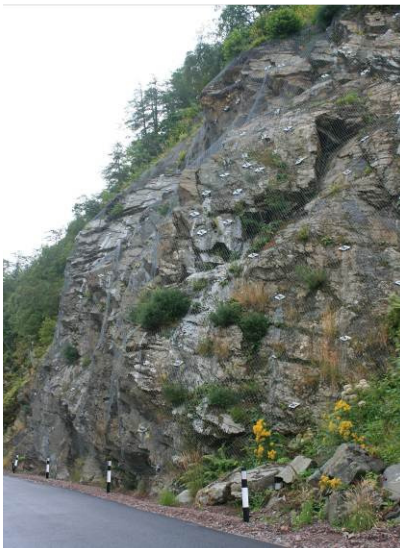
Stromeferry Review of Tunnel Options

February 2014

47065084-T01-01

Prepared for:
The Highland Council



REVISION SCHEDULE

Rev	Date	Details	Prepared by	Reviewed by	Approved by
00	January 2014	Draft Issue	Scott O'Neill Principal Engineering Geologist	David Adams Associate – Tunnelling	David Taylor Technical Director
01	February 2014	Updated following client comments	B Parabaran Technical Director	David Adams Associate – Tunnelling	David Taylor Technical Director

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1 INTRODUCTION

1.1 Background

URS has been asked to provide advice on the tunnelling aspects of the Stromeferry/ A890 diversion appraisal works.

The A890 bypass has historically suffered from rock fall and other debris landing on the carriageway and adjacent railway, necessitating repair work and temporary road closures. Several options for remedial measures or diversion of the route have been undertaken and are presented separately.

Following the issue of the Stage 1 Report (URS Reference STAG1 Part 1/DRMB PART 1 Report in May 2013), this report focuses on the proposed construction of a new highway tunnel to enable diversion of the route. Tunnelling forms a key part of the proposals for two of the identified options, namely the North shore route and On-line route. This report considers the tunnel elements of these two route options.

This report does not attempt to contextualise the project or provide in-depth detail regarding the regional or local geology, or the project setting. It is assumed that any reader has knowledge of the project and access to existing information regarding the works to date undertaken by others (A890 Stromeferry Bypass, New Route Studies: Tunnel Route 2, Preliminary Assessment, Mott MacDonald, August 1993) and the recent works undertaken by URS. Sufficient research has been undertaken at this stage of the project to support the assumption that the tunnels described can be constructed through what appears to be competent rock.

1.2 Scope

A review of the current conceptual tunnelling options is presented in this report alongside a review of design guidance and regulations relevant to UK highway tunnels.

In order to inform the study, a site walkover was carried out, including the potential tunnel sites identified in the North shore route and On-line route options. Photographs taken during the site walkover are presented within this report.

This report also provides budget cost estimates for the tunnel sections considered in order to allow comparisons to be made and the options to be evaluated.

The tunnelling options proposed at Stromeferry are characterised by relatively long tunnel lengths (by the standards of UK highway tunnels) and relatively low anticipated traffic volumes. UK highway tunnel experience and guidance focuses on highly trafficked trunk roads. For this reason, in addition to a review of the UK tunnel standards and design requirements, a review of the Norwegian tunnelling practice has been carried out. Norwegian tunnelling experience offers a useful comparison due to the relatively high numbers of highway tunnels that form part of the Norwegian road network and because site conditions, including ground conditions and traffic levels, are similar to those anticipated at Stromeferry.

1.3 Site Walkover

An inspection of the carriageway on both sides of Loch Carron and the shoreline on both sides of Strome Narrows was undertaken on 13th August 2013 by representatives of the URS tunnelling team. It should be noted that this inspection was limited to areas accessible on foot without the need for vegetation clearance or rope access measures.

This report includes details of the inspection with commentary regarding the potential feasibility of the two tunnel options.

2 TUNNEL DESIGN REQUIREMENTS

2.1 Design Standards

The Highland Council have confirmed that Transport Scotland would be the Technical Approval Authority (TAA) for the proposed tunnel. As such, the applicable design standard for road tunnels constructed as part of the scheme would be BD 78/99 'Design of Road Tunnels'. This standard has been taken into account in the preparation of this report.

For the purpose of comparison, a low cost alternative based on Norwegian tunnelling methods has also been considered. It should be noted that this alternative does not necessarily meet all the requirements of the design standard BD 78/99. However, it should be recognised that DMRB is a set of standards appropriate to Trunk Roads and Motorways and it is not unusual, particularly in the Highlands of Scotland, for departures to be granted for the Local Road network.

2.2 Other Design References

Road tunnels which form part of the trans-European transport network and exceed 500m in length must be designed in accordance with the Road Tunnel Safety Regulations 2007, which transposed into UK law Directive 2004/54/EC of the European Parliament and of the Council.

It is understood that the A890 does not form part of the trans-European transport network and, therefore, is not subject to the entirety of these regulations. The regulations do, however, exist as an example of best practice and provide relevant guidance intended to minimise risk in road tunnels. It is, therefore, considered that the design of a new tunnel as part of the A890 should be in accordance with relevant requirements of the regulations as referenced below:

Directive 2004/54/EC of the European Parliament and of the Council of 29 April 2004 on minimum safety requirements for tunnels in the Trans-European Road Network

Statutory Instruments, 2007 No. 1520, Highways, Tunnels, The Road Tunnel Safety Regulations 2007

2.3 Risk Management

Risk Evaluation and Risk Management are key components in road tunnel design and several sources provide guidance

The British Tunnelling Society has published a code of practice that sets out guidance on the identification, minimisation and management of risks associated with tunnelling works. This document, listed below, is relevant to the design and construction process for any tunnel option considered for the A890 diversion.

The Joint Code of Practice for Risk Management of Tunnel Works in the UK, prepared jointly by The Association of British Insurers and The British Tunnelling Society, published by The British Tunnelling Society, 2003

The World Road Association (PIARC) provides guidance on the management of operational risks for road tunnels. This guidance is published online as the *PIARC Road Tunnels Manual.*

2.4 Interpreted Design Requirements and Guidance

The references cited above provide important requirements and guidance for the design of new road tunnels and these should be considered at the option evaluation and design stages. Relevant requirements and guidance is summarised below;

- The Road Tunnel Safety Regulations provide requirements for tunnels which fall within the scope of these regulations. Whilst the tunnels considered in this report are outside the scope of these regulations, the regulations should be considered as guidance. The regulations should also be considered with regard to long term management of the tunnel by the relevant administrative authority, assumed in this case to be The Highland Council. In particular, the regulations would suggest the following be considered for any tunnel forming part of this scheme;

    - Duties of the Tunnel Manager
    - Appointment of a Safety Officer
    - Appointment of an Inspection Entity
    - Appointment of a Technical Approval Authority (anticipated to be Transport Scotland)
    - Use of Risk Analysis to assess operating risks prior to design

- Suitable signage should be provided as indicated within the 2007 Regulations Annex I.

- Emergency equipment and exits and the provision of information to tunnel users in an emergency should be in accordance with the 2007 Regulations Annex I.

- Planning and design of the tunnel and ground investigation for tunnelling should be in accordance with the BTS/ABI Code of Practice referenced above.

- Pedestrians and Animals are generally not permitted to use road tunnels under the requirements of BD 78/99. Therefore, specific design requirements must be considered if pedestrians and animals are to be permitted to use the tunnel. This may require the use of a dividing wall within the tunnel to provide a separate structural cell for the use of pedestrians and animals.

- BD 78/99 requires classification of the tunnel by length and traffic volume to determine safety measures and requirements. Based on an annual average traffic flow (AADT) of 1164 vehicles/day or less and tunnel lengths of between 1km and 3km, both tunnel options would be classified as Tunnel Category B. This classification would lead to the following principal safety and fire protection requirements;

    - Emergency Telephones
    - Fire Extinguishers
    - Pressurised Fire Hydrants
    - Emergency Exit Signs
    - Lane Control and Tunnel Closure Signs/ Signals
    - Emergency Stopping Lane
    - Emergency Walkway
    - Ventilation for Smoke Control

  In addition, the following equipment or measures may be required depending on Tunnel Design and Safety Consultation Group (TDSCG)

    - Radio rebroadcasting system
    - Traffic Loops

- CCTV
- Fire Hose Reels
- Escape Doors

Based on the safety requirements outlined above, and the need to provide pedestrian and cycling access through the tunnels, it is likely that the pedestrian and cycling route through the tunnels would need to be separated from the carriageway. This would potentially enable the pedestrian route to be used as an emergency escape in the event of a fire or other emergency within the road tunnel. It is envisaged that this separation would be provided by a concrete floor to ceiling concrete wall with emergency doors at intervals giving access from the carriageway.

The design standard BD 78/99 requires escape access at 100m intervals in dual-bore tunnels. The standard does not provide a similar requirement for single-bore tunnels and, therefore, spacing of escape routes would be subject to more detailed design considerations combined with rigorous risk analysis. At this stage it is envisaged the separation wall would be designed for appropriate fire resistance to allow escape via the pedestrian and cycling cell to either portal.

2.5 Transport of Dangerous Goods

BD 78/99 requires assessment of the risks associated with the carriage of dangerous goods through road tunnels and the adoption of suitable safeguards. Dangerous Goods are defined as explosives, flammables, radioactives and toxins.

Assessment of the risks involved would include consideration of the types of materials that are likely to be carried, patterns of traffic flow and the risks associated with passage through the tunnel compared to alternative routes.

Research has been carried out of the World Road Association (PIARC) regarding the assessment of risks associated with the passage of dangerous goods through tunnels. This research has resulted in the development of a Quantitative Risk Assessment Model (QRAM) for Dangerous Goods Transport through Road Tunnels. The software model allows parameters for the tunnel and alternative routes to be entered and permits evaluation of tunnel facilities and safety measures.

Where there is no suitable alternative route for hazardous goods or the alternative routes give rise to significant risks, it is usual to provide specific safety measures, such as isolation of vehicles carrying hazardous goods from other tunnel users.

Given the relatively low traffic flows expected within the tunnels considered in this report, it is likely that controlled entry of vehicles carrying dangerous goods into the tunnel could be implemented without causing significant delays to other road users. Consideration could therefore be given to limiting access to other traffic during passage of vehicles carrying hazardous goods by use of stop lights or barriers.

3 REVIEW OF NORWEGIAN PRACTICE

A review has been carried out to determine possible 'lower-cost' Norwegian tunnelling methods for both the North Shore Route option and On-line Route option. This review has focused on the arrangement and construction of drill and blast rock tunnels for highways in Norway, where significant numbers of such tunnels have been constructed. The Norwegian tunnelling industry is recognised for providing relatively low cost tunnels in similar conditions to those anticipated at Stromeferry.

It should be noted that Norway is not a full member of the European Union and, therefore, it is not expected that the examples reviewed comply entirely with the tunnel regulations referred to in Section 2.2. A review of Norwegian tunnel standards has not been undertaken as part of the current commission.

The reduced cost of Norwegian tunnels is attributed to the following key factors (in no particular order):

- **Tunnel Linings**: The Norwegian highway tunnels are typically constructed in relatively high quality rock masses and utilise structural linings only where necessary to provide additional support. Tunnels generally include local shotcrete support and rock-bolting, but do not include a continuous concrete lining.
- **Water Ingress**: Norwegian tunnels, including sub-sea tunnels, do not typically provide a water-tight lining, but instead allow some degree of water ingress which is dealt with by tunnel drainage. There is potential for increased operational cost associated with pumping water ingress to the surface. Water ingress is typically limited by providing relatively large depths of cover and by grouting the rock mass during construction.
- **Cross-section:** Norwegian tunnel cross-sections reflect reduced lining requirements, as described above, and relatively low traffic volumes. Tunnel cross-sections are typically in the region of 50 to 60m^2, which allows for two lanes of traffic, but does not provide provision for a segregated escape route or dedicated stopping lane. Locally widened sections of tunnel are typically provided to allow emergency lay-bys containing safety stations (fire extinguishers and emergency telephones).
- **Tunnel Lengths:** Norway has the longest road tunnel in the world with a length in excess of 24km. Typical road tunnel length is in the order of 1km. Norwegian standards place more emphasis on traffic volume and less emphasis on length when determining safety requirements, compared to the BD78/99.
- **Escape Routes / Refuges:** Segregated escape routes or refuges are not generally provided in single bore tunnels.
- **Contractual Arrangements:** Norwegian contracts for tunnelling schemes typically include a risk share mechanism that places the majority of project risks, such as target cost or cost-reimbursable contract, with the client. Such arrangements minimise the risk exposure to the contractor, thereby allowing for a reduction in project cost at the expense of greater uncertainty of cost to the client.

The Norwegian tunnelling approach therefore provides potential cost savings and is suitable for lightly trafficked areas with good quality rock. However, the following disadvantages are apparent when comparing the Norwegian approach to typical UK road tunnel specifications.

- Reduced cross-sectional area precludes some safety measures, such as a segregated emergency exit or service corridor. Therefore, it is only suitable where risks are low, such as tunnels with very low traffic intensity.
- Reduced cross-sectional area also means that there is no provision for pedestrian access or other Non-Motorised Users (NMU).
- Absence of full lining increases tunnel lighting requirements and may reduce aesthetic appeal. It also reduces ease of cleaning. Exposed rock areas may require increased inspection and maintenance compared to lined tunnels.
- Non-existence of a water-tight lining requires that all infiltration is pumped to the surface unless the geometry of the tunnel allows gravity drainage. Infiltration is likely to be more widespread and measures such as internal water management may be necessary to control seepage water. Grouting requirements may be increased to avoid excessive infiltration.
- Depending on the chosen contract, an increased allocation of risk to the client would add to the uncertainty of overall capital cost to the client.

4 NORTH SHORE ROUTE

4.1 Description

The North Shore Route option considers a tunnelled crossing of the loch at Strome Narrows in conjunction with upgrade to the road on the northern shoreline of the loch as an alternative to the current A890 alignment.

The road is currently in very poor condition and the gradients and bends encountered close to the narrows would require significant re-engineering to provide a suitable link to any crossing.

4.2 Alignment

An indicative road alignment is shown on the URS Drawing 47065084-1011, Rev 0. Consideration of a tunnel crossing has been based on this alignment.

Constraints imposed by the topography and approach roads lead to an indicative alignment with comparatively sharp bends in the tunnel and approaches.

4.3 Crossing at the Strome Narrows

Consideration has been given to the construction of a bridge or tunnel to cross the narrows.

It is understood that current proposals show a tunnel or bridge structure to cross the narrows perpendicular to the shoreline. It is suggested that consideration be given to aligning any crossing across the narrows (i.e. diagonally) to allow suitable gradients and curves to be generated for any approach earthworks or cuts.

The approach to any bridge structure from either the northern or southern shore would require extensive approach earthworks construction. This could be accommodated on the southern shore line where the topography is gentle enough to allow the construction of an approach earthwork, but on the north would require considerably more engineering to achieve compliant gradients. It is believed that the controlling factor for any bridge design would be the requirement to provide 20m of freeboard to accommodate mast height.

In order to advance more detailed options, further bathometric and geotechnical data would be required to determine the required depth of the tunnel beneath the narrows.

Photograph 1: Looking North across the Narrows from Stromeferry. The spit of land would provide an ideal position for the approach to any tunnel or bridge option; however the existing dwellings and the Castle may cause planning concerns.

Photograph 2: Looking North across the Narrows from Stromeferry at water level. The existing ferry slipway can be noted in the left of the image at water level. Bedrock can also be seen exposed in the northern shoreline.

Photograph 3: Looking North West between Creag Mhaol and Craig. This would be the approximate area that any access road from the A890 to the south would have to pass around the western side of Craig Mhaol to meet any approach earthwork or cut for a tunnel or bridge crossing across the narrows.

Photograph 4: Dipping exposure of the Lewisian Complex exposed in the shoreline along the northern side of the loch adjacent to the ferry slipway. Rocks are generally thinly laminated heavily fractured metamorphic with numerous veins throughout.

Photograph 5: Looking South West across the Narrows from Stromemore. The Hill in the left of the image is Creag Mhaol. The raised beach can be noted in the centre of the image and it may be possible to obscure any earthwork approach/cut in this plateau area to reduce visual impact. This would also allow any highway to be constructed at a suitable gradient to allow the tunnel crown to be at a sufficient depth below the sea bed.

It is assumed for the purposes of this report, that the bathometry of the loch is as would be expected for a Fjord or infilled glacial Trough. It is therefore anticipated that the sea bed at the mouth of the narrows would be at a higher datum when compared to the sea bed on either side, i.e. in the loch or along the coastline.

Similar approach constraints would exist for a tunnel option. It is envisaged that a tunnel crossing would be in the form of a driven tunnel passing through the underlying bedrock. Use of an immersed tube tunnel at this location is unlikely to be feasible due to the topography, ground conditions and disturbance of the environmentally sensitive seabed.

In addition, due to the topography and the raised beaches on the southern side, it may be possible to use the existing landscape to reduce the impact of any tunnel option. This would however, increase the length of the tunnel.

Notable constraints to any tunnel option would include:

- Depth of sediment at the narrows
- Bathometry of the narrows itself
- Required land take on both sides of the narrows
- Requirement to either cross over or under the railway along the southern shoreline.
- The existing dwellings on either side of the crossings

- The ruins of Strome Castle

4.4 Construction Issues

Any approach cuts required from tunnelling options could be achieved through drill and blast or a ripper (to be confirmed with ground investigation).

It should be noted that any construction works in or in the vicinity of the loch will likely require stringent pollution controls to prevent debris (including site runoff) entering the loch. This will be of particular concern to the local economy as Loch Carron houses a Salmon farm.

4.5 Geotechnical Conditions

The northern route is likely to be predominantly a combination of schist, gneiss and amphibolites. The area is covered by glacial material and at the current time differentiation of underlying rock types and lateral extents and limits is not possible.

4.6 Cross Section

It is envisaged that the tunnel cross section would be of a ‘horseshoe’ profile conventionally used in rock tunnelling, accommodating two lanes of traffic and a pedestrian/ escape path.

In the event that investigations show high quality rock mass, the curved sides of the tunnel profile could potentially be replaced with vertical walls to reduce excavation volume.

An indicative profile as shown in Figure 1 has been developed on the basis outlined above. The tunnel cross section is based on the following criteria;

- 3.00m width per lane (2 lanes)
- 0.65m hard strips both sides
- Single 1.00m wide footway within vehicle compartment for emergency use
- 5.4m total headroom (see TD27/05)
- Lateral kinematic clearance 0.6m
- 3.00m wide pedestrian/ escape passage (assumed, subject to traffic requirement)

A requirement for emergency stopping lanes is given in BD 78/99, however, this document also notes that continuous emergency stopping lanes are generally not provided due to the high costs associated and that suitable additional lane width and verges are a suitable alternative. Given the relatively low anticipated vehicle flow, it is anticipated that the 0.65m hard strips and 1m verge provided in the indicative cross-section are sufficient to temporarily allow traffic to pass a stranded vehicle. Further consideration should be given at a later design stage to the widths provided and the potential for enlarged sections of tunnel to provide lay-bys as an alternative to providing additional width in the whole tunnel length.

In order to accommodate access for pedestrians and provide an escape route separated from the main tunnel, the cross section incorporates a full height concrete wall separating the pedestrian passage from the carriageway. To comply with regulations, this wall should incorporate fire doors for access at 100m spacing. The separate pedestrian access/ escape route would require independent ventilation, including the ability to provide a higher air pressure within the escape route, to prevent smoke from a fire in the main tunnel from entering the escape route.

A gradient across the carriageway should be provided depending on road speed and curve radius and for drainage.

Given that the tunnel is constructed at lower level and beneath the loch, there is potential for significant groundwater inflow. Experience in similar Norwegian tunnels suggests that this may be outweighed by improved rock mass quality and the presence of overlying impermeable strata, however the potential for water inflow remains. Given the geometry of the tunnel, infiltration water will need to be pumped out of the tunnel from the lowest point and therefore represents an on-going operational cost.

It is likely that the tunnel would be constructed with a structural invert and an un-drained lining in order to avoid significant inflow into the completed tunnel. The tunnel lining would therefore incorporate a complete ring of waterproof barrier and the concrete lining designed to resist full water pressures anticipated, therefore requiring a thicker lining and greater excavation area than an equivalent tunnel above sea level.

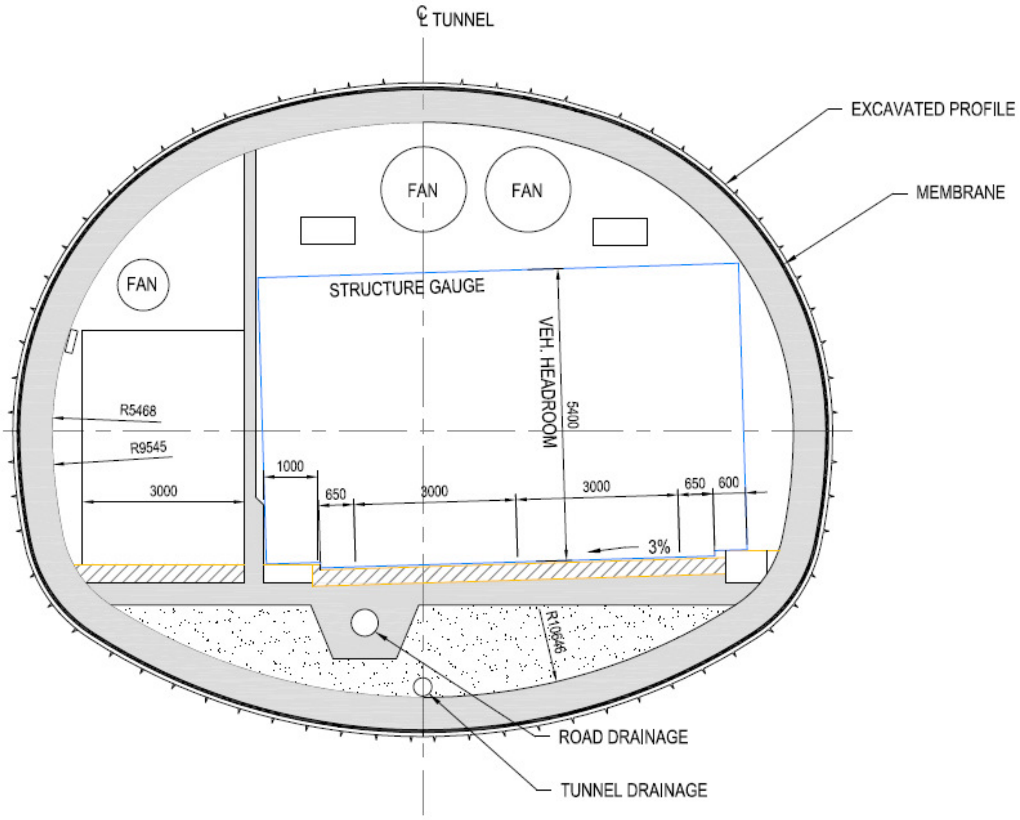

Figure 1: URS Indicative Tunnel Profile (Un-drained Lining)

4.7 Drainage

A pumped highway drainage system will be required in order to carry any water inflow from the surface or carried in by vehicles from sumps within the tunnel to suitable drainage outlets at the surface.

Whilst the tunnel is likely to be designed as a water-tight structure, some seepage is inevitable and this inflow will also need to be pumped out of the tunnel from a suitable sump.

4.8 Portals

Portals will be subject to similar considerations to those discussed below for the On-line tunnel. In addition, suitable measures will have to be taken to ensure that the portal structures are not subject to flooding that may flood the entire tunnel. Portal structures may therefore need to incorporate flood walls that line the approach cuttings until the road level exceeds design flood/tidal surge levels

Approach structures may include a combination of cutting and cut and cover tunnel with tunnelling commencing when suitable strata and depth of cover is reached.

4.9 Construction Methodology

It is likely that drill and blast tunnelling will offer the most efficient construction methodology in the anticipated ground conditions. Given the greater potential for groundwater inflow, consideration must be given at the investigation and design stages to ensure that groundwater inflow is limited sufficiently to avoid delaying construction progress. Site investigation will need to identify areas where faulting or fragmentation of the rock mass make inflow more likely and where mitigation measures such as grouting are required. Probing will be necessary during construction to identify area of high potential inflow ahead of the face to allow grouting to be carried out as the tunnel progresses.

4.10 Construction Rates/ Programme

An excavation advance rate of 2m per day or some 14m per week (7-day working) could be anticipated. Assuming that tunnelling will commence from both portals, for an anticipated length of tunnel of approximately 2.5km, excavation could take a minimum of 90 weeks and perhaps longer if significant areas of poor/ faulted ground were encountered. The installation of the concrete lining could follow on behind, as drill & blast operations continue, with completion of the lining estimated at some 2 to 3 months post drill and blast operations. Additional fit out works for installation of E&M plant is anticipated to take a further 2 to 3 months – staggered with the civils works.

4.11 Ground Investigation

In order to confirm initial design assumptions, it is recommend that a number of inclined cored rotary boreholes be undertaken to intercept the faults and attempt to establish fault widths and orientation. These boreholes could be drilled using a combination of rotary open hole and rotary core drilling to allow ‘spot coring’ at targeted areas to reduce drilling costs.

Shallow intrusive holes will also be required to establish the thickness and lateral extent of the glacial materials. It is anticipated that these holes would be undertaken using a combination of cable percussive rotary drilling , window sampling and machine excavated trial pits; depending on the number of cobbles and boulders encountered in the glacial materials.

It is anticipated that additional GI could be undertaken from the existing highway (directional drilling) depending on confirmed tunnel alignments.

It is recommended that inclined boreholes be undertaken at the crossing location to confirm the loch bed geology. Overwater drilling may also be a suitable option dependent on cost and programme (and prevalent weather conditions at the time of any proposed GI).

4.12 Cost Estimate

Estimated budget costs for the North shore route option tunnel are given below. These are based on the alignment discussed above and an assumed maximum gradient of 6%, which is derived from the design standard BD 78/99 that is referenced in Section 2.1. These parameters indicate a tunnel length of approximately 2.5km, though there may be opportunity to reduce this by varying the route and/or increasing gradients.

URS Profile in line with current highway standards:
Generic costs for a **150m²** tunnel (shown in Figure 1) are as follows:

	Quantity		Rate		Value
Tunnel Cross-sectional area / m²	**150**				
Tunnel Length / m	**2550**				
Excavated Perimeter / m	**45**				
Excavation Volume / m3 / m	150	£	150.00	£	22,500
Number of rock bolts / m	20	£	75.00	£	1,500
Volume of lining / m3 / m	34	£	200.00	£	6,800
Reinforcing Mesh /m3 concrete	34	£	25.00	£	850
			total / linear metre	**£**	**31,650**
Drainage costs					10%
M&E Costs					25%
Site set-up costs					15%
On Costs OH&P					10%
Portal costs					20%
			total additions		**80%**
			Total / linear metre	£	56,970
			Total for tunnel	£	145,273,500
Contigency					10%
			Anticipated Construction Costs	**£**	**159,800,850**

This estimate excludes the costs associated with road realignment. It also excludes client & design costs.

4.13 Lower-bound cost solution based on Norwegian practice

The example tunnel profile, provided in Figure 2, has been used successfully for sub-sea crossings in Norway in similar rock-types to those anticipated at Stromeferry. As the tunnel is not fully lined, it depends on a suitable layer of intact rock between the tunnel and the loch above to limit water inflow. Norwegian guidance suggests a minimum rock cover of 25m above the crown of the tunnel. Whilst this is achievable, the additional depth required, coupled with limits on tunnel gradient, increases the necessary length of tunnel, extending the tunnel further under the land either side of the narrows. The absence of a water-tight lining is also likely to increase the on-going operational costs associated with pumping out water, which infiltrates the tunnel compared to a tunnel with a full watertight lining.

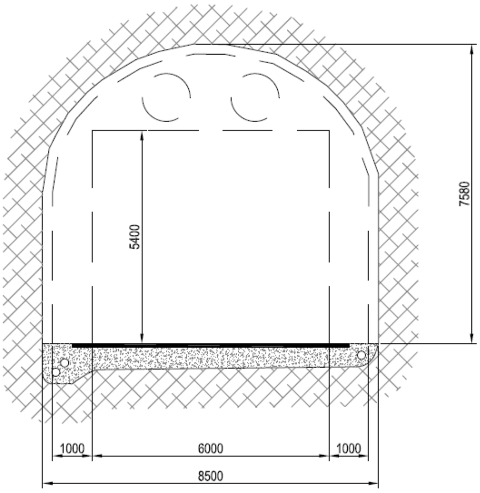

Figure 2: Example Norwegian tunnel profile

The Norwegian tunnel cross-section above shows a dual-lane tunnel with approximately 60m^2 cross-sectional area. This cross-section is typical for existing Norwegian tunnels, including sub-sea tunnels in good quality rock. This cross-section provides an indicative lower-bound cost solution for the Stromeferry tunnel.

In order to minimise the cross-section and cost of the example tunnel profile, no provision has been included for a separate pedestrian route, and a slightly reduced overall carriageway section has been adopted, 8.0m as against 8.9m as recommended by BD78/99. Whilst used here as an illustration of possible cost reductions acceptance of a reduced carriageway cross section lies with the approval authority. It is assumed that an alternative route would be provided for pedestrian traffic. Likewise, the section does not provide a segregated escape route for use in the event of fire or other emergency within the tunnel. Use of this profile is therefore dependent on the risks of such an emergency arising and the severity of the resulting event being shown to be acceptable due to the relatively low volume of traffic expected within the proposed tunnel.

	Quantity	**Rate**	**Value**
Tunnel Cross-sectional area / m^2	**60**		
Tunnel Length / m	**2700**		
Excavation Volume / m3 / m	60	£ 150.00	£ 9,000
Number of rock bolts / m	10	£ 75.00	£ 750
Volume of lining / m3 / m	6	£ 200.00	£ 1,200
Reinforcing Mesh /m3 concrete	6	£ 25.00	£ 150
		total / linear metre	**£ 11,100**
Drainage costs			10%
M&E Costs			25%
Site set-up costs			15%
On Costs OH&P			10%
Portal Costs			20%
		total additions	**80%**
		Total / linear metre	£ 19,980
		Total for tunnel	£ 53,946,000
Contigency			10%
		Anticipated Construction Costs	**£ 59,340,600**

This estimate excludes the costs associated with road realignment. It also excludes client & design costs.

Whilst offering a significant cost saving, a solution based purely on Norwegian practice is not recommended to be taken forward in this location based on the following:

- Alternative escape routes in the form of adits cannot be provided.
- An alternative route for non-motorised users is by means of a long detour and will require additional capital and maintenance costs.
- On-going operational and maintenance costs will be required due to the nature of the tunnel construction.
- Increased rock cover requirements beneath the loch require a longer tunnel than the fully lined option.

5 ON-LINE ROUTE

5.1 Description

In an attempt to maintain an open highway, an appraisal into the feasibility of moving the carriageway away from the southern shoreline of Loch Carron has been undertaken. One of the options highlighted as a potential solution to the problem is the driving of a tunnel into the hillside of Cnoc Nam Mult to effectively bypass the free rock faces. This option is termed the On-line Route option.

5.2 Alignment

The On-line Route option has been developed with a new tunnel providing a means of bypassing the most problematic areas of the current road alignment between Cuddies Point and Ardnaff. The proposed alignment would run from the current alignment at each end, arcing away from the shoreline to maintain rock cover to the tunnel.

An indicative alignment for the road is shown on the URS Drawing 47065084-5061, Rev 0. With an allowance for sufficient cover at the portals, the length of tunnel required for this alignment is approximately 1.5km. The tunnel option discussed in this report is based on this alignment, with potential for minor development of the portal positions to suit local topography. This alignment would retain a length of existing carriageway west of the tunnel where remedial measures are likely to be necessary to stabilise rock slopes.

The proposed alignment includes cover to the tunnel up to approximately 150m in depth. The road level varies from approximately 9m AOD at the western portal to 23m AOD at the eastern portal. This change in level should facilitate gravity drainage. However, specific drainage measures or a short uphill section into the tunnel at the eastern portal should be provided to prevent rainwater or spilled liquids running into the minimised section. It is desirable to minimise gradients as much as possible in order to avoid slowing large vehicles and increasing emissions and ventilation requirements. The indicated gradient of less than 1% is comparatively light and could be varied at later design stages if required. European regulations suggest that gradients above 3% should attract further consideration due to increased risks associated with the passage of heavy vehicles.

The proposed horizontal alignment provides a curve at each end to allow the tunnel to be orientated away from the face of the rock slope. This provides adequate rock cover to the tunnel and also provides clearance from potentially fragmented or damaged rock masses adjacent to the existing road alignment. The curves at the portals are also beneficial in that they limit the daylight entry into the tunnel and therefore allow the transition from tunnel to daylight to be better controlled by suitable lighting and portal arrangements. It is desirable to minimise curve radius within the tunnel in order to preserve sightlines and therefore a single large radius has been indicated over the remainder of the tunnel. BD 78/99 gives 470m radius as a desirable minimum for a design speed of 70km/h in tunnels against 360m radius for an open road.

5.3 Inspection results - Southern side of Loch Carron

The loch itself is a typical flooded glacial trough, or fjord, with glacio-isostatic modification of the shoreline around the narrows (raised beaches). The hillside on the south side dips steeply dipping towards the loch (i.e. in a north-westerly direction) with a slope break approximately 30-40m above the carriageway where the hillside becomes predominantly exposed free face (Photograph 6). The ridge line at the slope break level is wooded with imported tree flora, many of which are over mature and leaning. Published geological data shows that the rocks composing the hillside of the southern side of the loch are primarily gneissic and schistose.

The rock face was not inspected in detail at the time of the inspection, although it is understood that detailed face mapping has been previously undertaken by others.

Photograph 6: General panorama of the southern side of Loch Carron. Despite the scale, the full width is approximately 4km, the exposed vertical faces can be noted in the centre of the image.

Travelling in a south-westerly direction from Strathcarron, the A890 passes over Maman Hill. It is understood that part of the wider on-going appraisal work is looking to improve gradients of Maman Hill in order to avoid steep gradients which are understood to cause traffic issues, especially for HGVs during the winter months. An inspection of this area was excluded from the recent inspection.

The carriageway then drops to loch level and passes through the mouth of the Attadale Valley and then climbs again to Cuddies point. From here, the road drops again to a few metres above the shoreline level and proceeds along the length of the loch to Ardnaff where it climbs again before dropping finally to reach Stromeferry. The railway runs parallel to the carriageway along much of the shoreline and, as such, is a major consideration for any road redevelopment.

Photograph 7: Example of the netting works undertaken to date along much of the exposed faces adjacent to the A890.

Along much of the A890 the exposed free faces are separated from the edge of the carriageway by 1 – 2m, or less. The exposed faces have been covered by netting (Tacomesh/

Maccaferri double twist hexagonal mesh – Photograph 2) and bolting during recent stabilisation works, which have sought to remediate the immediate high risk areas.

It is understood that the proposed tunnel at this location would be approximately parallel to the general shoreline though the structure of the strata should be taken into account in determining any tunnel alignment.

Photograph 8: General view of the southern side of Loch Carron looking northeast, Cuddies Point is visible in the background along with Maman Hill. The image gives a good indication of the overall hillside slope angle along with the narrow strip of forested land at the crest of the free faces. The height of the faces can be noted from the traffic moving along the A890.

From the observations made on site it may be possible to locate a northerly portal to the south of Cuddies Point as the carriageway bends into the hillside (Photographs 9 and 10). This would most likely result in the creation of an approach cut some 20-30m in length, on the southern side, which will require stabilisation measures but, due to the location the height of any cut, is likely to be <20m.

Photograph 9: Approach to possible Northern Portal position (facing south west). It may be advisable to straighten the road leading to the portal by realigning the bend through the removal of the free face at the left hand side of the bend.

Photograph 10: Possible location of northern portal, further assessment would be required to confirm the angle of entry and the amount of cover rock (currently covered by mesh) that could be retained.

The following 1.2 – 1.5 km of the carriageway is situated adjacent to the exposed free face before, presumably due to a change in geology, the slope break disappears and the natural topography continues into the loch – with the carriageway cut in along the shoreline.

5.4 Construction Issues

The most suitable position for a site compound during the works would likely be in the Attadale valley or in Achmore. There is very little open flat ground elsewhere – there is nothing of sufficient footprint along the route of A890 along the southern shoreline. The exact size and dimensions of any compound/prefabrication, storage area would be for the Client to agree at contract stage. Consultation with landowners would likely be required to facilitate the creation of laydown areas and suitable access roads.

Excavation of the tunnel itself could presumably be undertaken using blasting or a road header. It should be noted that it is likely that any tunnelling works would require road closures of the existing A890. This would be inevitable at the portal structures and may be required during works in the tunnel itself, although it may be possible to implement temporary closures to minimise disruption. It is recommended that alternative measures be considered for the duration of the works.

Spoil material would probably have to be stored (either temporarily or permanently) at Attadale or Achmore. It may, however, be possible to end tip clean uncontaminated material into the loch itself subject to the availability of suitable access to the loch even though access is limited due to the existing railway. Again, any cleaning of spoil would be undertaken at Attadale or Achmore due to land constraints. It is likely that any clean rock spoil would be suitable for use as engineering rock fill either elsewhere in the project or sold to third party companies for use elsewhere.

Previous studies have suggested that the inland tunnel option may not require lining. However given the size of the gullies visible in the hillside, and assuming they are fault related, it is likely that advance grouting would be required to prevent excessive water ingress into the tunnel during driving and operation. Ground investigation and in-situ testing would be required to establish any inflow rates within the tunnel.

The controlling factors for the offset from the existing free face (lateral cover) to the tunnel are likely to be as follows:

- Allowance for further degradation and weathering of the exposed face
- Horizontal extents and thickness of overbreak arising from the original blasting of the face using lifting charges (well documented in other project specific literature).
- The presence of any faulting or other natural discontinuities parallel to the faces
- The depth of the numerous incised gullies along the hillside, and in particular the two large gullies that run down from the summit of Aonacch Baile na Creige.
- The presence of any faulting perpendicular to the face that may be responsible for the creation of the gullies mentioned above.

All of the above constraints would require further investigation and analysis prior to developing the tunnel route option further. It is therefore recommend that a detailed topographical survey be undertaken and combined with the results of the available mapping data. Any survey should establish the base of any channels and gullies present with the hillside and as such should be extended to a level above that of the existing tree line.

In addition to the above it is advised that a number of intrusive investigation points be undertaken. These should consist of trial pits in the portal areas to establish the depth of any scree material and to locate a rock profile in the colluvial materials. Boreholes with wireline logging drilled on both the horizontal and vertical planes should be commissioned to establish the orientation of both natural and man-made discontinuities. These boreholes should be undertaken from the break in slope (vertical) and the road level (horizontal).

Due to the proximity of the railway it would be advisable to have suitable equipment and personnel on permanent standby (at the site compound) to clear any minor rock falls from the railway that may occur during the works. In addition it is recommended that blasting works are timed to coincide with no train activity. Further discussion with Network Rail will be required on this matter.

5.5 Geotechnical Conditions

Based on the Mott MacDonald assessment carried out previously (Mott MacDonald Scotland, A890 Stromeferry Bypass New Route Studies: Tunnel Route Preliminary Assessment, August 1993), the ground conditions at the tunnel location are anticipated to primarily consist of gneiss and schist. The assessment anticipates that, although the majority of the alignment will be constructed in competent rock there will be significant areas of faulting and fractured rock mass.

The Mott MacDonald report assumes that all faulting is vertical. This is unlikely to be the case and as a result the volumes of different rock types will probably change.

Borehole positions should be selected based on the available GI information along with ensuring that a representative spread of holes are available during the detailed design works. It is advised that a minimum spacing of 150m is adopted with additional holes as required.

5.6 Cross Section

The internal cross section of the On-line route tunnel would be subject to the same criteria as the North shore route tunnel, accommodating two lanes of traffic and a pedestrian/ escape path.

It is likely that a structural invert would not be required unless the rock mass was heavily weathered or fragmented and, therefore, it is anticipated that the arch will be founded on the rock without a structural invert. There is potential for a structural invert being required at portals where the rock mass quality is likely to be lower.

An indicative profile as shown in Figure 3 has been developed on the basis outlined above. The tunnel cross section is based on the following criteria:

- 3.00m width per lane (2 lanes)
- 0.65m hard strips both sides
- Single 1.00m wide footway within vehicle compartment for emergency use
- 5.4m total headroom (see TD27/05)
- Lateral kinematic clearance 0.6m
- 3.00m wide pedestrian/ escape passage (assumed, subject to traffic requirement)

Given the proximity of the tunnel to the existing road, there is potential to provide one or more intermediate escape adits from the existing road to the pedestrian/ escape passage. There is also potential to provide a pedestrian and cyclist route on the alignment of the existing road to avoid the need for pedestrian access to the tunnel.

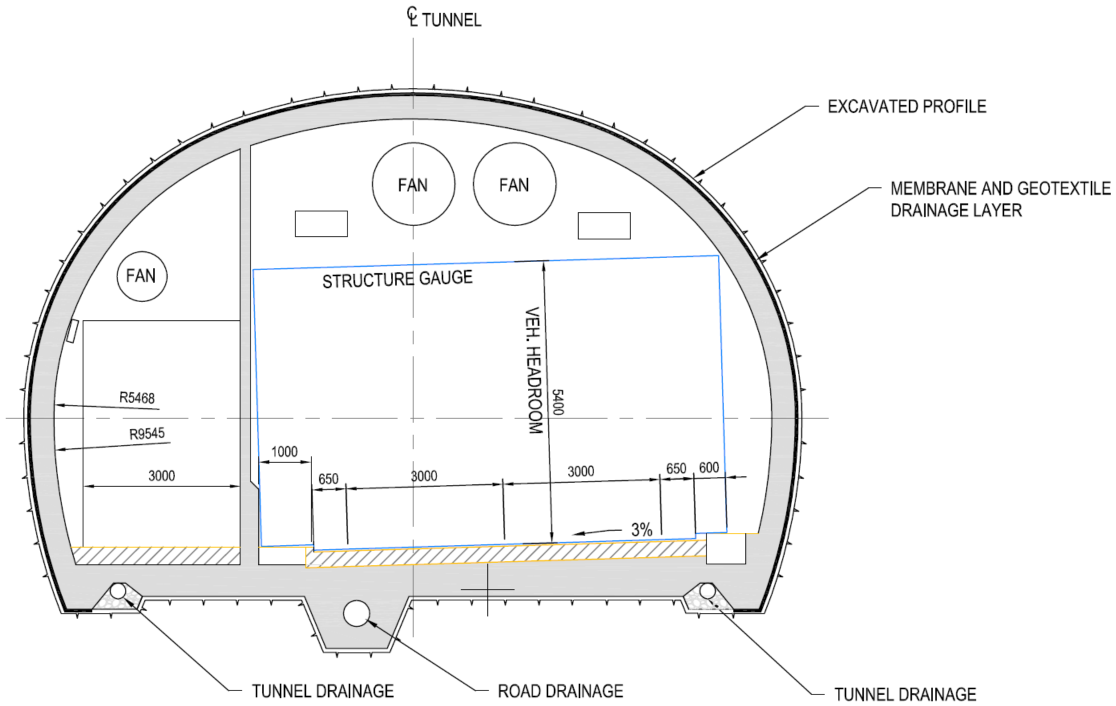

Figure 3: URS Indicative Tunnel Profile (Drained Lining)

5.7 Drainage

It is assumed that the tunnel will be designed as a drained tunnel, as is typical for such tunnels in rock. The lining will therefore incorporate a drainage layer behind the internal lining to take seepage water from the rock mass to drains at the base of each tunnel wall. Given the gradient of the tunnel, it is likely that seepage water can be gravity fed to a suitable outlet at the lower portal.

A separate highway drainage system will be required for water from the carriageway. This system should also allow gravity drainage, though consideration should be given to dealing with potential fuel spills or other liquid spills from vehicles using the tunnel.

5.8 Portals

Additional rock cuttings will be required at both tunnel portals in order to access a section of rock face with sufficient cover of competent rock to allow tunnelling to commence. In the permanent condition, it is likely that a permanent portal structure incorporating some form of canopy would be necessary in order to protect the roadway from potential rock falls from the slope above the portal. Minimum length of protective canopy depends on rock slope above the crown of the tunnel and mountainside/cutting immediately adjacent. It is possible that an 'avalanche' canopy is required to both portal approaches.

A review of the proposed alignment shown on URS Drawing 47065084-5061 Rev 0 together with additional topographical information has indicated that the western tunnel portal should be adjusted slightly. It is therefore proposed that the portal be located further westwards and also orientated such that the tunnel enters the 'corner' of the hill at approximately the 40m contour to provide the required rock cover above the tunnel. The road alignment will need to be amended to suit the necessary radius of curvature. A sketch plan has been prepared and is included in Appendix A. This sketch shows the adjusted location of the western portal and the associated abutment walls at the entrance to the portal. Also shown is a new culvert that will be required to channel the stream below the diverted road. If feasible, this culvert may be incorporated into the abutment wall/ portal during design development.

5.9 Construction Methodology

It is likely that excavation by drill and blast tunnelling methods would be most economical in the anticipated ground conditions in which excavation advances in a series of steps with the rock mass drilled and explosives installed to break the rock at each advance. Excavation using a TBM (closed face or road header type) would also be technically possible, but is unlikely to be cost-effective given the comparatively short length of tunnel and the high set-up costs associated with TBM excavation.

Based on a drill and blast methodology, rock support would be installed as required as the tunnel advances, including rock bolts, sprayed concrete and steel mesh or fibre reinforcement depending on rock mass quality. Installation of a permanent structural lining would follow, including the installation of a suitable drainage layer behind the permanent lining. Permanent lining could take the form of either in-situ cast or sprayed concrete.

It is envisaged that tunnelling would be carried out from both portals concurrently, without intermediate construction shafts given the high rock cover.

5.10 Construction Rates/ Programme

An excavation advance rate of 2m per day or some 14m per week (based on 7-day working) could be anticipated. Assuming that tunnelling will commence from both portals, for an anticipated length of tunnel of approximately 1.5km, excavation could take a minimum of 54 weeks, but perhaps longer if significant areas of poor/ faulted ground was encountered. The installation of the concrete lining could follow on behind, as drill and blast operations continue, with completion of the lining estimated at some 3 to 4 months post drill and blast operations. Additional fit out works for installation of E&M plant is anticipated to take a further 3 to 4 months – staggered with the civils works.

5.11 Ground Investigation

In order to confirm initial assumptions and to permit more detailed consideration of potential tunnel options, it is recommended that a number of inclined cored rotary boreholes be undertaken to intercept the faults and attempt to establish fault widths and orientation. These boreholes could be drilled using a combination of rotary open hole and rotary core drilling to allow 'spot coring' at targeted areas to reduce drilling costs.

It is anticipated that additional GI could be undertaken from the existing highway and possibly from the rock face (roped access) depending on confirmed tunnel alignments. Roped access work will be more expensive, but may provide more useful information depending on the geological feature being targeted and it's orientation within the large rock mass (particularly related to faults). Please also refer to Sections 5.4 and 5.5.

5.12 Cost Estimate

Original MM Profile – update based on inflation & increased length:

Generic costs for a 100m^2 tunnel, similar in profile to the original MM proposal (shown in Figure 4) are as follows:

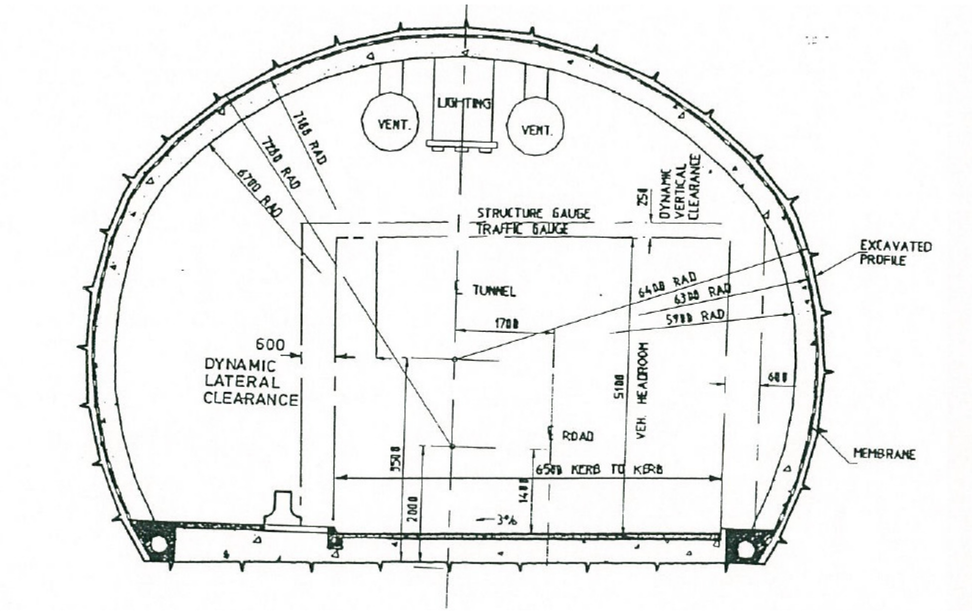

Figure 4: Mott MacDonald Tunnel Profile August 1993

	Quantity		Rate		Value
Tunnel Cross-sectional area / m^2	**100**				
Tunnel Length / m	**1500**				
Excavation Volume / m3 / m	100	£	150.00	£	15,000
Number of rock bolts / m	16	£	75.00	£	1,200
Volume of lining / m3 / m	12	£	200.00	£	2,400
Reinforcing Mesh /m3 concrete	12	£	25.00	£	300
			total / linear metre	**£**	**18,900**
Drainage costs					10%
M&E Costs					25%
Site set-up costs					15%
On Costs OH&P					10%
Portals					15%
			total additions		**75%**
			Total / linear metre	£	33,075
			Total for tunnel	£	49,612,500
Contigency					10%
			Anticipated Construction Costs	**£**	**54,573,750**

This estimate excludes the costs associated with road realignment. It also excludes client & design costs.

Increased URS Profile in line with current highway standards:

Generic costs for a **130m^2** tunnel profile (as shown in Figure 3) are as follows

	Quantity		Rate		Value
Tunnel Cross-sectional area / m^2	**130**				
Tunnel Length / m	**1500**				
Excavated Perimeter / m	**45**				
Excavation Volume / m3 / m	130	£	150.00	£	19,500
Number of rock bolts / m	20	£	75.00	£	1,500
Volume of lining / m3 / m	22.5	£	200.00	£	4,500
Reinforcing Mesh /m3 concrete	22.5	£	25.00	£	563
			total / linear metre	**£**	**26,063**
Drainage costs					10%
M&E Costs					25%
Site set-up costs					15%
On Costs OH&P					10%
Portals					15%
			total additions		**75%**
			Total / linear metre	£	45,609
			Total for tunnel	£	68,414,063
Contigency					10%
			Anticipated Construction Costs	**£**	**75,255,469**

This estimate excludes the costs associated with road realignment. It also excludes client & design costs.

5.13 Lower-bound cost solution based on Norwegian practice

Adoption of the example tunnel profile shown in Figure 5 offers the potential to significantly decrease the tunnelling costs associated with the On-line route option.

The constraints imposed by the Strome Narrows crossing do not apply to the On-line route option and therefore, disadvantages associated with the Norwegian approach are less severe for the On-line route option:

- The requirement to deepen the tunnel to provide adequate rock cover does not apply and therefore the length of tunnel can be minimised
- Vertical alignment should allow for gravity drainage of the tunnel, reducing operational costs compared to the North shore route, which would require pumped drainage.

The reduced cross-sectional area therefore represents a significant potential cost saving, compared to the baseline tunnel options, providing that the need for a pedestrian passage and segregated emergency route can be avoided. To facilitate the reduction in cross-sectional area, it is suggested that the possibility of providing a surface bridleway on the route of the existing road is investigated.

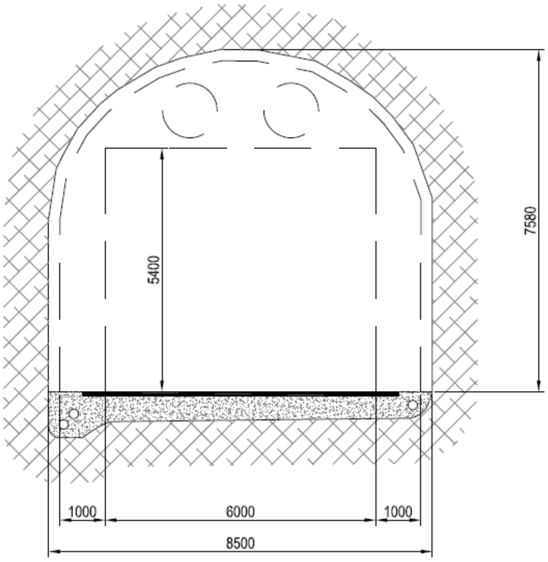

Figure 5: Example Norwegian Tunnel Profile

The Norwegian tunnel cross-section above shows a dual-lane tunnel with approximately 60m^2 cross-sectional area. This cross-section is typical for existing Norwegian tunnels. This cross-section provides an indicative lower-bound cost solution for the Stromeferry tunnels options.

In order to provide a lower-bound cost estimate for the tunnel, no allowance has been made for pedestrian access or access for cycles and horses in consideration of the tunnel profile. Instead, it is assumed that the existing carriageway will be made available with sufficient rock-fall protection to allow part of it to be used as a bridleway. It is accepted this will introduce additional capital and maintenance costs. The lower-bound cost solution also does not allow for a separate egress route within the tunnel profile. Emergency egress could however be provided in the form of one or more lateral adits, connecting the tunnel with the existing carriageway. Lateral adits could also be used as a means of ventilation in order to limit the requirements for longitudinal ventilation measures within the tunnel. The practicality of providing lateral escape adits would be dependent on further design development since a significant number of adits may be necessary. As a guide, on the basis of 100m spacing of escape routes, a total of 14 adits would be required, this seems excessive. Further analysis is required to confirm spacing and the cost effectiveness of adits as an escape solution. In addition the disruption to traffic on the existing road will have to be considered during the construction of this element.

Based on a reduced cross-sectional area, relaxation in safety requirements to suit light traffic and provision of rock support only where specifically required to support the rock mass, the following estimate of tunnelling costs has been prepared.

It is recommended that a suitable risk assessment is carried out prior to considering this option further.

Norwegian Profile:
Generic costs for a **60m²** tunnel, (profile as shown in Figure 1), are as follows:

	Quantity		**Rate**		**Value**
Tunnel Cross-sectional area / m^2	**60**				
Tunnel Length / m	**1500**				
Excavation Volume / m3 / m	60	£	150.00	£	9,000
Number of rock bolts / m	10	£	75.00	£	750
Volume of lining / m3 / m	6	£	200.00	£	1,200
Reinforcing Mesh /m3 concrete	6	£	25.00	£	150
			total / linear metre	**£**	**11,100**
Drainage costs					10%
M&E Costs					25%
Site set-up costs					15%
On Costs OH&P					10%
Portals					15%
			total additions		**75%**
			Total / linear metre	£	19,425
			Total for tunnel	£	29,137,500
Cost of Adits/Escape solution				£	5,000,000
Contigency					10%
			Anticipated Construction Costs	**£**	**37,051,250**

This estimate includes an allowance for an assumed 5No. escape adits.

Given the application of BD78/99 to the proposed tunnel options, it is likely that the Norwegian practices discussed will not be accepted in their entirety. It is, however, possible that elements of the Norwegian practices could be adopted. These may include the approach to construction risk and the targeted use of rock support rather than providing a fully lined tunnel. Further assessment is required, but at this stage adopting this philosophy may offer savings in the order of 10% to 20% on the BD77/99 costs.

5.14 Potential development for reduced cross-section

The possibility of providing a reduced tunnel cross-section containing a single-lane carriageway, providing alternating single-direction traffic has been considered. This option would require either traffic lights and or a barrier system at each end of the tunnel to control traffic access. The risks associated with limited turning widths in the tunnel and potential for collisions within the tunnel would need to be fully evaluated.

This option has been compared against the Objectives set by the Stakeholder Group and rejected on the grounds of accessibility and improved standards.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 North Shore Route

Any crossing at the narrows is likely to have significant impact on the landscape on both shorelines. Although it may be possible to use the existing topography to reduce visibility on the southern side, on the northern side is likely that any civil engineering works will be highly visible.

If the North shore route option is to be progressed to allow the progression of either a bridge or tunnel crossing at the Strome Narrows, it is recommend that the following works be undertaken:

- Bathometric survey of the sea bed in the vicinity of the narrows
- Borehole investigations to establish rock type, discontinuity type and spacing, permeability and other fundamental rock properties required for design. These boreholes should be undertaken on both shorelines and in the narrows itself.

It is likely that a tunnel across the narrows will represent a longer, more complex and more expensive solution than the On-line route option tunnel because of the need to construct beneath the loch and provide adequate cover above the tunnel.

- **THE FOLLOWING RECOMMENDATIONS ARE MADE REGARDING THIS OPTION:**The BD78/99 tunnel option will provide a safe all weather crossing of the Strome Narrows. Construction will be complex but the risks and construction difficulties encountered should be readily accommodated within an appropriate suite of contract documentation prepared by an experienced client and delivered by an experienced contractor.
- The rock cuts leading in and out of the tunnel are likely to be extensive and visually intrusive.
- Whilst offering significant savings the Norwegian tunnel cross section should rejected at this location on the grounds of safety and amenity.

6.2 On-line Route

The On-line route tunnel option along the southern shoreline would create a robust, safe, all weather route for the A890. It is likely that any tunnel option would be costly, but would be operational despite weather conditions.

Construction of any tunnel option is likely to result in significant disruption whilst the works are undertaken and, as such, any planning should take into consideration the requirement for temporary road closures.

If the On-line route option is to be progressed to enable a more detailed appraisal of the tunnel option to be carried out, it is recommended that the following items of work be undertaken:

- Topographic survey of the free faces and the hillside to a suitable distance up the hill. A specification of the level of detail required for this work can be supplied as required.

- Boreholes drilled vertically and horizontally along the proposed route to establish rock type, discontinuity type and spacing, permeability and other fundamental rock properties required for design.

The following recommendations are made regarding this option:

- The BD78/99 tunnel option will provide a safe all weather bypass of the existing rockfall area and should be progressed further. Construction will be complex but the risks and construction difficulties encountered should be readily accommodated within an appropriate suite of contract documentation prepared by an experienced client and delivered by an experienced contractor.

6.3 Norwegian Tunnel Profile, On-line Route

For both the North shore route and On-line route options, a Norwegian tunnel profile has been considered. The Norwegian tunnel cross-section provides a lower-bound cost solution.

As the Norwegian tunnel is not fully lined, exposed rock areas may require increased inspection and maintenance compared to lined tunnels. Additionally, no provision has been made for pedestrian access or other non-motorised users.

The tunnel cross-section does not provide a segregated escape route for use in the event of fire or other emergency within the tunnel.

The typical Norwegian tunnelling cross-section, as considered in this review of tunnelling options offers significant cost benefits but will not totally satisfy the UK design standards and safety regulations. Robust risk analysis and management techniques would have to be applied before it would satisfy the code of practice for risk management of tunnel works in the UK and taken further. Areas to consider include:

- Geology/Hydrogeology
- Drainage/Groundwater
- Pedestrians & Cyclists
- Operation & Maintenance
- Ventilation
- Escape & Refuge

- **THE FOLLOWING RECOMMENDATIONS ARE MADE WITH RESPECT TO USE OF THE TYPICAL NORWEGIAN PROFILE FOR THE ONLINE OPTION:** From work to date and following the risk analysis it is likely the Norwegian cross section can be developed such that risks are As Low As Reasonably Practicable. This process may include selecting key aspects of Norwegian practice and developing a hybrid solution of the online options outlined within this report.

- With regard to compliance with the UK standard BD78/99, we would recommend on going dialogue and meetings are held with the client; The Highland Council and Transport Scotland as the Technical Approval Authority to set a series of 'Approval Gateways' where the subject is fully explored with the aspiration of final acceptance should the tunnel emerge as a preferred route option.

6.4 Hybrid Solution

- If an on-line tunnel is to be considered further it is recommended a hybrid solution is developed, taking aspects from the Norwegian design and incorporating them within a design to BD78/99. This solution would offer economies in price whilst conforming to standards. It should also be noted the current standard is some 15 years old. The overseeing authorities are aware of changing technologies for low trafficked roads which may be reflected in expected updates.

REFERENCES

The following documents have been referred to in preparation of this report.

1. A890 Stromeferry Bypass, New Route Studies: Tunnel Route 2, Preliminary Assessment, Mott MacDonald, August 1993
2. Stromeferry Appraisal, 47065084 STAG Part 1 / DMRB Stage 1 Report, Final, URS, May2013

APPENDIX A

Western Portal Sketch Plan

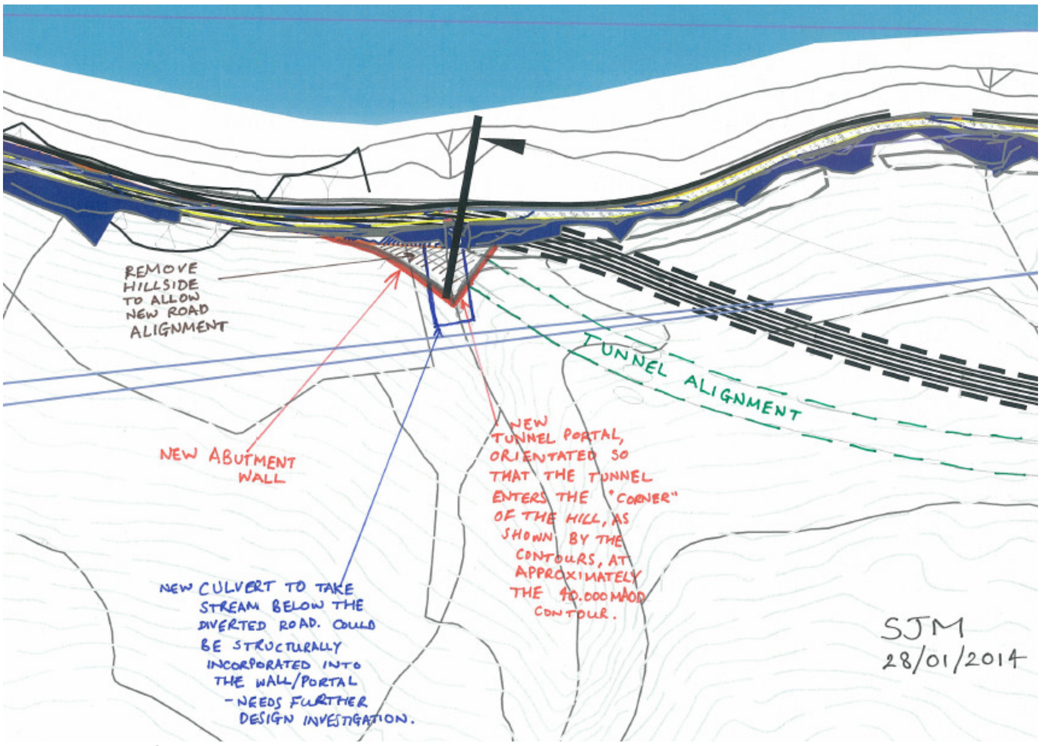

Figure A.1 Sketch plan showing adjustment of the western portal location from that shown in URS Drawing 47065084-5061 Rev 0