bridge and tunnel at the ends of the bridge[7] indicates that the anchoring cable pairs extend into rock anchorage above the line of the approach tunnels. There are no suspended back spans with the majority of the bridge length contained on the single main span.

5.3.13 The Hardanger Bridge towers are at the shoreline ensuring that their construction is carried out 'in the dry', or at least as far as is possible, founding on the shoreline. At Loch Long, towers located offshore would entail deep marine construction which would necessitate the use of caissons. Locating, lowering and sealing caissons on steeply sloping sub-shore gradients would prove very difficult. It is clearly far preferable to locate the towers, as has been done at Hardanger, on the shore.

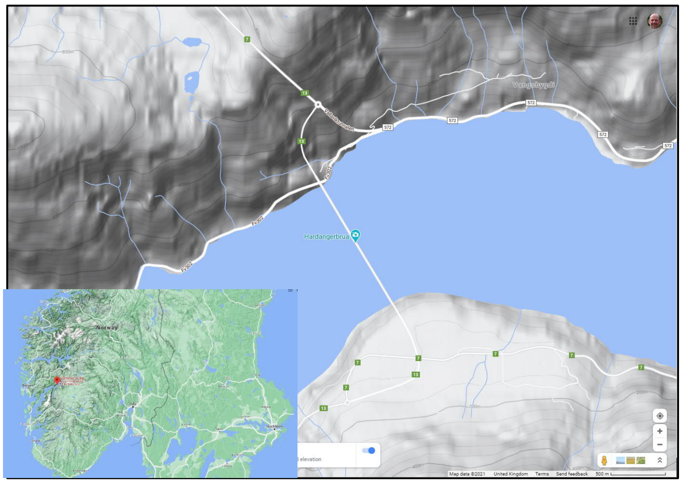

Figure 11: Hardanger Bridge Terrain

5.3.14 To obviate the approach tunnels in the 'minimum level' arrangement, the deck could be located at, or above, the 100m contour on the east shore. To do so would not necessarily increase the length of the main span but would increase the height of the towers and the overall length of bridge deck. If deck height is above 100m, tower heights are estimated to be 250 to 300m. It is estimated that the suspension bridge solution would comprise a main span of approximately 1200m with back spans of up to 150-200m (total length up to 1,600m).

5.3.15 The high level arrangement landfalls farther up the slope of the opposing west hillside and the alignment link to ascend/descend to Barnacabber is more problematic than for the low level arrangement.

3 https://structurae.net/en/structures/dornoch-firth-bridge
4 https://en.wikipedia.org/wiki/Cromarty_Bridge
5 https://structurae.net/en/structures/hardanger-bridge
6 https://www.google.co.uk/maps/@60.4773946,6.8316283,3a,75y,128.04h,96.88t/data=!3m6!1e1!3m4!1sLAHvktz8xgBoTHWLrb6ryw!2e0!7i16384!8i8192?hl=en&authuser=0
7 https://www.google.co.uk/maps/@60.4829382,6.8248506,3a,75y,310.21h,97.09t/data=!3m6!1e1!3m4!1sWZVlAZkp4gknsu7ZwHN-Ow!2e0!7i16384!8i8192?hl=en&authuser=0

5.3.16 The high and low-level alternatives illustrate the significant effects on cost that the topographic variables present and it is anticipated that within these constraints there is an optimal solution for a bridge crossing at this location.

5.3.17 The bridge deck must be wind resilient and will require wind barriers similar in form to those provided on the Queensferry Crossing. However, a slender single carriageway long span suspension bridge presents a design challenge to ensure the adequacy of the deck's aerodynamic response.

5.3.18 Consideration should be given to winter resilience of the Loch Long cable supported bridge, principally deck surface and cable/tower de-icing.

Associated Structures

5.3.19 Control buildings would be necessary for the bridge crossing and approach tunnels to monitor traffic and pedestrian actions and to maintain safety, fire and collision detection. An associated depot would be required for tunnel and bridge maintenance, electrical supply, water, service and repair and parts (lighting, collision damage to parapets etc.).

5.3.20 On the west shore, the ascending western approach road running from Barnacabber/Ardentinny north to the west approach tunnel entrance crosses a number of watercourses draining perpendicularly towards Loch Long. These would require culverts or discrete bridge structures. However, the hillside is steep and a topographic survey would be required to determine whether it were practical to locate the road alignment in cutting or whether a sidelong viaduct is necessary. The area is currently forested.

Construction

5.3.21 There is minimal existing access to the bridge location on the west shore and no significant access on the east. Temporary access would need to be provided in advance both for the bridge and tunnel entrances. These works will likely involve use of some hill climbing plant and extensive construction of temporary retaining walls or permanent cuttings in the slope.

5.3.22 West approach: construction of the road from the A815 and south to Barnacabber would proceed in advance of commencement of the bridge. To obtain access to the bridge anchorages, haul road access would be required although the earthworks would be part of the earthwork required for the west approach link to the approach tunnel (for low or high level options). A temporary haul or improved access road would be required on the shoreline to the location of the west tower foundation.

5.3.23 East approach: construction of the east approach tunnel would enable access to the east shoreline for construction traffic hence, cable anchorage and construction of the east tower would have to follow completion of the east tunnel. The alternative would be a temporary access road to the location of the east tower necessitating a temporary road from a location at the Portincaple roundabout and considerable disruption of the shoreline south. Whilst this could be remediated, there would be short to medium term impact on the shoreline slopes.

5.3.24 The single carriageway bridge deck will require high twin legged 'A-frame' towers founded on rock. Their proximity to the shoreline suggests that foundation installation may have to be designed for underwater construction or complex temporary works will be necessary to exclude water ingress for construction in the dry. The reinforced concrete towers would be constructed incrementally by jump forming with concrete being pumped up the towers as their height incrementally increases. Concrete volumes would warrant batching plants on site on the east and west shores (for the east shore, ready mix delivery may also be feasible).

5.3.25 Concrete batching could be carried out by a temporary facility at Barnacabber or Portincaple with delivery to the towers by haul road or marine barge, the economics of these alternatives being subject to the Contractor's assessment. Deck segments would be fully or partially fabricated remotely depending on the Contractor's commercial arrangements.

5.3.26 Remotely fabricated segments would be delivered to an assembly yard in for example, Gourock, and from there transported to the bridge location by marine barge, although such a 14km barge movement is considerable and is likely to be vulnerable to tidal and weather effects. Additionally, marine movements in Loch Long must allow for existing marine traffic, including submarines, and liaison and marine management would be an important factor.

5.3.27 The cable anchorages would be formed first and the twin suspension cables formed by aerial spinning. Cable spinning would be carried out insitu. Main span segments would be progressively lifted onto the suspension catenary progressing out from the towers until closure at midspan.

5.3.28 Lifting would require GPS placement of barges and their station protected by an exclusion zone on the main navigation channels in Loch Long. This will clearly affect marine vessel navigation. The duration of barges on-station for the lift is expected to be comparatively lengthy at approximately 12 – 16 hours. This allows for anchoring (2- 3 hours) and strand jack lifting which, owing to the deck height, could take up to 12 hours to achieve. For the relatively prolonged operation, wave height and wind conditions may limit the number of available weather windows for lifting as unexpected or variable conditions 'on the day' could impede the lifting operations.

5.3.29 DIO consultation will be required for a number of specific security and operating restrictions such as;

- potential restriction to deck access during the passage of military or large oil transportation vessels.
- Construction activities effect on secure channel communications between RNAD Coulport and nearby refuelling and berthing/arming facilities.
- The possible effect of a large-scale bridge structure on radar and sonar.
- Security exclusion zones.

5.3.30 It is also likely that the suspension bridge construction could have a potential impact on commercial and fishing activities and marine navigation and management to reduce impacts would be necessary.

5.4 Cairndow Multi-span viaduct

5.4.1 Cairndow multi-span viaduct is a new 400m long multi-span steel composite bridge with reinforced concrete leaf piers on piled foundations. This is shown in Figure 12.

5.4.2 The design and construction of the viaduct would be similar to other viaducts described previously in this technical note.

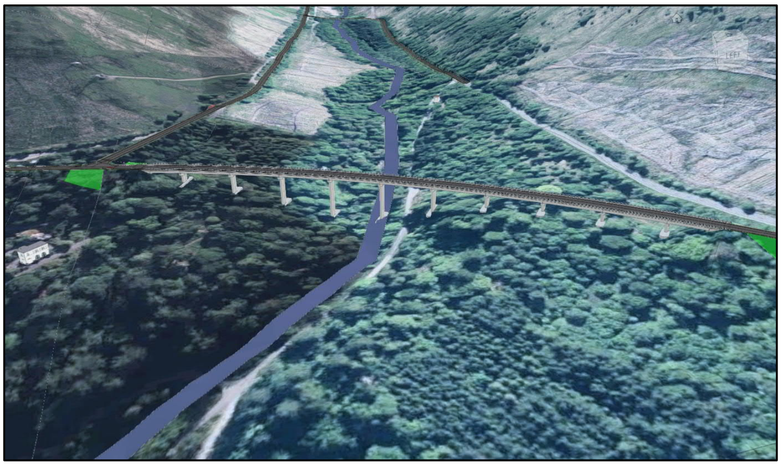

Figure 12: Cairndow Multi-span Viaduct (Autodesk InfraWorks 360, 2021)

6. Route Corridor 5 - A82 - Cowal – Lochgilphead

6.1 Description

6.1.1 This route corridor would be a combination of new offline carriageway and online upgrading works which generally follows the existing road network with new fixed link crossings at Loch Long, Loch Striven and Loch Fyne.

6.2 Structures

6.2.1 The major structures within Route Corridor 5 are:

- Loch Long (N) Bridge
- Loch Striven Bridge
- Loch Fyne Bridge

6.3 Loch Long (N) Bridge

6.3.1 The bridge would be as described for Route Corridor 4 in Section 5.3 of this technical note.

6.4 Loch Striven Bridge

Design

6.4.1 A crossing is required over the head of Loch Striven as depicted in Figure 13.

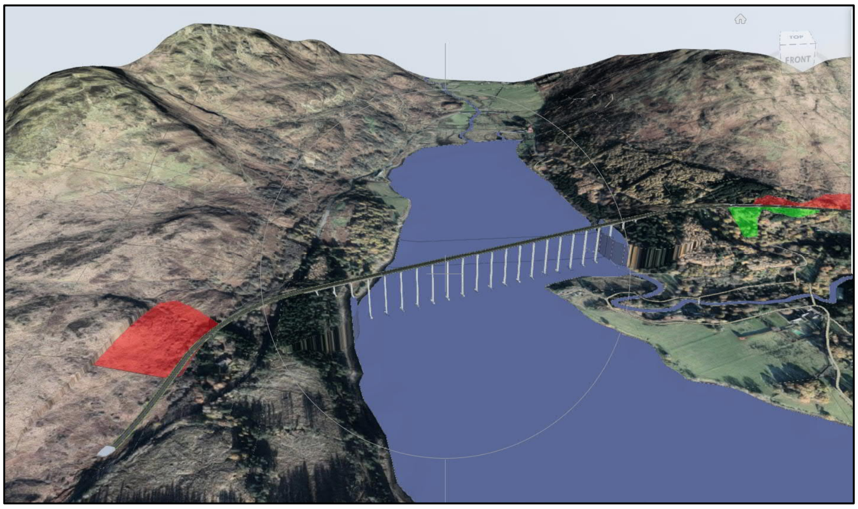

Figure 13: Loch Striven Bridge Location (Autodesk InfraWorks 360, 2021)

Note: In Figure 13 the design modelling software default bridge type is showing a viaduct structure, however due to the length of the bridge it would be cable stayed.

6.4.2 The bridge's main span would be approximately 500m between two A-frame towers with a total length of approximately 820m. The cable stayed form obviates cable ground anchors as would be the case for a suspension form and greatly improves durability especially with regard to the relative ease of cable replacement.

6.4.3 Water depth is approximately 20m deep with the loch bed comprising sand[8]. The height of the bridge carriageway depends largely on the levels at which the road departs the east and west slopes. The notional arrangement illustrated in Figure 13 is shown with the height of the carriageway approximately 95m above loch surface level. Approach viaducts would be required supported on piers before the cable stay supported section of the bridge.

6.4.4 Foundation type would have to be determined but the water depth and 'sands' soil type suggests in-water tower construction is feasible with caissons. Depth to rock is unknown but assumes no more than 15 – 20m depth. Spread footing/caisson mass foundations appear feasible.

6.4.5 An example of the bridge type required at this location is the Skarnsund Bridge in Norway[9]. The overall proportions of the bridge are similar to that required at Loch Striven; however, the clearance at Skarnsund is +45m and is therefore considerably less than the 85m (95m carriageway level, less 5m for deck construction less 5m for deflection). The towers at Skarnsund are 152m in height. It is estimated that tower height at Loch Striven would be approximately 200m – 250m. Like the other major marine crossings in the route corridors considered, the bridge would be required to be wind resilient and would require wind barriers. As can be seen from Google Street View[10], specific wind protection is not provided at Skarnsund and it is presumed the bridge may be subject to closure above certain pre-defined wind gust limits.

[8] Bathymetry is estimated by reference courtesy of gpsnauticalcharts.com http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Loch+Long+and+Loch+Goil+boating+app#14.75/56.0033/-5.1256

[9] https://structurae.net/en/structures/skarnsund-bridge

[10] https://www.google.co.uk/maps/@63.8444141,11.0801903,3a,75y,232.96h,90t/data=!3m7!1e1!3m5!1s7FSizsP7cLXuRDLN-suOHA!2e0!6s%2F%2Fgeo1.ggpht.com%2Fcbk%3Fpanoid%3D7FSizsP7cLXuRDLN-suOHA%26output%3Dthumbnail%26cb_client%3Dmaps_sv.tactile.gps%26thumb%3D2%26w%3D203%26h%3D100%26yaw%3D210.28874%26pitch%3D0%26thumbfov%3D100!7i16384!8i8192?hl=en-GB&authuser=0

6.4.6 The aerodynamic design of the slender single carriageway deck at Loch Striven Bridge will need special consideration. Consideration should also be given to winter resilience of the bridge, principally deck surface and cable/tower de-icing.

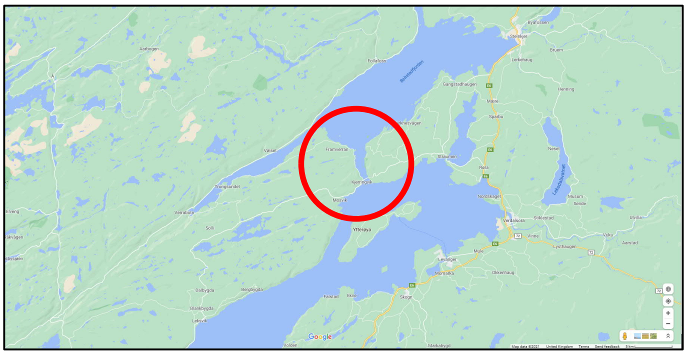

Figure 14: Skarnsund Bridge, Norway (location 63°50'35.2"N 11°04'29.3"E)

Construction

6.4.7 There is access to both east and west ends of the bridge although the existing carriageway is single lane with passing places so construction access would require improvement prior to bridge construction. Marine access also appears relatively straightforward with access from the south of the loch.

6.4.8 The tower foundations will be in water. However, there appears to be little, if any, navigation demand at this location at the head of Loch Striven so construction could progress from causeways constructed out from the shores. However, these would impede later segment erection from marine barge so would most likely need removal. Access to tower construction from land would eliminate the need for marine concrete transport.

6.4.9 The foundation installation would be designed for underwater construction. The reinforced concrete towers would be constructed incrementally by jump forming with concrete being pumped up the towers as their height incrementally increases. Concrete volumes, especially given the nearby tunnel construction would warrant batching plants on site.

6.4.10 Steel box deck segments would be fabricated nationally and/or internationally and delivered to a staging area at a nearby facility constructed onshore in the south of the loch. Segments would be transported by barge to below their location in the span. Main span segments would be progressively lifted onto the towers by alternating balanced cantilever progression out from the towers until closure at the bridge abutments and then at midspan.

6.4.11 Lifting would require GPS placement of barges and their stations would be protected by an exclusion zone, although there is very little marine traffic in this locale. Given the height of the deck, the duration of barges on-station for the lift is expected to be comparatively lengthy at approximately 8 – 10 hours. This allows for anchoring (2- 3 hours) and strand jack lifting which, owing to the deck height, could take up to 7 hours to achieve. For the relatively prolonged operation, wave height and wind conditions may limit the number of available weather windows for lifting as unexpected or variable conditions ‘on the day’ could impede the lifting operations.

6.4.12 Climbing tower cranes fixed to the main towers will lift materials and equipment to deck level.

6.4.13 It is also likely that the suspension bridge construction could have a potential impact on commercial and fishing activities and marine navigation and management to reduce impacts would be necessary.

6.5 Loch Fyne Bridge

Design

6.5.1 The Loch Fyne Bridge would span the loch from Otter Ferry near the A886 on the east side of the loch to the A83 Trunk Road at Carrick in the west, as shown in Figure 15 and Figure 16. The bridge would be approximately 3000m long.

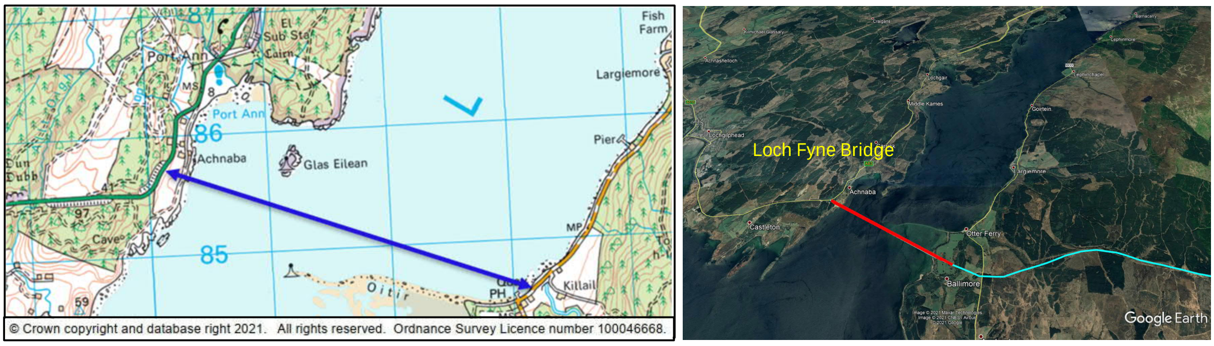

Figure 15: Location of the Loch Fyne Bridge

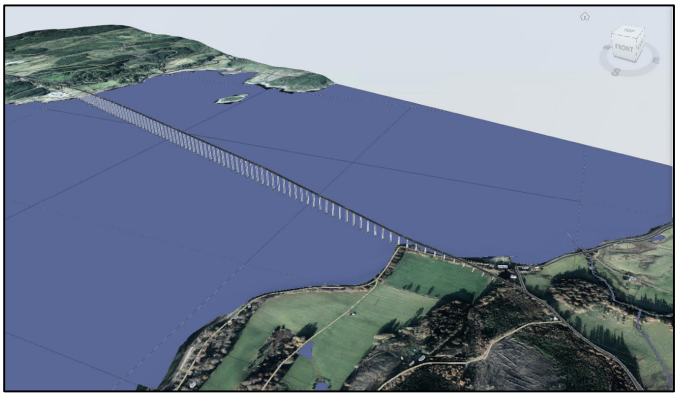

Figure 16: Loch Fyne Bridge (Autodesk InfraWorks 360, 2021)

6.5.2 The Otter Spit shown in Figure 15 suggests variable drift geology extending to the landform between Otter Ferry and Ballimore and it is proposed to utilise the narrows at this location for the crossing of Loch Fyne.

6.5.3 The water depths[11] suggest that a multi-span viaduct with relatively short supports on piled foundations such as at A9 Cromarty may not be appropriate for the main channel whose depth reaches between 27m and 33m. Examples of this type of crossing include the A9 Dornoch Bridge and A90 Tay Road Bridge. At Dornoch, large diameter cased reinforced concrete piles were constructed which were integral with the portal legs of the bridge piers. At Tay Road Bridge, columns are supported by reinforced concrete pilecaps and steel H piles.

6.5.4 With further study of the geotechnical aspects, it might be possible to arrive at a mixed multi-span

[11] Bathymetry is estimated by reference courtesy of gpsnauticalcharts.com http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Loch+Long+and+Loch+Goil+boating+app#13.51/56.0123/-5.3569

viaduct with a main span over the deepest part of the channel over the 'narrows' portion to the west (Figure 15).

6.5.5 A single span across the deepest part of the channel will approximate to 650m requiring a cable supported structure. For comparison, the main cable stayed span of Kessock Bridge in Inverness is 240m. A non-cable supported structure is not feasible for this span; Skye Bridge approaches the upper limit of prestressed box girder construction with a main span of 250m.

6.5.6 For a cable stayed bridge, the cable supported length would be approximately 1,600m of the overall bridge length of 3,000m and would comprise a steel composite box girder and reinforced concrete slab. The bridge's main span would be approximately 1,100m between two A -frame towers.

6.5.7 Unlike the other crossings which must cater for the passage of large commercial and military vessels, the navigation clearance to the Loch Fyne Bridge need be only the minimum clearance required for commercial navigation, +45m.

6.5.8 The two towers would be reinforced concrete founded on spread footings onto rock. Sands overlie rock so a mass concrete filled caisson would transfer load below the water line.

6.5.9 The bridge deck must be wind resilient and will require wind barriers similar in form to those provided on the Queensferry Crossing. However, the cable supported length is significant and a slender single carriageway long span cable stayed bridge presents a design challenge to ensure the adequacy of the deck's aerodynamic response.

6.5.10 Consideration should also be given to winter resilience of the bridge, principally deck surface and cable/tower de-icing.

Construction

6.5.11 There is access to both east and west ends of the bridge although the existing carriageway on the east shore at and to Otter Ferry is single lane with passing places so construction access would require improvement prior to bridge construction. Marine access also appears relatively straightforward with access from the south.

6.5.12 The eastern approach viaduct would be constructed by the temporary formation of an access causeway or jetty extending from the shore at Otter Ferry and placement of a series of cofferdams at the pier locations onto the Otter spit.

6.5.13 The piers for the approach viaduct would be founded on steel piles driven to rock or into sand/gravel dependent on the geotechnical design. Pile caps would be formed in reinforced concrete in the cofferdams with leaf or discrete piers erected to deck level.

6.5.14 The viaduct would be a post-tensioned concrete spine box girder or composite steel box section launched from the eastern shore. This would require a construction bay formed at Otter Ferry with delivery of concrete and/or fabricated steel components. Box assembly would take place in the assembly bay.

6.5.15 The cable supported length of the single carriageway bridge deck will require high twin legged 'A-frame' towers founded on rock. The tower foundations will be in water. There appears to be limited navigation demand at this location so construction could progress from causeways/jetties constructed out from the shores. However, these would impede later segment erection from marine barge so would most likely need removal. Access to tower construction from land would eliminate the need for marine concrete transport. Access to the east tower would most likely require an extended causeway across the Otter spit.

6.5.16 The foundation installation would be designed for underwater construction. The reinforced concrete towers would be constructed incrementally by jump forming with concrete being pumped up the towers as their height incrementally increases. Concrete volumes, especially given the nearby tunnel construction at Loch Striven would warrant batching plants on site.

6.5.17 Steel box deck segments would be fabricated nationally and/or internationally and delivered to a staging area at a nearby facility constructed onshore in a location within approx. 3km of the bridge. Segments would be transported by barge to below their location in the span. Main span segments would be progressively lifted onto the towers by alternating balanced cantilever progression out from the towers until closure at the bridge abutment on the west, the approach viaduct end on the east and then at midspan.

6.5.18 Lifting would require GPS placement of barges and their stations would be protected by an exclusion zone, although there is very little marine traffic in this locale. Given the moderate height of the deck, the duration of barges on-station for the lift is expected to be approximately 5 hours. This allows for anchoring (1 hours) and strand jack lifting which could take up to 4 hours to achieve. Wave height and wind conditions may limit the number of available weather windows for lifting as unexpected or variable conditions 'on the day' could impede the lifting operations. Climbing tower cranes fixed to the main towers will lift materials and equipment to deck level.

6.5.19 It is also likely that the suspension bridge construction could have a potential impact on commercial and fishing activities and marine navigation and management to reduce impacts would be necessary.

7. Route Corridor 6 - Inverclyde - Cowal – Cairndow

7.1 Description

7.1.1 This route corridor would be generally online linking the A78 Trunk Road at Inverclyde to Cowal, with the provision of a fixed link crossing of the Firth of Clyde. The structure will require to span a deep section of the Firth of Clyde as well as have adequate clearance for large marine vessels.

7.2 Structures

7.2.1 The major structures within Route Corridor 6 are:

- Dunoon Firth of Clyde Bridge
- Cairndow multispan viaduct

7.3 Dunoon Firth of Clyde Bridge

Design

7.3.1 The crossing at Dunoon requires a very significant structure crossing the Firth of Clyde between the A770/A78 roundabout at Ardgowan in the east and the A885 south of Dunoon in the west as shown in Figure 17.

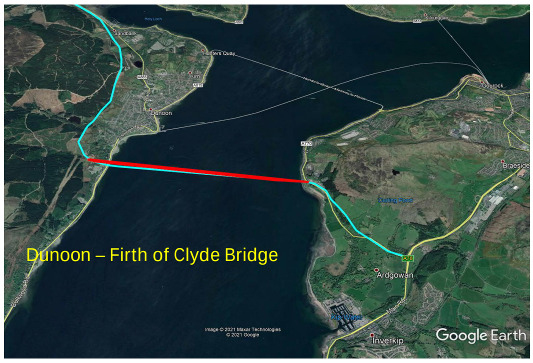

Figure 17: Dunoon Firth of Clyde Bridge location

7.3.2 The 3,900m crossing length is comparable with the Akashi Kaikyo (AK) Bridge in Japan, which, with a main span of 1,991m and a total length of 3,911m is the world's longest suspension bridge.

7.3.3 An approximate comparison for the crossing is made with the Queensferry Crossing. The three tower Queensferry Crossing takes advantage of the mid channel island Beamer Rock. The three tower configuration allows for two 650m spans and this arrangement enabled the crossing to be a cable stayed bridge.

7.3.4 Whilst there is no central island at the Dunoon Bridge, there is a possibility that the relatively shallower mid-channel Warden Bank[12] could support a central tower dependent on geology. Nevertheless, the bank is submerged by 11m and a central tower foundation would require a significant caisson for construction. Moreover, it is not known at what depth rock would be reached. Without the central tower, a single span bridge over the Firth of Clyde of this length would exceed the span range for a cable stayed bridge and the bridge would need to be a suspension bridge.

7.3.5 For a three-tower cable stayed arrangement, the flanking towers would be founded in water comparable, perhaps deeper, than the flanking towers at Queensferry Crossing.

7.3.6 The three-tower cable stayed form would be preferable to the suspension form for all of the reasons that Queensferry Crossing was the preferred form in its location – principal among them, durability and the ability of the cable stays to be completely replaced if required. However, for the Dunoon Bridge, it is anticipated that the main spans on a 3 tower structure would be approximately 900m and would put such a bridge in the top 6 longest cable stayed bridges in the world. Such a cable stayed bridge would approach the limits of technology.

Figure 18: Queensferry Crossing – 3 tower cable stayed bridge

[12] Bathymetry is estimated by reference courtesy of gpsnauticalcharts.com http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Loch+Long+and+Loch+Goil+boating+app#14.14/55.9347/-4.9113

7.3.7 For navigation clearance, a deck carriageway minimum height of approximately +75m must be attained. The deck height and slim road cross section suggest that the aerodynamic characteristics of the design would be a critical factor. The bridge would require wind resilience measures similar to the barriers installed on the Queensferry Crossing. The bridge configuration, especially with regard to torsional rigidity would require specific wind analysis and testing which may prolong scheme development and final design duration.

7.3.8 High towers are necessary, estimated to be 250m to 300m (note: the deck carriageway level is at +85m above water level; +75m plus approx. 10m for deck construction and deflection).

7.3.9 Consideration should also be given to winter resilience of the bridge, principally deck surface and cable/tower de-icing.

7.3.10 The three main towers and possibly some approach viaduct foundations would need to be designed for ship collision, most likely with the mass of the underwater foundations providing sufficient energy absorption.

Construction

7.3.11 Access to the east side of the bridge is relatively straightforward with good access to the Central Belt road network. Access to the west shore is more limited so it is anticipated that primary works offices and staging will be on the eastern shore.

7.3.12 Foundation construction for the approach viaducts would be on shore and over water. Marine foundations for the approach viaducts would entail construction of cofferdams in shallower depths and piling to rock. For deeper approach viaduct foundations, foundations may entail prefabricating and sinking of caissons with either piling to rock or underwater spread footings onto rock. The central tower located on Warden Bank would require a caisson sunk onto the bank and lowered to rock level. Once sealed, underwater concreting would form the spread footing possibly of the order of 30 – 40m deep upon which the base for the tower could be formed. Similarly, caissons would be fabricated and placed for the flanking towers whose foundations would also be formed by underwater concreting.

7.3.13 Concrete batching could be from the marine facility (possibly at Greenock) and transported to the tower and pier locations by barge. Concrete to the towers would be pumped from the barges to pumps on the tower bases and thereby to the incremental jumps in the towers.

7.3.14 The construction of the western abutment will cause significant disruption on the A815 in Dunoon and would require a long-term temporary diversion to maintain connectivity along the coastline, which would potentially be difficult to locate. It may be worth considering moving the abutment out into the water to maintain the existing A815 to avoid needing to construct a new permanent route around the coast for traffic not using the viaduct in the long term as well, although the depth of water would not make this a simple piece of construction.

7.3.15 Similarly, the eastern abutment construction will sever the connection along the A770 coast road. Although this area is somewhat less inhabited, the route provides a connection between Inverkip and Castle Levan so the loss of connectivity could present a notable issue for residents and businesses. This abutment would therefore warrant a similar consideration to the western abutment.

7.3.16 Steel box deck segments would be fabricated nationally and/or internationally and delivered to a staging area at a nearby facility. It is likely that marine facilities at Greenock would be suitable for the staging area for precasting of the composite deck slab. Weather and tide will be important factors in segment erection. Given the military, commercial and private/leisure marine navigation demand in this area of the Clyde Estuary, marine management and control is a construction programme risk.

7.3.17 Segments would be transported by barge to below their location in the span. Main span segments would be progressively lifted onto the tower and extend incrementally from the towers in an alternating balanced cantilever sequence on each of the three towers until closure at the approach viaducts and then at the midspans of the two main spans. Lifting would require GPS placement of barges and their station protected by an exclusion zone on the main navigation channels. This will clearly affect marine vessel navigation. The duration of barges on-station for the lift is expected to be comparatively lengthy at approximately 8 – 10 hours. This allows for anchoring (2 -3 hours) and strand jack lifting which, owing to the deck height, could take up to 7 hours to achieve. For the relatively prolonged operation, wave height and wind conditions may limit the number of available weather windows for lifting as unexpected or variable conditions 'on the day' could impede the lifting operations.

7.3.18 Climbing tower cranes fixed to the main towers will lift materials and equipment to deck level.

7.3.19 DIO consultation will be required for a number of specific security and operating restrictions such as;

- Potential restriction to deck access during the passage of military or large oil transportation vessels.
- Construction activities effect on secure channel communications between RNAD Coulport, Faslane, Holy Loch etc.
- The possible effect of a large-scale bridge structure on radar and sonar.
- Security exclusion zones.

7.4 Cairndow Multi-span Viaduct

7.4.1 The bridge would be as described for Route Corridor 4 in Section 5.4 of this technical note.

8. Route Corridor 7 - Inverclyde - Cowal – Lochgilphead

8.1 Description

8.1.1 This route corridor would be generally online linking the A78 Trunk Road at Inverclyde to Cowal, with the provision of fixed link crossings of the Firth of Clyde and Loch Fyne. The structure will require to span a deep section of the Firth of Clyde as well as have adequate clearance for large marine vessels.

8.2 Structures

8.2.1 The major structures required for Route Corridor 7 are:

- A cable stayed or suspension bridge over the Firth of Clyde – see Section 7 of this technical note.
- A cable stayed bridge across Loch Striven – see Section 6.4 of this technical note.
- A bridge across Loch Fyne – see Section 6.5 of this technical note.

9. Route Corridor 8a - North Ayrshire - Cairndow via Colintraive

9.1 Description

9.1.1 This route corridor is a combination of new offline carriageway and online upgrading works which generally follows the existing road network, with new fixed link crossings to the Isle of Bute and Cowal. The route corridor includes a connection from the A78 Trunk Road in North Ayrshire to Cowal via an approximate 3.0km fixed link crossing between the mainland (within the vicinity of Portencross) and Little Cumbrae Island, an approximate 2.53km fixed link crossing between Little Cumbrae Island and the Isle of Bute and an approximate 0.7km fixed link crossing between the Isle of Bute and Cowal (within the vicinity of the Colintraive to Rhubodach ferry crossing).

9.2 Structures

9.2.1 The major structures in Route Corridor 8a are:

- 1 no. new 3,000m long suspension bridge between the coast at Portencross to the southern shore of Little Cumbrae Island.
- 1 no. new 2,530m long (2,150m main span) suspension bridge between Little Cumbrae Island and the southern coast of Bute.
- 1 no. new 700m long multi-span concrete box girder bridge at Colintraive.
- 1 no. new 400m long multi-span steel composite viaduct near the tie-in to the existing A83 Trunk Road.

9.2.2 The Bute to Ardrossan east and west bridge locations are shown in Figure 19.

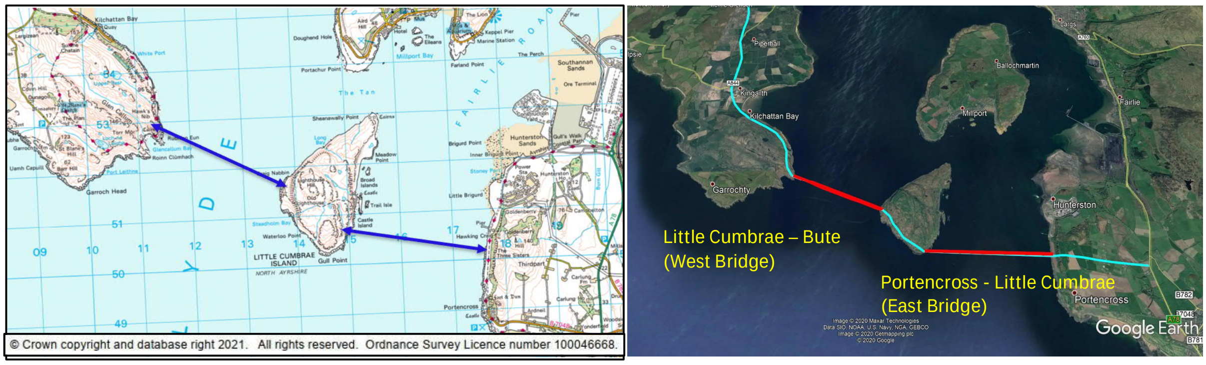

Figure 19: Location of the Portencross – Bute bridges

9.3 Portencross – Little Cumbrae Bridge

Design

9.3.1 The Portencross - Little Cumbrae (East) Bridge requires an approximate 3,000m length of crossing. The water depth reaches approximately 60m in a N-S channel[13].

[13] Bathymetry is estimated by reference courtesy of gpsnauticalcharts.com http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Loch+Long+and+Loch+Goil+boating+app#13/55.7178/-4.9597

9.3.2 As with the other marine crossings, given the need for navigation minimum clearance of +75m and allowing for deck construction depth and deflection, the carriageway would have to be placed at approximately +85m above sea level.

9.3.3 The towers would extend to heights of approx. 200 -250m which would be upwards of 300m from sea-bed level.

9.3.4 Ship collision protection to the towers would be a major factor. Navigation transit velocities through the channels depends on the Clyde Piloting arrangements and transit speed for vessel steering may increase to allow for tidal currents.

9.3.5 The bridge decks must be wind resilient and will require wind barriers similar in form to those provided on the Queensferry Crossing. However, a slender single carriageway long span suspension bridge presents a design challenge to ensure the adequacy of the deck's aerodynamic response. This is particularly important for these long span suspension bridges. Research and wind tunnel testing would be required to determine if a slender single carriageway suspended road deck of that length is feasible. Conceivably, additional lateral and vertical restraint/damping would be required.

Construction

9.3.6 The channel depth east of Little Cumbrae Island reaches 60m and marine construction will be necessary. Marine management and control are crucial factors governing the construction process.

9.3.7 The eastern approach from the connection with the A78 Trunk Road is relatively straightforward comprising a continuous approach viaduct rising to the east end of the east suspension bridge. The viaduct form would be a post-tensioned concrete box or a steel composite box girder deck on discrete or leaf piers on piled foundations. Incremental launching would appear a feasible construction methodology.

9.3.8 The location of the towers would require large diameter caissons fabricated nationally or internationally. Single or twin caissons would be required for each tower footing, floated by semi-submersible into location and sunk to seabed possibly in up to 60m depths. These would then be sunk by their own mass and by perimeter jetting to penetrate and sink through to rockhead where jet grouting would form a seal prior to excavation and underwater concreting. An alternative foundation method would be the construction of large diameter pilecaps within the caissons and large diameter piles to rock.

9.3.9 The mass of the caisson along with the internal concrete would be designed to provide the energy absorption required to resist ship impact loading and may govern the overall diameter of the caissons. It is estimated caissons of approx. 30m diameter would be required. Large fendering installation would be necessary to prevent hull over-sail impacting the towers. The potential for submarine collision is also an unusual factor.

9.3.10 Topography on the landfall on Little Cumbrae suggests that a significant approach viaduct may be required to align the approach roads. The isolation of the island suggests that a considerable marine transfer operation would be required between the Ayrshire coast and the island throughout the works. Moreover, marine transfer of personnel, materials and equipment would be a major challenge where four towers and the island would require to be serviced by east-west marine transport across a very busy north-south navigation route.

9.3.11 Equally important is the time that deck segment delivery barges must stay on-station to allow segment lifting onto the suspension catenaries. The channel depth lengthens the time taken to anchor the barges on-station – anchor line length is considerable in 115m depths. The deck height of +85m lengthens the time taken to jack the segments to deck level. On-station times of up to 12 hours could be expected (2 hrs GPS locating and anchoring, 10 hrs jacking). During this time exclusion zones will limit or divert marine traffic. Military vessel movements would have to be carefully managed – consultation would be required at an early stage to determine specific requirements and constraints.

9.3.12 The other aspects of construction are broadly similar to the other major fixed link crossings described previously.

9.3.13 The road linking the east and west bridges passes across the southern portion of Little Cumbrae skirting the southern shoreline. The road alignment passes to the west coast of the island and then to Little Cumbrae - Bute (West) Bridge to the southern tip of Bute.

9.3.14 The topography of the south shore on Little Cumbrae suggests there may need to be considerable structures content to traverse the relatively steep shoreline.

9.4 Little Cumbrae – Bute Bridge

Design

9.4.1 Little Cumbrae - Bute (West) Bridge to the west of Little Cumbrae is approximately 2,530m in length crossing the main navigation channel entrance to the Clyde Estuary. Water depth is significant with the main channel extending to approx. 115m depth. The channel shape is also significant; the water depth reaches between 30m to 100m close to the shorelines and therefore bridge towers would preferably be located as close to the shores as possible in relation to the main span length.

9.4.2 It is estimated that the main span would have to cross 85% of the shore-shore distance; 2150m. This is longer than the currently longest bridge in the world (Akashi Kaikyō, Japan main span 1991m). To proportion the bridge for the backspans required would therefore move the towers into deeper water. This increases the sub-sea works.

9.4.3 The span and length proportions suggest a suspension form similar to the Xihoumen Bridge, China[14] with a main span of 1650m and a total length of 2,588m.

9.4.4 Ship collision protection to the towers would be a major factor; navigation includes military surface and submarine vessels and very/ultra large crude oil carriers (VLCC/ULCC). Navigation transit velocities through the channels depends on the Clyde Piloting arrangements and transit speed for vessel steering may increase to allow for tidal currents. Particularly for the VLCC and ULCC, their masses combined with transit speed is expected to result in considerable potential impact energies that must be able to be absorbed by the bridge footings/ship collision protection measures.

9.4.5 The west bridge deck landfall onto the southern coast of Bute suggests difficult terrain; sharp escarpments immediately alongside the shoreline. This suggests challenging geometry to achieve a bridge backspan capable of descending on the shoreline to meet the A844 at Kingarth. Such an arrangement would suggest a multi-pier approach sidelong viaduct on the shoreline. Suspension cables would be anchored on the escarpments suggesting a difficult geometric interaction.

9.4.6 Alternatively, the bridge could be aligned to intercept the upper levels of the escarpment and traverse the upland area adjacent to Upper Reservoir before descending to Kingarth. Whilst this approach eases the geometric issue at the bridge's western landfall, it introduces a more difficult road alignment from

[14] https://structurae.net/en/structures/xihoumen-bridge

the upper landform near Kilchattan Bay to Kingarth.

Construction

9.4.7 The western bridge is slightly shorter than the east but is in deeper water. In all significant respects, its construction methodology resembles the eastern bridge. However, the increased water depth, and it is suspected relatively greater marine traffic volume exacerbate the difficulties.

9.4.8 The west end of the western bridge requires a sidelong approach viaduct at the escarpments present on the southern tip of Bute. A number of discrete columns would be located between the escarpments and the shoreline and would facilitate a descent towards Kingarth. Infrastructure in this area is minimal for construction operations on this scale and therefore all materials delivery and operations for construction would be sourced from the Ayrshire coast, perhaps with a staging area on Little Cumbrae.

9.4.9 Infrastructure in Bute generally is minimal for construction on this scale and unless the bridge at Colintraive is built in advance of the two southern suspension bridges, all operations on Bute would be serviced entirely by marine transfer. With the bridge at Colintraive in service, the delivery route via this crossing to the south of Bute is long.

9.5 Bute – Colintraive Bridge

Design

9.5.1 The Bute – Colintraive Bridge crosses on a skew and has a shore-to-shore distance of 700m (Figure 20). This length is comparable with the Skye Bridge[15] (length 500m). The skew crossing could comprise a multi-span viaduct of the type at Dornoch Bridge or a long span box girder bridge of the type at Skye Bridge. However, a cable stayed bridge would also be a feasible solution at this location[16].

9.5.2 Design aspects would be broadly similar to the major viaducts or cable stayed bridges described previously.

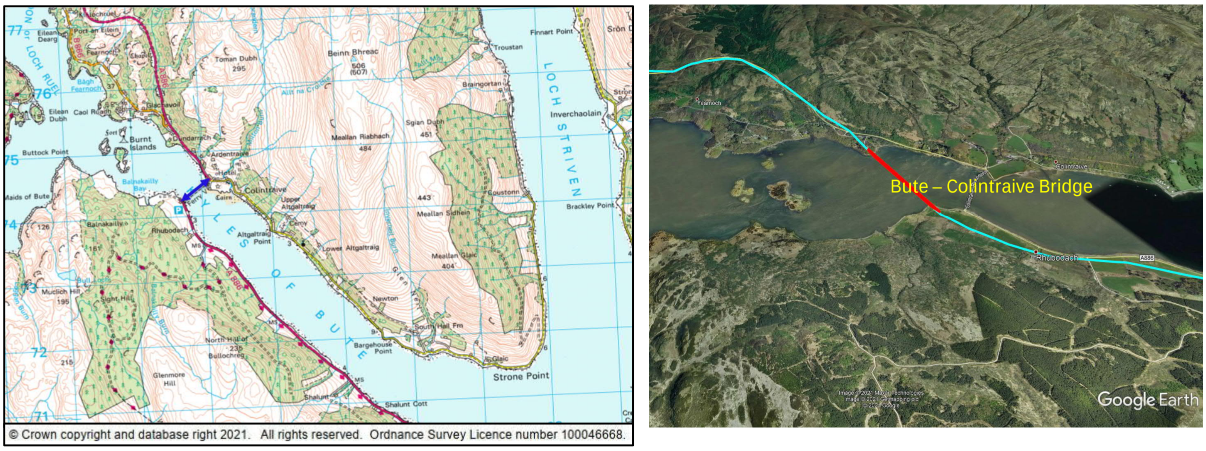

Figure 20: Location of the Bute – Colintraive Bridge

[15] https://structurae.net/en/structures/skye-bridge
[16] Bathymetry is estimated by reference courtesy of gpsnauticalcharts.com http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Loch+Long+and+Loch+Goil+boating+app#14.48/55.9251/-5.1671

Construction

9.5.3 For a multi-span viaduct (similar to Dornoch Bridge) construction would involve installation of sheet piled large diameter cofferdams with dewatering. Large diameter steel pile tube casings would be driven to rock in co-alignment with A-frame type pier legs. Inside the casings is reinforced concrete placed from marine delivered insitu concrete. A batching plant could be stationed on the north shore. The piles would extend upwards to form the pier legs with a crosshead section supporting bearings. The deck would be an incrementally launched post-tensioned form constructed on the north shore and launched southwards.

9.5.4 For a long span post-tensioned box girder (similar to Skye Bridge) construction would involve installation of sheet piled large diameter cofferdams with dewatering. Piled foundations supporting reinforced concrete piers to the post-tensioned concrete deck constructed by segmental lifts by jump forming. The main and back spans would be constructed insitu by balanced cantilever. Concrete delivery would be by pumped delivery from temporary jetties from shore.

9.5.5 For a cable stayed bridge, the medium length single carriageway would suggest a steel composite or concrete road deck supported on A-frame towers. Foundations would be constructed similar to those above. Segment construction would require delivery from barges and lifted vertically. There appears to be little marine traffic on this crossing and there is an available alternative navigation route to the west of Bute. The construction aspects for the cable stayed option would therefore be broadly similar to the other bridges described previously.

9.6 Cairndow Multi-span Viaduct

9.6.1 The bridge would be as described for Route Corridor 4 in Section 5.4 of this technical note.

10. Route Corridor 8b - North Ayrshire - Cairndow via Dunoon

10.1 Description

10.1.1 This route corridor is a combination of new offline carriageway and online upgrading works which generally follows the existing road network with new fixed link crossings to the Isle of Bute and Cowal. The route corridor is the same as Route Corridor 8a between Portencross and Bute but crosses back to the mainline from Bute at Ardmaleish, continuing through Dunoon and along the A815 before re-joining the line of Route Corridor 8a near Strachur.

10.2 Structures

10.2.1 The major structures in Route Corridor 8b are:

- 1 no. new 3,000m long suspension bridge between the coast at Portencross to the southern shore of Little Cumbrae Island.
- 1 no. new 2,530m long (2,150m main span) suspension bridge between Little Cumbrae Island and the southern coast of Bute.
- 1 no. new suspension bridge 2,250m long between Ardmaleish and Cowal.
- 1 no. 400m long multi-span steel composite viaduct near the tie-in to the existing A83 Trunk Road.

10.3 Portencross – Little Cumbrae Bridge

10.3.1 The bridge would be as described for Route Corridor 8a in Section 9.3 of this technical note.

10.4 Little Cumbrae – Bute Bridge

10.4.1 The bridge would be as described for Route Corridor 8a in Section 9.4 of this technical note.

10.5 Ardmaleish – Cowal Bridge

Design

10.5.1 The Ardmaleish Bridge crosses from Ardmaleish in the west to the opposing shore on Cowal, south of Knockdow and then connects to the A815 northwards towards Dunoon as shown in Figure 21. The bridge would be approximately 2,248m long shore-to-shore.

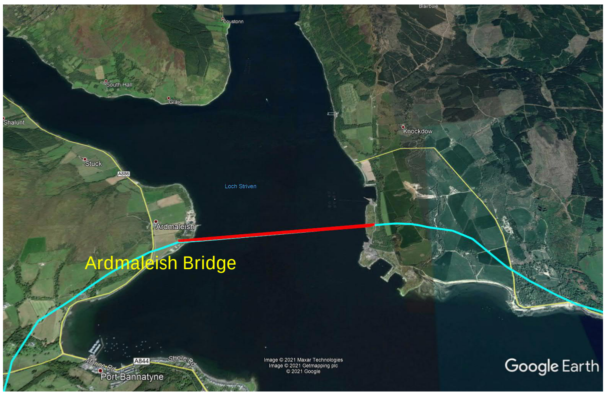

Figure 21: Ardmaleish Bridge

10.5.2 The bathymetry indicates water depths of approximately 50m on mud and sands[17]. It is not known at what depth rock occurs.

10.5.3 The length of the Ardmaleish Bridge is comparable to the Bute – Ardrossan Bridges, although water depths are slightly less. A suspension bridge form would be required.

10.5.4 The design aspects of the bridge would be similar to the suspension bridges described for Route Corridor 8a.

Construction

10.5.5 The construction aspects of the bridge would be similar to the suspension bridges described for Route Corridor 8a.

10.5.6 The western approach from a realigned A886 at Ardmaleish is relatively straightforward comprising a continuous approach viaduct rising to the west end of the suspension bridge. The viaduct form would be a post-tensioned concrete box or a steel composite box girder deck on discrete or leaf piers on piled foundations. Incremental launching would appear a feasible construction methodology. The east

[17] Bathymetry is estimated by reference courtesy of gpsnauticalcharts.com http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Loch+Long+and+Loch+Goil+boating+app#14/55.8765/-5.0648

approach from the A815 would be similar.

10.6 Cairndow Multi-span Viaduct

10.6.1 The bridge would be as described for Route Corridor 4 in Section 5.4 of this technical note.

11. Route Corridor 9 - North Ayrshire - Cowal – Lochgilphead

11.1 Description

11.1.1 This route corridor would be a combination of new offline carriageway and online upgrading works which generally follows the existing road network with new fixed link crossings to the Isle of Bute and Cowal. The route corridor follows the line of Route Corridor 8 between Portencross and Cowal and then Route Corridor 5 to Lochgilphead.

11.2 Structures

11.2.1 The major structures in Route Corridor 9 are:

- 1 no. new 3,000m long suspension bridge between the coast at Portencross to the southern shore of Little Cumbrae Island – see Section 9.3 of this technical note.
- 1 no. new 2,530m long (2,150m main span) suspension bridge between Little Cumbrae Island and the southern coast of Bute – see Section 9.4 of this technical note.
- 1 no. new 700m long multi-span bridge at Colintraive – see Section 9.5 of this technical note.
- A bridge approximately 3,000m long (1,100m main span) across Loch Fyne – see Section 6.5 of this technical note.

12. Route Corridor 10 - Helensburgh - Cowal - Cairndow

12.1 Description

12.1.1 This route corridor would be generally online linking the A814 and A818 at Helensburgh to Cowal, with the provision of fixed link crossings at Gare Loch and Loch Long then following the line of Route Corridor 4 to Cairndow.

12.2 Structures

12.2.1 The major structures in Route Corridor 10 are:

- 1 no. new 1,500m long (900m main span) cable stayed or suspension bridge across Gare Loch.
- 1 no. new 2,600m long suspension bridge across Loch Long.
- 1 no. new multi-span 400m long steel composite single carriageway viaduct on piled reinforced concrete abutments and piled intermediate piers (at Cairndow)

12.3 Gare Loch Bridge

Design

12.3.1 The bridge across Gare Loch from Helensburgh to Castle Point would be approximately 1500m long. The length of bridge suggests a cable stayed bridge may be an option and would offer the benefit of enhanced long term durability. However, for the location at the mouth of the loch and navigation by large military surface and submarine vessels, there may be an advantage in locating the towers as close to shore as possible. This increases the main span favouring a suspension bridge form. The precise requirements of ship/submarine navigation would need due examination and liaison with the DIO. For the present, a suspension form is assumed. The approximate bridge location is shown in Figure 22.

Figure 22: Gare Loch and Loch Long (S1) Bridges

12.3.2 The bridge design aim would be to minimise its length, locate the towers as close to shore as possible and set the deck level at a height above Gare Loch to enable the passage of commercial and military marine vessels. The DIO has advised that the required clearance is +75m above sea level. For the purposes of initial estimation, an allowance of 5m is made for the maximum deflection of a suspension bridge deck and 5m for its construction depth. Thus, the carriageway height would require to be at least +85m above loch level.

12.3.3 The east approach commences at the A818 Luss Road north of Helensburgh and descends on the landform to a point between the built up areas of Helensburgh and Rhu. An approach viaduct would be required.

12.3.4 The western landfall is at Castle Point where an approach viaduct would descend to the road network.

12.3.5 It is estimated that the suspension bridge solution would comprise a main span of approximately 900m with back spans of up to 300m (total length up to 1,500m). The bridge must remain straight with consequences for the approach alignment on both the east and west shores.

12.3.6 The towers would be high and with a deck height of +85m, tower heights are estimated to be 200 – 250m.

12.3.7 The bridge deck must be wind resilient and will require wind barriers similar in form to those provided on the Queensferry Crossing. However, a slender single carriageway long span suspension bridge presents a design challenge to ensure the adequacy of the deck's aerodynamic response.

12.3.8 Consideration should also be given to winter resilience, principally deck surface and cable/tower de-icing.

12.3.9 An important consideration for this route corridor will be the finalised location of the crossing. On the east side of Gare Loch at Helensburgh, there are a number of properties in close proximity of the crossing point. This could result in a complex arrangement being required to limit the impact on these properties or the consideration to move the crossing further north. Moving the crossing of Gare Loch to a point north of Rhu would also result in a longer route around the southern shore of the Rosneath Peninsula or traversal across the width of the peninsula to the bridge at the Loch Long (S1) crossing. Traversal of the peninsula would entail a tunnel. The combined effect would be to approach the routing considered for Route Corridor 4.

Construction

12.3.10 Road access to east and west ends of the bridge are reasonably good and would be used for access for aspects of the bridge construction.

12.3.11 Marine access would also be required. Navigation includes military surface vessels, submarines and commercial and private/leisure craft. Marine management and control are crucial factors governing the construction process, as is similar for other marine fixed link crossings.

12.3.12 The overall construction of the suspension bridge would be similar to that described for other major fixed link crossings in this technical note.

12.3.13 The abutments are both located in populated areas and construction of these is likely to cause significant disruption to the road network comprising the B833 and A814 on each side of Gare Loch. Impact on the community may also be significant due to the size of the piers and extensive working areas, plant and equipment required to construct.

12.3.14 The eastern approach between Helensburgh and Rhu is a curved elevated viaduct while the west may also have to be curved to follow the shoreline at Castle Point and obtain the descent to the road network. Both east and west viaducts would be concrete box or steel composite decks on leaf piers on piled foundations. The approach viaducts' curvatures would appear to preclude incremental launching these would likely be built conventionally span by span.

12.4 Loch Long (S1) Bridge

Design

12.4.1 The approximate bridge location is shown in Figure 22 above. A suspension bridge crossing is required, approximately 2,600m long shore-to-shore. The bathymetry indicates water depths of approximately 60m on mud and sands[18]. The bridge crosses the main navigation channel entrance to Loch Long. The length of bridge and location would mean the bridge is similar to the Little Cumbrae – Bute bridge described for Route Corridor 8a and the design aspects for the bridge are as described in Section 9.4 of this technical note.

12.4.2 The west approach to the bridge is considerably constrained by topography and a curved approach viaduct is required to connect the bridge's western landfall to Ardentinny in the north.

[18] Bathymetry is estimated by reference courtesy of gpsnauticalcharts.com http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Loch+Long+and+Loch+Goil+boating+app#13.7/56.0162/-4.8875

Construction

12.4.3 Construction of the suspension bridge would be as described for the other major fixed link crossings of this type.

12.4.4 The west end of the bridge is isolated and extensive temporary haul road construction would be required from Strone in the south or from Ardentinny in the north – however, access from the north would require substantial completion of the road and tunnel works from Whistlefield through Glen Finart. Alternatively, considerable marine transfer operations would be required between landfalls at both sides of the loch.

12.4.5 Marine transfer of personnel, materials and equipment to the towers would be a major challenge where east-west construction marine transport would cross the north-south navigation route.

12.4.6 Cable installation will be by aerial spinning. This will occupy additional land and require careful alignment interaction with the approach road/viaduct alignments, especially at the west approach.

12.4.7 The time that deck segment delivery barges must stay on-station to allow segment lifting onto the suspension catenaries is important for the deck construction interface with marine traffic. The channel depth lengthens the time taken to anchor the barges on-station. The deck height of +85m lengthens the time taken to jack the segments to deck level. On-station times of up to 10 hours could be expected (2 hrs GPS locating and anchoring, 8hrs jacking). During this time exclusion zones will limit or divert marine traffic. Military vessel movements would have to be carefully managed – consultation would be required at an early stage to determine specific requirements and constraints.

12.5 Cairndow Multi-span Viaduct

12.5.1 The bridge would be as described for Route Corridor 4 in Section 5.4 of this technical note.

13. Route Corridor 11 - Helensburgh - Cowal – Lochgilphead

13.1 Description

13.1.1 This route corridor is generally online linking the A814 and A818 at Helensburgh to Kintyre via Cowal, with the provision of fixed link crossings at Gare Loch, Loch Long and Loch Fyne.

13.2 Structures

13.2.1 The major structures in Route Corridor 11 are:

- 1 no. new 1,500m long (900m main span) cable stayed or suspension bridge across Gare Loch.
- 1 no. new 2,980m long (1,980m main span) suspension bridge across Loch Long.
- 1 no. new cable stayed bridge 820m long (500m main span) across Loch Striven.
- 1 no. new bridge approximately 3,000m long (1,100m main span) across Loch Fyne.

13.3 Gare Loch Bridge

13.3.1 Please refer to Section 12.3 of this technical note for details of a bridge across Gare Loch.

13.4 Loch Long (S2) Bridge

Design

13.4.1 The bridge would cross Loch Long at the south from Cove on the east side of the loch to Strone on the west side[19]. The crossing is 2980m in length and is therefore among the longest of its type in the world. The Loch Long (S2) channel accommodates submarine traffic accessing Coulport to the north and the submarine exercise area in the northern portion of the loch. The towers would have to be located relatively close to the shores and consequently the bridge would require a significant main span of approx. 1,947m.

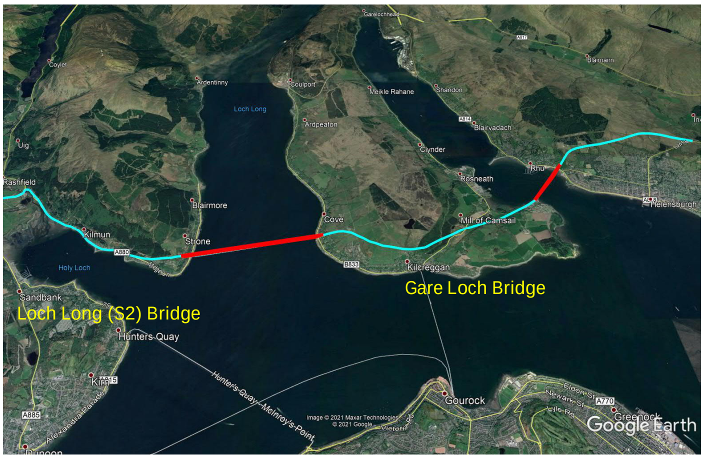

Figure 23: Location of Loch Long (S2) Bridge

13.4.2 On the west approach to the Loch Long (S2) Bridge, the alignment would have to pass to the north of the existing headland, cutting through the hillside to meet the A880. Whether this could be accomplished with cuttings or whether an approach tunnel would be required would involve further and more detailed study.

13.4.3 The length of bridge and location would mean the bridge is similar to the Little Cumbrae – Bute bridge described for Route Corridor 8a and the design aspects for the bridge are as described in Section 9.4 of this technical note.

Construction

13.4.4 Construction of the suspension bridge would be as described for the other major fixed link crossings of this type.

13.4.5 The eastern approach from the Rosneath Peninsula is from elevated land east of Cove and will require a curved approach viaduct. The western landfall is more difficult in that the approach has to descend in a constrained shoreline space towards Kilmun on the A880. The viaduct form would be a post-tensioned concrete box or a steel composite box girder deck on discrete or leaf piers on piled foundations and would enter a tunnel for the descent to the A880.

13.4.6 The west end of the bridge is isolated and would require a haul road at Strone. Alternatively, considerable

[19] Bathymetry is estimated by reference courtesy of gpsnauticalcharts.com http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-charts-navigation.html?title=Loch+Long+and+Loch+Goil+boating+app#13.7/55.9892/-4.8849

marine transfer operations would be required across the loch.

13.5 Loch Striven Bridge

13.5.1 See Section 6.4 of this technical note.

13.6 Loch Fyne Bridge

13.6.1 See Section 6.5 of this technical note.

14. Route Corridor 12 – Inveruglas to Butterbridge

14.1.1 Please refer to Appendix F of the Preliminary Assessment Report for details on tunnels within the route corridors.

15. Route Corridor 13 – Glen Loin

15.1 Description

15.1.1 Route Corridor 13 originates at Arrochar and ascends through Glen Loin curving westwards to a tunnel to Butterbridge (See Tunnels appendix). The eastern portion of the route through Glen Loin is shown in Figure 24.

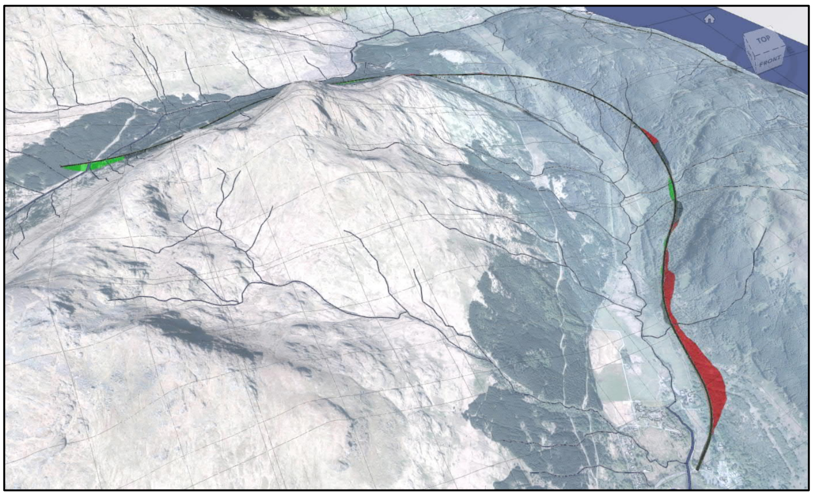

Figure 24: Route Corridor 13 - Glen Loin (Autodesk InfraWorks 360, 2021)

15.1.2 The major bridge structures comprise two viaducts. These are approximately 1265m length viaduct as shown in Figure 25 and an approximate 320m length viaduct shown in Figure 26.

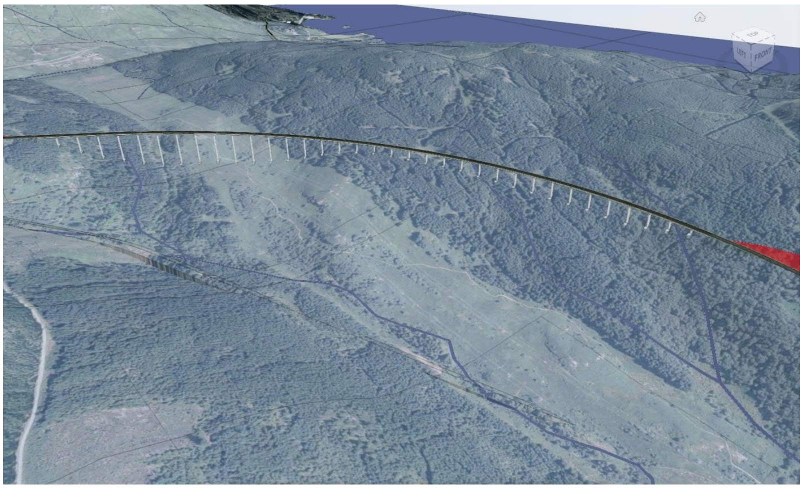

Figure 25: 1265m viaduct (Autodesk InfraWorks 360 2021)

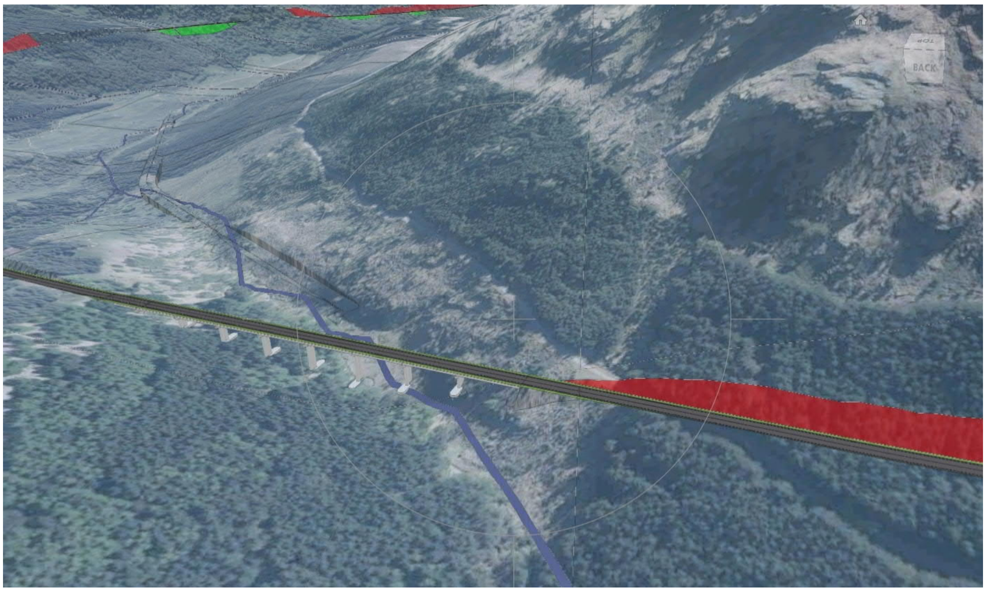

Figure 26: 320m viaduct (Autodesk InfraWorks 360, 2021)

15.2 Design

15.2.1 The 1,265m and 320m long viaducts would comprise composite steel box girder or concrete box spine beam decks on intermediate leaf piers up to approximately 65m in height. End supports would be reinforced concrete abutments or bankseats. Spans would likely be of up to 60m. Foundations would be spread footings or piled.

15.3 Construction

15.3.1 Foundations and piers would be constructed by conventional techniques. The taller piers would be jump formed. Steel box girder sections could be fabricated off-site nationally or internationally and transported by road to a staging area e.g. Greenock and then marine transported to a temporary dock near to Ardgartan. Alternatively, box girder components could be transported entirely by road to the site. Final phase fabrication would take place at the site of the viaducts.

15.3.2 Deck construction could adopt a number of construction techniques including incremental launching (for constant curvature decks), span-by-span gantry launched construction or by strand-jack lifting where infill span sections are lifted from the ground between already installed box sections over the piers. This technique requires significant craneage and temporary works for the installation of the pier sections. Once the steelwork is assembled, a composite concrete deck slab is cast insitu.

16. Route Corridor 14 – Coilessan Glen

16.1 Description

16.1.1 Route Corridor 14 departs the existing A83 Trunk Road at Ardgartan and bears south parallel to the western shore of the northern end of Loch Long before turning westwards into tunnel in Coilessan Glen connecting to the route of the B839.

16.1.2 There is one 565m long viaduct required as shown in Figure 27.

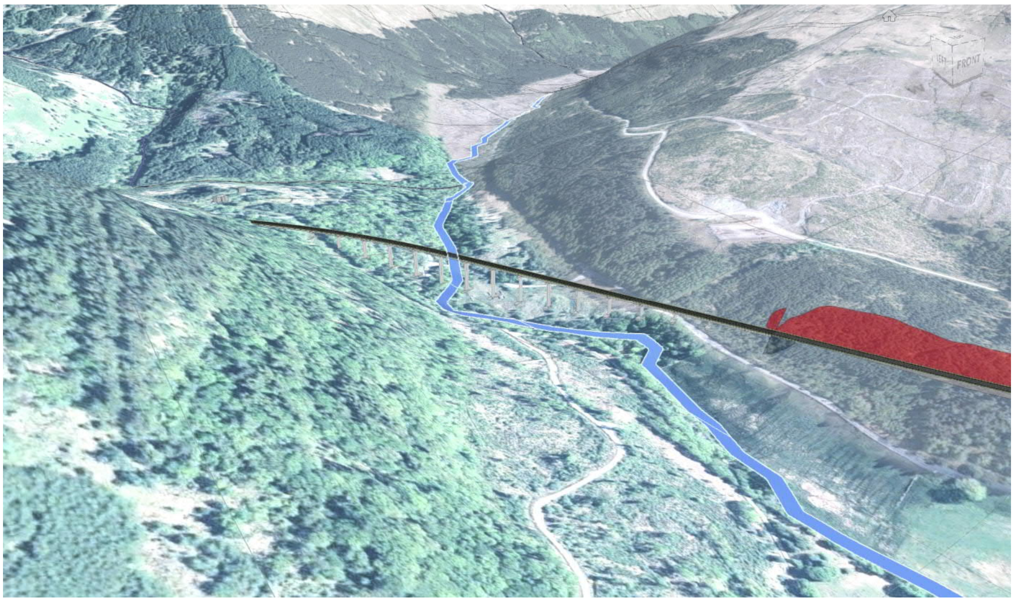

Figure 27: 565m viaduct (Autodesk InfraWorks 360, 2021)

16.2 Design

16.2.1 The multi-span viaduct would comprise a continuous composite steel box girder or composite concrete spine box deck on intermediate leaf piers and end bankseats. Foundations would be spread footing and/or piled.

16.3 Construction

16.3.1 Deck construction could adopt a number of construction techniques including incremental launching, span-by-span gantry launched construction or by strand-jack lifting where infill span sections are lifted from the ground between already installed box sections over the piers. This technique requires significant craneage and temporary works for the installation of the pier sections. Once the steelwork is assembled, a composite concrete deck slab is cast insitu.

17. Route Corridor 15 – Arrochar to Butterbridge

17.1.1 Please refer to Appendix F of the Preliminary Assessment Report for details on tunnels within the route corridors.